Department of Geological Sciences, Faculty of Sciences
Masaryk University/Brno
& Czech Geological Society
September 12-14, 2011

Short Course on Geological Hazards

Topic 1: Introduction and Basic Principles:

Hazard & Risk Assessment / Management

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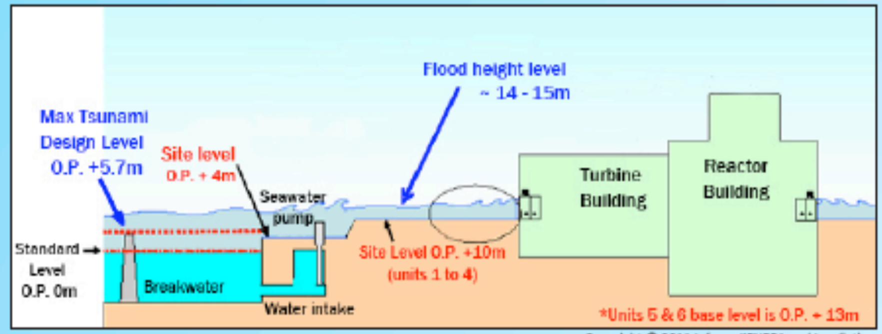
organize



Short Course on Geological Hazards

presented by

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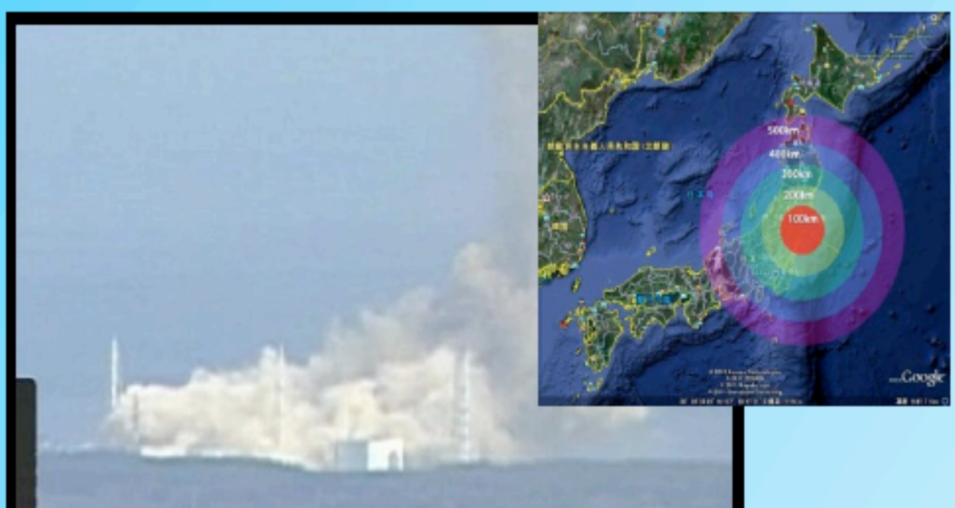
12.–14.9.2011



NEW EXPLOSION AT FUKUSHIMA DAIICHI NUCLEAR REACTOR
March 13, 2011. Hydrogen explosion at Unit No. 3. *(Nippon News Network)*

Topics to be covered include:

Topic 1: Basic Principles of Hazards and Risk Assessment / Risk Management

Topic 2: Natural Hazards vs. Man-Made Hazards and Basic Principles of their Quantification
- a) Probabilistic quantitative
- b) Scenario Events (quantitative)
- c) Qualitative Methods

Topic 3: Seismic Hazards with emphasis on „stable continental regions“ with low or modest seismicity

Topic 4: Continuation of Topic 3, but with application to „Essential Facilities“ (i.e. short-lived nuclear power plants and long-lived „spent fuel repositories“)

Topic 5: Climate Change and flooding hazards (coastal/sea-level-rise and inland/river flooding)

Topic 6: Landslides and other natural hazards

Topic 7: Global Issues, Politics, Policies, Insurance Issues, and Best Practices of Disaster Risk Management

Introduction:

Principles of

- Hazard Assessment,
- Risk Assessment

  and

- Risk Management.

The Historian - Philosopher
Will Durant (1885-1981) wrote:

"Civilization exists by geological consent,

subject to change without notice."

"…. without notice."
??

“Natural” Disasters occur at the Intersection of Vulnerable Societies with Extreme Events that are an Integral Part of Natural Processes

We need to understand the workings of both, Society and Nature, to create sustainable and disaster-resilient communities.

Natural Disasters:

Natural Disasters (misnomer): when extreme natural events occur whose frequency-magnitude distributions are statistically predictable, and which are an integral part of natural processes, then

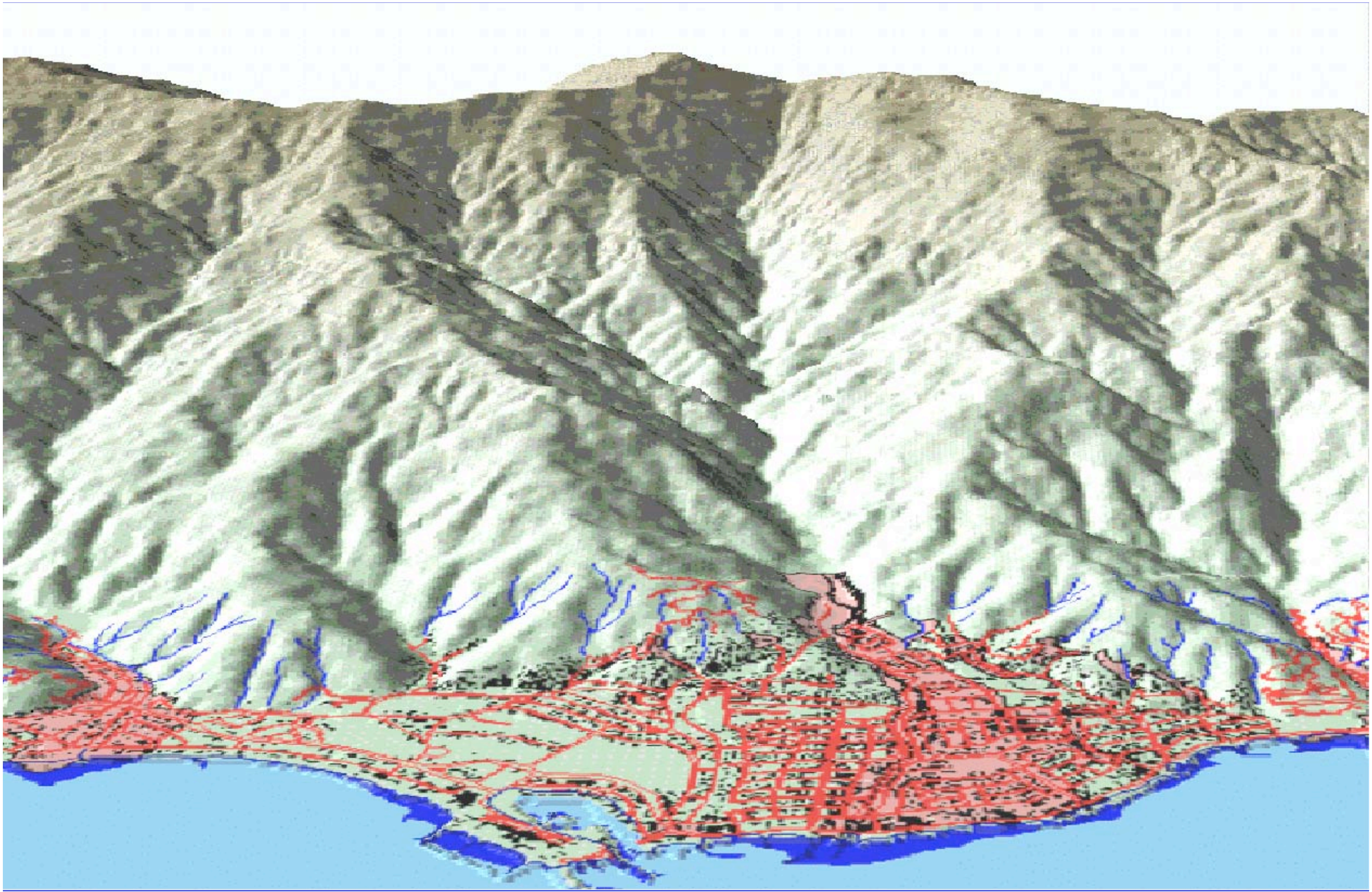
a) **if there is no human society - there are no disasters, just natural events**

b) **if natural hazards hit resilient societies - there are acceptable losses, but not disasters**

c) **if natural hazards hit vulnerable societies - disasters are inevitable**

Lesson: The Problem is Societal Vulnerability, not Nature! Nature is. Societies Evolve.

Issue: How can societies (re-)adapt to extreme natural events.



Example: North Coast of Venezuela, Province of Vargas, near Caracas, Mudslide Disaster, December 1999

Dec 1999 Flashfloods killed >30,000 in Venezuela

So: Why do Societies Take Risks, and Expose Lives and Assets to Hazards, Often Quite Unmitigated?

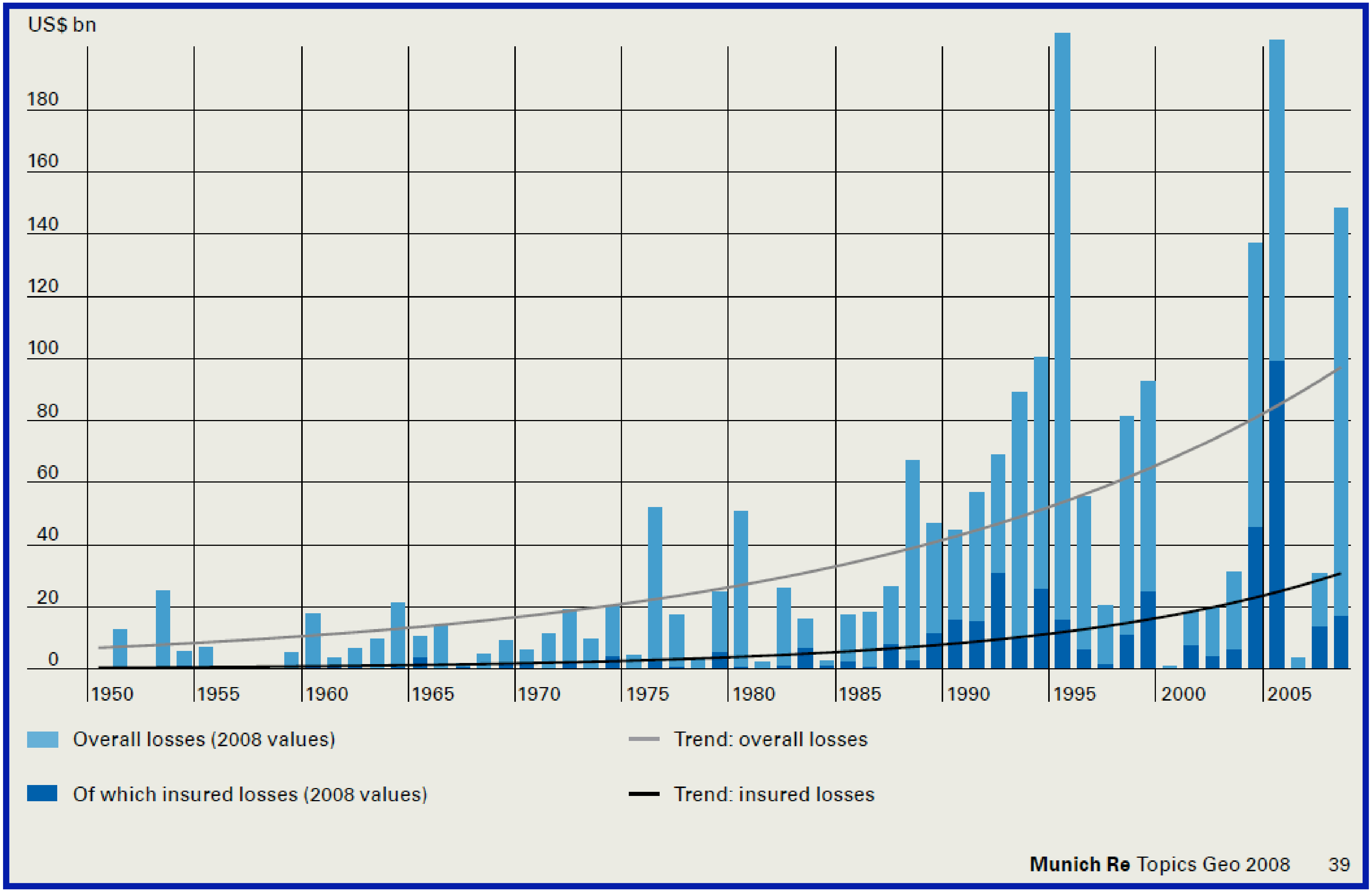
- **Disconnect** of Modern Societies from Nature. Geological vs. human time horizons. Ignorance of Real Hazards and Vulnerabilities, and hence of Risks, results often in a false Sense of Security.

- **Many People** have no Choice (Poverty, Equity & Equality, Political Issues) . But some People and Communities have Choices: Risk-Taking is Misplaced Hubris/Arrogance.

