QUANTIFICATION OF GLOBAL PROBABLISTIC TSUNAMI RISK – INITIAL RESULTS

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ABSTRACT

Frequently, tsunamis devastate coastlines all around the world: from mega-events such as in the Indian Ocean in 2004 to more regional events like the 2009 Samoa tsunami. Most coastal regions are prone to tsunami hazard, some more often than others, but on a long-term perspective, tsunamis have been seen almost everywhere in the world, especially in regions with active subduction processes. In the past, tsunami hazard and some rare risk assessments focused mostly on regional studies assessing the potential tsunami impact. This new study highlights the methodological changes for the compilation of a global tsunami risk model with respect to tsunami source and likelihood modelling, speed-up of tsunami wave propagation computations and the assessment of socio-economic risks. Detailed statistical analysis in conjunction with machine learning technologies and high-performance computing have been utilized to assemble a robust rapid tsunami risk modelling methodology which can be applied for tsunami-prone regions all around the world. Focusing on tsunamis triggered by megathrust earthquakes (Mw>8.0), more than 70 sources which are likely to produce potential megathrust earthquakes have been identified globally and assessed regarding their maximum magnitude and earthquake return periods. Source variability is considered using heterogeneous slip distributions while wave propagation and inundation patterns computed using the GPU-driven tsunami simulation toolbox TsuPy. Initial applications for the Caribbean, Cascadia, South East Asia and other locations, provide risk metrics on a comparable scale and highlight the long-term potential impact of tsunami events on a country-by-country basis. This study outlines the complete methodological framework of tsunami risk modelling with a focus on global applicability and introduces first results for the Caribbean.

Keywords: Tsunami; Risk; Probabilistic; Caribbean; Global

1. INTRODUCTION

Tsunamis are among the most fatal and costly natural disasters but also very infrequent. With a decade of strong tsunamis since 2004, tsunami research has accelerated, and a variety of hazard studies have been taken out. Yet, the quantification of tsunami risk still remains a difficult task due to major uncertainties in regards of hazard and the limited empirical vulnerability data. Tsunamis can be triggered by various sources, yet earthquakes contributed most. Thus, a focus on earthquake-triggered tsunamis is appropriate for the initial development of a global tsunami hazard and risk model. Most prominent problem is the absence of a specific modelling scheme for tsunamis, thus the common understanding of how tsunami hazard should be modelled is still under development. It starts with the low probability of occurrence compared to other events, tumbles over the complexity of earthquake rupture processes and ends with an extremely high demand on computational efficiency. In addition, the assessment of risk only relies on a small number of well-constrained vulnerability assessments, which are mostly derived from a hand full of recently observed events. Probabilistic tsunami hazard assessments have been developed by various authors but always focused on a specific region. For example, Horspool et al. (2014) provide a probabilistic tsunami hazard

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assess the coasts of Oregon in regards of potential tsunamis along the Cascadia subduction zone. A larger region was assessed by Sorensen et al. (2012) covering the whole Mediterranean. A global study on probabilistic tsunami hazard was published by Davies, et al. (2017) who quantified peak coastal amplitudes along the coast line for various return periods.

