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Global risk assessment: A fully probabilistic seismic and tropical cyclone wind risk assessment

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ABSTRACT

The aim of the Global Risk Assessment, GRA, for the UN-ISDR's Global Assessment Report on Disaster Risk Reduction, GAR 2013, has been to obtain disaster risk figures for all countries in the world using a first-time fully probabilistic methodology to evaluate risk due to tropical cyclone and earthquake hazards at global level. Since hazard is represented through a set of stochastic scenarios, risk indicators such as the average annual loss and probable maximum loss for a fixed return period were obtained at country level. This paper describes the risk calculation carried out for the GRA. This coarse grain probabilistic risk assessment was performed using CAPRA-GIS, the CAPRA Platform's risk calculator. The results were normalized by economic indicators such as the produced capital and the gross fixed capital to provide a reference of the relative economic impact and coping capacity of the countries. Risk maps and rankings at global level, by region and by economic development level were generated to easily visualize and interpret the risk results. For the case of flooding, in selected countries in the Caribbean and South Asia region the average annual loss was calculated directly from the intensity exceedance curve. Results are intended to capture the attention of financial and planning national decision makers to advocate them to assess risk with better resolution and details at national and sub-national levels, using consistent information appropriate with the scale of analysis but with the same probabilistic approach of the GRA.

1. Introduction

For the UN-ISDR Global Assessment Report on Disaster Risk Reduction 2013 (GAR13) a fully probabilistic risk assessment was conducted at a coarse grain scale for more than 200 countries. Seismic and tropical cyclones wind risk were probabilistically calculated in terms of the Average Annual Loss (AAL) and the Probable Maximum Loss (PML) for a fixed return period of 250 years. Additionally, as an example of what can be achieved, the full

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Loss Exceedance Curve (LEC) was calculated for a set of countries around the Globe.

It is generally recognized that, with a few exceptions, there is limited information about catastrophic events that occurred in the past and even less about events that could occur in the future. In most cases the worst disasters are still yet to occur. When considering the possibility of highly destructive events occurring in the future, the risk analysis should be addressed through the use of probabilistic analytical models which allow for the available information to be used in predicting potential catastrophic consequences. The risk evaluation of extreme events should follow a prospective focus, thus anticipating the occurrence of events and the scientifically based feasible consequences that may occur, as well as considering the uncertainties associated with estimating the severity and frequency for their occurrence.

Accordingly, for a probabilistic catastrophe risk analysis the relevant components of the risk such as the exposed assets, their physical vulnerability and the hazard intensities must be represented in such a way that they can be consistently added through a robust procedure, in both analytical and conceptual terms. The probabilistic risk analysis is a state-of-the-art technique that allows accounting for the uncertainties associated to the hazard intensities and the physical vulnerability characterization. The main result from this analysis is the LEC which represents the annual frequency with which a loss, usually expressed in monetary units, can be equaled or exceeded in the future. Generally, it is highly recognized that the LEC is the most robust technique for catastrophe risk assessment representation [1]. Once the LEC is obtained, other common representation of the results, especially on the reinsurance industry such as the Annual Exceedance Probability (AEP) and the Occurrence Exceedance Probability (OEP) can be derived from it [2].

Disasters are implicit contingent liabilities that increase the fiscal vulnerabilities of any country. In other words, a future disaster is an uncertain hidden public debt that becomes a certain liability when the event occurs. This “contingent debt” that represents the potential losses has to be added to the current explicit debt. If the total value is greater than the discounted present value of future primary surpluses of the country, there is an unbalance in the equation of the country's fiscal sustainability. Governments should therefore recognize that future disasters need to be considered in the country's balance sheets, as they can generate important macroeconomic imbalances. This is related to the country's fiscal responsibility, which corresponds to losses to public assets as well as those affecting the low income population dwellings. The best way of assessing these potential losses is by using a probabilistic model, which allows the governments to measure disaster risk in the context of fiscal sustainability. In this way it is then possible to identify optimal strategies for financial protections in terms of transferring or retaining this sovereign risk [3].

Risk analysis was performed using the CAPRA[1] Platform risk calculator, CAPRA-GIS [4], where the convolution between hazard and the physical vulnerability of the exposed assets was done in order to obtain the expected direct damage and their correspondent direct monetary losses. CAPRA hazard and vulnerability modules [5,6,7] were also used to generate the required information on each topic.

[1] Comprehensive Approach to Probabilistic Risk Assessment (www.ecapra.org).

2. Methodology

Since the occurrence of hazardous events through time cannot be predicted and the total time window is an unknown quantity, two separate sets of stochastic events for earthquakes and tropical cyclones wind are generated. Each scenario is characterized with its frequency of occurrence, expressed in times per year, as well as the first two statistical moments for the intensities which accounts for a fully probabilistic hazard representation. Furthermore, for calculating risk, for each scenario and for each element included in the exposed assets portfolio and considering its geographical location and the hazard intensity at that point, the loss and its variance are calculated using the associated vulnerability function. This is repeated for all the elements included in the database and when the calculation is finished, the loss probability distribution is calculated for the event. When this procedure is concluded for all the events contained in the set of stochastic scenarios, the loss exceedance rate for the whole portfolio, in this case grouped by countries, is calculated from the event's loss probability distribution functions and their frequency of occurrence. Fig. 1 presents the flowchart for this calculation process.

3. Seismic hazard

The seismic hazard at bedrock level is calculated based on historical information recorded in the seismic catalogs [8]. Using said information, which is related to the magnitude and the location of the hypocenter of each earthquake, the intensity of the events is calculated by a set of stochastic scenarios, considering in this way the events' intensities of those that have not yet occurred. This is carried out taking into account the attenuation of the seismic energy with the distance, in the surroundings from where each event strikes. This evaluation thus gives, for example, a curve of the probability of exceeding an acceleration level in a point where a certain asset is located. Given that said curve is obtained for each one of the points within the calculation grid, it is possible to calculate the seismic hazard maps for various spectral ordinates and return periods.

The Globe was divided into a set of tectonic regions in order to account for different tectonic environments, mechanisms, maximum magnitudes and associated Ground Motion Prediction Equations (GMPE's) [9–12]. The calculation of the *a* and *b*-values for each of the 401 considered regions was performed using a smoothed seismicity approach [13] because of the global scope of the analysis.

A set of stochastic scenarios for 32 different intensities (spectral acceleration and 5% damping) was generated at global level with more than 1 million events. Each event is characterized by its geographical (location) and temporal (frequency of occurrence) characteristics. From the information contained in the set of scenarios, it is possible to calculate seismic hazard parameters such as the intensity exceedance curve (for each spectral ordinate), as well as

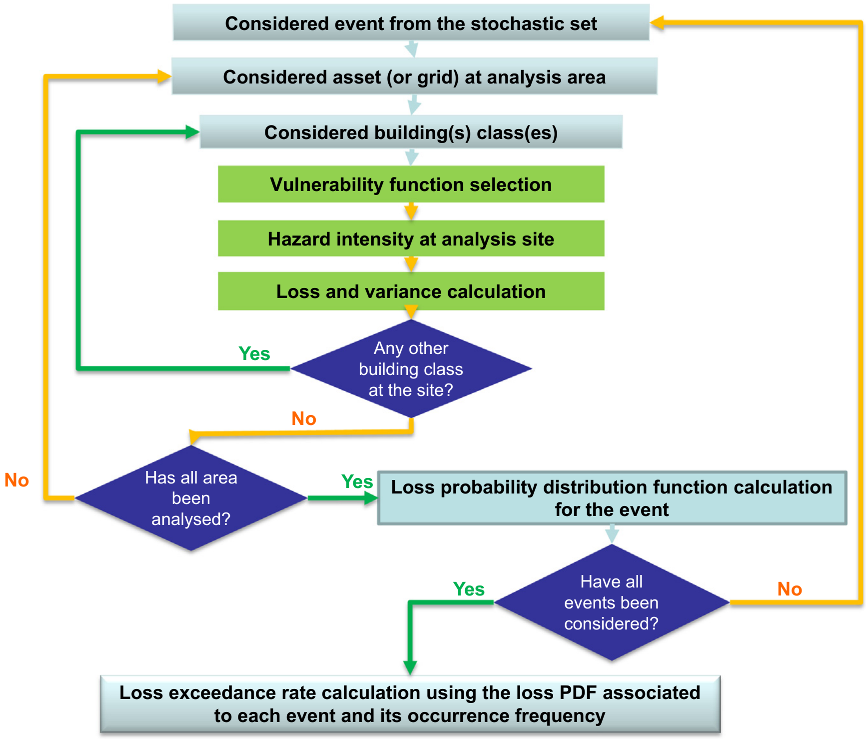

Fig. 1. Probabilistic risk assessements flowchart.

uniform hazard spectrums for each point of interest since the calculation has been conducted for several spectral ordinates. With this information it is also possible to generate hazard maps such as the one presented in Fig. 2 which presents the expected seismic hazard intensities for the peak ground acceleration (PGA) and 1000 year return period. For further details, see [14].