- **The Up-front Costs** of Hazard Mitigation are often Perceived to Outweigh the Long-Term Benefits. (Turns out not to be true, in most cases)

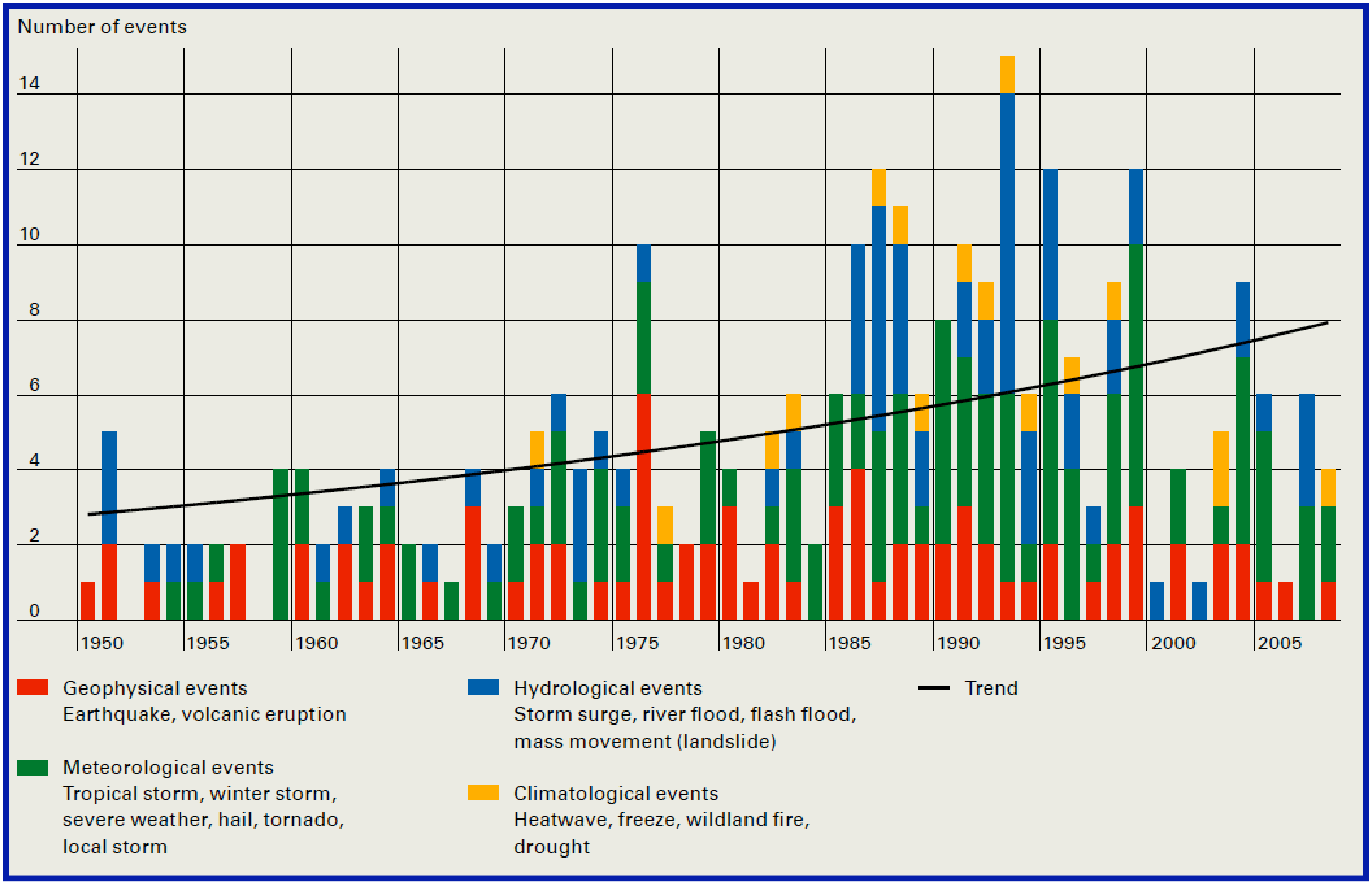
Rising Global Losses from Natural Disasters through 2008 (Munich Re)

http://www.munichre.com/publications/302-06026_en.pdf

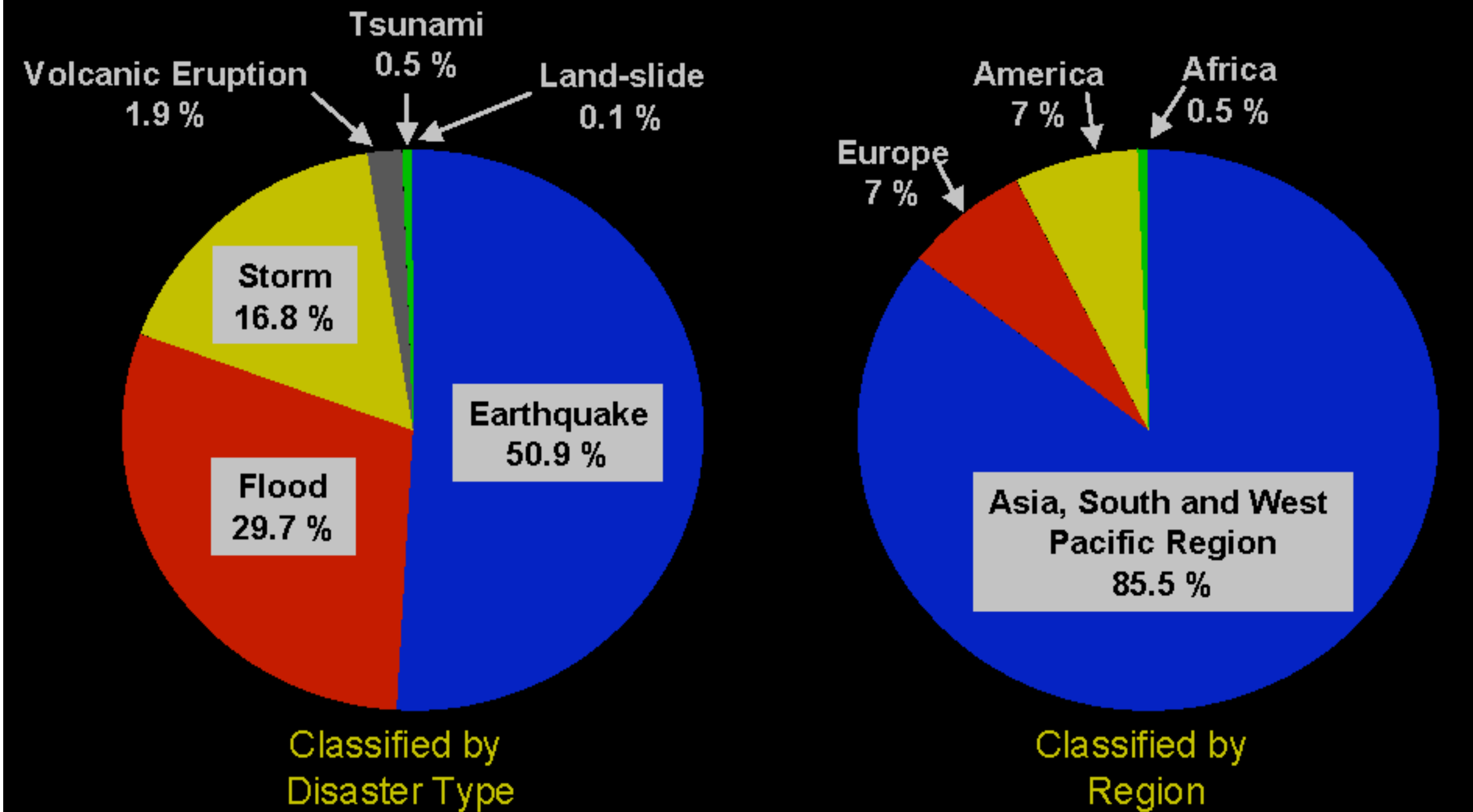


Number of Global Natural Disasters through 2008 (Munich Re)

http://www.munichre.com/publications/302-05703_en.pdf



Classification of Natural Disasters (Fatalities)



Note: No Drought Fatalities are shown !
Related Famines are often not considered of Natural Origin.

What is Risk ?

P= Probability (in the Future, => Uncertain)

P (Loss) = P (Hazard) x P (Consequence)

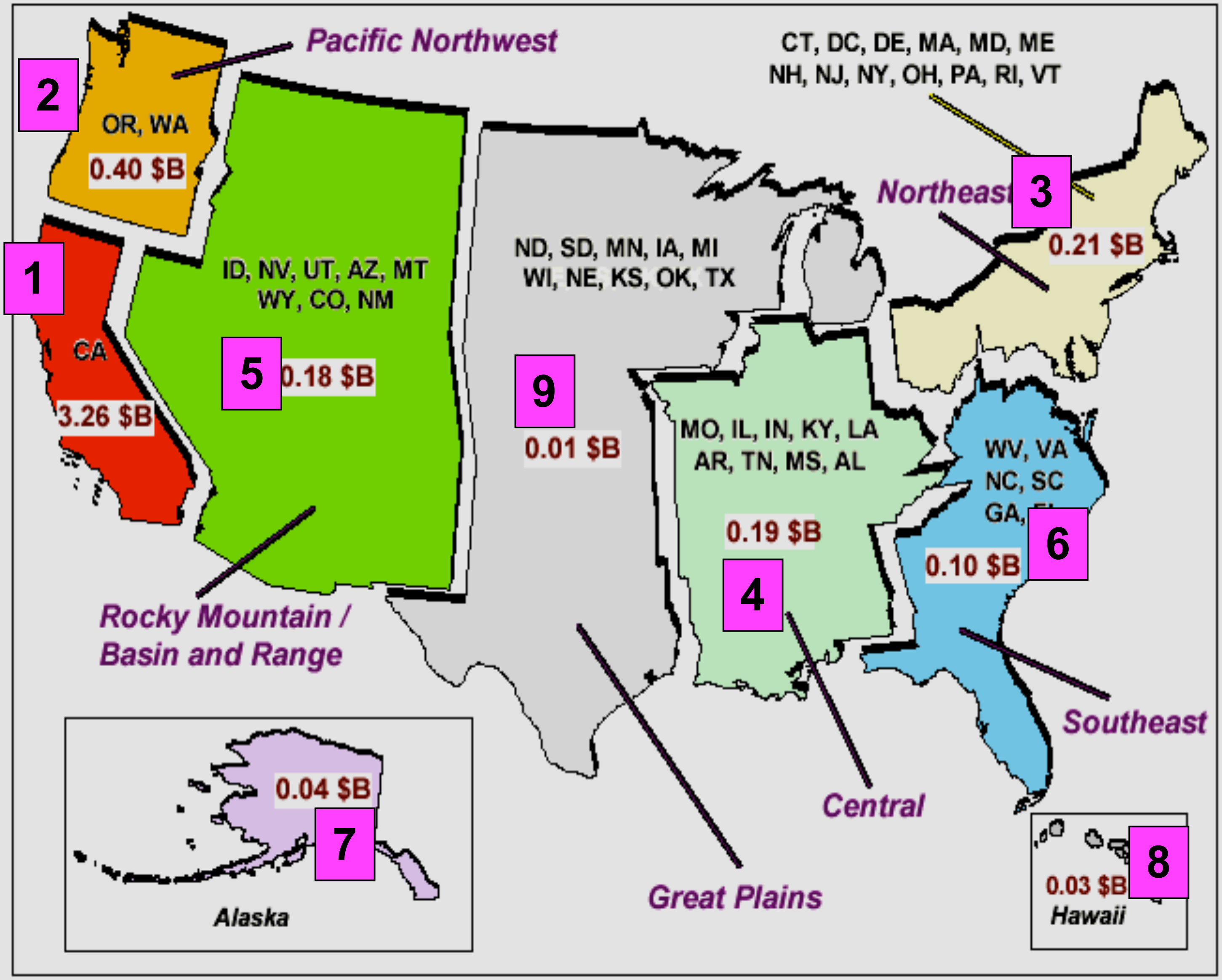
Risk (the expected future Loss) is the Product of 3 Factors, summed up over a given region:

$$\text{Risk} = \sum_{\text{Region}} (\text{Hazard} \times \text{Assets} \times \text{Fragility})$$

Risk can be evaluated probabilistically (annual exceedance probability) or deterministically for given scenario events (what if ..... ?).

Earthquake Losses for the United States

Estimated <u>ANNUALIZED</u> Earthquake Losses in the US



Two Types of Risk and Vulnerability: **Physical** vs. **Social**

$$\textbf{Risk} = \sum_{\text{Region}} (\textbf{Hazard} \times \textbf{Assets} \times \textbf{Vulnerability})$$

We differentiate between Physical Risks and Social/Economic Risks.