So far, such studies have one common problem. Either they are limited to a certain region allowing the simulation of inundation, or they are limited by resolution due to size of the assessed area. Thus, such studies can only focus on peak coastal amplitudes which are the expected run-up heights computed from wave heights at about 100m depths using Green’s Law. Another simplification is the reduction of the tsunami wave propagation to its linear components to allow the superposition of smaller events to build larger scenarios and thus reducing the whole computational demand. Any tsunami hazard study so far was always trying to find the best trade-off between simulation resolution, quality and the area of assessment. The computation of earthquake return periods is a common task among all studies and not limited by computation time but on the historic and instrumental data available to constrain the results on earthquake and tsunami reoccurrence times. Thus, the key driver behind the quality of tsunami hazard studies is the efficient simulation of tsunami wave propagation and propagation. Yet, the field of tsunami risk assessments is not populated with many studies. The definition of risk is hereby dependent on the considered study. For example, Strunz et al. (2011) defined risk as the combination of probabilistic hazard and exposed population. Jelinek et al. (2012) provide a selected review of previous tsunami risk assessments and highlights the diversity of such approaches. For example, Pararas-Carayannis (1988) defined risk qualitatively in terms of event occurrence and quality of mitigation planning. Nadim & Glade (2006) defined risk in regards of annually expected number of fatalities in conjunction with a tolerance level. Similarly, Tinti, et al. (2008) also defined risk in regards of expected casualties. However, Gonzalez-Riancho Calzada, et al. (2014) describe the full scale of risk assessments including human, environmental, socio-economic and infrastructure risk and computes the risk qualitatively using an indicator system. Wiebe & Cox (2014) used tax lot data to estimate the economic loss of building structures during for several Cascadia tsunami scenarios. Jaimes, et al. (2016) introduced a framework to compute probabilistic tsunami risk using stochastic catalogues of tsunami events including non-linear wave propagation and inundation, however lacking a detailed computation of those metrics. Okumura, et al. (2017) also developed a risk assessment methodology, however on a limited number of scenarios, but with a detailed assessment of potential damage and loss of life with the focus on a cost-benefit analysis on mitigation measures. These proposed frameworks are methodologically similar to the one introduced in the following sections. However, this new model is focusing on the quantitative assessment of probabilistic and deterministic tsunami risk. Risk is hereby defined as the probability that a certain amount of loss occurs within a specific time frame or within a scenario. First, the methodology is described with respect to its modelling components. This risk model is afterwards applied within an exploratory case study for the Lesser Antilles and most of its island states.

![Figure 1. Overview of the structure for the tsunami risk modelling framework](image)

2. A GLOBAL FRAMEWORK FOR TSUNAMI RISK

The development of a global tsunami risk assessment framework covers 6 major components. Each with its specific uncertainties, limitations and computational demands. Figure 1 lines out the main components of the global tsunami risk model. First, the tsunami-genic source needs to be described. In
this study, focusing on earthquakes, sources of tsunami-genic activity are limited to subduction zones. The second element focuses on the quantification of their maximum magnitude and their occurrence probability. Afterwards, the earthquake events need to be discretised regarding their tsunami triggering process based on heterogeneous rupture models which are prone to major uncertainties. With the sea floor disturbance of an earthquake described, the wave propagation process demands computational efficiency especially when simulating inundation processes. All these components combined provide probability estimates for the exceedance of inundation depth which is used as the input metric to calculate potential economic and social losses. To compute those, exposure needs to be identified together with its specific vulnerability. Combining all those components provides a risk estimate for a site of interest.

2.1 Structure

First, the hazard on its own is examined. Thus, considering the expected annual number of occurrences \( v_S(z|x) \) at site \( x \) that the inundation depth \( Z \) is greater or equal to \( z \) of tsunamis from source \( S \). The inundation depth \( Z \) is computed through the numerical tsunami propagation and inundation simulation \( I \). The simulation is based on the rupture model \( R \) which contains a specific location, slip distribution and sea floor deformation. The rupture model \( R \) depends on the earthquake magnitude \( M \). With the magnitude-dependent occurrence probability \( \lambda_S(M) \), \( v_S(z|x) \) can be described by the following equation.

\[
v_S(z|x) = \int [\lambda_S(M) \times R(M|y_S)] \times I(Z \geq z|R, x) dM
\]

Thus, assuming a Poisson process, the inundation exceedance probability \( H_S(x|M) \) can be computed

\[
H_S(x) = 1 - e^{-v_S(z|x)}
\]

The hazard component comprises 4 of the main components, the source \( S \), the event probability \( \lambda_S \), the rupture model \( R \), and the wave simulation \( I \). With the two remaining components, the exceedance probability of the annually average expected loss \( L_0 \) being larger than \( L \) can be computed by combining the hazard \( H \) of all relevant subduction zones \( S \) with the vulnerability \( V \) with the value of asset \( E \) at location \( x \).

\[
Pr(L > L_0|E(x)) = \sum_S H_S(x) \times V(E(x))
\]

With this system, the average annual loss (AAL), the probable maximum loss (PML) for certain return periods can be computed. Same holds also for the exceedance probability of fatalities, providing average annual deaths (AAD) and probable maximum number of deaths (PMD).