4. Tropical cyclones wind hazard

The hazard modeling for tropical cyclones takes into account the effects related to the speed of the wind, rainfall intensity and storm surge in terms of wave's height. For this study, the effects are only related to the wind speed at a global scale.

The hazard model used here forecasts the maximum intensities associated with the potential occurrence and track of a tropical cyclone in a spatial region. The calculations are done for each of the selected historical tracks and for a set of "children" tracks obtained through the application of 100 bi-dimensional Wiener processes to the historical ones, which allows generating random tracks that keep the main characteristics of the historical ones. With that approach, the wind fields for each historical cyclone are obtained by computing for each location the statistical moments for all wind speed fields of the "children" tracks.

For each historical cyclone the associated wind field is calculated. Each calculated wind field is denoted as a *scenario* and represents the spatial variation of the wind speed given the occurrence of a tropical cyclone. The wind field is expressed in terms of the geographical distribution of the wind's peak speed measured in 5 s gusts. This speed is calculated as a random variable that follows a Gamma distribution and is defined trough two probability moments (the expected value and the variance). This analysis is then repeated for all the historical cyclones. The final set of probabilistic wind fields, obtained from the historical cyclones set comprises the final result. As in the case of the earthquakes, each event is characterized by its annual occurrence frequency. In total 2534 scenarios of tropical cyclones are generated; 826 for the Atlantic Ocean basin, 290 for the Indian Ocean basin and 1418 for the Pacific Ocean basin.

All meteorological and climatological characteristics are inputs for the model. This hazard model that is presented here does not correspond to a meteorological or climate model, and then, the main cyclone's characteristics are obtained from the collected data at global level from various meteorological agencies and grouped in the NOAA IBTrACS database [15]. In this way, particular phenomena from the cyclonic dynamics such as the effects of tropical to extra-tropical regions transitions and landfall effects are implicitly included in the input data.

Calculation of the tropical cyclones wind requires information about the topography, ground roughness and previous tropical cyclones. For this, a digital elevation model with a 1 min resolution was obtained from the National Oceanic and Atmospheric Administration [16] for the topography, derived information from the GlobCover initiative [17] and the Socioeconomic Data and Applications Centre [18] was used to determine the ground roughness, and IBTrACS database for historical events was employed. Hazard estimations were calculated for six different basins. As in the case of the seismic hazard, from the set of stochastic scenarios information the intensity exceedance curves can be

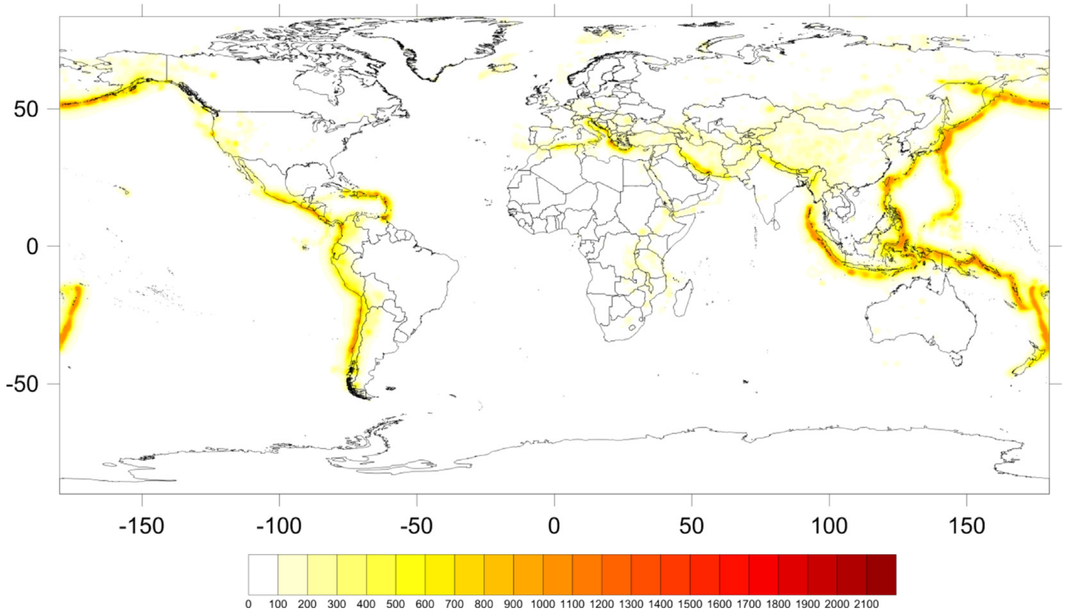

Fig. 2. PGA seismic hazard map. TR = 1000 years (cm/s^2).

generated and with them the hazard maps for a fixed return period. Fig. 3 presents the hazard map for the North Atlantic Ocean Basin for 50 years return period. Bernal et al. [19] present a description of this process.

5. Exposed assets database

The description, characterization and appraisal of the physical inventory of the exposed elements for a probabilistic disaster risk assessment has been, in every case and at any scale, a process that has presented serious challenges for modeling. In this case, a series of assumptions have been made and these naturally increase the epistemic uncertainty in the risk modeling, even in those cases where a relative amount of detailed information is available (for example when at urban scale a building by building mapping information and characterization is available). Appealing to the law of large numbers, characterizations and evaluations are carried out assuming that a certain type of excess or decreasing errors are expected, in a way that they compensate in the final results by involving large estimations of exposed assets. In the portfolios for insured buildings or government owned buildings, for example, despite the fact that gathering as much information as possible is intended, there are always doubts regarding the accuracy and reliability of certain data and because of that, it is known and expected that the results from the risk assessment should always be seen as approximations that can only give an order of magnitude for potential losses.

The objective of this process is to construct a Global Exposure Database (GED) in order to carry out a probabilistic risk assessment at a country level, with a resolution level at urban areas in 5×5 km cells. For each of them a set of records have been modeled representing the building class distribution at each location, also taking into account disaggregation on usage groups (residential, public, commercial, industrial, etc.). In addition to this, the way the classification was performed allows obtaining results that take the government's interest into consideration by not only establishing a proxy estimation for the entire portfolio of exposed assets (country's urban buildings), for the public and private sectors, but also for the government's fiscal responsibility portfolio which includes state owned property and the low income level dwellings that would require support from the government should a disaster occur.

The GED was constructed by the group from the University of Geneva, UNIGE, using information relative to the population distribution throughout the world and socio-economic indicators along the globe. The global exposure database was implemented using the urban areas (populated centers) with occupation density higher than 2000 inhabitants per square kilometer. Different building classes that are representative of the exposed assets were obtained based on population indicators by usage groups (residential, commercial, educational, public and private health and Governmental) and predominant building typologies in each country. Fig. 4 presents a flowchart of the different inputs and characteristics employed to define the GED.

The exposure models can be constructed using either a "top-down" or a "bottom up" approach. This exposure database is constructed for indicative risk estimation at global scale from national socioeconomic indicators and urban population distribution following an top-down model specifically considering only the direct physical damage on the urban buildings.

The GED distribution of structural types was carried out in accordance with the population that lives or occupies each one of the construction classes in each country and not in accordance to the number of buildings. The labor force, income level, the health and education services were used for estimating the amount of the built area at a sub-national level in accordance with the levels of complexity

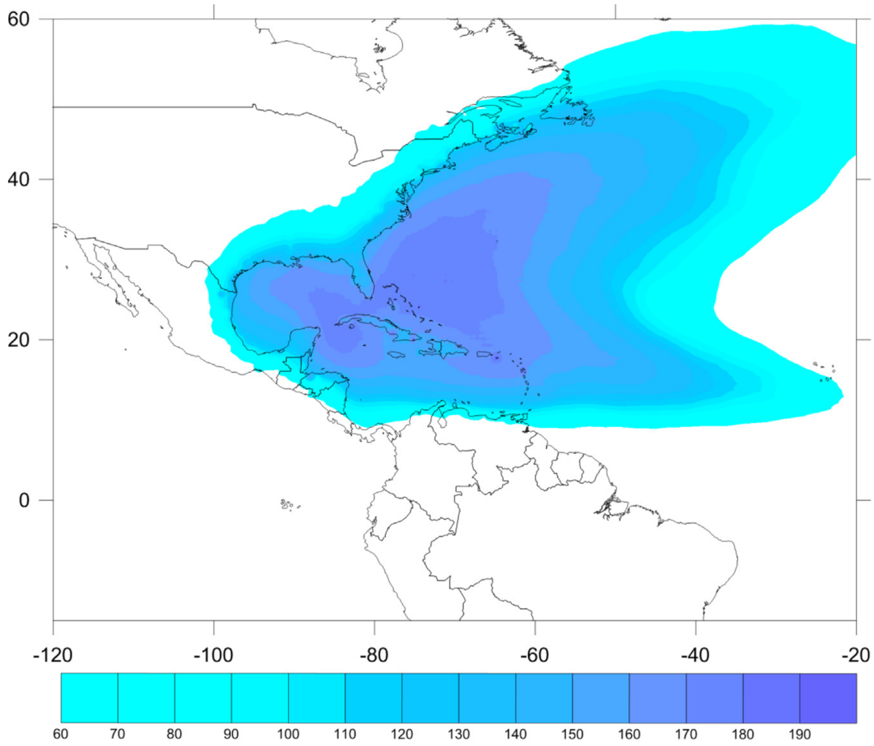

Fig. 3. Wind speed hazard (kph) for the North Atlantic Ocean Basin. 50 years return period.

