



# Caribbean Regional Technical Workshop on CCRIF Models

## Session: The SPHERA EQ risk model

With financial support from the European Union in the framework of the Caribbean Regional Resilience Building Facility, managed by the Global Facility for Disaster Reduction and Recovery (GFDRR)

CARIBBEAN REGIONAL RESILIENCE BUILDING FACILITY



**GFDRR**  
Global Facility for Disaster Reduction and Recovery



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**THE WORLD BANK**  
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- Introduction
- Geographical area
- Exposure (review)
- Earthquake hazard and vulnerability
- EQ loss computation and insurance scheme
- EQ real-time operation
- Updates 2023
- EQ EP curves

- Caribbean and Central America TC and EQ model (SPHERA - System for Probabilistic Hazard Evaluation and Risk Assessment):
  - To be used by country-level institutions, e.g. governments
  - Provides payouts around two weeks after the event
  - Based on a physically-based hazard models
  - Extensive and detailed asset exposure database (including buildings, infrastructure and crops)
  - Calibrated against reported losses of historical tropical cyclone and earthquake events

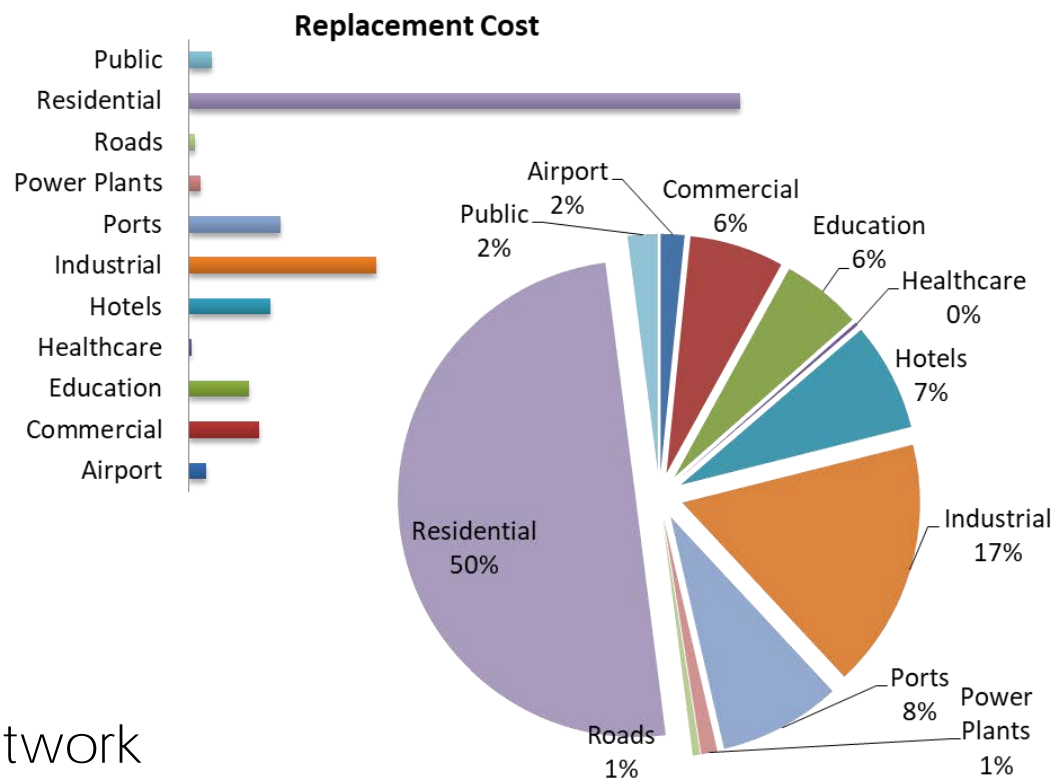
# Geographical area

- Caribbean and Central America (single and unified domain)



- Categories included:
  - Residential buildings
  - Commercial buildings
  - Public Buildings
  - Industrial facilities
  - Hotels and restaurants
  - Healthcare infrastructure
  - Energy Facilities
  - Education infrastructure
  - Airports and ports
  - Transportation (roads) network
  - Crops

Example: St Kitts and Nevis



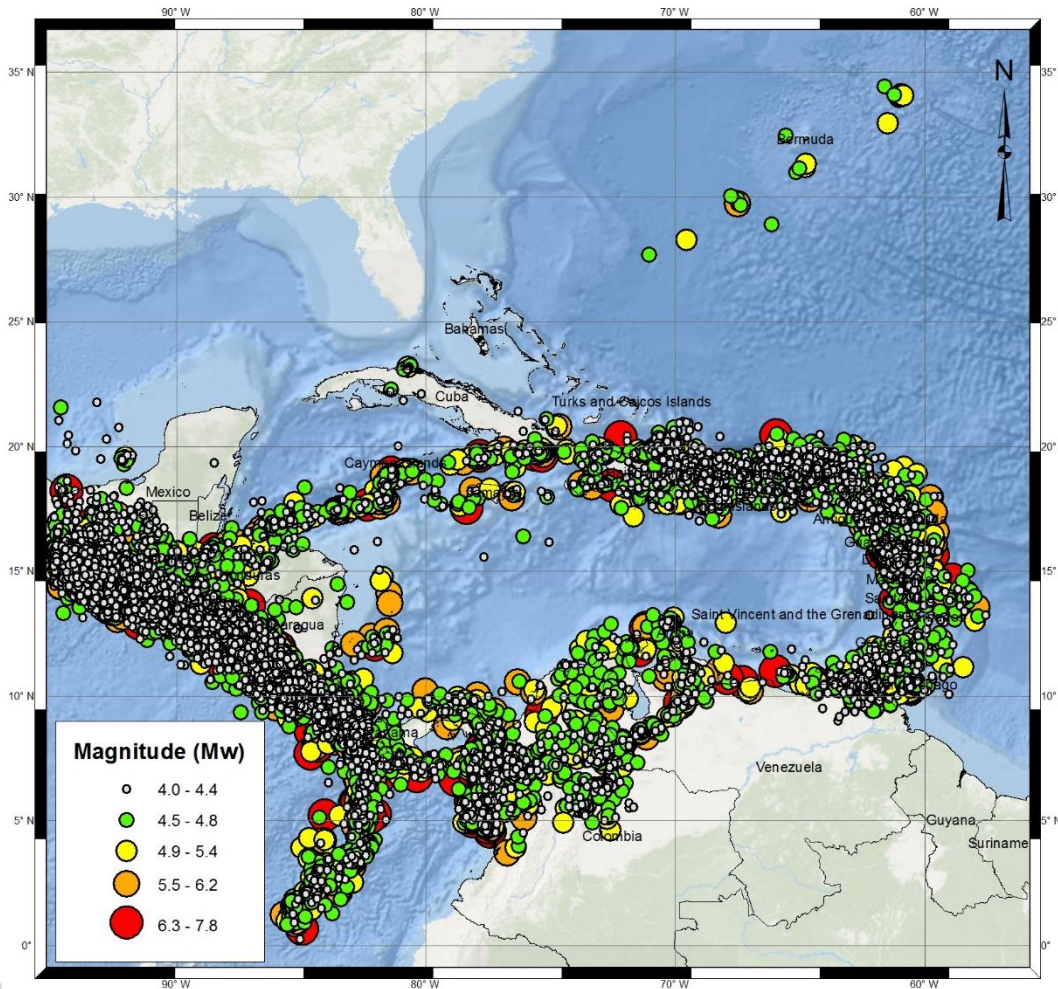
# SPHERA EQ hazard and vulnerability

System for Probabilistic Hazard Evaluation and Risk Assessment

- Summary
  - Classic PSHA approach to estimate long-term relations between ground motion intensities and exceedance rates
  - Seismic zonation and representation of the sources using different geometric models
  - Review, homogenization and declustering of the historical seismicity
  - Seismicity parameters estimated using Poissonian models
  - Selection and combination of ground motion prediction equations by tectonic environment
  - Generation of a stochastic event-set statistically consistent with the historical seismicity in the region
  - A recent update of the PSHA was carried out for Jamaica, Haiti and Cayman Islands to explicitly account for fault data



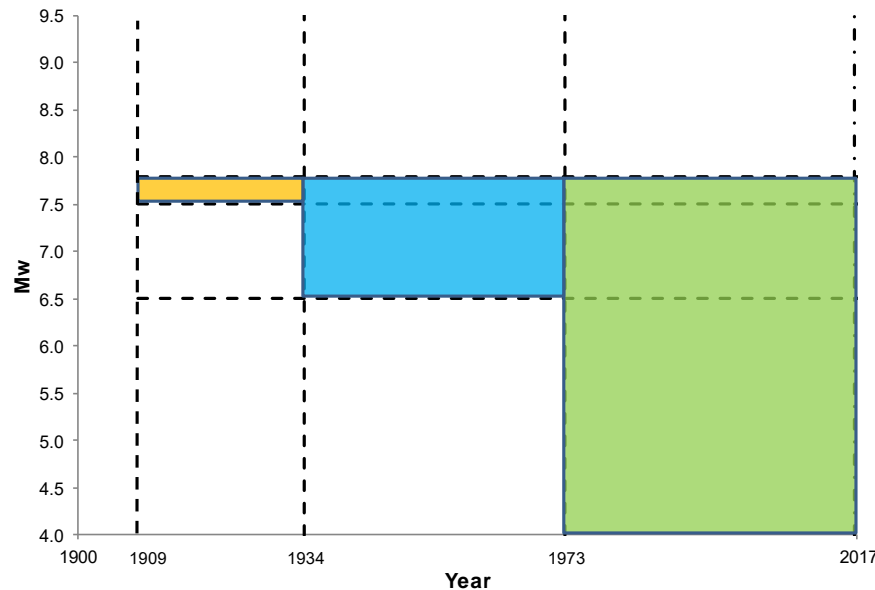
- Instrumental catalogue (1900-2021)



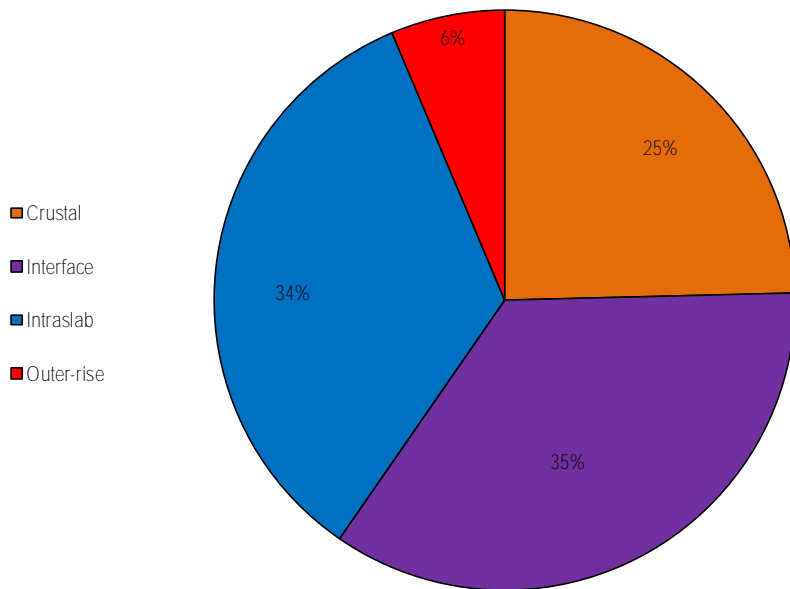
- Several data sources:
  - NEIC/USGS
  - RESIS-II (NORSAR)
  - ISC-GEM
  - UWI/EUCENTRE
- M<sub>min</sub>=4.0



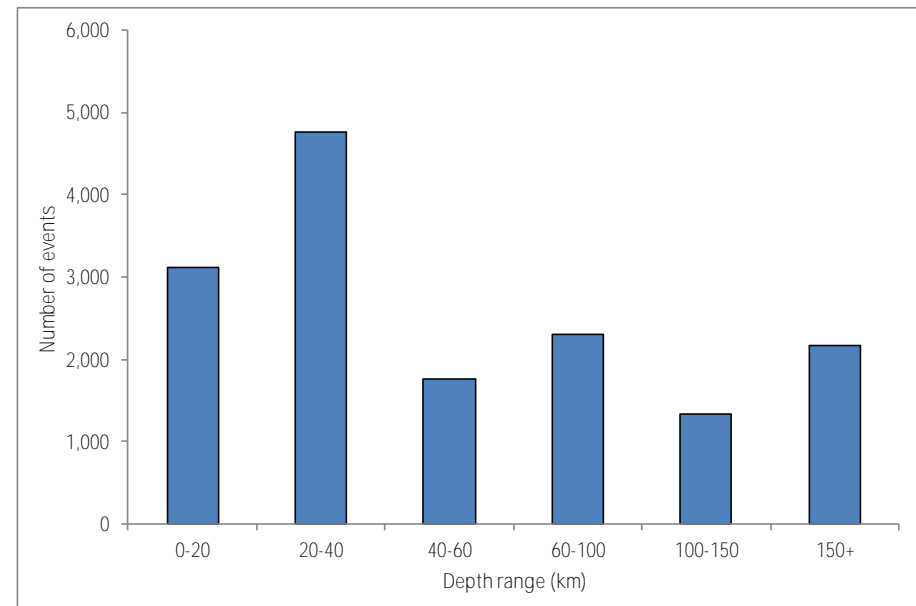
- Completeness analysis
  - Sub-regional verification
    - Mexico and Central America
    - The Caribbean
    - Northern Andes
  - Estimation of completeness windows for different threshold magnitudes



- Declustering
  - Only main shocks are included in the working catalog
  - 15,438 earthquakes remain in the working catalog