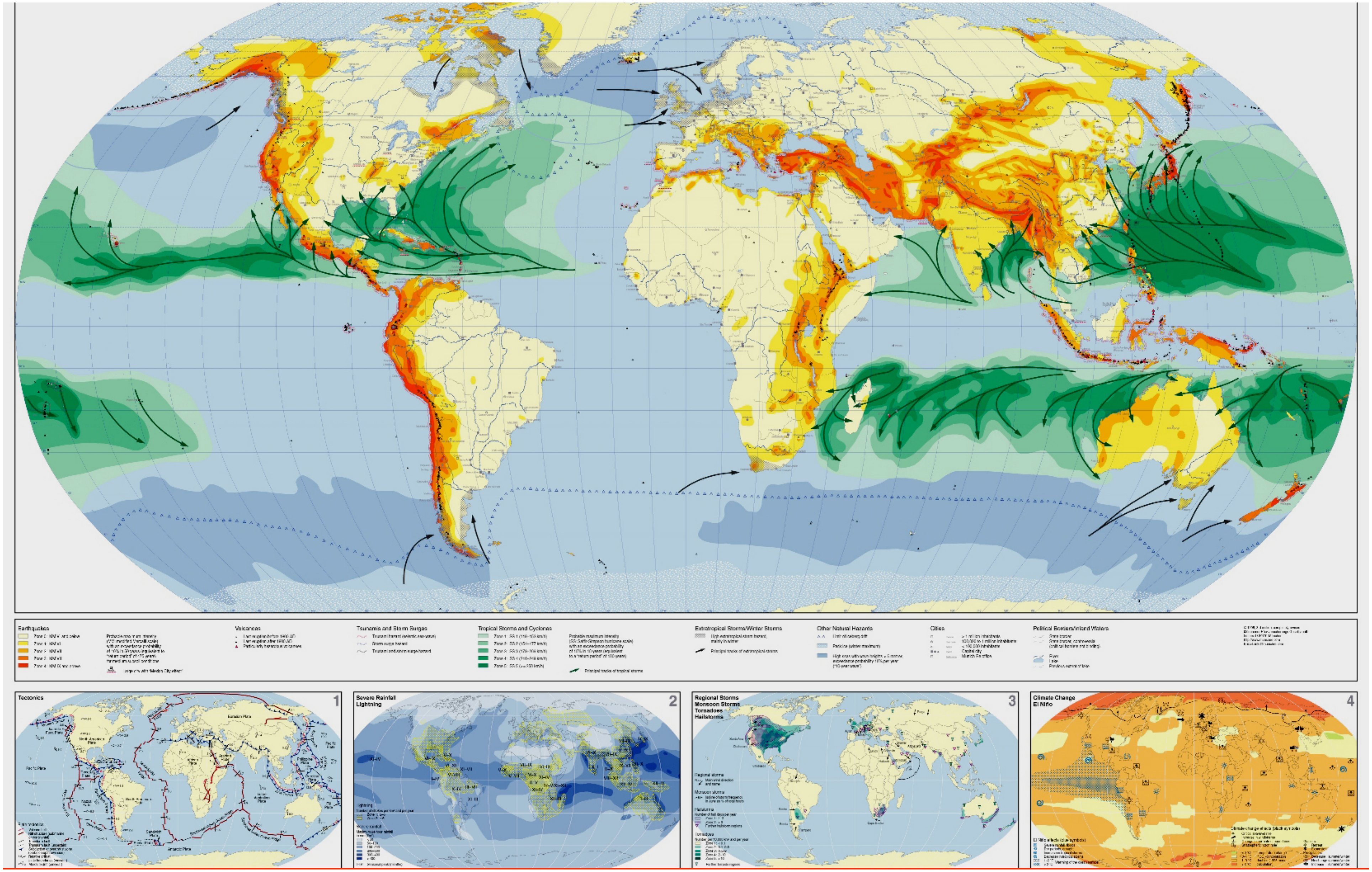
When assessing the Physical Risks & Associated Financial Costs then the Physical Vulnerability (also known as "Fragility", F) of the assets needs to be known (it is the fraction, ranging between 0 and 1, of the *Replacement Value* of an asset that is damaged or lost during an hazardous event of a given size (F=0, no damage; F=1, total destruction and hence total loss). The physical vulnerability F increases as the hazard severity increases.

The Social Vulnerability is a more complex construct. Its prime indicator is Poverty. And when hazardous events strike poverty-stricken societies, then both people's Lives *and* Livelihoods are at high risk.

But also the political stability of an entire country can be at risk after a major disaster (e.g. Nicaragua Earthquake, Dec 1972, 20,000 deaths in Managua, lead to the eventual fall of the conservative and autocratic Somoza Gov., and replacement by the more democratic socialist Sandinista in 1979).

Some Key Issues:

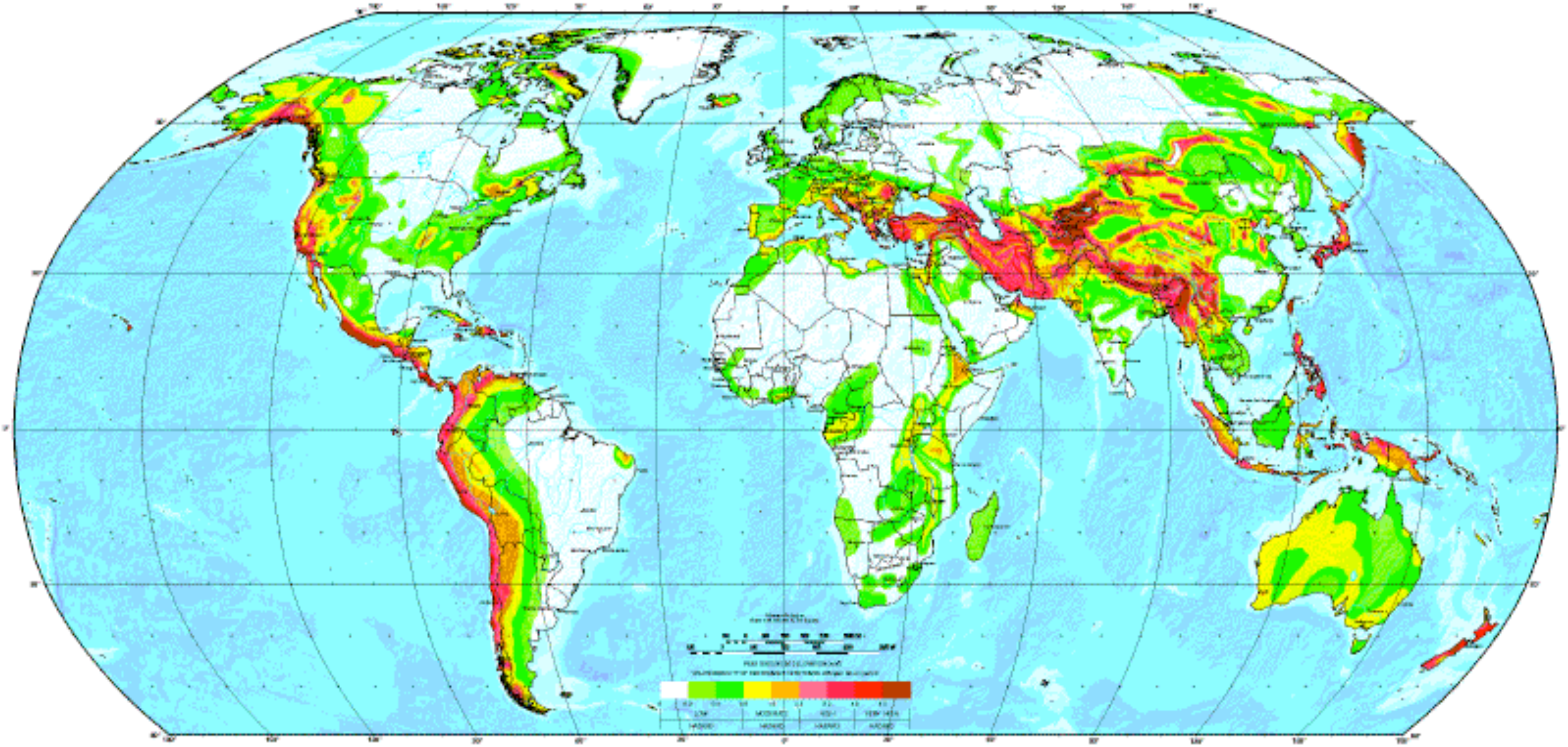
- **Hazards** (Natural Environment, ≈ const., except Climate)
- **Assets** (Demographic & Economic Trends, Urbanization)
- **Fragility** (Quality of Built Environment)
- **Risks** (Assets, Hazard, Fragility)
- **Vulnerability** (Social / Institutional Environment.)
- **Risk Management** (Risk Reduction; Vulnerability Reduction; Risk Distribution / Risk Sharing).



We will return to this & similar hazard maps in more detail

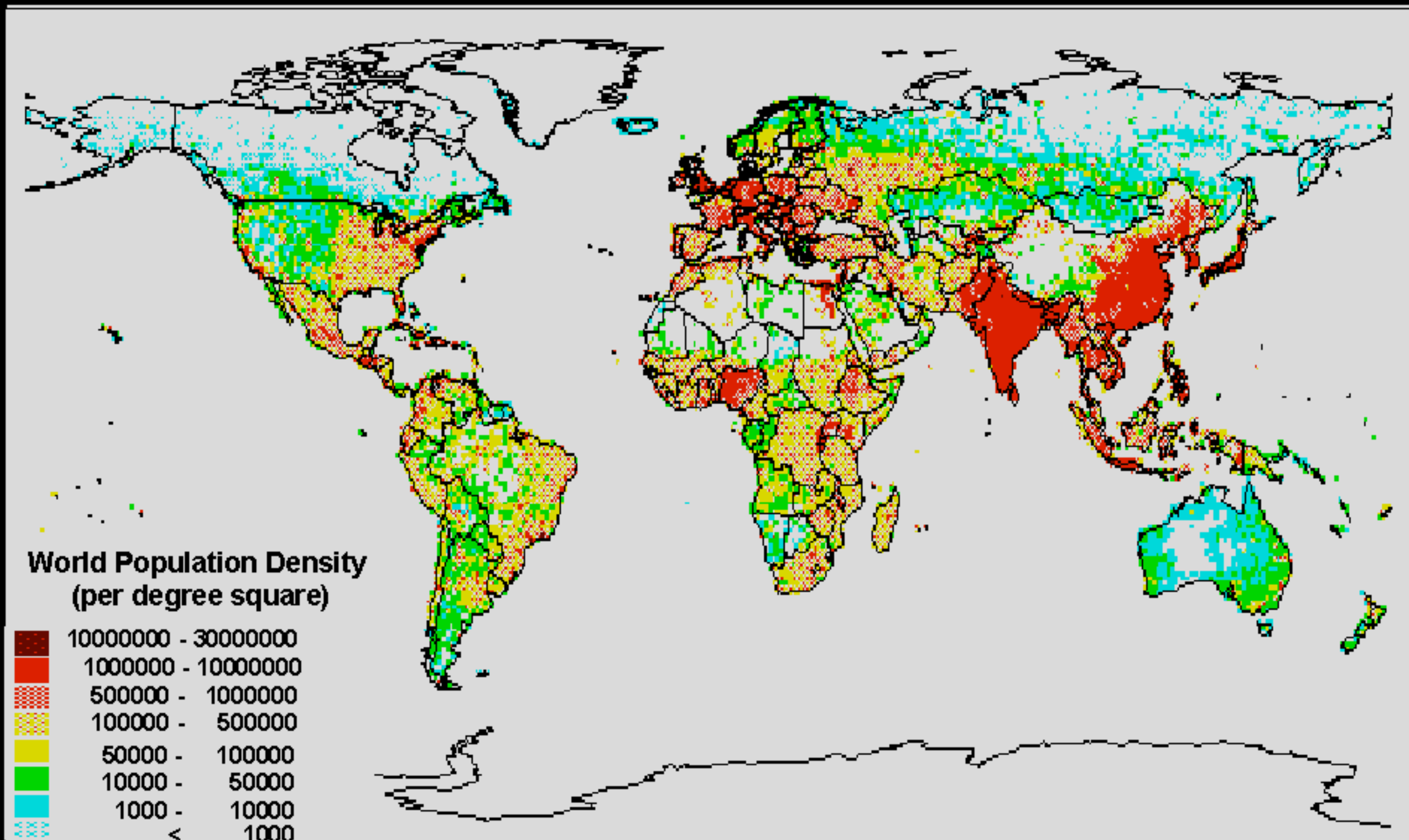
Source: Munich Re

GSHAP earthquake shaking hazard map



Shown is the level of ground shaking that is expected to be reached or exceeded with a probability of 10% in 50 years (or 90% probability <u>not</u> to be exceeded in 50 years), corresponding to an average recurrence period of ~ 500 years

Global Population



"ASSETS": ~7 Billion ($7x10^9$) People in 2011, and growing

Risk and Vulnerability (continued):

$$\text{Risk} = \sum_{\text{Region}} (\text{Hazard} \times \text{Assets} \times \text{Vulnerability})$$

For the same severity of hazardous events, **Financial** Losses in "More Developed" Countries (MDCs) are often higher (high assets) than in "Less Developed" Countries (LDCs); the reverse is true for Loss of Lives (MDCs = low vulnerability; LDCs = High vulnerability). And in MDCs the livelihood of families and communities is more likely to stay largely intact because of access to contingency resources, including insurance.

In LDCs hazardous events tend to kill a much larger fraction of the population, and while the fiscal losses may be in absolute terms smaller than in MDCs, they usually destroy more severely the livelihoods of communities, and recovery is hindered by lack of access to contingency resources or insurance. Help from the outside can be vital, but can bring with it new social stresses as well.

Vulnerability has been defined[1] as:

"The conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of Hazards".

[1] UN/ISDR. Geneva 2004.