2.2 Description and potential of tsunami-genic sources

Focusing on earthquake-tsunamis, the prior source of these events are subduction zones. They provide a sufficiently large rupture area to produce very strong earthquakes. However, also smaller magnitudes \((6.5 < M_w < 8.0)\) can produce significant regional tsunamis, but often associated with a co-triggered landslide amplifying the tsunami impact (Ten Brink, et al., 2006). Within this global tsunami risk framework, 76 subduction zones have been identified globally from which at least 50 which are generally capable of producing regional and trans-oceanic tsunami impact. Figure 2 provides an overview of those subduction zones together with the potential maximum magnitude and the minimum expected return period of \( M_w \geq 8.0 \) earthquakes. Those results have been computed considering tapered Gutenberg-Richter earthquake statistics, plate motion modelling and an ensemble correlation study analysis of subduction-related parameters similar to Schellart and Rawlinson (2013), Heuret, et al. (2012) or Rong, et al. (2014). The resulting expected \( M_{max} \) are shown in Figure 2.
2.3 Source Variability

The source mechanism of an earthquake-tsunami is represented by a heterogeneous slip distribution. Those rupture models can be retrieved from various publications (e.g. Rhie et al. (2007), Shao et al. (2013)) or the SRCMOD database (Mai, 2016). With almost 230 slip distributions from earthquakes of the last few decades, their geometric characteristics can be quantified in a set of magnitude-dependent relationships. Those findings are in the line of previous studies like Wells and Coppersmith (1994) and Leonard (2010). However, the results of Goda et al. (2016) also comprise the spectral characteristics to quantify the heterogeneous slip distribution. Those characteristics are used to stochastically compute random slip distributions depending on a given moment magnitude. As shown by Schäfer and Wenzel (2017) or Goda et al. (2014), such source models introduce a major variability to the following tsunami and are thus a very important element the whole risk model.

2.4 Wave Propagation

The numerical simulation of tsunami wave propagation is a task which has been methodologically solved previously by many studies (e.g. Wang (2009), Titov and Gonzalez (1997)). However, the biggest problem if this component is its computation speed. The simulation of an individual tsunami, especially when also considering inundation processes of sufficient resolution (<250m grid size), takes very long; sometimes several hours, which is a big problem when maybe several hundreds of events need to be calculated. So far, the only option was to use high performance computing to get results within a reasonable amount of time. However, such supercomputing power is expensive and not easily available. Thus, a computationally efficient wave propagation solver is preferred. In this study, the wave propagation solver Tsupy of Schäfer and Wenzel (2017) was developed which is using the computational power of GPUs. It was shown that, compared CPU-based computation the GPU system is faster by a factor of 10-100 (depending on the problem to solve).

For the simulation of tsunami wave propagation, bathymetry and topography data is necessary on sufficient resolution. As a basis, the 1km GEBCO bathymetry (Weatherall et al. 2015) is used and overlaid with 90m SRTM topography data (Jarvis et al. 2008). Even though, there are higher resolution models available, 90m was found to be the best trade-off between resolution and calculation time.

Figure 2. Map of expected $M_{max}$ for most subduction zones around the world. In case of higher uncertainties, the upper maximum $M_{max}$ is indicated by differently colored outline. Line thickness indicates qualitative tsunami-genic potential. Plate boundaries based on Bird (2003).
2.5 Loss Modelling

The last component of the risk model comprises the elements of exposure and vulnerability. The first part has been resolved using the data of Daniell (2014) and combined with topography data to compile a country-level coastal exposure database considering population and capital stock. The exposure is based on the global GHS population model Pesaresi, et al. (2016) and thus also underlies specific uncertainties. Each raster value of the exposure model is associated with the number of people living, e.g. within a 90x90m cell and the associated capital stock.

The vulnerability has been discretized using 3 building classes resolved under consideration of the global building inventory database of Daniell et al. (2011) and empirical vulnerability and fragility functions resolved from damage observations of the 2004 Sumatra-Andaman, 2009 American Samoa and 2011 Tohoku tsunamis. Those building classes comprise light, average and solid buildings based on the description of Tarbotton, et al. (2015). Similarly, a vulnerability function for fatalities has been developed combining the results of Suppasri et al. (2016) and Latcharote et al. (2017). Thus, fatality ratios not only depend on inundation depth, but also on the arrival time. However, most of the empirical data came from the 2011 Tohoku tsunami, thus there is a potential bias expected to potentially underestimate fatalities and loss in regions where coastal protection and early warning systems are not equally well developed.