of each urban area. The total exposed value of each country corresponds to the physical stock capital distributed at a sub-national level in accordance with the population distribution and with the distribution of the Gross Domestic Product (GDP) in the country. This indicator presents the value of the infrastructure of public service buildings, transport and others according to its coverage throughout the country. These are not exposed assets that were aimed to be in the exposure model. To summarize, the exposure model has the following assumptions and limitations:

- The total population of each country corresponds to the official information for 2010.
- The exposed value of the country is based on the physical stock capital derived from the GDP.
- The geographical distribution of the population corresponds to the coverage offered by LandScan [20] with a 1 km resolution ($30'' \times 30''$).
- The exposure is represented as a group of buildings in each point or cell under analysis with a resolution of 5×5 km (approximately in the equator).
- The group buildings in urban zones are categorized in accordance with the usage group, estimating the number of persons living in each usage group of buildings based on national indicators for the number of students, hospital beds and labor force.
- In the disaggregation of the entirety of the exposure information in usage groups, classified by their building classes, sub-national geographical variations are not considered; in other words, uniform indicators are used for the whole country (top-down model).
- The building classes in each country correspond to the classification proposed by the *World Agency of Planetary Monitoring and Earthquake Risk Reduction* – (WAPMERR).
- The capital stock is distributed in each point/cell of analysis according to the relative number of persons living in each sector and building class, taking into account other factors such as the occupation density and the unitary cost.
- The exposed economic value includes the entirety of the physical stock capital, although the vulnerability considered is in a series of construction classes and usage groups that do not necessarily correspond to all the assets that make up said stock capital.
- With this methodology we can create an indicator for economic appraisal associated with the country's physical capital stock, geographically distributed according to population.

Each usage group was disaggregated in types of exposed assets for which physical vulnerability can be represented through physical damage functions. The following information was required for each of them:

- ID
- Geographical location
- Replacement value
- Occupation (number of inhabitants)
- Building class

De Bono [21] presents a description of this process.

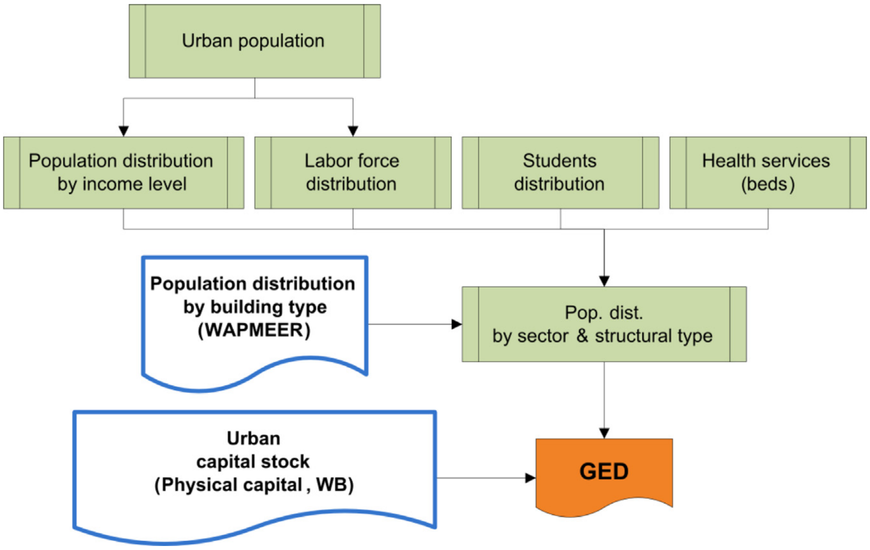

Fig. 4. Inputs and characteristics for the Global Exposure Database generation.

6. Vulnerability functions

For probabilistic disaster risk assessment, the vulnerability of exposed elements is assessed using functions that relate the intensity of the phenomenon that the hazard represents to the mean damage ratio or relative direct physical impact. Such functions are called vulnerability functions and they must be estimated for each one of the construction and occupancy classes, so that a particular vulnerability function can be assigned to each one of the components in the exposure database. Each vulnerability function is characterized by a value known as the mean damage ratio (MDR) and its corresponding variance for each level of hazard intensity. This enables estimating the loss probability function at each level of intensity for the hazards under study.

The general objective of this analysis is to describe the expected behavior (in terms of vulnerability) of the different construction classes at a global level when faced by the different hazards under study as well as to establish a reasonable procedure for assigning the functions to specific countries according to variables such as construction quality and the compliance level of expected design codes. The vulnerability functions should allow differentiating structural behavior by construction class in the different regions of the world as well as the expected behavior for different types of hazard zones on a global level. Aspects such as construction quality and code compliance levels of different structural types were considered in the analysis.

Vulnerability functions are presented for each one of the hazards under study: earthquake and tropical cyclone winds. For the earthquake hazard, the parameter used for hazard intensity is the elastic spectral acceleration for 5% damping and the estimated structural vibration period for each representative construction class, to determine the spectral values. To calculate these functions, the proposed methodology follows the main principles adopted by the methodological approach HAZUS-MH MR3 [22], complemented with some additional considerations proposed by Yamin et al. [23]. Fig. 5 presents some of the employed seismic vulnerability functions.

For the cyclone winds hazard, the parameter used for hazard intensity is maximum wind velocity in kilometers per hour (kph) sustained for five seconds gusts at ten meters above ground level with a low roughness level. The roughness factor is used to differentiate among the different locations of the particular buildings. Functions were represented using the expression indicated in ATC-13 [24] and factors from the HAZUS MH 2.1 *Hurricane Model* [25]. Fig. 6 presents some of the wind vulnerability functions.

It is worth mentioning that the modeling is aimed to capture the general vulnerability characteristics at a regional level compatible with the level of resolution used in the exposure database and that no specific considerations have been made for any particular country or structural system.

To assign the vulnerability functions on a global scale in different countries and regions around the world and for the purpose of being able to establish a differentiation in terms of the general construction quality, the basic seismic design level required in each area, and the expected seismic design code compliance level, the following parameters were employed:

- Country development level from the World Bank Country Classification [26]
- Complexity level [27]
- Hazard level from this analysis

Yamin et al. [28] present a description of this process.

7. Risk analysis

A probabilistic risk analysis has the main objective to determine the loss probability distribution that exposed assets may suffer over a given time period, as a consequence of the occurrence of natural hazards, rationally integrating the uncertainties that exist at different stages of the process. The basic question that a probabilistic analysis attempts to answer is, given that there is a set of assets exposed to the

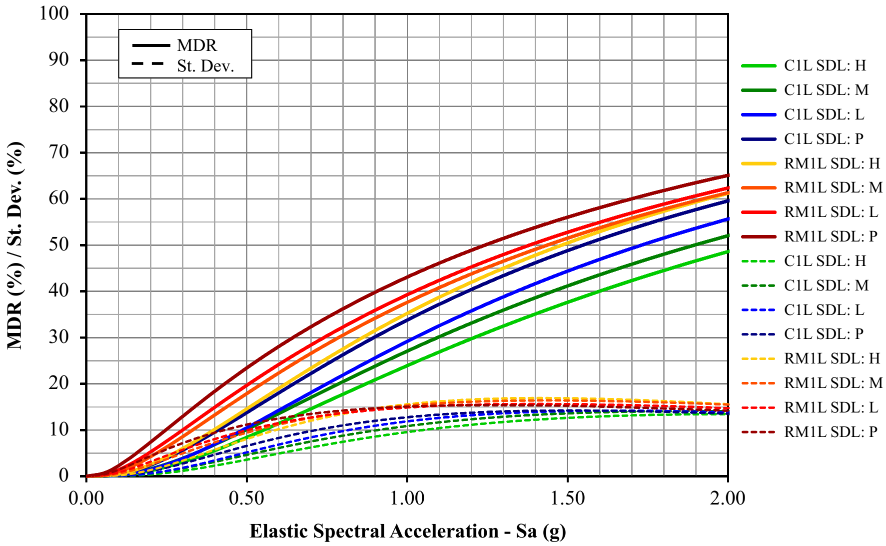

Fig. 5. Seismic vulnerability functions.

effects of one or more natural hazards, how often will losses exceeding a certain value occur?