Social Vulnerability (in the context of disasters)

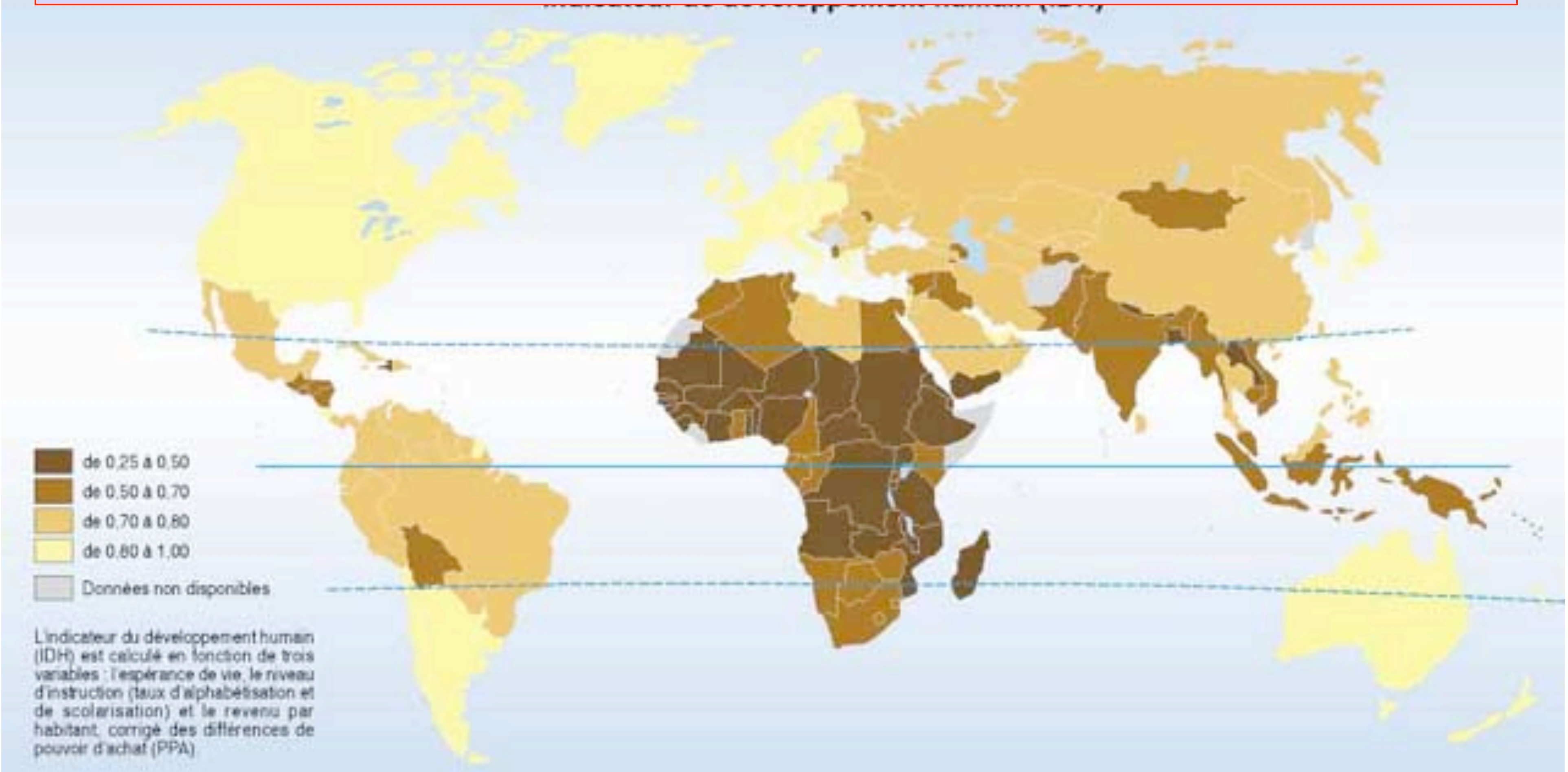
is the lack of personal, institutional or societal resilience to cope with the incurred losses and related social impacts of disasters (loss of shelter, sustenance, health & livelihood, disruption of social networks and support systems, trauma, crime, personal safety).

What are key factors that contribute to Vulnerability?

Some Examples of Vulnerability Factors:

- Poverty & Income Inequality
- Lack of Access to Coping-Resources incl. Knowledge
- Unavailability of Land Titles (perpetuates fragile Squatter & Shanty Towns)
- Inadequate participation of large sectors of civil society in the ‘democratic’ process (government).
- Governments lack the institutional infrastructure to provide risk management, emergency services, mitigation plans, and produce / enforce regulations.
- Means of Risk Distribution (Insurance) and for Providing Emergency Relief are often poorly developed or absent in vulnerable countries and communities.

Example of How to Measure Vulnerability: Human Development Index (HDI) of the United Nations Development Program, as determined for countries at the end of the 1990s



The HDI is calculated based on a combination of three factors:
1) Live Expectancy,
2) Educational Level (Literacy and Knowledge)
3) Income Level (Adjusted for Purchasing Power)

Disaster Risk Management (DRM):

- Mitigation by Reduction of Risk Exposure
- Adaptation to Risk (Preparedness, Build Resilience & Coping Capacity)
- Distribution of the Remaining Risk (Mutual Aid, Insurance)

There are various elements and stages of Disaster Risk Management:

- Constitutional / Legal / Institutional Framework, i.e. DRM requires clear organizational structures, e.g. Emergency Management Administrations at *all* Government Levels (I,N,R,L,F)
- Quantitative Hazard & Risk Identification & Assessment
- Risk Minimization (Long-term Mitigation, Cost-Benefit Analyses)
- Pre-Disaster Preparedness (Capacity Building, Education)
- Disaster Response (*First* Responders executing a Disaster Response Plan - Command and Control Issues, Incident Command System [ICS] provides Coordination, Information, Communication, Logistics, and Resource Allocation)
- Post-Disaster Relief (temporary), and then Recovery (final*)
- Risk Distribution (Mutual Aid Agreements, Insurance)

* Includes Mitigation against Future Events

Some Basic Principles and Tools of Disaster Risk Management:

- Nothing can be well managed that cannot be measured.
- Hence, the need for **Risk Assessment as a Starting Point.**
- How is Risk assessed?
  - By *quantifying* the different **Hazards,** in terms of their spatial distributions of severity and frequency of occurrence.
  - By evaluating the **Assets** (their monetary value and livelihood importance) that are exposed to the different hazards.
  - By evaluating the **Vulnerability** (Fragility) of the Assets to different Hazard Types and Hazard Severity.
  - By computing the risk via the *risk equation* (aided by computerized GIS tools, where available). Estimate the loss magnitudes vs. their frequency of occurrence. Add up all likely losses (small and big) over time, over space and analyze their economic *and* social impacts on the nation(s), regions, communities, and by sectors of the national and local economies.

Risk Management Tools (continued):

- One Objective of Risk Management is Minimizing the Risk via Risk Mitigation Measures (Let's use the Risk Equation !) :

Risk = Sum (Hazard x Assets x Vulnerability)

$$\underbrace{\text{Hazard} \times \text{Assets}}$$

Land Use Planning & Zoning,
Considerate Placements of new Assets,
Relocation of Essential Assets. Equity Issues.

or, alternatively by

Risk = Sum (Hazard x Assets x Vulnerability)

$$\underbrace{\text{Assets} \times \text{Vulnerability}}$$

Good Engineering, Construction Quality-Control,
Codes and Code Enforcement, Retrofitting

- Multiple Risk Computations may be needed to explore the Optimal Mitigation Measures by Cost-Benefit Analysis for various Levels of Performance: Life Safety, Sustainable Livelihood, Acceptable Economic Losses. Essential vs. Ordinary Facilities.

More Risk Management Tools (continued):

- Pre-Disaster Preparedness
  - Planning, Capacity Building, Institutions, Rehearsing, Education
- Disaster Response
  - Command and Control (ICS) including international coordination
  - Communication and Information
  - Logistics
  - Field Execution
  - Accounting and Checking
- Post-Disaster Relief and Ultimate Recovery
  - Who is in charge, what resources are available, strict accounting and avoidance of corruption, humanitarian & equality issues. Long-term Mitigation vs. Short-term Recovery Needs. Preplanning (Master Plan) prior to Disasters!
- Risk Distribution :
  - Aid Agreements and Insurance.

Summary:

- A disaster is not the time to start DRM planning. “PEPPER”:
  Pre-Event Preparedness, Post-Event Recovery
- Extreme Events become Disasters only when they strike Vulnerable Communities.
- DRM includes 3 options: Mitigate Risk (Landuse, Zoning, Codes, Engineering)
  Adapt to Risk (Preparedness, Coping Capacity)
  Distribute Risk (Insurance etc.).
- Long-term Essence of DRM: Reduce Physical & Social Vulnerability to Disasters (Reduce Poverty !! Feedback !!).
- DRM is intrinsically interwoven with the Sustainable Development of Countries.
- Bottom-up involvement of Communities in DRM tends to be more effective than top-down DRM.
- Long-term Mitigation is Cost-Effective (in US: about ~ 4 : 1 benefit/cost-ratio).
- Global Climate Change increases some Risk Exposure for all Nations, but more so for a few (e.g. small islands and Pacific atoll nations).

Questions?

1a

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Topic 1b :
Natural (mostly Equ.) Hazards & Risks: Basic Concepts (Continued)

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What is Risk ?

P (Loss) = P (Hazard) x P (Consequence)

Risk (the expected future Loss) is the Product of 3 Factors, summed up over a given Region:

Risk	= SUM	(**Hazard**	x	**Assets**	x	**Fragility**	)
[Prob of $/T]	Region	[Prob. of $H \geq h$/Time T]		A [$]		$[0 \geq F(h,A) \geq 1]$	

Risk can be evaluated probabilistically (annual exceedance probability) or deterministically (P=1) for given scenario events (what if ….. ?).

Some Basic Principles and Tools of Disaster Risk Management (Repeat from Lecture 1a !):

- Nothing can be well managed that cannot be measured.
- Hence, the need for **Risk Assessment as a Starting Point.**
- How is Risk assessed?
  - By *quantifying* the different **Hazards,** in terms of their spatial distributions of severity and frequency of occurrence.
  - By evaluating the **Assets** (their monetary value and economic & livelihood importance), that are exposed to the different hazards.
  - By evaluating the **Vulnerability** (Fragility) of the Assets to different Hazard Types and Hazard Severity.
  - By computing the risk via the ***risk equation*** (aided by computerized GIS tools, where available). Estimate the loss magnitudes vs. their frequency of occurrence. Add up all likely losses (small and big) over time, over space and analyze their economic *and* social impacts on the nation(s), regions, communities, and by sectors of the national and local economies, security, and political stability.

Statistical Predictability:

- Magnitude (Size) Distributions of Natural Events, Their Frequency of Occurrence, and Probability of Losses and Fatalities as a Function of Event Size (Power Law Distributions, Fractal Dimensions)

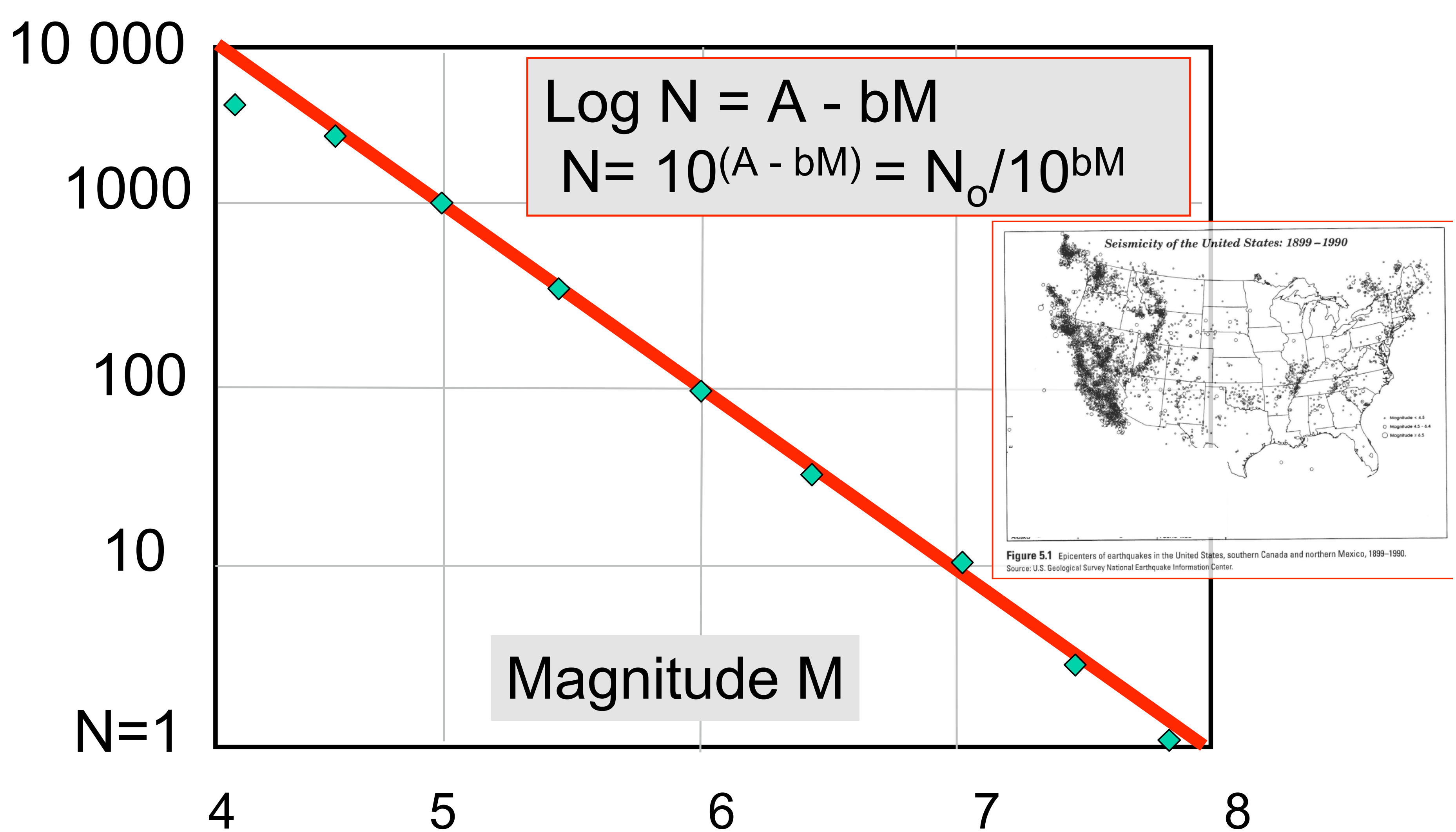
- Statistical Predictability ("on average ...", "but with given dispersion or variance from the average")

- A single event does not make a statistics, but each single event contributes to it.

