Probabilistic tsunami risk assessment methodology compatible with multi-hazard frameworks

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AGITHAR Scientific kick-off meeting

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What is disaster risk?

Potential losses of property and/or welfare

Reality vs. possibilities

Source: http://blog.barnabybenson.co.uk/2012/01/take-break-from-hackneyed-travel-copy.html

Why a probabilistic approach?

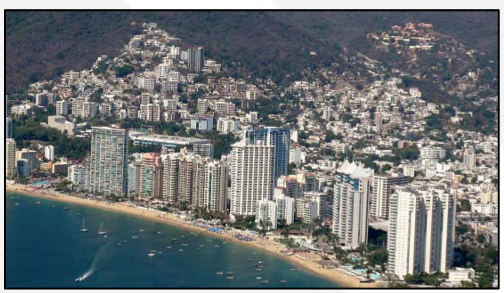
- Hazard intensities have occurrence frequencies
- There are uncertainties in the hazard and vulnerability components
- Risk should always be expressed in occurrence rates or return periods
  - Not only how big but also how often
- We need risk metrics that account for these requirements
- We need to be able to compare and/or aggregate losses caused by different types of hazards
- The largest catastrophes have not yet occurred

Conceptual framework

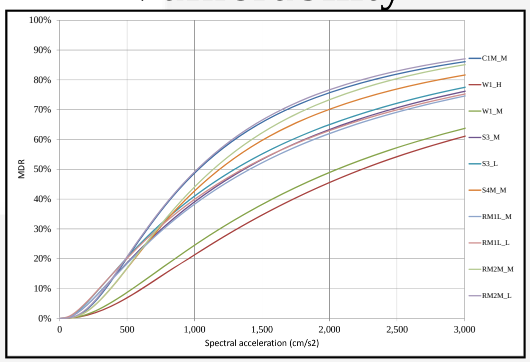
RISK = *f* (HAZARD, VULNERABILITY)

Hazard

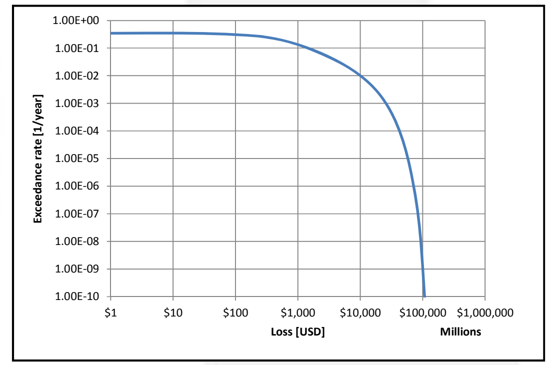
Exposure

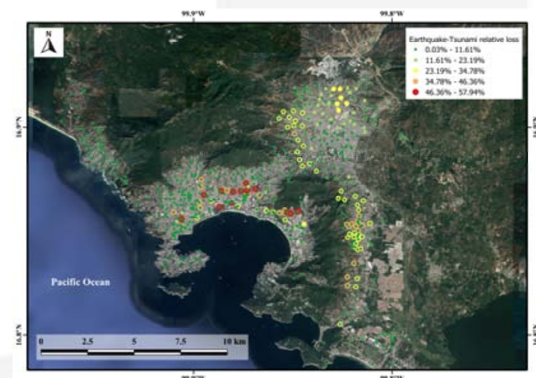


Vulnerability



Risk





Hazard representation

- The occurrence of future events cannot be predicted
- The observation timeframe remains being an unknown quantity
- The feasible hazard manifestations need to be represented by means of a stochastic (synthetic) event set

→ Different hazard intensity measures

→ Tendency grid

→ Dispersion grid

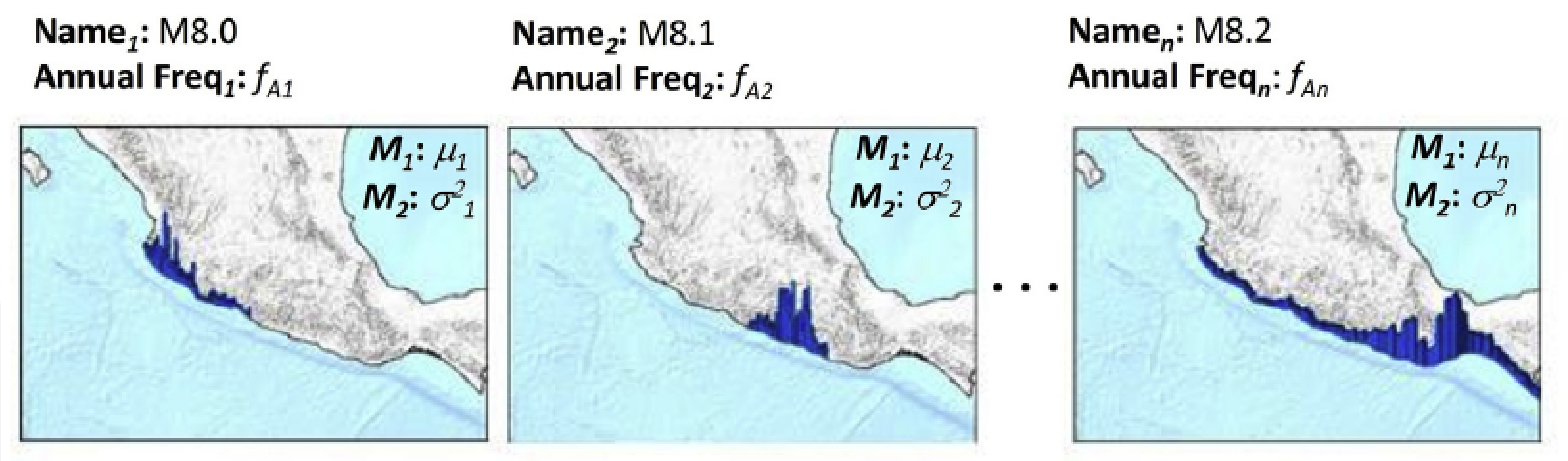
→ Occurrence frequency

Hazard representation

- The event-based approach allows obtaining several probabilistic risk metrics
- It is a requirement to estimate the loss exceedance curve (or EP curve)
- Nowadays it is desirable to have the complete risk panorama (AAL is not enough)
- The same hazard representation is valid for different hazards with different origins (peril-agnostic risk assessments)

Hazard representation

*.AME format (a grid array)



No limit of events included in the *.AME file

Source: Jaimes et al., 2016

Exposure databases

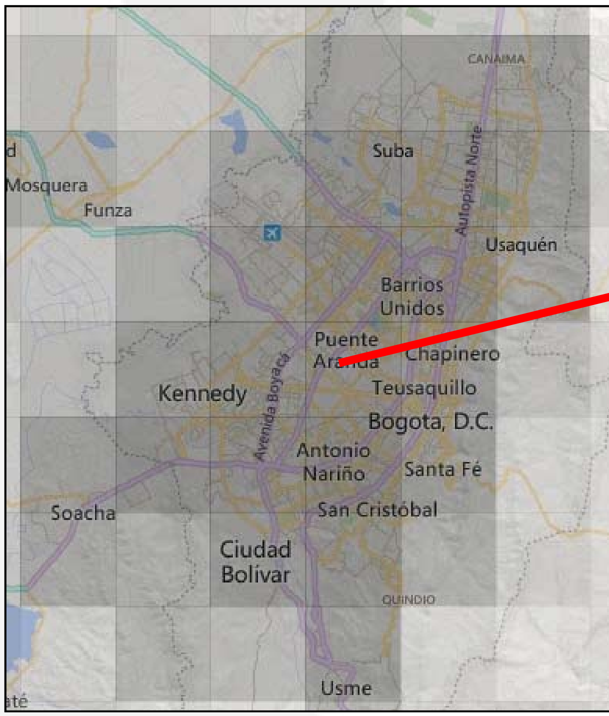
- Identification and characterization of assets susceptible to be damaged by the considered perils
- Assignment of structural characteristics that are relevant for each considered hazard
- Some of these characteristics are common to 2 or more hazards, some are unique

Exposure databases

- A common exposure database can include all relevant characteristics in a multi-hazard risk assessment
- Assets that share certain characteristics are grouped into typologies
- Typologies are usually defined by hazard, each of them are needed for the association to a damage/loss model
- Usually a large number of assets is required so that results obtained with this approach are representative

Exposure databases

The same representation can be used at different resolution levels (again, is not of interest of the algorithm)