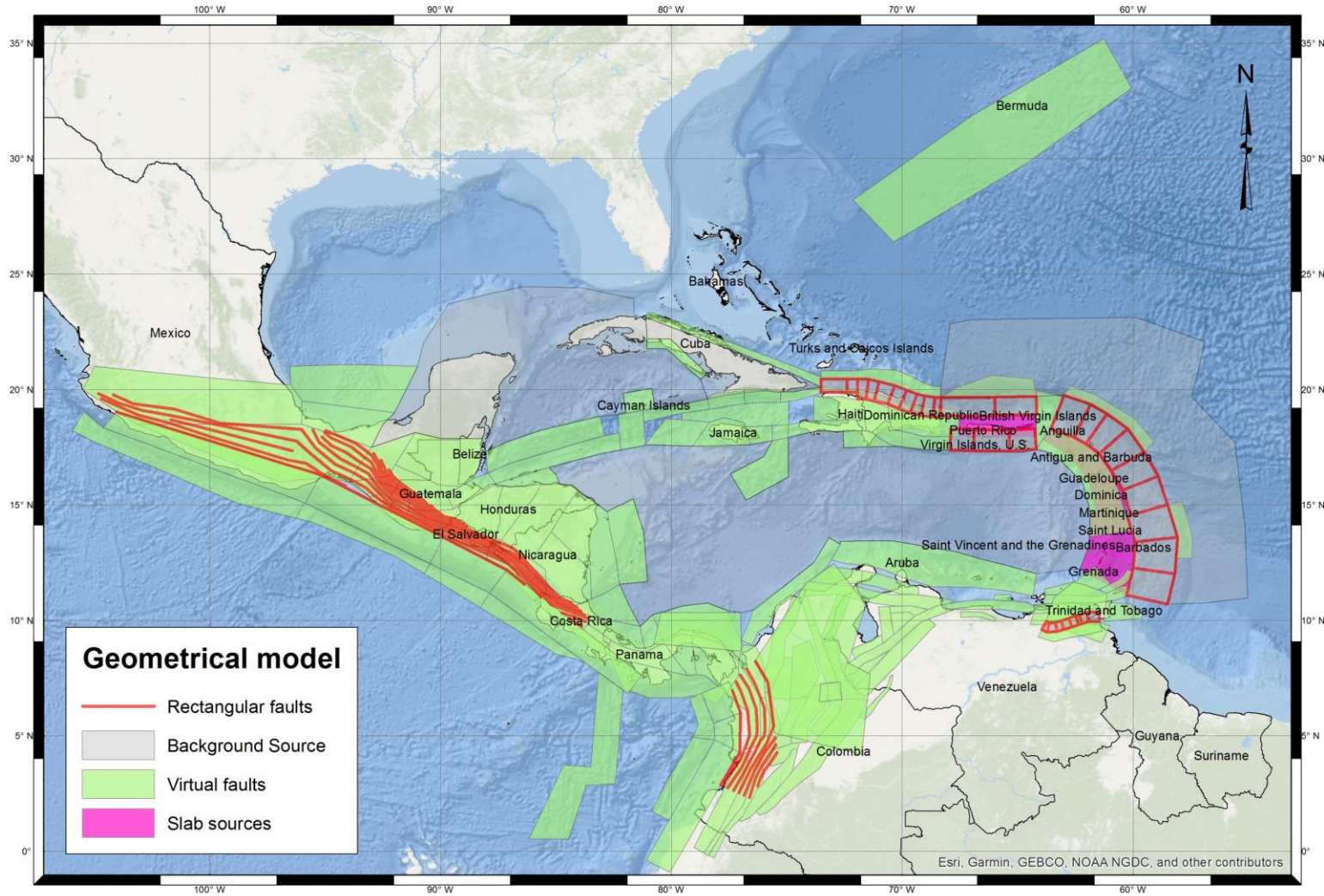


Classification by tectonic environment

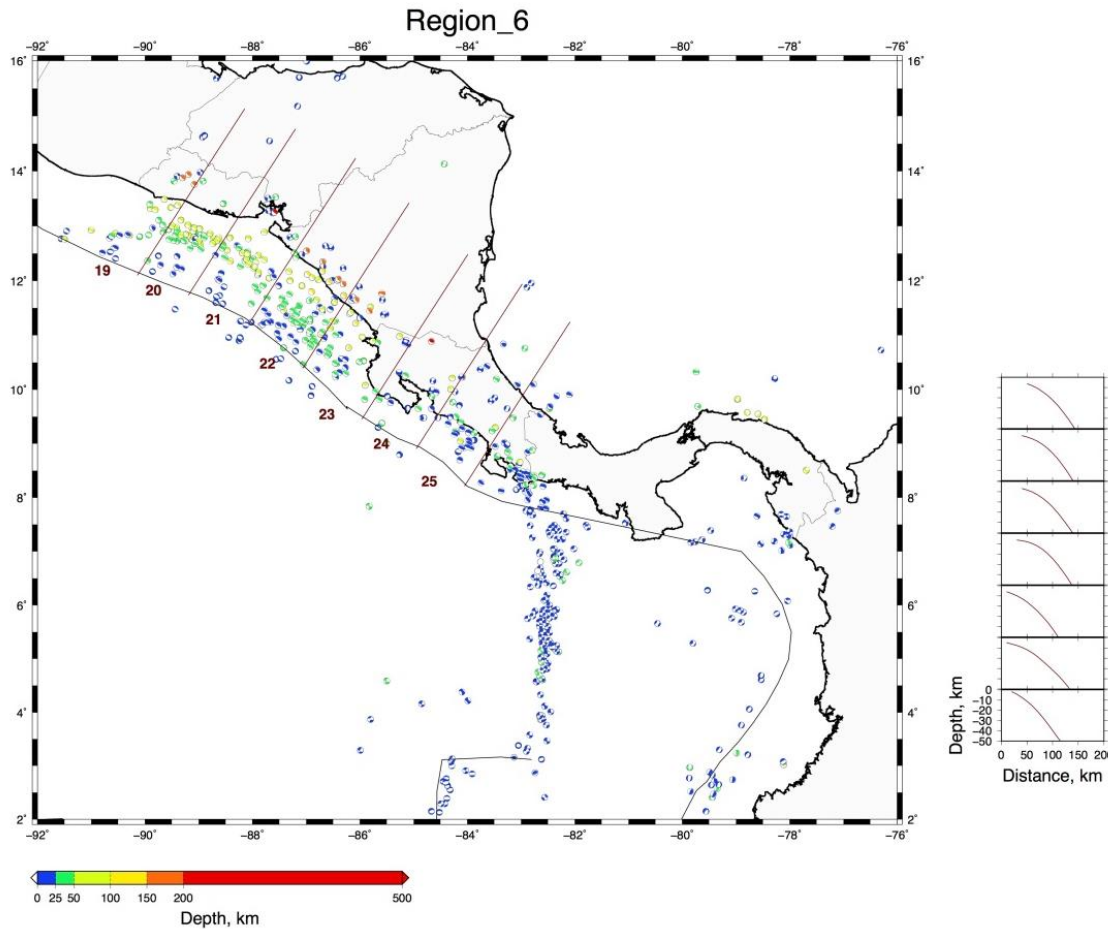


Classification by depth

- Zonation and geometric models

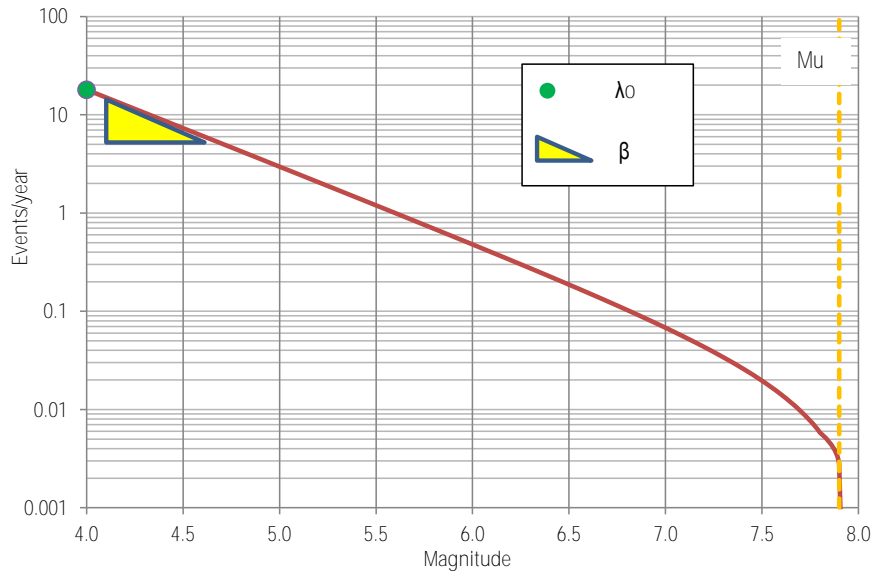


## Tectonic zonation – subduction zones

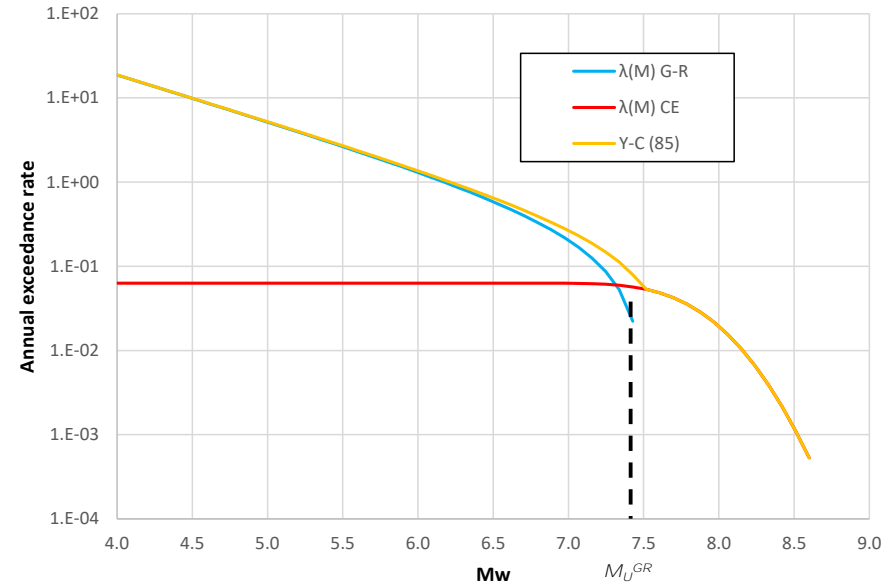


- Detailed interface and intraslab zonation based on SLAB dataset
- Cross sections to determine geometries of the subduction processes

- Seismicity models



Modified  
G-R model



Modified  
Youngs and Coppersmith model

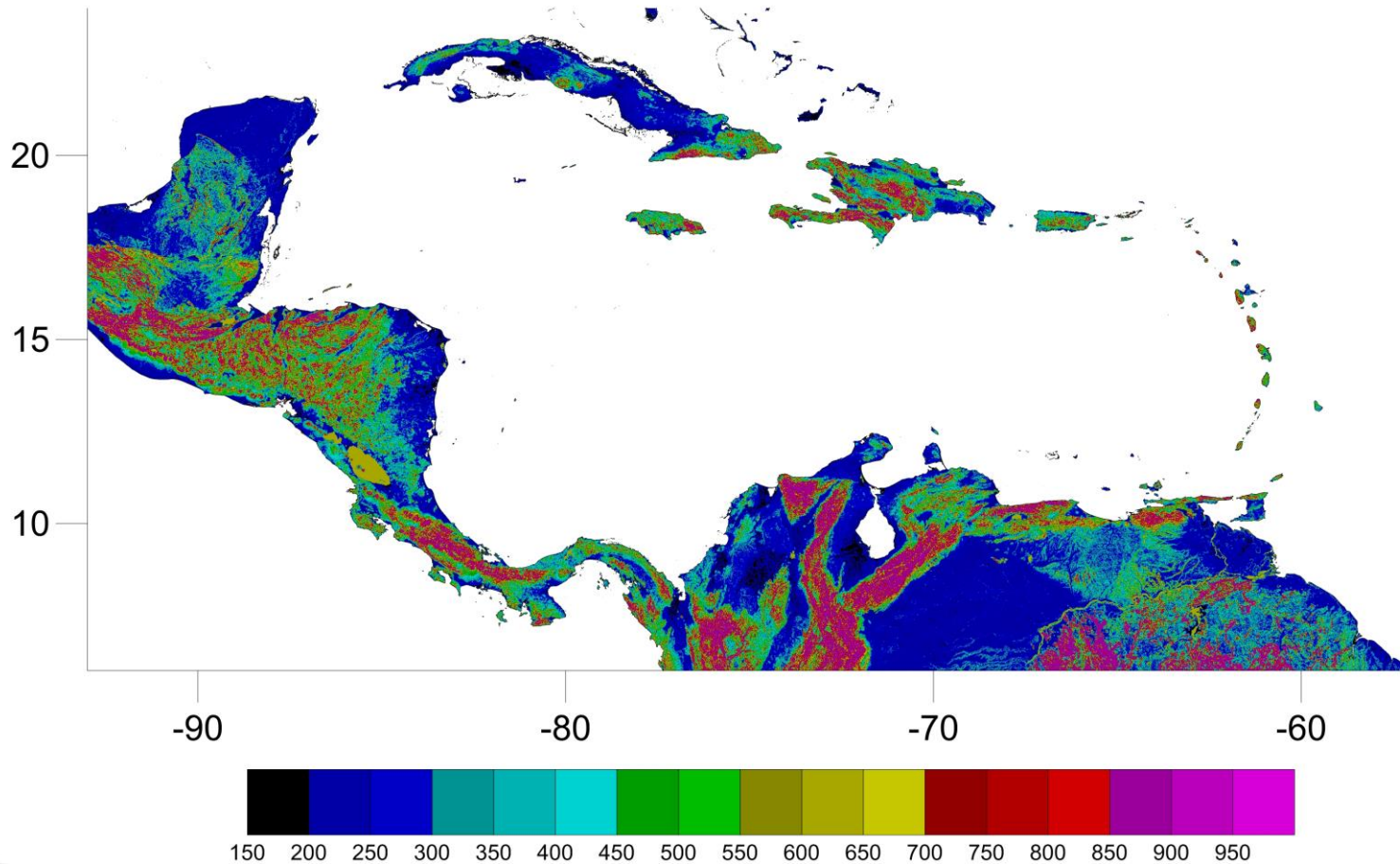
Estimation of the seismicity parameters using maximum likelihood procedures and combining completeness windows

- Ground motion prediction equations
  - Composite model approach that allows combining different models
  - Selection made based on previous studies and recommendations for the region
  - Where available, local models are included

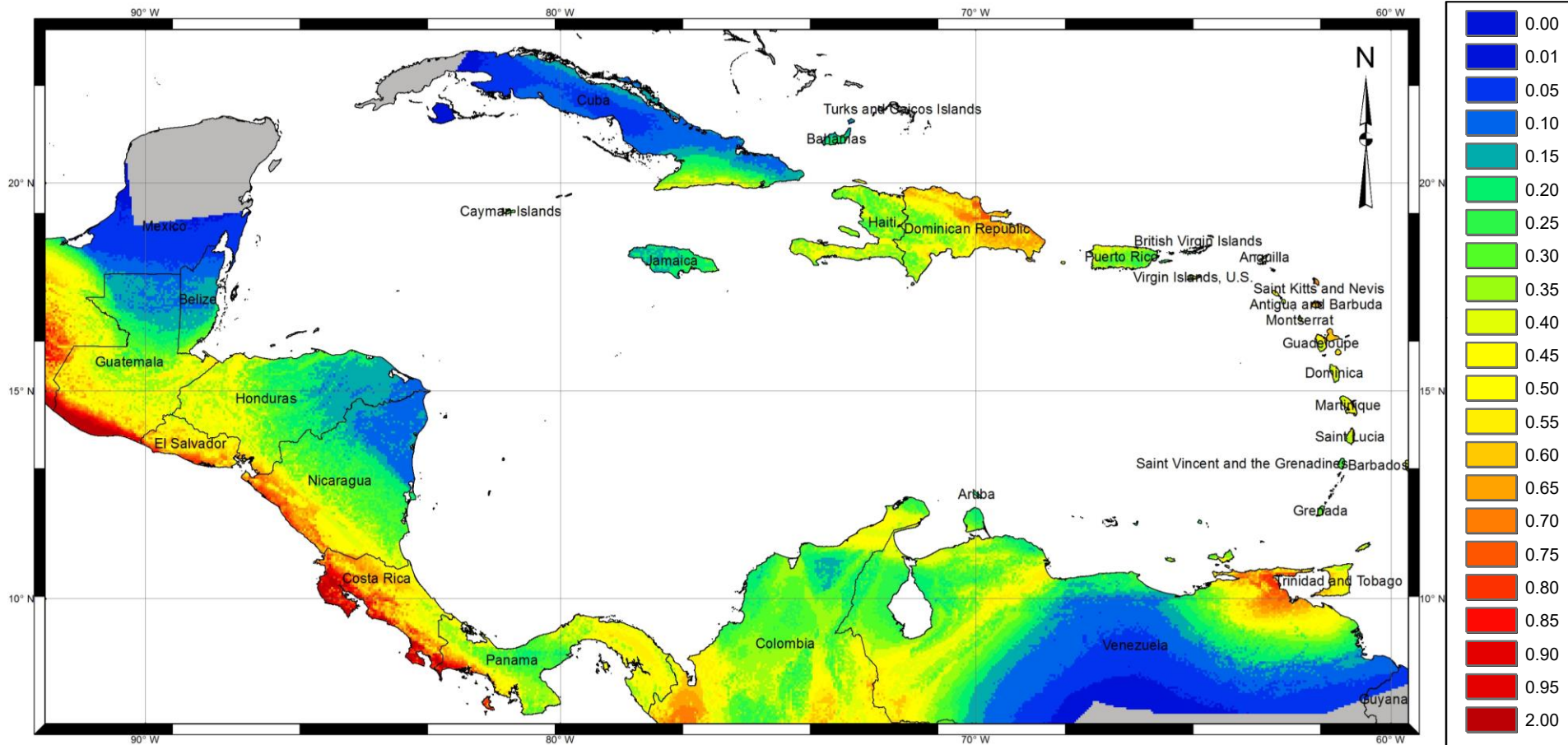
| Region/Country                    | Tectonic environment | Base GMPEs   |
|-----------------------------------|----------------------|--|
| Mexico                            | Crustal              | Chiou-Youngs (2014) - Abrahamson et al. (2014) - Zhao et al. (2006)                    |
|                                   | Interface            | Zhao et al. (2006) - Youngs et al. (1997) - Lin and Lee (2008) - Arroyo et al. (2010)  |
|                                   | Intraslab            | Zhao et al. (2006) - Youngs et al. (1997) - Kanno et al. (2006) - Garcia et al. (2005) |
| Central America and the Caribbean | Interface            | Zhao et al. (2006) - Youngs et al. (1997) - Lin and Lee (2008)                         |
|                                   | Intraslab            | Zhao et al. (2006) - Youngs et al. (1997) - Kanno et al. (2006)                        |
|                                   | Outer-rise           | Zhao et al. (2006)   |
|                                   | Crustal              | Chiou-Youngs (2014) - Abrahamson et al. (2014) - Zhao et al. (2006)                    |
| Northern Andes                    | Interface            | Zhao et al. (2006) - Youngs et al. (1997) - Lin and Lee (2008) - Bernal (2014)         |
|                                   | Intraslab            | Zhao et al. (2006) - Youngs et al. (1997) - Kanno et al. (2006) - Bernal (2014)        |
|                                   | Crustal              | Chiou-Youngs (2014) - Abrahamson et al. (2014) - Zhao et al. (2006) - Bernal (2014)    |