Given that the frequency of catastrophic events is particularly low, it is not possible to answer that question by using purely empirical models for the process of occurrence of such events. This then requires probabilistic models for those estimations such as the one that is described here. It is worth to mention that before the generalized implementation of these probabilistic methodologies, some well-known actuarial techniques such as Generalized Pareto Distribution were used on historical losses. In the reinsurance industry, they still are used to validate these models.

The procedure for probabilistic calculation is therefore, an evaluation of losses that will affect a group of exposed assets for each of the scenarios that collectively describe the hazard, and then probabilistically integrate the obtained results using the frequency of occurrence of each scenario as a weighting factor.

The probabilistic analysis of risk involves uncertainties that cannot be ignored, and that should be correctly propagated throughout the calculation process. This section describes the general basis of calculation that can be used to achieve the objective proposed. The risk assessment requires three analytical steps, before the convolution process to obtain the annual loss frequency, as follows:

- *Hazard assessment*: For each of the natural phenomena considered, a set of events is defined along with their respective frequencies of occurrence which is an exhaustive representation of said hazard. Each scenario contains spatial distribution parameters that will permit the construction of the probability distributions for the intensities produced by their occurrence.
- *Definition of the inventory of exposed assets*: An inventory of the exposed assets must be constructed and this should specify the geographical location for each, and the following main parameters to classify them: (a) replacement value and (b) building class to which the asset belongs to.
- *Vulnerability of the exposed assets*: Each building class must be associated to a vulnerability function for each type of hazard. This function characterizes the structural behavior of the asset during the occurrence of the hazard phenomena. The vulnerability functions define the loss probability distribution as a function of the intensity produced during a specific scenario. This is defined through a set of curves that relate the expected value of damage and standard deviation of damage with the intensities for each scenario.

7.1. Analytical procedure

Considering the basic objective of the probabilistic risk analysis, a specific methodology must be followed in order to calculate the frequencies of occurrence of specific loss levels in the exposed assets over defined periods of time given the occurrence of natural hazards.

A scenario approach for the hazard representation and risk calculation was chosen to account for all possible events; the advantage of this methodology is well explained in Ref. [29]. The risk to natural hazards is commonly described through the loss exceedance curve which specifies the frequencies, usually expressed annually, with which events will occur exceeding a specified loss value. This annual loss frequency is also known as the exceedance rate, and it can be calculated using the following equation which is one of the many forms the total probability theorem can adopt:

$$\nu(p) = \sum_{i=1}^{Events} \Pr(P > p|Event\ \ i) F_A(Event\ \ i) \tag{1}$$

In this equation, $\nu(p)$ is the loss exceedance rate of loss p, and F_A $(Event\ i)$ is the annual frequency of occurrence of the $Event\ i$, while $Pr(P > p(Event\ i)$ is the probability that

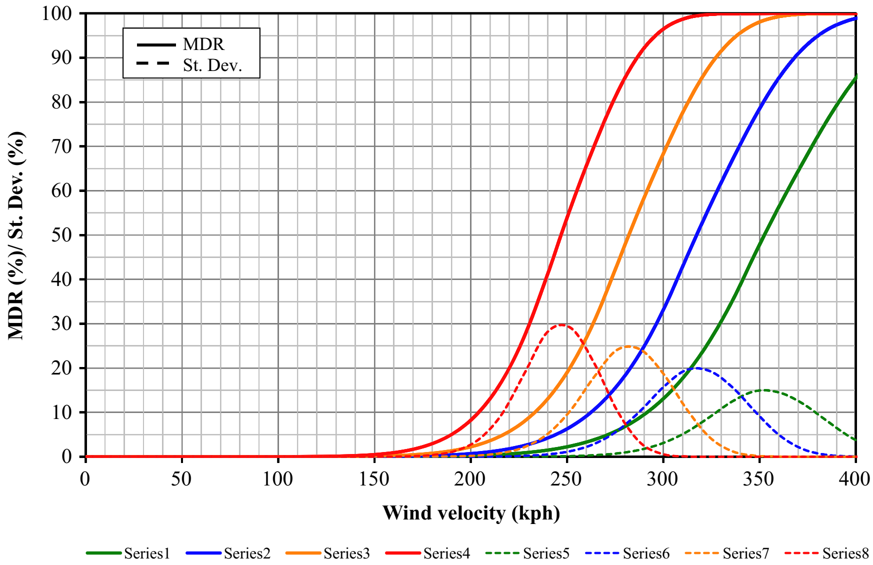

Fig. 6. Wind vulnerability functions.

the loss will be higher than p, given that the ith event occurred. The sum of the equation is made for all potentially damaging events. The inverse of $\nu(p)$ is the return period of loss p, identified as Tr.

As is presented in a following section, the loss curve contains all the information required to describe in a probabilistic way the process of occurrence of events that generate losses.

The loss p referred in Eq. (1) is the sum of the losses that occur to all the exposed assets. The following issues should be borne in mind:

- The loss p is an uncertain quantity, whose value, given the occurrence of an event, cannot be precisely known. Therefore, it must be seen and treated as a random variable, and methodologies should be constructed to know its probability distribution conditional to the occurrence of a certain event.
- The loss p is calculated as the sum of the losses that occur in each of the exposed assets. Each of the items in the sum is a random variable, and there is a certain level of correlation between them which should be included in the analysis.

A careful approach to Eq. (1) for, the probabilistic loss calculation gives the following sequence:

1. For a scenario, determine the loss probability distribution in each of the exposed assets.
2. Based on the loss probability distribution of each asset, determine the probability distribution for the sum of these losses, taking account the correlation that exists between them.
3. Once the probability distribution for the summed losses is determined for that event, calculate the probability that this will exceed a given value of loss p.
4. The probability determined in step 3, multiplied by the annual frequency of occurrence of the event, is the contribution of this event to loss exceedance rate of loss p.

The calculation is repeated for all events, and in this way the result indicated by Eq. (1) is obtained.

It is also interesting to note that in Eq. (1) there is no distinction between events that belong to different hazards. In effect, the sum in this equation may include, for example, earthquakes and tropical cyclones or earthquakes and floods. This happens because the assumption is that events associated with the same hazard and events associated with different hazards do not occur simultaneously. However, some phenomena that are potentially damaging do occur simultaneously, and in such cases special care should be taken in determining the distribution of the probability of loss p.

As observed in Eq. (1), and as proposed above, the loss in a group of exposed assets during a given scenario is an uncertain quantity which should be treated as a random variable.

Generally, it is not practical to make a direct calculation of the loss probability distribution in the exposed assets, conditional on the occurrence of a given scenario. In other words, for example, it is not practical to determine the probability distribution of the loss in an element, given that, a magnitude 6.0 earthquake occurs at 100 km distance.

For methodological reasons, the probability of loss exceedance, given that an event occurs, is commonly expressed as follows:

$$\Pr(P > p|Event) = \int_I \Pr(P > p|I) f(I|Event) d\,I \tag{2}$$

The first term of the items to be integrated, $\Pr(P > p|I)$ is the probability that the loss will exceed the value p given that the local intensity was I; this term, therefore accounts for the uncertainty that are included in the vulnerability functions. Further, the term $f(I|Event)$ is the probability density of the intensity, conditional to the occurrence of the event. This term takes account of the fact that, given that an event occurred, the intensity at the analysis site of interest is uncertain.

As indicated above, the curve obtained by applying Eq. (1) contains all the information required to characterize the process of occurrence of events that produce losses. However, it is sometimes not practical to use a complete curve, and therefore it is convenient to use specific estimators of risk that will allow it to be expressed by a single number. The two most commonly used specific estimators are described here described as follows:

(a) *Average annual loss* (*AAL*): this is the expected value of the annual loss. It is an important quantity, since it indicates, for example, assuming that the process of occurrence of the damaging event is stationary from here to eternity, its accumulated cost will be the equivalent of having the AAL paid annually. Therefore, in a simple insurance scheme, the annual average loss would be the pure premium. AAL can be obtained by integrating $v(p)$, or by the following expression:

$$AAL = \sum_{i=1}^{Events} E(P|Event\ \ i)F_A(Event\ \ i) \tag{3}$$

(b) *Probable maximum loss* (*PML*): This is a loss that does not occur frequently and then is associated with long return periods (or, alternatively, low exceedance rates). There are no universally accepted standards to define what is meant by “not very frequently”. In fact, the choice of a specific return period for a decision making process depends on the risk aversion of who are deciding. For this case, a PML for a fixed return period of 250 years was calculated for all countries.