Approximate

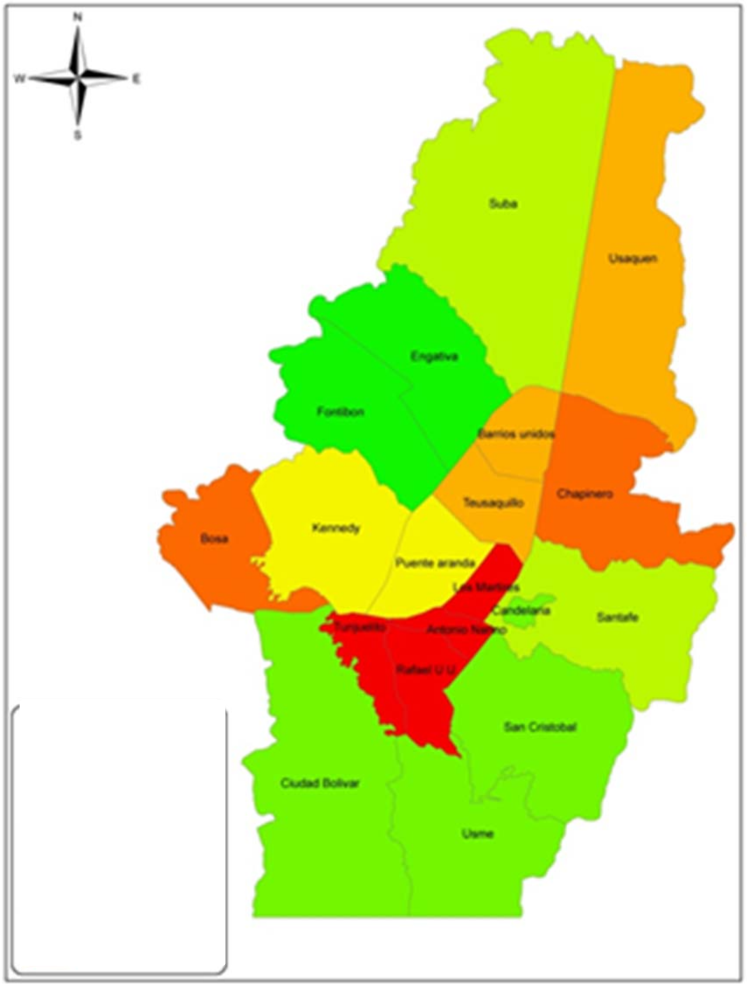
5km

Pixel *i*

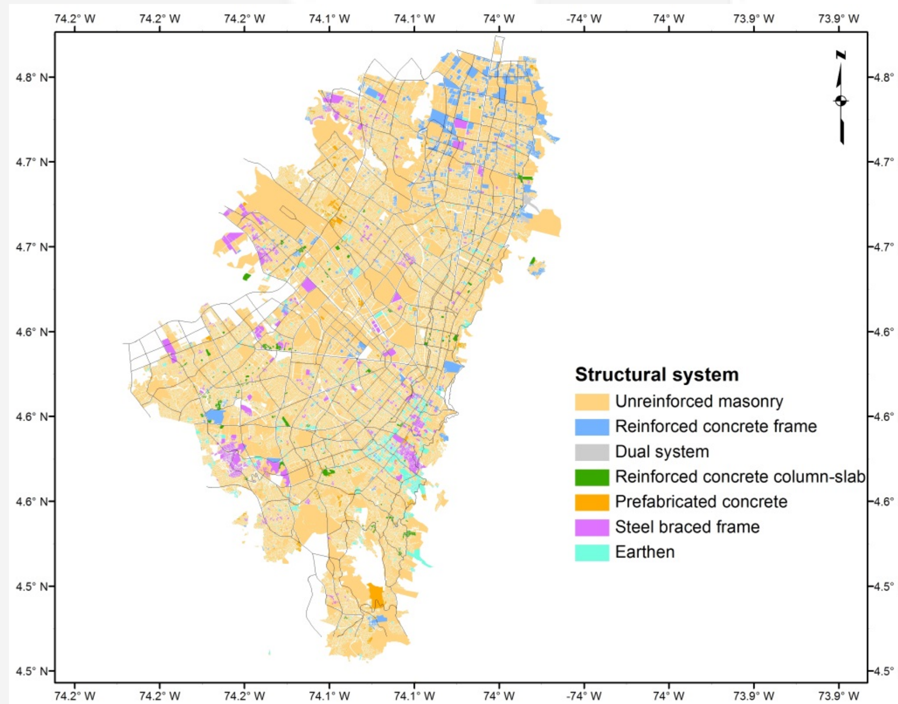
- Share of building classes
- Replacement cost ($)
- # of occupants

5km

Exposure databases



Intermediate



Detailed

Vulnerability

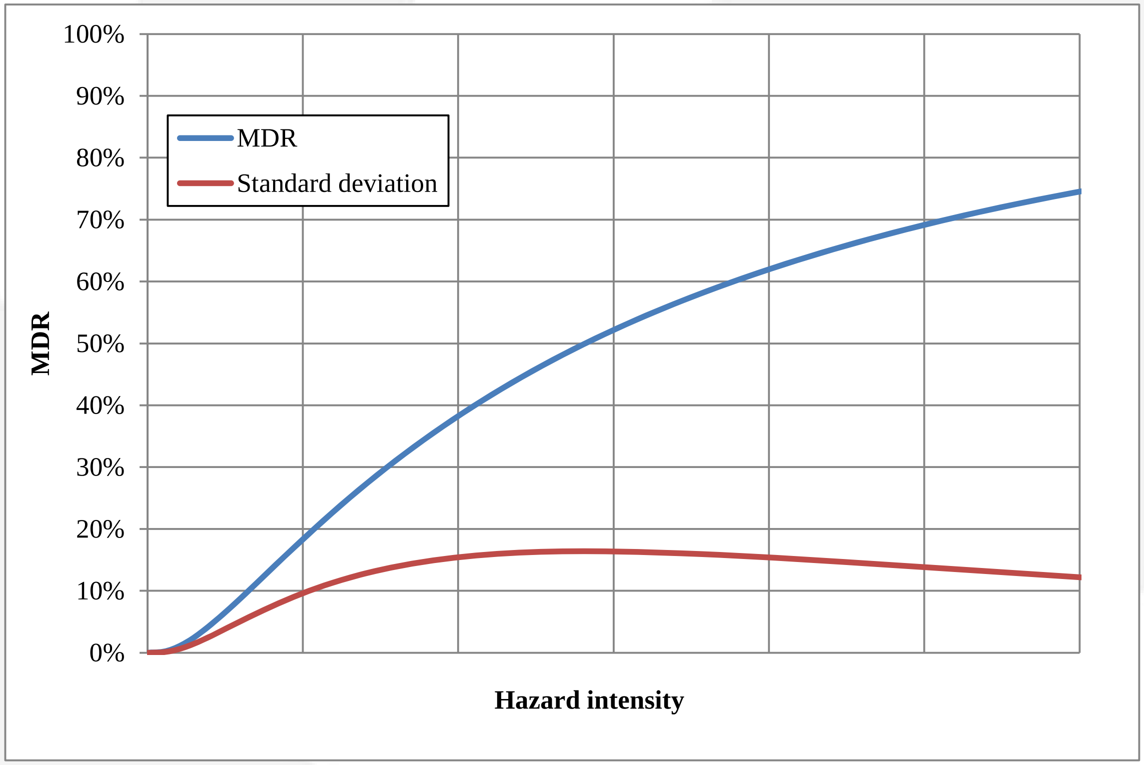
Vulnerability can have several dimensions

- Physical
- Human
- Social
- Environmental
- Economical
- Gender
- Many more….

Vulnerability

- In our case the ones of interest are usually the physical and human ones
- We need functions to provide relationships between hazard intensities and damages and losses
- Preferably, these relationships must be probabilistic
- In a peril-agnostic framework, the vulnerability representation must be common for all perils
- Vulnerability functions are usually preferred than fragility curves, although they are related