Example 1: Earthquake Frequency vs. Magnitude

Example 2: Natural Disaster Loss Distribution

Example 3: Earthquake Fatality Distribution

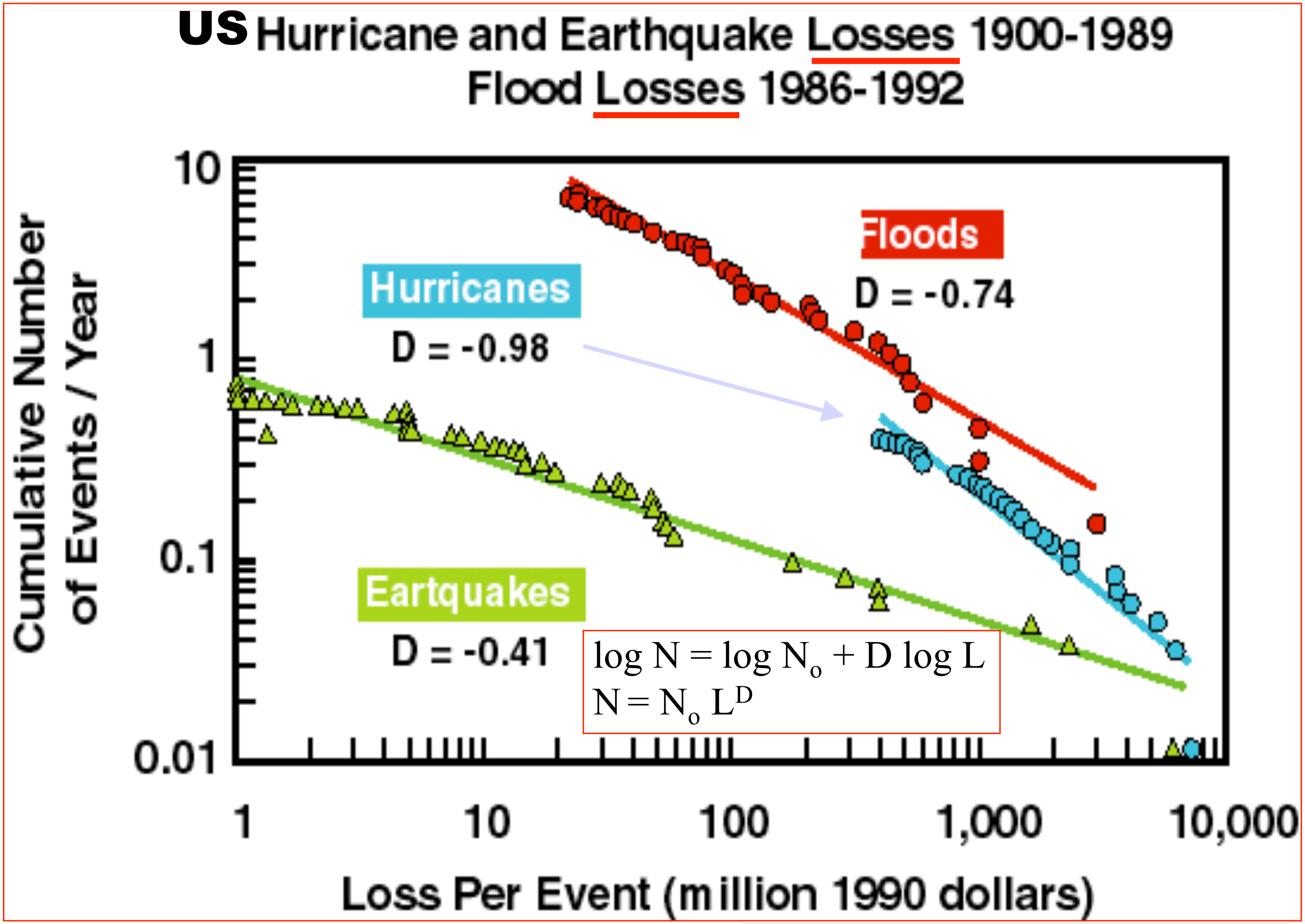


Schematic Example 1: Gutenberg-Richter Magnitude / Frequency Relation

Cumulative Number N of Earthquakes per 100 yr in the Contiguous US vs. Magnitude M (and larger).

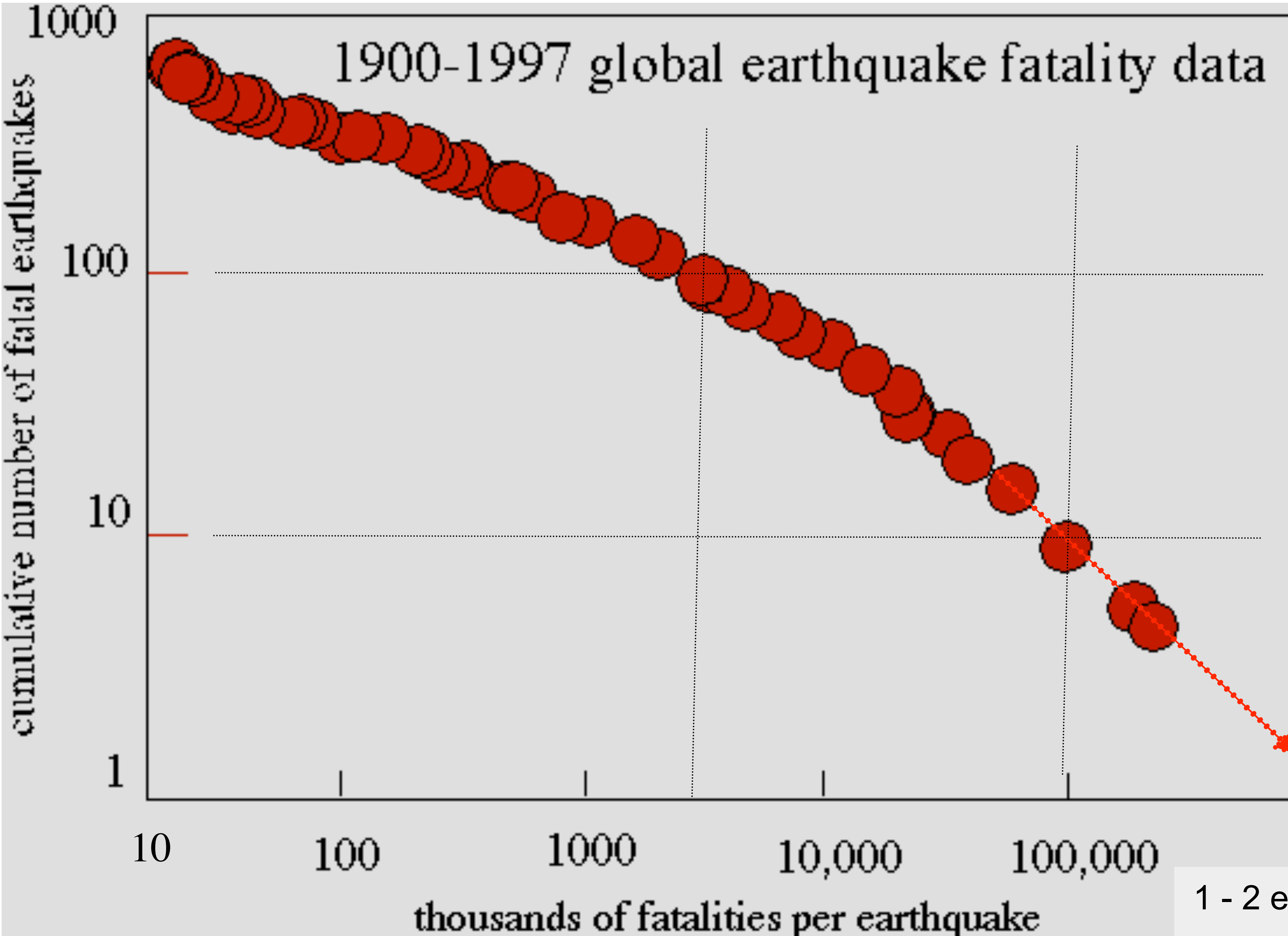
Example: A=8, and b=+1 (Slope is -1); "Cumulative Power Law"

Example 2: Annual US Nat. Disaster Losses (US $)



D is called the "Fractal Dimension"

Example 3:



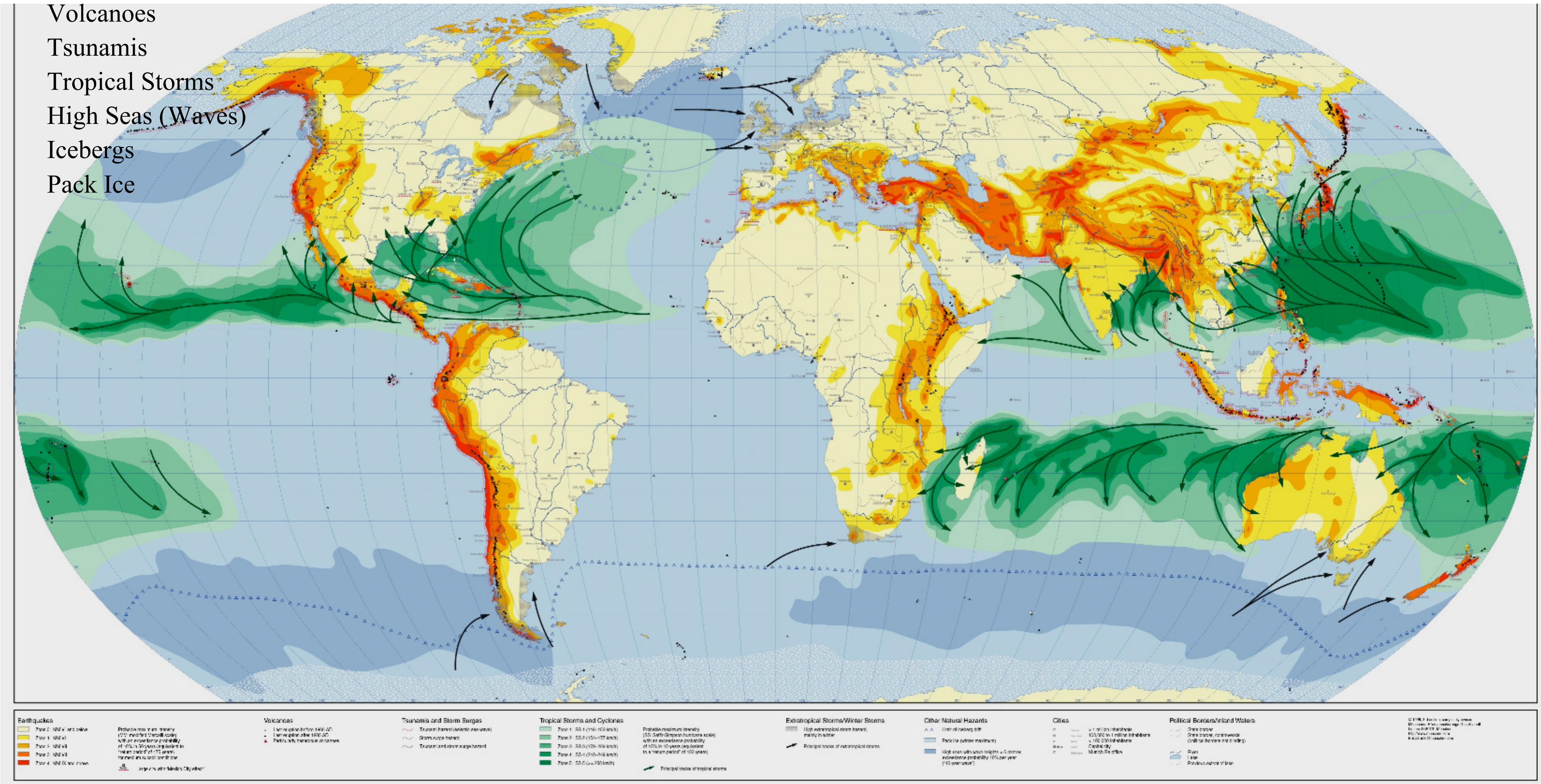
1 - 2 events per century with 1 Million fatalities

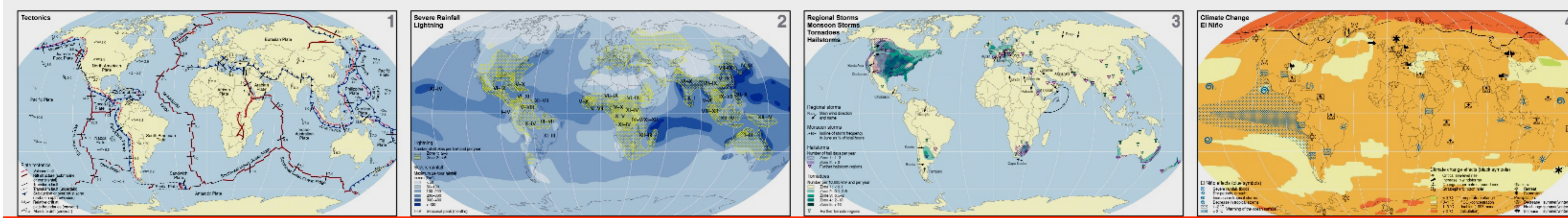
There are different Types of Natural Hazards (Perils)

- **Geologic Hazards**
  - Earthquakes
  - Landslides
  - Volcanoes
  - Land Subsidence/Uplift
  - ....
- **Atmospheric, Hydrological & Climate Change Hazards**
- **Extraterrestrial Hazards**

