GEM

GLOBAL EARTHQUAKE MODEL

working together to assess risk

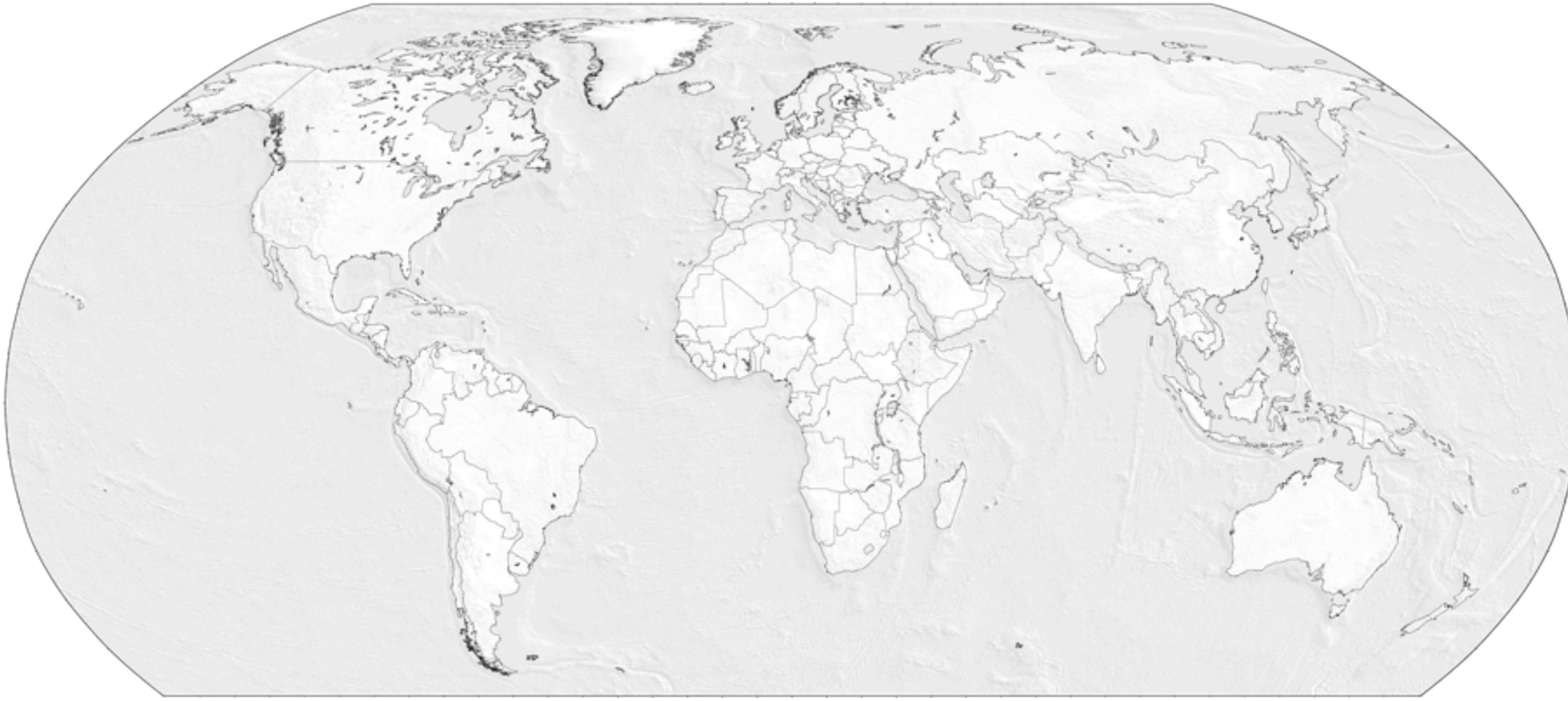
GEM's Global Seismic Risk Model

Vitor Silva, on behalf of the risk team and collaborators

OPENQUAKE

December, 2018 – Pavia, Italy

This is how we started...



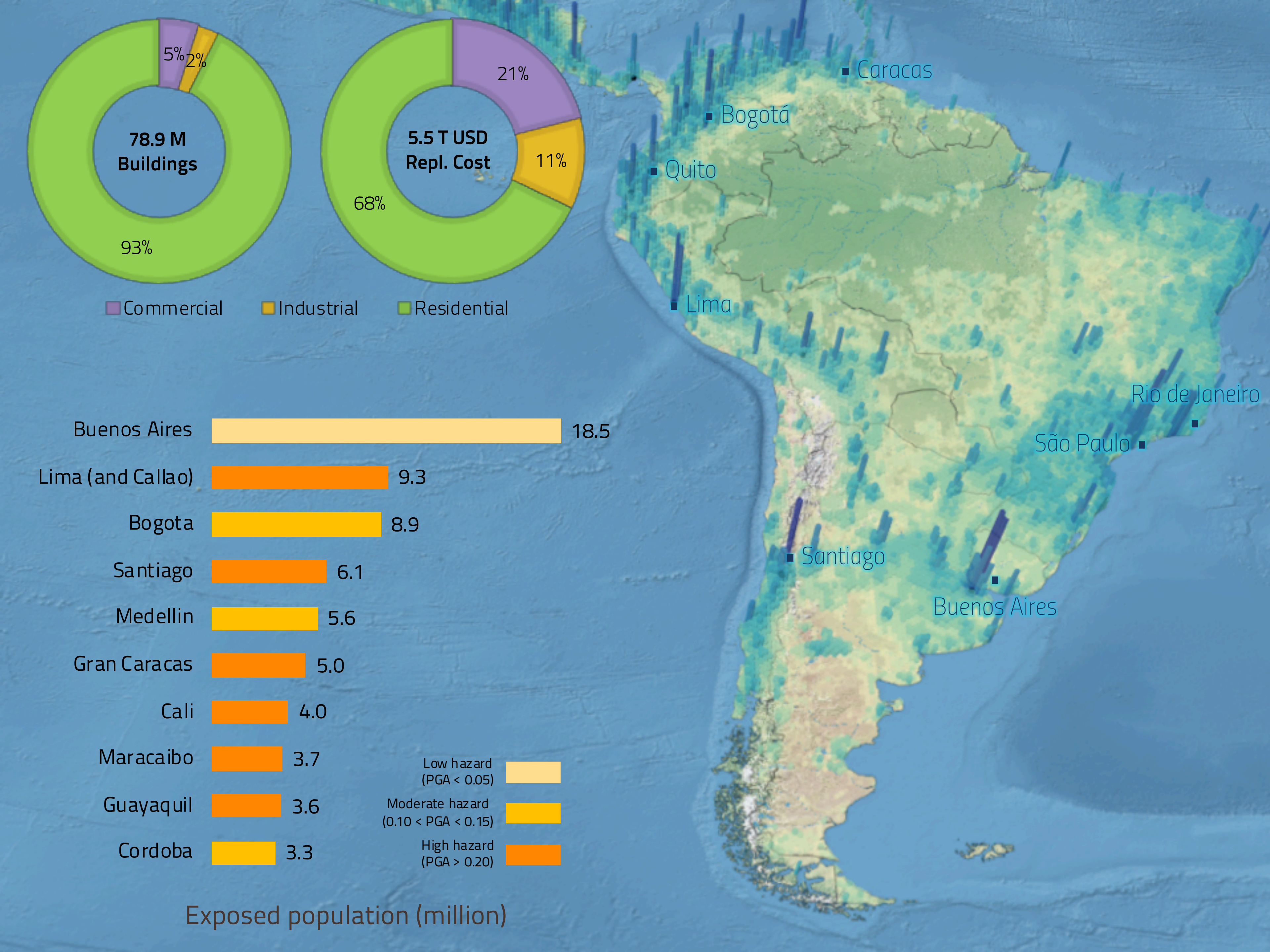
Exposure Modelling

Photo by Johnny Miller

And the journey begins...

South America

Swiss Re
Foundation

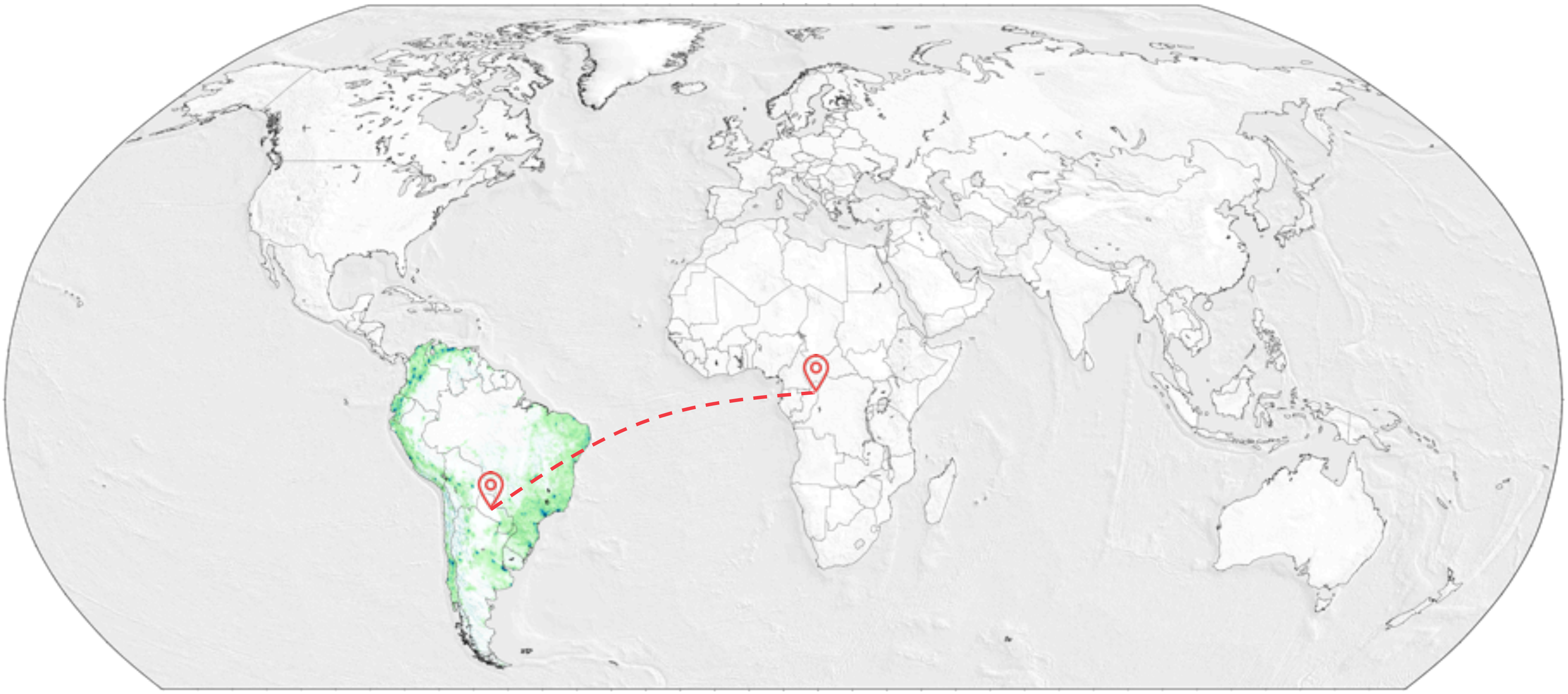


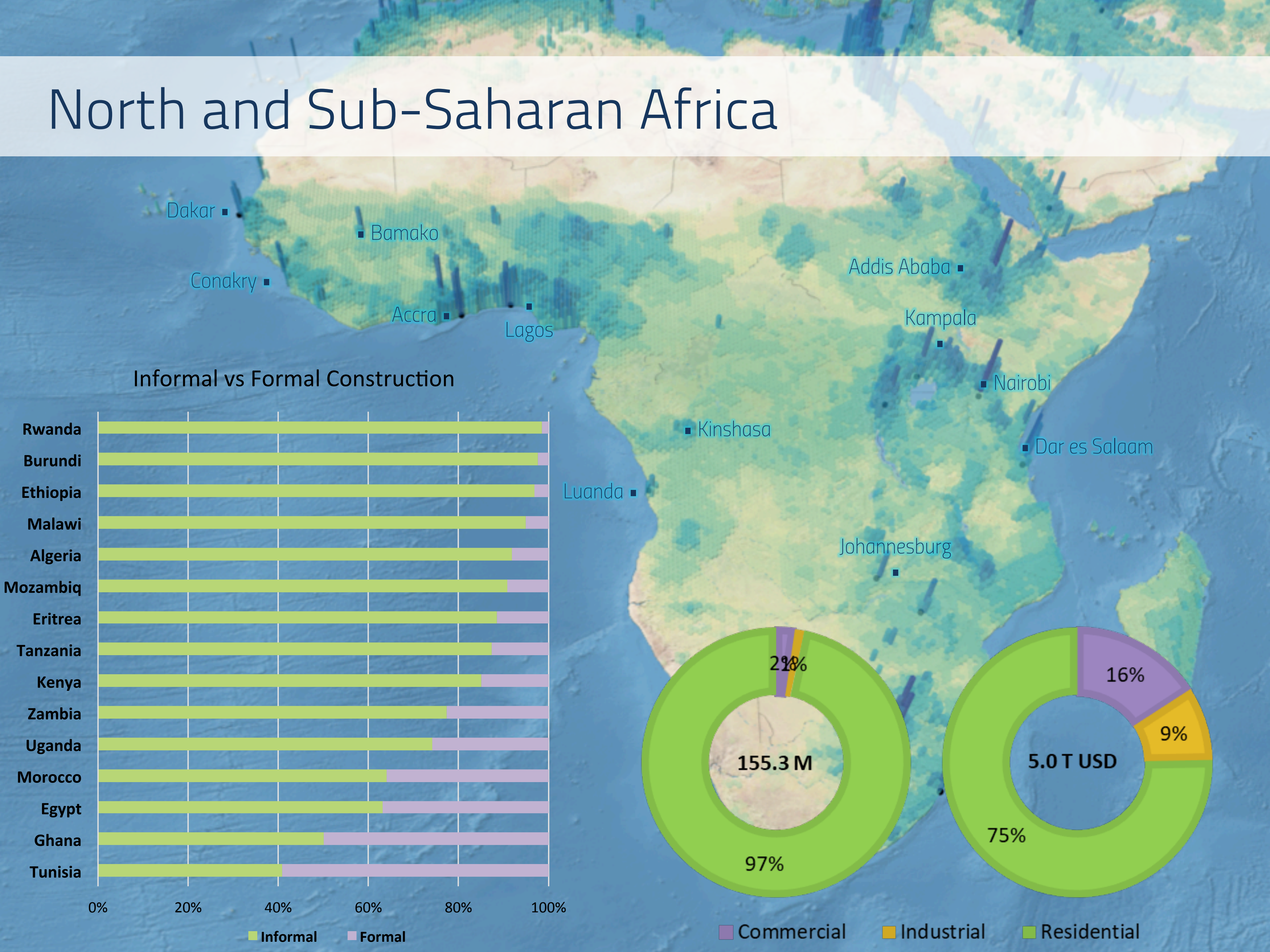
5%
2%
78.9 M Buildings
93%
21%
5.5 T USD Repl. Cost
11%
68%
Commercial
Industrial
Residential
Caracas
Bogotá
Quito
Lima
Rio de Janeiro
São Paulo
Santiago
Buenos Aires
Buenos Aires 18.5
Lima (and Callao) 9.3
Bogota 8.9
Santiago 6.1
Medellin 5.6
Gran Caracas 5.0
Cali 4.0
Maracaibo 3.7
Guayaquil 3.6
Cordoba 3.3
Low hazard (PGA < 0.05)
Moderate hazard (0.10 < PGA < 0.15)
High hazard (PGA > 0.20)
Exposed population (million)


OPENQUAKE


Conceptos básicos sobre modelos de fragilidad
Vulnerability model

‘This time for Africa”

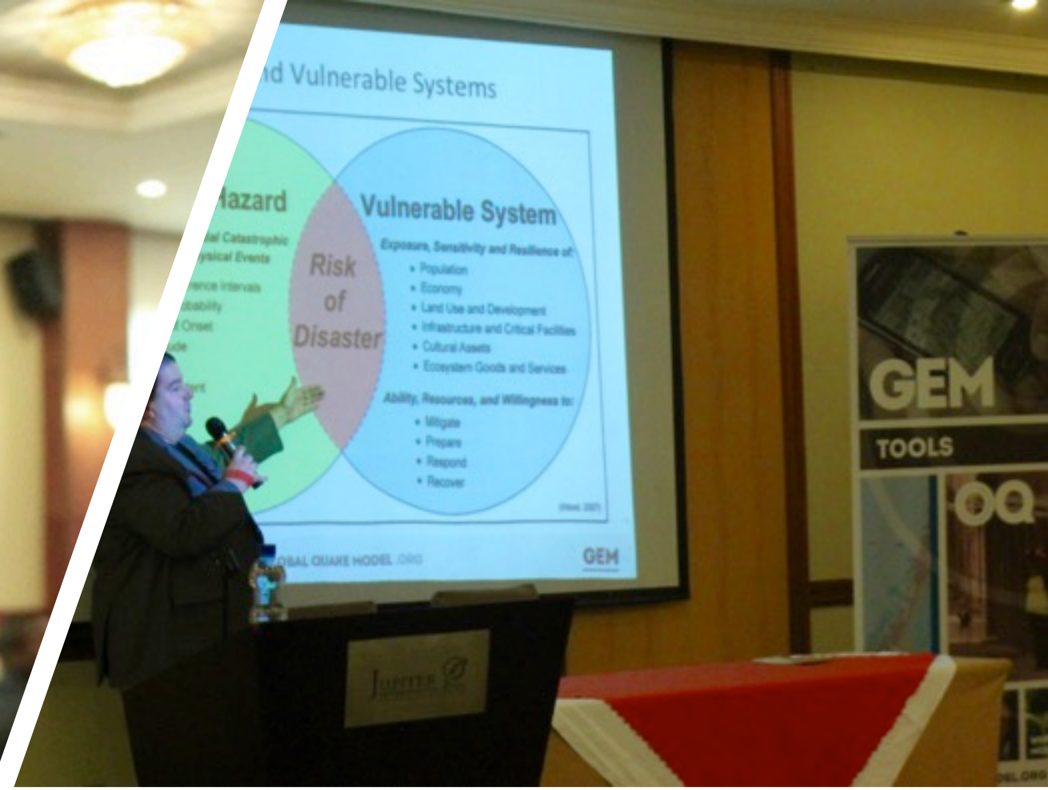



North and Sub-Saharan Africa
Dakar
Bamako
Conakry
Accra
Lagos
Addis Ababa
Kampala
Nairobi
Kinshasa
Dar es Salaam
Luanda
Johannesburg
Informal vs Formal Construction
Rwanda
Burundi
Ethiopia
Malawi
Algeria
Mozambiq
Eritrea
Tanzania
Kenya
Zambia
Uganda
Morocco
Egypt
Ghana
Tunisia
0%
20%
40%
60%
80%
100%
Informal
Formal
2%
1%
155.3 M
97%
16%
9%
5.0 T USD
75%
Commercial
Industrial
Residential

RWANDA HOUSING AUTHORITY
RHA
CITY GOVERNMENT OF ADDIS ABABA
ADDIS ABABA UNIVERSITY
NADMO
GHANA
HEKIMA NI UHURU
UNIVERSIDADE EDUARDO MONDLANE
UNITED STATES AGENCY INTERNATIONAL DEVELOPMENT
USAID

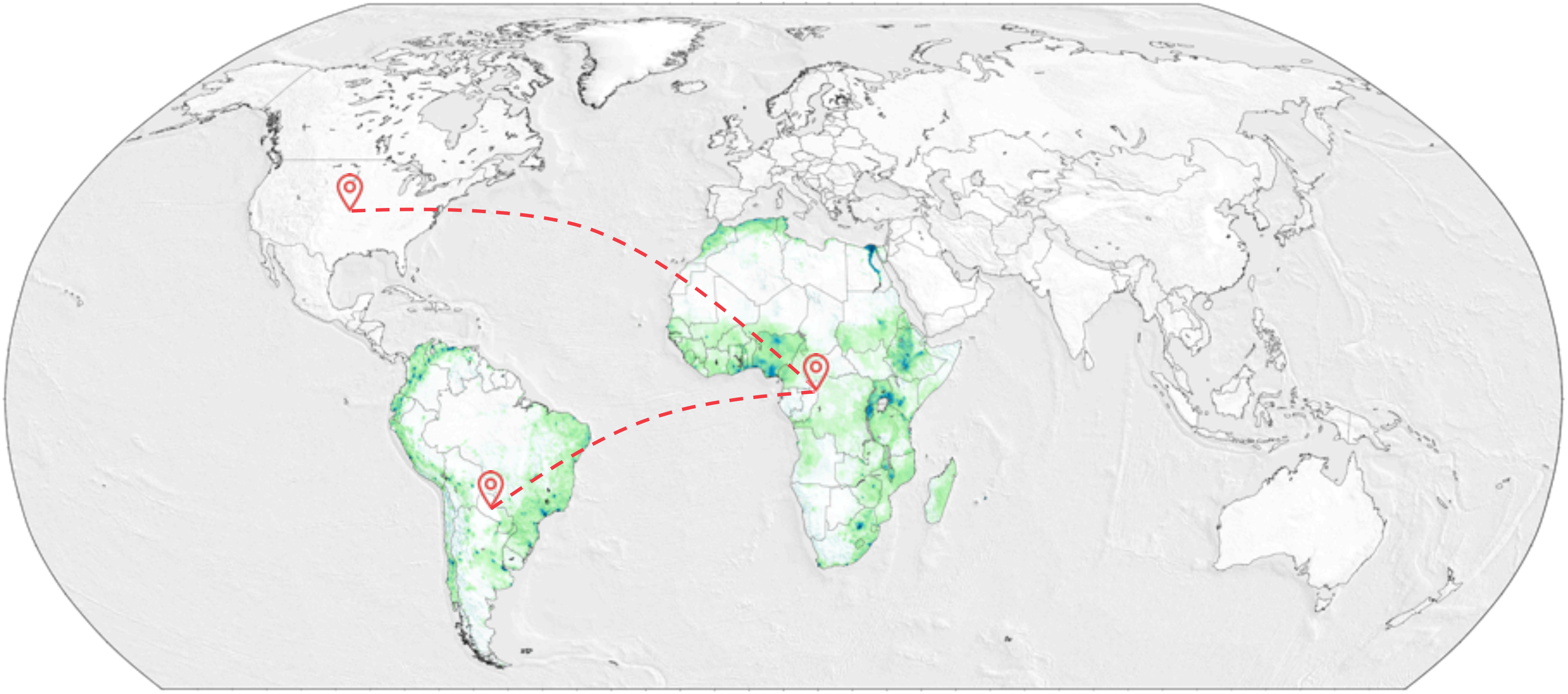

USAID


GEM
TOOLS
USAID


Vulnerable System
Exposure, Sensitivity and Resilience of:
Population
Economy
Land Use and Development
Infrastructure and Critical Facilities
Cultural Assets
Ecosystem Goods and Services
Ability, Resources, and Willingness to:
Mitigate
Prepare
Respond
Recover
Risk
of
Disaster
GEM
GEM
TOOLS
OQ
JUPITER


RISK ASSESSMENT FOR
AFRICA

Next stop: United States



United States

California exposure (value)

80% in wood-frame structures

6% in reinforced-masonry structures

'High-Code' and 'Moderate-Code'

New York exposure (value)

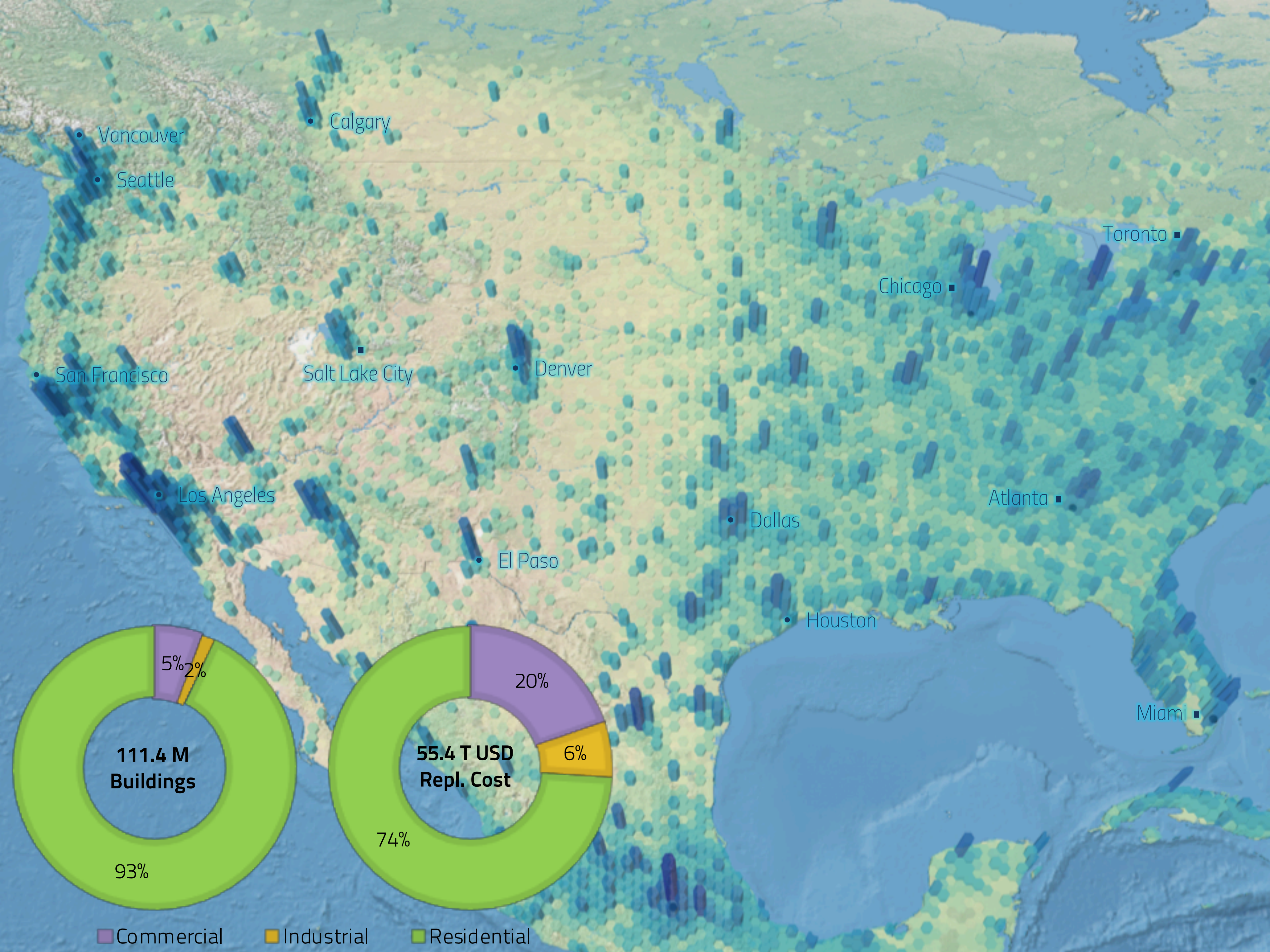
50% in wood-frame structures

20% in unreinforced-masonry

'Pre-Code' and 'Low-Code'

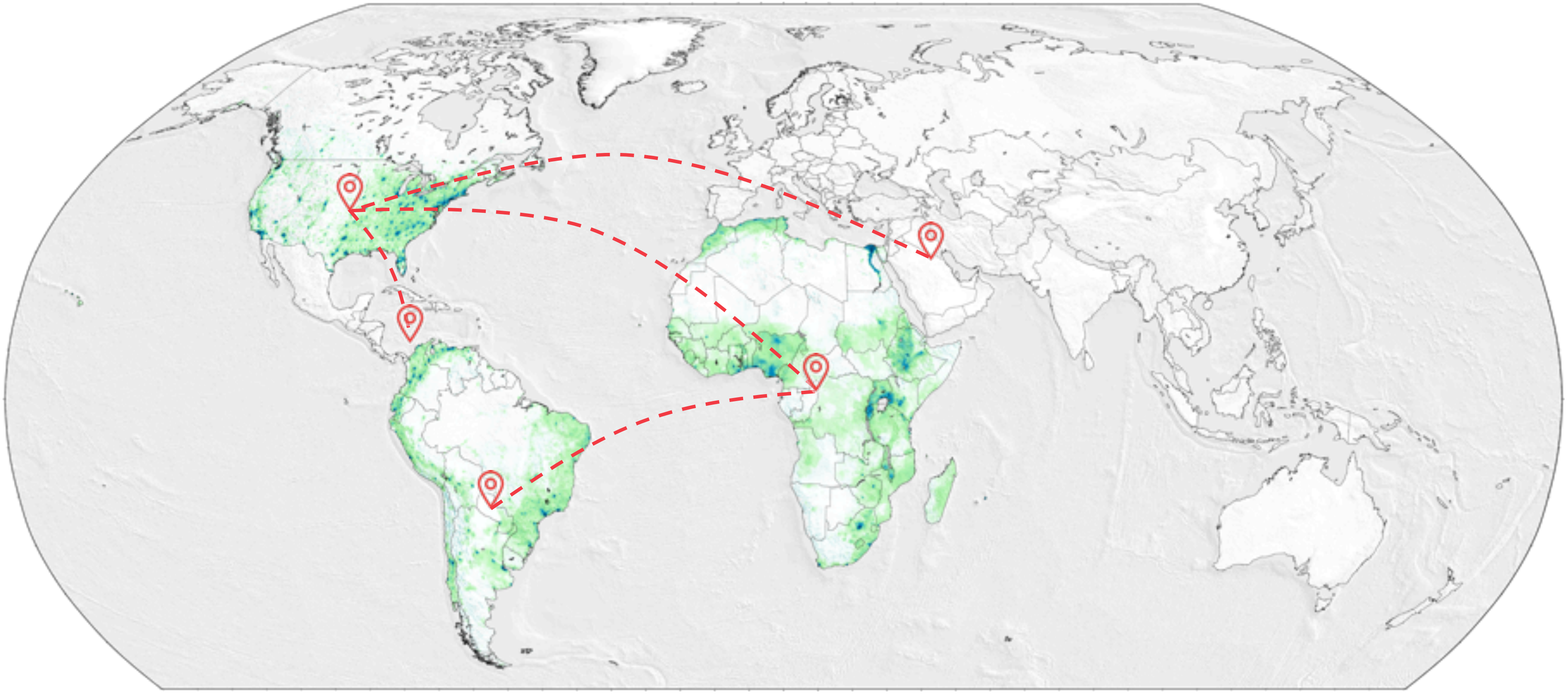
Sources for the building inventory

- Hazus 4.1 General Building Stock (GBS) database, Census Tract Level
- Hazus 4.2 Dasymetric Building Inventory, Census Block Level
- USACE National Structure Inventory (NSI), Building Level Exposure
- Federal Emergency Management Agency. (2017). FEMA P-366: Hazus® Estimated Annualized Earthquake Losses for the United States.