7.2. Risk results

The probabilistic risk analysis for 205 countries was performed using the CAPRA Platform. For each country, two analysis were performed; a first analysis considering the total number of exposed assets (national), and a second analysis considering only the elements which repairing would be a Governmental responsibility in case of a disaster (fiscal responsibility). Results in terms of two risk metrics, the average annual loss (AAL) and the probable maximum loss (PML) for 250 years return period, were obtained.

AAL refers to the value, in monetary terms or relative to the total exposed value that should be saved annually in order to cover all future losses in a very large time window. PML represents the loss value, associated usually to a large return period where it is important to bear in mind that a loss return period may be different to the event (hazard) return period since there is usually correlation between the losses.

Using the two main risk metrics, a series of indicators are generated allowing the categorization and ranking of countries in terms of the impact [3]. For this purpose, economic flow variables are used to normalize the risk values:

- AAL/GNE: *Average annual loss* with respect to the *Gross National Expenditure*.
- AAL/GFCF: (National) *Average annual loss* with respect to the *Gross Fixed Capital Formation*.
- AAL/GNS: (Fiscal) *Average annual loss* with respect to the *Gross National Savings*.
- PML_{250}/GDP: *Probable maximum loss* with respect to the *Gross Domestic Product*.
- PML_{250}/GNI: *Probable maximum loss* with respect to the *Gross National Income*.

Table 1 summarizes the main input characteristics in terms of hazard, exposure and vulnerability for the risk calculation process.

Fig. 7 shows the earthquake AAL distribution (in monetary units) by country.

Given that the previous figure may show not where the highest losses are located, but where the most expensive assets are placed, it is important to normalize the AAL by the total replacement value to make results comparable. These results are presented in Fig. 8.

Since the PML for a fixed return period of 250 years was calculated, it is also possible to present these results in a graphical way. Fig. 9 presents the geographical distribution of this parameter, relative to the exposed value, due to earthquake risk at global level.

Figs. 10–12 present the same information for the case of the tropical cyclone wind risk results.

As was mentioned, the full LEC was calculated for a set of countries around the Globe. Figs. 13–17 present these results for simultaneous hazards (earthquakes and tropical cyclones) for Australia, Canada, Colombia, Madagascar and Mexico.

7.3. Risk rankings

Since risk was analyzed using the same methodology for every country, it is possible then to compare risk results and create risk rankings using the risk analysis outputs combined with some macroeconomic indicators. According to the economic resilience, this kind of composed indicators can show the non-explicit contingent liability that seismic and tropical cyclones wind risk represent as well as the macroeconomic consequences and public and private investment implications that are derived from it [3].

Fig. 18 shows some of the rankings using these indices that allow identifying the most vulnerable countries for the earthquake risk. Countries are identified by their A3 ISO 3166 code[2]. Results are presented for the national risk and for the fiscal risk; for the first case the AAL is combined with the Gross National Expenditure (GNE) that accounts for the household final consumption expenditure, general government final consumption expenditure and the gross capital formation. For the second case the PML_{250} is combined with the Gross Domestic Product that accounts for the value of all the goods and services produced in an economy plus the value of the goods and imported services, less the goods and services that are exported.

From the analysis it is clear that the Philippines, Afghanistan, Honduras, El Salvador and Japan are placed in the top 5 ranking in the national (complete portfolio) analysis; it is

[2] ftp://ftp.fu-berlin.de/doc/iso/iso3166-countrycodes.txt.

important to note that all countries are located within high seismic hazard zones. For the fiscal portfolio 3 countries keep their position within the top-5 ranking but there is an important decrease of the risk value for Japan that can be explained by a solid economy and a lower physical vulnerability for the national and low income infrastructure.

Countries' economies can be classified in different categories and because of that, results can be disaggregated.

Table 1
Summary of parameters and characteristics.

Number of earthquake scenarios	1,022,129
Number of tropical cyclones scenarios	2534
Number of building and occupancy classes	41,184
Number of earthquake vulnerability functions	192
Number of wind vulnerability functions	192
Number of countries covered	205

Fig. 19 shows the fiscal seismic risk ranking for middle-high economies in terms of the AAL combined with the GNE from where it can be seen that Costa Rica and Colombia have an important risk level for the fiscal portfolio. Fig. 20 presents the seismic risk ranking for the Latin America and Caribbean region in terms of the PML for 250 years return period combined with the GNP. It is clear that countries in Central America have the highest risk values compared for example with others located in South America where in zone areas, hazard intensities have the same order of magnitude.

It is also possible to generate risk rankings for the case of tropical cyclone risk. Fig. 21 presents the ranking for the Latin American and Caribbean region. From the figure it is clear that Honduras and Mexico have the highest risk given by this index, where it should be noted that these two countries may be affected by events occurring both in the North Atlantic and North Pacific basins.

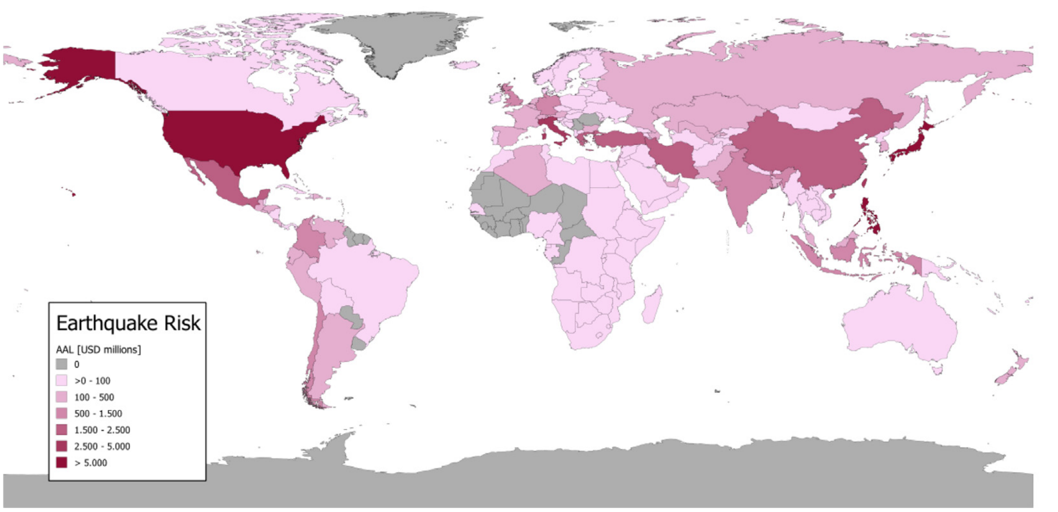

Fig. 7. Earthquake AAL distribution by country.

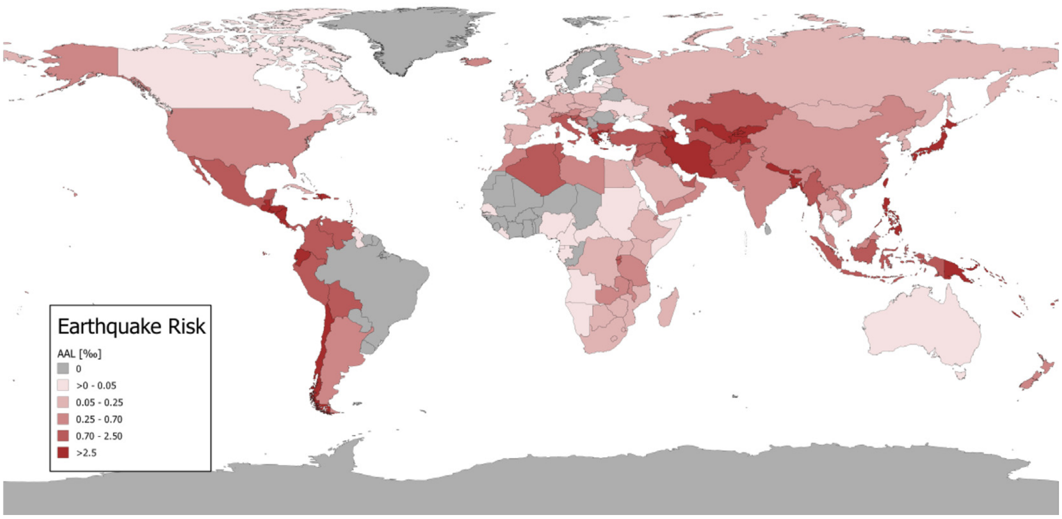

Fig. 8. Earthquake AAL distribution, relative to the exposed value by country.