\- **Slow- and Fast-Onset Hazards**

\- **Local, Regional, Global**





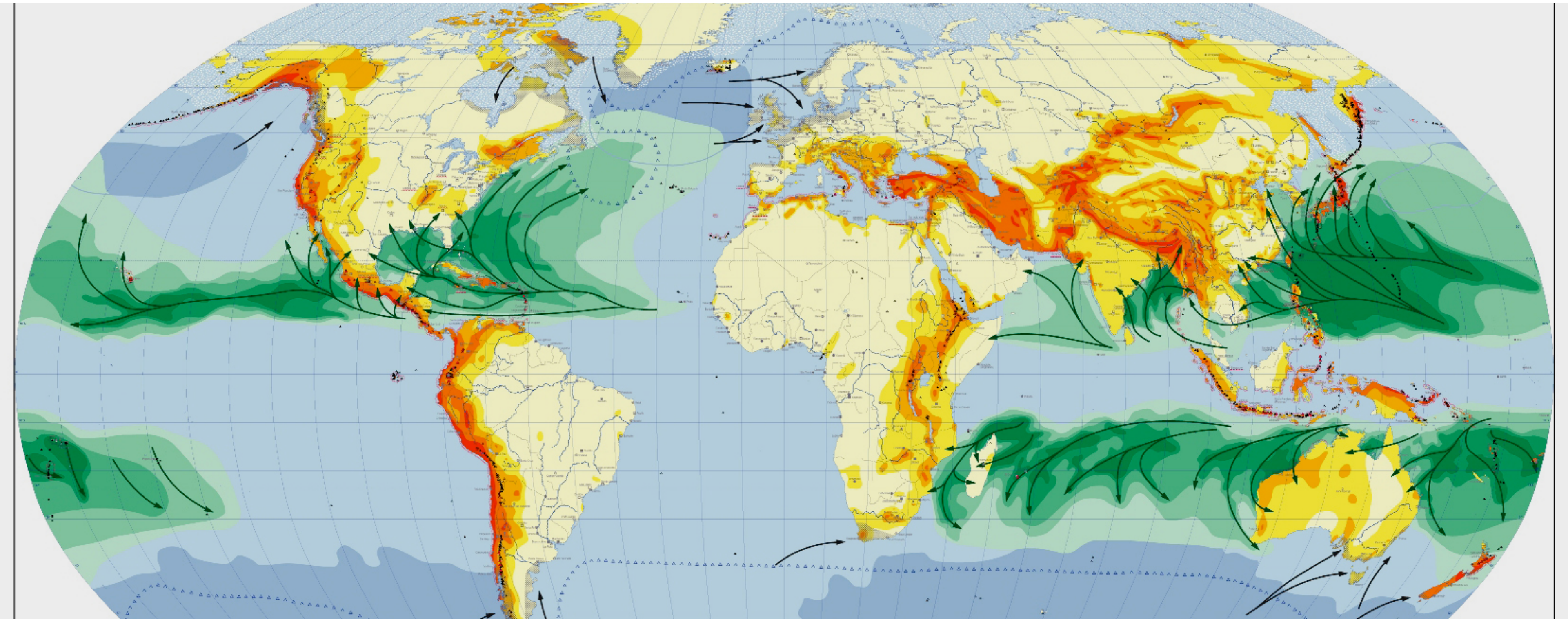
Tectonics

Severe Rain & Lightning

Storms: Regional, Monsoon , Hail, Tornadoes

Climate Change: Rising Temp., El Nino - Southern Oscillation - ENSO, Draught, SLR .....

Source: Munich Re



Earthquakes

- Zone 0: MM V and below
- Zone 1: MM VI
- Zone 2: MM VII
- Zone 3: MM VIII
- Zone 4: MM IX and above

Probable maximum intensity (MM: Modified Mercalli scale) with an exceedance probability of 10% in 50 years (equivalent to a "return period" of 475 years) for medium subsoil conditions.

Osaka Large city with "Mexico City effect"

Tropical cyclones

Peak wind speeds*

- Zone 0: 76–141 km/h
- Zone 1: 142–184 km/h
- Zone 2: 185–212 km/h
- Zone 3: 213–251 km/h
- Zone 4: 252–299 km/h
- Zone 5: ≥ 300 km/h

* Probable maximum intensity with an exceedance probability of 10% in 10 years (equivalent to a "return period" of 100 years).

Typical track directions

Volcanoes

- Last eruption before 1800 AD
- Last eruption after 1800 AD
- Particularly hazardous volcanoes

Tsunamis and storm surges

- Tsunami hazard (seismic sea-wave)
- Storm surge hazard
- Tsunami and storm surge hazard

Iceberg drifts

Extent of observed iceberg drifts

Types of Natural Hazards

- Geologic Hazards

    Earthquakes & Seismic Hazards

        Overview (later lectures more quantitative)

    Land Subsidence/Uplift

    Landslides

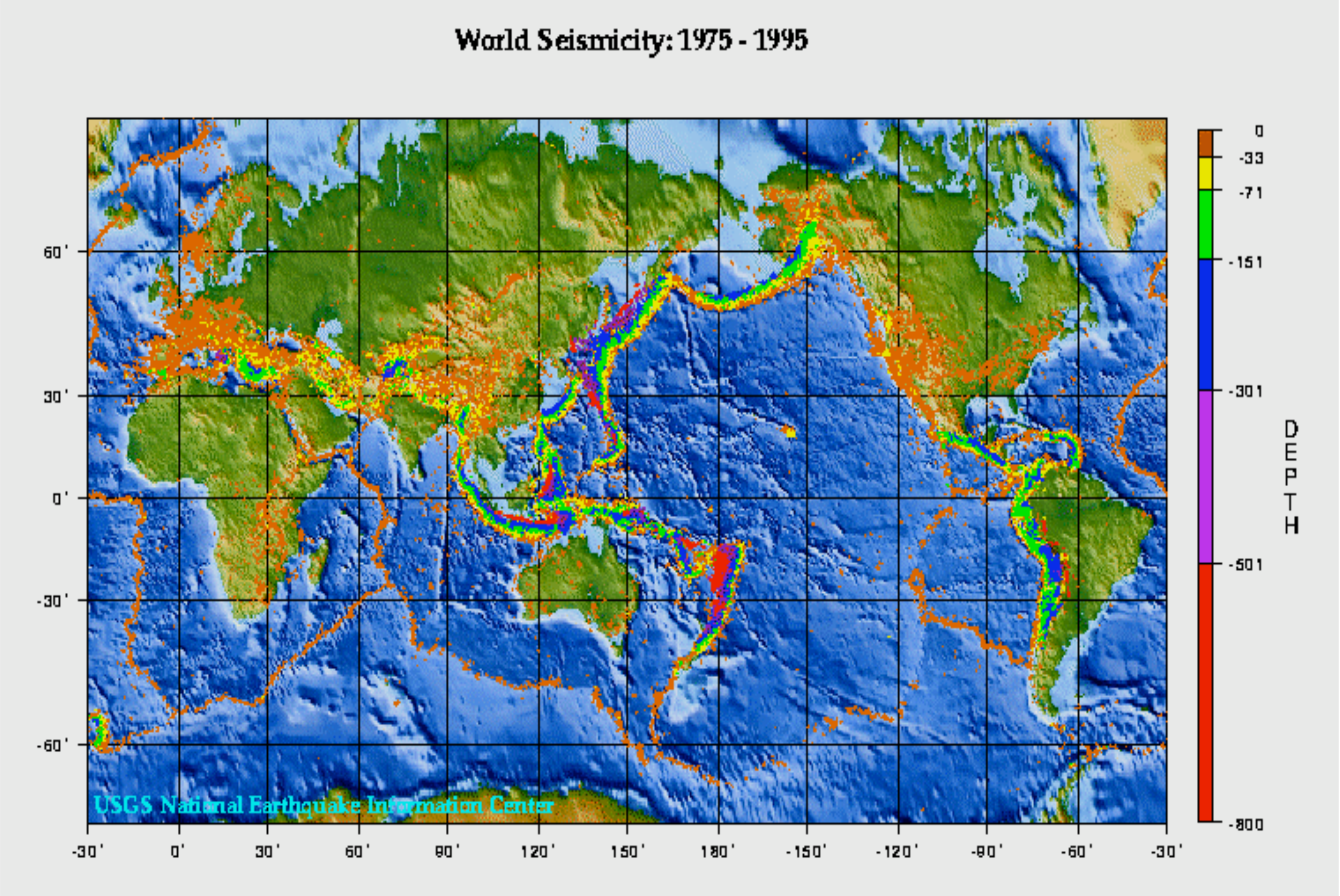
    Volcanoes

    ....

- Atmospheric, Hydrological & Climate Change Hazards

- Extraterrestrial Hazards

- Slow- and Fast-Onset Hazards
- Local, Regional, Global


World Seismicity: 1975 - 1995
60'
30'
0'
-30'
-60'
-30'
0'
30'
60'
90'
120'
150'
180'
-150'
-120'
-90'
-60'
-30'
0
-33
-71
-151
-301
-501
-800
DEPTH
USGS National Earthquake Information Center

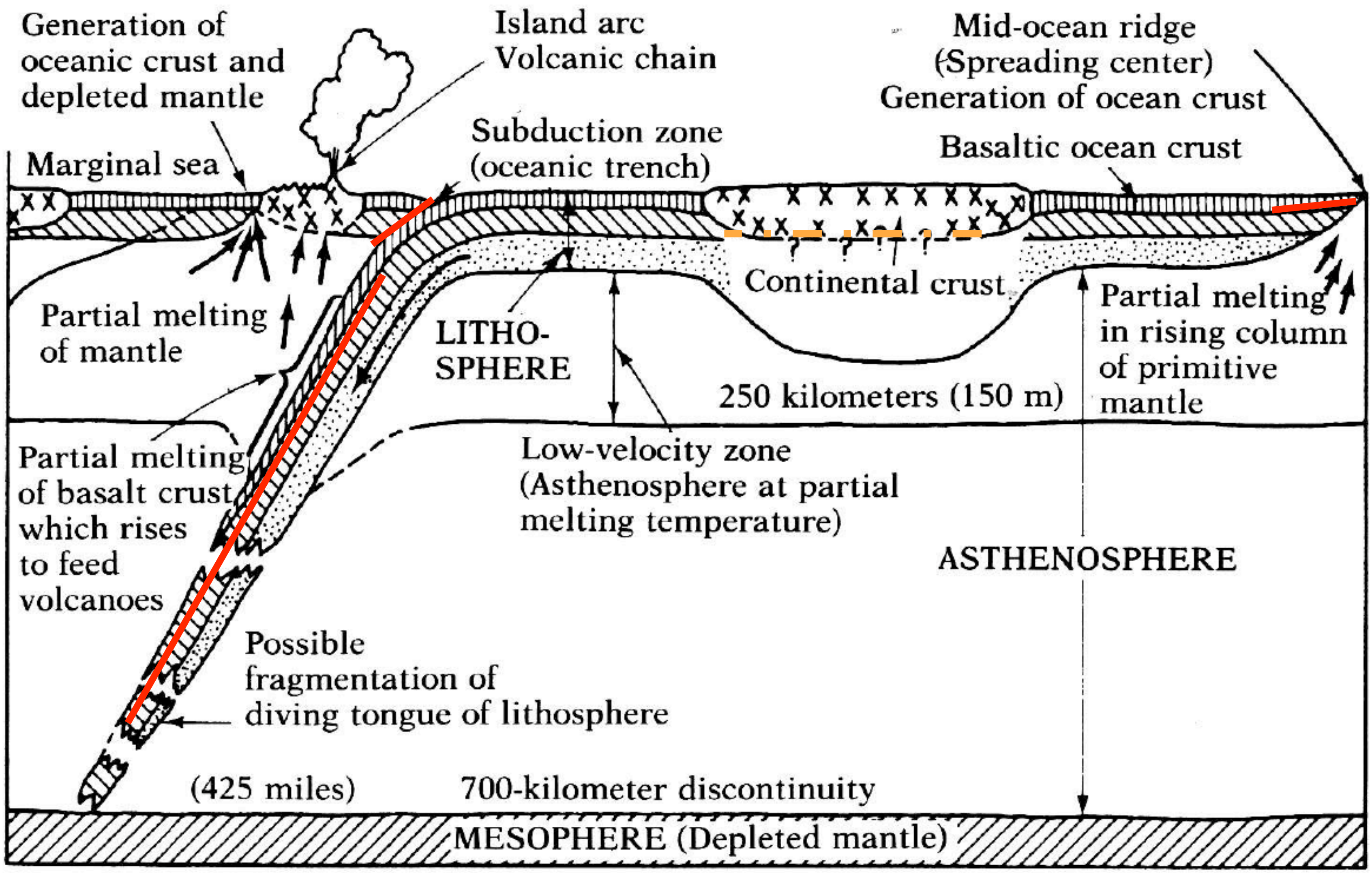
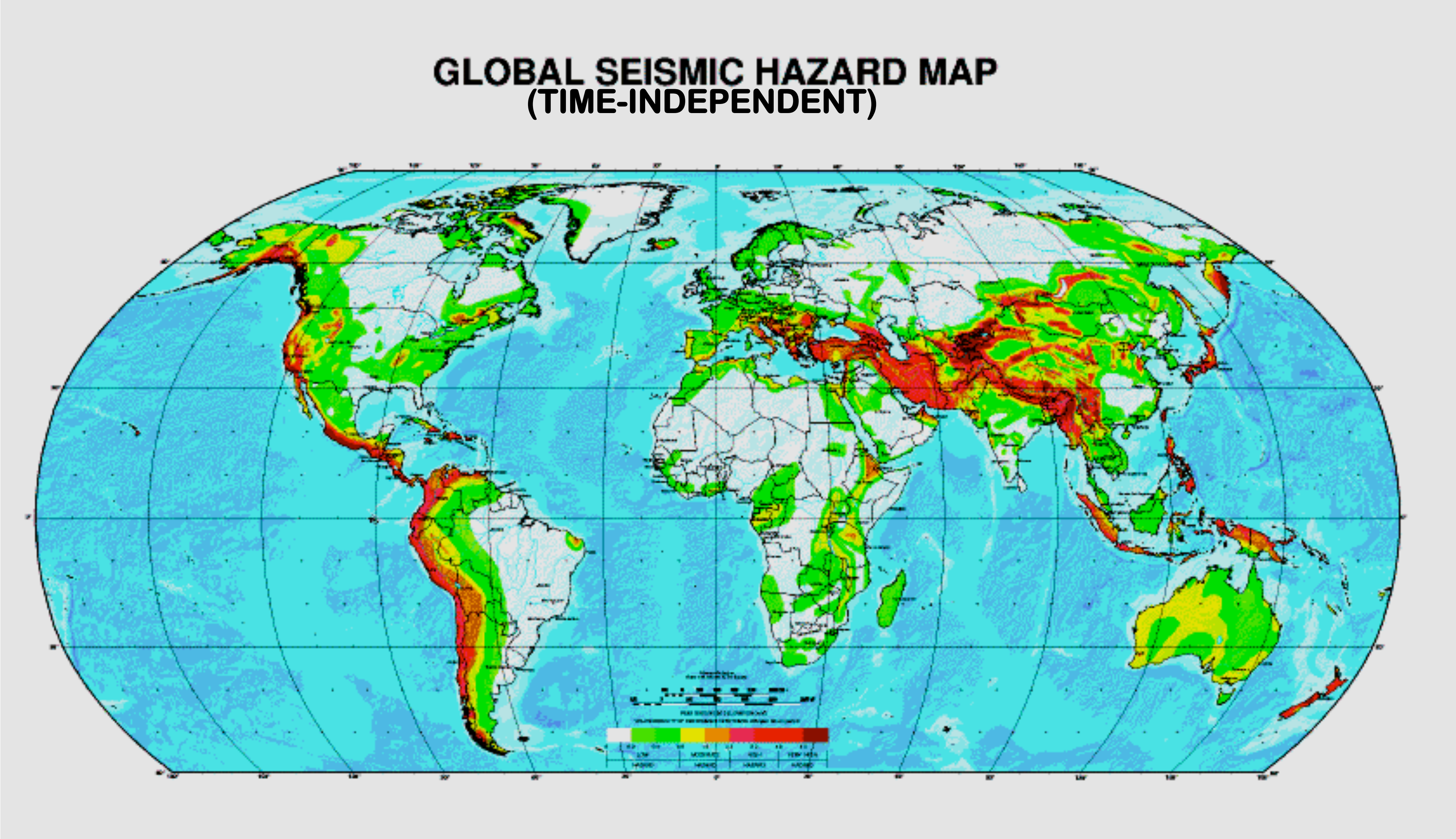