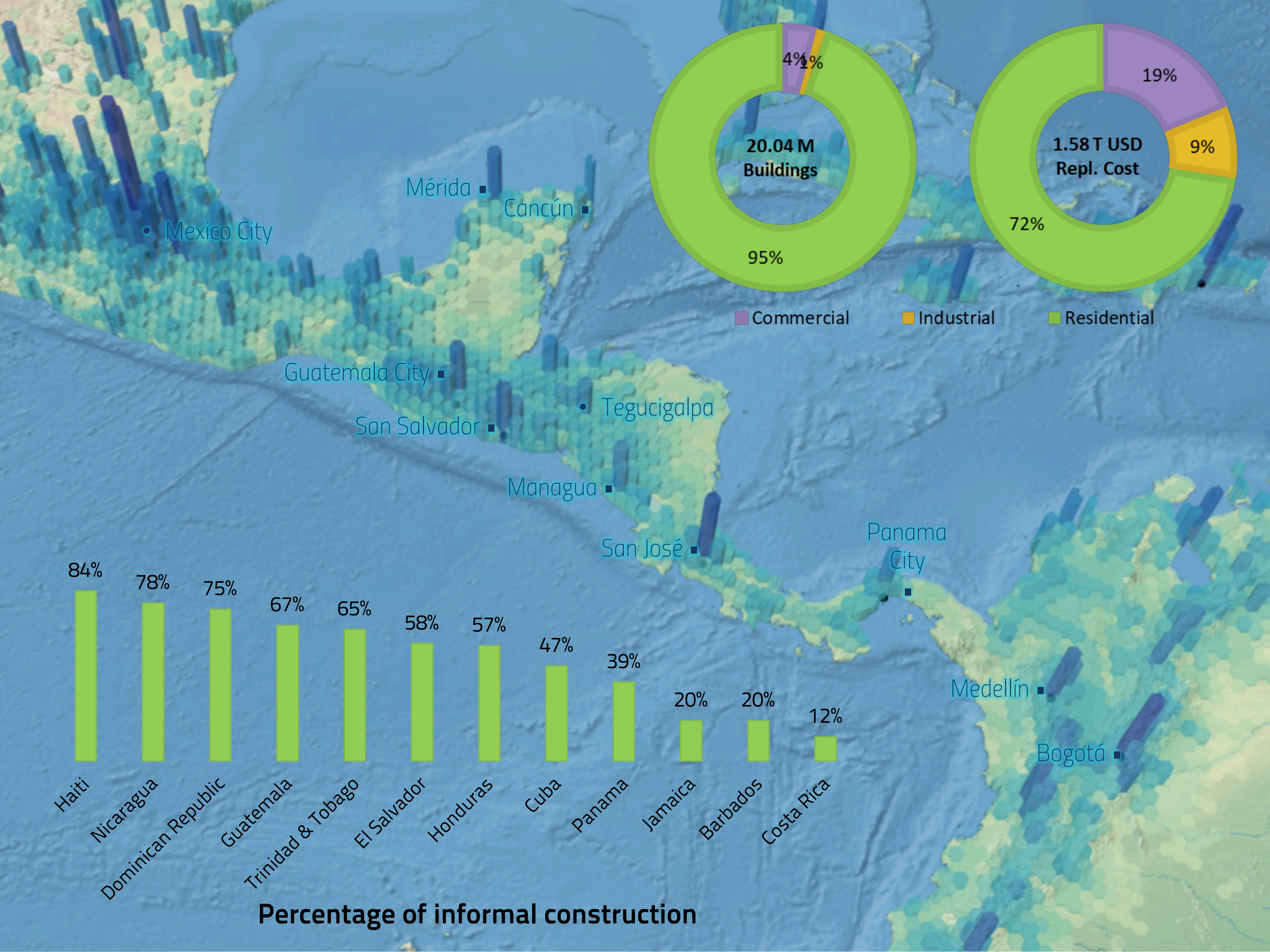


Vancouver
Calgary
Seattle
San Francisco
Salt Lake City
Denver
Los Angeles
El Paso
Dallas
Houston
Chicago
Toronto
Atlanta
Miami
5%
2%
93%
111.4 M
Buildings
20%
6%
74%
55.4 T USD
Repl. Cost
Commercial
Industrial
Residential

Next stop: Central America and the Caribbean



Central America and the Caribbean

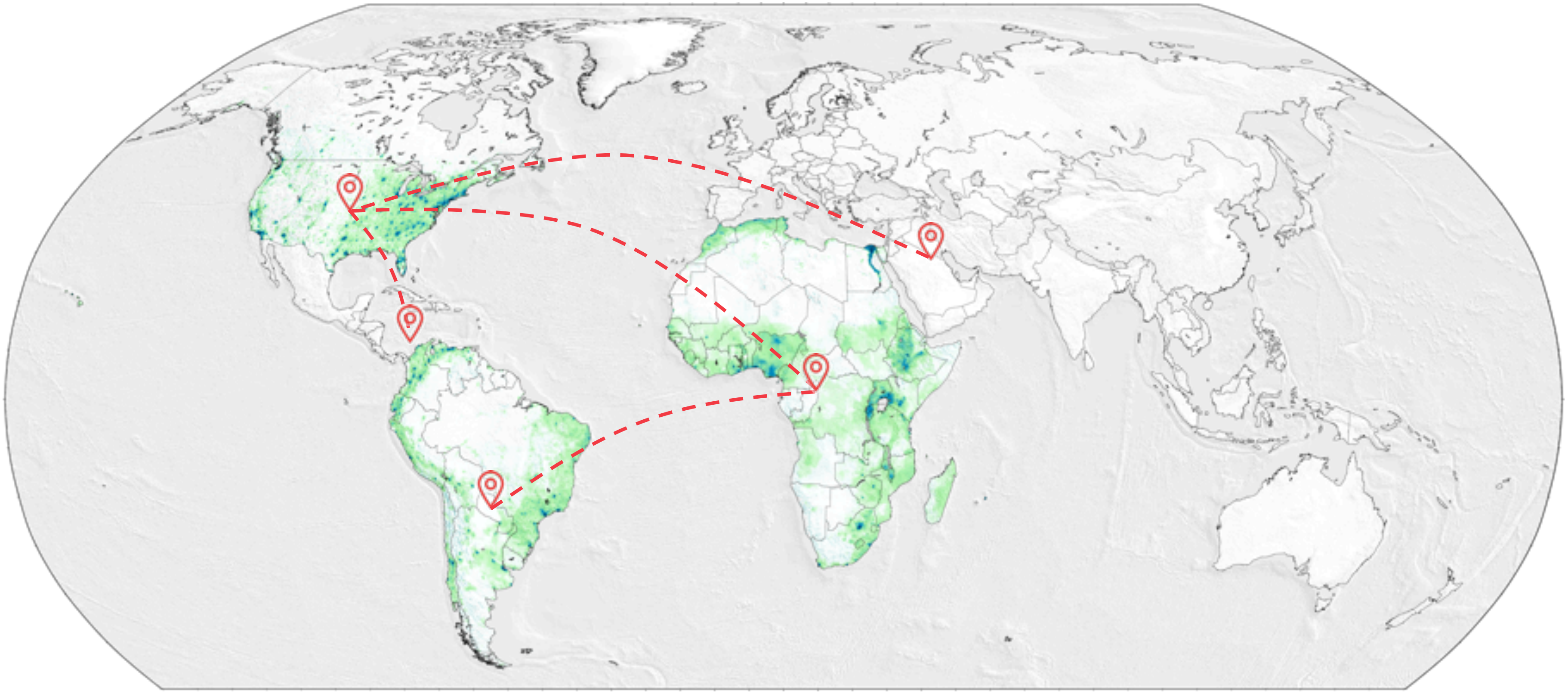

4%
1%
95%
20.04 M
Buildings
19%
9%
72%
1.58 T USD
Repl. Cost
Commercial
Industrial
Residential
Mérida
Cancún
Mexico City
Guatemala City
San Salvador
Tegucigalpa
Managua
San José
Panama City
Medellín
Bogotá
84%
78%
75%
67%
65%
58%
57%
47%
39%
20%
20%
12%
Haiti
Nicaragua
Dominican Republic
Guatemala
Trinidad & Tobago
El Salvador
Honduras
Cuba
Panama
Jamaica
Barbados
Costa Rica
Percentage of informal construction


Marzo 21, 2018
Santo Domingo,
República Dominicana
International Symposium
WORKING TOGETHER TO
ASSES RISK IN CENTRAL
AMERICA AND
THE CARIBBEAN

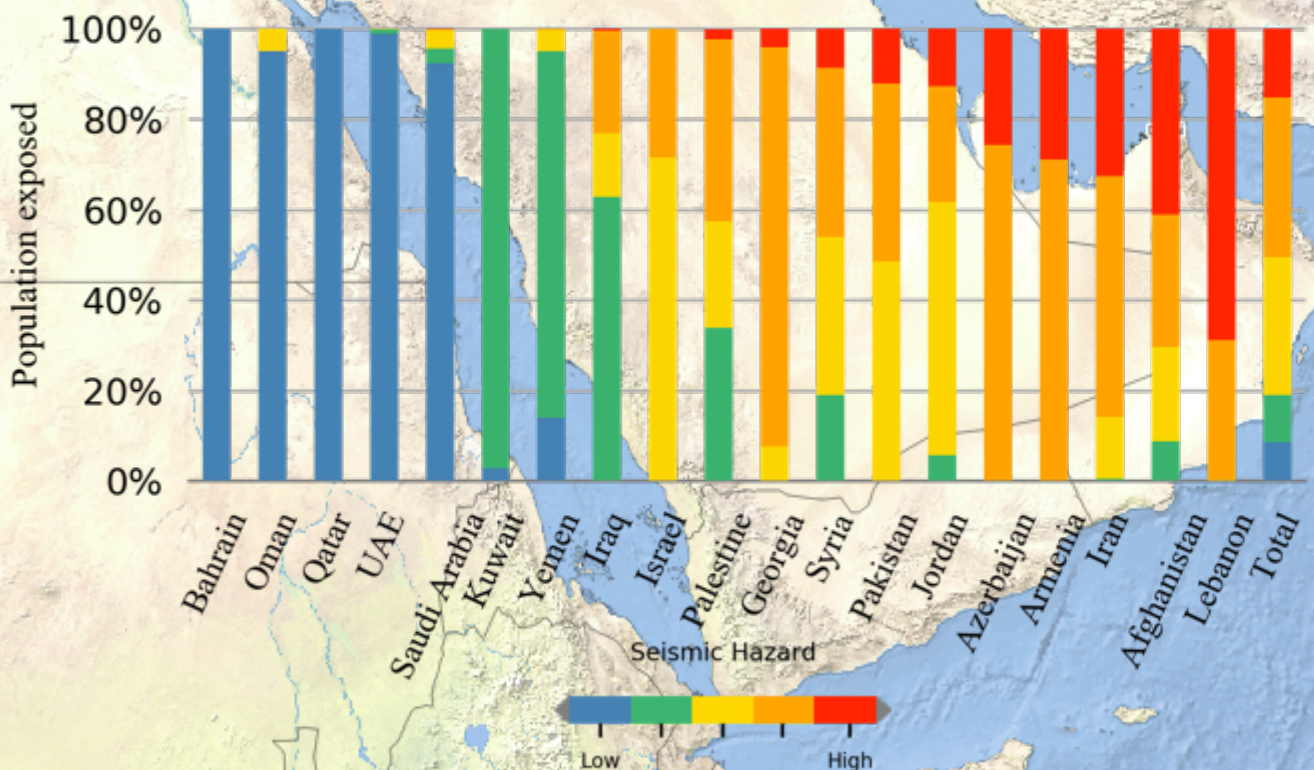


COE

Next stop: Middle East



Arabic Peninsula and Middle East



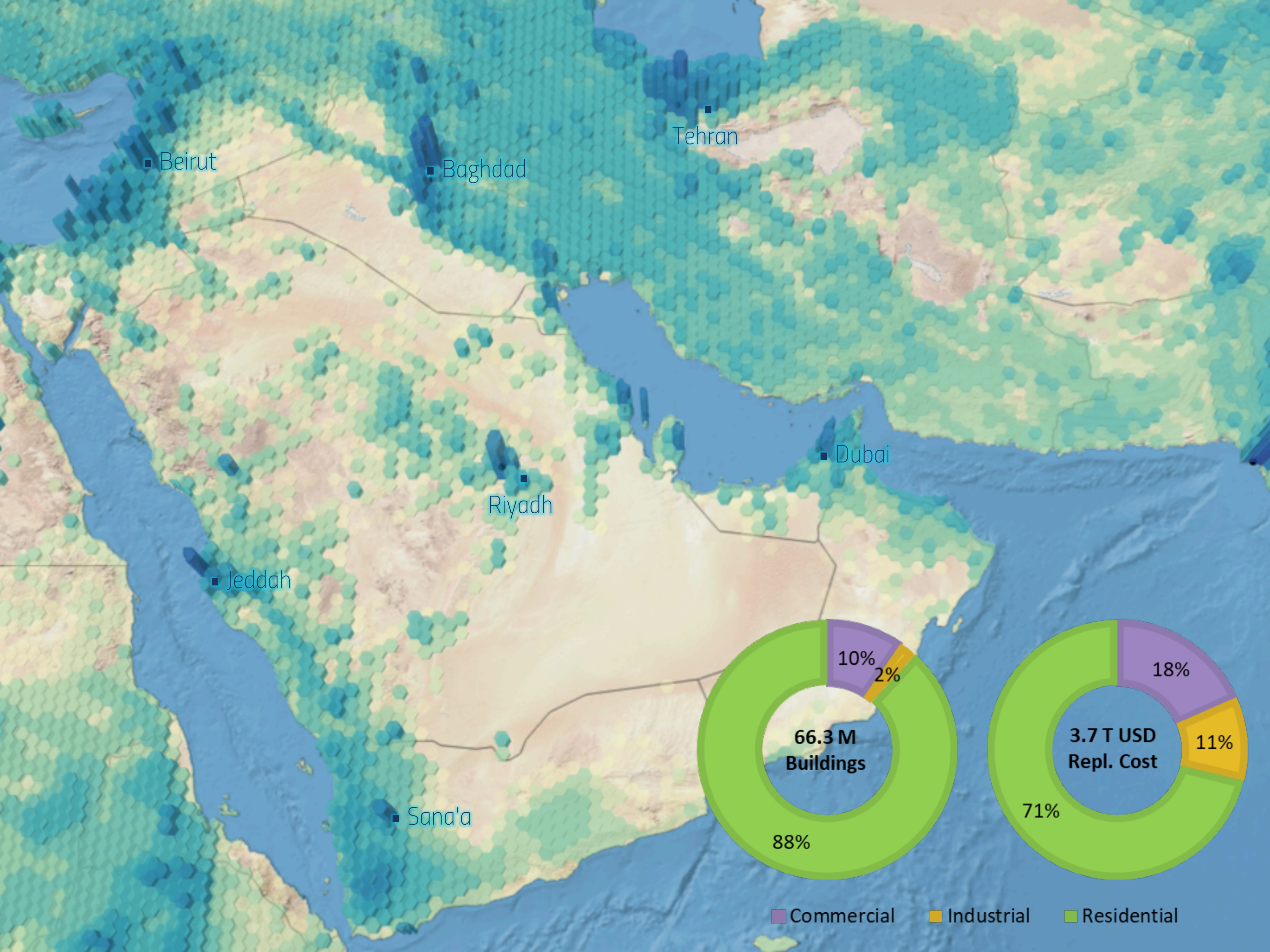
IIEES

DAMASCUS UNIVERSITY

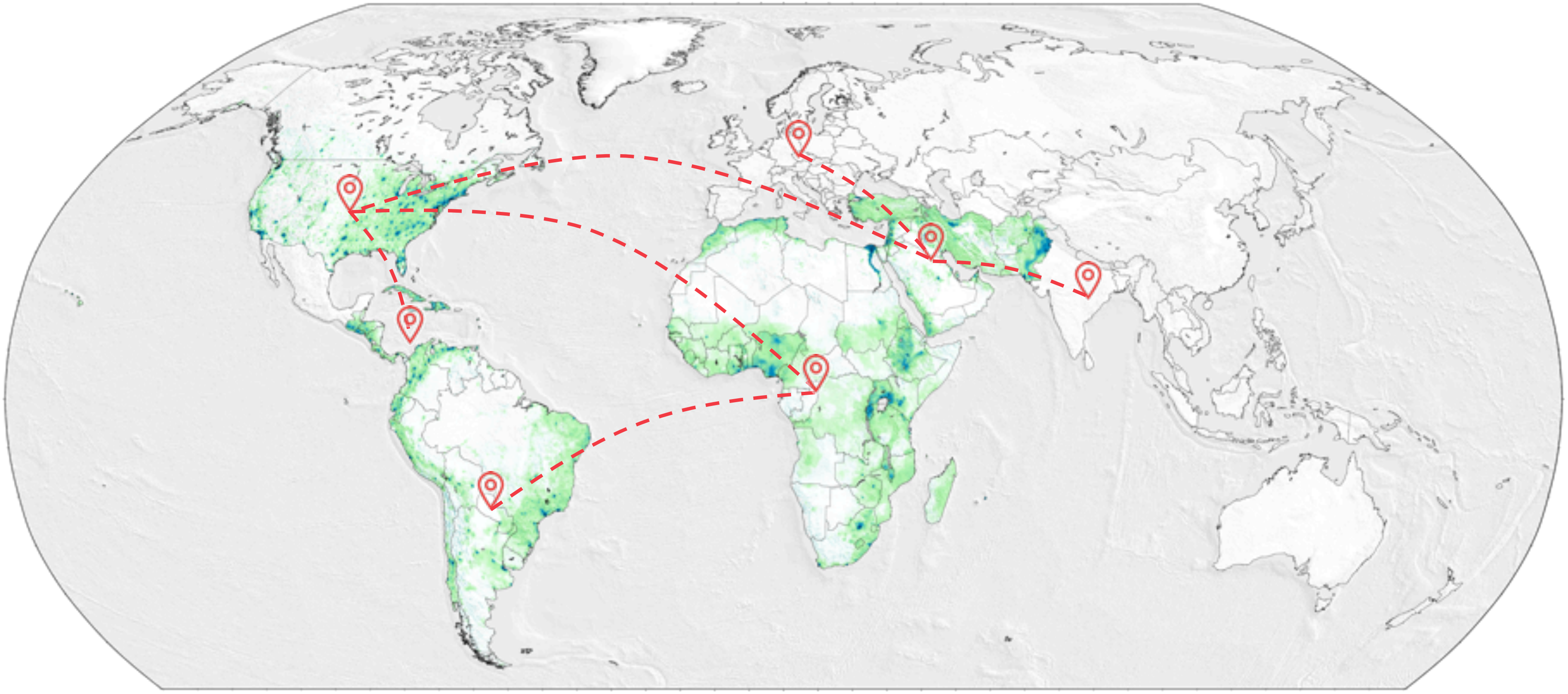
جامعة النجاح الوطنية
An-Najah National University

JORDAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

AON
Empower Results®

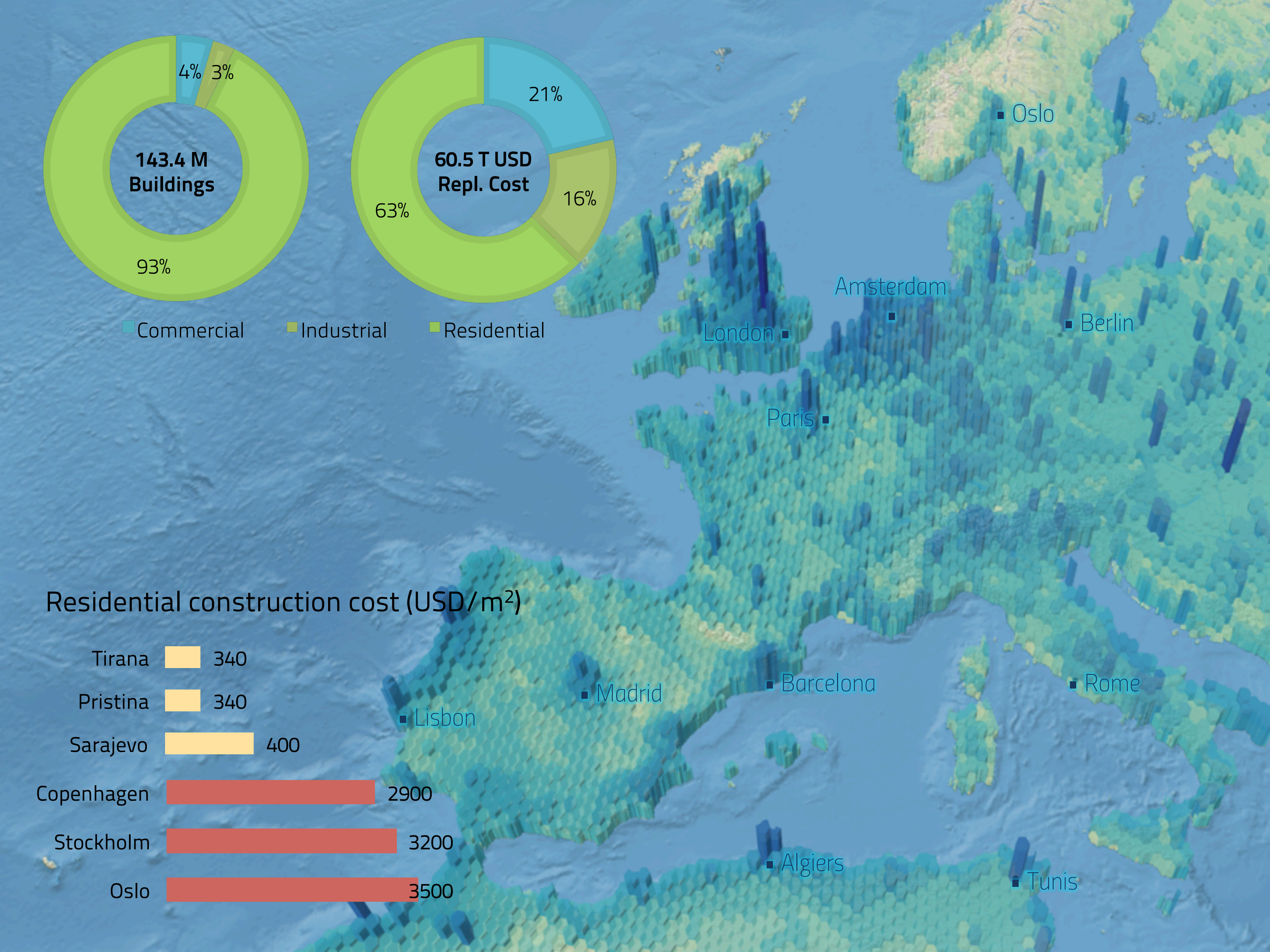

Beirut
Baghdad
Tehran
Dubai
Riyadh
Jeddah
Sana'a
10%
2%
66.3 M
Buildings
88%
18%
11%
3.7 T USD
Repl. Cost
71%
Commercial
Industrial
Residential

Next stop: Europe and South Asia



Europe

UNIVERSITY OF TRENTO - Italy
ETH zürich
U.PORTO
BOĞAZİÇİ ÜNİVERSİTESİ 1863
UNIVERSITY OF ICELAND
IZIIS
University of Zagreb
brgm
ARISTOTLE UNIVERSITY OF THESSALONIKI
University of Cyprus
IFSTTAR
GFZ
Helmholtz-Zentrum POTSDAM
JRC
EUROPEAN COMMISSION
EUCENTRE
FOR YOUR SAFETY.
SERA
Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe


4%
3%
143.4 M
Buildings
93%
21%
60.5 T USD
Repl. Cost
16%
63%
Commercial
Industrial
Residential
Oslo
Amsterdam
Berlin
London
Paris
Barcelona
Rome
Madrid
Lisbon
Algiers
Tunis
Residential construction cost (USD/m²)
Tirana 340
Pristina 340
Sarajevo 400
Copenhagen 2900
Stockholm 3200
Oslo 3500

India Risk Model

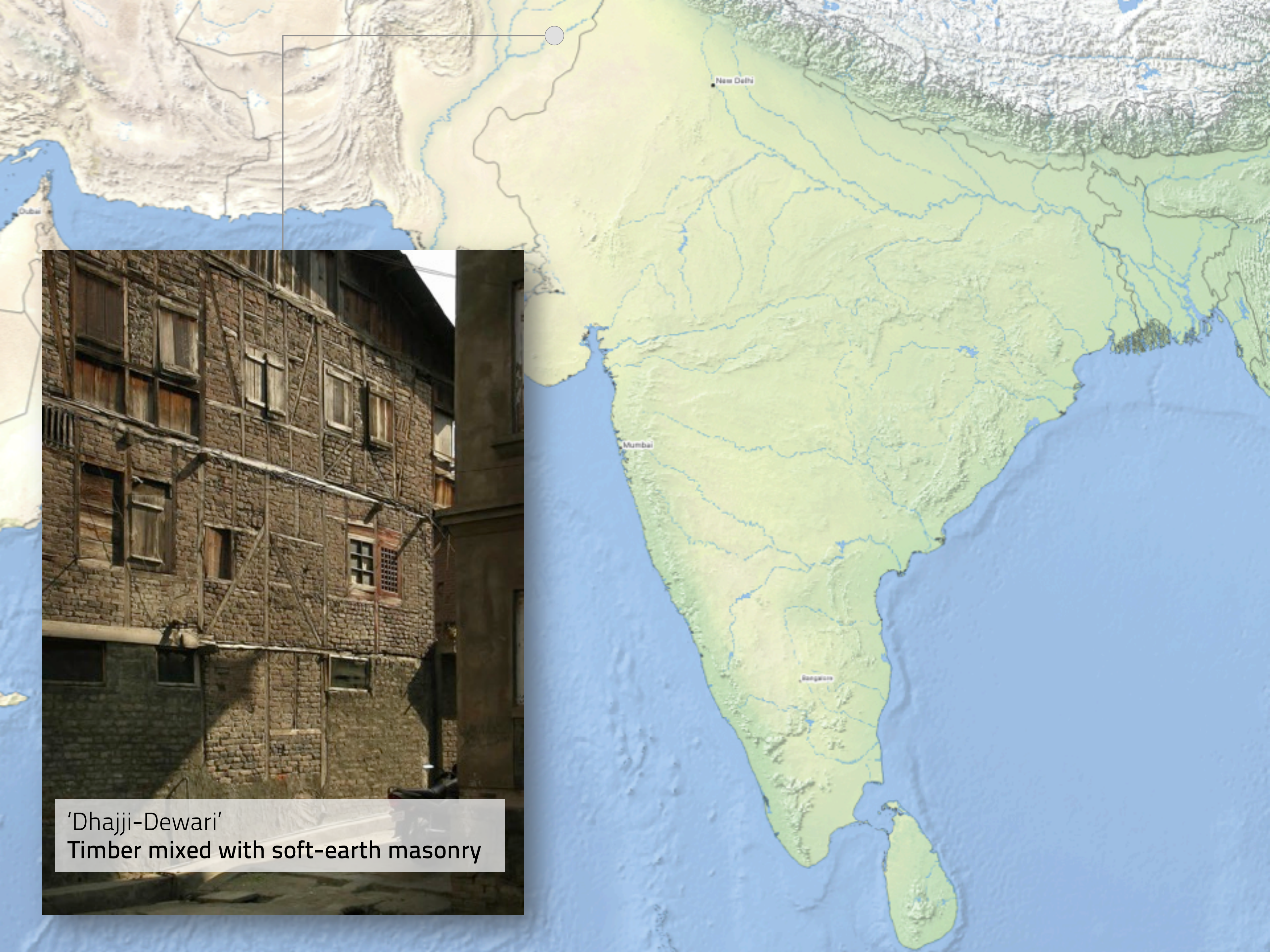
IIT Roorkee
Dr. Yogendra Singh

IIT Guwahati
Dr. Hemant B. Kaushik
Dr. Kaustubh Dasgupta

IIT Gandhinagar
Dr. Svetlana Brzev
Dr. Manish Kumar

IIT Bombay
Dr. Siddhartha Ghosh
Dr. Jayadipta Ghosh
Dr. Meera Raghunandan

IIT Madras
Dr. Arun Menon
Dr. S.T.G. Raghukanth
Dr. A. Meher Prasad



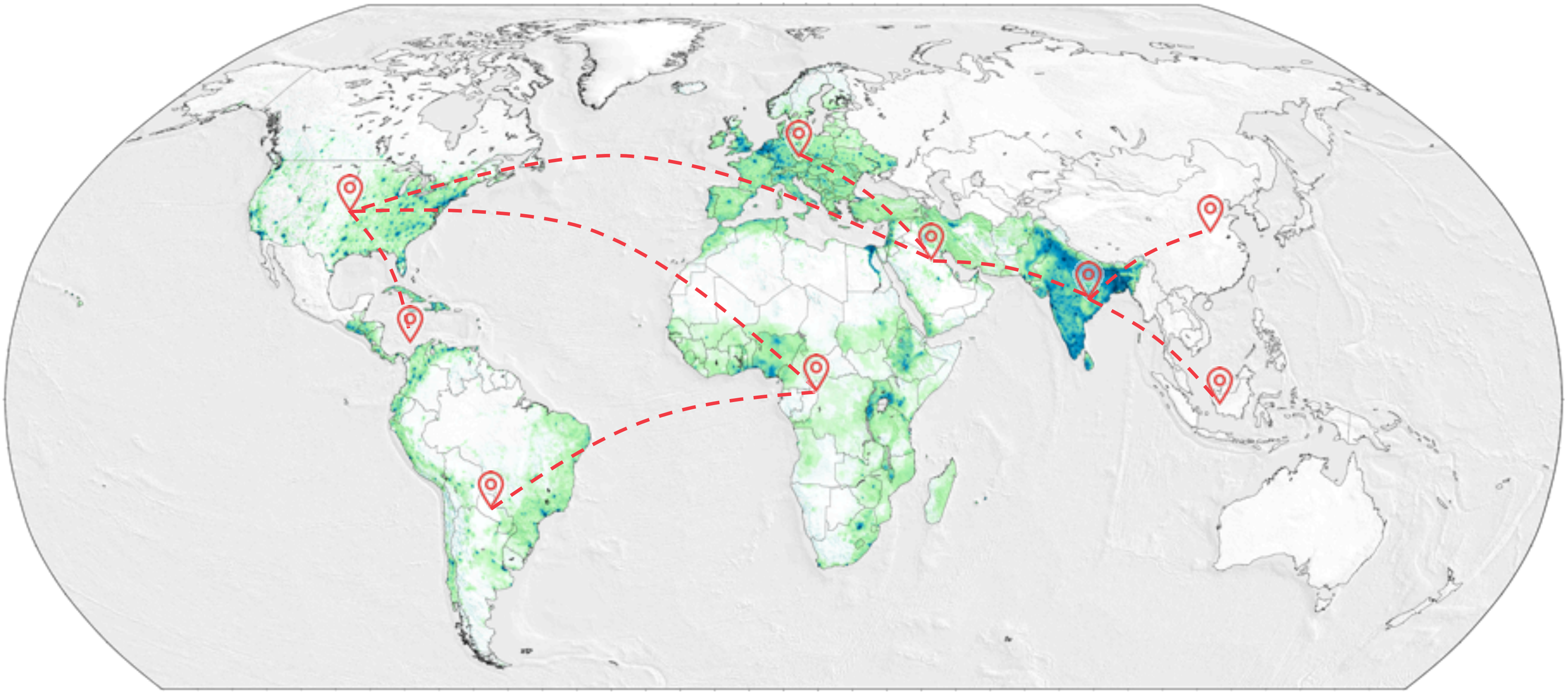
‘Dhajji-Dewari’
Timber mixed with soft-earth masonry