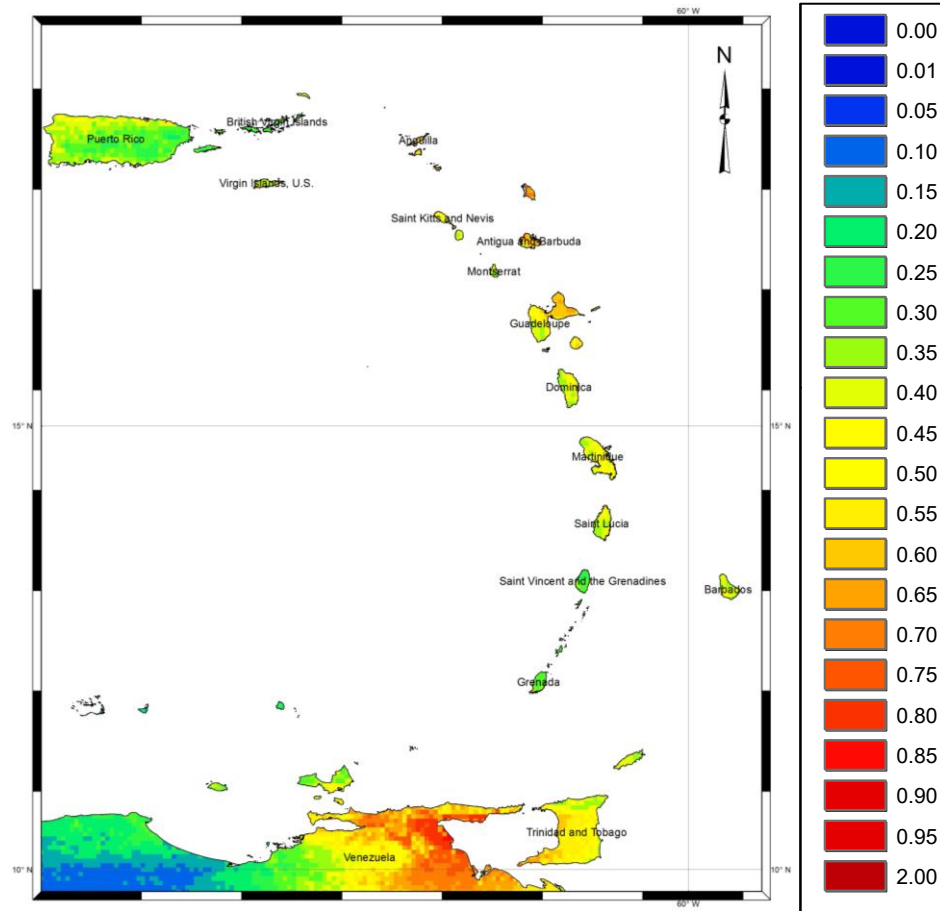
- Site effects
  - Vs30-based (USGS)



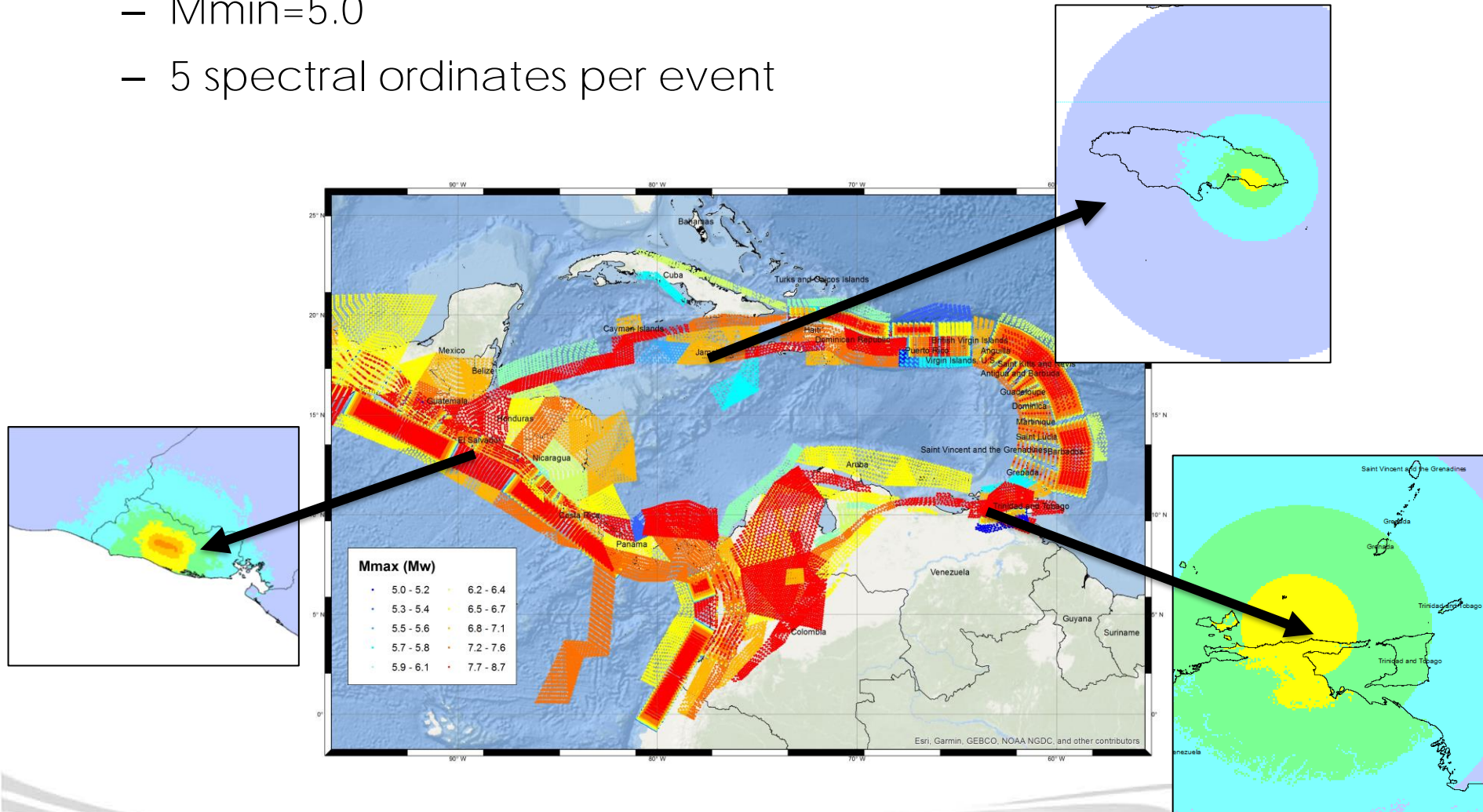
- Final hazard model (pga – 475 years on soil – g)



- Final hazard model (pga – 475 years on soil – g)

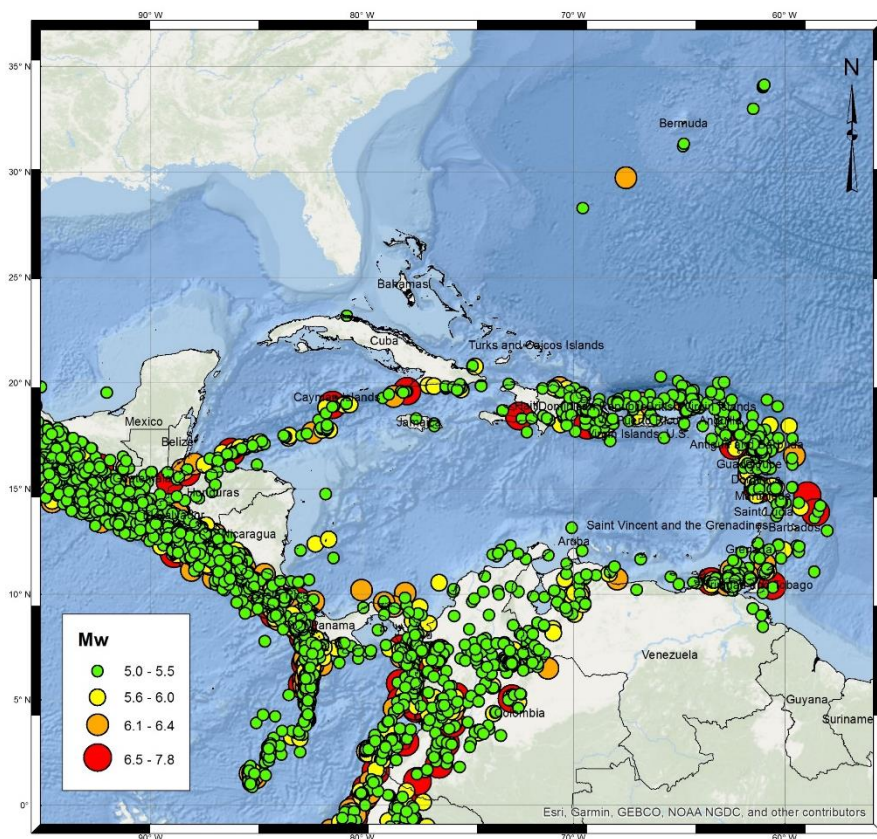


- Stochastic event set (616k events)
  - $M_{min}=5.0$
  - 5 spectral ordinates per event

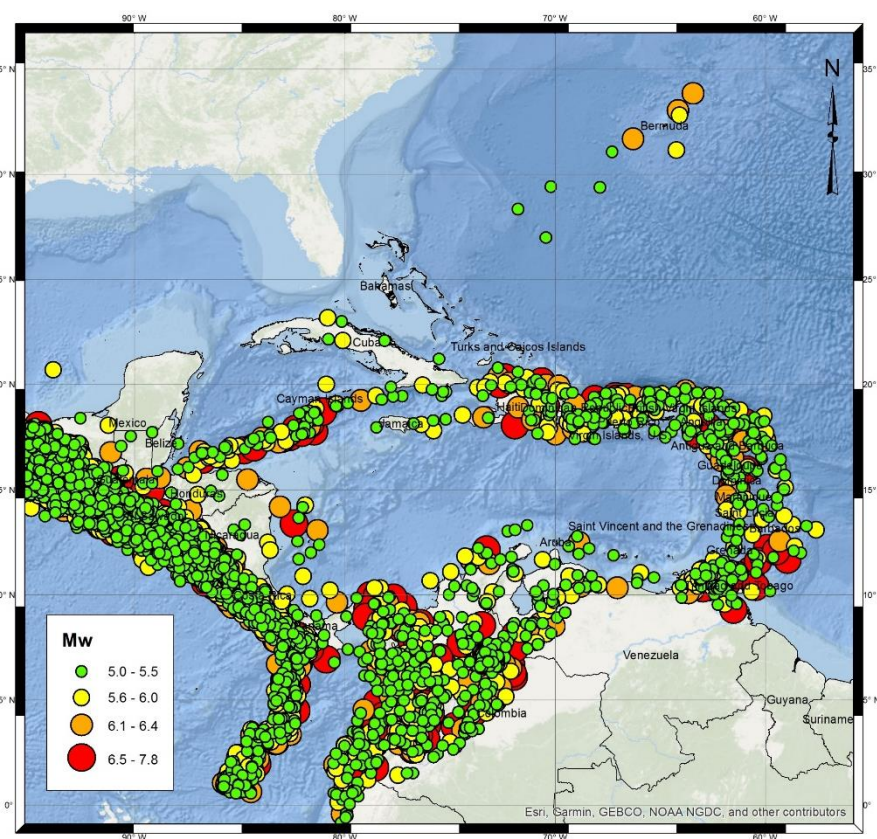




## Stochastic catalog generation



Historical catalog  
1973 - 2017



Stochastic catalog  
t=45 years

- Vulnerability classes

| Country                          | Code | Quality | Vulnerability Code |
|----------------------------------|------|---------|--------------------|
| Anguilla                         | AIA  | Good    | VG1                |
| Antigua and Barbuda              | ANT  | Good    | VG1                |
| Bahamas                          | BHS  | Good    | VG1                |
| Barbados                         | BRB  | Good    | VG1                |
| Bermuda                          | BMU  | Good    | VG1                |
| Cayman Islands                   | CYM  | Good    | VG1                |
| Costa Rica                       | CRI  | Good    | VG1                |
| Guadeloupe                       | GLP  | Good    | VG1                |
| Martinique                       | MTQ  | Good    | VG1                |
| Panama                           | PAN  | Good    | VG1                |
| Saba - Sint Eustatius            | SAB  | Good    | VG1                |
| Saint Kitts and Nevis            | KNA  | Good    | VG1                |
| Sint Marteen                     | SXM  | Good    | VG1                |
| Aruba                            | ABW  | Mean    | VG2                |
| Bonaire                          | BON  | Mean    | VG2                |
| British Virgin Islands           | VGB  | Mean    | VG2                |
| Curaçao                          | CUW  | Mean    | VG2                |
| Dominica                         | DMA  | Mean    | VG2                |
| Dominican Republic               | DOM  | Mean    | VG2                |
| El Salvador                      | SLV  | Mean    | VG2                |
| Grenada                          | GRD  | Mean    | VG2                |
| Guatemala                        | GTM  | Mean    | VG2                |
| Honduras                         | HND  | Mean    | VG2                |
| Puerto Rico                      | PRI  | Mean    | VG2                |
| Saint Lucia                      | LCA  | Mean    | VG2                |
| Saint Vincent and the Grenadines | VCT  | Mean    | VG2                |
| Trinidad and Tobago              | TTO  | Mean    | VG2                |
| Turks and Caicos Islands         | TCA  | Mean    | VG2                |
| Jamaica                          | JAM  | Mean    | VG2                |
| Belize                           | BLZ  | Low     | VG3                |
| Guyana                           | GUY  | Low     | VG3                |
| Montserrat                       | MSR  | Low     | VG3                |
| Nicaragua                        | NIC  | Low     | VG3                |
| Suriname                         | SUR  | Low     | VG3                |
| Haiti                            | HTI  | Poor    | VG4                |

- Extensive research on the building stock at country level
- Four classes to consider the relative vulnerability level

| Vulnerability Code | Description                    |
|--------------------|--------------------------------|
| VG1                | High building stock quality    |
| VG2                | Average building stock quality |
| VG3                | Low building stock quality     |
| VG4                | Poor building stock quality    |