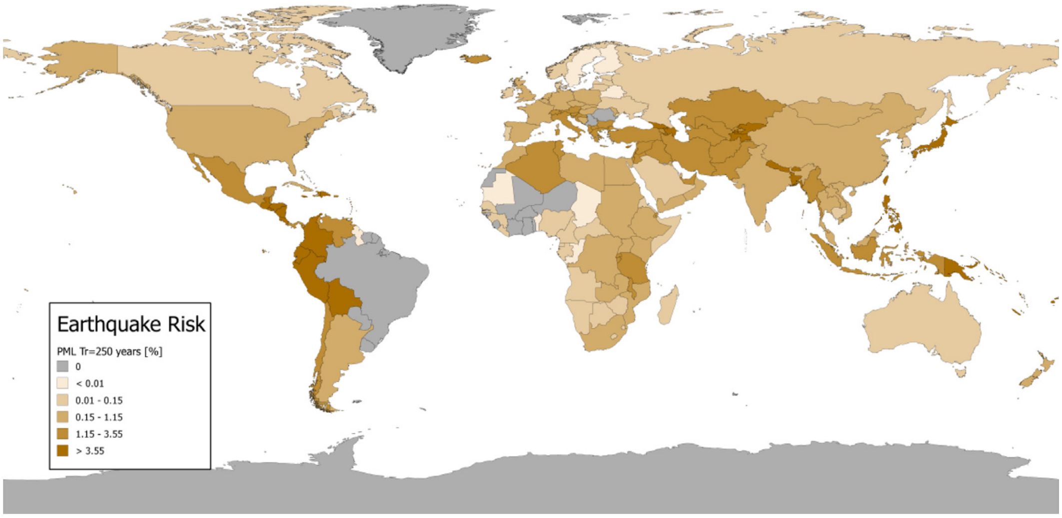

Fig. 9. Earthquake PML_{250} distribution, relative to the exposed value by country.

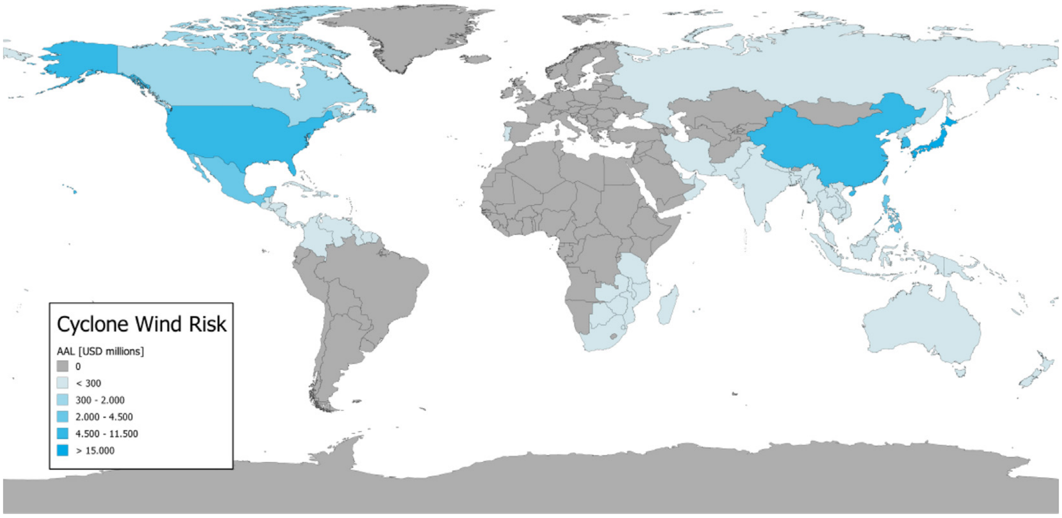

Fig. 10. Tropical cyclone (wind) AAL distribution by country.

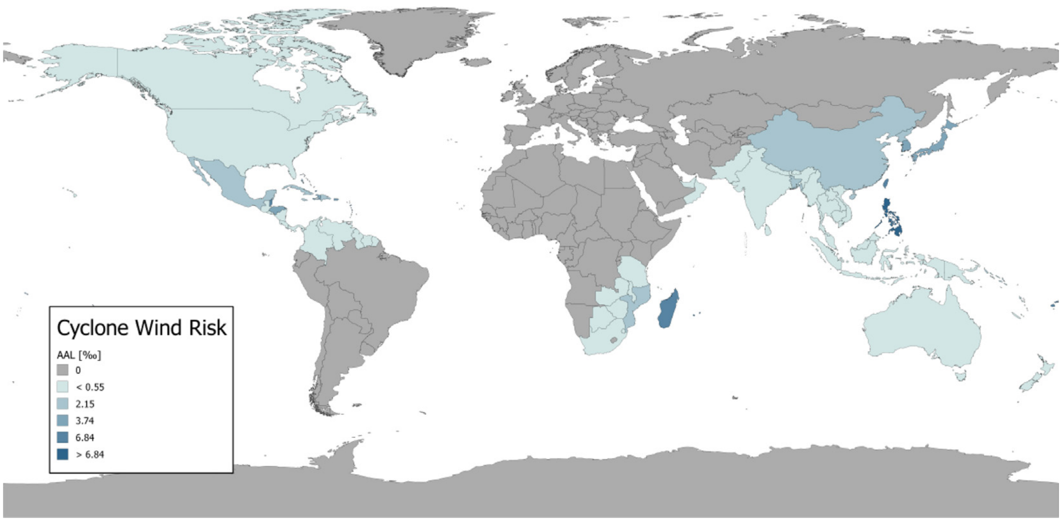

Fig. 11. Tropical cyclone (wind) AAL distribution, relative to the exposed value by country.

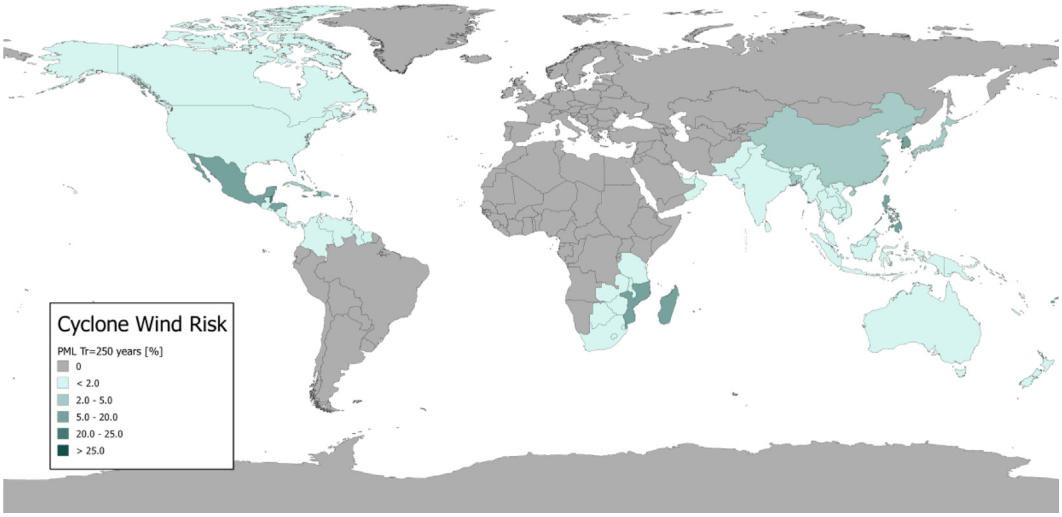

Fig. 12. Tropical cyclone (wind) PML_{250} distribution, relative to the exposed value by country.

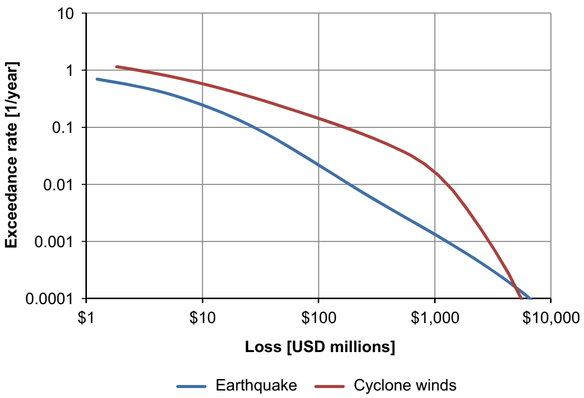

Fig. 13. Simultaneous hazards LEC for Australia.

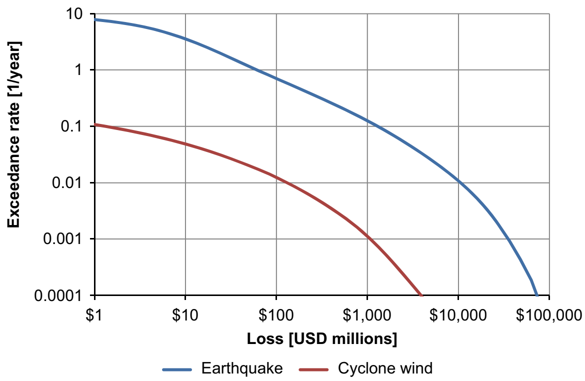

Fig. 15. Simultaneous hazards LEC for Colombia.