'Kath-Kunni'
Mixed stone and timber

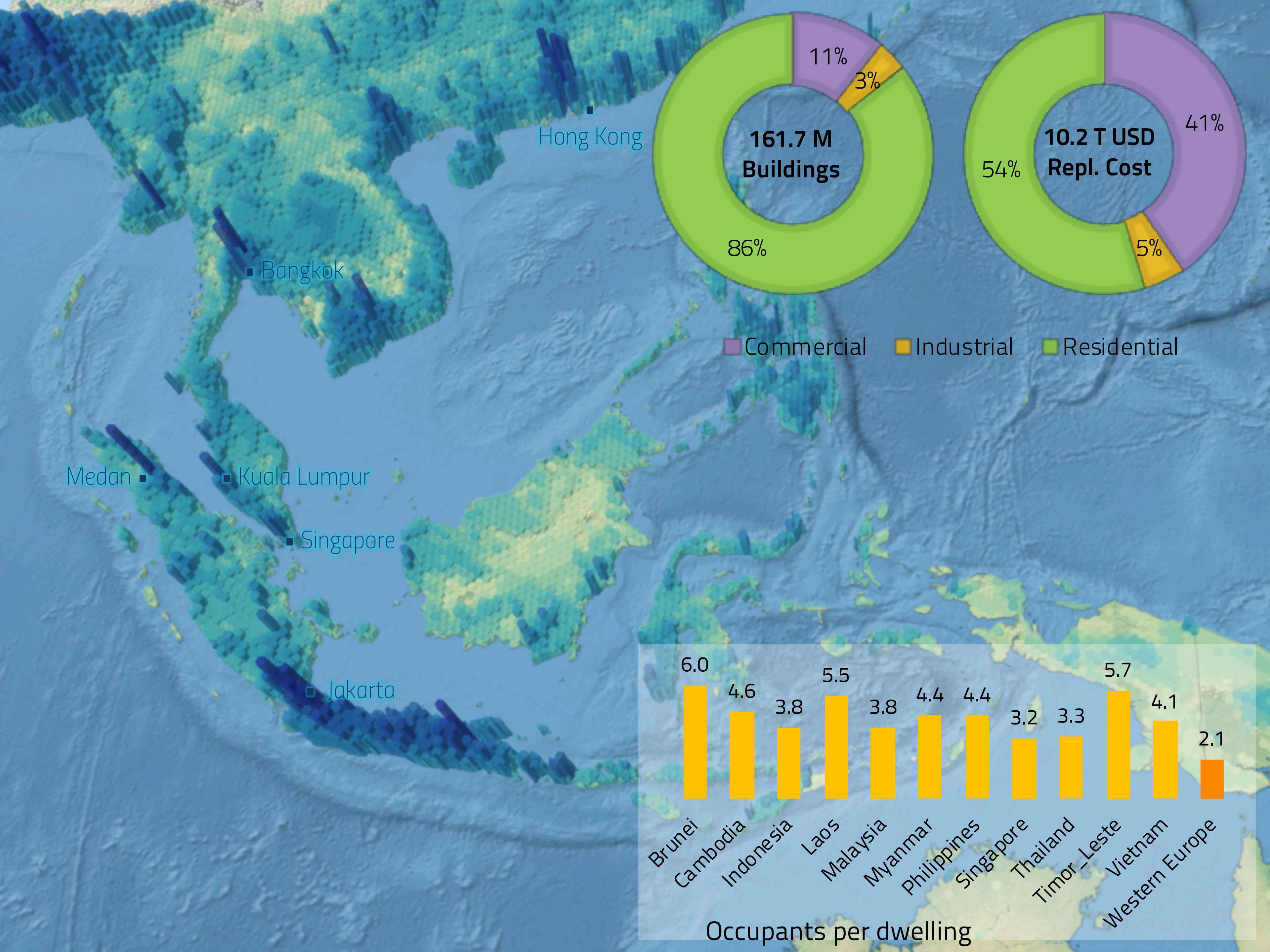
'Ikra' Construction
Bamboo frame houses

High-Density Slum Dwellings
Mumbai

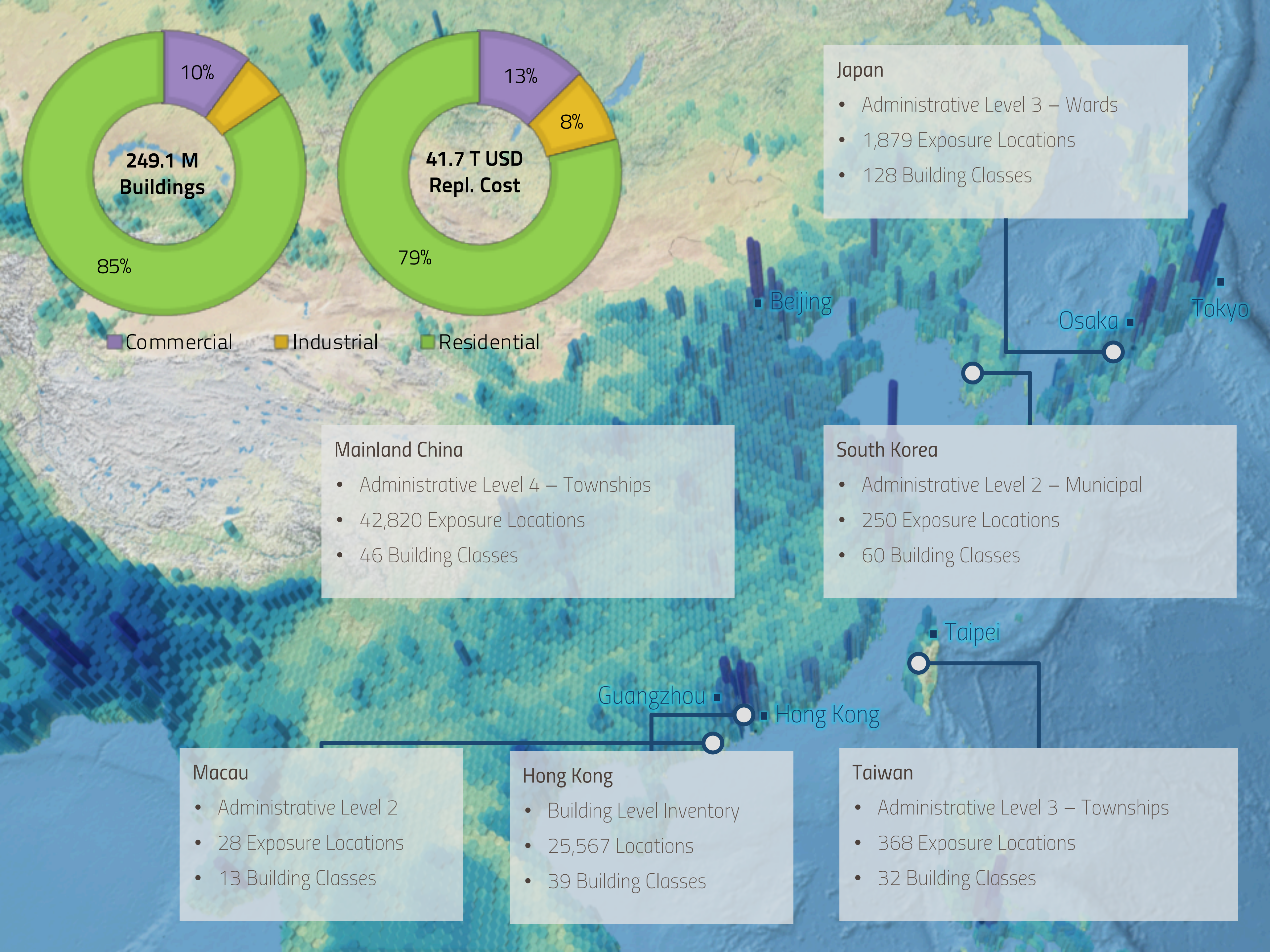
Next stop: Eastern and South-East Asia




Guangzhou
Shenzhen
Hong Kong

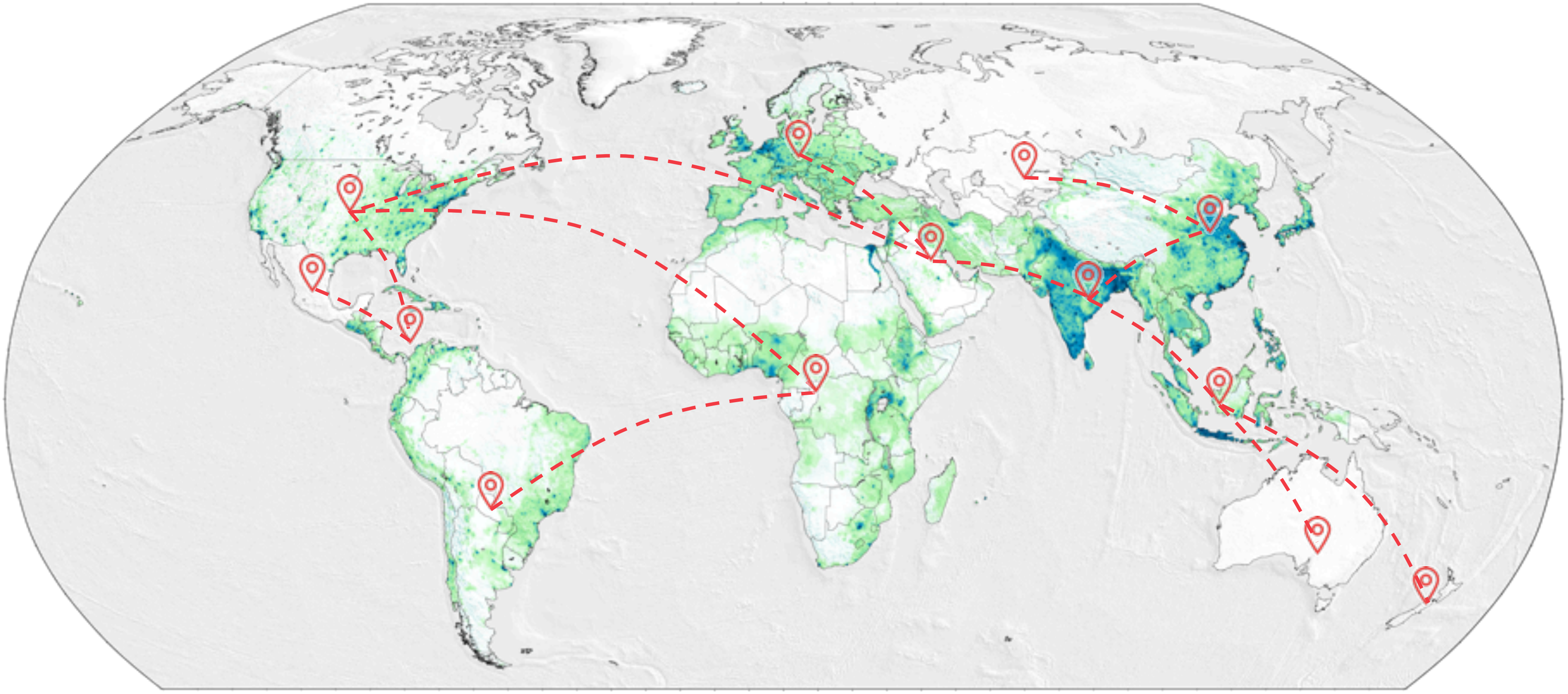


Hong Kong
Bangkok
Medan
Kuala Lumpur
Singapore
Jakarta
161.7 M Buildings
11%
3%
86%
10.2 T USD Repl. Cost
41%
5%
54%
Commercial
Industrial
Residential
6.0
4.6
3.8
5.5
3.8
4.4
4.4
3.2
3.3
5.7
4.1
2.1
Brunei
Cambodia
Indonesia
Laos
Malaysia
Myanmar
Philippines
Singapore
Thailand
Timor_Leste
Vietnam
Western Europe
Occupants per dwelling

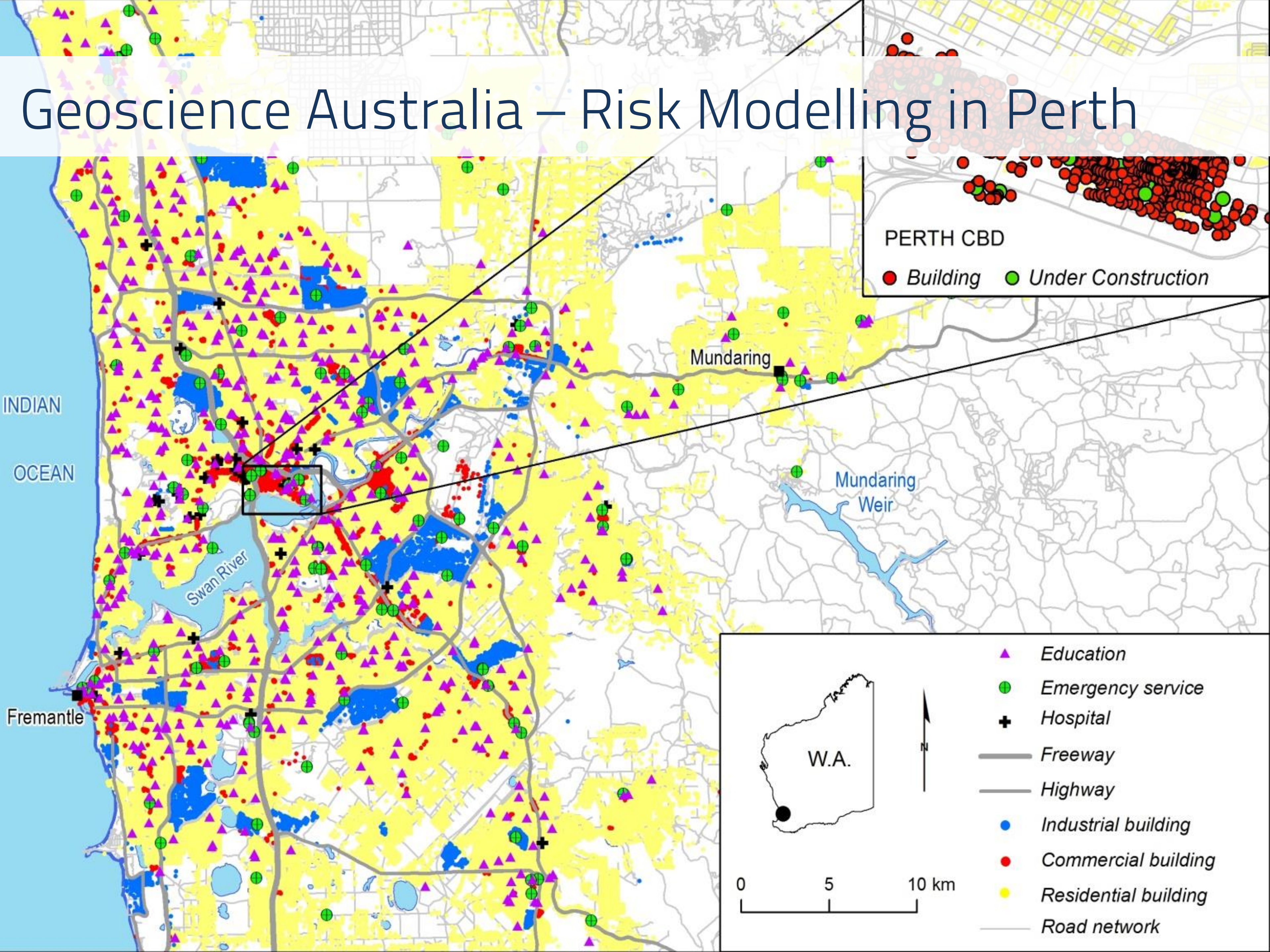

10%
249.1 M Buildings
85%
13%
8%
41.7 T USD Repl. Cost
79%
Commercial
Industrial
Residential
Japan
Administrative Level 3 – Wards
1,879 Exposure Locations
128 Building Classes
Beijing
Osaka
Tokyo
Mainland China
Administrative Level 4 – Townships
42,820 Exposure Locations
46 Building Classes
South Korea
Administrative Level 2 – Municipal
250 Exposure Locations
60 Building Classes
Taipei
Guangzhou
Hong Kong
Macau
Administrative Level 2
28 Exposure Locations
13 Building Classes
Hong Kong
Building Level Inventory
25,567 Locations
39 Building Classes
Taiwan
Administrative Level 3 – Townships
368 Exposure Locations
32 Building Classes


42,820 TOWNSHIP LEVEL DIVISIONS
· 6,686 Urban Sub-districts
· 19,322 Semi-urban Towns
· 15,029 Rural Townships
· 1,783 Other Township Level Divisions
HEILONGJIANG
Haerbin
Changchun
Shenyang
INNER MONGOLIA
Wulumuqi
XINJIANG UYGUR
Beijing
Dalian
Tianjin
Yinchuan
Taiyuan
Zibo
SHANXI
GANSU
NINGXIA
Lanzhou
QINGHAI
Jinan
Qingdao
Xinyi
SHAANXI
Zhengzhou
Xian
Nanjing
Shanghai
XIZANG
ANHUI
Wuxi
Hangzhou
Chengdu
HUBEI
ZHEJIANG
CHONGQING
Nanchang
Chongqing
Changsha
Wenzhou
JIANGXI
HUNAN
Fuzhou
Guiyang
Kunming
Xiamen
GUANGXI
Guangzhou
Shenzhen
Nanning
HAINAN

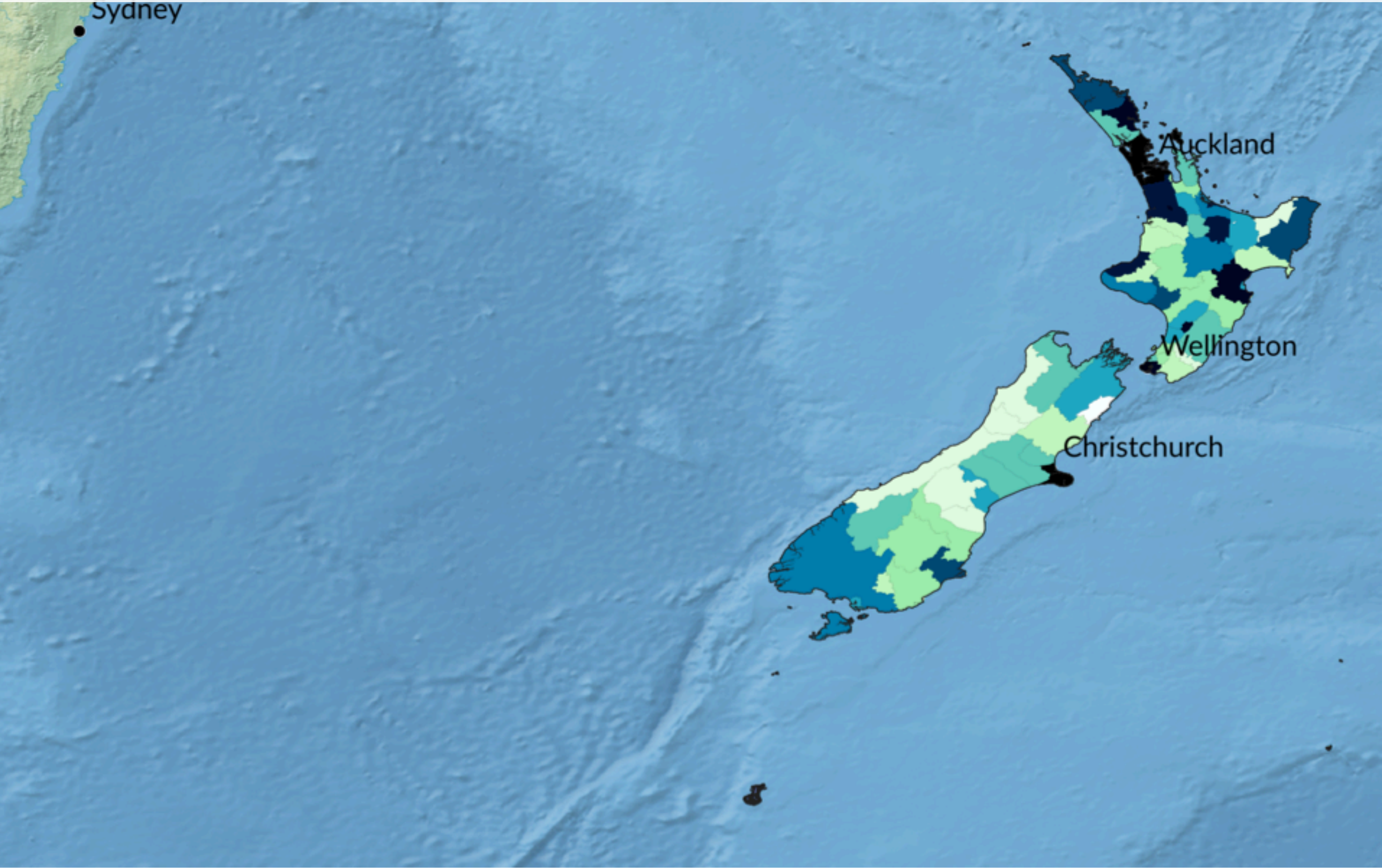
Last stop: Partners !



Geoscience Australia – Risk Modelling in Perth



GNS Science – National Seismic Risk Model



Earthquake Model Central Asia

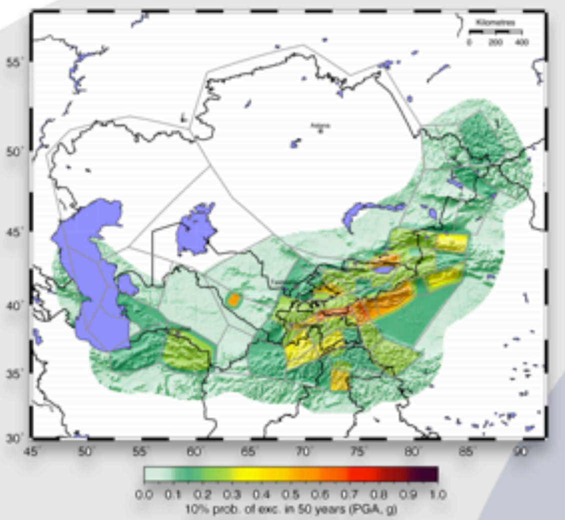
M. Pittore[a], K. Fleming[a], D. Bindi[a], G. Weatherill[a], F. Cotton[a], S. Parolai[ab], B. Moldobekov[d], V. Silva[g], L. Martins[g], D. Amo-Oduro[g]

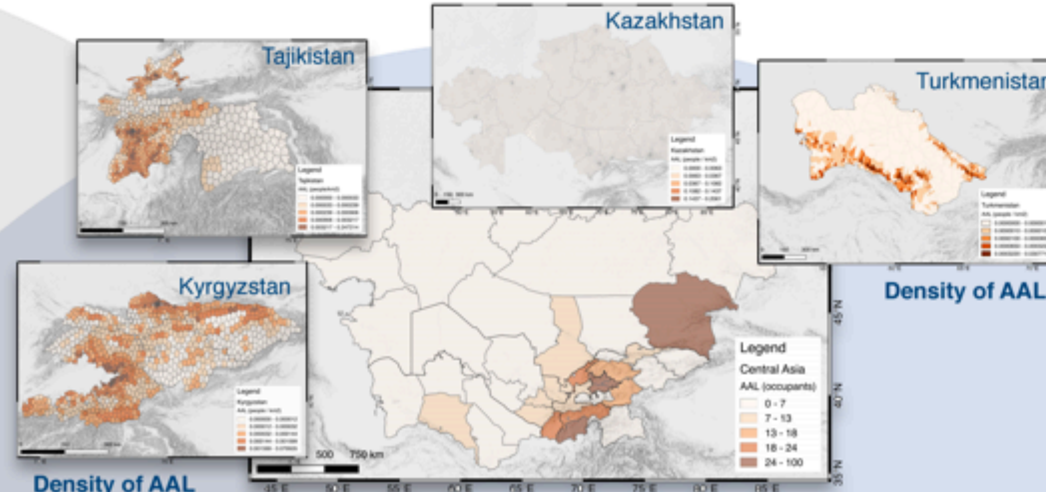
[a] GFZ (Germany), [b] OGS Trieste (Italy), [d] CAIAG (Kyrgyzstan), [g] GEM (Italy)

EMCA
EARTHQUAKE MODEL CENTRAL ASIA

Helmholtz-Zentrum Potsdam
Deutsches GeoForschungsZentrum

Probabilistic Seismic Hazard Model

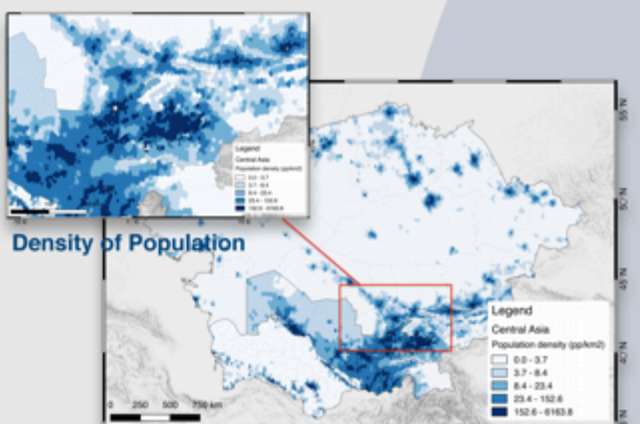




Density of AAL

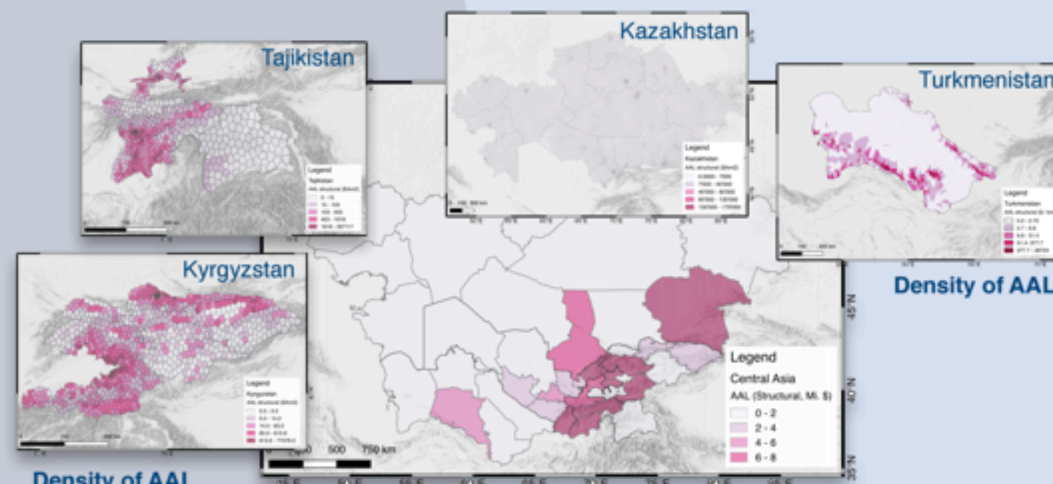
Density of AAL

Annual Average Loss (Fatalities)



Density of Population

Dynamic, Multi-resolution Exposure Model

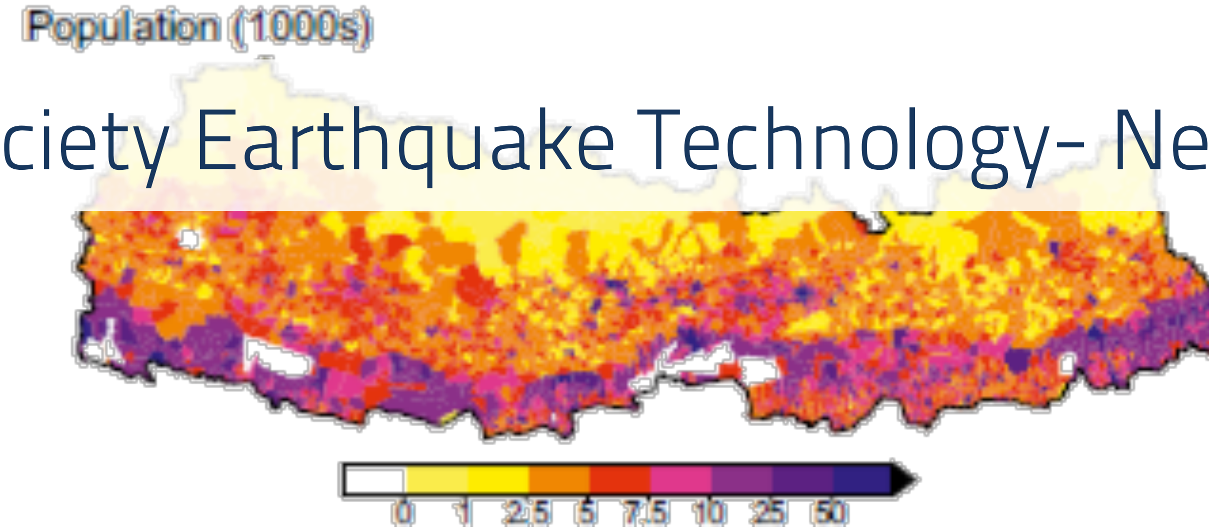


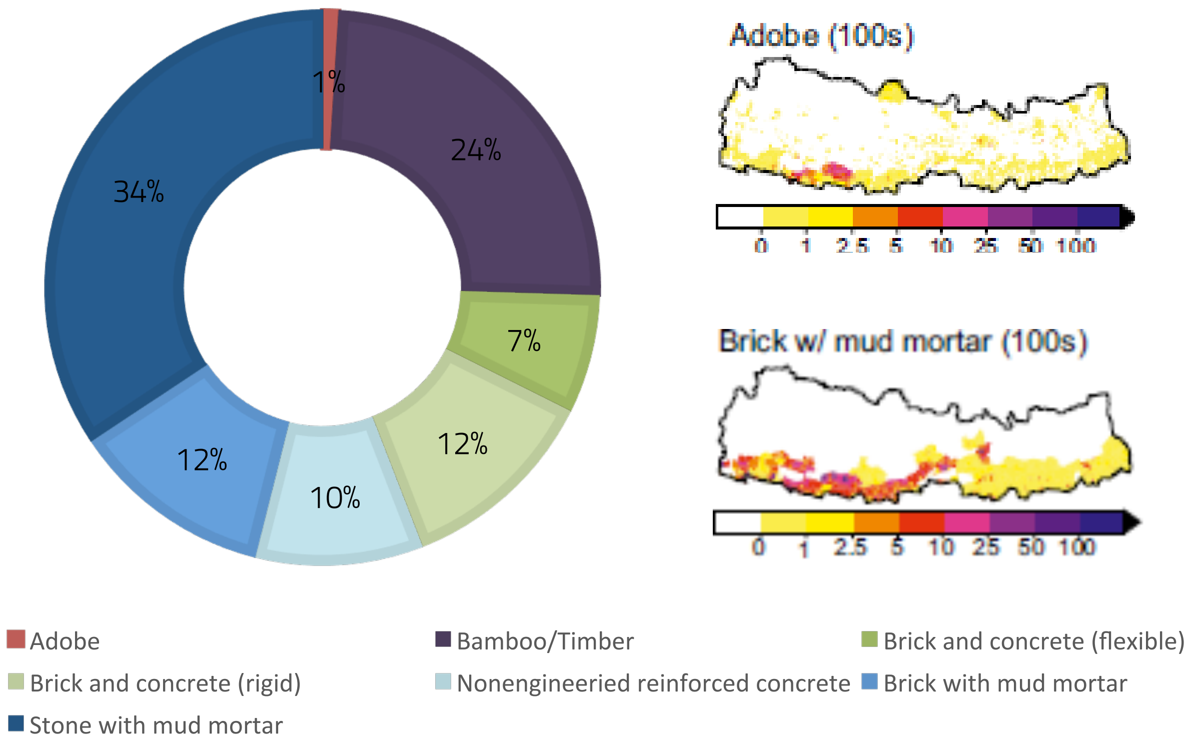
Density of AAL

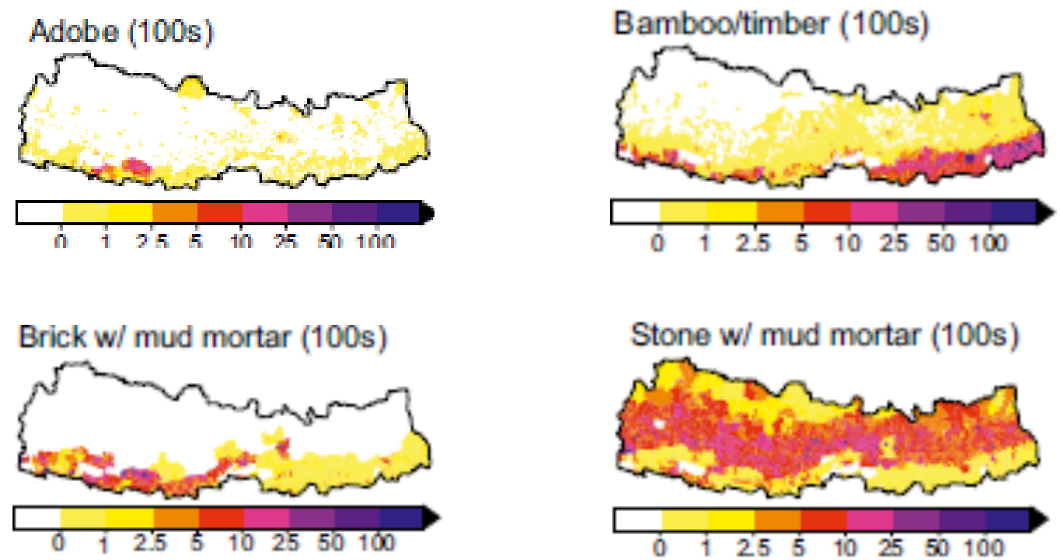
Density of AAL

Annual Average Loss (structural consequences)

National Society Earthquake Technology- Nepal







Robinson et at (2018)