- Vulnerability classes - examples



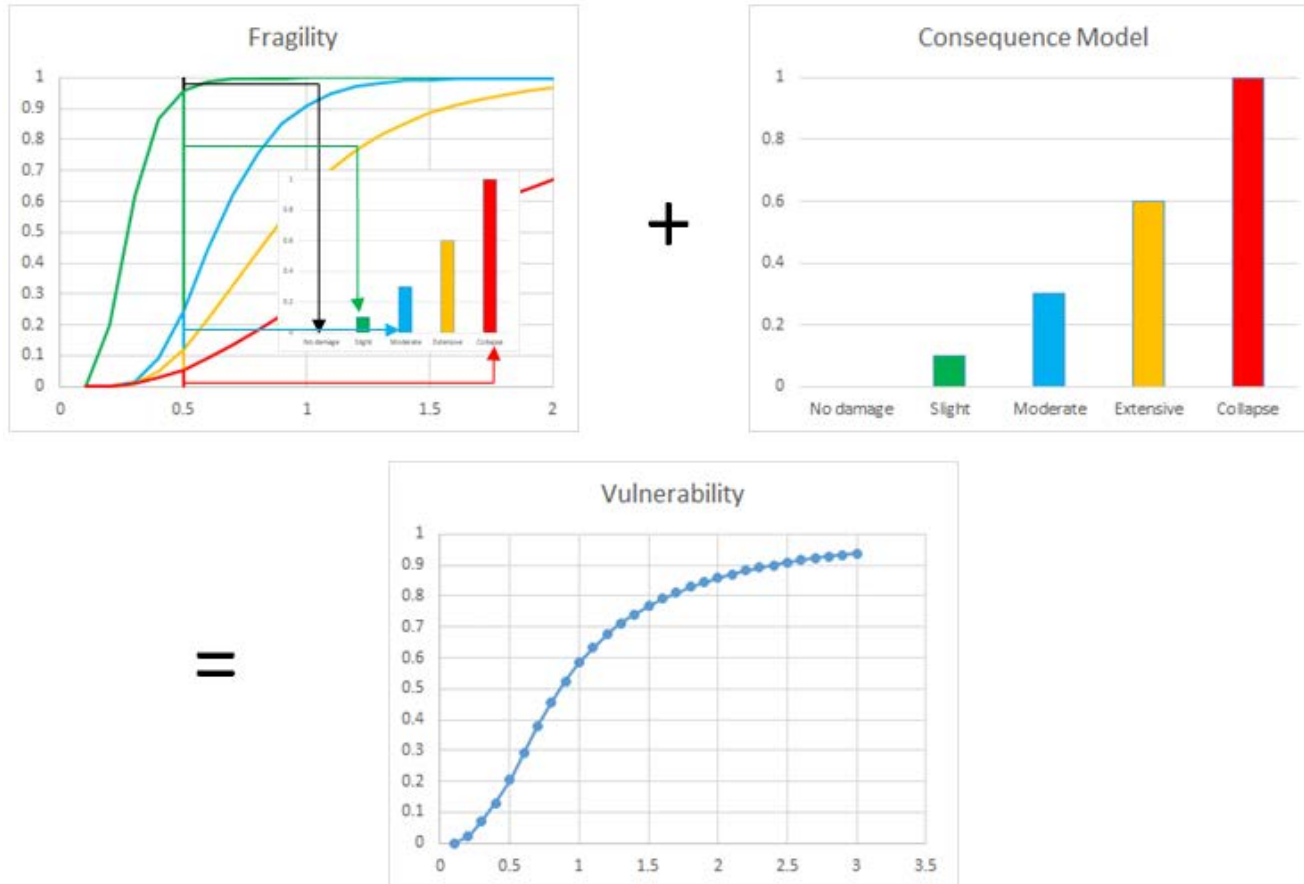
Anguilla buildings (VG1 – Good quality) examples



Haiti buildings (VG4 – Poor quality) examples

- Methodology
  - Analytical approach
  - For each building class:
    1. Median capacity curve defined (along with a set of coefficients of variation)
    2. Synthetic building portfolio developed and 100 capacity curves computed based on a set of ground motion records
    3. Record Selection
    4. Distribution of damage vs ground shaking intensity measure (IM) derived
    5. Derivation of sets of fragility functions fitted to these distributions
    6. Computation of vulnerability functions using an ad-hoc damage-to-loss model

- Methodology



Spectral acceleration used as ground motion intensity measure

Consequence database: reported losses

A consequence database of 25 country-scale events was collated, covering from the 1907 from several disaster databases (EM-DAT) and Desinventar, earthquake consequences database (GEMECD), international agencies (ECLAC), and insurance/re-insurance companies (MunichRe, SwissRe, AON).

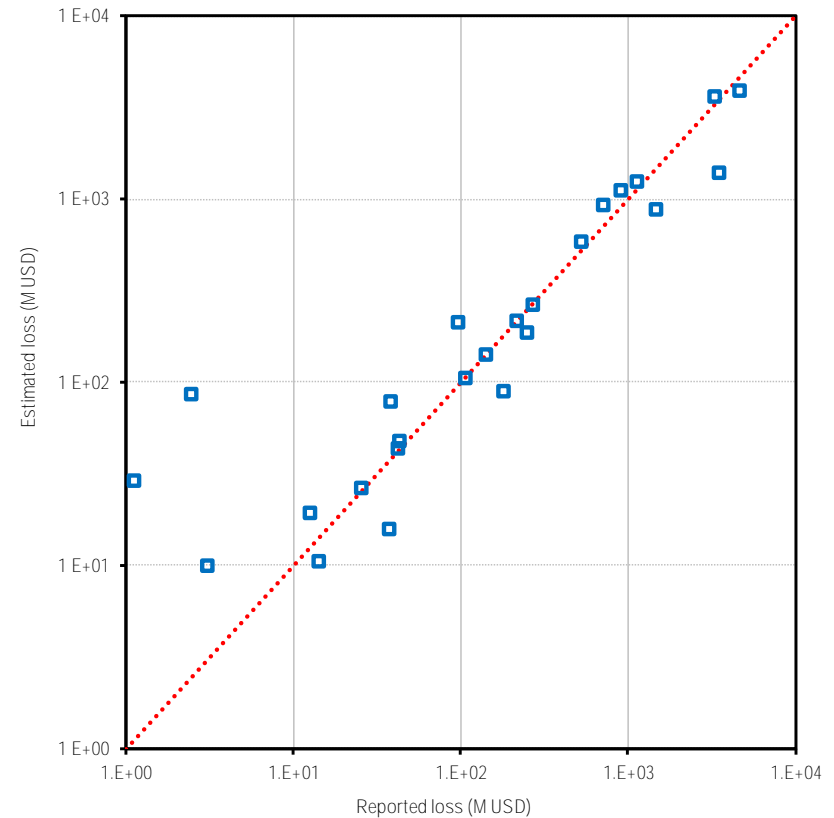
Limitations of the reported losses:

- Trending to 2015 USD
- Uncertainty: different sources give very different values
- What do the reported values include? Business interruption, contents, ...?

A preferred value has been selected and justified for comparison purposes against losses obtained with SPHERA

Consequence database. Reported losses – 25 events with country level data

| Date (YY/MM/DD) | Mw  | Depth (km) | Country             | SPHERA losses (M USD) | Reported losses (M USD) |
|-----------------|-----|------------|---------------------|-----------------------|-------------------------|
| 1907/01/14      | 6.5 | 25         | Jamaica             | 915                   | 715                     |
| 1931/03/31      | 6.1 | 15         | Nicaragua           | 581                   | 524                     |
| 1951/05/06      | 6.2 | 10         | El Salvador         | 214                   | 215                     |
| 1952/10/27      | 6.2 | 25         | Haiti               | 89                    | 180                     |
| 1965/05/03      | 5.9 | 15         | El Salvador         | 265                   | 267                     |
| 1968/01/04      | 4.8 | 5          | Nicaragua           | 10                    | 14                      |
| 1972/12/23      | 6.3 | 10         | Nicaragua           | 1,373                 | 3,471                   |
| 1973/04/14      | 6.5 | 33         | Costa Rica          | 29                    | 1                       |
| 1976/02/04      | 7.5 | 25         | Guatemala           | 3,596                 | 3,307                   |
| 1982/06/19      | 7.3 | 50         | Guatemala           | 19                    | 13                      |
| 1983/04/03      | 6.8 | 20         | Costa Rica          | 86                    | 2                       |
| 1986/10/10      | 5.7 | 7          | El Salvador         | 872                   | 1,478                   |
| 1990/12/22      | 6.0 | 15         | Costa Rica          | 78                    | 38                      |
| 1991/04/22      | 7.6 | 10         | Costa Rica          | 1,108                 | 902                     |
| 1992/09/02      | 7.6 | 30         | Nicaragua           | 48                    | 43                      |
| 1997/04/22      | 5.9 | 25         | Trinidad and Tobago | 16                    | 37                      |
| 2001/01/13      | 7.7 | 56         | El Salvador         | 1,246                 | 1,141                   |
| 2001/02/13      | 6.6 | 20         | El Salvador         | 185                   | 251                     |
| 2009/01/08      | 6.2 | 20         | Costa Rica          | 141                   | 141                     |
| 2009/05/28      | 7.3 | 20         | Honduras            | 43                    | 42                      |
| 2010/01/12      | 7.0 | 13         | Haiti               | 3,902                 | 4,661                   |
| 2012/09/05      | 7.6 | 30         | Costa Rica          | 209                   | 97                      |
| 2012/11/07      | 7.4 | 21         | Guatemala           | 105                   | 107                     |
| 2014/04/10      | 6.1 | 10         | Nicaragua           | 10                    | 3                       |
| 2014/07/07      | 6.9 | 53         | Guatemala           | 26                    | 25                      |



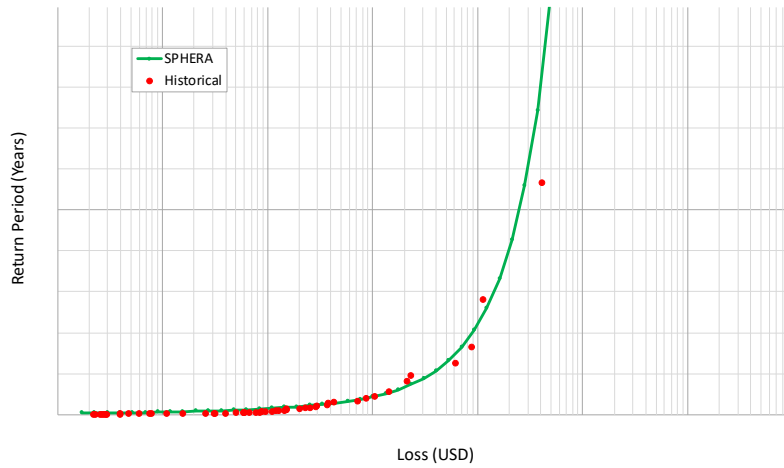


# Model validation

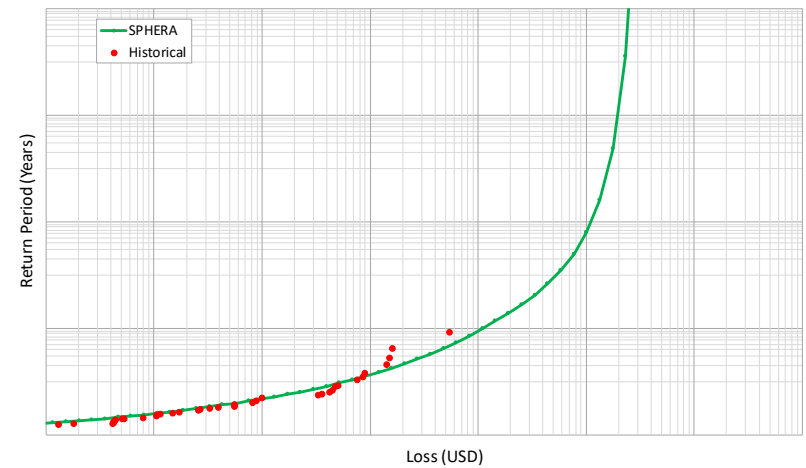
Historical vs. stochastic events

Historical events with  $M \geq 5$  at country level

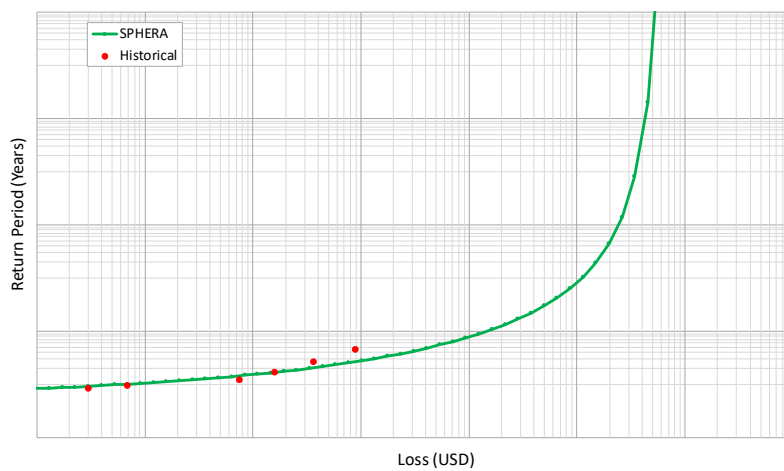
**COSTA RICA**



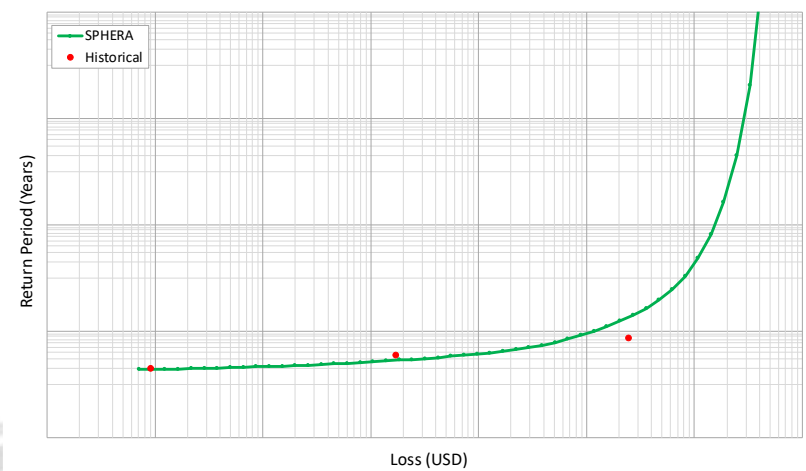
**NICARAGUA**



**TRINIDAD AND TOBAGO**



**ANTIGUA AND BARBUDA**



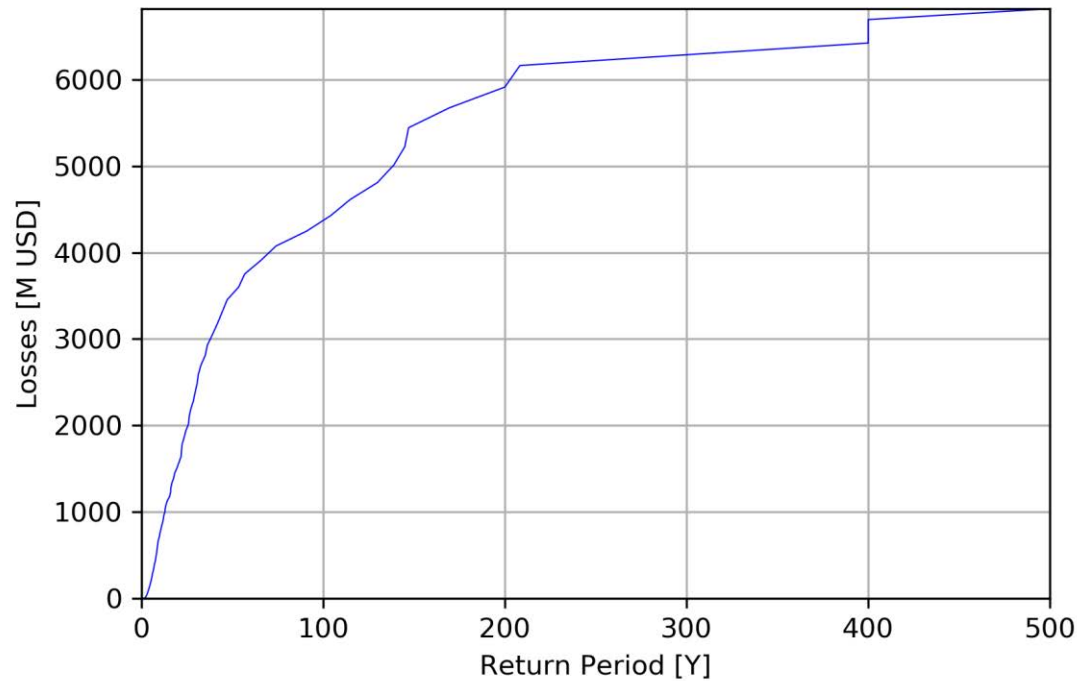


# SPHERA loss computation and insurance scheme

System for Probabilistic Hazard Evaluation and Risk Assessment

- Risk assessment:
  - Estimate the likelihood of losses exceeding a threshold
  - Example: exceedance probability curve