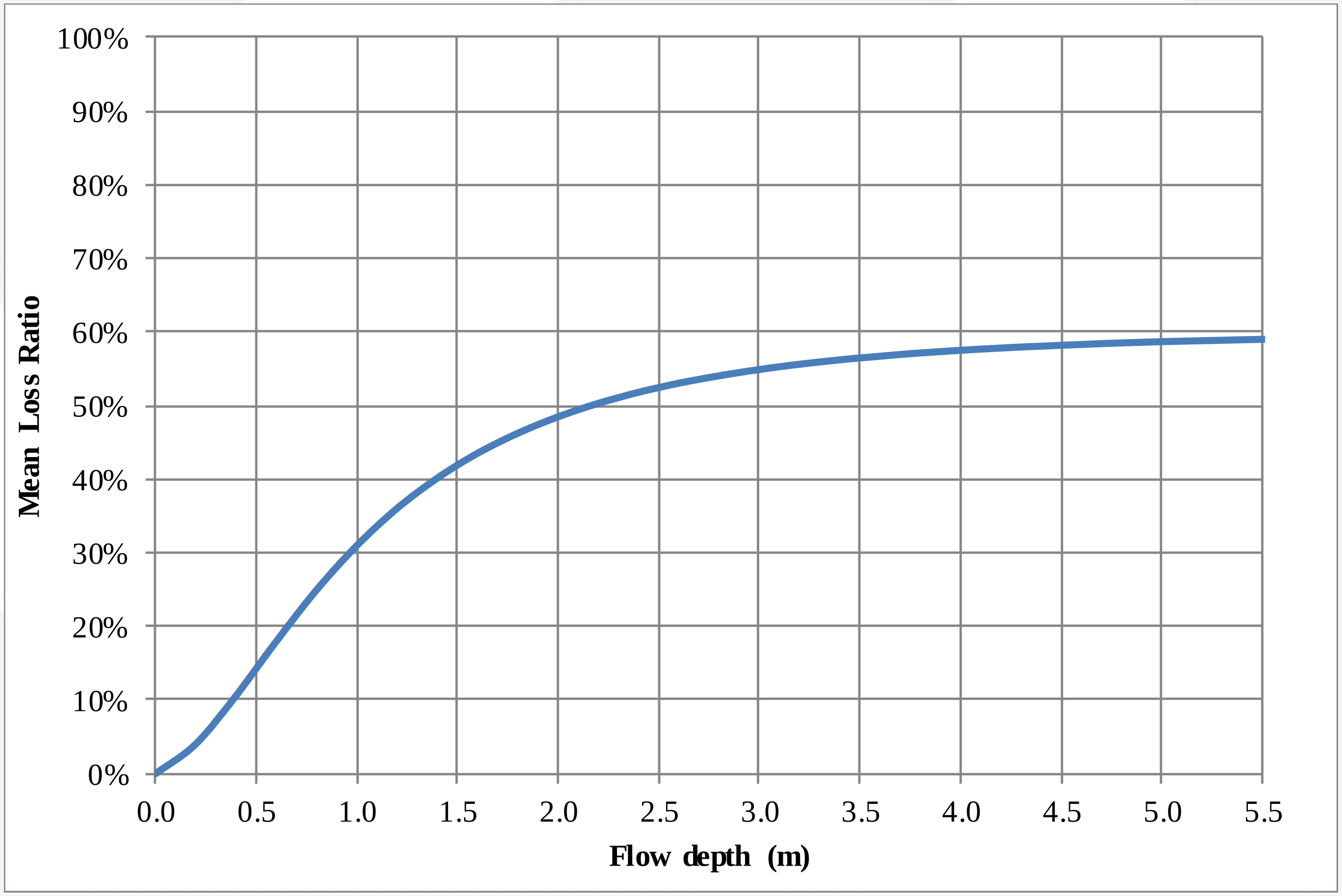
Vulnerability functions



- Continuous
- Quantitative
- Probabilistic

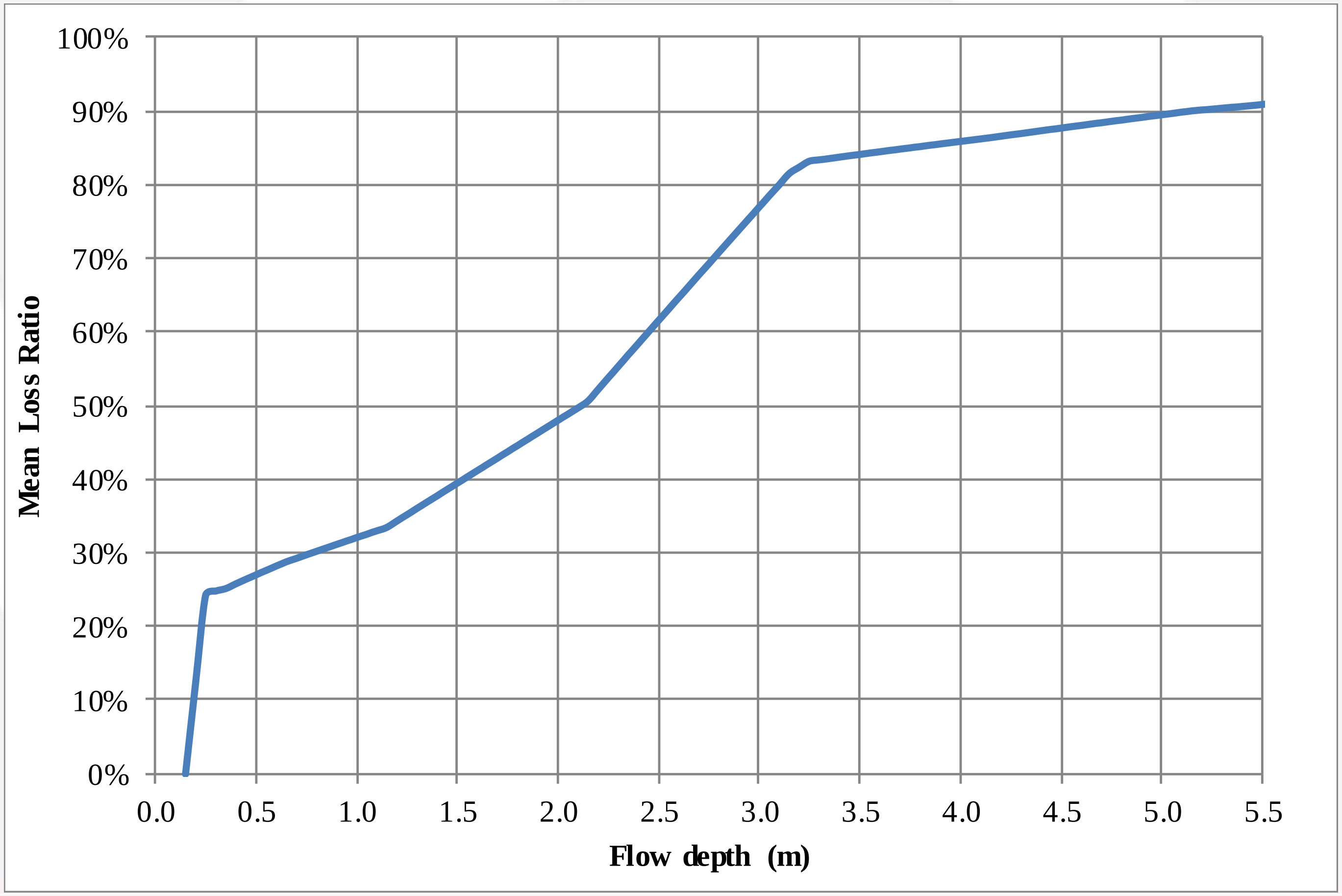
Example of TS vulnerability functions

URM (Suppasri et al., 2013) – GAR Atlas



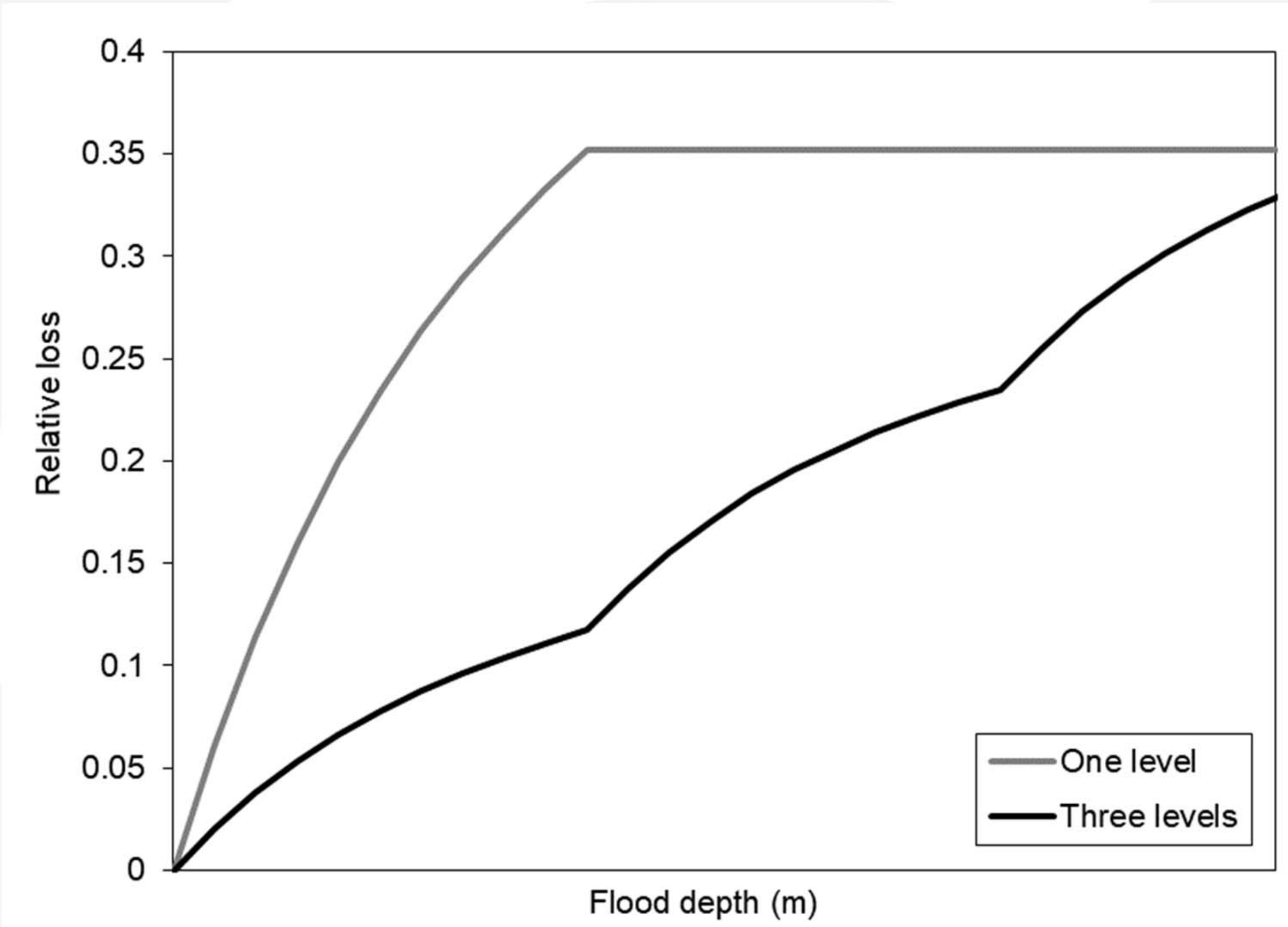
Example of TS vulnerability functions

URM (Expert Group Asia/Pacific) – GAR Atlas



Example of TS vulnerability functions

Public schools in Acapulco (analytical + expert criteria)



Derivation of vulnerability functions

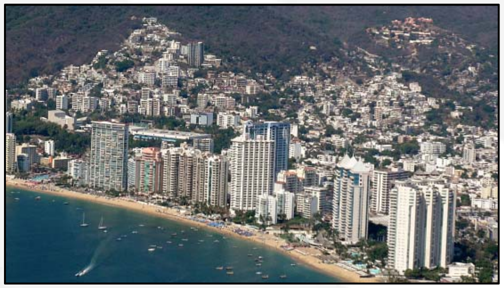
- There is no a unique approach to develop vulnerability functions
- Usually those are obtained combining different approaches:
  - Empirical
  - Analytical
  - Experimental
- Compared to other perils (EQ, WD, FL), tsunami vulnerability functions are in an early development stage
- Lack of empirical data for validation and calibration

Inputs and outputs

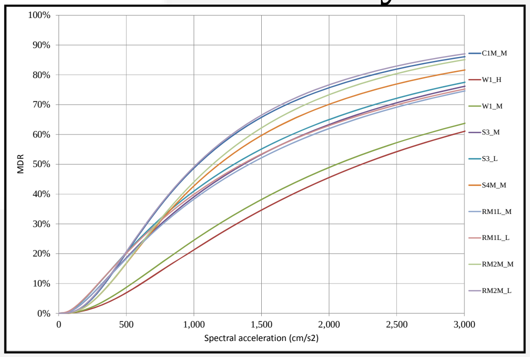
RISK = *f* (HAZARD, VULNERABILITY)

Hazard

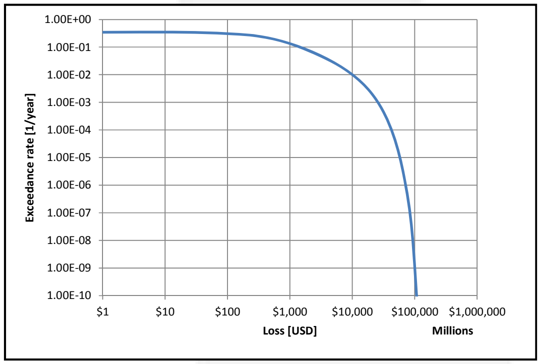
Exposure

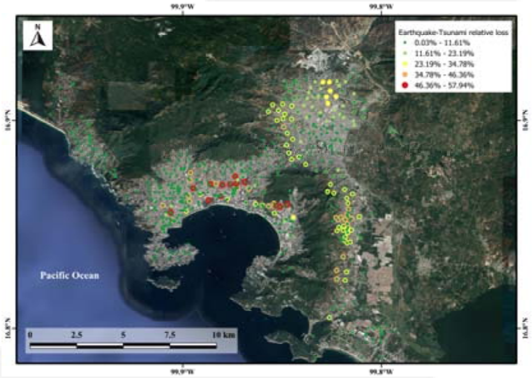


Vulnerability



Risk





Risk assessment methodology

Average annual exceedance rate of a loss value

Loss exceedance probability

Loss exceedance rate

$$v(p) = \frac{\sum \Pr(p \geq P)}{t}$$

Time window

Risk assessment methodology

One of the forms that the Theorem of Total Probability can take:

Loss exceedance rate

Loss exceedance probability

$$v(p) = \sum \Pr(p \geq P) \cdot F_A$$

Annual occurrence frequency of each scenario

Severity and frequency

Risk assessment methodology

Average annual exceedance frequency of a loss value

Loss exceedance probability, conditional to scenario occurrence

Loss exceedance rate

$$\nu(p) = \sum_{i=1}^{Eventos} \Pr(P > p \mid Evento\ \mathrm{i}) F_A(Evento\ \mathrm{i})$$

Loss

Scenario annual occurrence frequency

Sum for all scenarios

Risk assessment methodology

For each event a loss distribution is estimated

$$f\,(l \mid Event\ i)$$

This probability distribution is obtained concatenating probability distributions of hazard and vulnerability of the exposed elements:

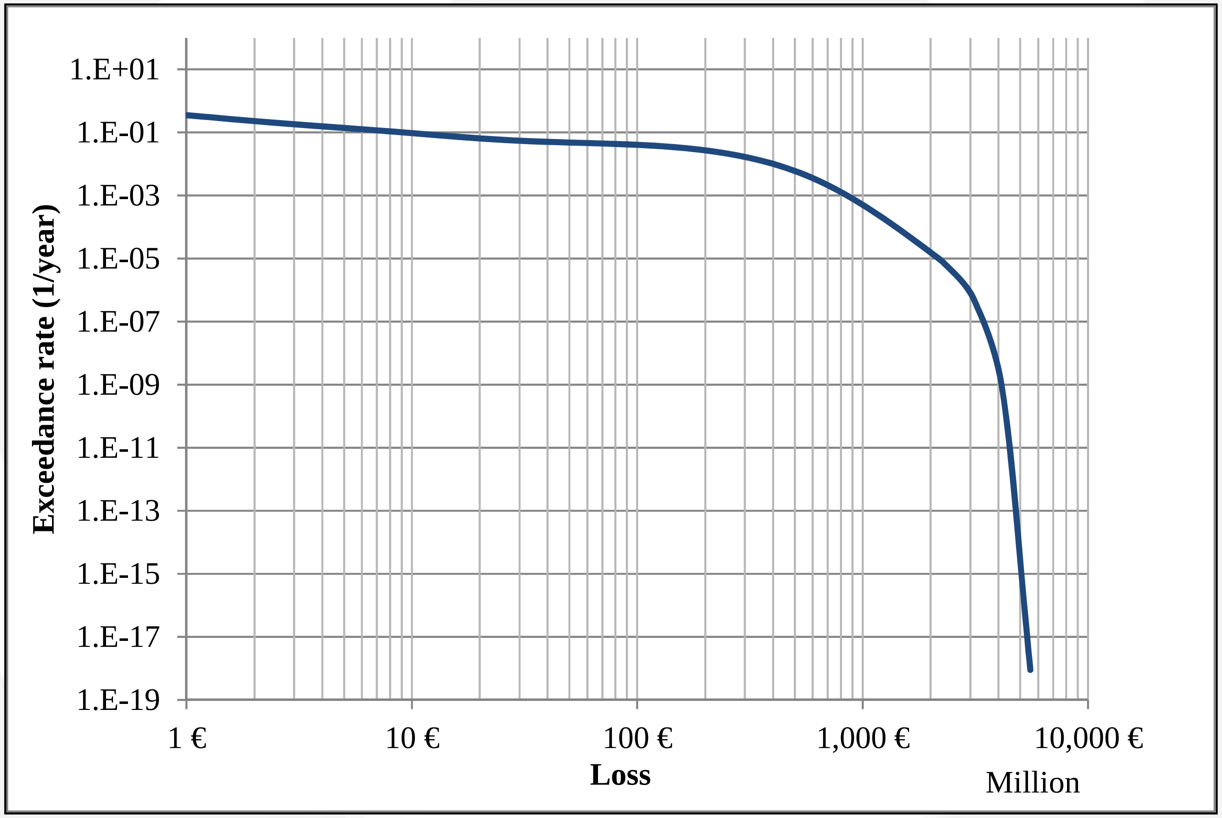
$$f\,(l \mid Event\ i) = \int_0^{\infty} \underbrace{f\,(l \mid Sa)}_{\text{Vulnerability}}\, \underbrace{f\,(Sa \mid Event\ i)}_{\text{Hazard}}\, dSa$$

Common risk metrics

- Loss Exceedance Curve: LEC
- Probable Maximum Loss: PML
- Average Annual Loss: AAL

Risk metrics

Loss exceedance curve



Risk metrics

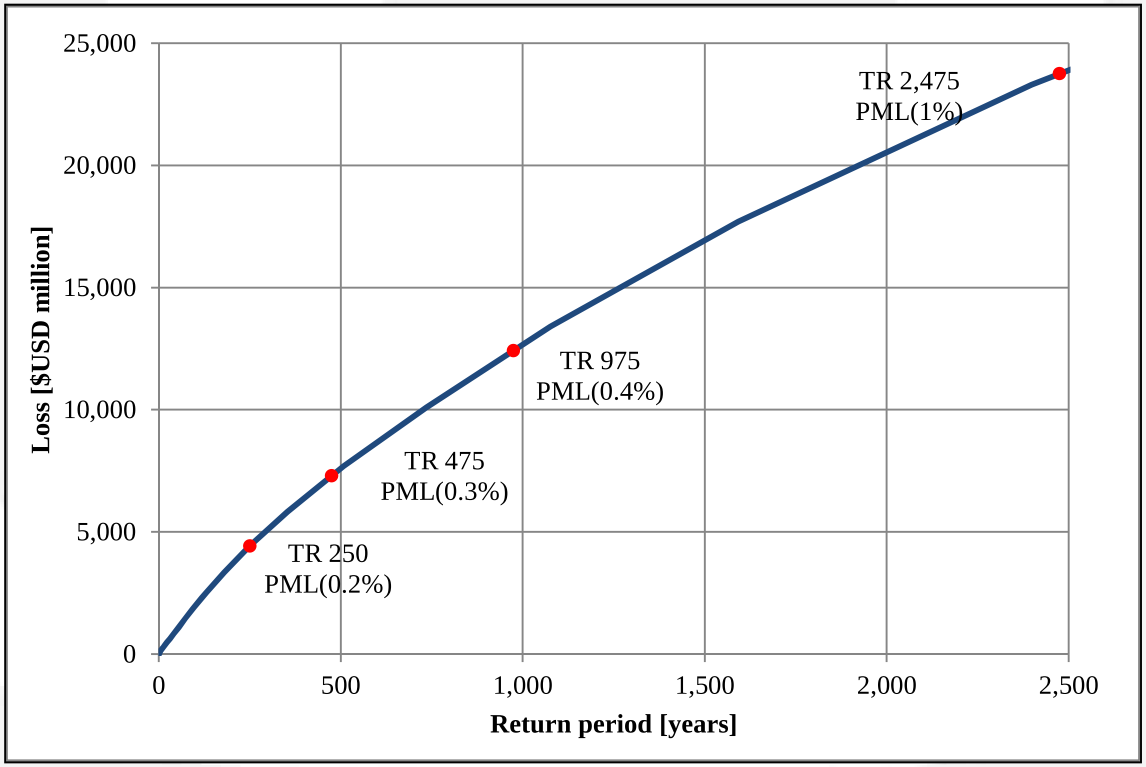
The return period

- There is a problem with its name. Duality and repetition of a temporal reference
- Relationship between return period, observation window and occurrence probability

$$\Pr(\text{obs})_t = 1 - e^{-\nu(\text{evento})\cdot t}$$

Risk metrics

Probable maximum loss



Risk metrics

Average annual loss

Annual Average Loss

Loss expected value, conditional to scenario occurrence

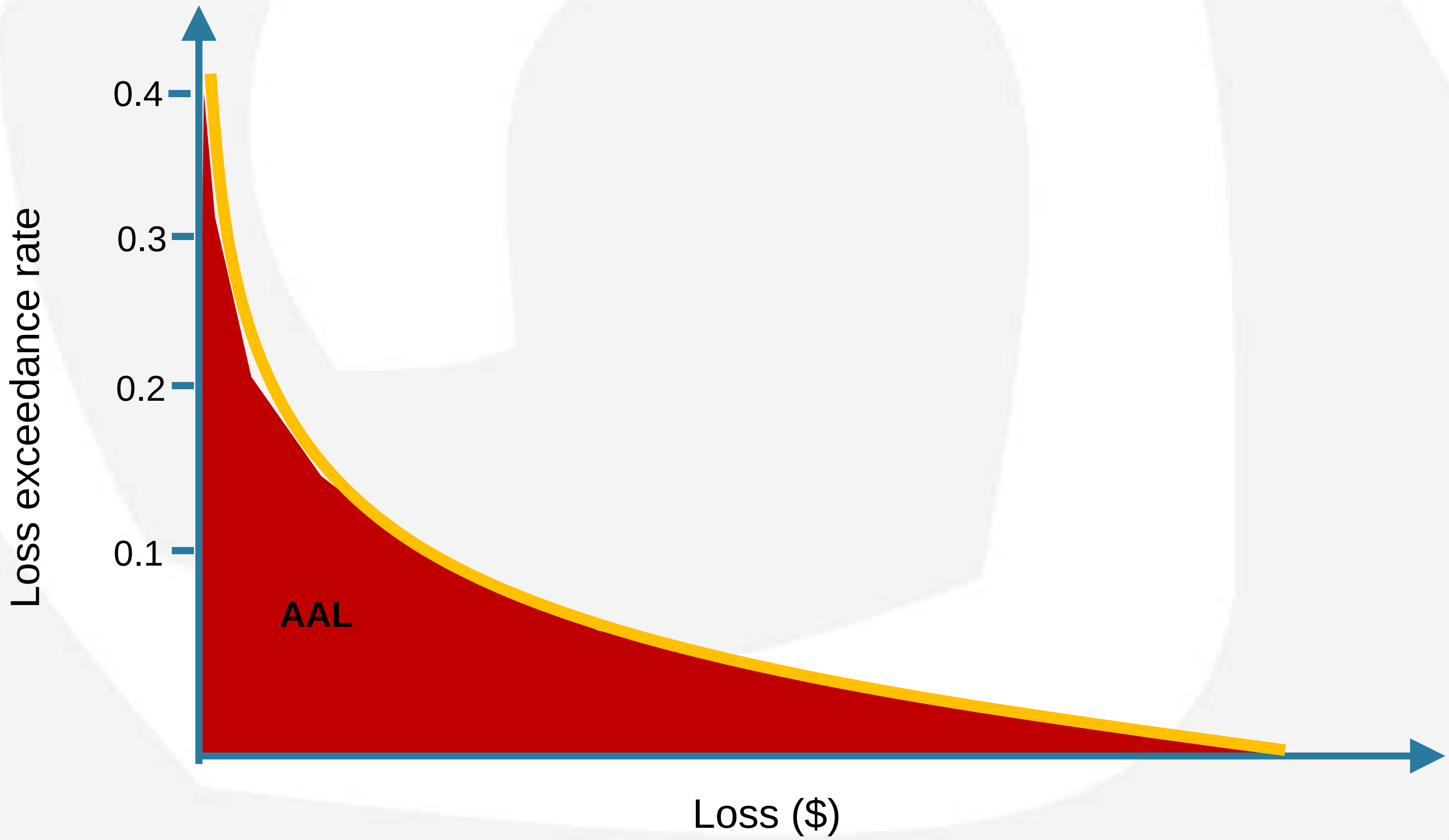
$$AAL = \sum_{All\ events} E(P \mid \text{event i}) F_i$$

Sum for all scenarios

Scenario annual occurrence frequency

Risk metrics

Average annual loss



Peril-agnostic approaches

- Quantifying risk regardless the hazard with the same arithmetic
- Quantifying risk regardless the resolution level with the same arithmetic
- Quantifying risk in terms of the same metrics accounting for different vulnerability dimensions
- Risk assessment tools become only calculators
- Allows including other hazards in the future without changes in the tool or in the methodology
- Challenges and responsibilities to the modeler: scale and resolution level compatibilities

Peril-agnostic approaches

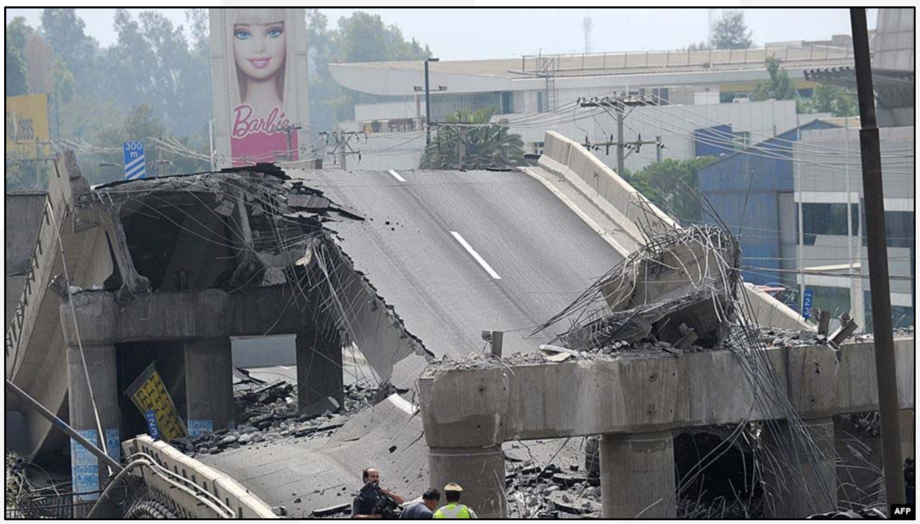
Tools: open and proprietary systems that incorporate peril-agnostic approaches for fully probabilistic disaster risk assessments

R-CAPRA

R-PLUS

Simultaneous loss assessment

Some hazards produce losses of different kind in a *simultaneous* way.