An Earthquake Risk Profile for British Columbia - *Physical Exposure*

Natural Resources Canada

Scenario Risk | Risk Reduction

Physical Exposure

Settled Areas of BC

↓

2011 Census & NHS

↓

Community Typology

↓

Neighbourhood Exposure Model

↑

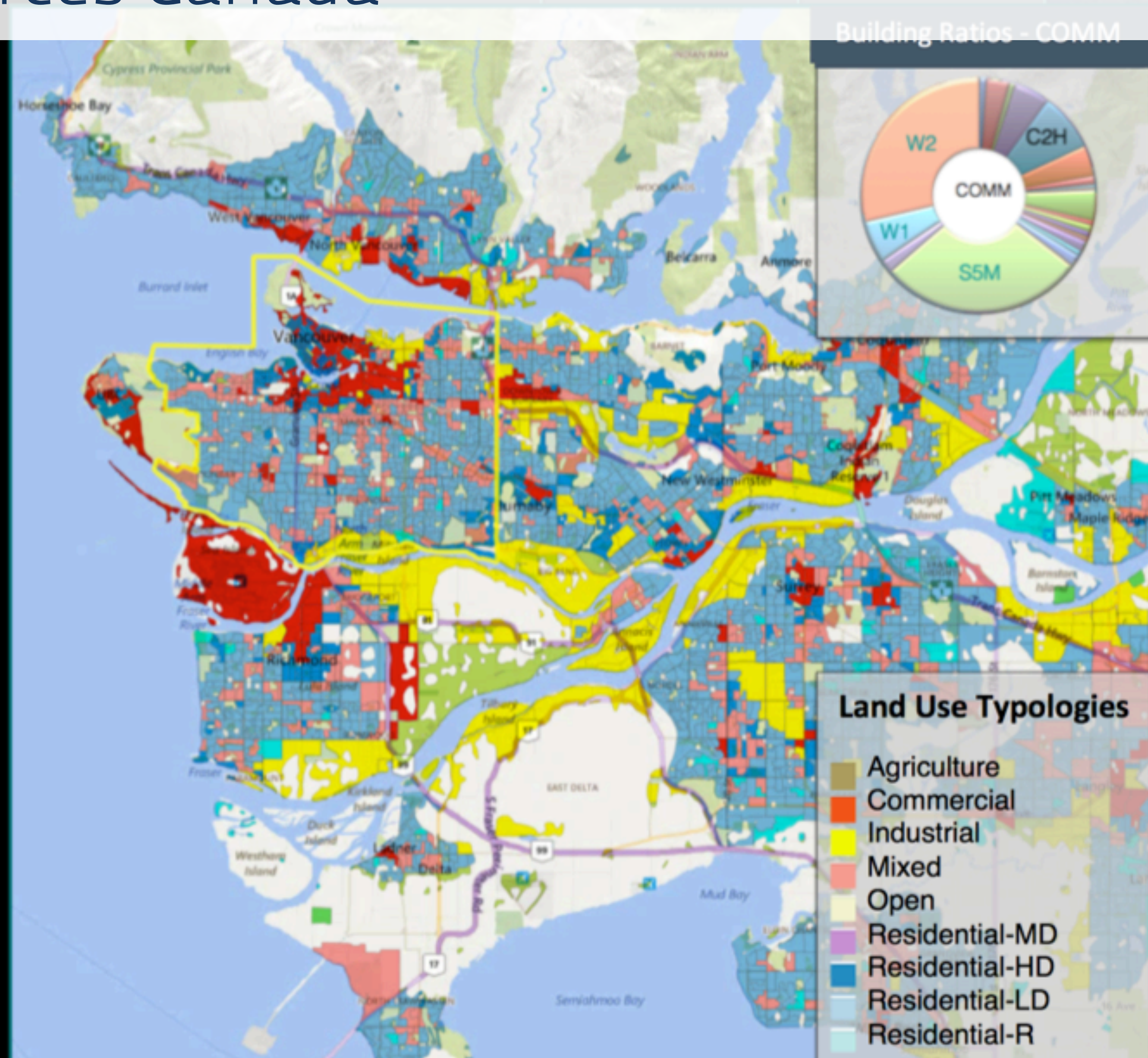
Building Type Ratios

↑

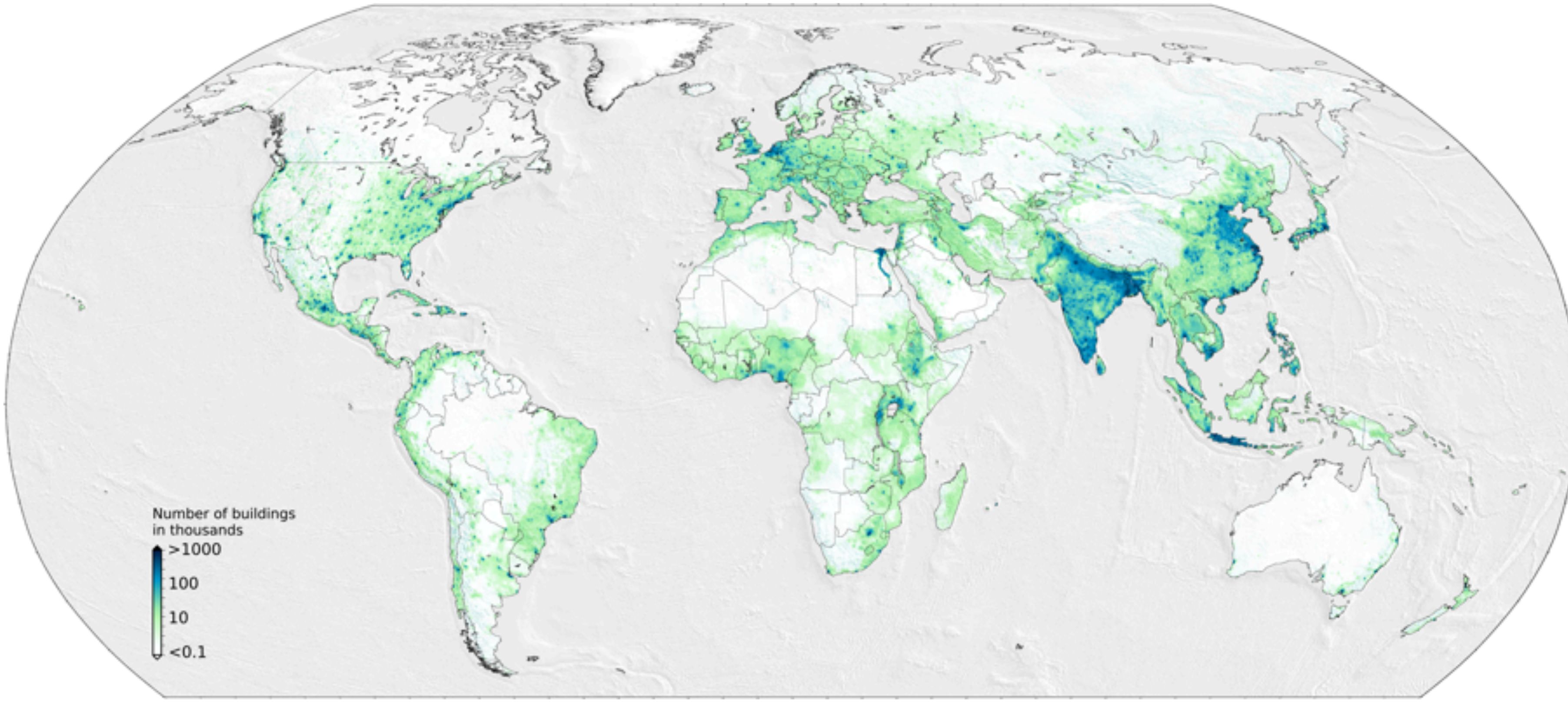
Land Use Typology

↑

Building Inventory

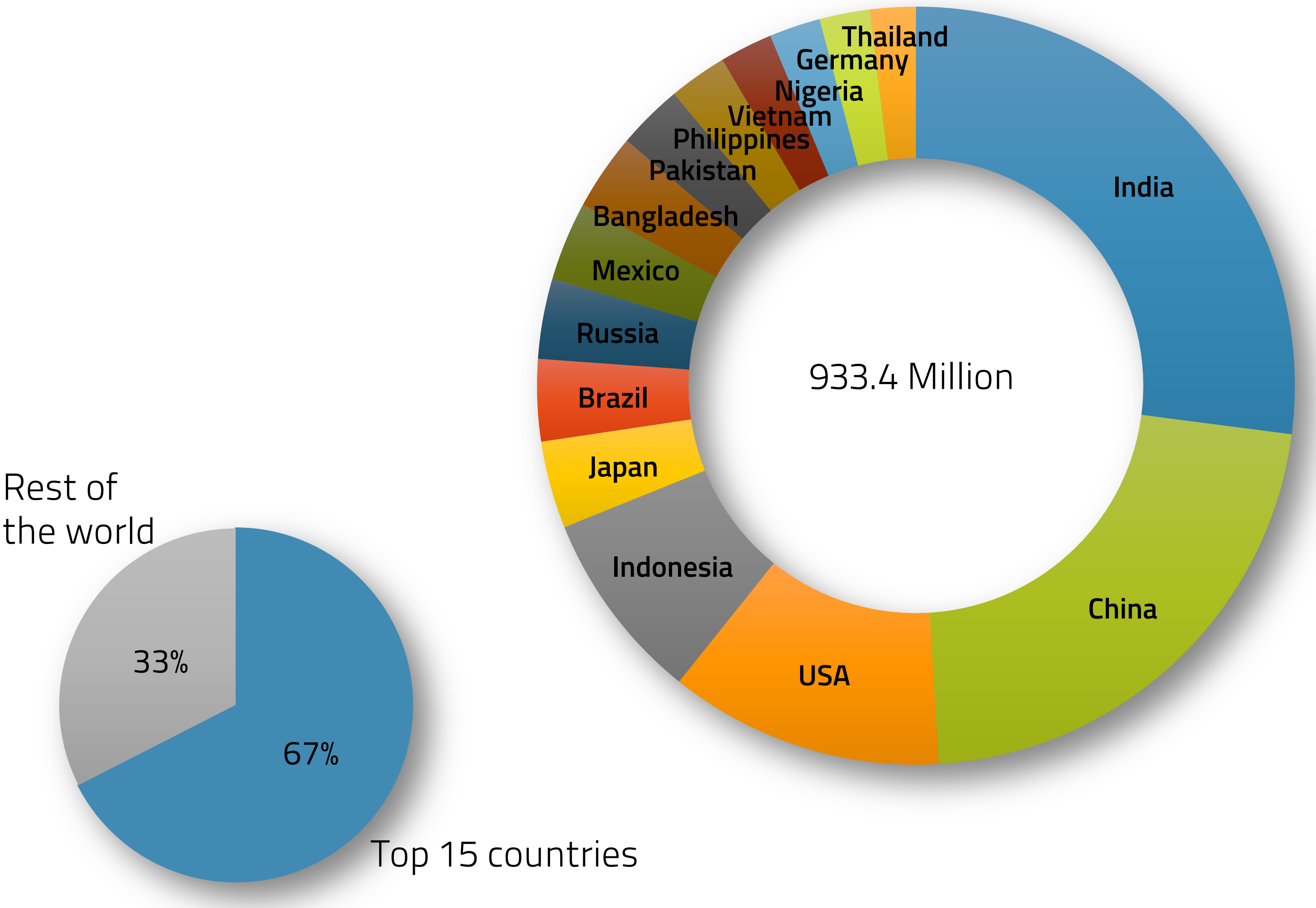


A Uniform Global Exposure Dataset



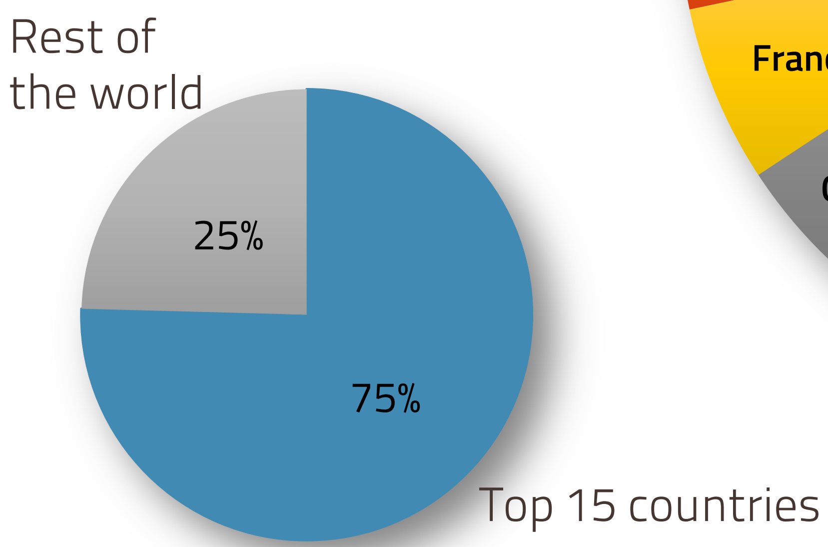
How many buildings do we have and where?

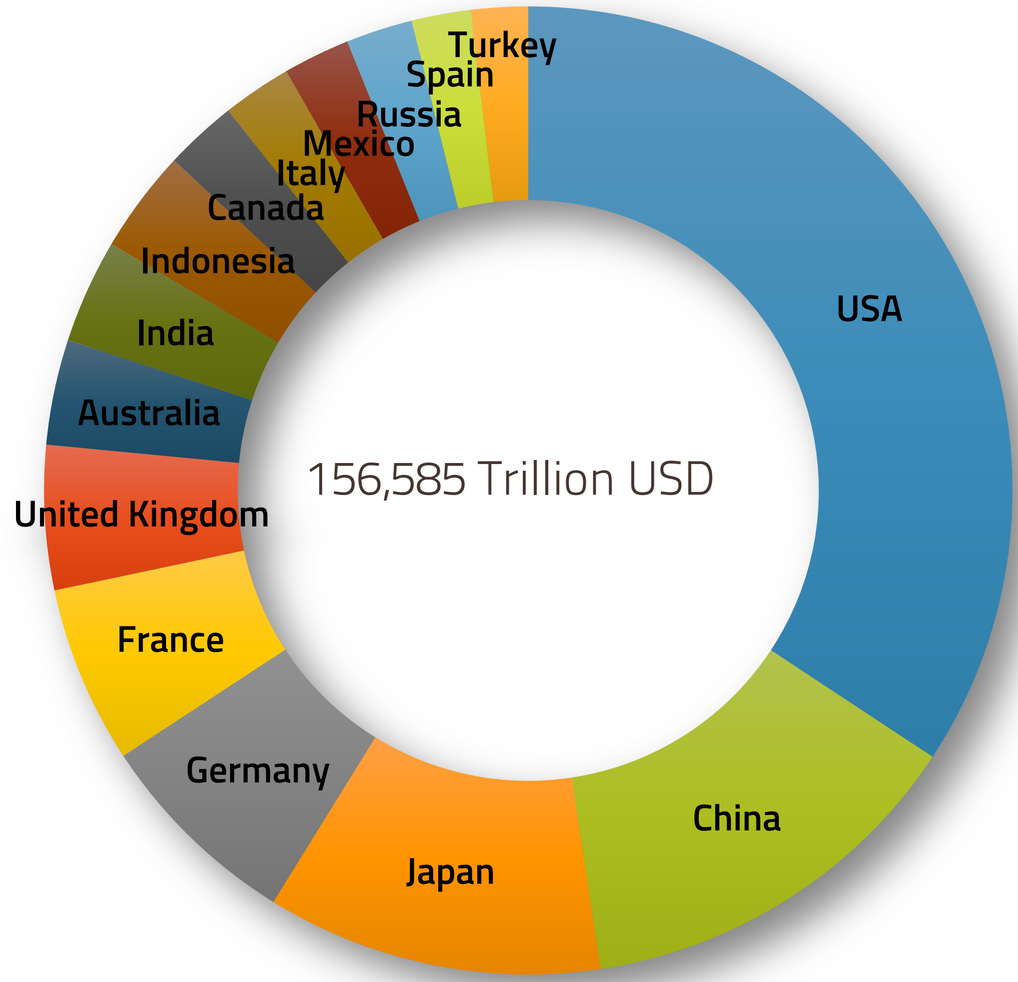
Total buildings: 1,383 Million



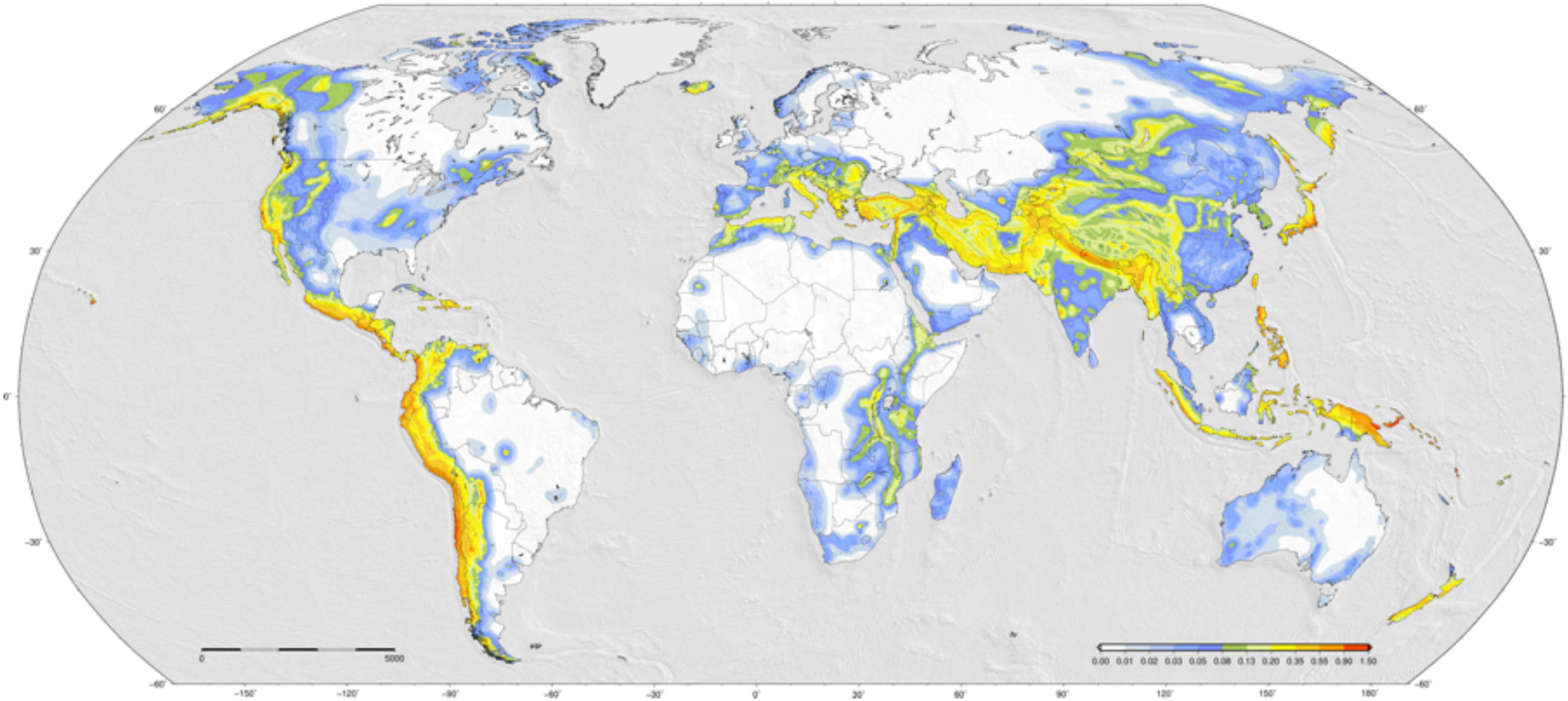
How much value do we have and where?

Total buildings: 207,616 Trillion USD



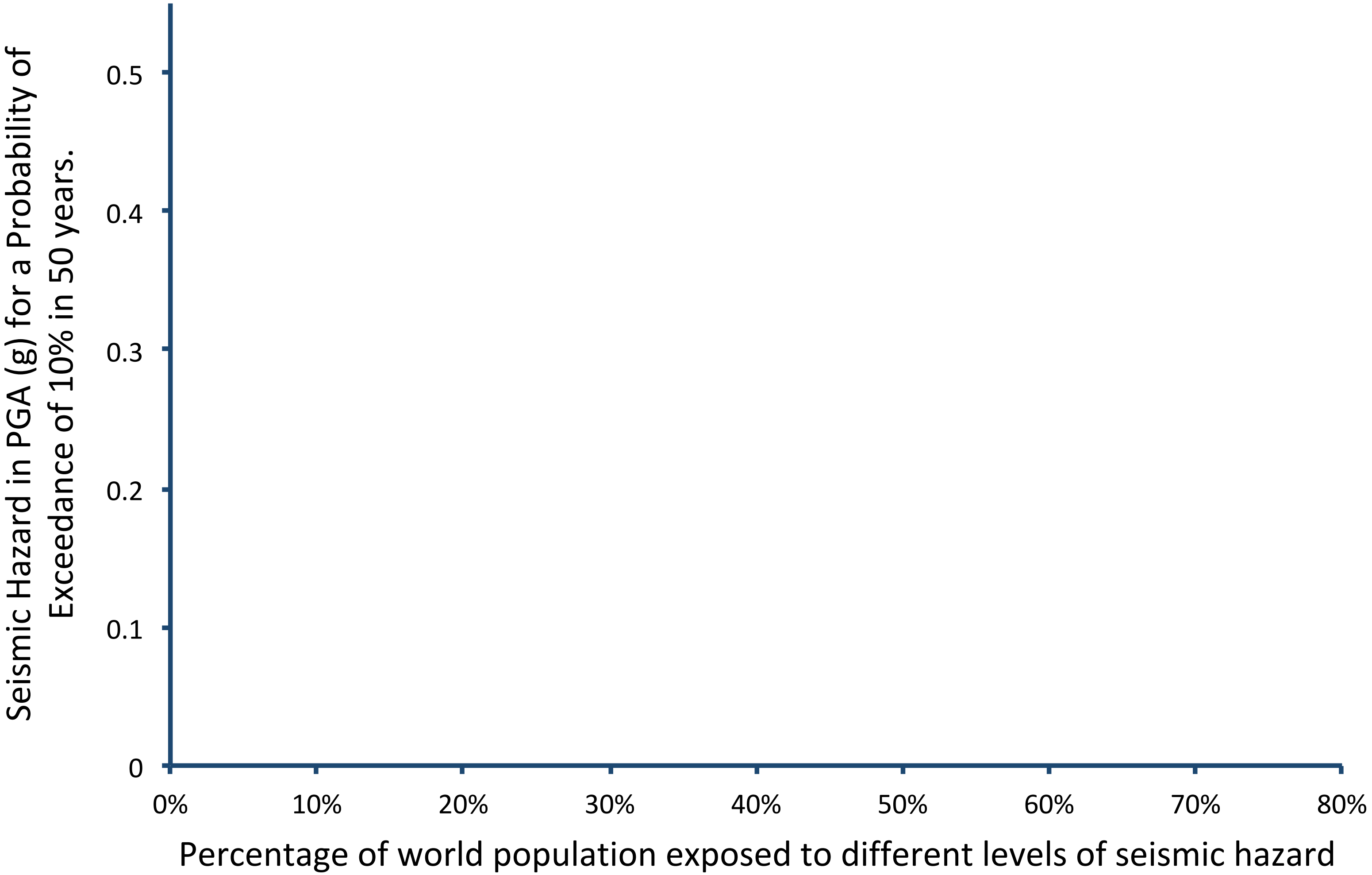


How much are we exposed to seismic hazard?

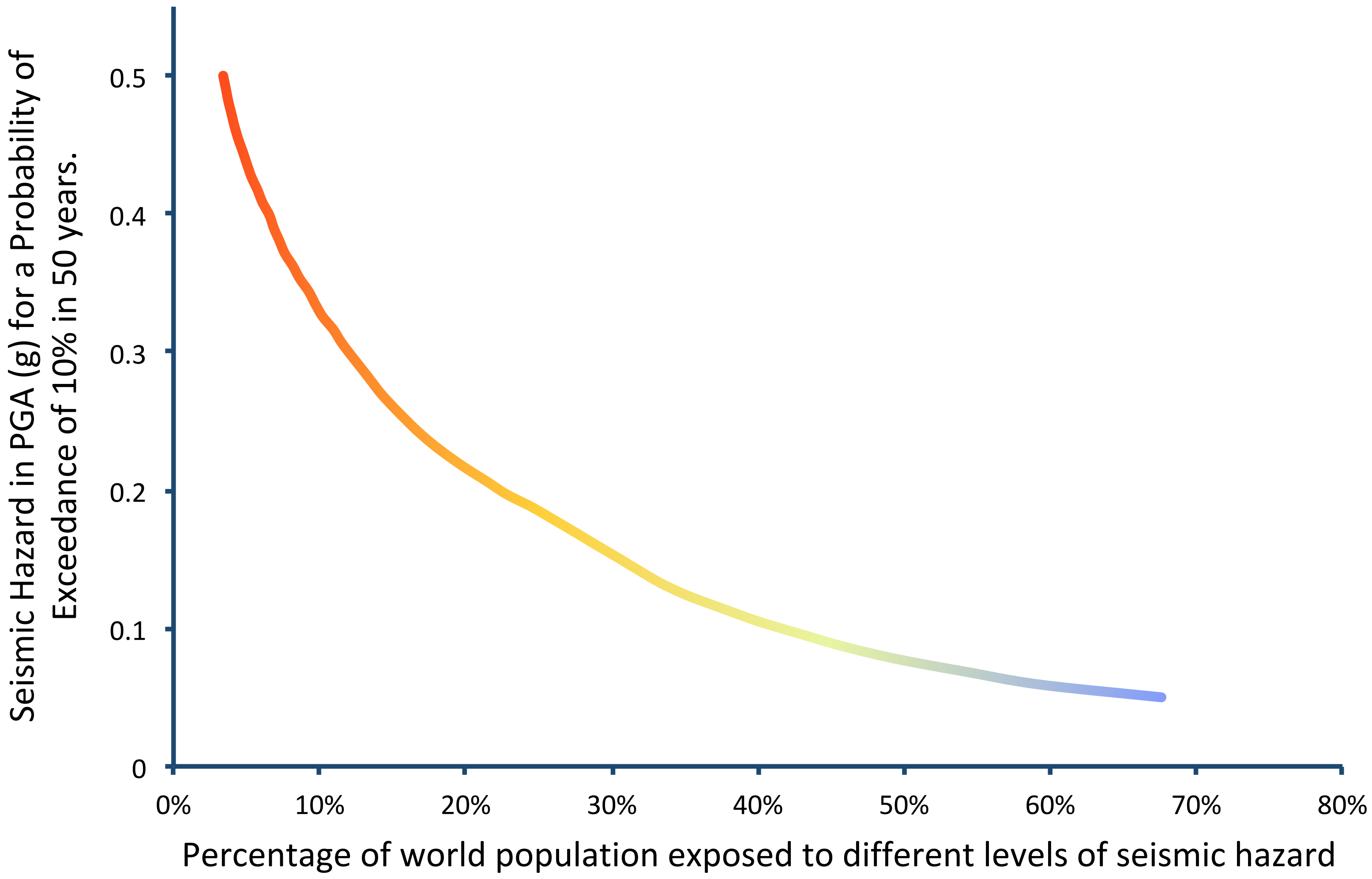


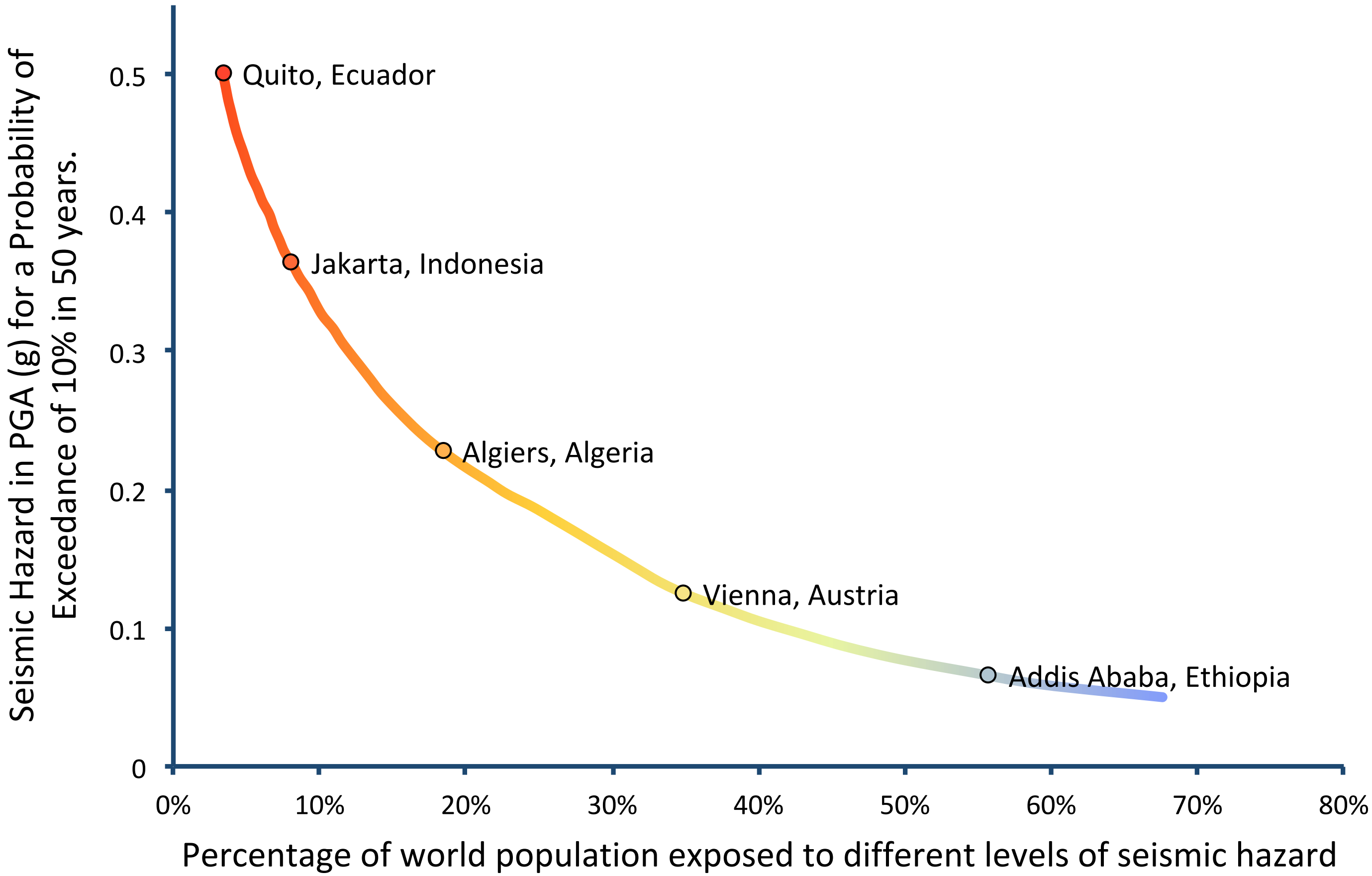
Global Seismic Hazard Map

How much are we exposed to seismic hazard?



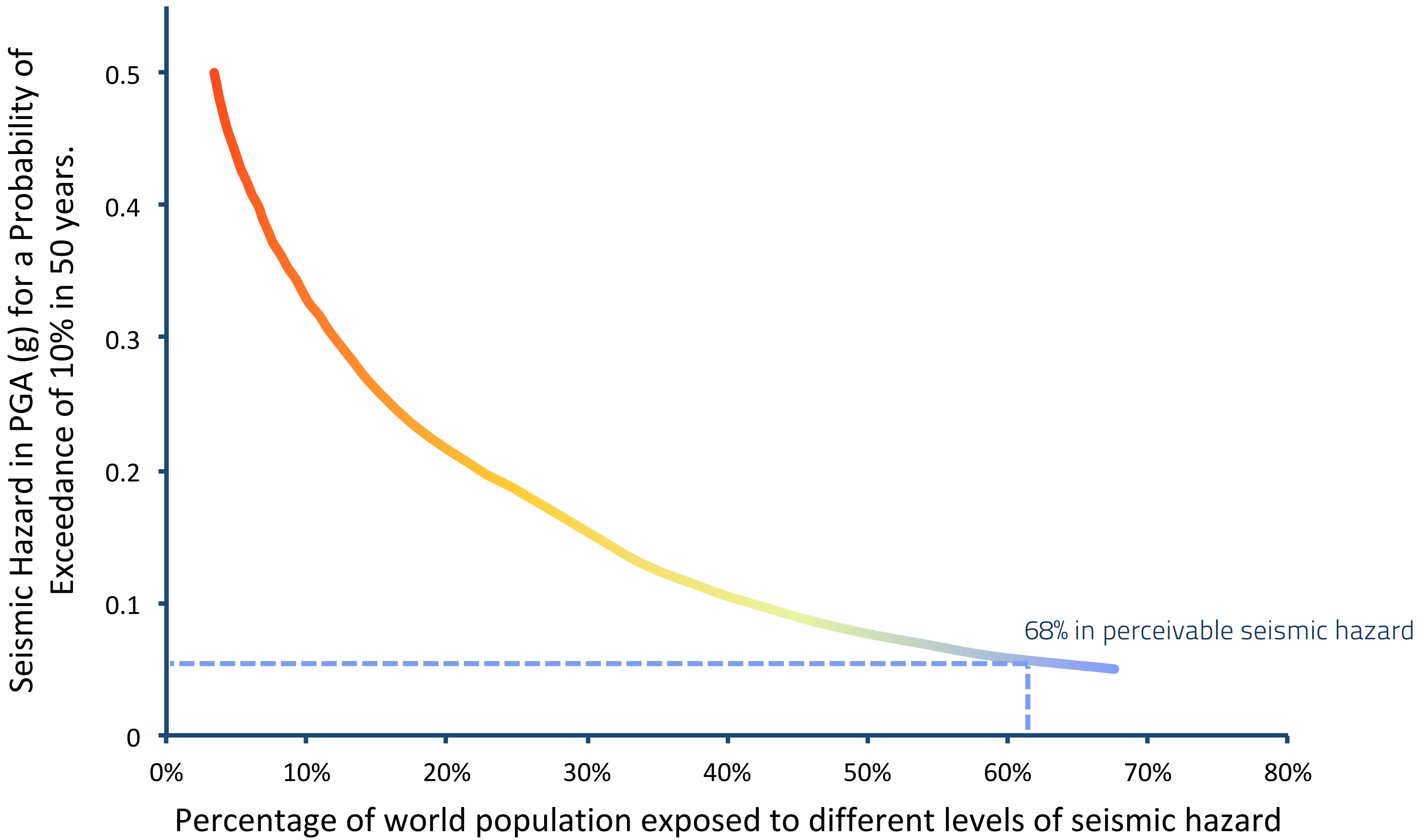
How much are we exposed to seismic hazard?



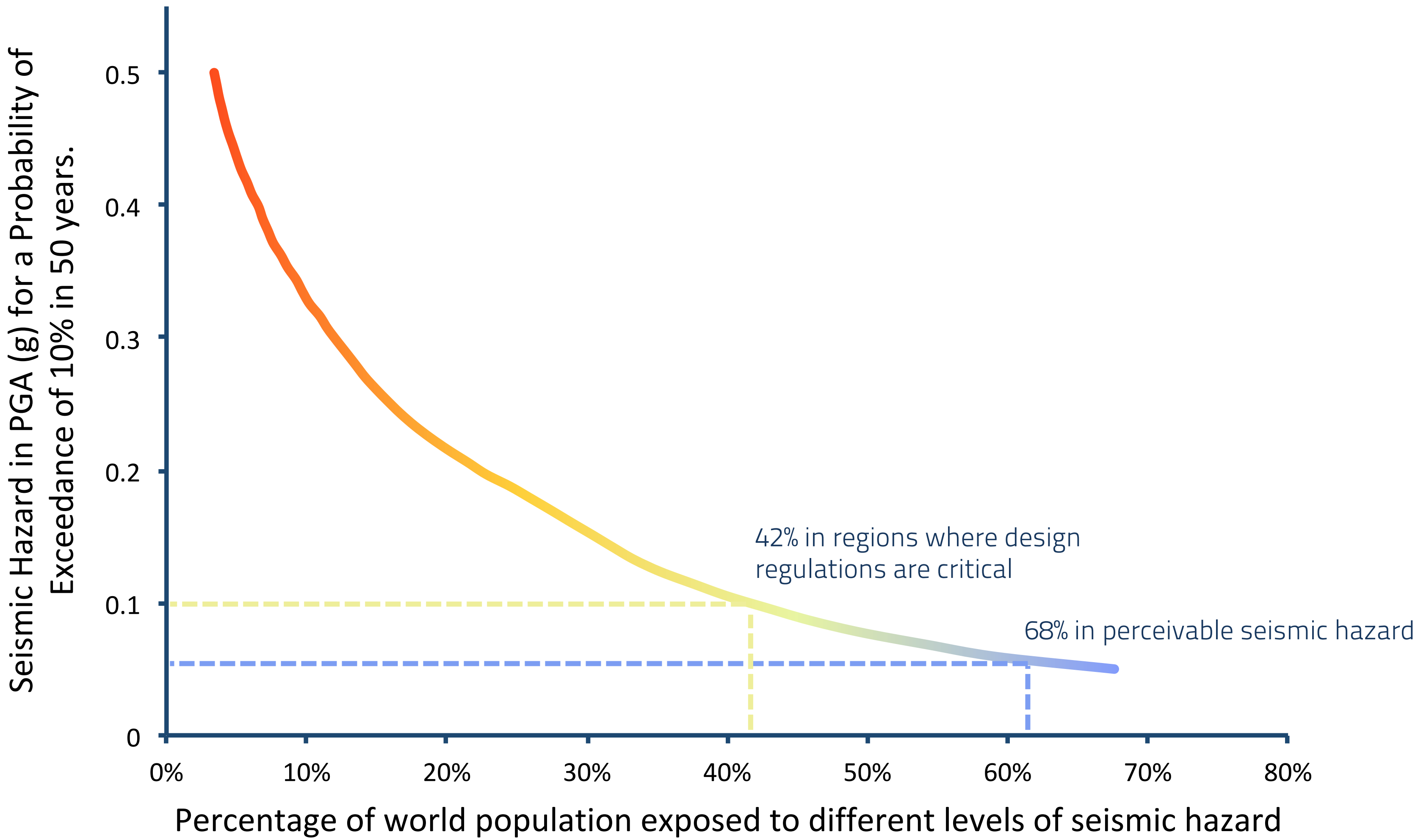


Seismic Hazard in PGA (g) for a Probability of Exceedance of 10% in 50 years.
0.5
0.4
0.3
0.2
0.1
0
Quito, Ecuador
Jakarta, Indonesia
Algiers, Algeria
Vienna, Austria
Addis Ababa, Ethiopia
0%
10%
20%
30%
40%
50%
60%
70%
80%
Percentage of world population exposed to different levels of seismic hazard

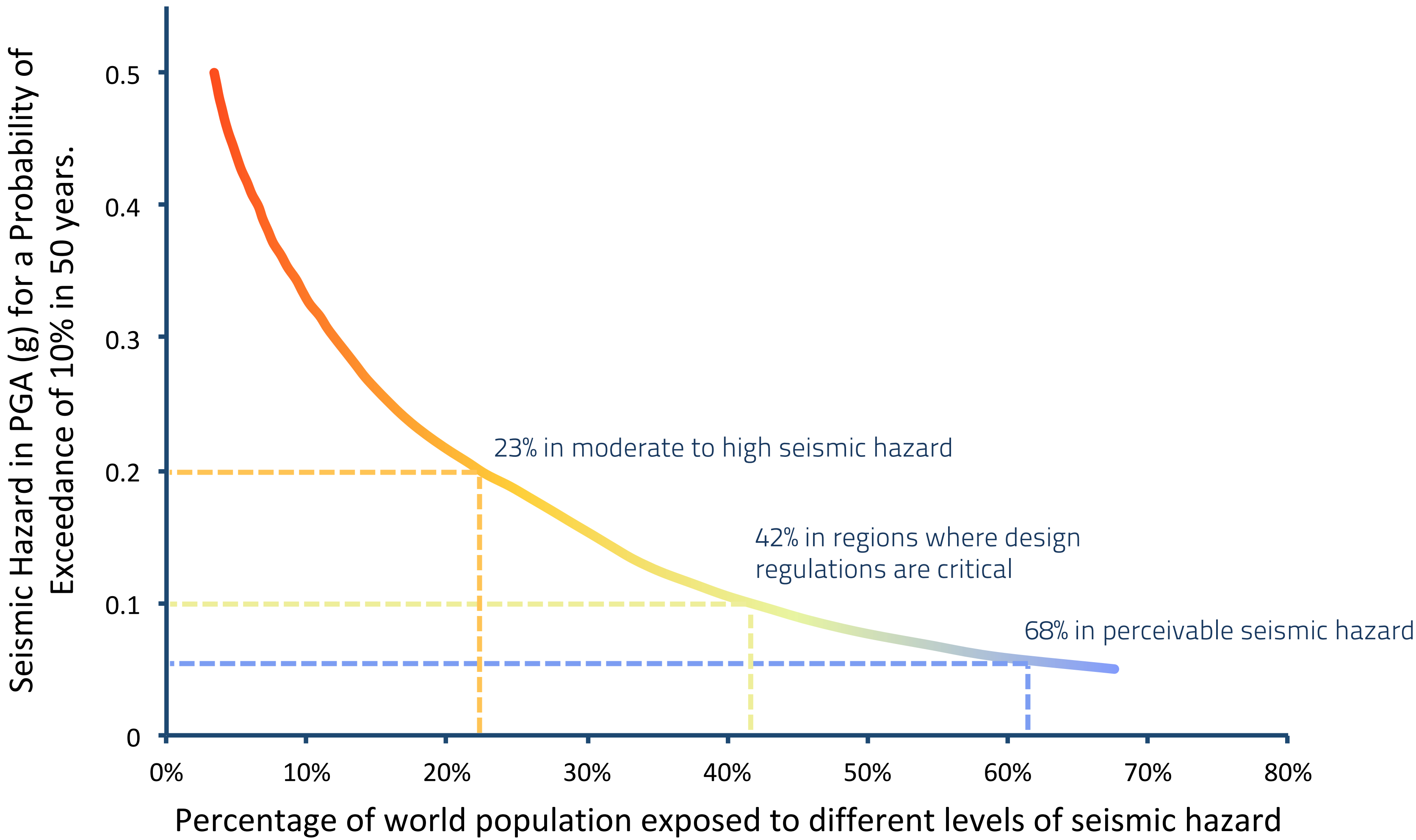
How much are we exposed to seismic hazard?