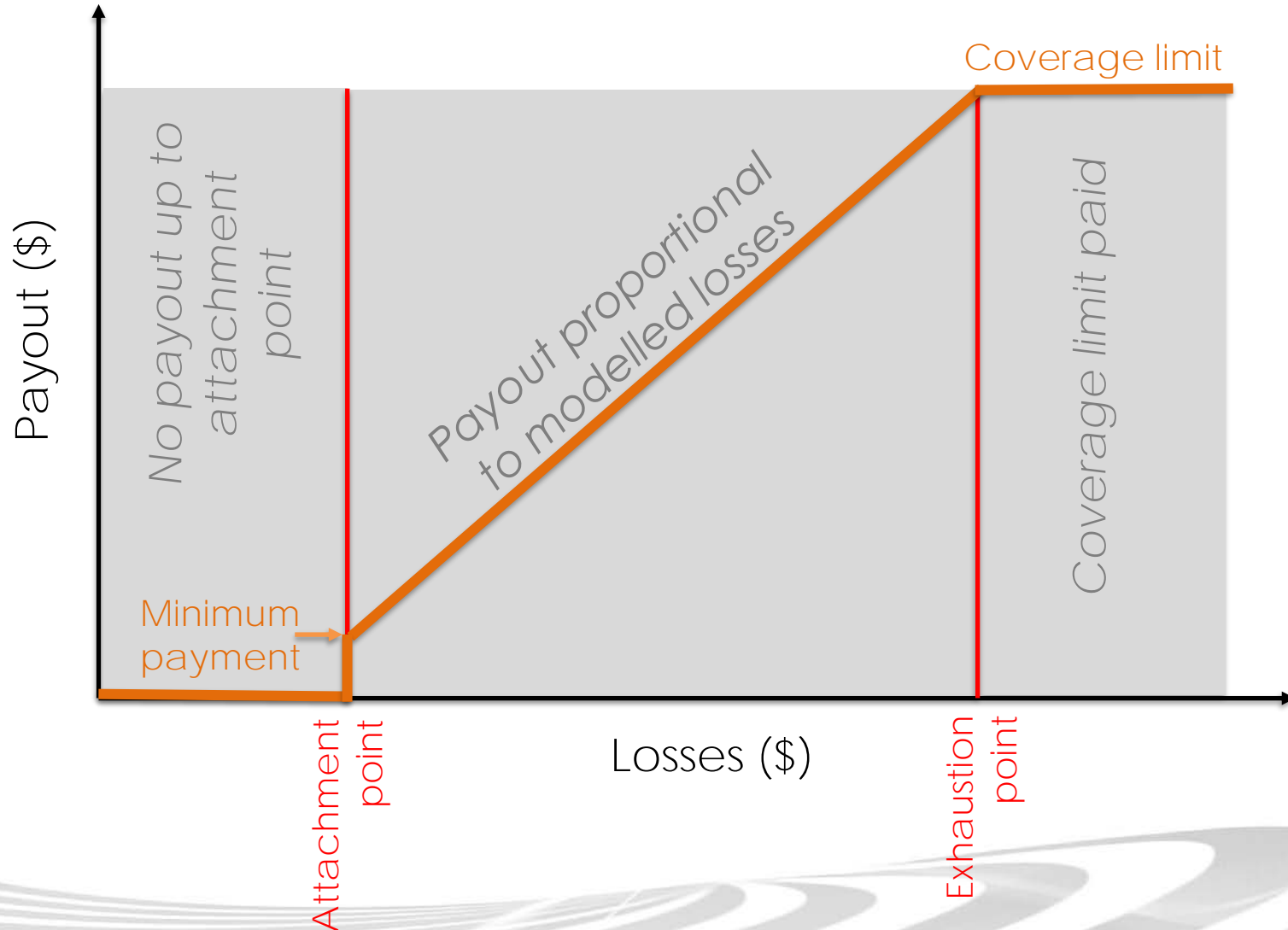
Losses:  
computed by  
the model,  
depending on  
hazard,  
vulnerability and  
exposure



Return period:  
estimated average  
time between  
events

# Insurance scheme

- Insurance policy



# SPHERA real-time operation

System for Probabilistic Hazard Evaluation and Risk Assessment

# Real-time operation (EQ)

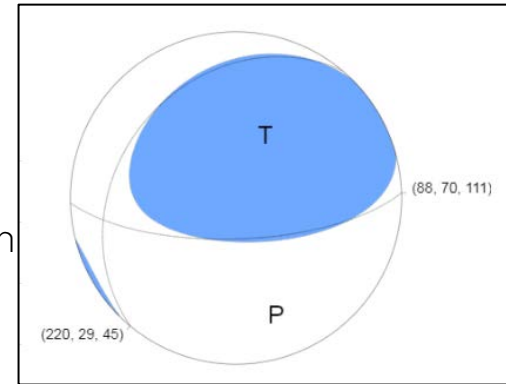
## Post-event (or quasi real-time) operational workflow

1 - USGS reports an EQ

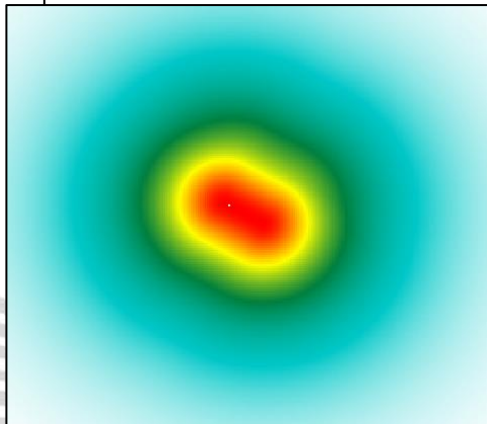


2 - USGS reports magnitude, depth and moment tensor solution

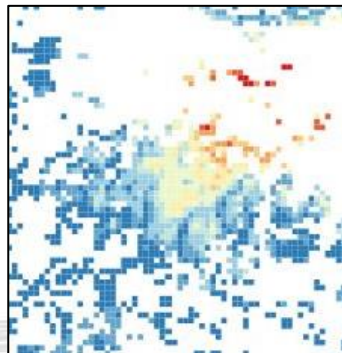
M=7.3  
10.773° N  
62.902° W  
Depth=146.8km



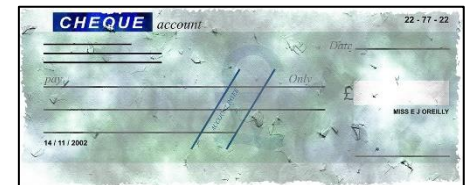
3 - CCRIF's calculation agent runs SPHERA using the USGS parameters as input



4 - SPHERA produces estimates of ground motion intensities and economic losses



5 - Given the country's policy parameters, if the losses are above the attachment point, a payout is computed



# Model updates 2023

System for Probabilistic Hazard Evaluation and Risk Assessment



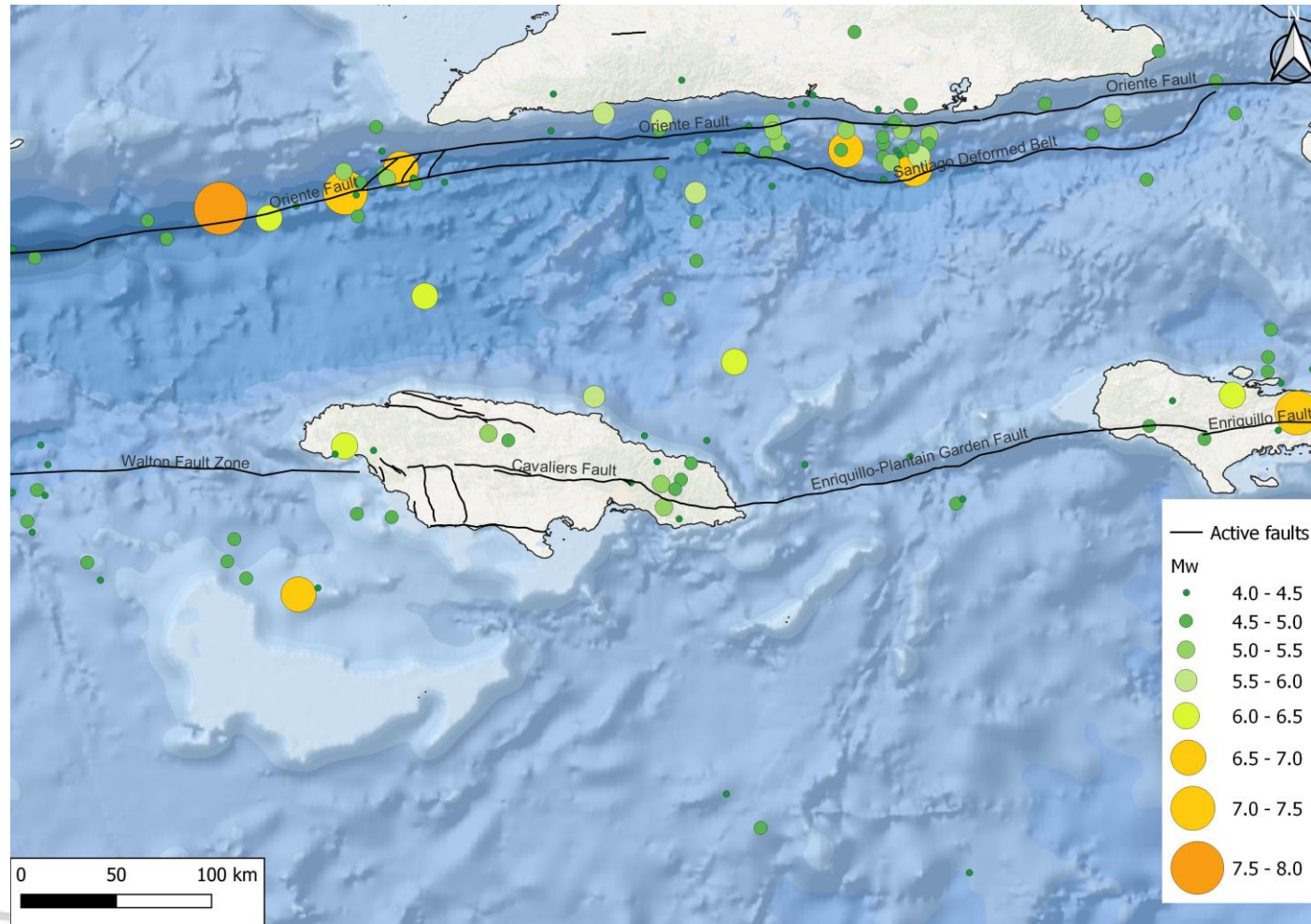
## Updates 2023

**Updated PSHA for Jamaica, Haiti and Cayman Islands**

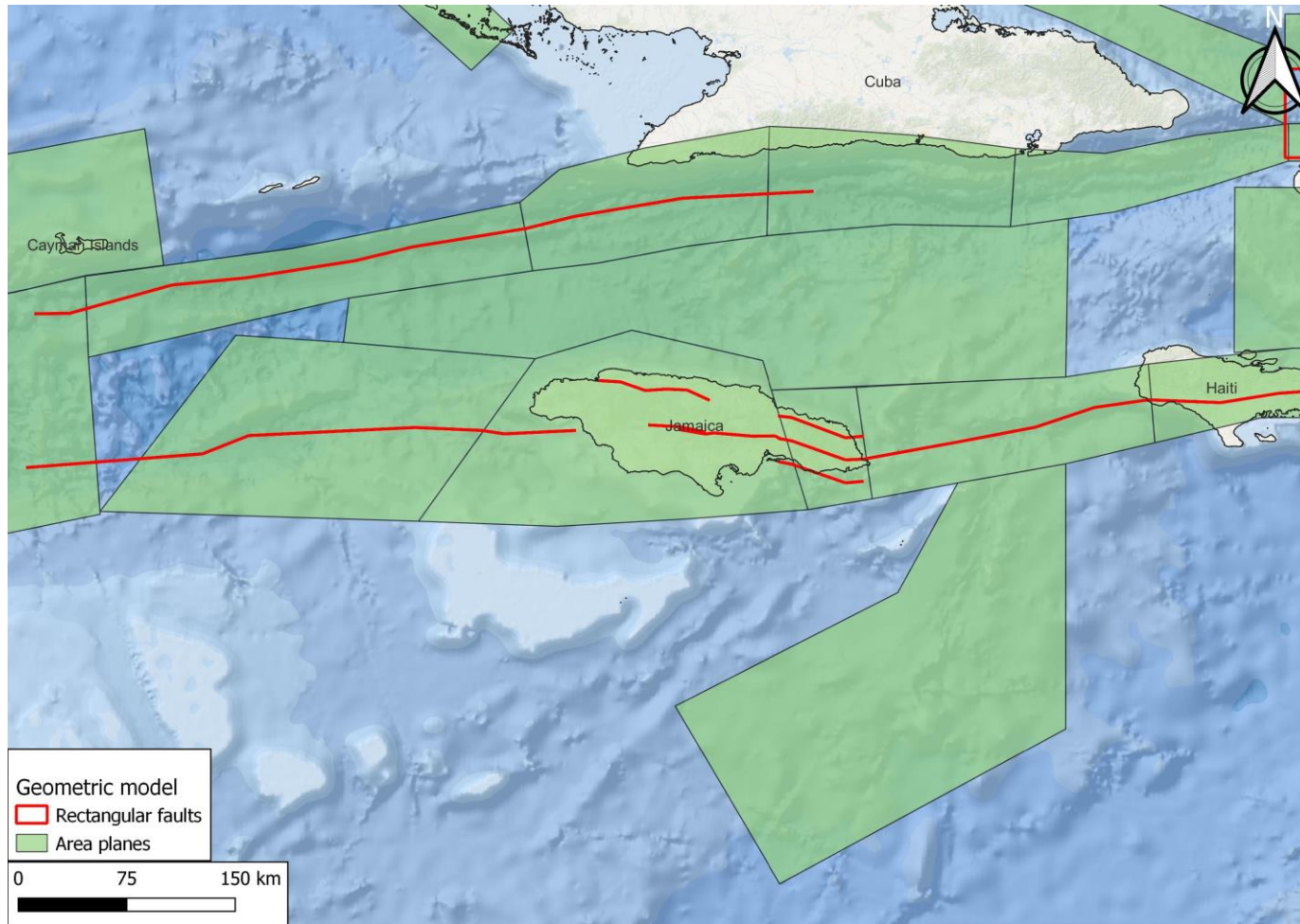
**Review of vulnerability classification for Jamaica**