Simultaneous loss assessment

To comply with the Poissonian framework correlated hazards are grouped into *temporalities*

Type of hazard	TEMPORALITY		
	1	2	3
Earthquake			
Tsunami			
Hurricane – Wind			
Hurricane – Storm-surge			
Hurricane – Rain			
Rainfall			
Flooding			
Landslide			

Simultaneous loss assessment

The loss for a given event is assessed considering the contribution of all perils that belong to the same temporality

Number of simultaneous hazards

$$L_i = 1 - \prod_{j=1}^{M} (1 - L_{ij})$$

Loss associated to event *i*

Loss associated to event *i* associated to the action of hazard *j*

Simultaneous loss assessment

- The number of events of each stochastic event set must be the same
- L_{ij} are random variables, therefore L_i is also a random variable
- The moments of the distribution probability of L_i can be determined
- Not considering the simultaneous occurrence of losses yields large underestimation of exceedance rates for large losses and in some cases, overestimation of AAL

Simultaneous loss assessment

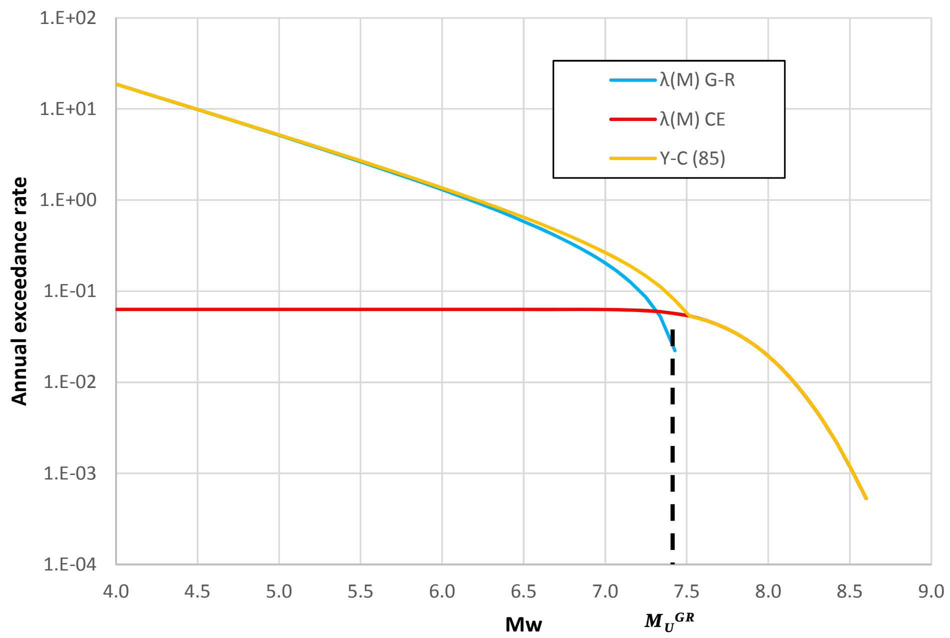
- When losses are not considered as simultaneous, by fixing a loss value, the exceedance rates are added
- When losses are considered as simultaneous, by fixing an exceedance rates, the losses are added using the combination rule
- When combined, it is not possible to determine what share of the total loss corresponds to each of the perils

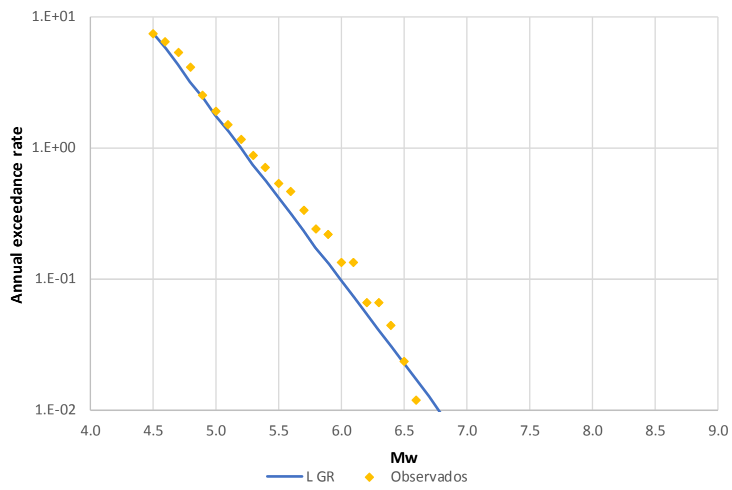
Integrating EQ and TS models

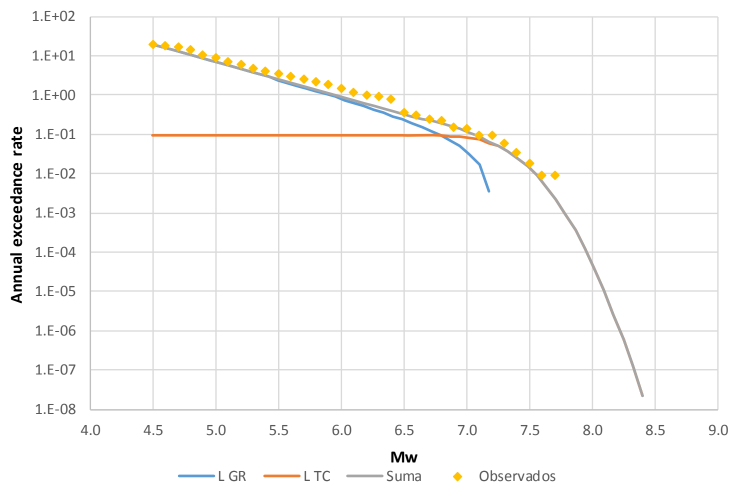
- ERN's tsunami model uses as input the synthetic earthquake catalogue
- Events with *M* higher than a threshold and located within subduction zones are considered as tsunami triggering events
- Based on location, depth, strike and dip values of each triggering event, the surface displacement is estimated
- Tsunami wave propagation is estimated using GeoClaw's (numerical) model
- The model's output is a stochastic tsunami catalogue

LAC EQ model

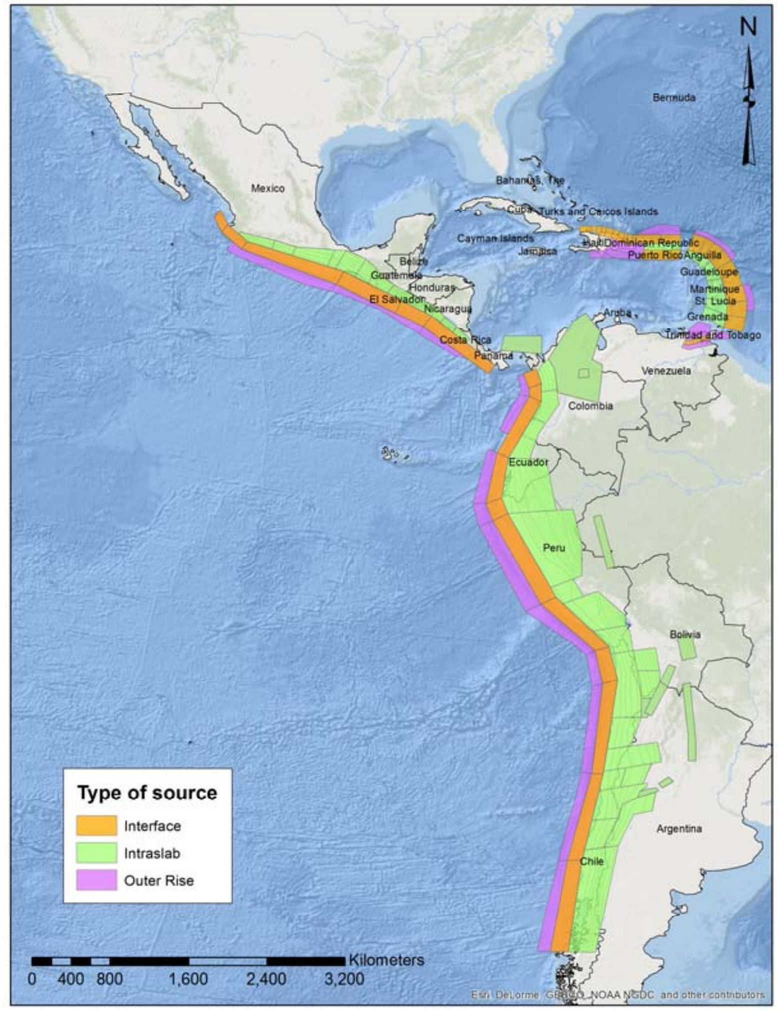
Different EQ occurrence models for interface sources