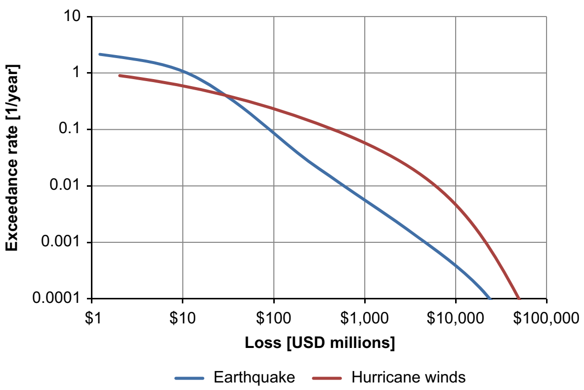

Fig. 14. Simultaneous hazards LEC for Canada.

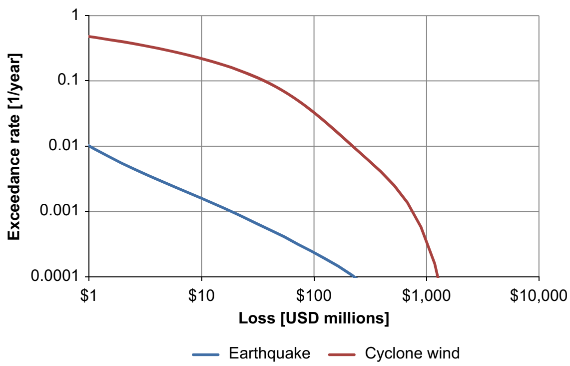

Fig. 16. Simultaneous hazards LEC for Madagascar.

Fig. 22 presents the ranking for Asia while Fig. 23 presents the ranking for high level economies that are exposed to cyclonic wind hazard. As in the case of earthquakes, the Philippines have a considerable highest risk if compared to neighbor countries; this due to its hazard and vulnerability levels. For this case, Japan and South Korea have a risk index of around 0.5% which constitutes a considerable risk concentration.

Since tropical cyclones are important to Small Islands Development States (SIDS), risk ranking has been conducted in a separate way for this category. Fig. 24 presents the national tropical cyclone wind risk in terms of the AAL combined with the GNE. African SIDS have relative low risk due to cyclone wind.

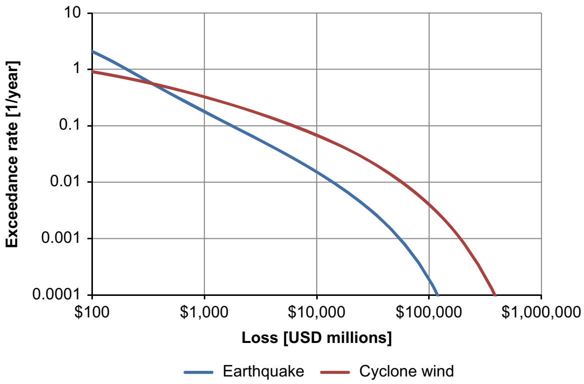

Fig. 17. Simultaneous hazards LEC for Mexico.

8. Conclusions

Risk assessment at global level, until now has been carried out based only on historical recorded events in the international disasters databases (GAR09). This Global Risk Assessment is the first of its kind that takes into account events that have not yet occurred by using a probabilistic methodology that quantifies the possible losses due to future events. Moreover, for the first time, a worldwide methodology consistent probabilistic risk assessment for earthquake and tropical cyclones wind has been conducted at global level, using coarse grain data of exposure, for more than 200 countries. Risk results have been quantified in terms of state-of-the-art metrics such as the AAL, the PML (for a fixed return period of 250 years) and for a selected set of countries the complete LEC was obtained for simultaneous hazards.

There may be aspects where this assessment is similar to the evaluations conducted by the insurance and reinsurance industry; however, an important difference is that for this case risk has been estimated using a proxy database that accounts for the total value of the assets of each country as well as the fiscal responsibility.

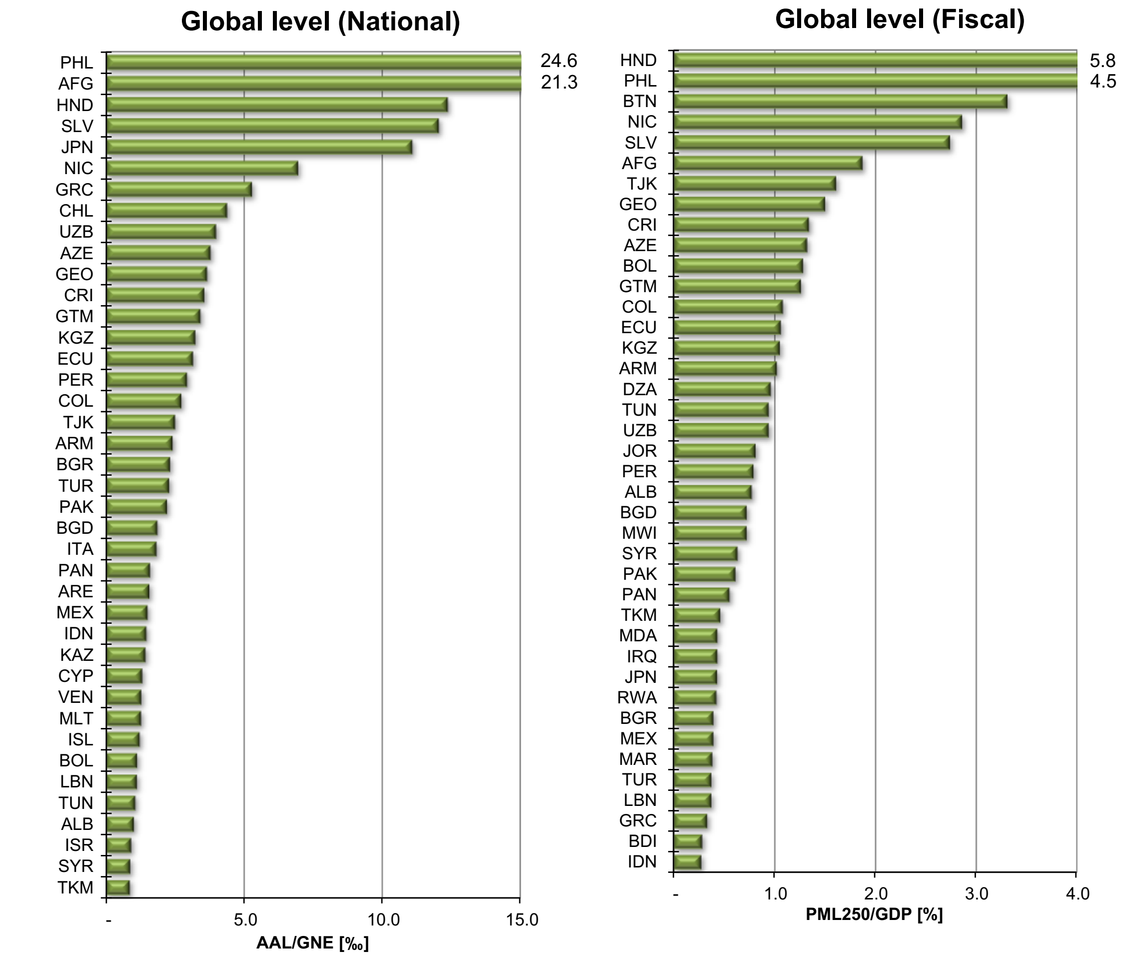

Fig. 18. Seismic risk ranking in terms of AAL relative to the Gross National Expenditure and the PML_{250} relative to the Gross Domestic Product.

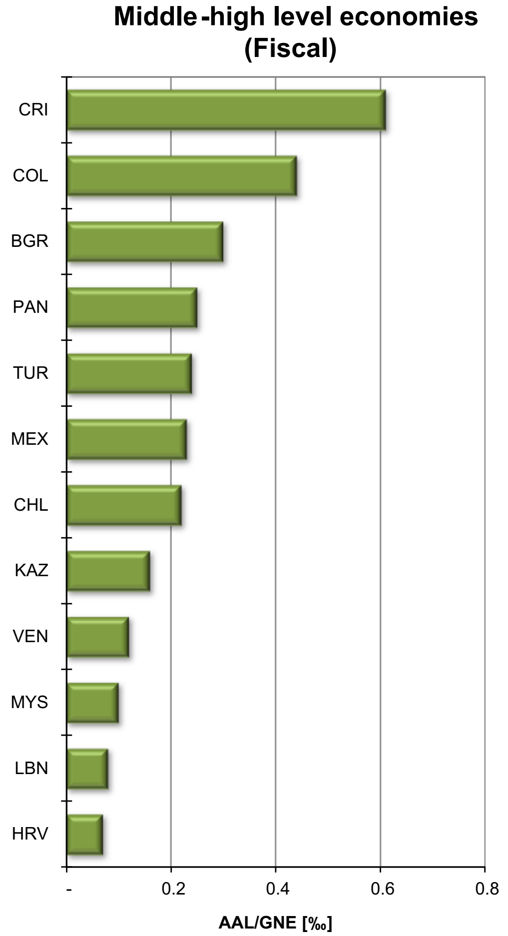

Fig. 19. Fiscal seismic risk ranking for middle-high level economies in terms of AAL relative to the Gross National Expenditure.