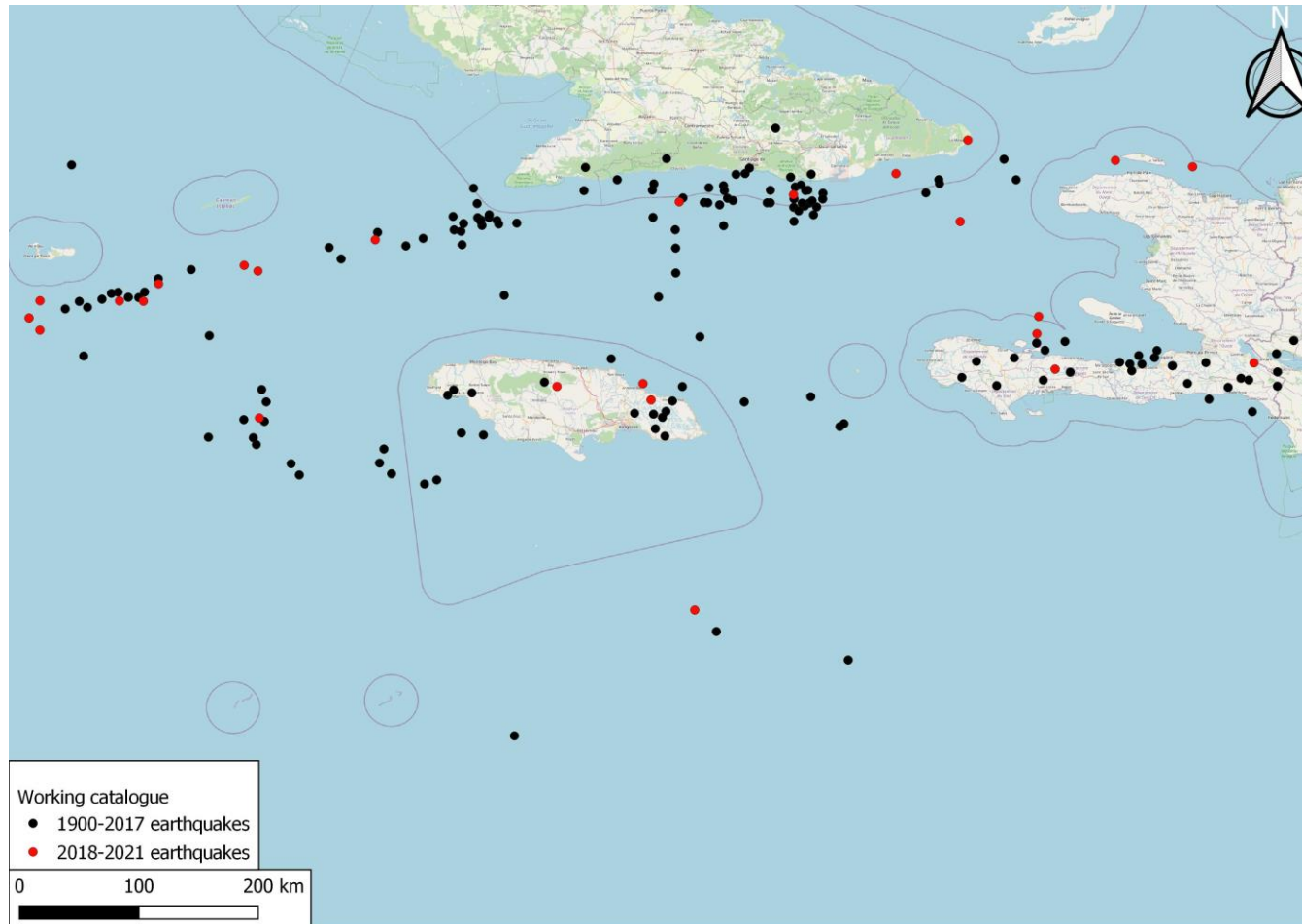
- Fault traces and activity were included in the updated model



- New seismogenic sources

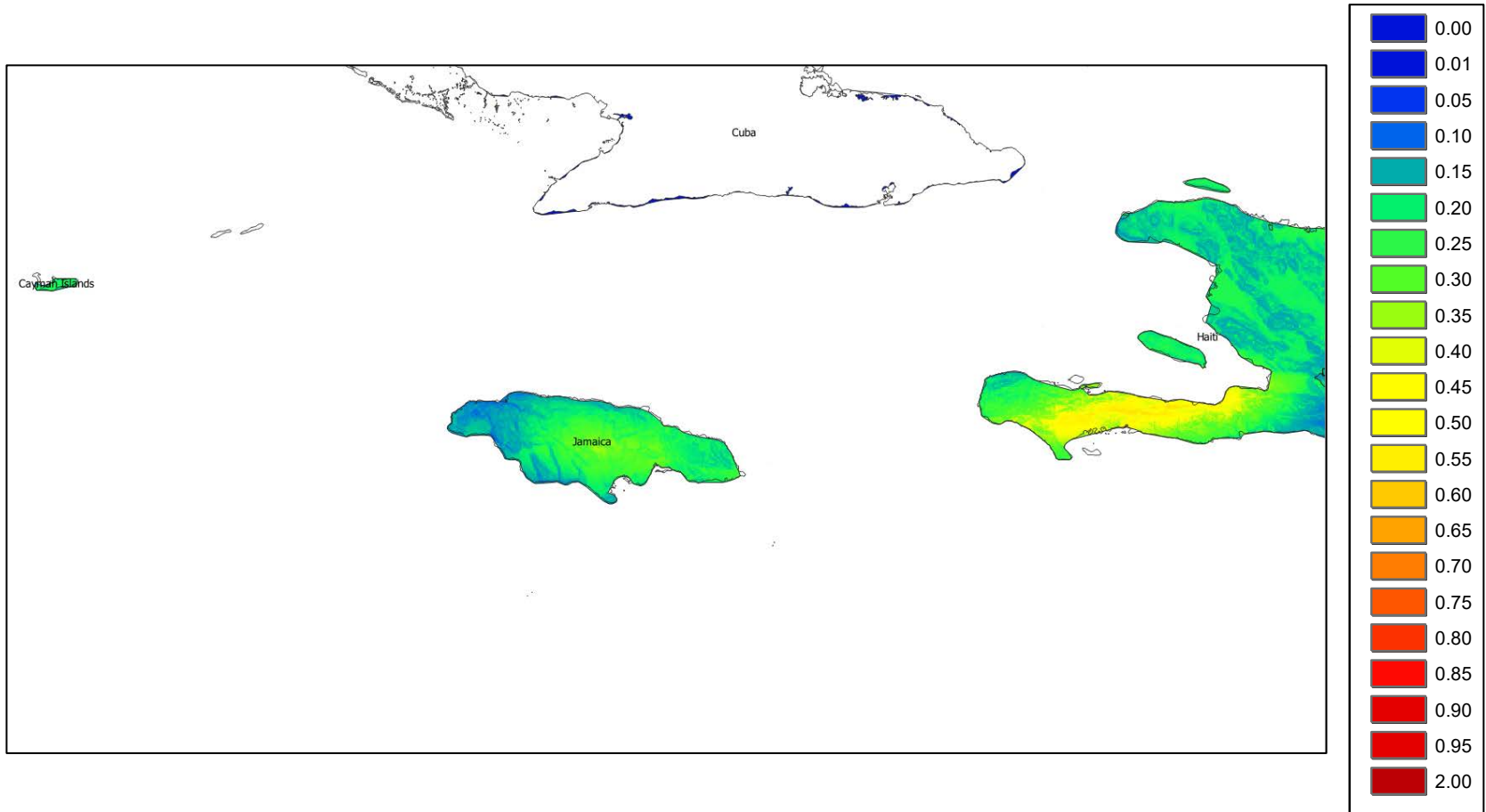


- Updated earthquake catalog (up to December 2021)

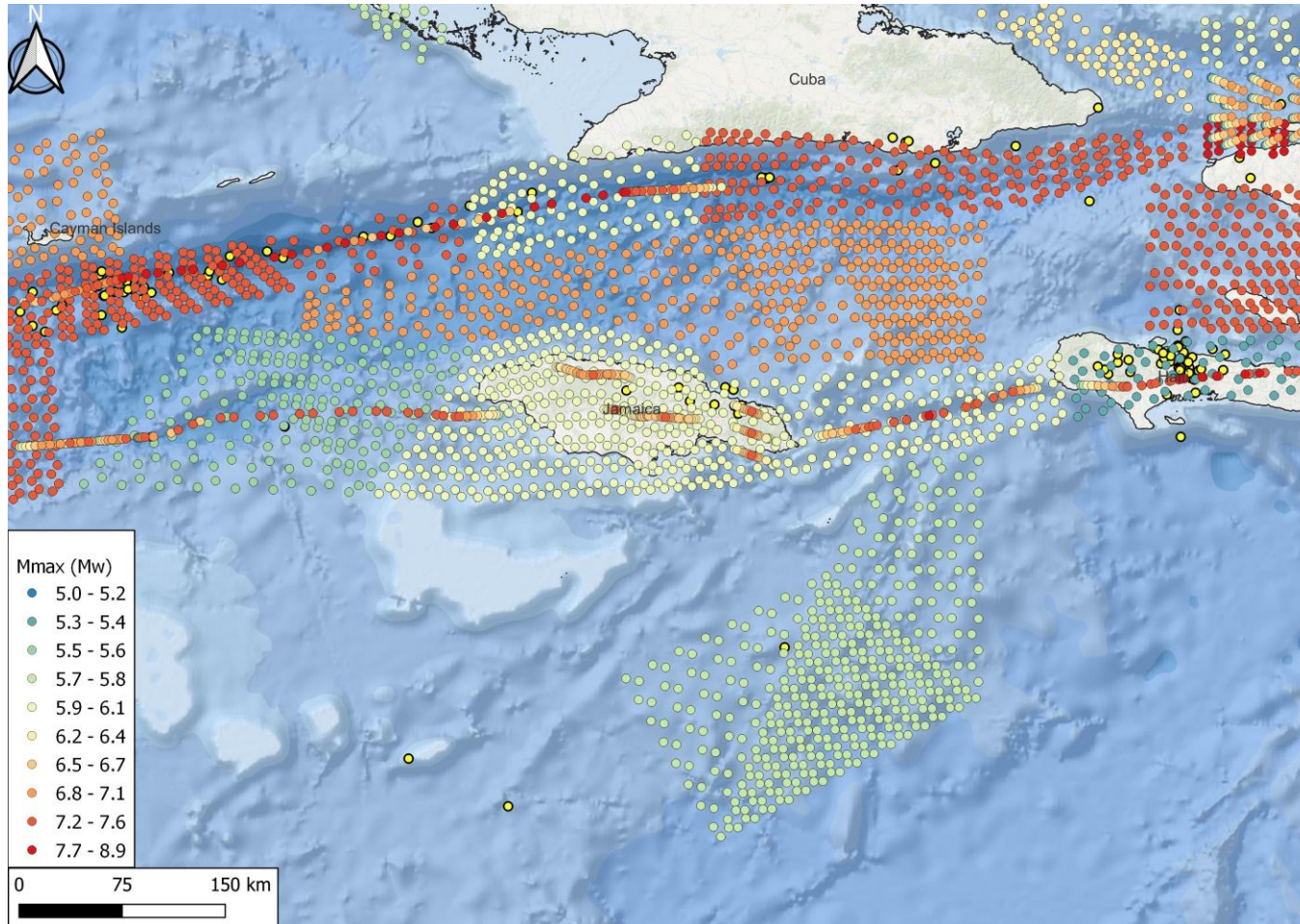




- Updated hazard values for the study area (pga – 475 years on soil – g)



- New stochastic event set for the updated area

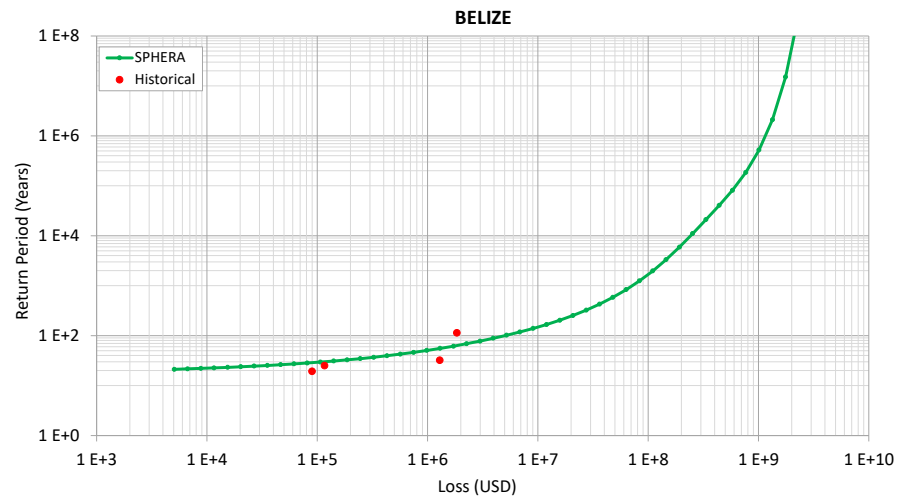
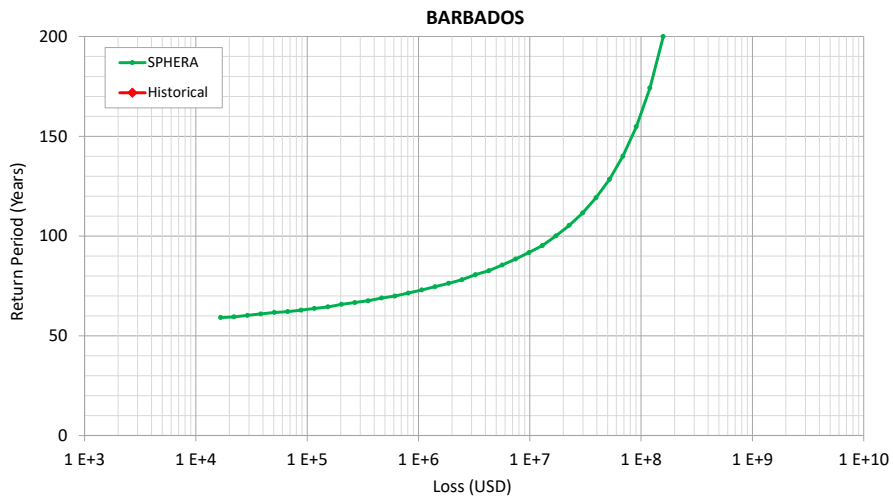
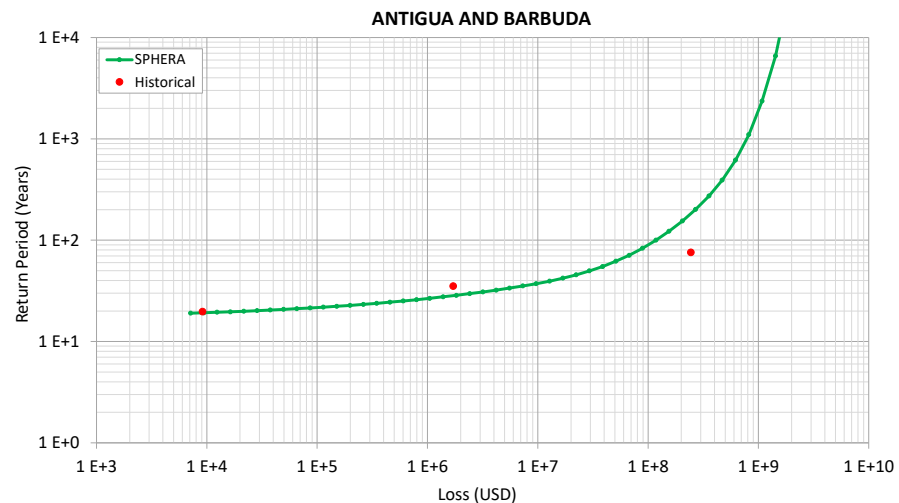
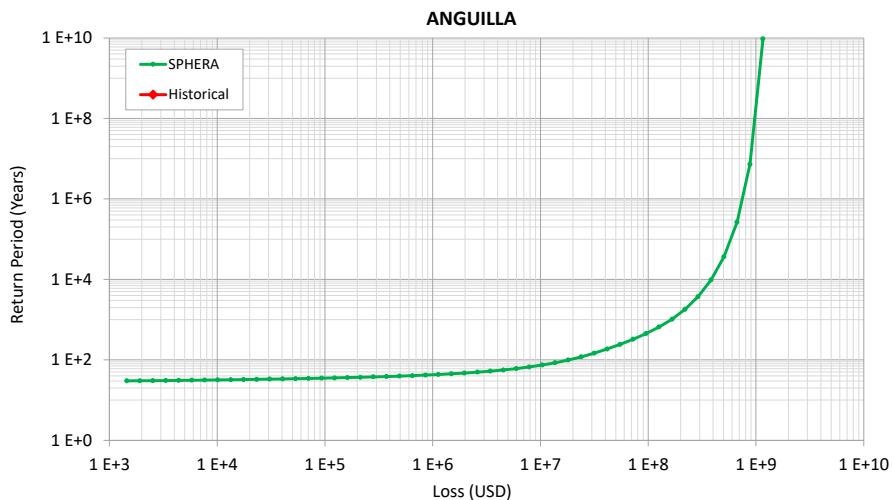