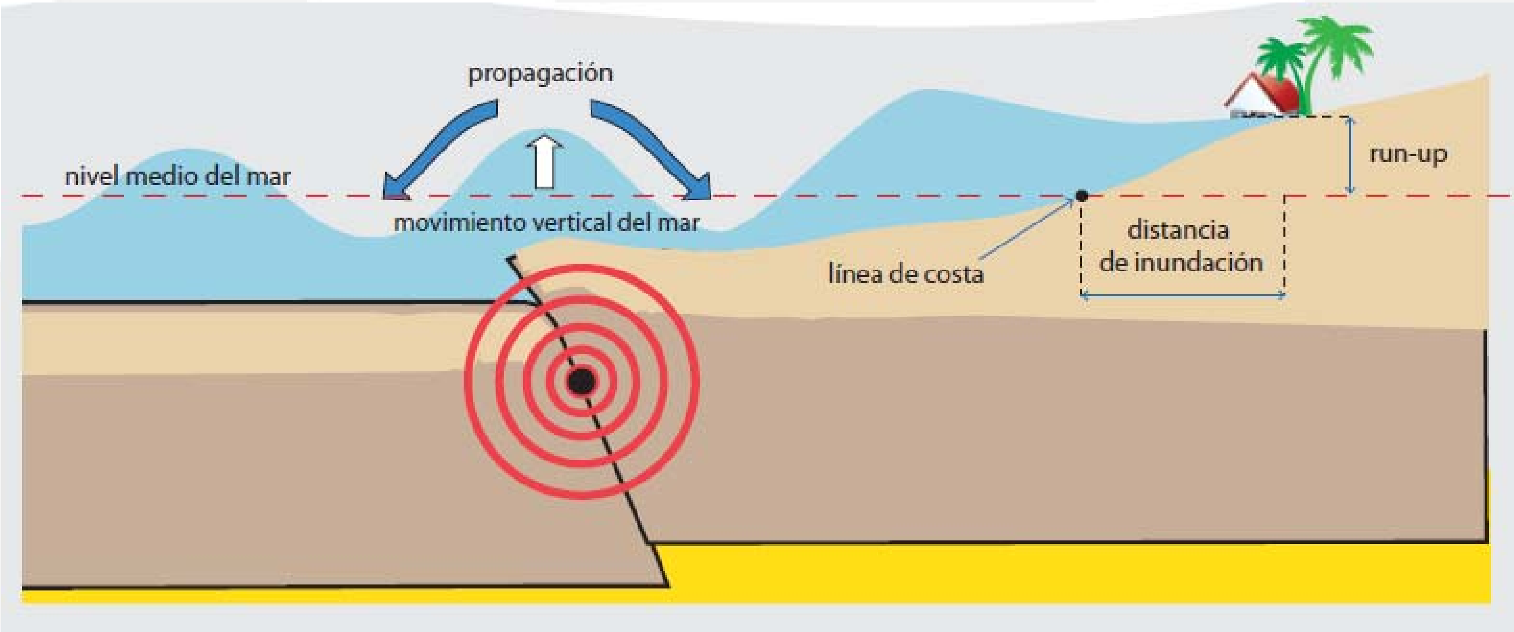


LAC tsunami model

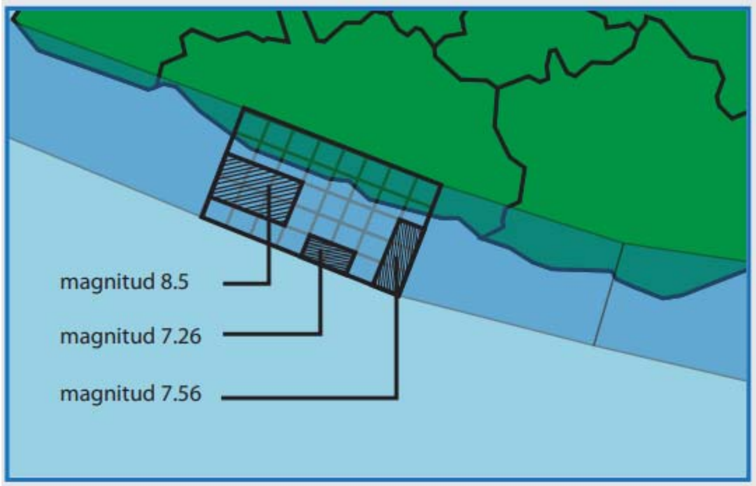


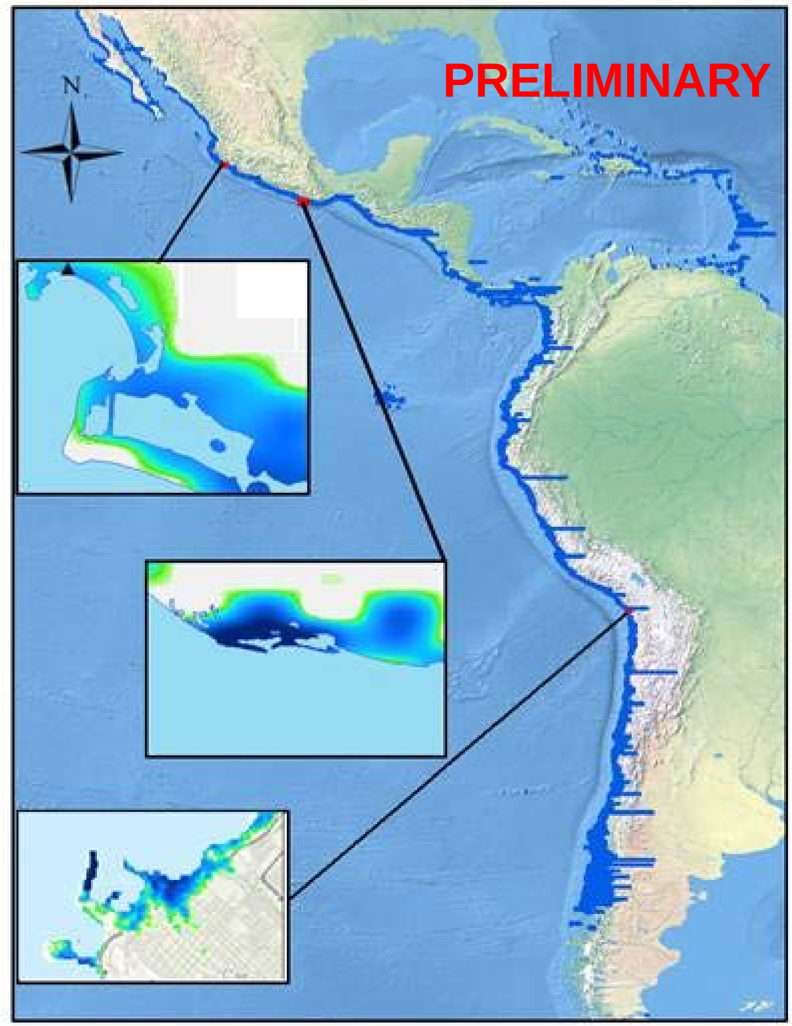
LAC tsunami model

- Bathymetric and topographic data are used for estimating run-up height and flood distance
- Openly available data are refined with more detailed datasets, where available



LAC tsunami model





Case study: schools in Acapulco

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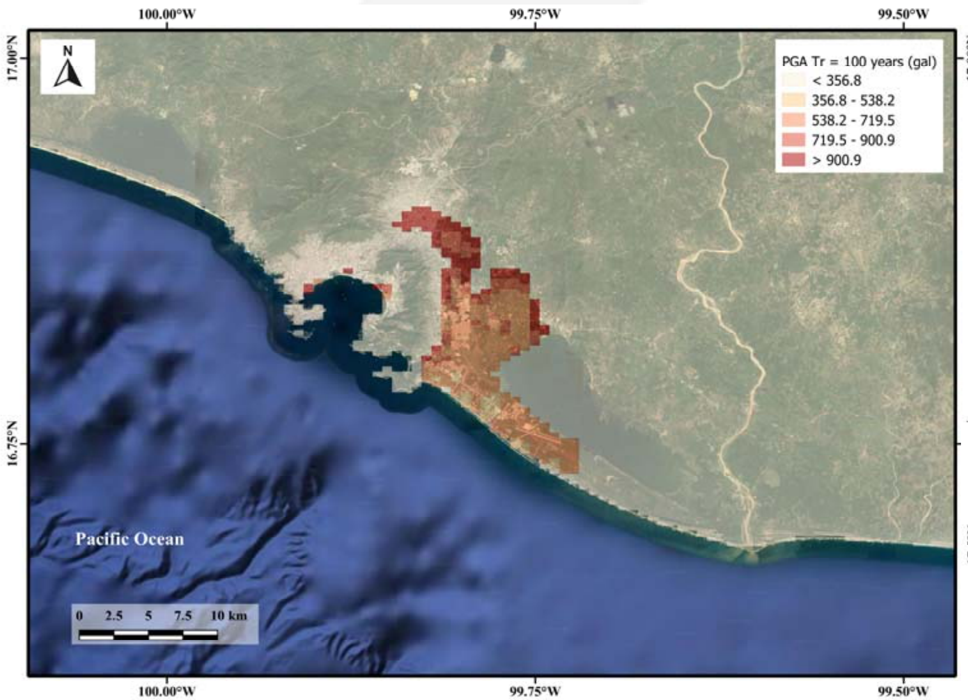
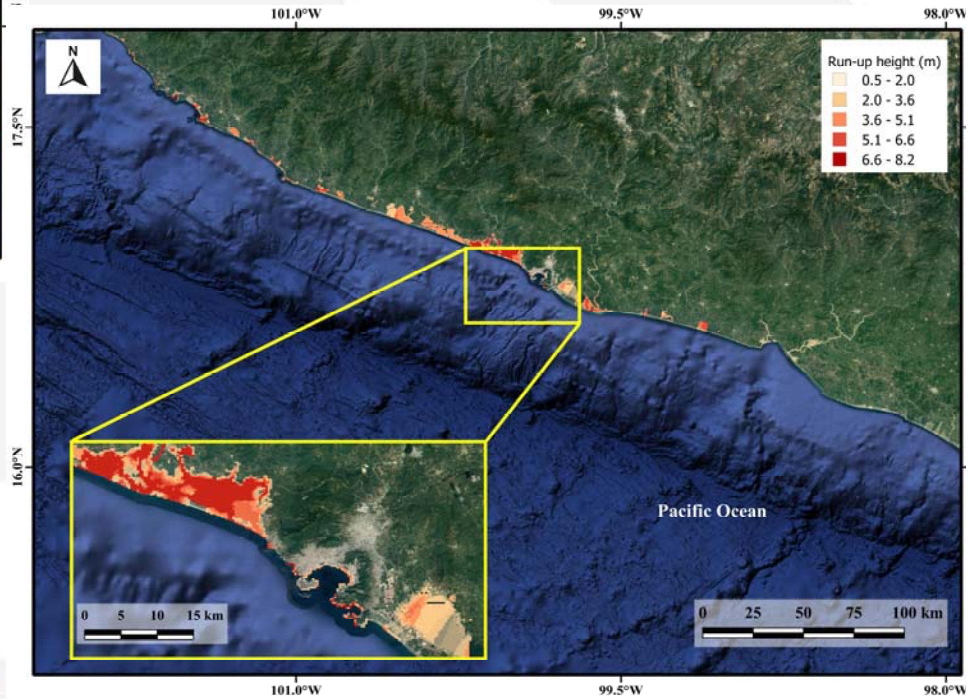
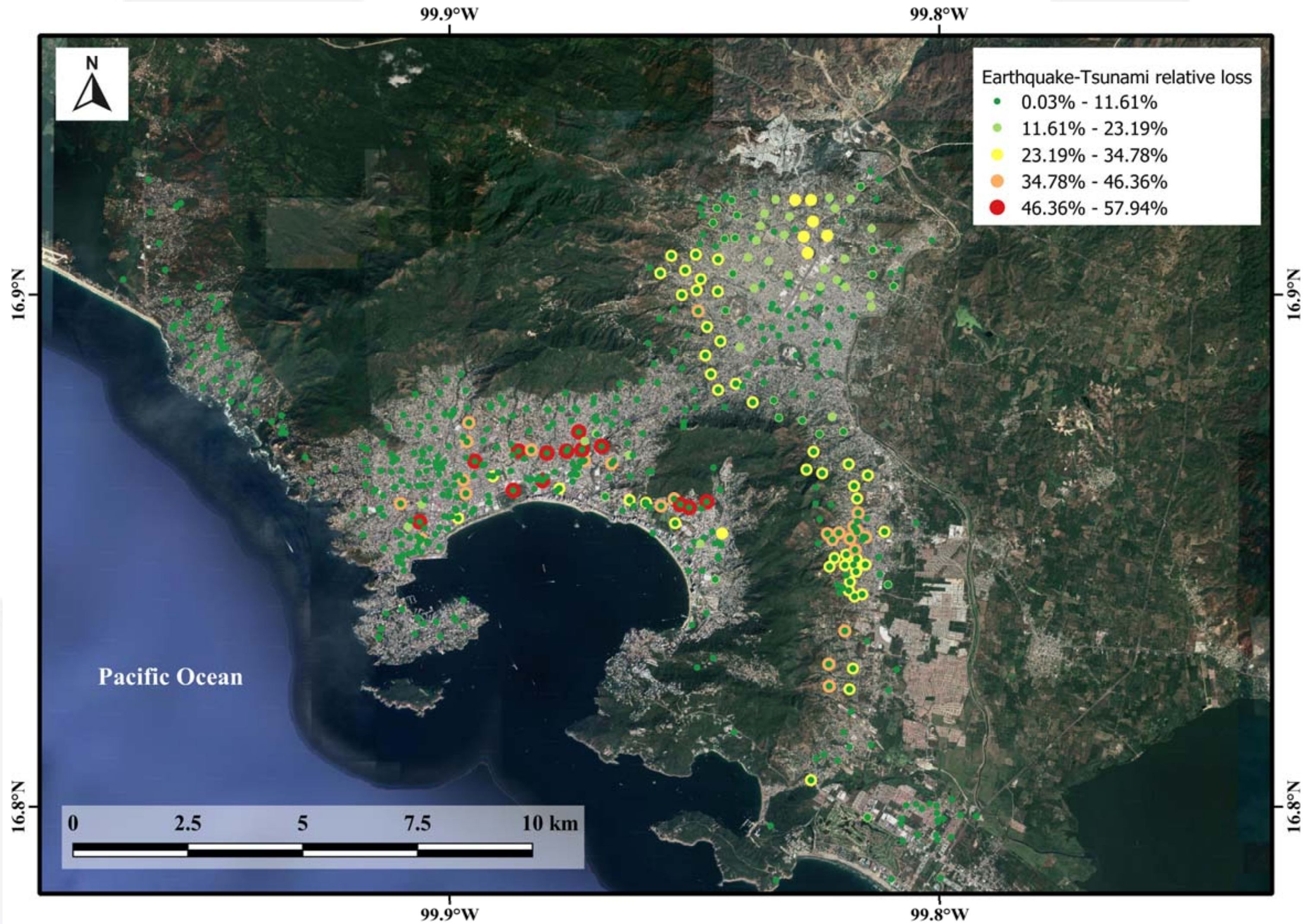