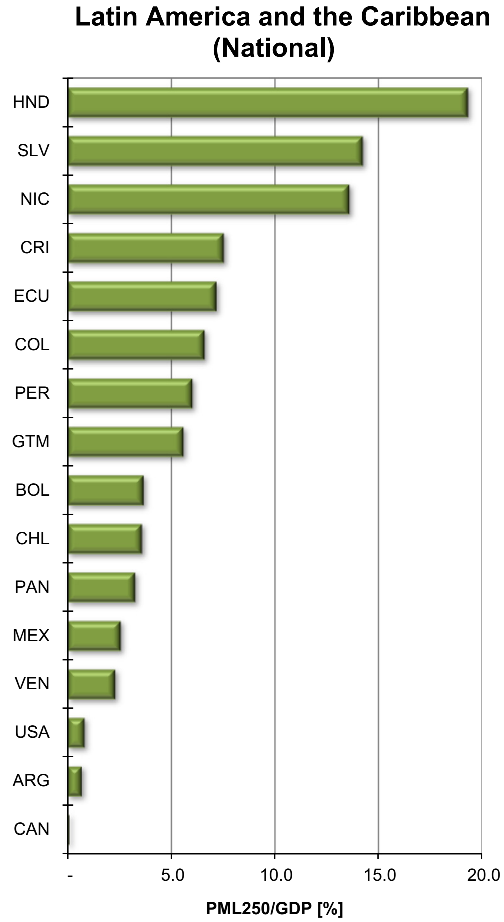

Fig. 20. National seismic risk ranking for Latin America and the Caribbean in terms of PML_{250} relative to the Gross National Product.

To implement risk management activities that usually involve measures of risk reduction, financial protection, preparedness and emergency attention, it is necessary to answer questions such as: which are the more frequent events and what are their associated intensities and losses? What are the maximum losses associated to recurrent events (20, 50 years return period) and rare events (100, 500, 1000+ years return period)? With the results presented in this paper these questions can be answered since risk has been expressed in terms of occurrence rates which implicitly take into account the intrinsic uncertainties.

The objective of conduction analyses for major hazards that result in catastrophic risk at global level was achieved. Additionally, the study has highlighted the need for countries to carry out risk analysis with higher resolution level at sub-national or local level when the required information is available or to start the data gathering process to carry those analyses in the future. This means that, using the same “arithmetic” or model it is possible to obtain risk results with better resolution that might be useful for decision-making at sub-national and local level [30].

It is important to notice that the resolution and accuracy are not only associated with the hazard assessment, but also to the representation of the exposure and the characterization of the vulnerability. For this reason, it is necessary to have consistency and compatibility on the level of rigor and details in the different phases of the risk assessment. The choice of the resolution is related to the type of decisions that the risk assessment will inform. For this study, the simplifications and assumptions, appropriate for this work at global level, meant that the accuracy was sacrificed. It has nevertheless resulted in a “common operating picture” of risk for the countries that allows a comparative initial view of their economic dimension and capability to recover from disasters. In other words, this analysis provides information on the economic resilience of the countries, in terms of indicators of the countries' economic flow. The model can be improved, especially on the data that could be used for an evaluation resulting in countries' risk profiles. The use of more detailed information is linked to the need of carrying out cost-benefit analyses on the implementation of disaster risk reduction measures. In other words, it is important to point out that the more the scale goes down into national and sub-

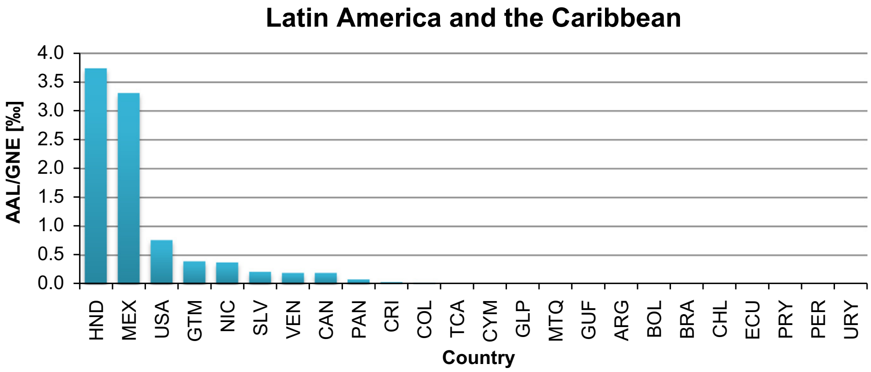

Fig. 21. National cyclonic wind risk ranking for Latin America and the Caribbean in terms of AAL relative to the Gross National Expenditure.

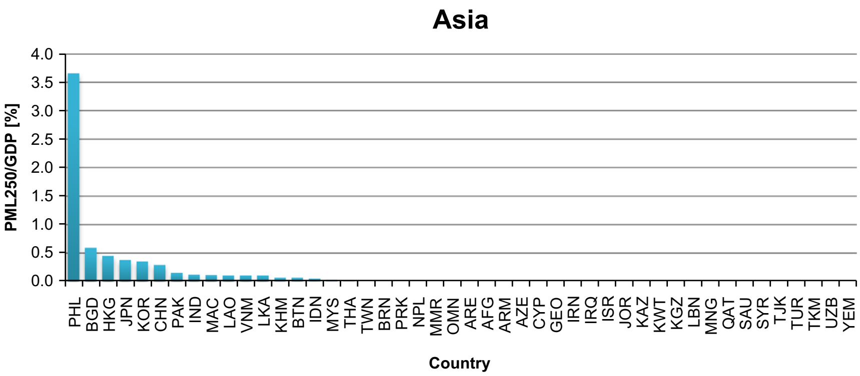

Fig. 22. Fiscal cyclonic wind risk ranking for Asia in terms of PML relative to the Gross National Product.

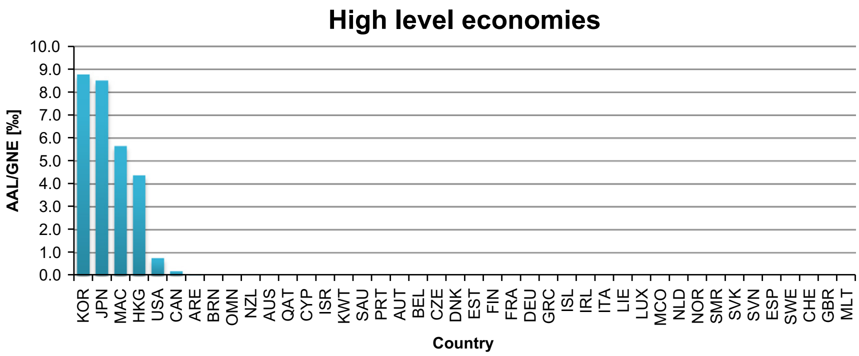

Fig. 23. National cyclonic wind risk ranking for high level economies in terms of AAL relative to the Gross National Expenditure.

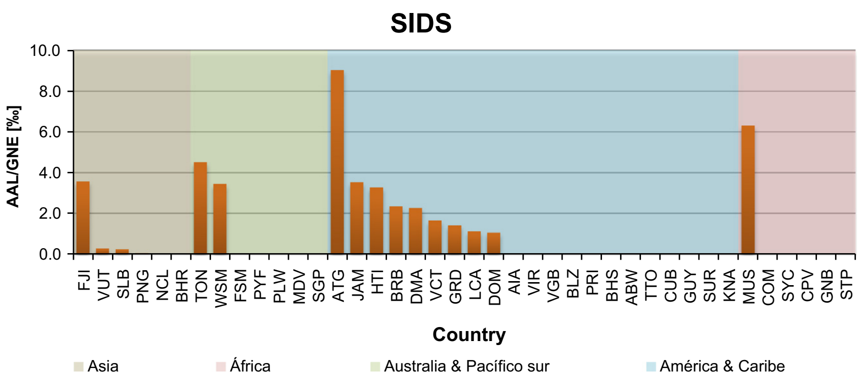

Fig. 24. National tropical cyclone wind risk by regions in terms of AAL relative to the Gross National Expenditure.

national levels, the more detailed the analysis is required, even if the same methodological approach used here is applied. The probabilistic metrics can be used at all territorial scales, and the appropriate accuracy to be adopted for the study depends on the required scope and use of the results.

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