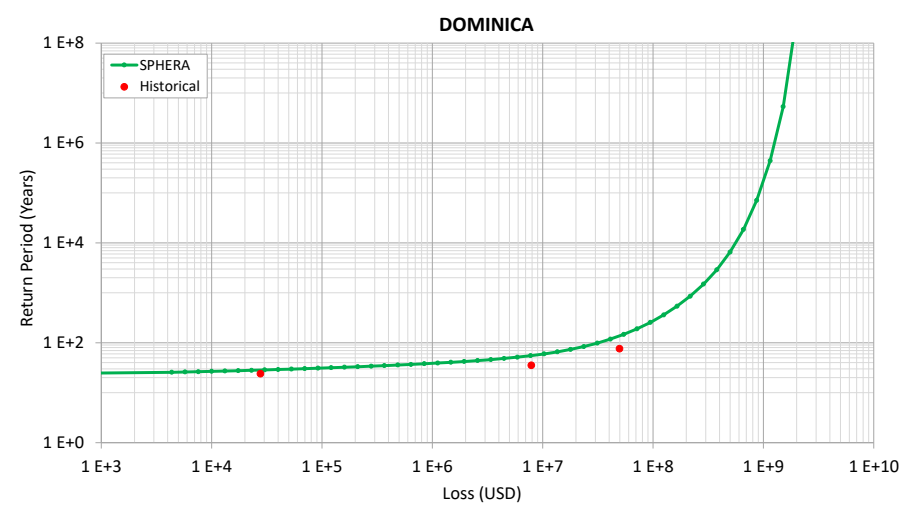
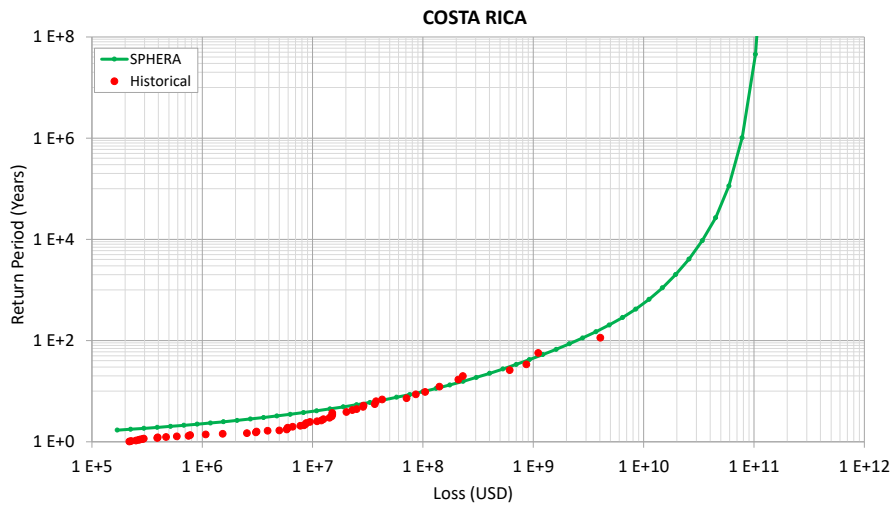
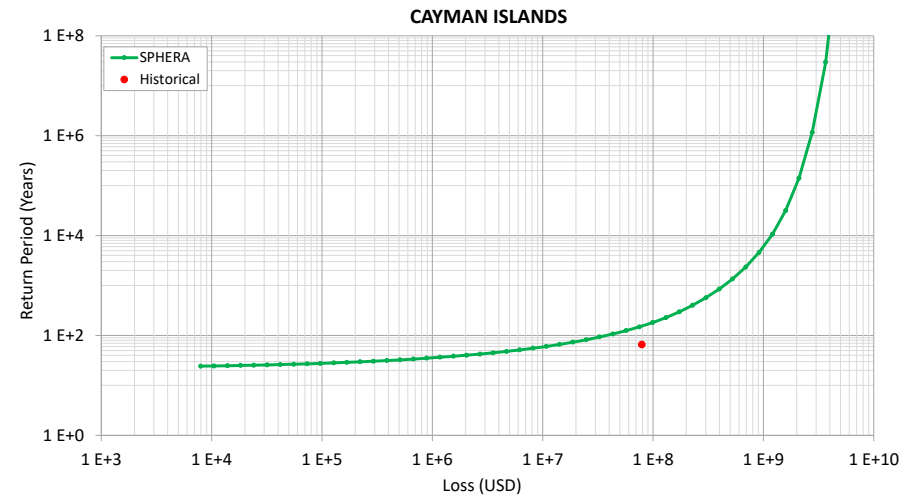
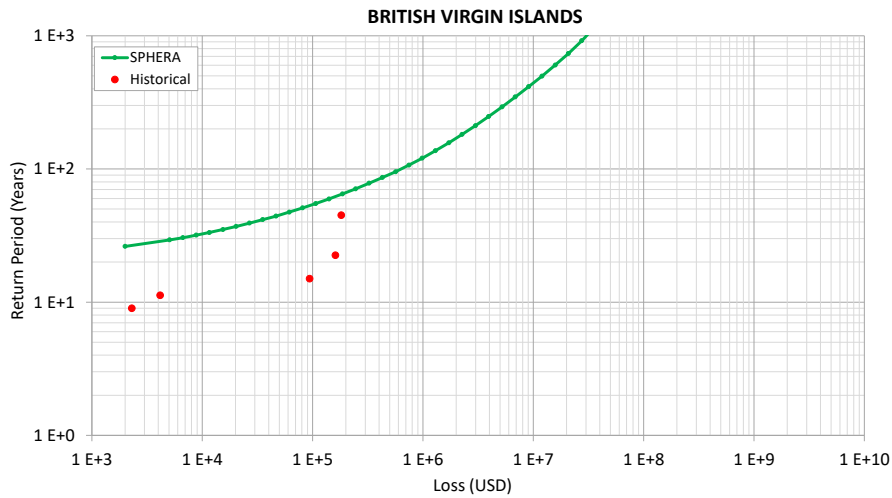
# EP curves by country