2.6 Summary

In summary, with the hazard components, tsunami source variability, fast wave propagation and inundation simulation and the framework to calculate direct economic and social losses for tsunamis, the whole system is capable of computing deterministic and probabilistic tsunami hazard and risk almost anywhere in the world. There are some acceptable limitations within this study. For example, several subduction zones which may be prone to tsunami-genic activity are still of high uncertainty, the simplification of the wave propagation process for the sake of computational speed or uncertainties in the current exposure and vulnerability model. Nonetheless, this framework provides a globally applicable and sufficiently well constrained tsunami risk model. It heavily relies on the computational framework, Tsupy, which has been significantly advanced and developed during this study.

3. CASE STUDY – CARIBBEAN

This case study focuses on a small and lucid area, the Lesser Antilles, a group of small island states. Most of these islands are not much larger than 1000 km². The advantage of choosing this area is first the presence of only one major source for large tsunamis, the Lesser Antilles subduction zone, a 1200 km long convergence zone between the oceanic North American plate and the Caribbean plate. Other potential sources in the region for regional tsunamis are the Puerto Rico and Hispaniola Trenches, the Muerto Trough and some smaller convergence zones near Jamaica and offshore Venezuela. However, in contrast to the Lesser Antilles the uncertainties for those sources are much larger and return periods are expected to be also much longer.

So far, only one major tsunami event has been reported in 1843. The event is still under debate and magnitude estimates reach from $M_w = 7.8 – 8.6$. However, recent studies are pointing more towards the top end of such estimates (e.g. Hough (2013)), even though the actual source and size may probably remain unknown. Beyond historic records, several paleo-tsunami sites indicate the existence of several pre-colonial tsunami events (e.g. Scheffers and Kelletat (2006), Engel et al. (2010)).

The known historic seismicity in the Eastern Caribbean is limited to colonial times, thus records exist to some extent for the last 500 years and indicate several tsunamis (O’loughlin and Lander, 2003), (Accary and Roger, 2010). $6 \ M_w > 7$ events occurred since the beginning of the last century, indicating a possible average return period of about 20 years for those magnitudes. Yet, the associated fault system of each event is not clearly defined, some occurred e.g. on the down-going slab (as in 2007) or happened through normal faulting (in 1974, see McCann et al. (1982)), while others may be associated with thrust processes in the accretionary prism (as in 1969).

One of the earliest studies on earthquake return periods for the Lesser Antilles was developed by
Molnar (1979), he considered the maximum possible magnitude based on the available seismic moment would be equivalent to an $M_w = 8.4$ earthquake. However, Rong et al. (2014) and McCaffrey (2008) estimated the potential maximum magnitude in the range of 8.8-9.3, which is in accordance to the results of this study of about 9.2. In addition, Hayes et al. (2014) identified a slip deficit in the Lesser Antilles for the last 100 years, equivalent to an $M_w = 8.2 \pm 0.4$ earthquake. In addition, the region was also affected by tele-tsunamis like the 1755 Lisbon tsunami, however, those distant sources are excluded in this case study.

Figure 3. Overview of the Lesser Antilles island states and the potential inundation based on a $M_w = 9.0$ tsunami-earthquake

### 3.1 Hazard Model

For a probabilistic assessment of tsunami risk from the Lesser Antilles Trench affecting several Caribbean island states, a total of 440 tsunami scenarios have been simulated with a magnitude range of $M_w = 8.0 - 9.1$ each having a unique slip distribution. From this event set, a stochastic catalogue of magnitudes is sampled. With an average b-value of 0.86 and an a-value of 4.56 the average return period based on a tapered Gutenberg-Richter model of earthquakes with $M_w \geq 8$ is about 200 years and for $M_w \geq 9$ earthquakes about 2700 years.