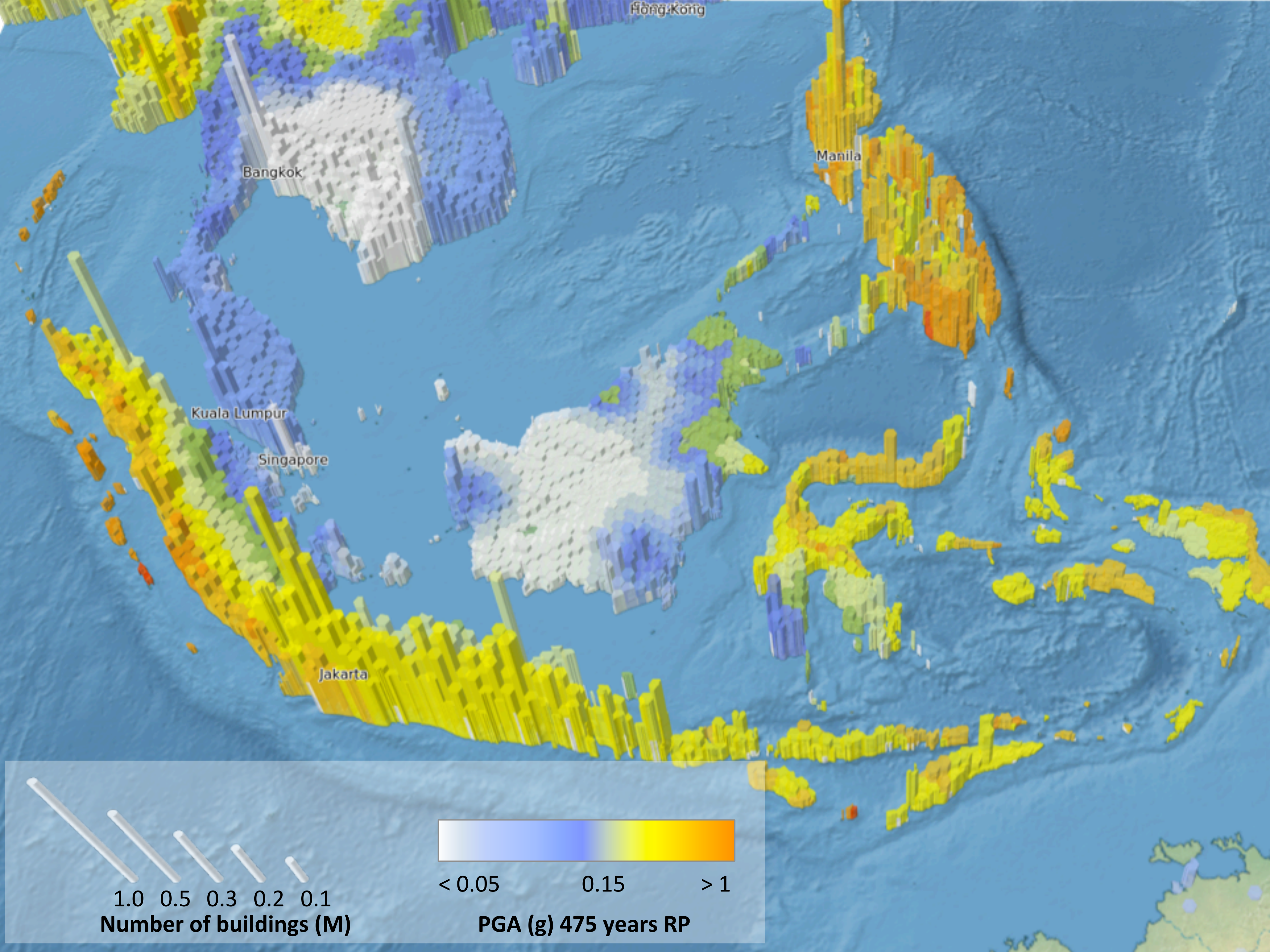


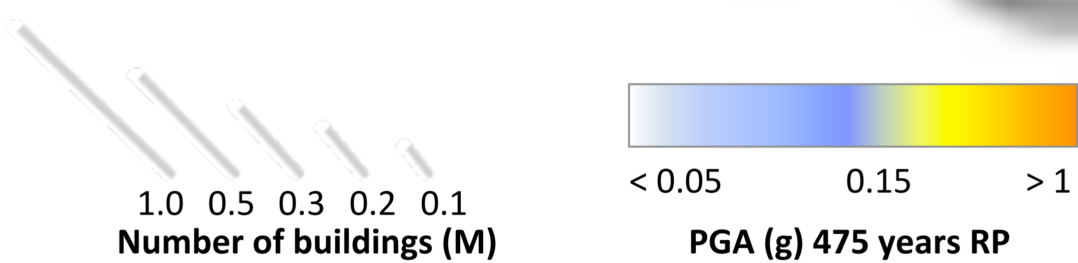
How much are we exposed to seismic hazard?

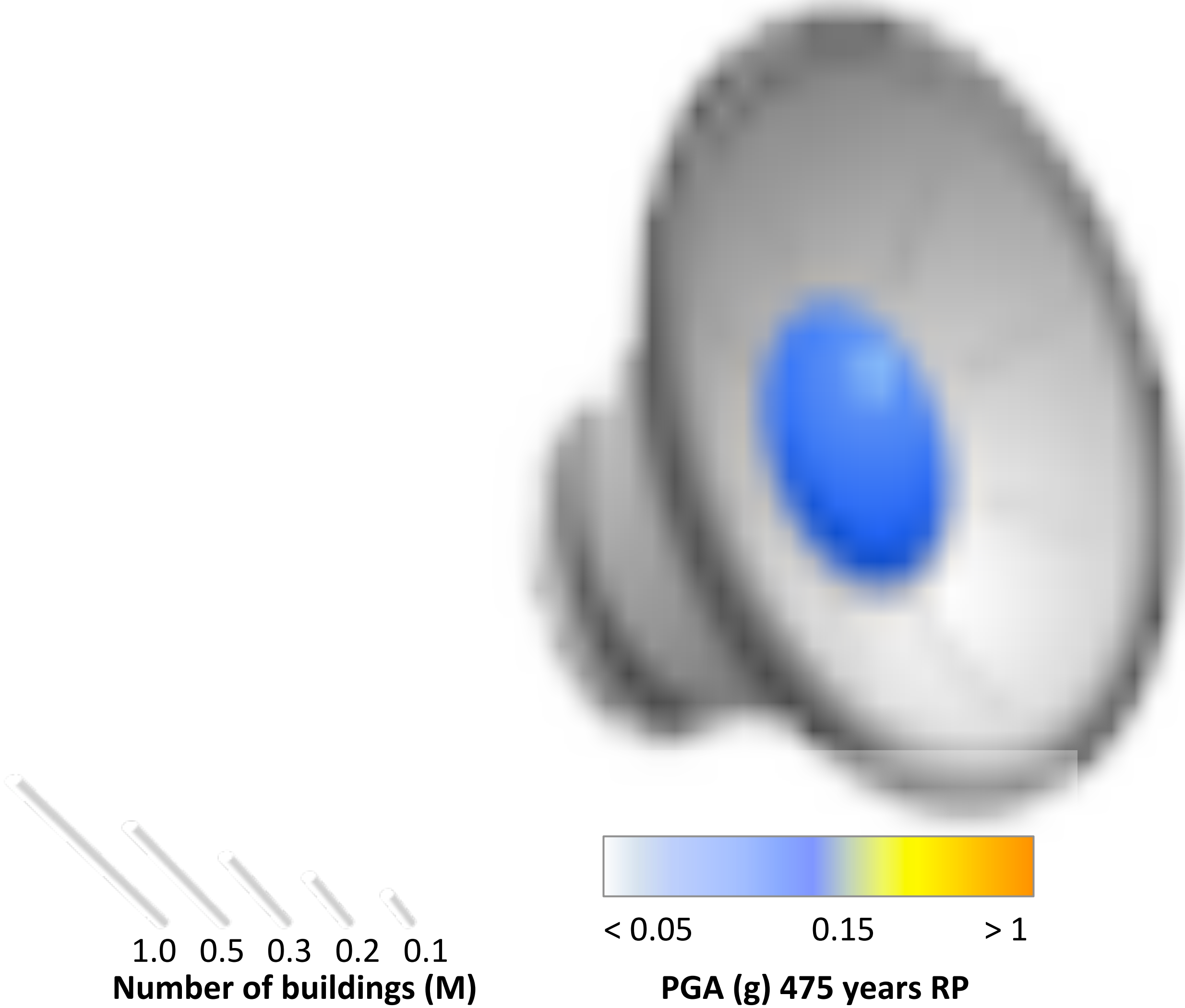


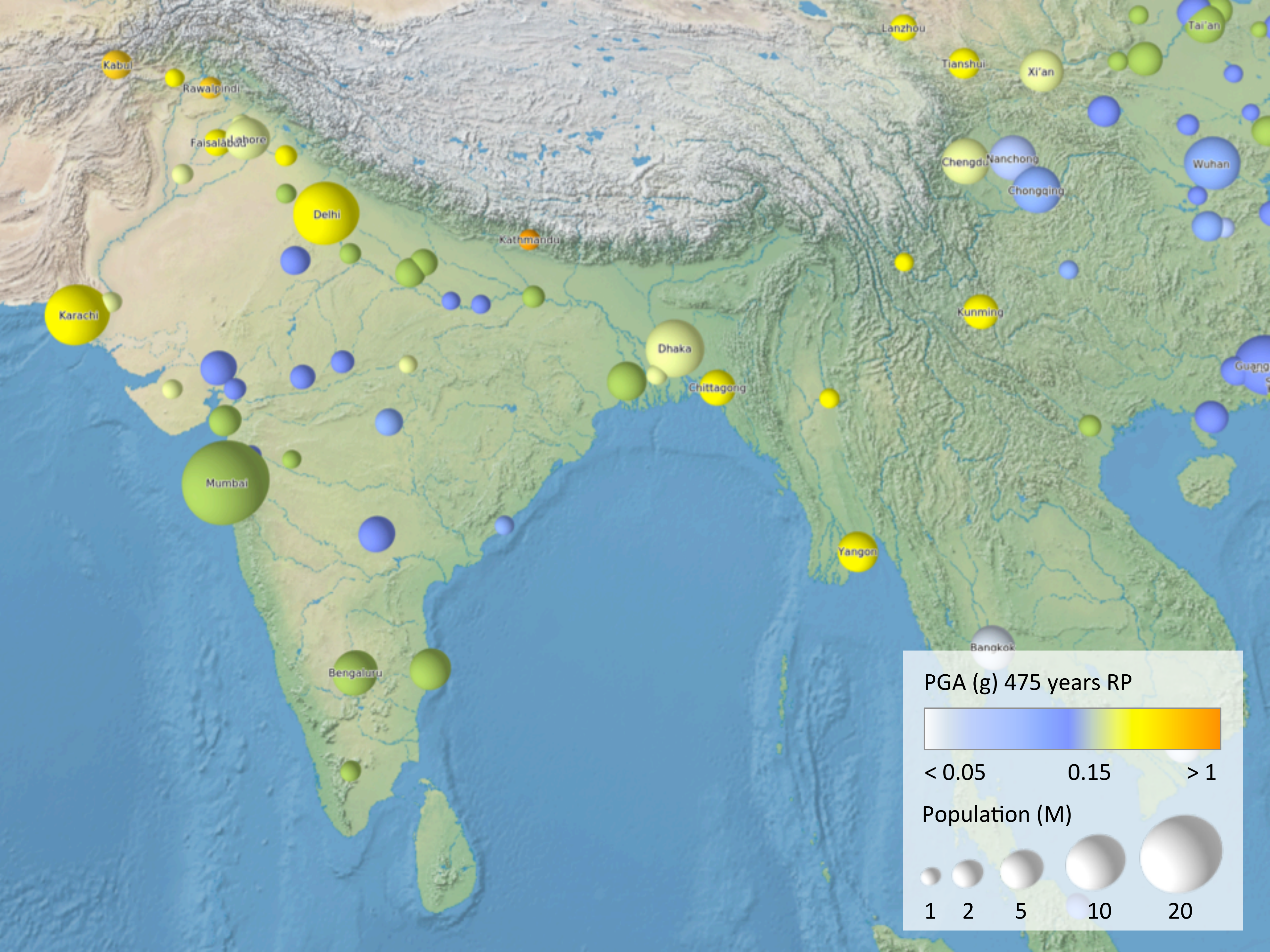
How much are we exposed to seismic hazard?



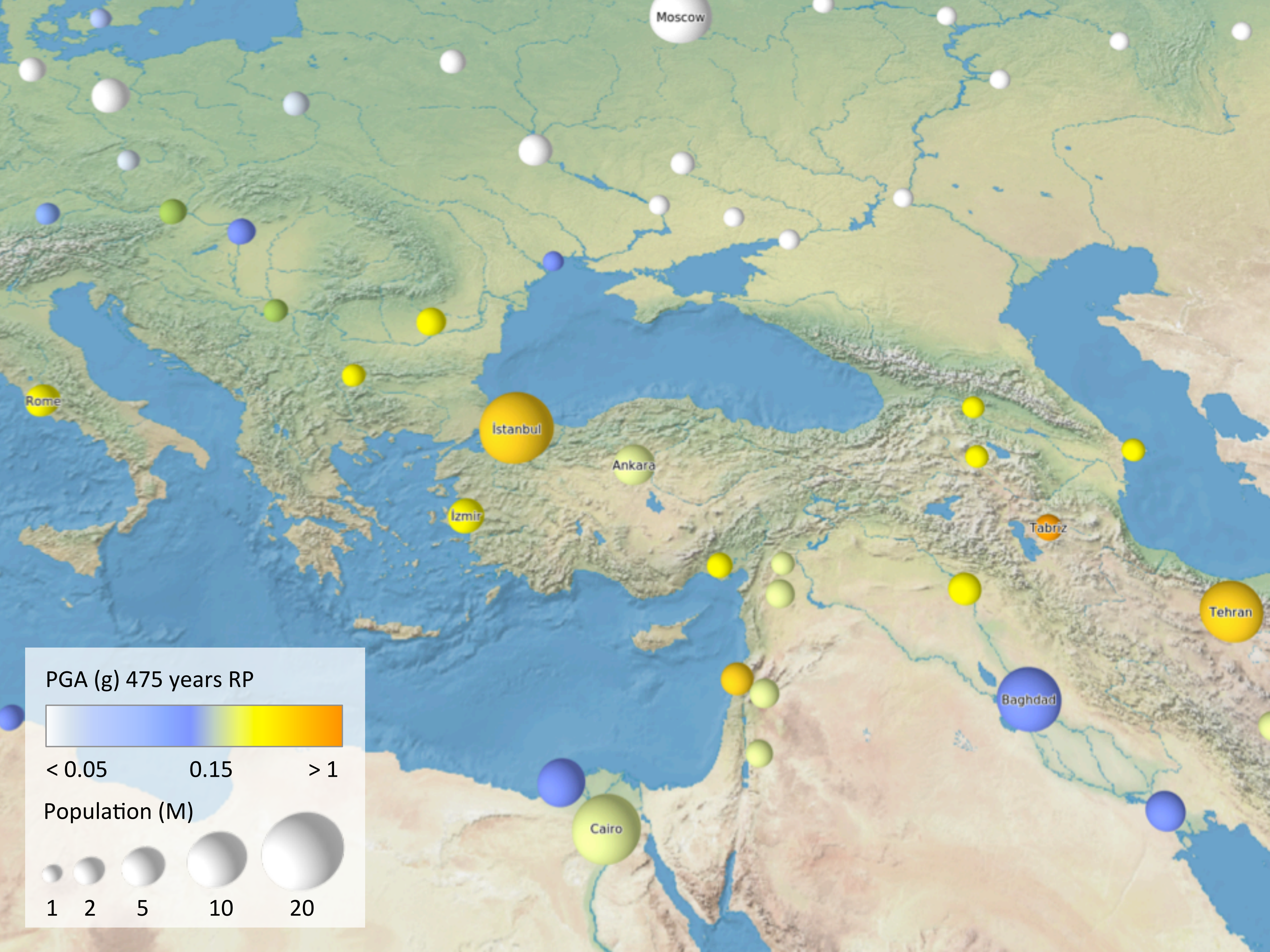

Hong Kong
Manila
Bangkok
Kuala Lumpur
Singapore
Jakarta
1.0 0.5 0.3 0.2 0.1
Number of buildings (M)
< 0.05 0.15 > 1
PGA (g) 475 years RP


1.0 0.5 0.3 0.2 0.1
Number of buildings (M)
< 0.05
0.15
> 1
PGA (g) 475 years RP


1.0 0.5 0.3 0.2 0.1
Number of buildings (M)
< 0.05 0.15 > 1
PGA (g) 475 years RP

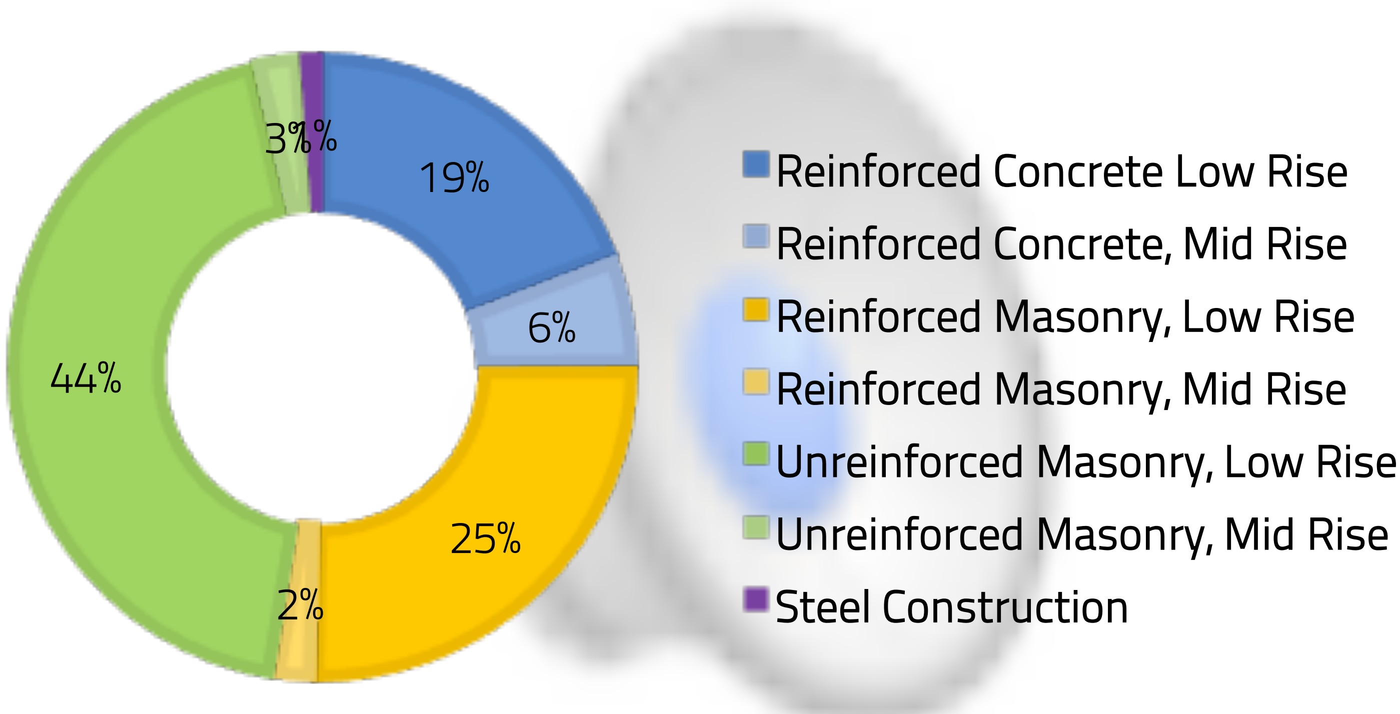


Lanzhou
Tai'an
Kabul
Rawalpindi
Tianshui
Xi'an
Faisalabad
Lahore
Chengdu
Nanchong
Wuhan
Chongqing
Delhi
Kathmandu
Karachi
Kunming
Dhaka
Chittagong
Mumbai
Yangon
Bangkok
Bengaluru
PGA (g) 475 years RP
< 0.05
0.15
> 1
Population (M)
1
2
5
10
20


Moscow
Rome
İstanbul
Ankara
İzmir
Tabriz
Tehran
Baghdad
Cairo
PGA (g) 475 years RP
< 0.05
0.15
> 1
Population (M)
1
2
5
10
20

Seismic Vulnerability

Classifying building vulnerability globally



Building classification for Italy (residential)
(by Dr. Elena Speranza)

+150 pubications + 40 WHE reports + experimental results


VULNERABILITY WORKSHOP
GEM
GLOBAL EARTHQUAKE MODEL

Development of a uniform approach

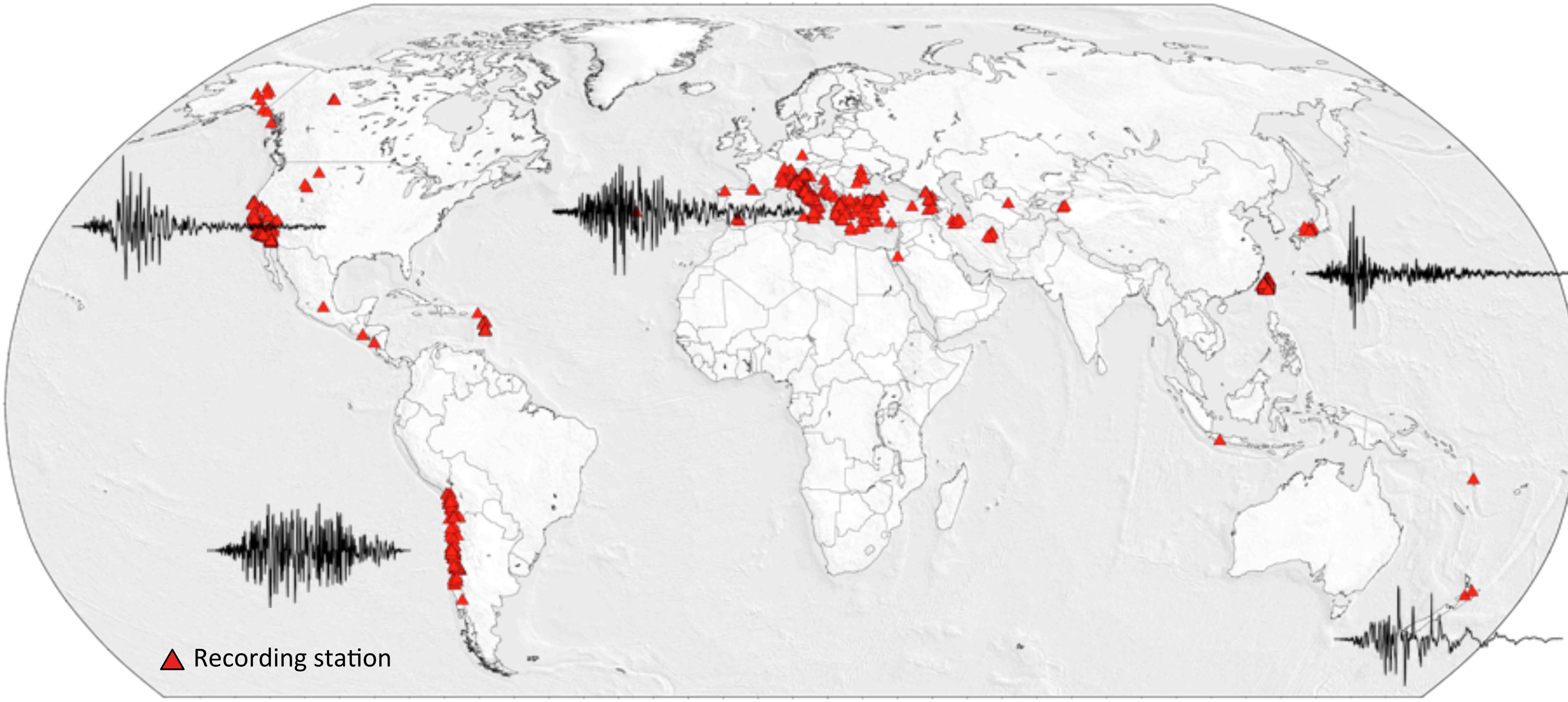
- Employment of nonlinear time-history analysis
- Consideration of single degree of freedom (SDOF) oscillators
- Consideration of a large set of ground motion records
- Avoid scaling factors below 0.5 or above 2
- Employment of four damage states (similar to HAZUS)
- Consideration of structural and non-structural components
- Consideration of building contents

From MDOF to SDOF – structural modelling

Multi-degree of freedom (MDOF) system

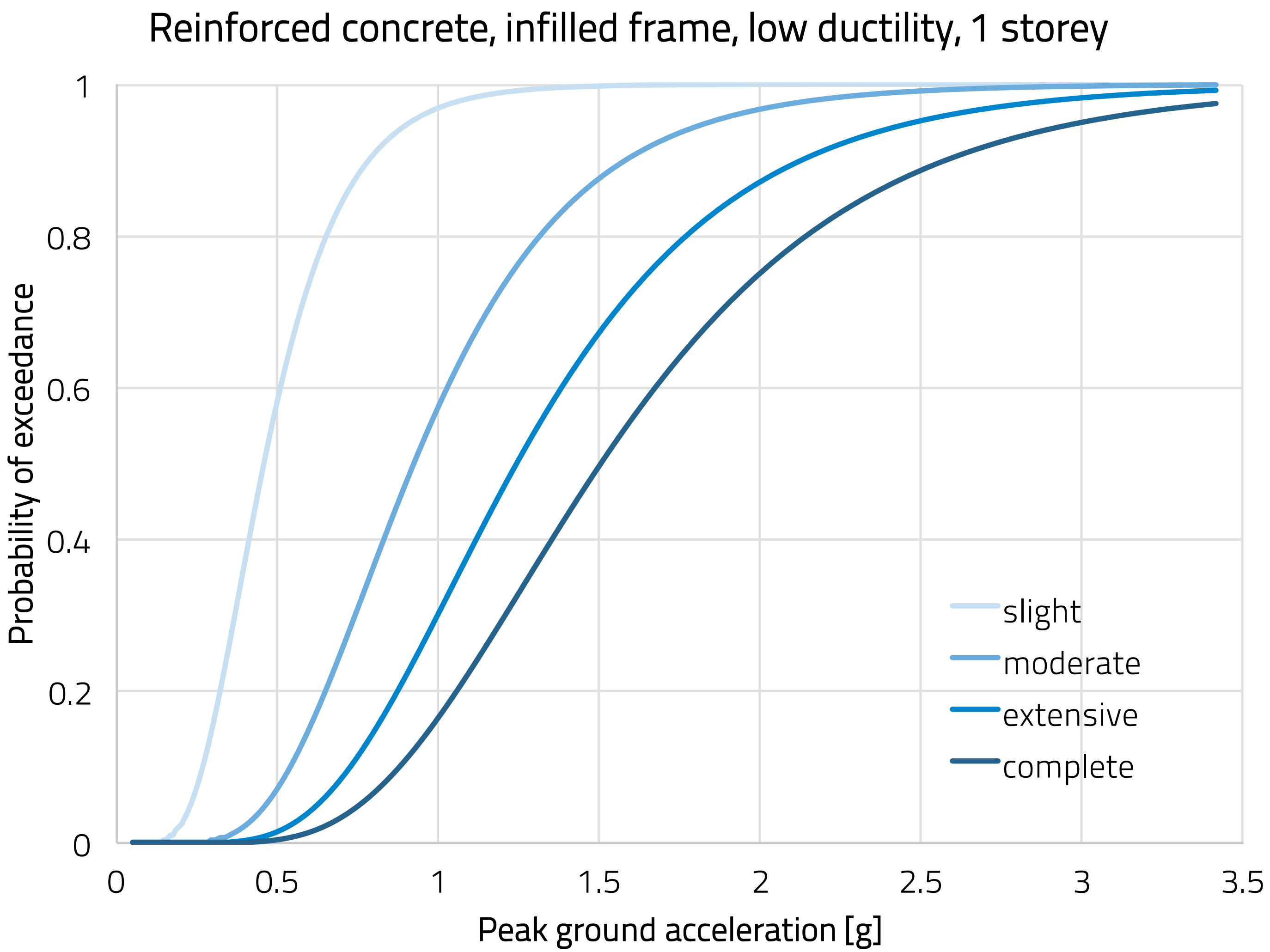
Single-degree of freedom (SDOF) system

Collection ground motion records globally

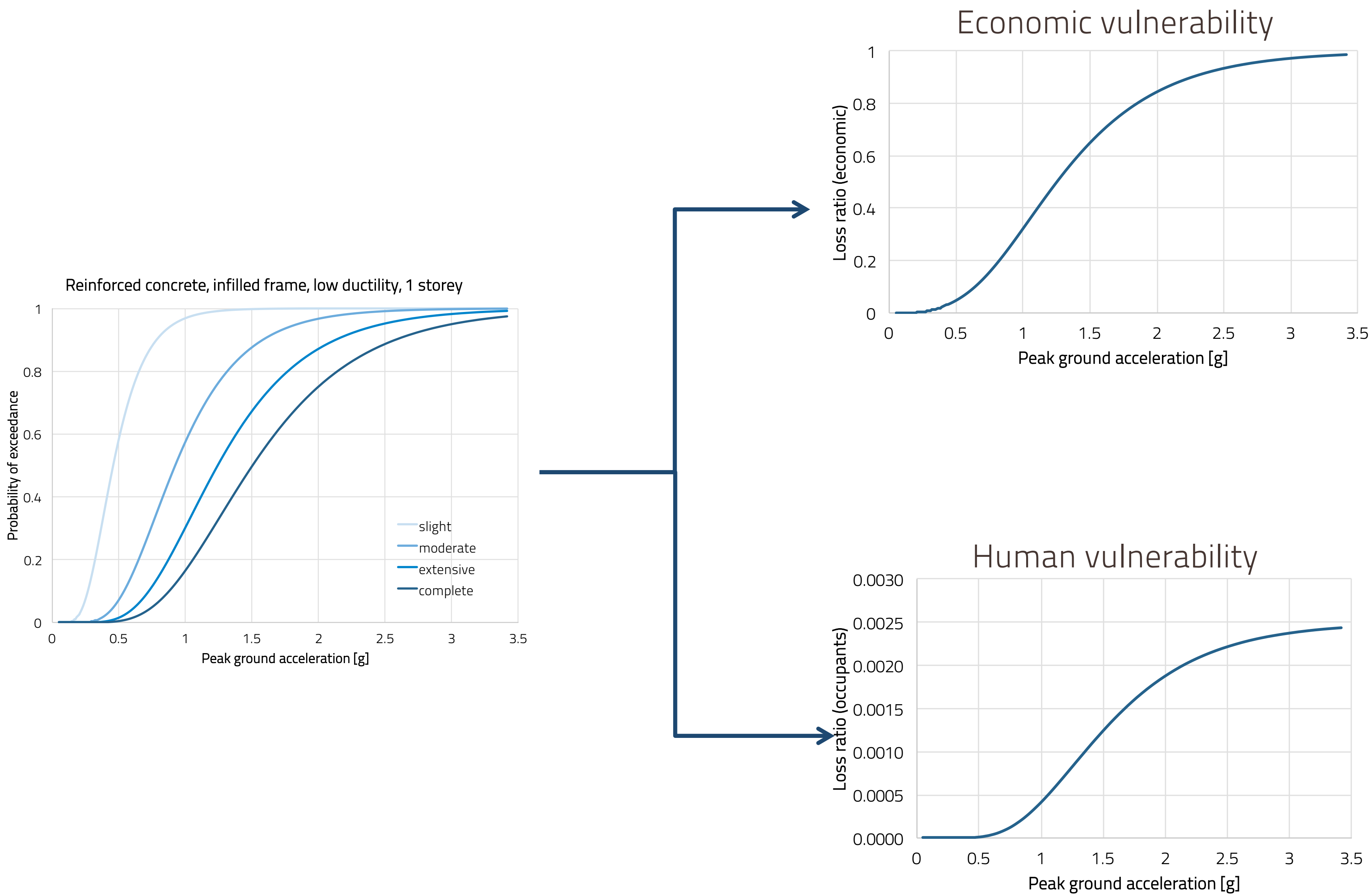


Over 3500 ground motion records collected.