System for Probabilistic Hazard Evaluation and Risk Assessment

# EQ EP curves

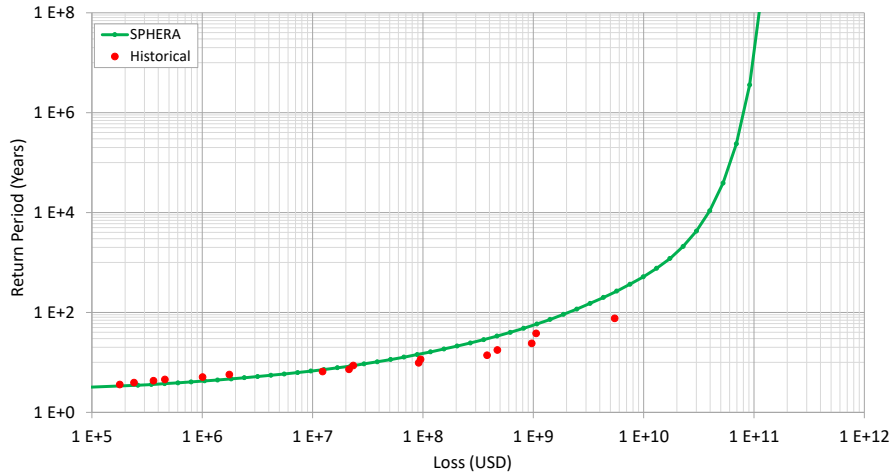


# EQ EP curves

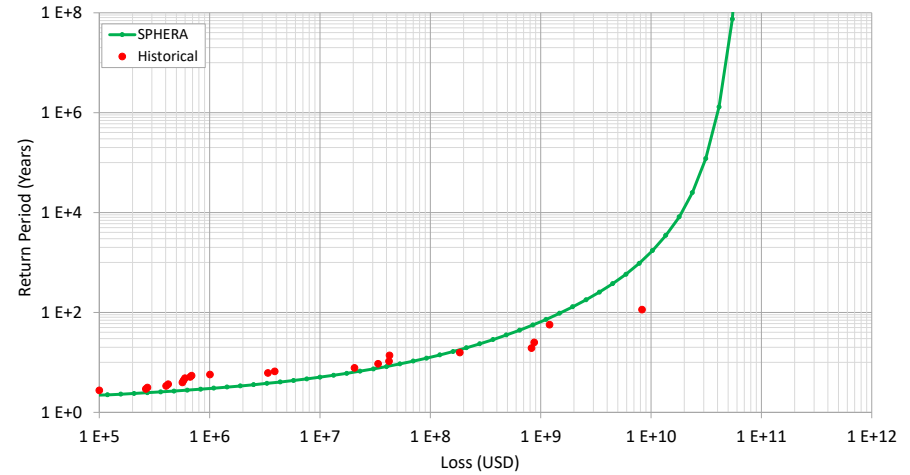


# EQ EP curves

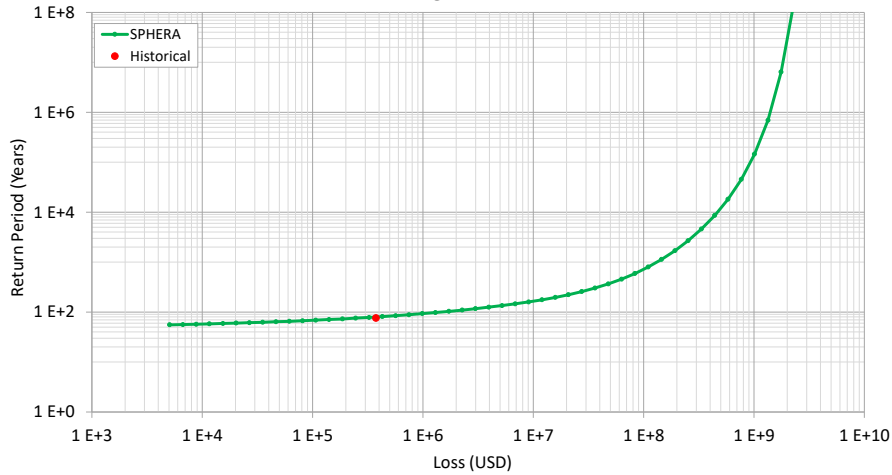
**DOMINICAN REPUBLIC**



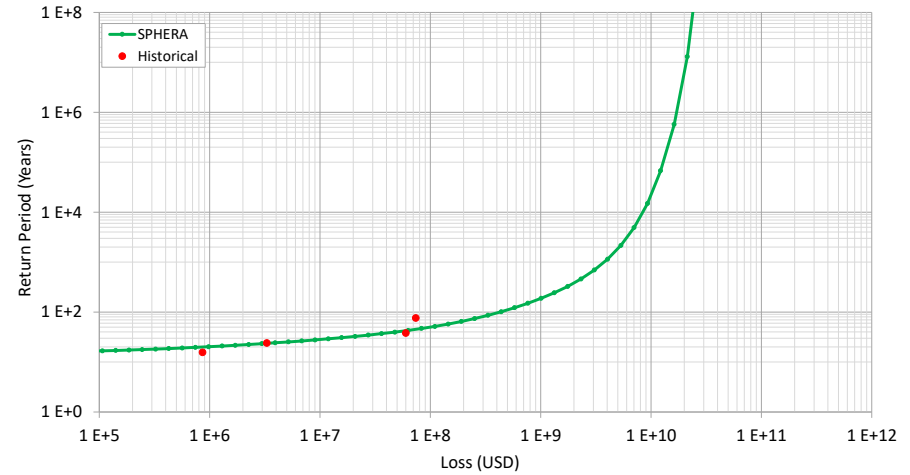
**EL SALVADOR**



**GRENADA**

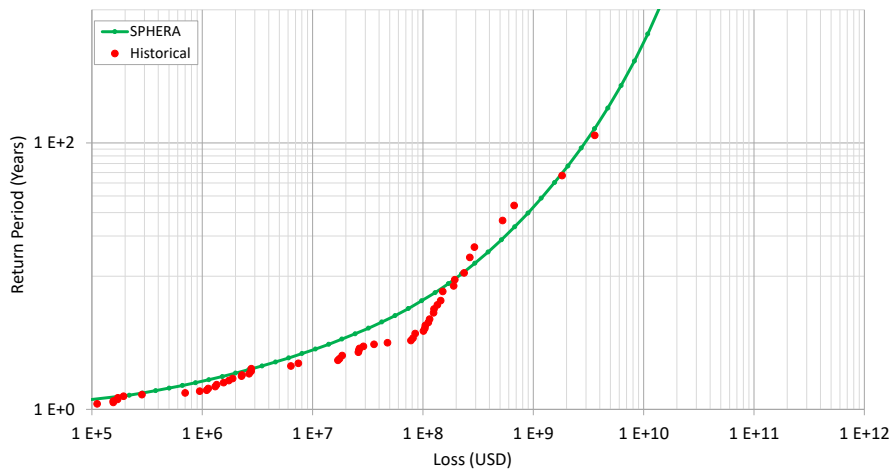


**GUADELOUPE**

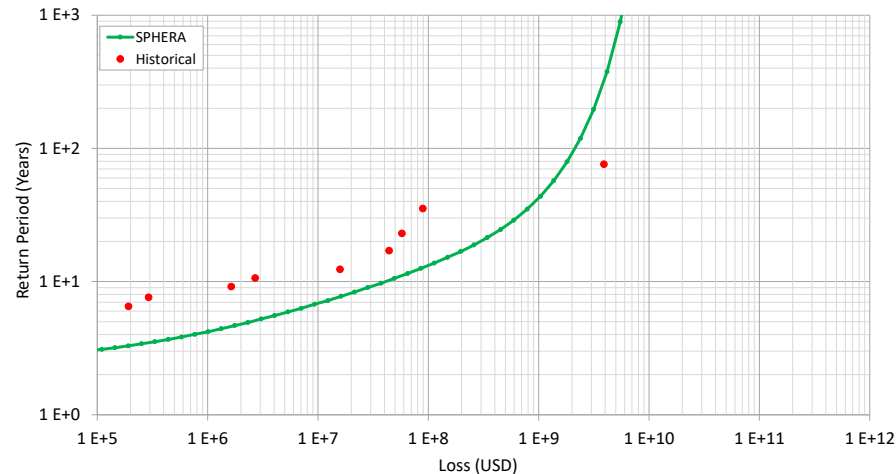


# EQ EP curves

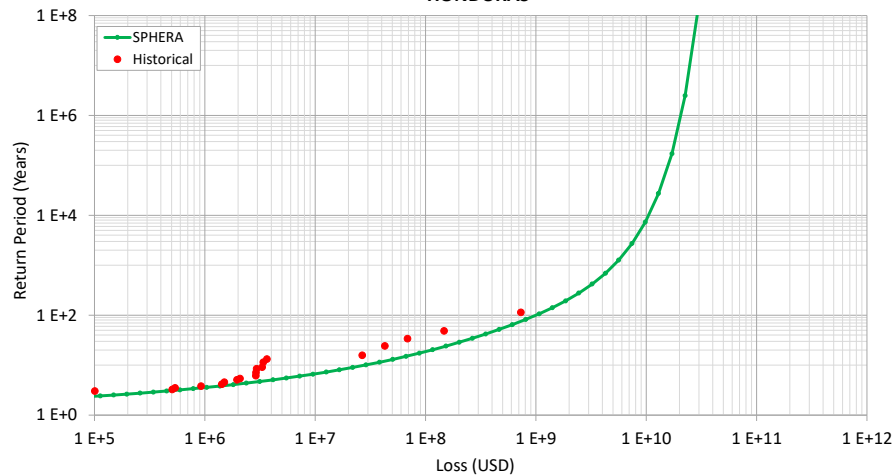
### GUATEMALA



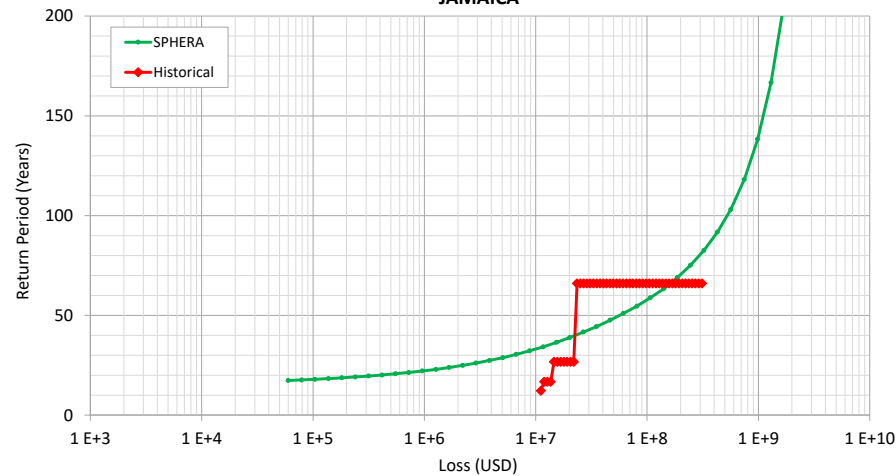
### HAITI



### HONDURAS

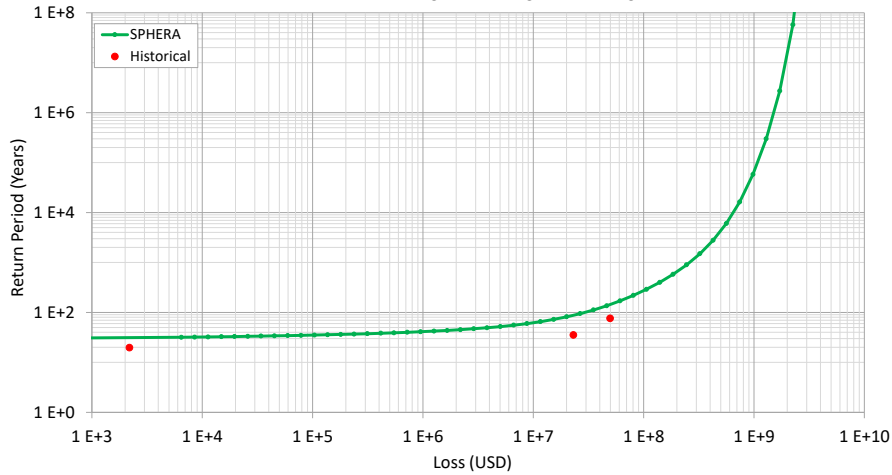


### JAMAICA

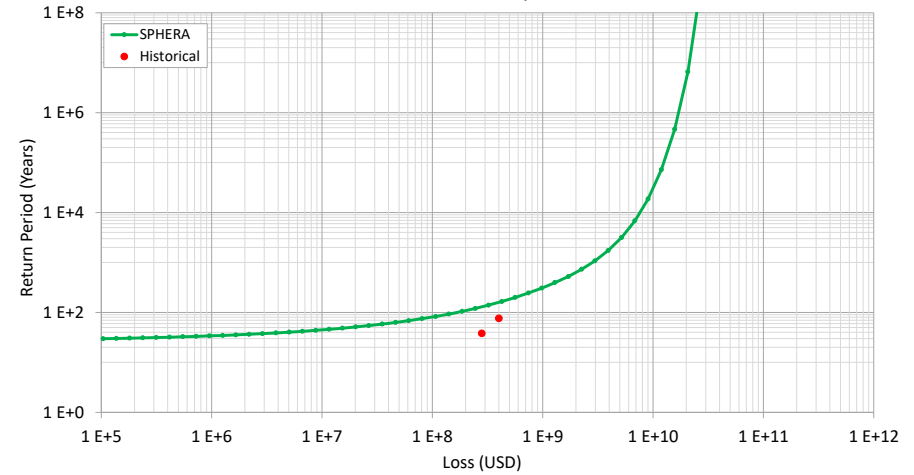


# EQ EP curves

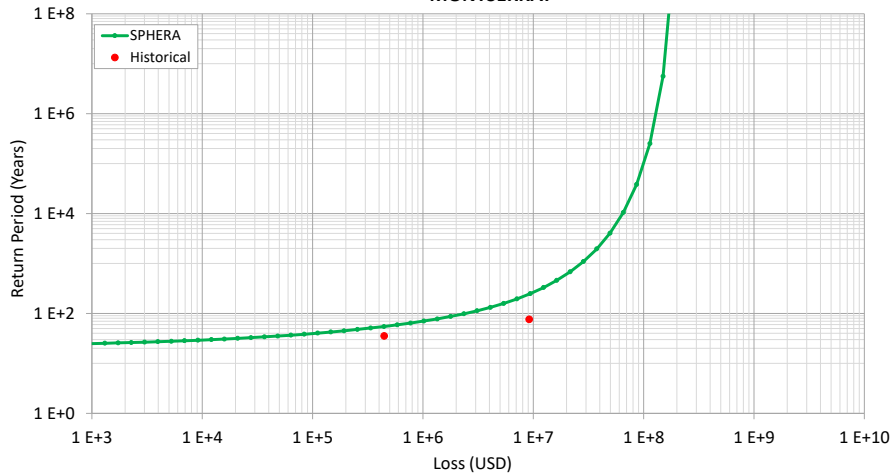
**SAINT KITTS AND NEVIS**



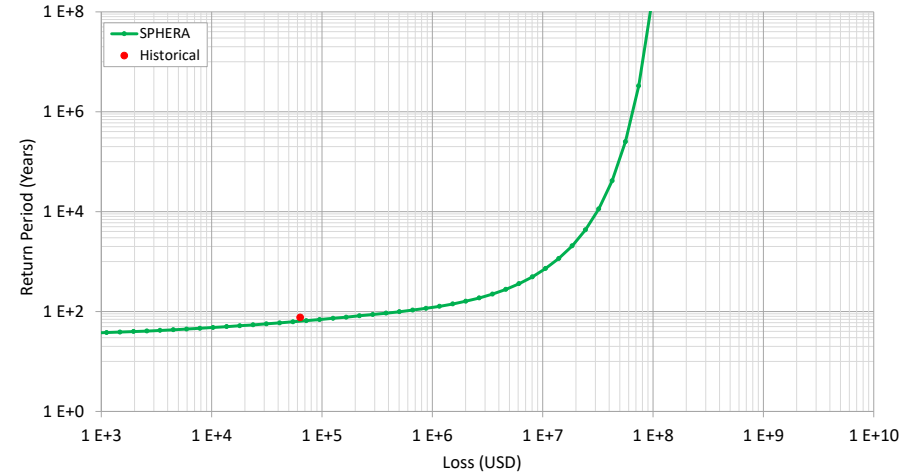
**MARTINIQUE**



**MONTSERRAT**

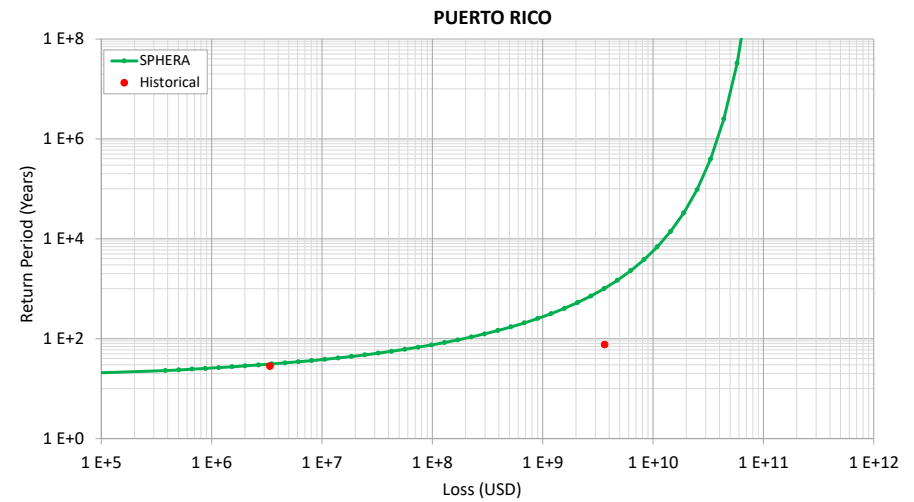
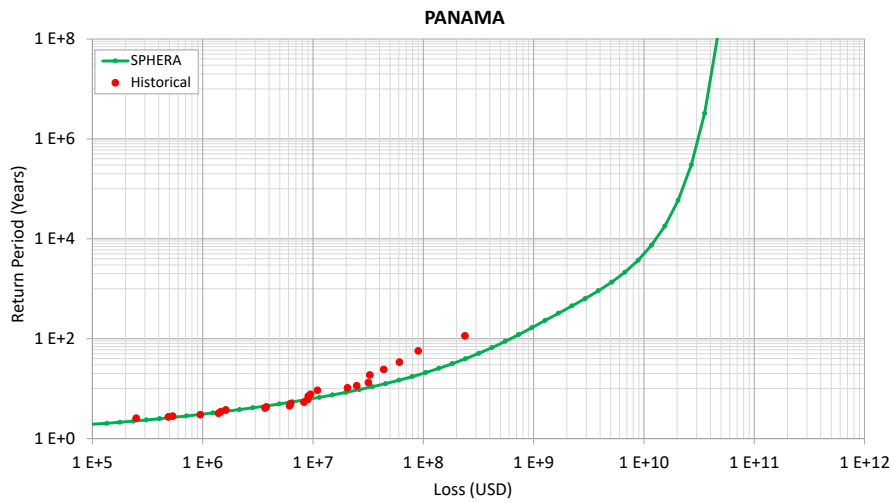
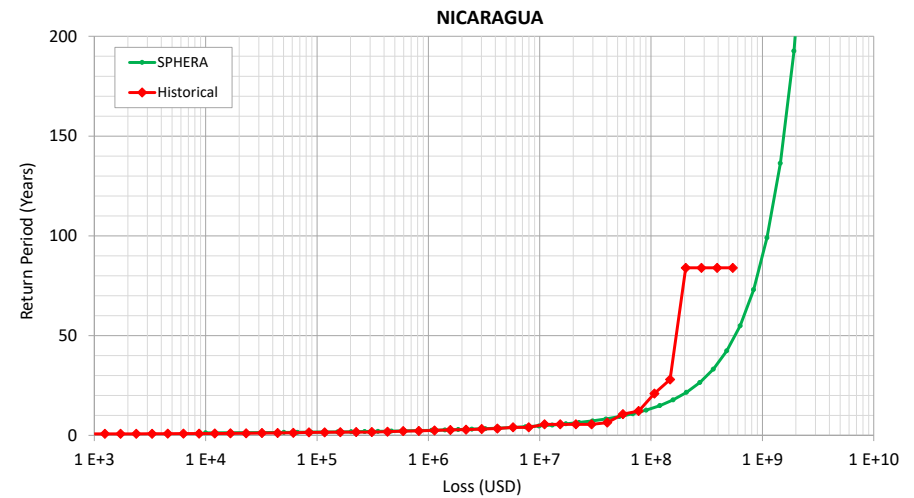
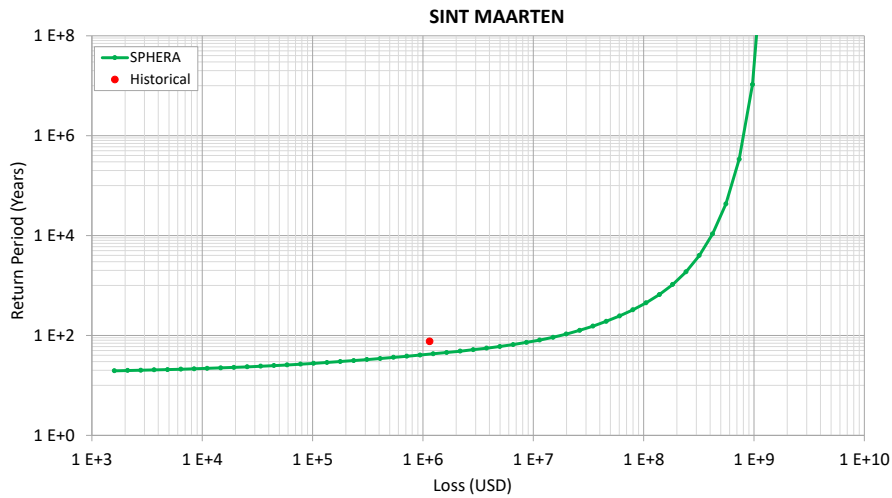


**SAINT EUSTATIUS**

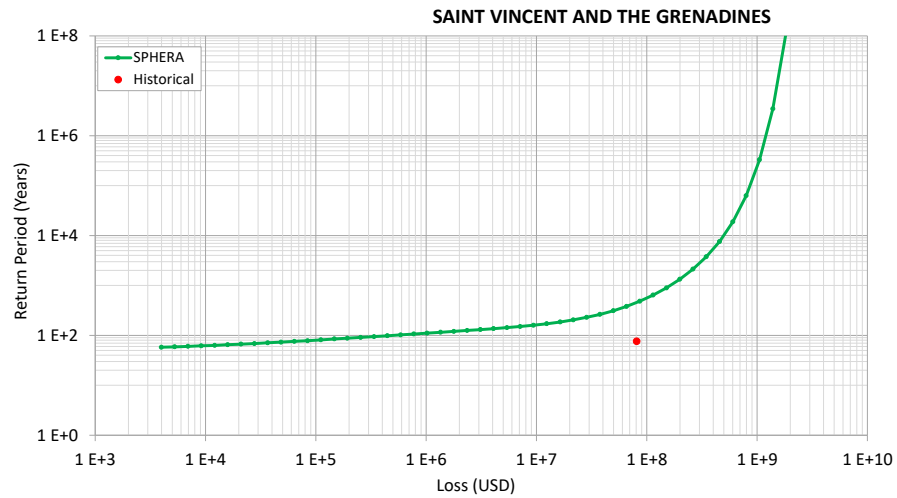
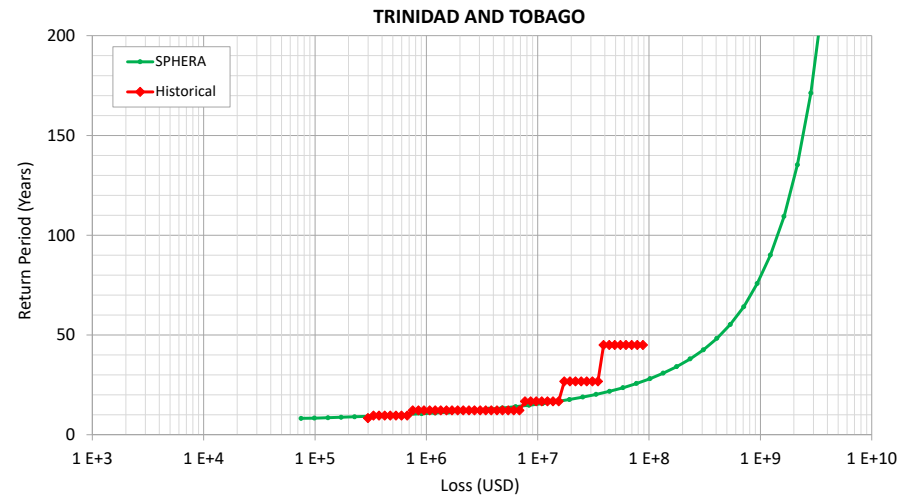
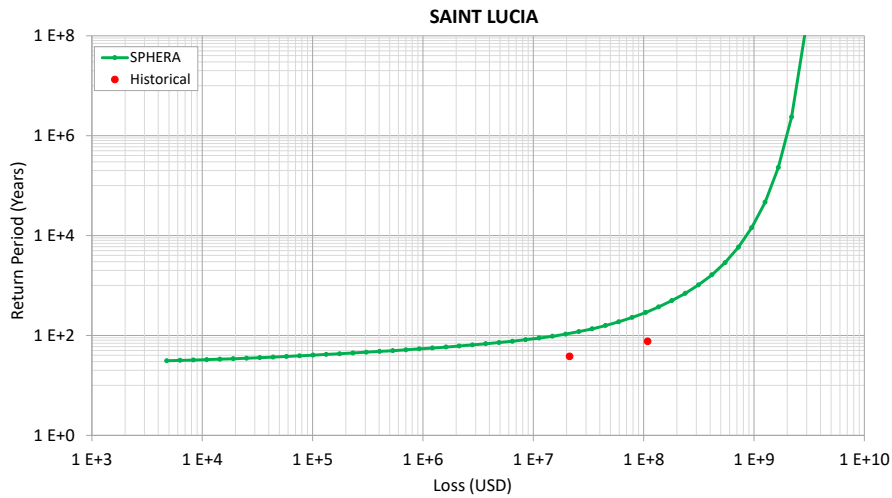




# EQ EP curves



# EQ EP curves



The RED & ERN Team

Thanks for your attention!