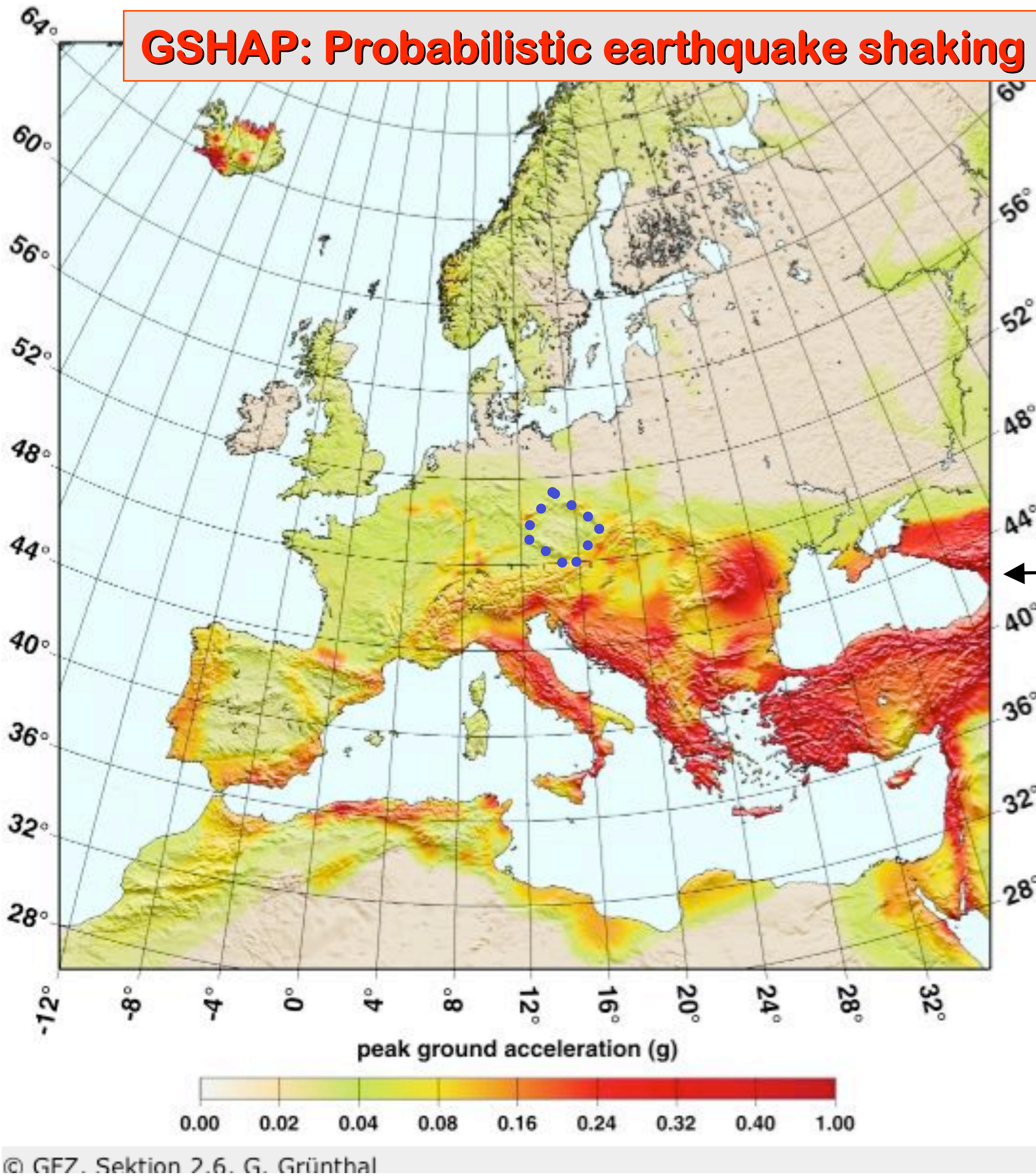
FIGURE 4.3 Schematic cross-section of a lithospheric plate (after Dewey 1972). Note that the mantle includes the mesosphere, the asthenosphere and the lower part of the lithosphere. Changes in rock composition or properties define the boundaries between these elements.

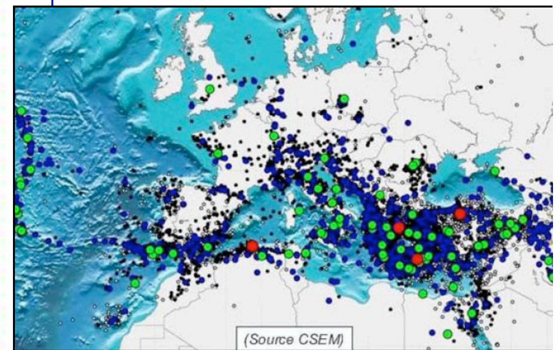
GSHAP: Probabilistic earthquake shaking hazard map



The indicated peak ground accelerations (in “g”) have a 10%probability to be exceeded in 50 years (Average recurrence period of ≈500 years)
(grn=2-8%g; ylw=8-16%g; rd=16-48%g; brwn≥48%g)

GSHAP: Probabilistic earthquake shaking hazard map

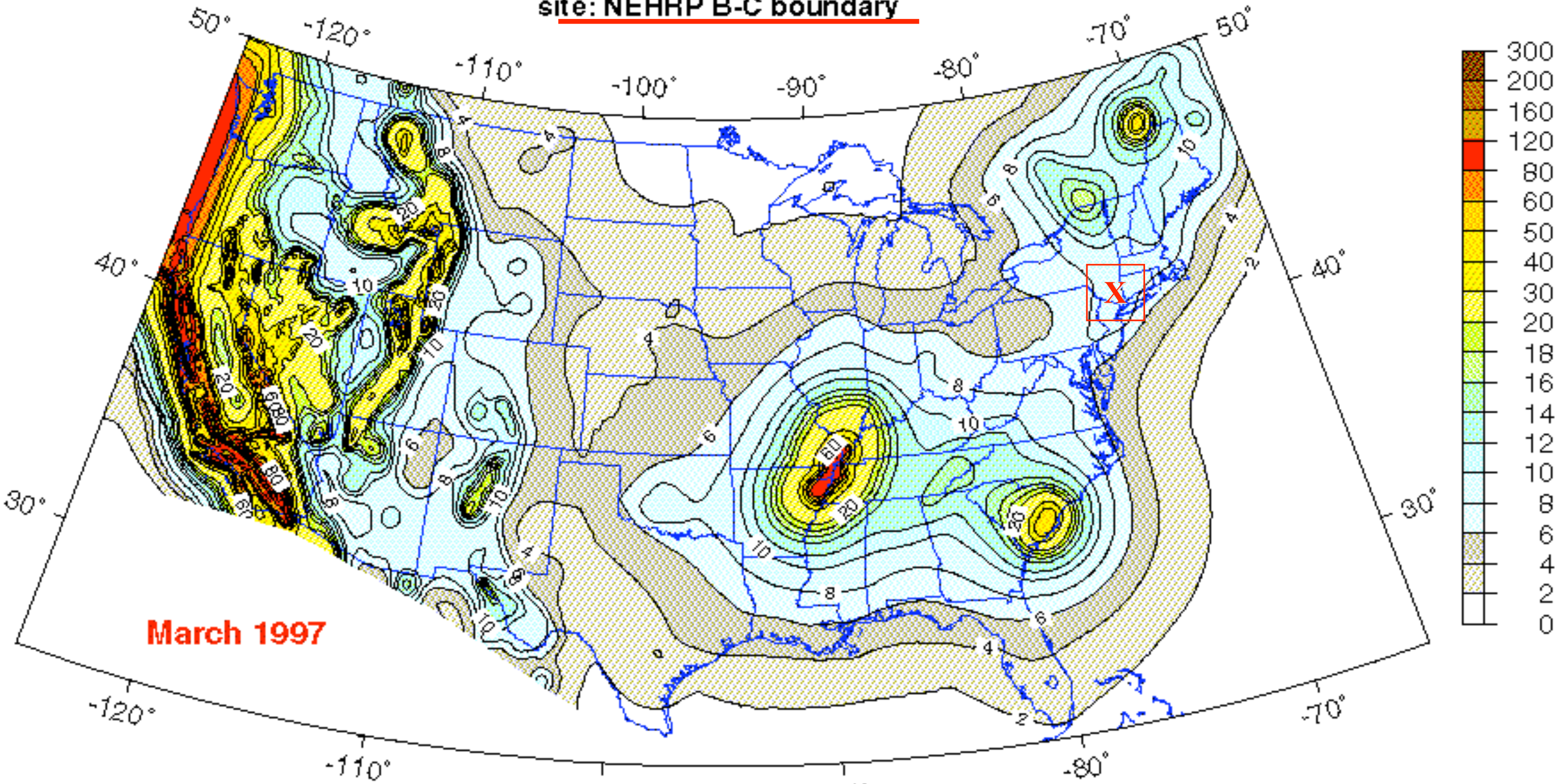




Shown is the level of ground shaking (peak acceleration, in units of Earth's gravitational acceleration g) that is expected to be reached or exceeded with a probability of 10% in 50 years (or 90% probability not to be exceeded in 50 years), corresponding to an average recurrence period of ~ 500 (actually 475) years