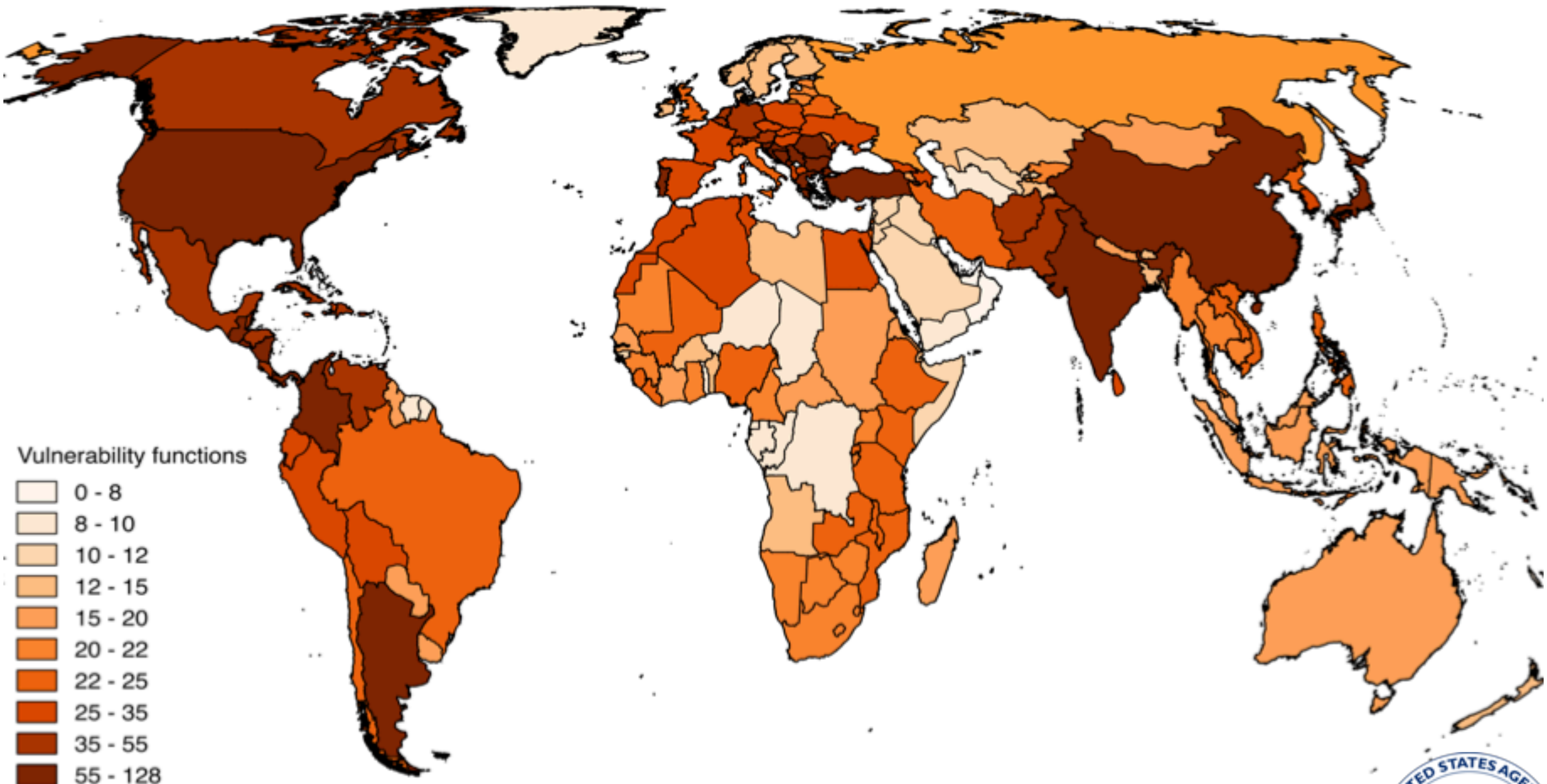
Derivation of fragility functions



Derivation of vulnerability functions



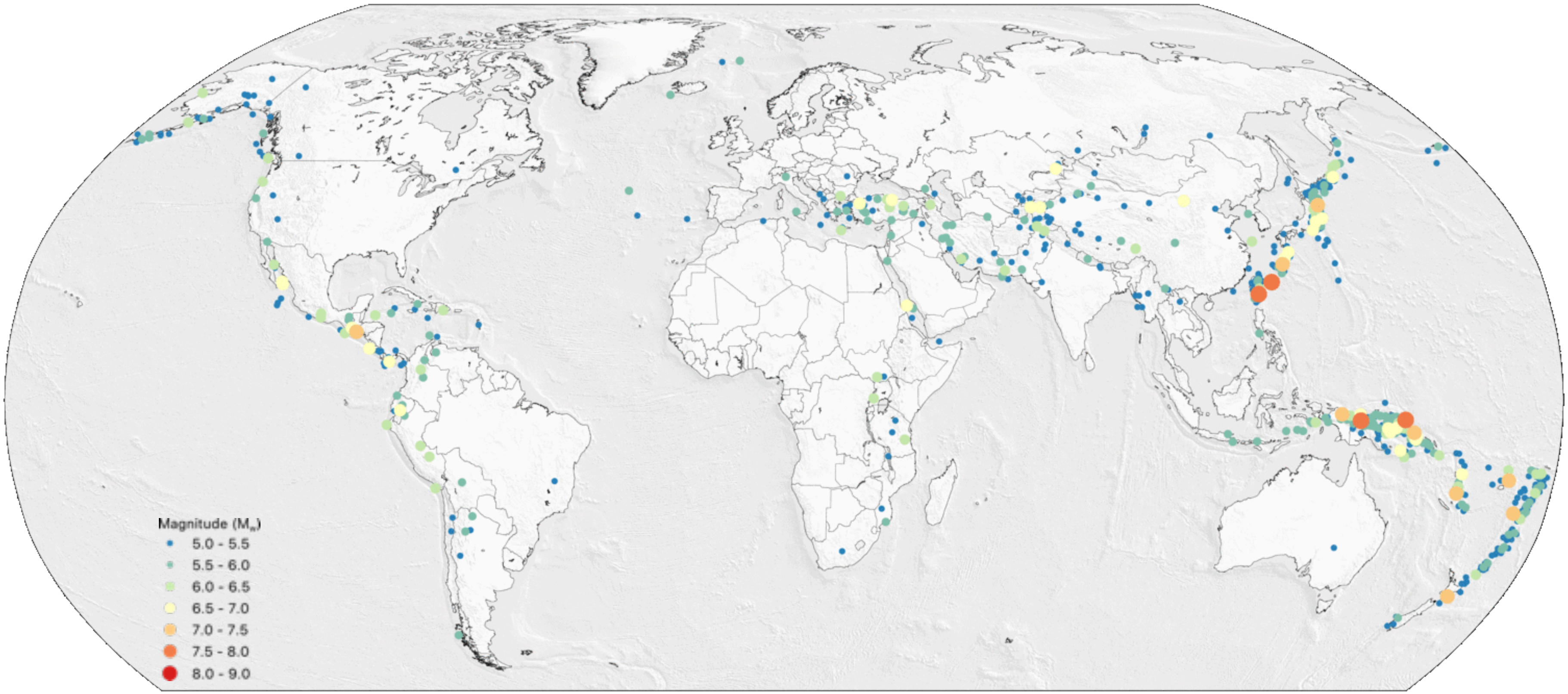
Current database of vulnerability functions



Approximately uniform 500 vulnerability functions

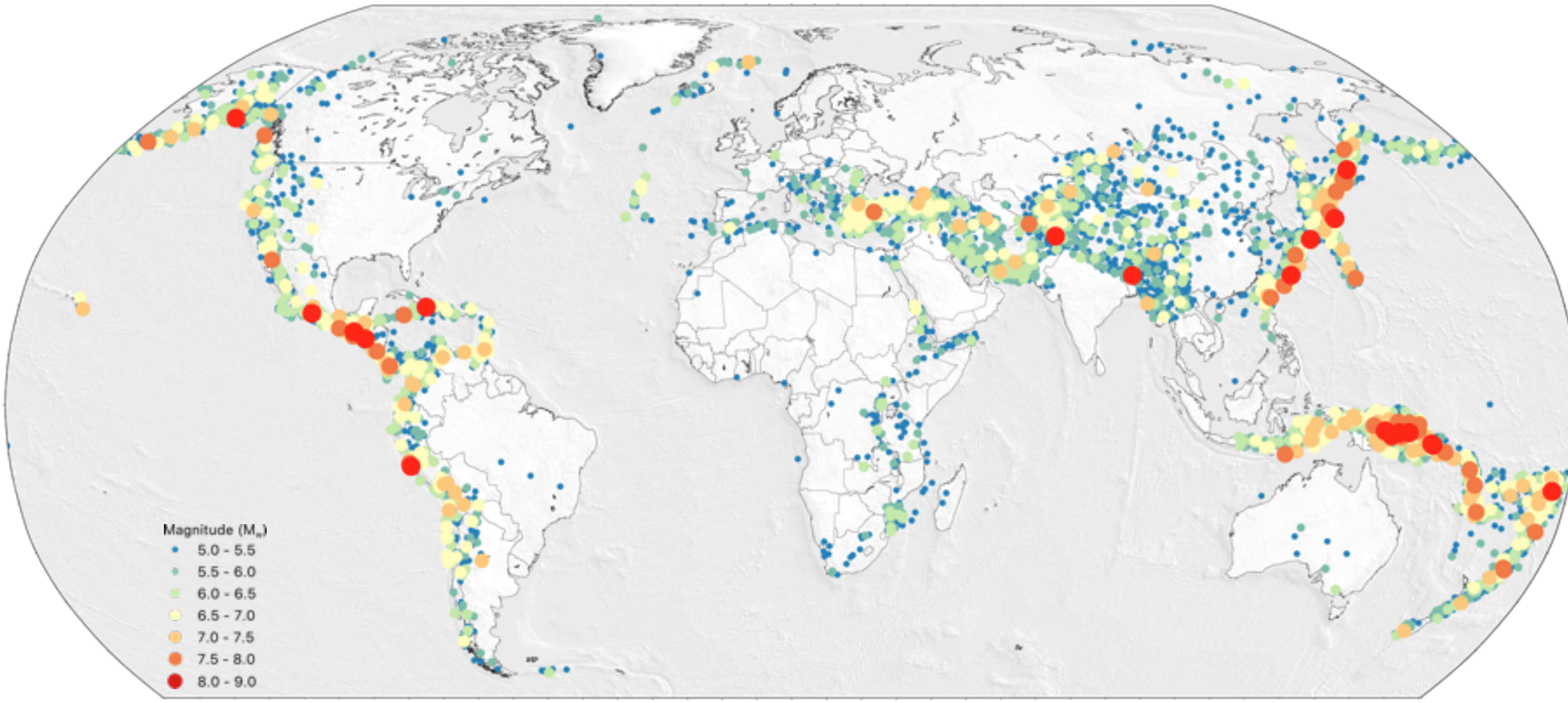
Seismic Risk

Generation of Stochastic Event Sets



Simulation of 1 year of seismic events

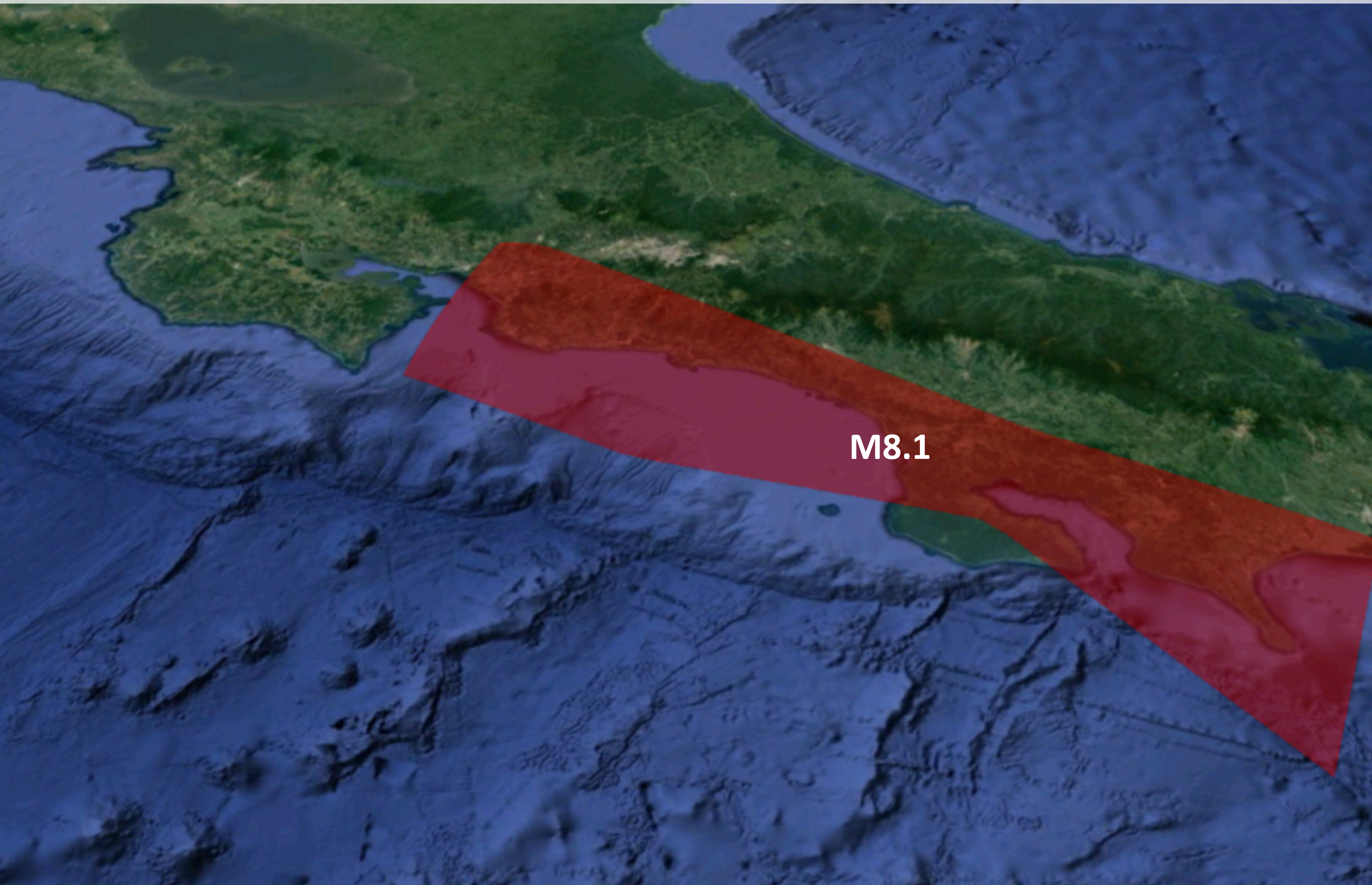
Generation of Stochastic Event Sets



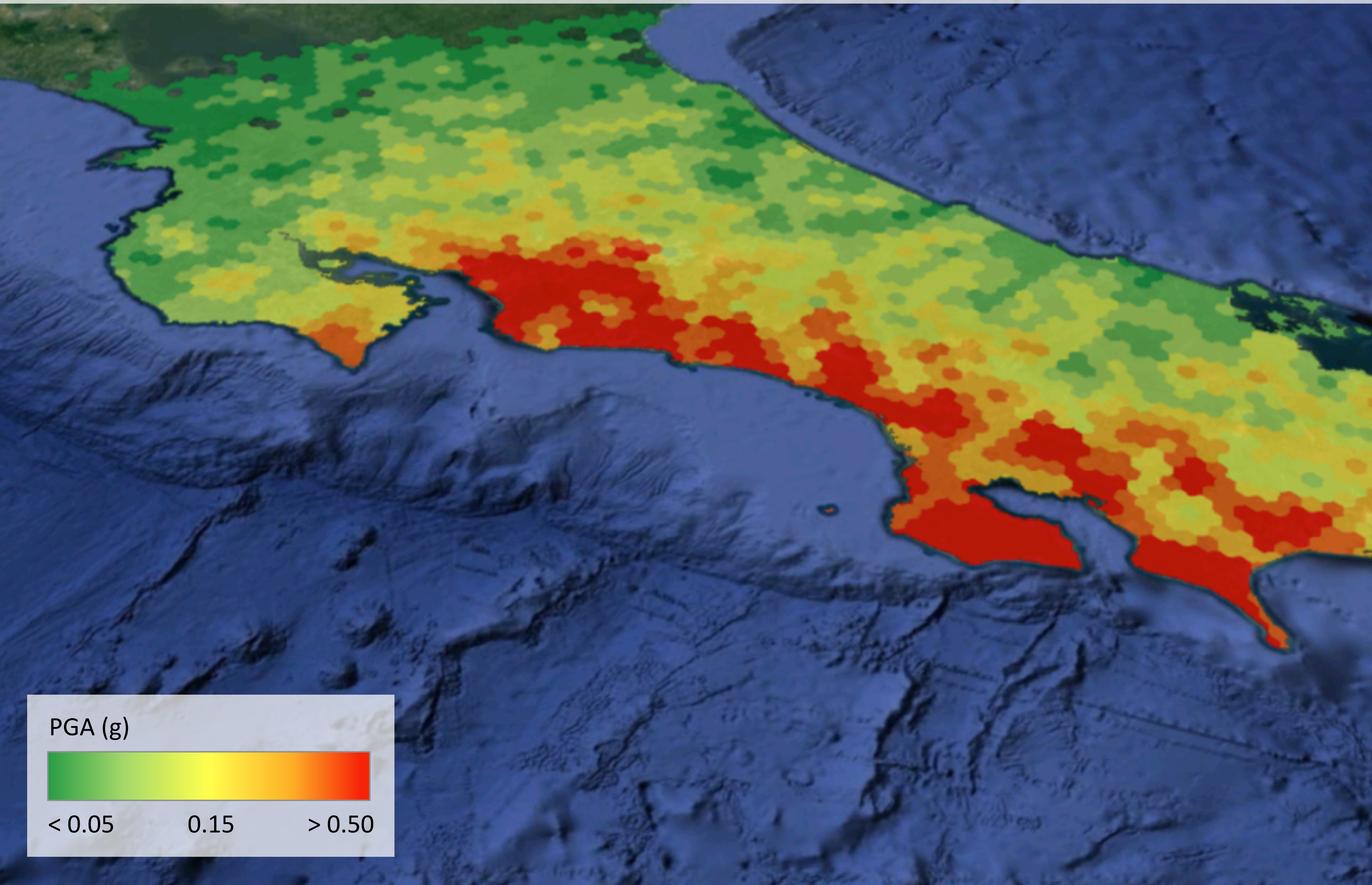
Stochastic event set equivalent to 50 years


Nicaragua
Costa Rica

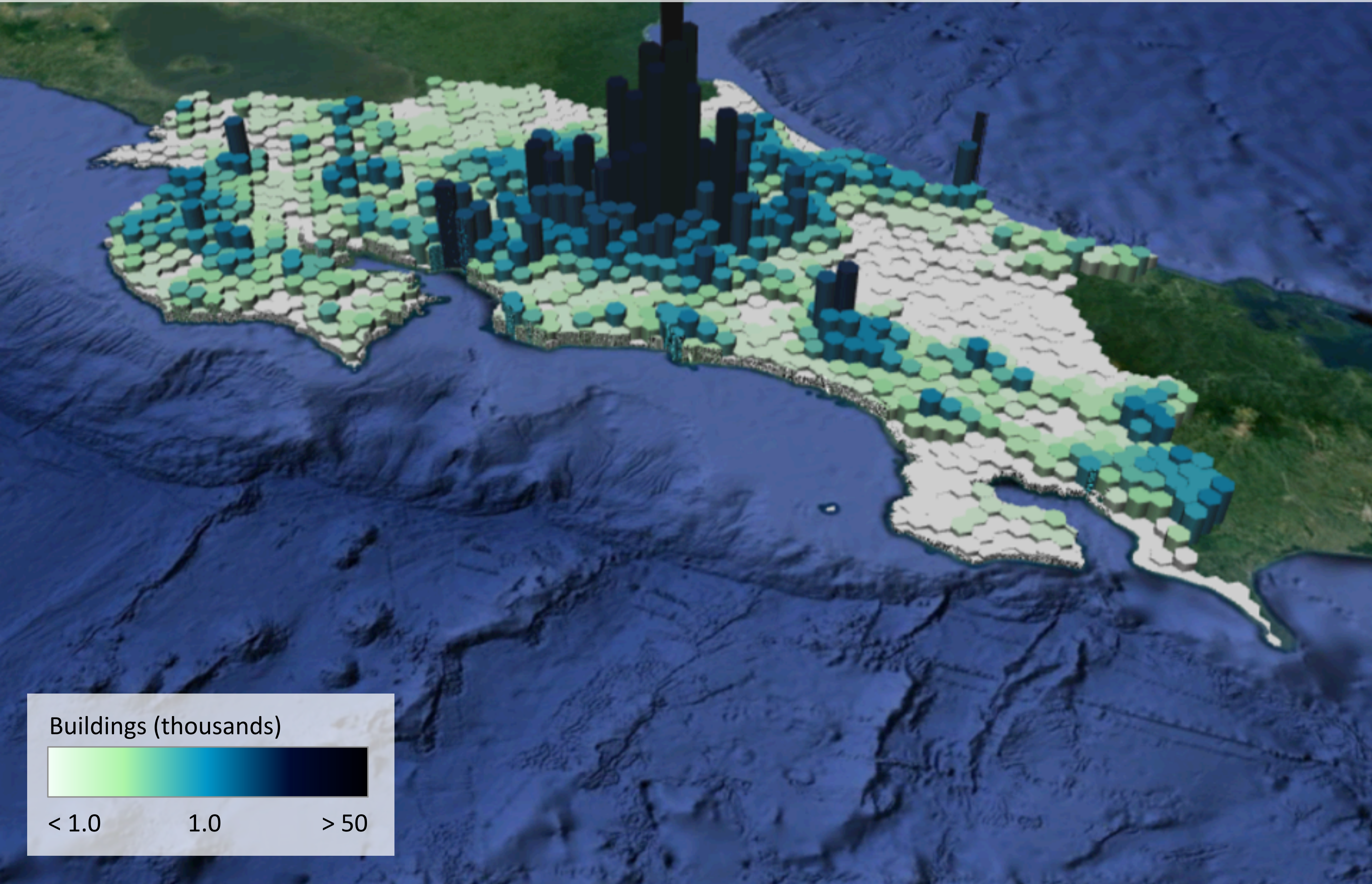
Modelling geometry of earthquake ruptures



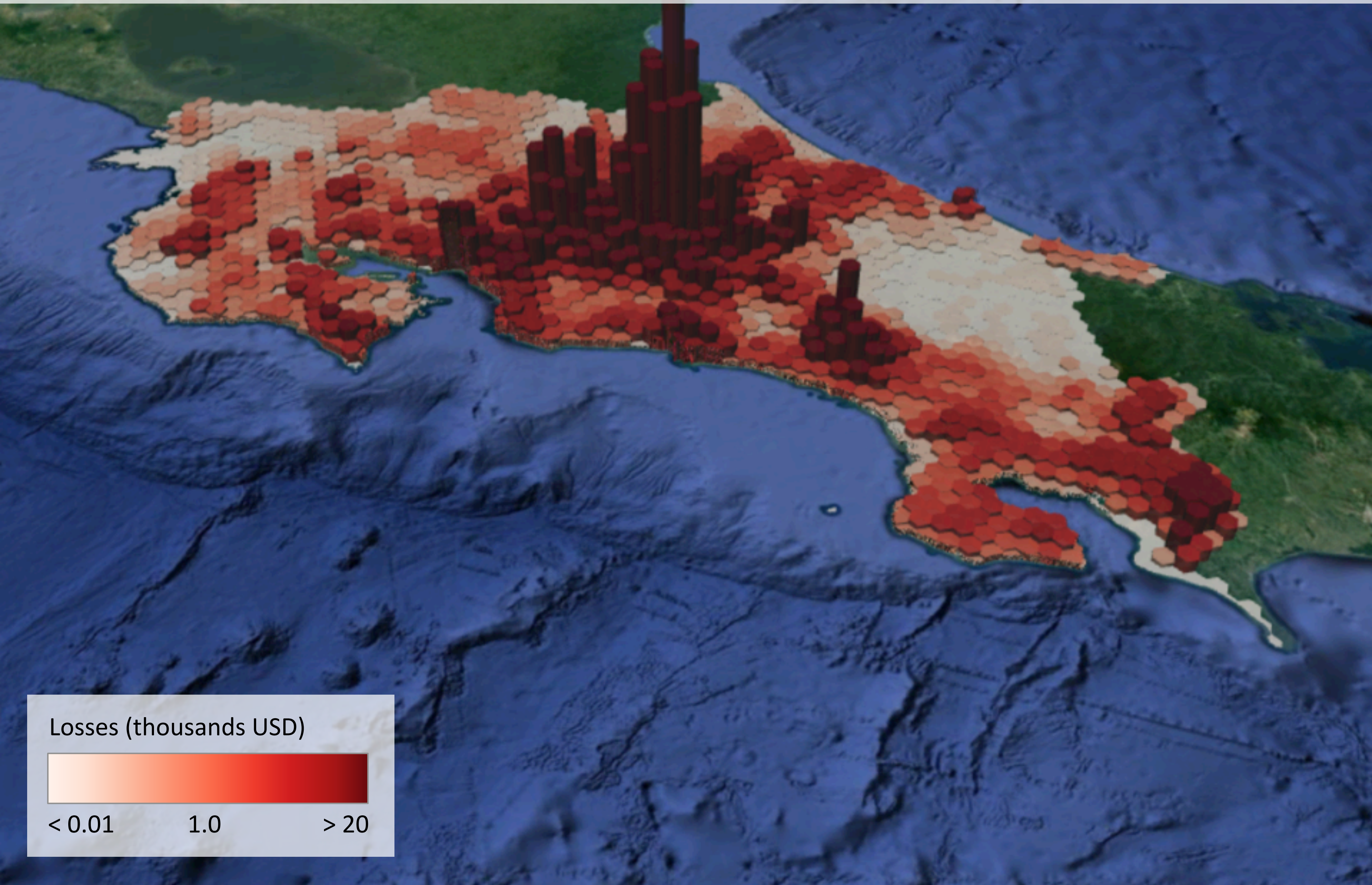
Propagating ground shaking variability (M8.1)



Exposure dataset for Costa Rica

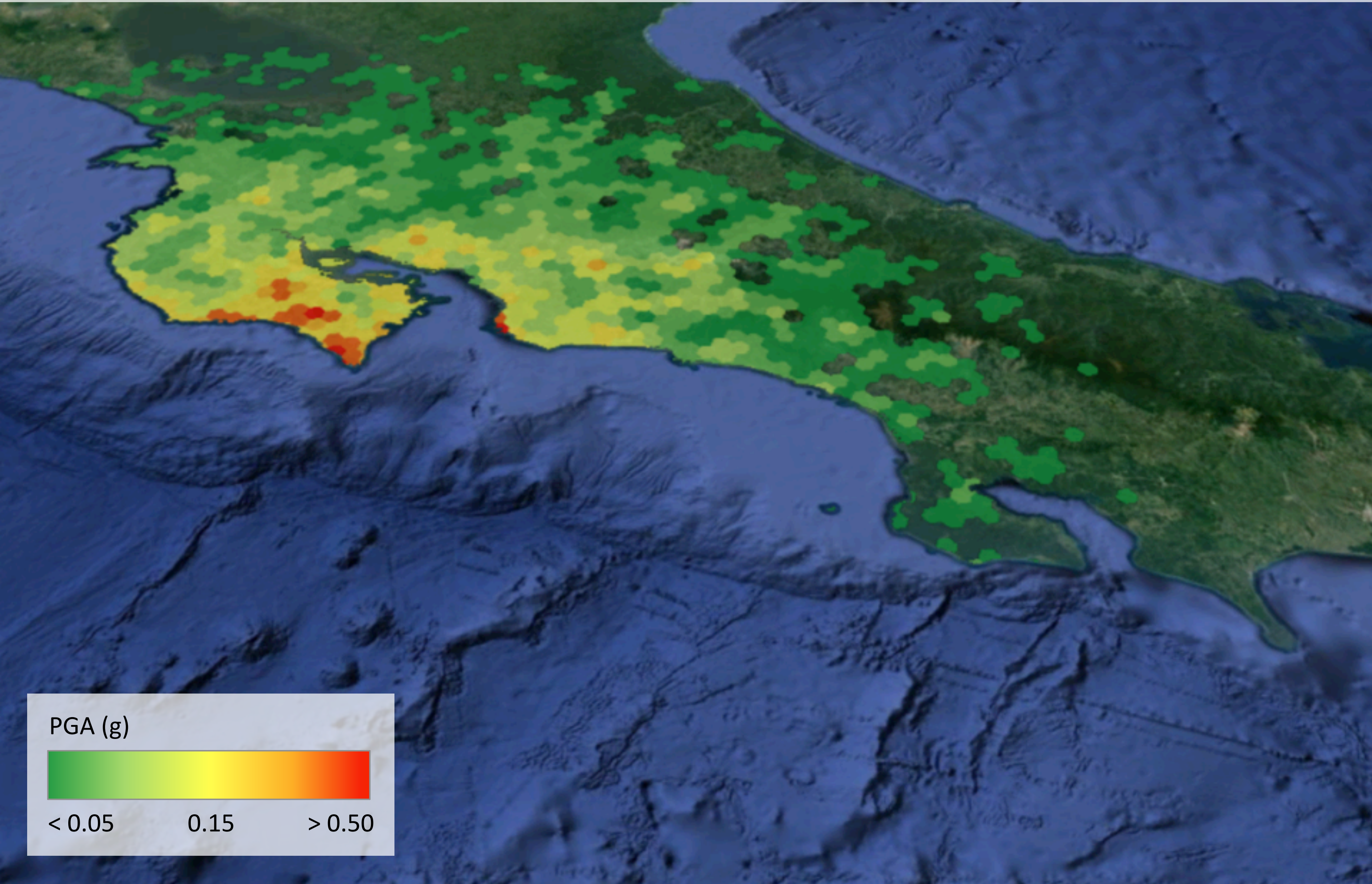


Estimated economic losses for Costa Rica (M8.1)