PSHA results with soil effects

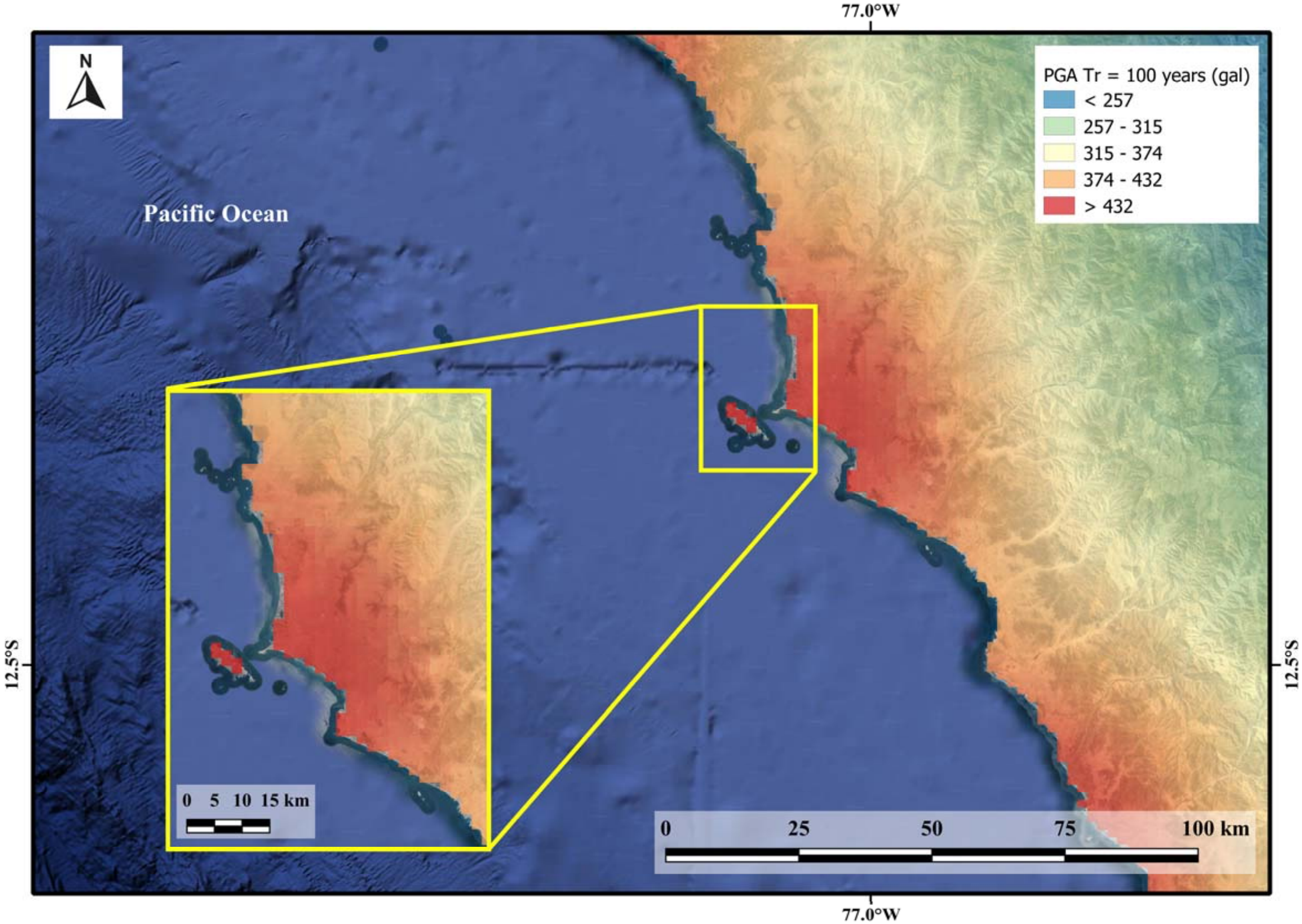


PTHA results

Case study: schools in Acapulco



Case study: buildings in Callao



Case study: buildings in Callao

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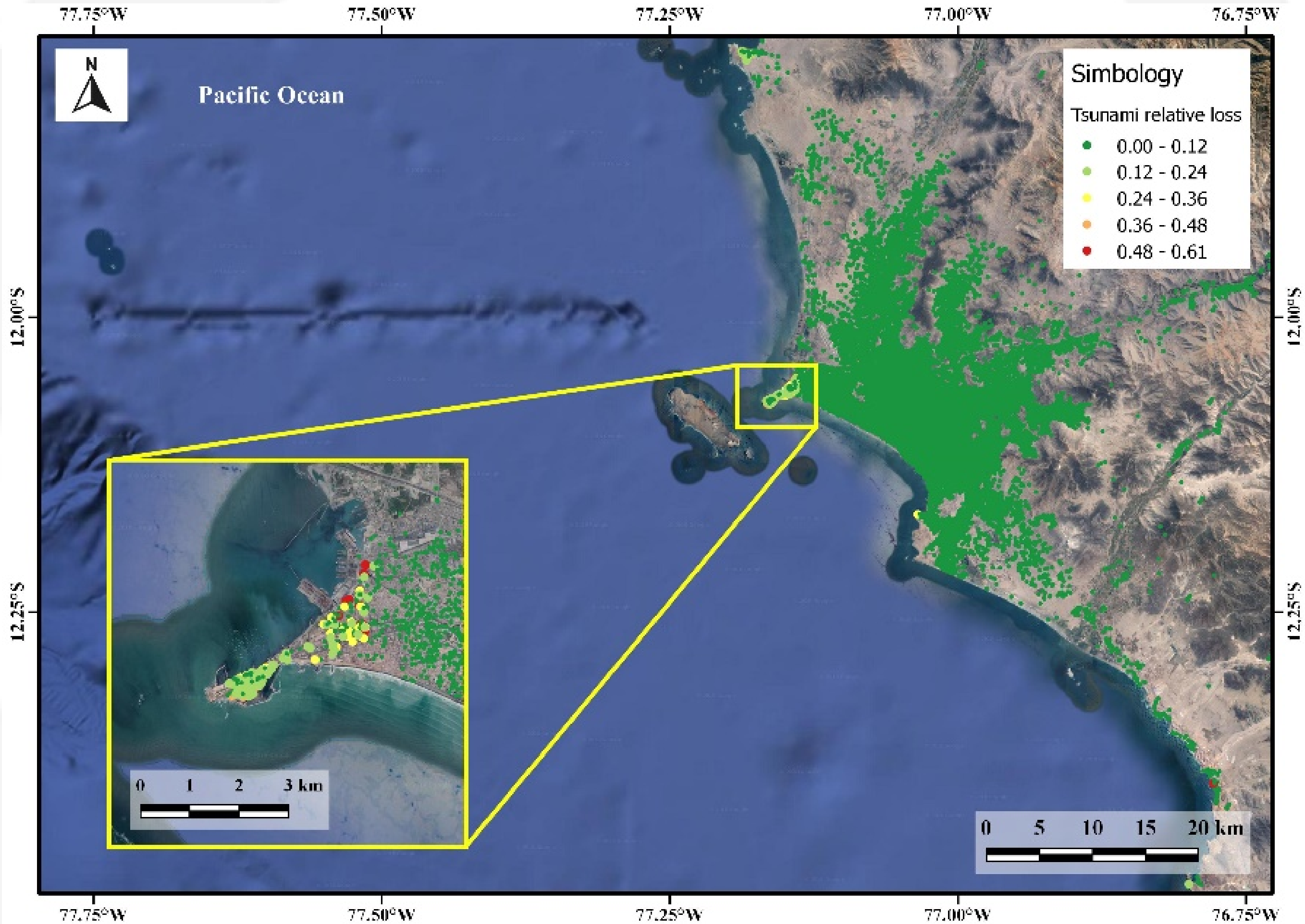