1.0 sec Spectral Accel. (%g) with 2% Probability of Exceedance in 50 Years

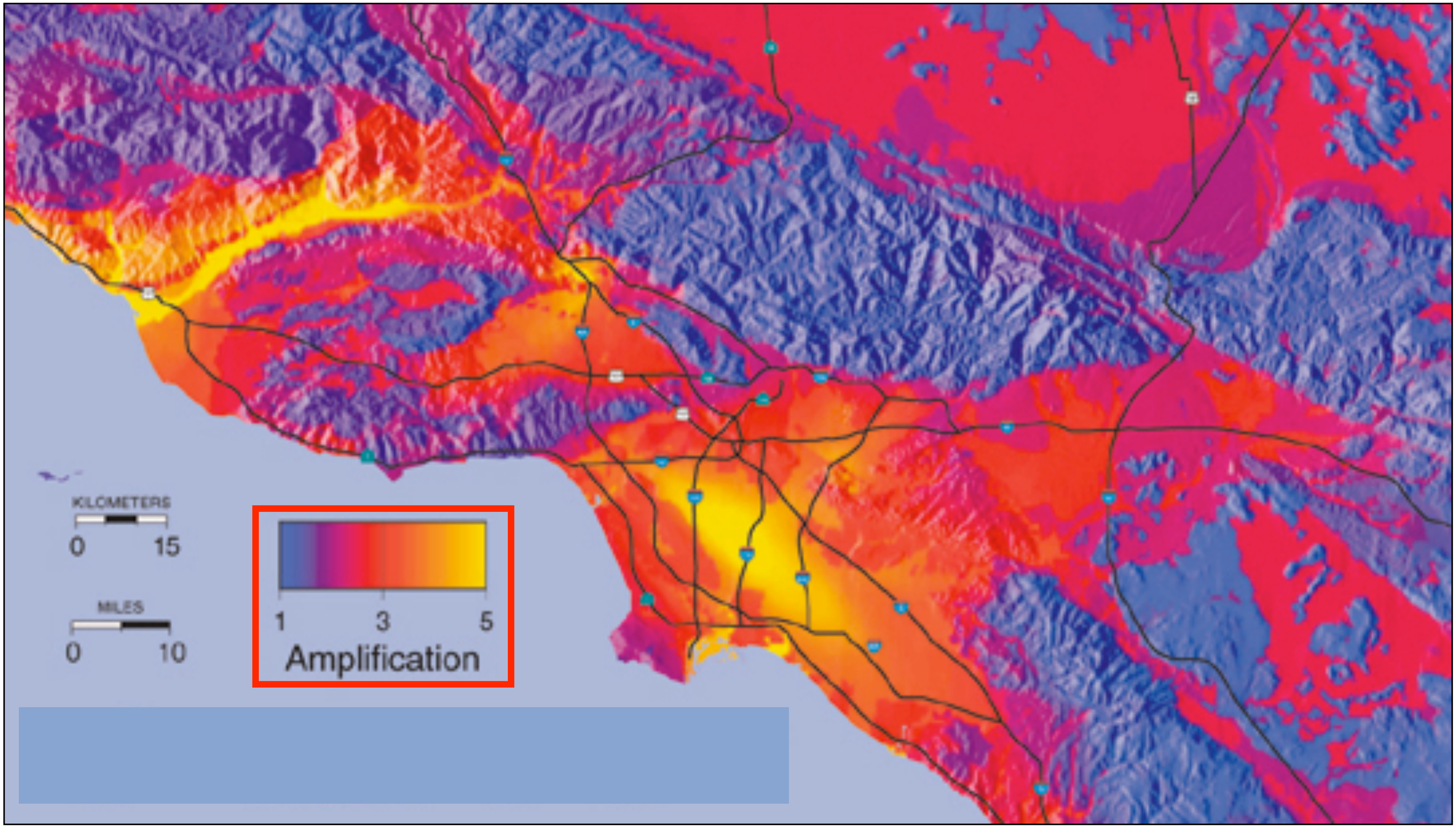
site: NEHRP B-C boundary



U.S. Geological Survey
National Seismic Hazard Mapping Project

$T_R = 2475 \text{ yr} \sim 2500 \text{ yr}$

Site Response / Microzonation



Site Response ..... is the local modification of ground motions due to near- & sub-surface soil and rock conditions. Microzonation Example: Ground Shaking Amplification Map of the L.A. Basin and vicinity (Field et. al., 2000)

Earthquake-Related Hazard Effects:

- Shaking & Related Collapse Hazards
- Soil Amplification, Liquefaction & Collapse
- Surface Faulting
- Land Deformation (Subsidence, Emergence)
- Land Slides & Rockfalls
- Tsunamis & Seiches
- Associated Hazards: Fires, Inundation
- Epidemiology of Earthquakes

Shaking :

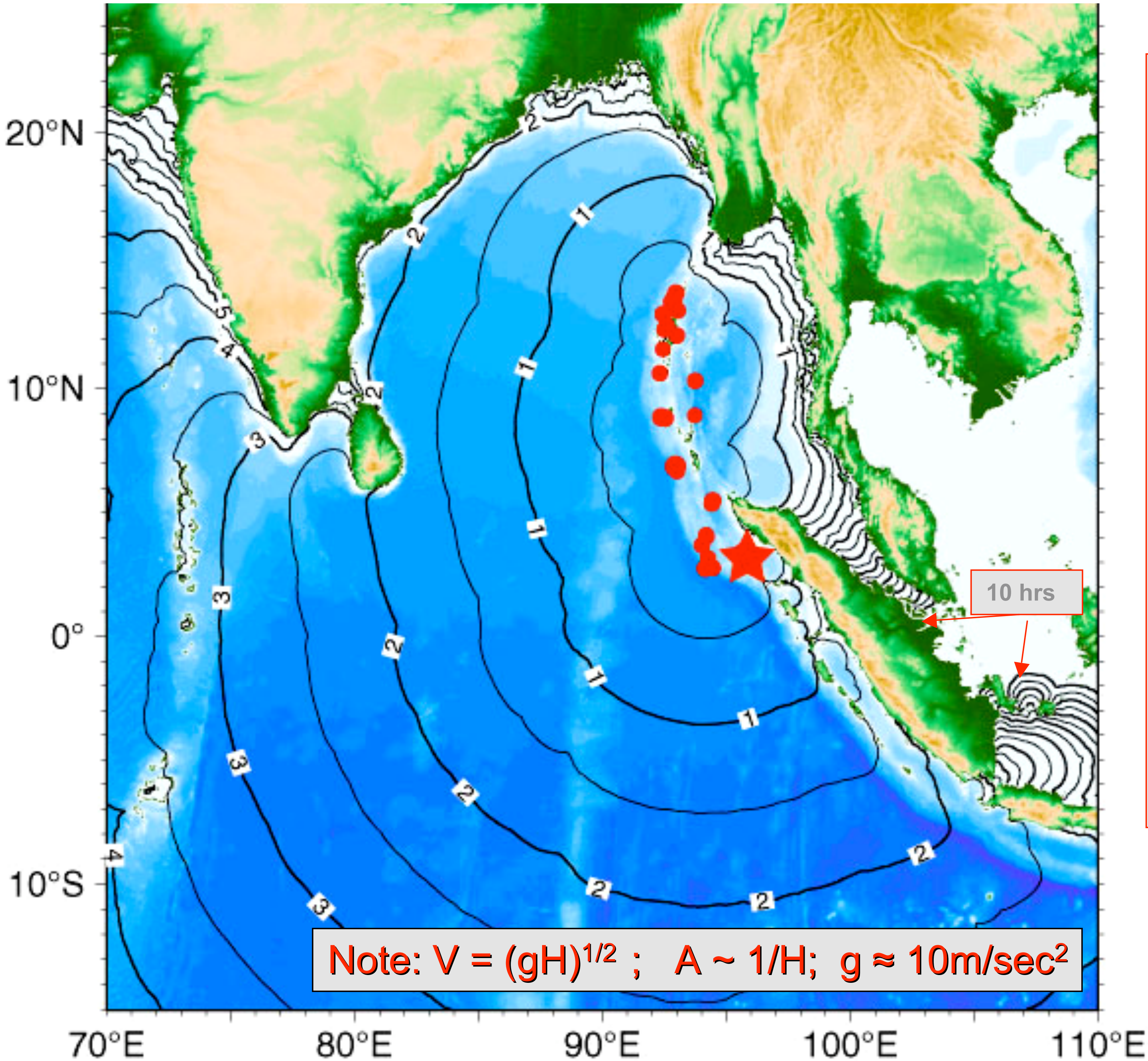
Earthquakes don't kill, Buildings do !!

Anchorage, Alaska, 1964
M_w=9.2

Shaking: Whittier Earthquake, CA, ca. 1986
Unreinforced Masonry is Brittle & Fails Easily

SOIL LIQUEFACTION: Niigata Earthquake, Japan: When Soils Liquefied and Lost their Bearing Strength, Houses Sank &Tilted Slowly

Tsunami during Alaska 1964 earthquake, M=9.2, causes damage to tank farm. Note: $V = (gH)^{1/2}$; $A \sim 1/H$; $g \approx 10 m/sec^2$



Indian Ocean Tsunami after Sumatra M9.2 Quake, Dec 2004.

Travel Times of First Tsunami Wave (hours):

2+hrs to Thailand and India,

6+ hours to Africa

Coast of Thailand 2 hours after the quake

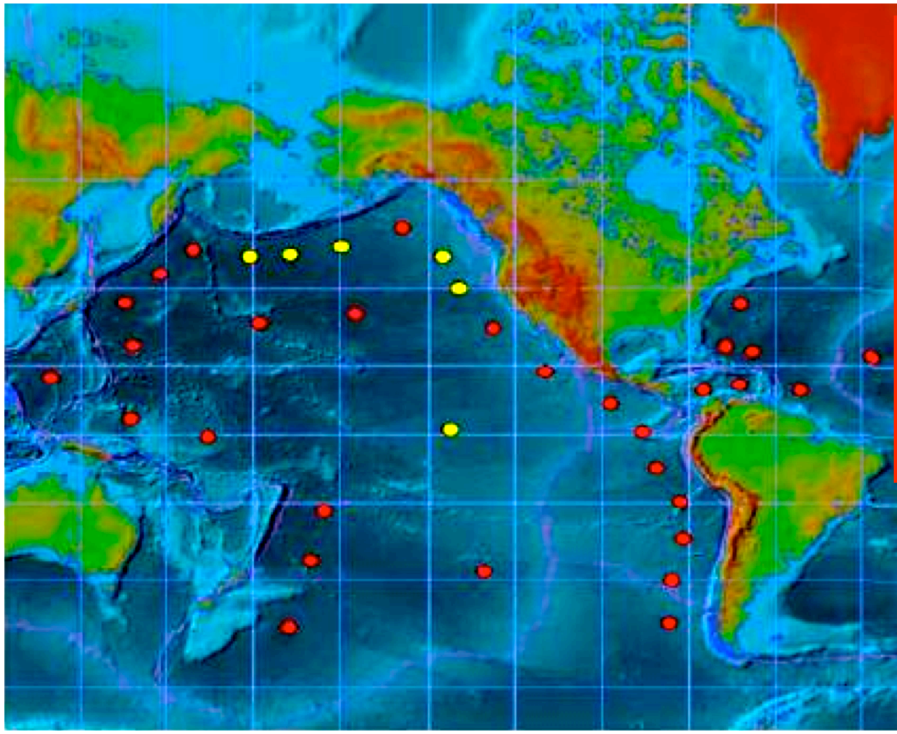
Note: $V = (gH)^{1/2}$; $A \sim 1/H$; $g \approx 10 m/sec^2$

A minute - or so - later, the first wave crushes ashore

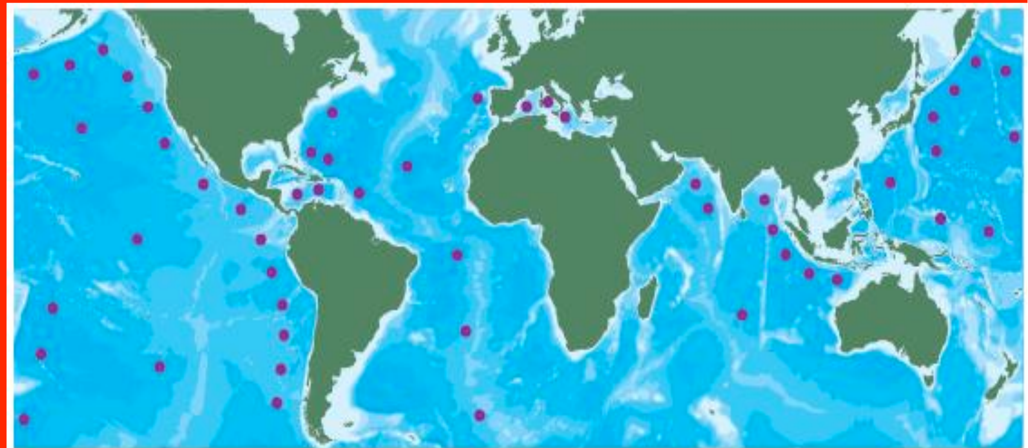
Indian ocean Tsunami after Sumatra Quake Dec 2004.

Without warning unsuspecting coastal populations are overwhelmed. With warning and evacuation plans many lives could have been saved.

Image shows City in Thailand 2 hours after the quake.



Yellow dots are existing DART system; Red dots are NOAA estimated DART system locations for an expanded Pacific, Caribbean,



CURRENT AND PROPOSED TSUANMI WARNING SYSTEMS

Upper Left: Existing (yellow) and Proposed (red) NOOA-Operated Pacific/Atlantic/Caribbean Tsunami alert Network using deep-ocean pressure sensors with acoustic Communications to buoys, and GOES satellite Communication to the Pacific Tsunami Warning Center in Hawaii

Upper Right: Proposed World-wide Tsunami warning system. Other proposals exist. Open Data Exchange between Countries still not agreed on, hindering effective implementation.

Science & Policy Lessons from 2004 Tsunami:

- Need rapid and reliable seismological methods to determine the magnitude of giant (M~9) earthquakes and of their tsunami potential. International Issue.

- Need global tsunami detection and warning dissemination system(s). Full International Cooperation is Essential, despite National Concerns.

- Need full integration of & communication between scientific establishments and the emergency agencies at international, national, regional and local levels.

- Coastal Demographic Trends and Landuse are unsustainable. More circumspect coastal rezoning is needed. Equity Issues.

Secondary Effects of Earthquakes: e.g. Fire. The San Francisco Earthquake of 1906 generated a Fire Storm that caused a larger damage than the earthquake shaking itself. About 30,000 people had to be evacuated by boat to escape from the inferno.
Other Examples: Tokyo 1923, Kobe 1995, ……

Medical Epidemiology of Earthquakes:

Injuries due to Collapse of Buildings:

Crushing,
Loss of Limbs
Suffocation from Dust / Fires
Crush Syndrome: Kidney Collapse
(after rescue it requires immediate access to Dialysis Machines / Artificial Kidneys)

Other Health Effects:

Severe Trauma
Risk of
Diarrhea, Typhoid, Cholera
Malaria, Dengue Fever, ….

Questions?

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