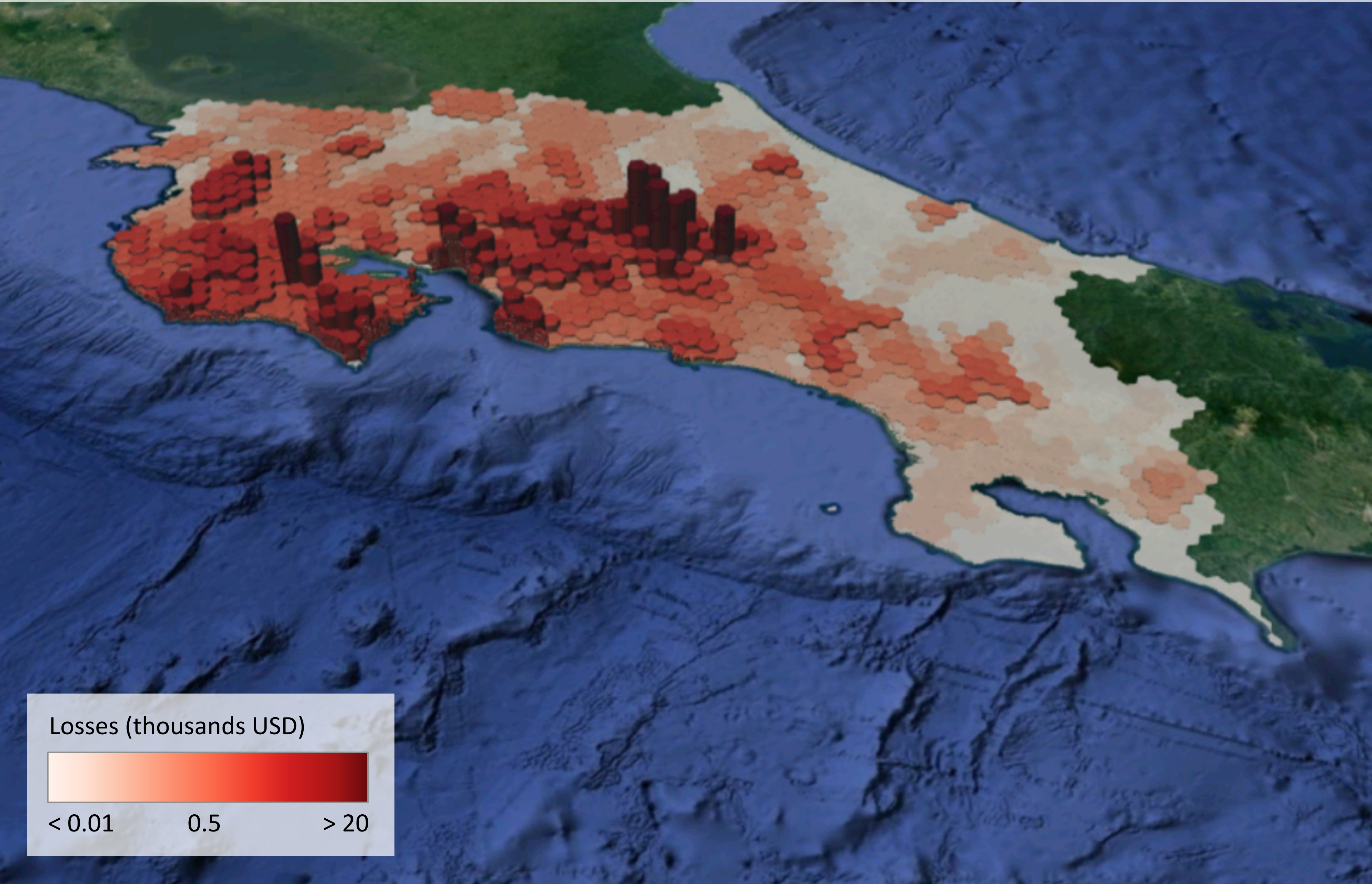


Offshore earthquake rupture (M7.0)

Median ground shaking distribution (M7.0)

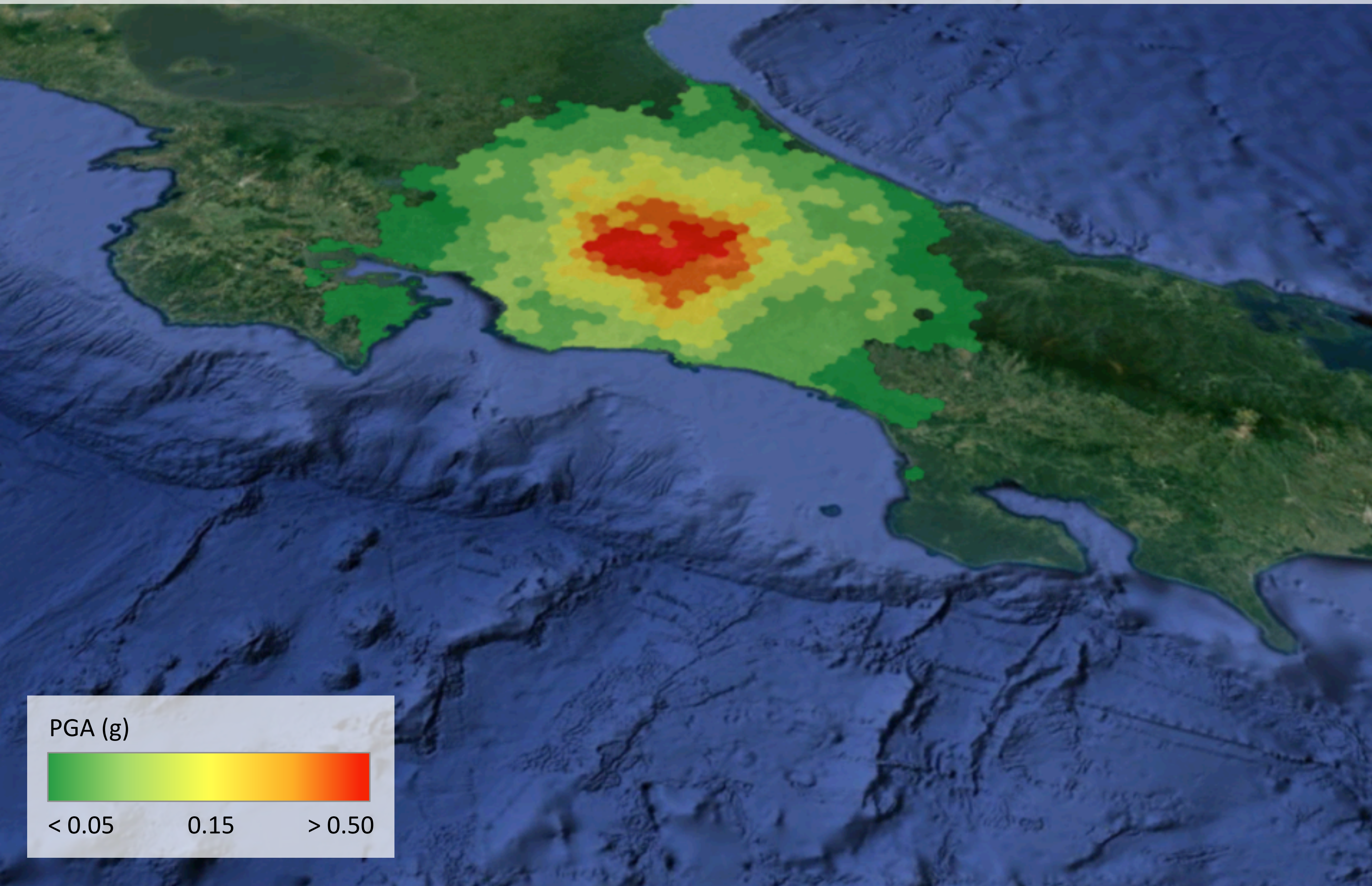


Estimated economic losses for Costa Rica (M7.0)

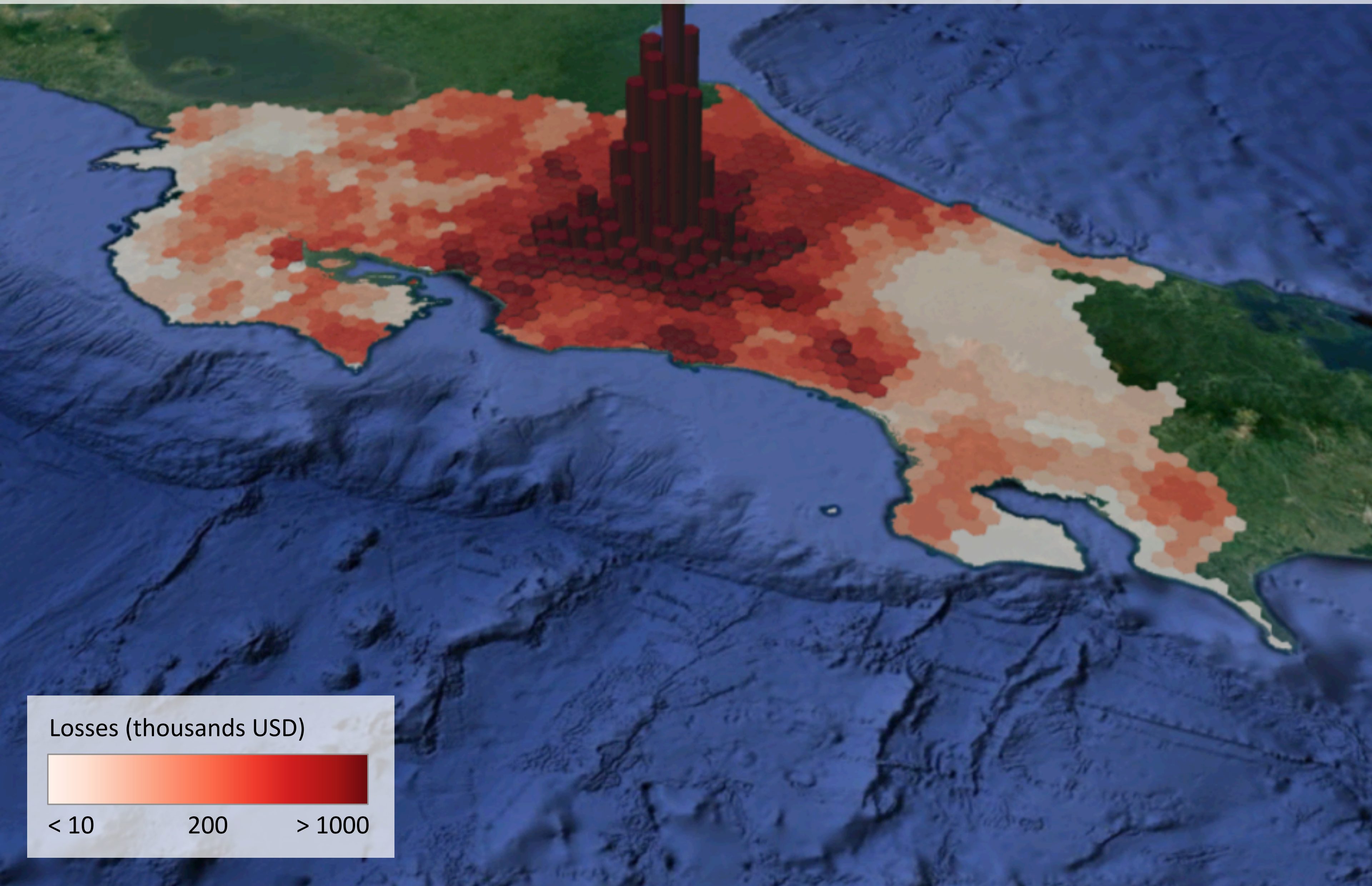


Earthquake rupture in the Central Valley (M6.5)

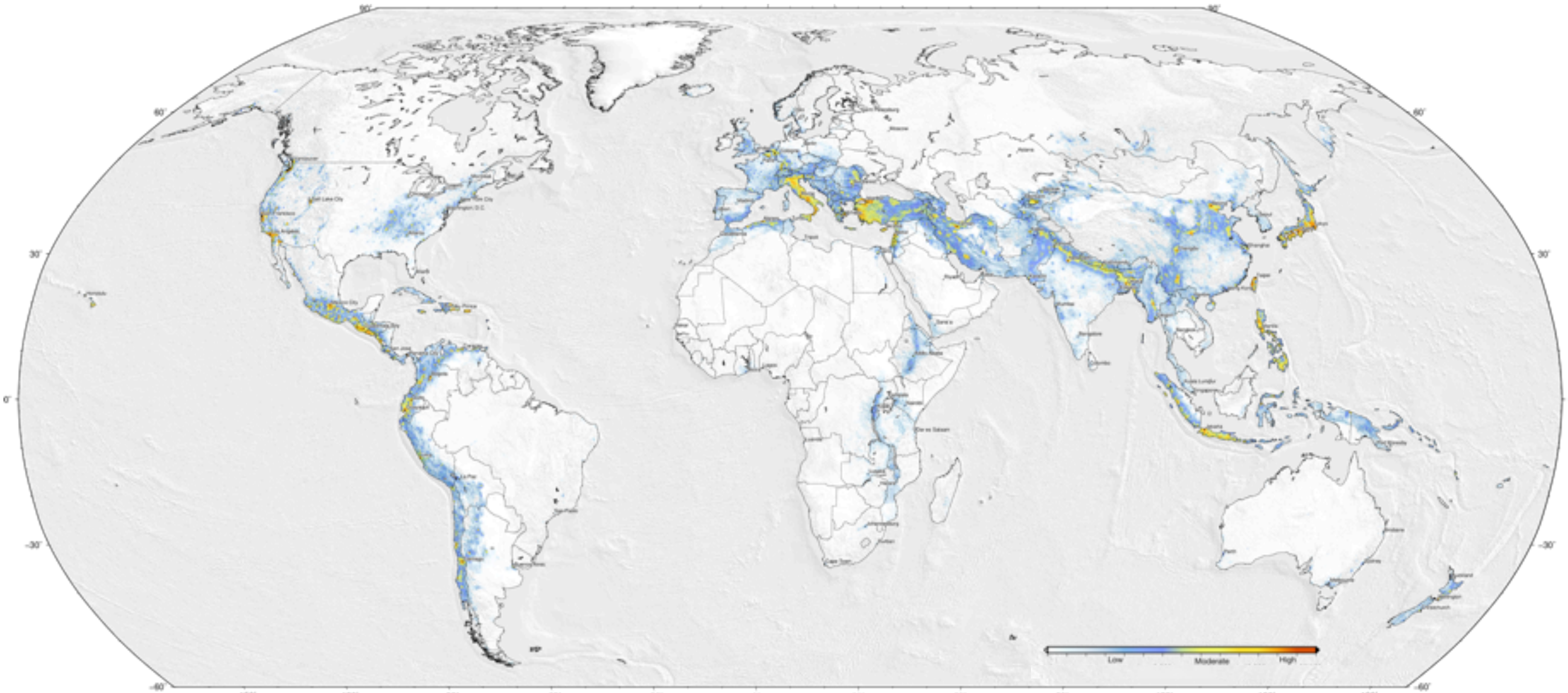
Median ground shaking distribution (M6.5)



Estimated economic losses for Costa Rica (M6.5)

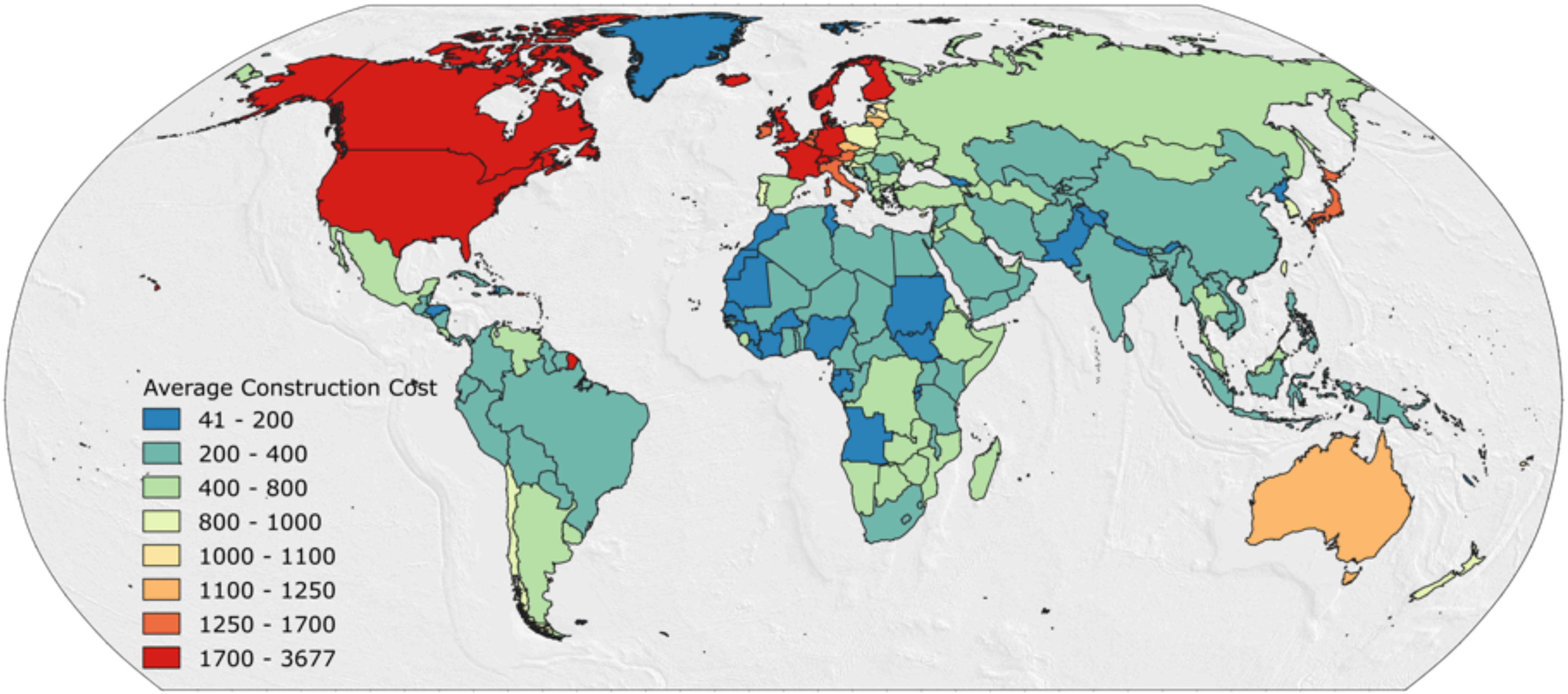


Global average annual losses



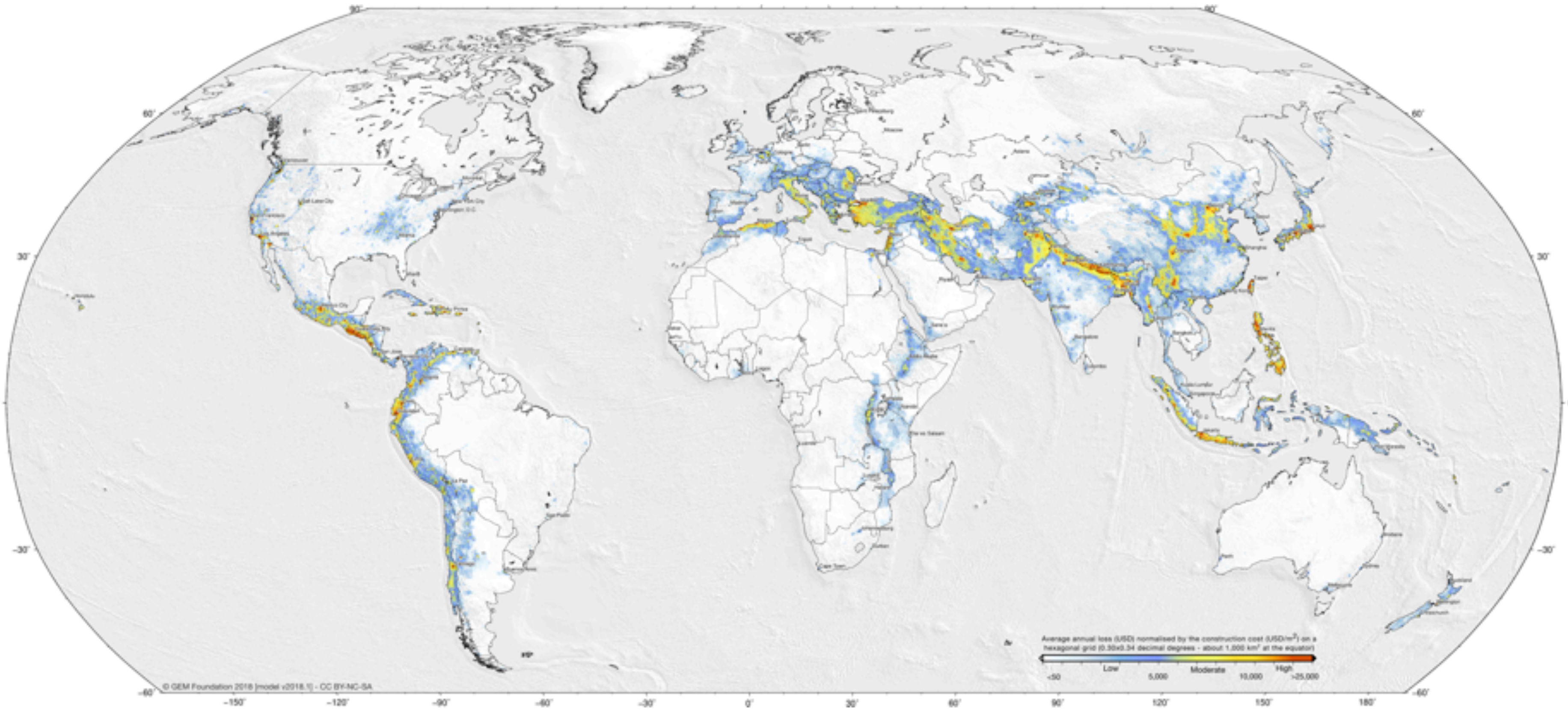
Presented on a hexagonal grid, with a spacing of 0.30 x 0.34 decimal degrees (approximately 1,000 km2 at the equator).

Variation of construction costs globally



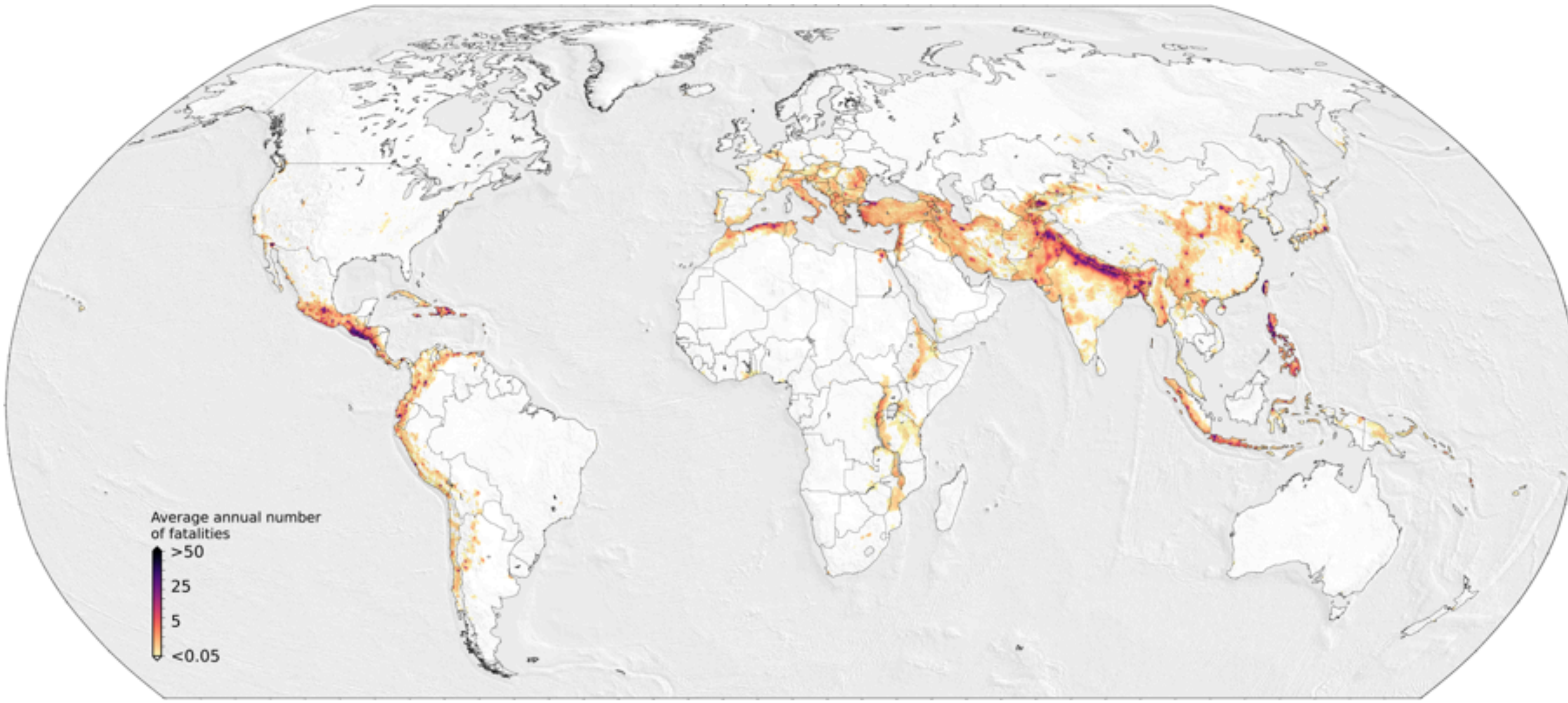
Construction costs can vary more than one order of magnitude between the developed and underdeveloped countries.

Global average normalized annual losses



Presented on a hexagonal grid, with a spacing of 0.30 x 0.34 decimal degrees (approximately 1,000 km2 at the equator).

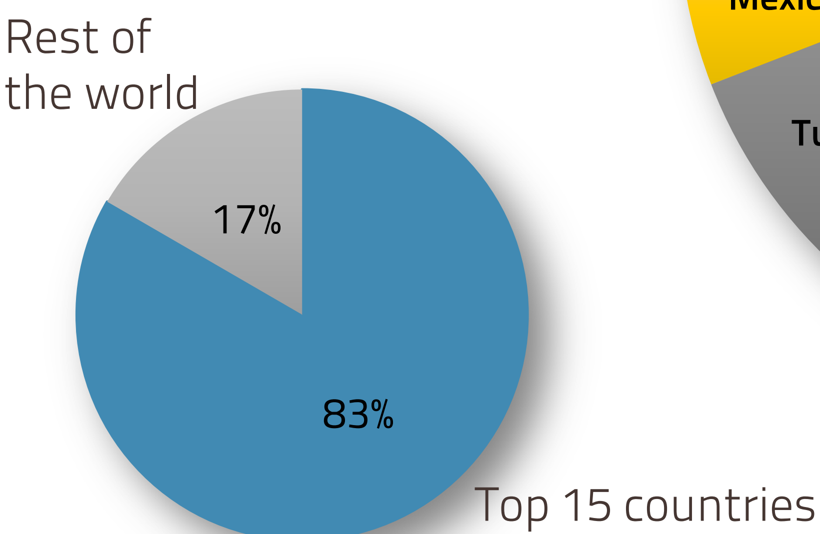
Global average annual human losses

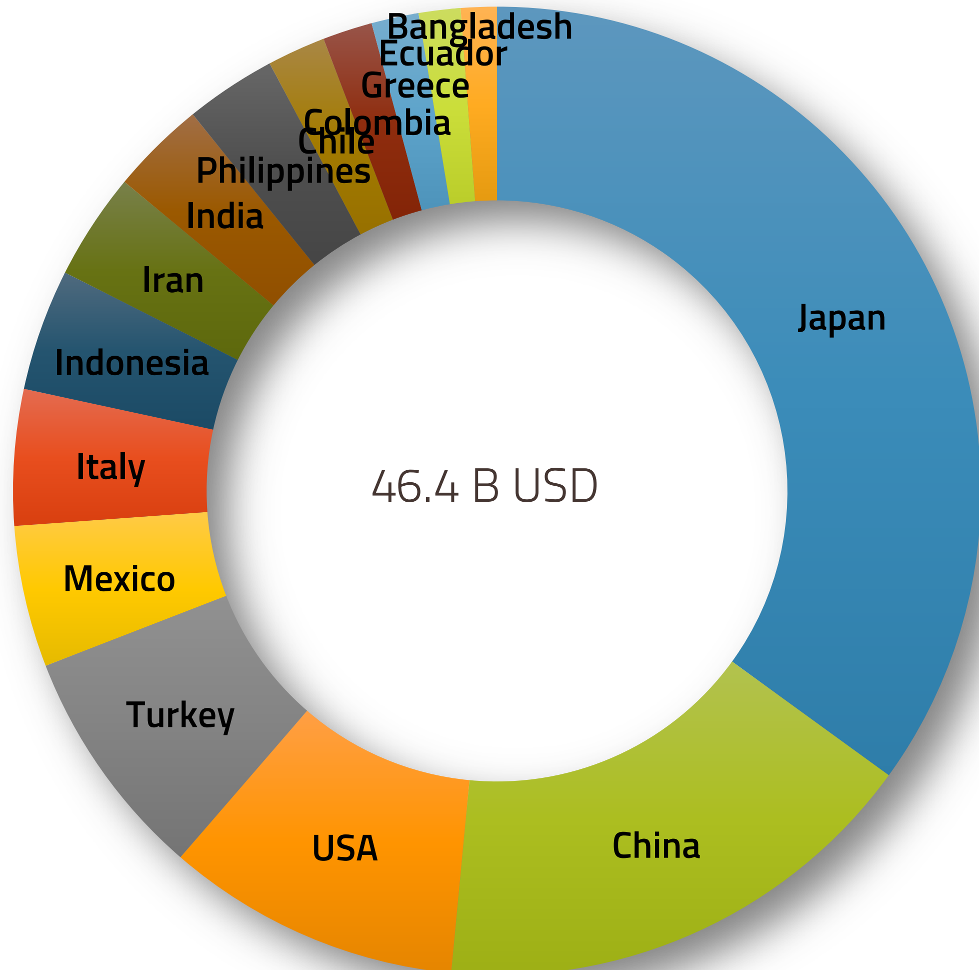


Presented on a hexagonal grid, with a spacing of 0.30 x 0.34 decimal degrees (approximately 1,000 km2 at the equator).

Average annual economic losses

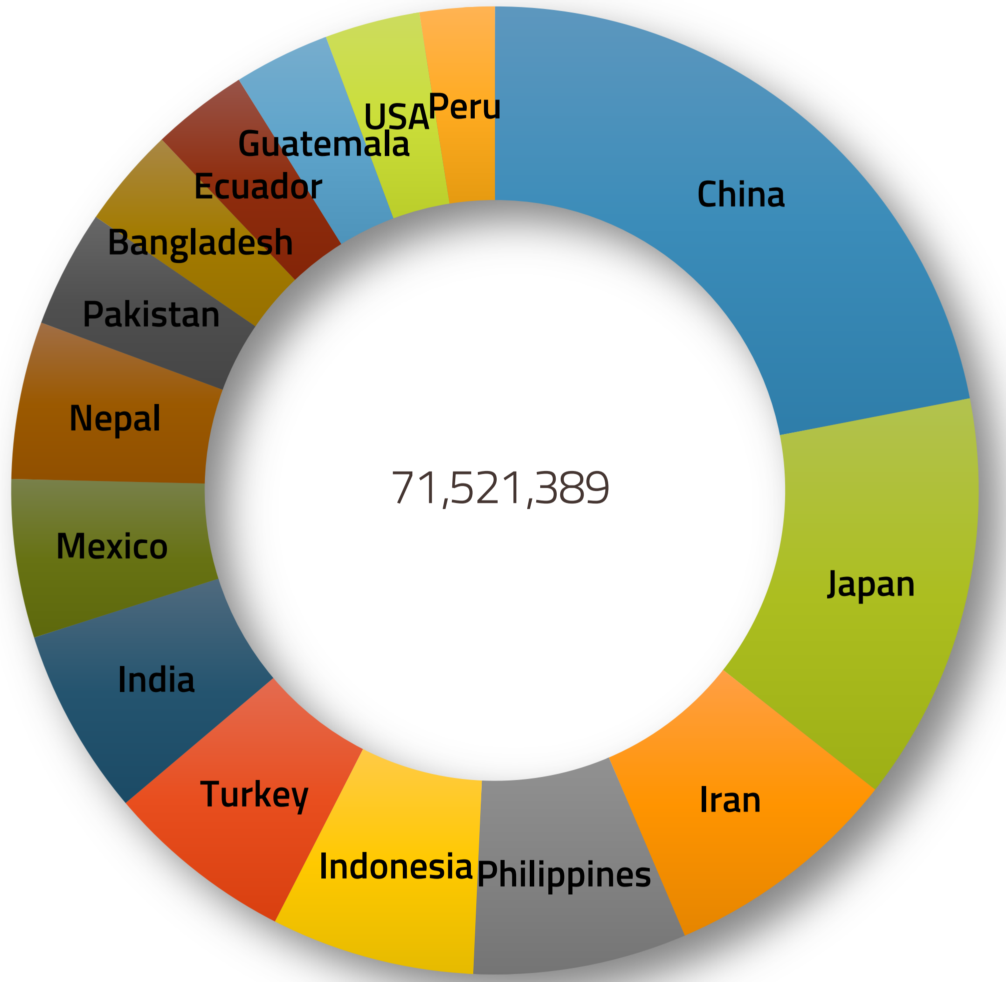
Total annual loss: 55.7 B USD

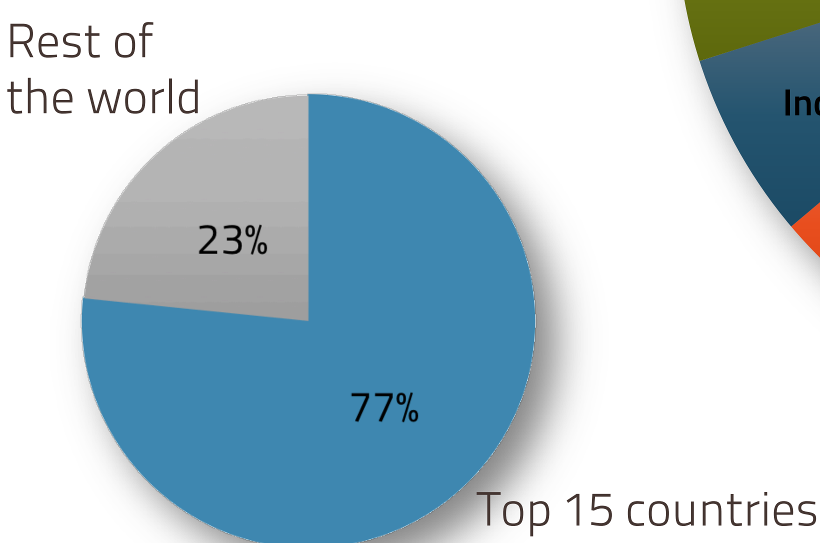




Average normalized annual economic losses

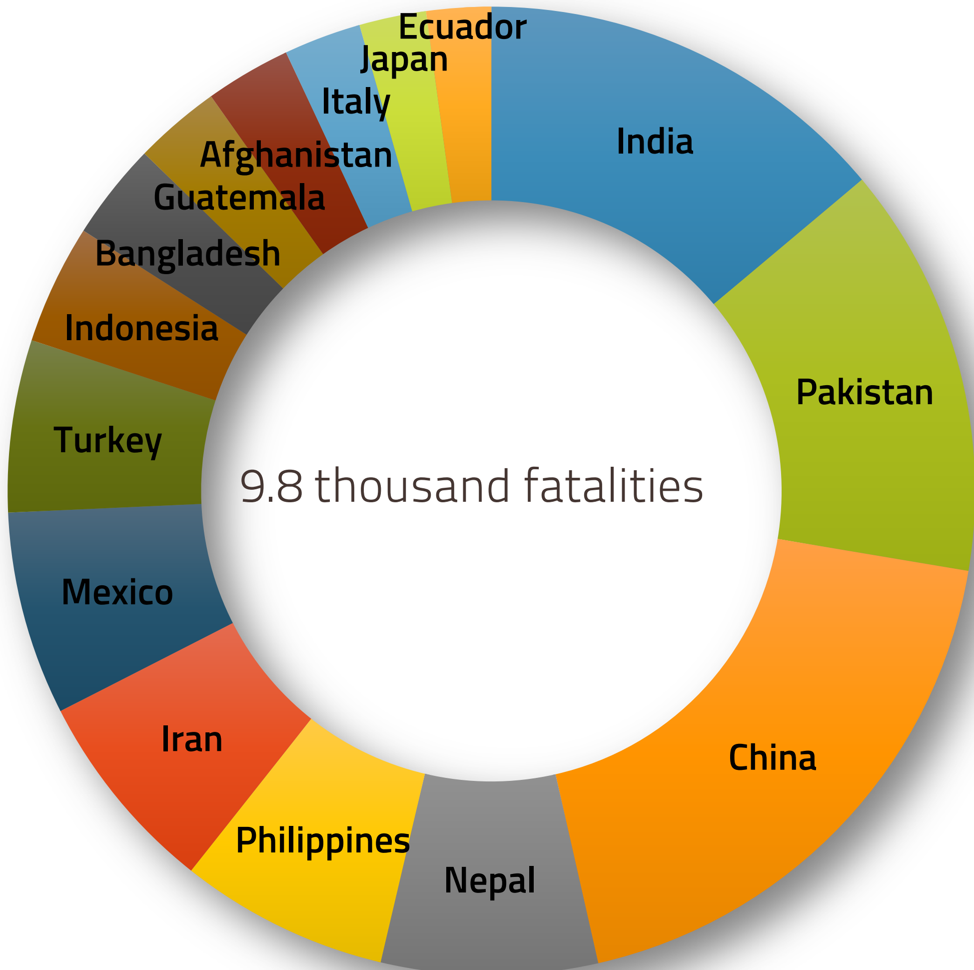
Total normalized annual loss: 93.7 M (m2)