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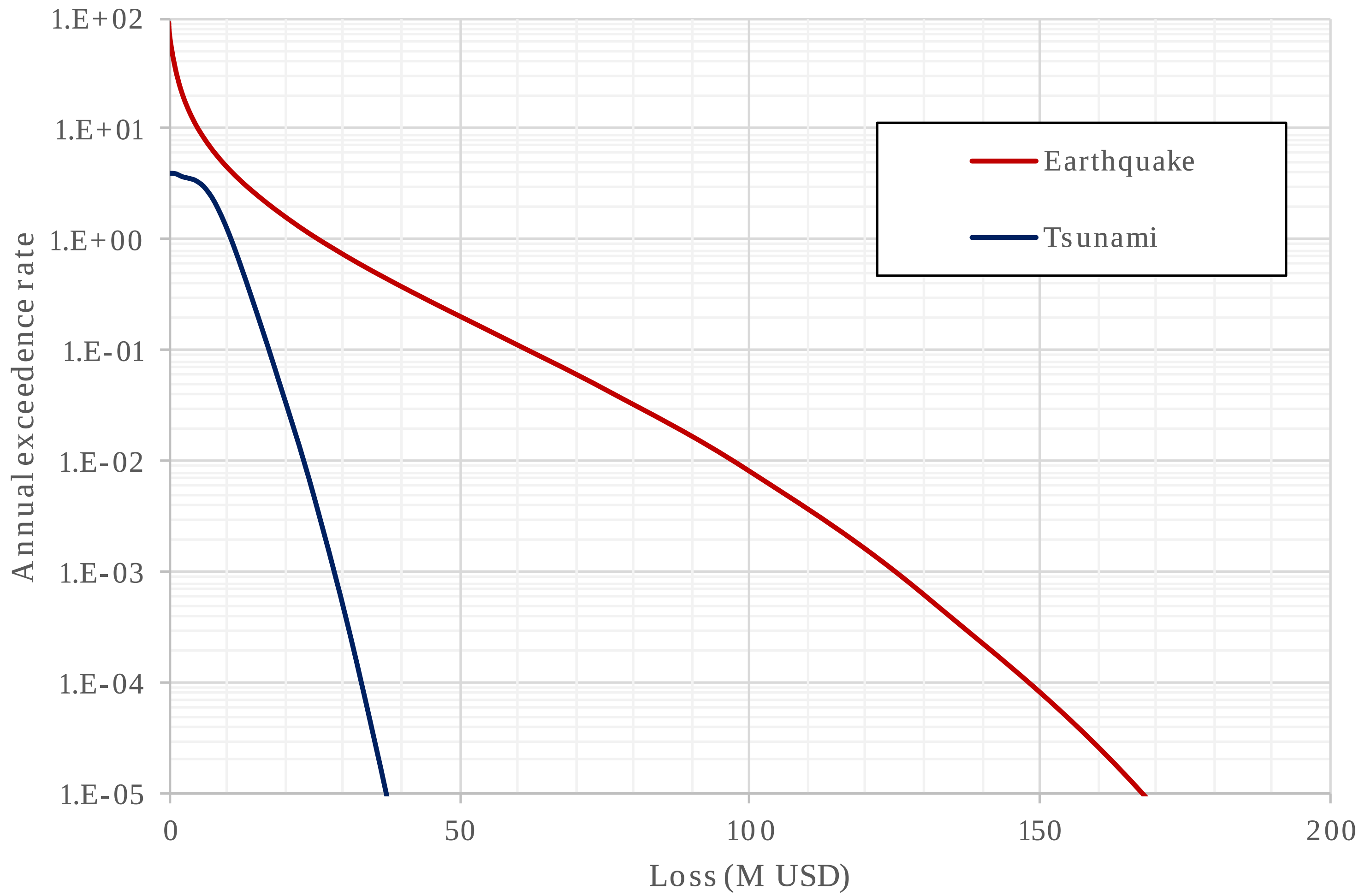

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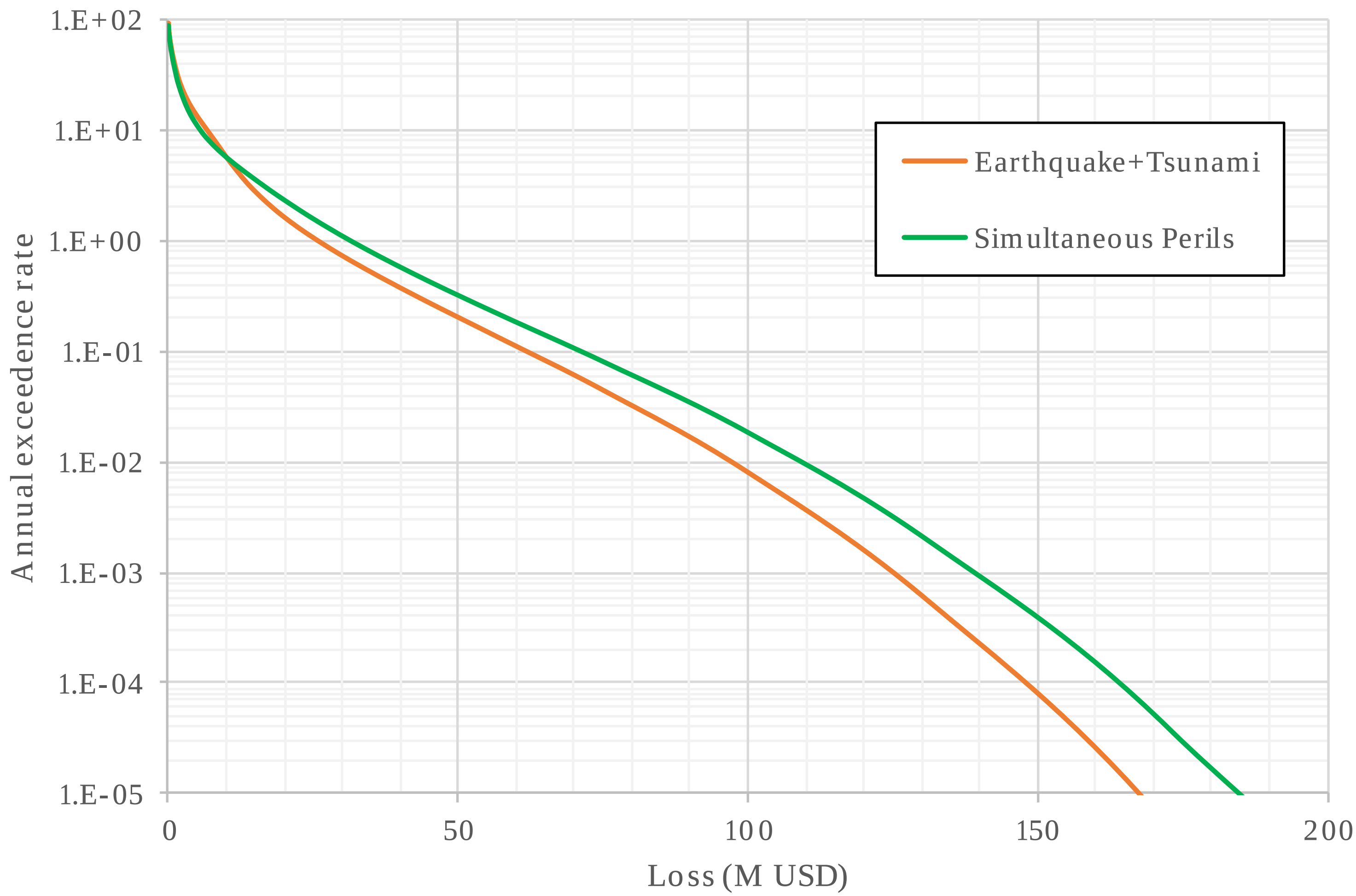

Case study: buildings in Callao

More details in: https://www.emerald.com/insight/content/doi/10.1108/DPM-09-2019-0295/full/html

The current issue and full text archive of this journal is available on Emerald Insight at:
www.emeraldinsight.com/0965-3562.htm

Considering the impacts of simultaneous perils

The challenges of integrating earthquake and tsunamigenic risk

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Abstract

Purpose – The development of multi-hazard risk assessment frameworks has gained momentum in the recent past. Nevertheless, the common practice with openly available risk data sets, such as the ones derived from the United Nations Office for Disaster Risk Reduction Global Risk Model, has been to assess risk individually for each peril and afterwards aggregate, when possible, the results. Although this approach is sufficient for perils that do not have any interaction between them, for the cases where such interaction exists, and losses can be assumed to occur simultaneously, there may be underestimation of losses. The paper aims to discuss these issues.
Design/methodology/approach – This paper summarizes a methodology to integrate simultaneous losses caused by earthquakes and tsunamis, with a peril-agnostic approach that can be expanded to other hazards. The methodology is applied in two relevant locations in Latin America, Acapulco (Mexico) and Callao (Peru), considering in each case building by building exposure databases with portfolios of different characteristics, where the results obtained with the proposed approach are compared against those obtained after the direct aggregation of individual losses.
Findings – The fully probabilistic risk assessment framework used herein is the same of the global risk model but applied at a much higher resolution level of the hazard and exposure data sets, showing its

Risk communication challenges

- Need for experts who not only know the methodologies behind the hazard and risk studies and understand the results, but know what to do with them
- Risk perception for non-frequent events is very low: “It will not happen to me”
- Difficulties to generate and operate a sustainable and comprehensive tsunami risk management strategy

Using the results

- Comprehensive PTHA and PTRA at local level can be integrated within land-use planning that accounts for disaster risk management
- Definition of different types of zones and areas to boost resilience
- Improvement of overall conditions by means of second order benefits (parks, green belts)
- Emergency planning for different scenarios

Current gaps and research fields

- Nature Based Design is a field with room for risk reduction and mitigation activities related to tsunamis
- Green buffer zones (Chile and Japan)
- Integrating tsunami risk results with land use and planning activities
- Need of a multi-discipli-nary approach

Source: Igualt et al., 2017

Current gaps and research fields

- Development of damage and loss functions
- Capturing the vulnerability changes in simultaneous hazards context
- Regional approach (first steps in GAR15)
- Analytical vs. numerical vs. empirical approaches
- Consideration of other vulnerability dimensions different than the physical
- Indirect losses and business interruption

Thank you

Evaluación de Riesgos Naturales

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