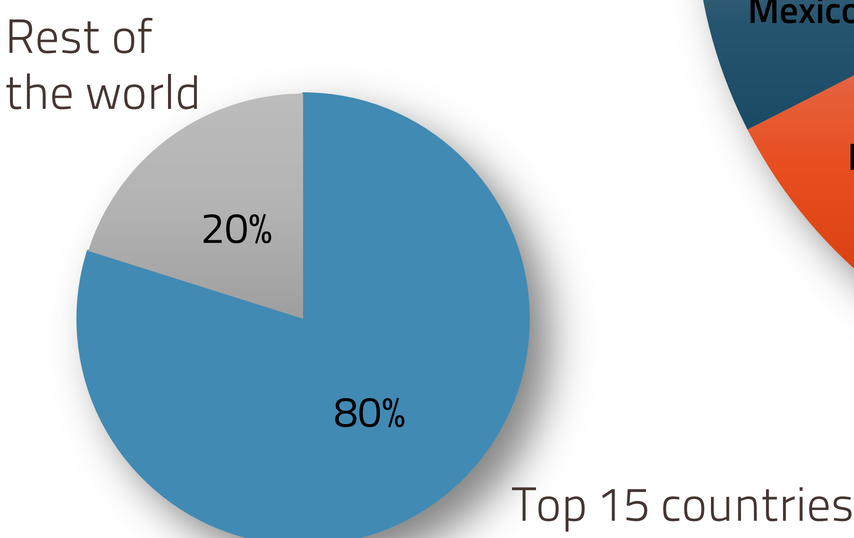


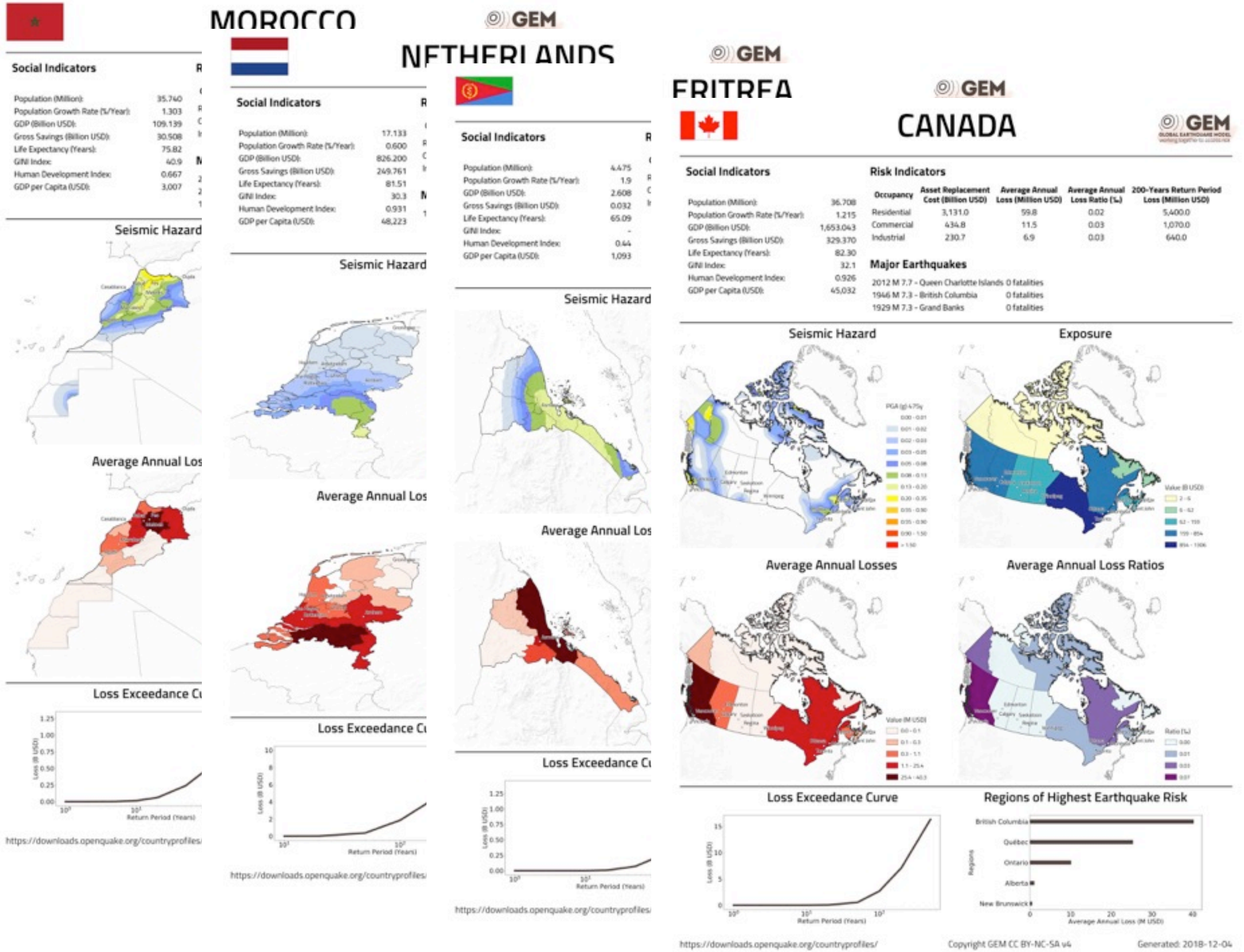


Average annualized human losses

Total annual fatalities: 12.5 thousand






MOROCCO
GEM
Social Indicators
Population (Million): 35.740
Population Growth Rate (%/Year): 1.303
GDP (Billion USD): 109.139
Gross Savings (Billion USD): 30.508
Life Expectancy (Years): 75.82
GINI Index: 40.9
Human Development Index: 0.667
GDP per Capita (USD): 3,007
Seismic Hazard
Average Annual Los
Loss Exceedance Cu
https://downloads.openquake.org/countryprofiles/
NETHERLANDS
GEM
Social Indicators
Population (Million): 17.133
Population Growth Rate (%/Year): 0.600
GDP (Billion USD): 826.200
Gross Savings (Billion USD): 249.761
Life Expectancy (Years): 81.51
GINI Index: 30.3
Human Development Index: 0.931
GDP per Capita (USD): 48,223
Seismic Hazard
Average Annual Los
Loss Exceedance Cu
https://downloads.openquake.org/countryprofiles/
ERITREA
GEM
Social Indicators
Population (Million): 4.475
Population Growth Rate (%/Year): 1.9
GDP (Billion USD): 2.608
Gross Savings (Billion USD): 0.032
Life Expectancy (Years): 65.09
GINI Index: -
Human Development Index: 0.44
GDP per Capita (USD): 1,093
Seismic Hazard
Average Annual Los
Loss Exceedance Cu
https://downloads.openquake.org/countryprofiles/
CANADA
GEM
Social Indicators
Population (Million): 36.708
Population Growth Rate (%/Year): 1.215
GDP (Billion USD): 1,653.043
Gross Savings (Billion USD): 329.370
Life Expectancy (Years): 82.30
GINI Index: 32.1
Human Development Index: 0.926
GDP per Capita (USD): 45,032
Risk Indicators
Occupancy | Asset Replacement Cost (Billion USD) | Average Annual Loss (Million USD) | Average Annual Loss Ratio (‰) | 200-Years Return Period Loss (Million USD)
Residential | 3,131.0 | 59.8 | 0.02 | 5,400.0
Commercial | 434.8 | 11.5 | 0.03 | 1,070.0
Industrial | 230.7 | 6.9 | 0.03 | 640.0
Major Earthquakes
2012 M 7.7 - Queen Charlotte Islands 0 fatalities
1946 M 7.3 - British Columbia 0 fatalities
1929 M 7.3 - Grand Banks 0 fatalities
Seismic Hazard
Exposure
Average Annual Losses
Average Annual Loss Ratios
Loss Exceedance Curve
Loss (B USD)
Return Period (Years)
Regions of Highest Earthquake Risk
British Columbia
Québec
Ontario
Alberta
New Brunswick
Regions
Average Annual Loss (M USD)
https://downloads.openquake.org/countryprofiles/
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Generated: 2018-12-04

Documentation and release of models

globalquakemodel | CCA

https://www.globalquakemodel.org/cca

GEM Global Mosaic of Risk Models

Caribbean and Central America (CCA)

The Central America and the Caribbean Earthquake Hazard and Risk Model was developed within the scope of a regional programme supported by the United States Agency for International Development (USAID), in collaborations with over a dozen local institutions from the region. This project features the development of a probabilistic seismic hazard model, a uniform exposure dataset covering the residential, commercial and industrial building stock, and a set of vulnerability functions characterizing the likelihood of loss given a seismic hazard intensity. This initiative also covered a number of local events to improve the local capacity to assess earthquake hazard and risk in the region.

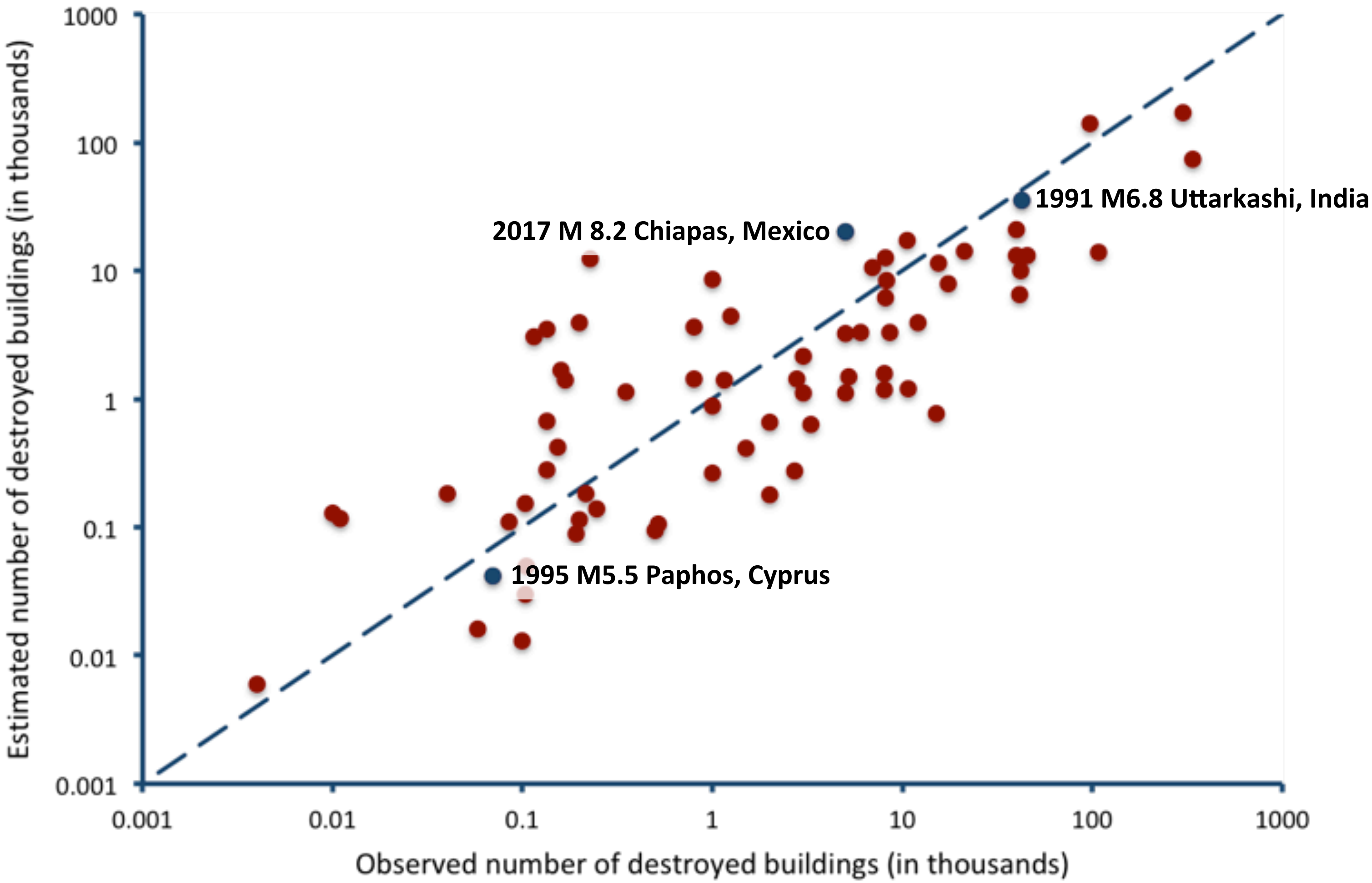
Exposure

Across Central America and the Caribbean, the most complete and updated databases containing exposure information were the national population and household census as well as data from the country Central Bank. With the exception of Haiti, every country in the region provides information about household and population associated to a geographical variable that is either publicly available online or upon request. Therefore both, population and household census were taken from the respective statistical offices to determine the number and location of the residential dwellings. Commercial and industrial data are much less detailed, and usually only the number and size of the facilities are available (See Table below). This data is subjected to the following four-step process in order to create an exposure model:

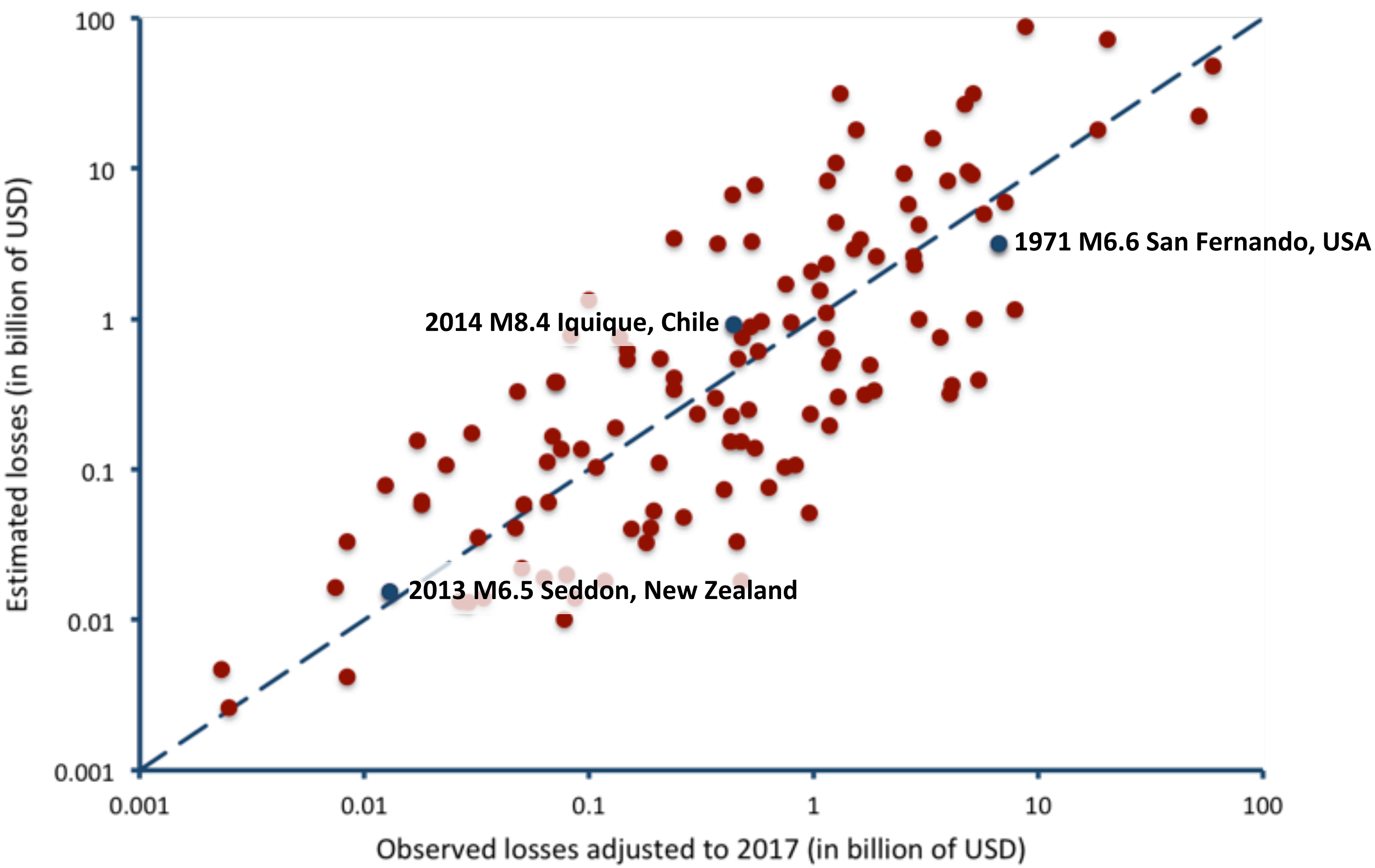
1. The most common building classes are identified using existing studies and the expert judgement. The World Household Encyclopedia has reports that include the building materials, architectural traits, construction process, socio-economic environment and even seismic performance of common dwelling configurations found in this region.
2. Census variables are crossed to segregate the dwellings into subgroups, which are then subjected to a process of conditional selection. If a dwelling meets the criteria to belong to a certain building class, then it is assigned to that class.
3. Once the dwellings have been distributed among the identified classes with specific structural attributes (e.g height and expected level of ductility), they are converted into buildings and assigned a replacement cost.
4. Models are calibrated based on expert judgement from over 80 professionals from the region providing feedback in key variables like code compliance, average dwelling area and average replacement cost per building class.

Country	Population	Dwellings	Commercial	Industrial
Guatemala (GTM)	16,176,133	2,574,908	226,352	49,595
Cuba (CUB)	11,167,328	3,644,001	4,806	3,410
Haiti (HTI)	10,291,060	N.A	N.A	N.A
Dom. Republic (DOM)	9,445,367	2,662,794	17,421	4,334

Verification of the Global Risk Model



Verification of the Global Risk Model



USGS
science for a changing world

Earthquake Shaking Orange Alert

GSN ANSS USAID FROM THE AMERICAN PEOPLE

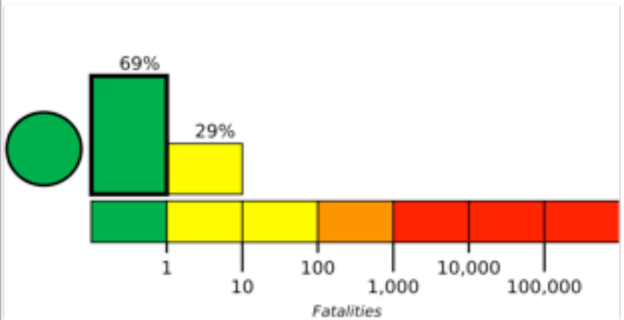
M 7.0, 13km N of Anchorage, Alaska

Origin Time: 2018-11-30 17:29:29 UTC (Fri 08:29:29 local)
Location: 61.3234° N 149.9234° W Depth: 44.1 km
FOR TSUNAMI INFORMATION, SEE: tsunami.gov

PAGER
Version 6

Created: 6 hours, 2 minutes after earthquake

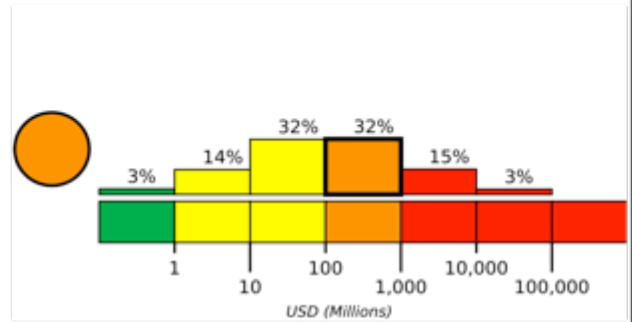
Estimated Fatalities



Orange alert for economic losses. Significant damage is likely and the disaster is potentially widespread. Estimated economic losses are less than 1% of GDP of the United States. Past events with this alert level have required a regional or national level response.

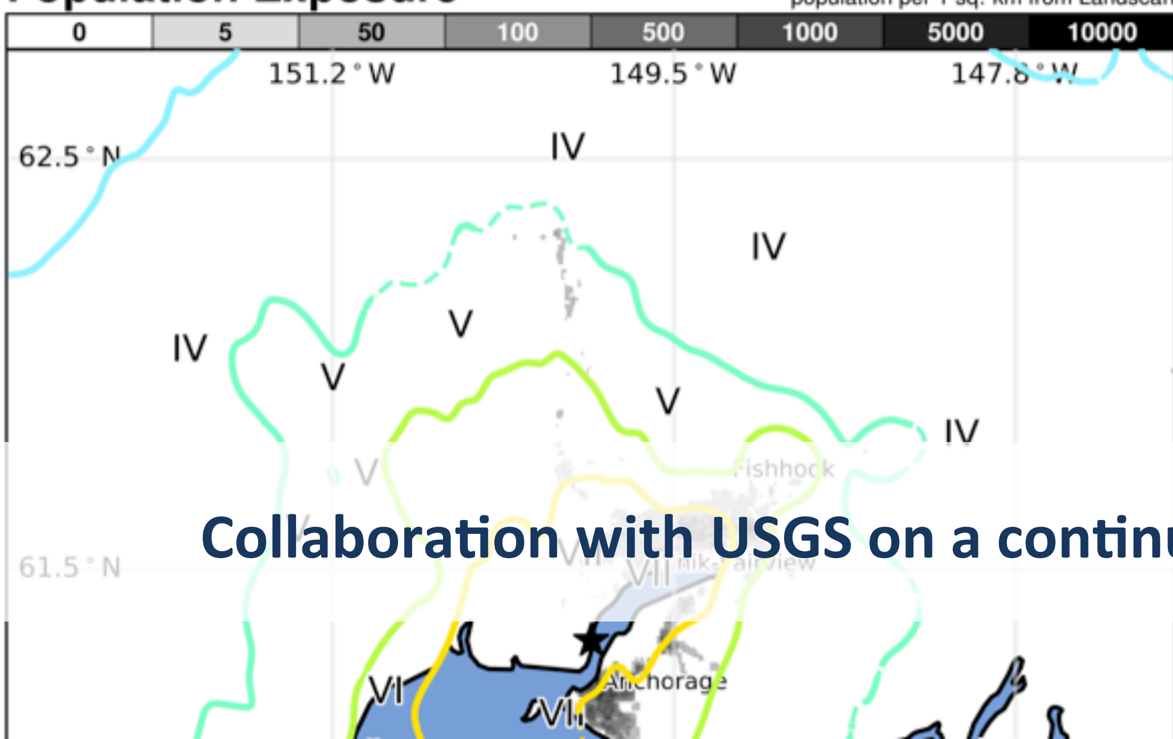
Green alert for shaking-related fatalities. There is a low likelihood of casualties.

Estimated Economic Losses



Population Exposure

population per 1 sq. km from Landscan



Structures

Overall, the population in this region resides in structures that are resistant to earthquake shaking, though vulnerable structures exist. The predominant vulnerable building types are unreinforced brick masonry and reinforced masonry construction.

Historical Earthquakes

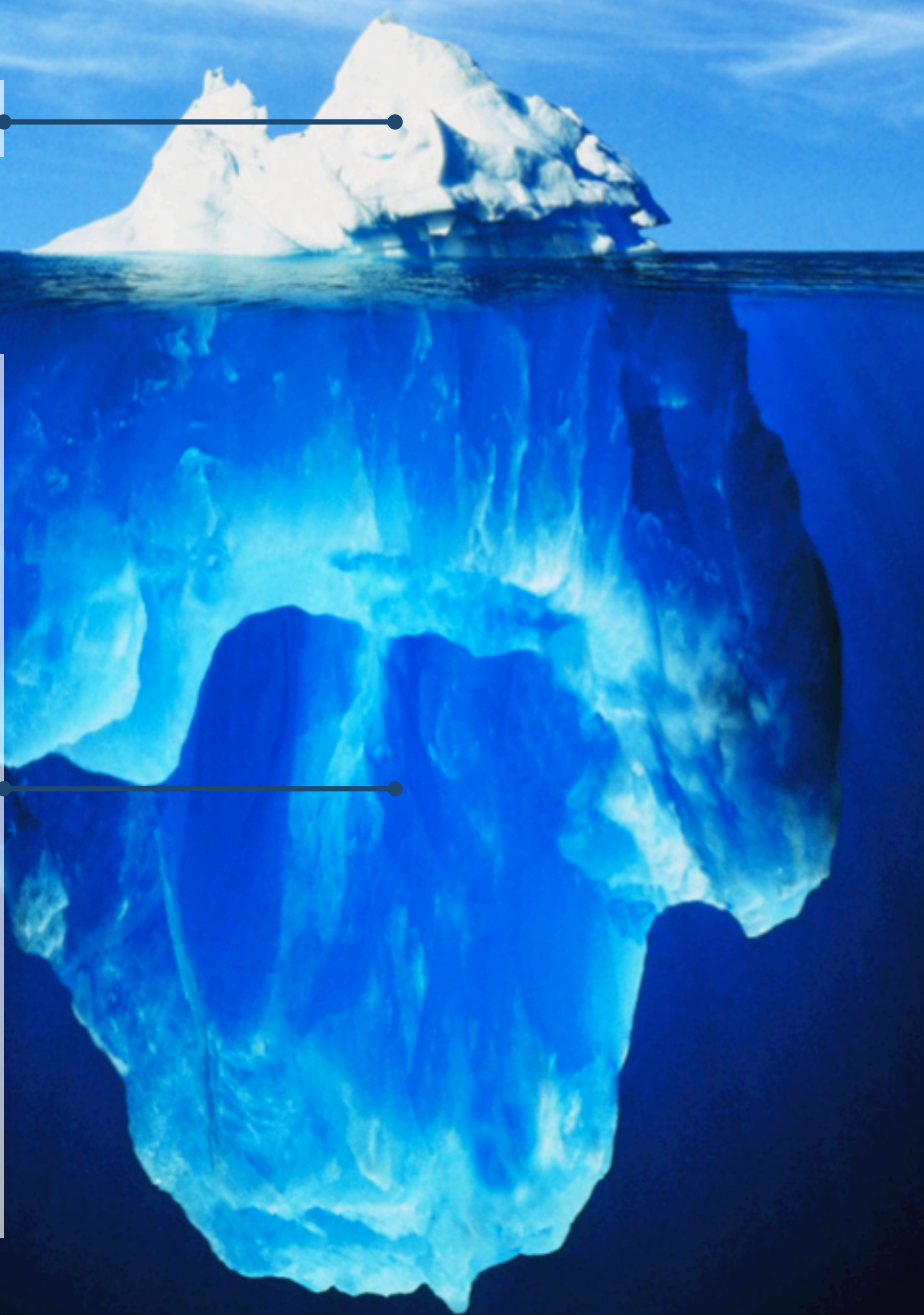
Date (UTC)	Dist. (km)	Mag.	Max MMI(#)	Shaking Deaths
2002-11-03	271	7.9	V(36k)	0
1964-03-28	127	9.2	VIII(24k)	–
1964-03-28	127	9.2	VIII(24k)	0

Recent earthquakes in this area have caused secondary hazards such as tsunamis, landslides and liquefaction that might have contributed to losses.

Collaboration with USGS on a continuous validation framework

Selected City Exposure

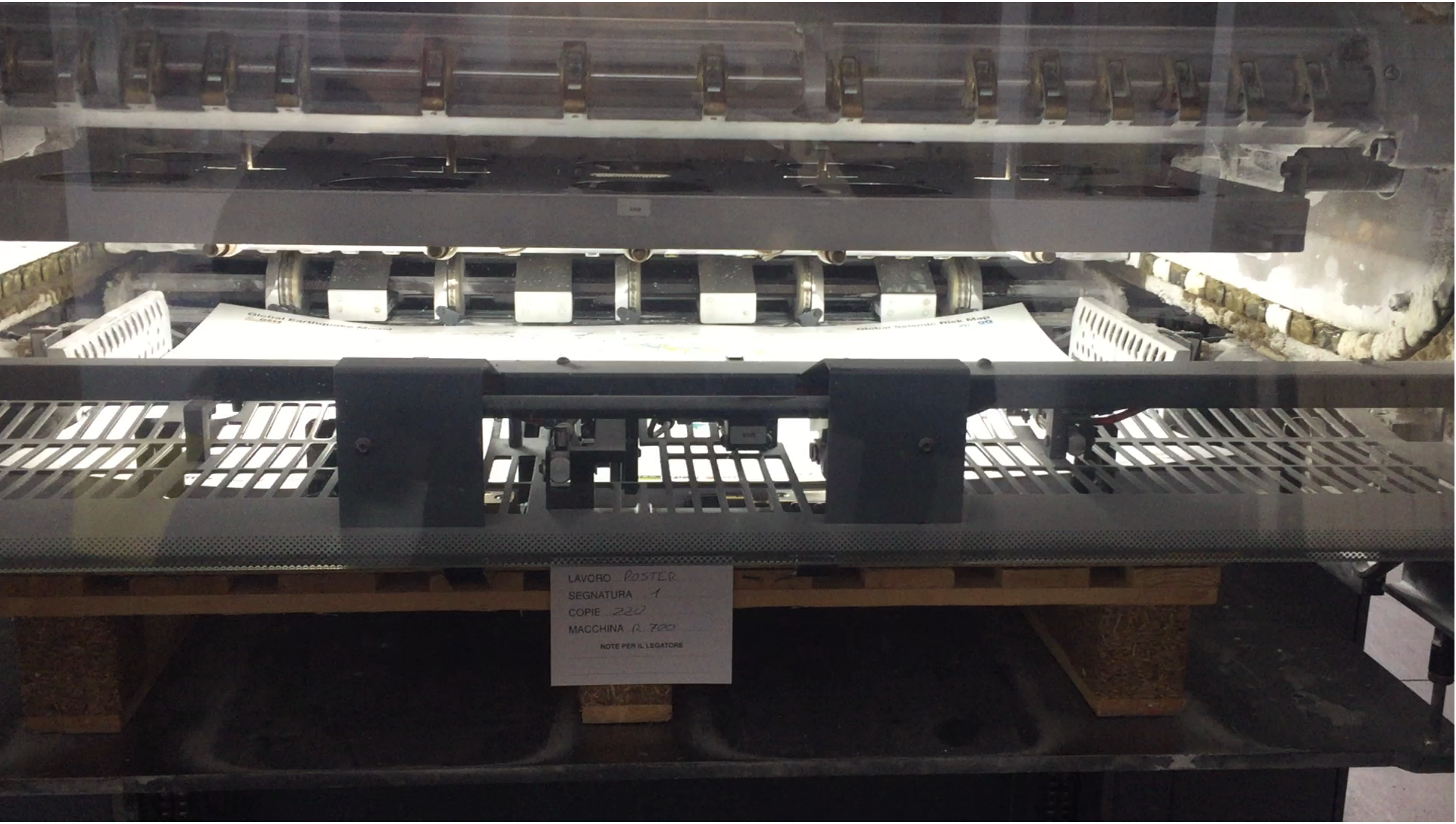
Where we are



Next Steps:

- Improvement of datasets in high risk regions.
- Further engagement of the scientific community and risk managers.
- Release of models and datasets (Q1-Q4)
- Calibration of existing model against empirical data.
- Investment in capacity building and training.
- Inclusion of model and tools in universities curricula.
- Involvement of committees responsible for the draft of design regulations.
- Extension of the current model to infrastructure risk assessment and secondary hazards.

Thank you


LAVORO POSTER
SEGNATURA 1
COPIE 220
MACCHINA R 700
NOTE PER IL LEGATORE