13 countries of the Lesser Antilles island arc are assessed, all of them are small to moderate sized islands or island groups and part of the Leeward and Windward Islands without the Virgin Islands. The simulation was taken out on a calculation grid with a resolution of 1 km between latitudes 9.5°N and 20.5°N and longitude 66°W and 55°W. In addition, the inundation of each state was computed using several 90m resolution grids with a geometry based on a rectangular outline of each island with a minimum distance between coast and calculation boundary of at least 5 km. Each simulation stored maximum inundation and the arrival time of the first 1m wave at each raster point. To compute sufficiently reliable statistics, a stochastic event catalogue of 1000000 years was computed from 440 simulated tsunami scenarios, however only assessing 100000 years of return period data.

### 3.2 Country-Risk

The results are summarized in Table 1 showing some distinct differences visible among the different island states. First, countries with a larger exposure of course also show a bigger AAL. The highest risk show Martinique, Guadeloupe, St. Lucia and Antigua and Barbuda. On the other side, Montserrat, Anguilla and St. Kitts and Nevis have less than $10,000 of average annual loss. Thus, it is very important to analyse loss compared to the total GDP of the country. To get an easy-to-read metric, the time period for the loss equivalent to 1% of GDP is computed based on the AAL. Thus, the most affected country is St. Martin in terms of loss, followed by Martinique, Antigua and Barbuda, St. Lucia and Grenada which all must expect at least 1% of GDP-equivalent reconstruction cost in less than a century. Anguilla, St. Kitts and Nevis and Montserrat will see such a level of damage not more
often than every 1000 years. In general, Anguilla and the North-Western islands are naturally better protected from tsunamis off the Lesser Antilles Trench due to their distance but also since they are well shielded by the other islands before the wave arrives, while St. Lucia, Martinique and Guadeloupe are most frequently hit. Anguilla is one of the safest places in regards of Lesser Antilles Trench tsunamis since it is located at the northern end of the island arc and thus shielded from tsunamis in many cases and the travel time of the tsunami wave is also longer than for most other places. But also since the exposure is relatively evenly distributed and not clustered along the coast. On the other side, it is located very close to the Puerto Rico Trench which may be the dominating source for tsunami risk for that island state, yet this is part of a future assessment.

Table 1. Overview of loss metrics for the Lesser Antilles island states. 1%-LRP describes the loss return period equivalent to 1% of GDP. AAL=Average Annual Loss, PML=Probable Maximum Losses, PMD=Probable Maximum Deaths.

<table>
<thead>
<tr>
<th>Country</th>
<th>AAL</th>
<th>1%-LRP</th>
<th>PML1000</th>
<th>PMD1000</th>
<th>PML10000</th>
<th>PMD10000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anguilla</td>
<td>2.2</td>
<td>1432</td>
<td>0.0</td>
<td>0.0</td>
<td>2318.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Antigua &amp; Barbuda</td>
<td>293.5</td>
<td>49</td>
<td>31551.7</td>
<td>0.3</td>
<td>644236.6</td>
<td>46.4</td>
</tr>
<tr>
<td>St. Barthelemy</td>
<td>50.3</td>
<td>50</td>
<td>1010.0</td>
<td>0.0</td>
<td>148807.5</td>
<td>6.3</td>
</tr>
<tr>
<td>Barbados</td>
<td>159.2</td>
<td>288</td>
<td>6402.0</td>
<td>1.5</td>
<td>314830.1</td>
<td>121.9</td>
</tr>
<tr>
<td>Dominica</td>
<td>39.9</td>
<td>130</td>
<td>973.2</td>
<td>0.1</td>
<td>95674.1</td>
<td>136.7</td>
</tr>
<tr>
<td>Guadeloupe</td>
<td>1327.1</td>
<td>77</td>
<td>92414.4</td>
<td>3.1</td>
<td>3422326.0</td>
<td>766.1</td>
</tr>
<tr>
<td>Grenada</td>
<td>236.0</td>
<td>43</td>
<td>22878.2</td>
<td>0.9</td>
<td>742776.3</td>
<td>554.8</td>
</tr>
<tr>
<td>St. Kitts and Nevis</td>
<td>13.3</td>
<td>691</td>
<td>1134.1</td>
<td>0.0</td>
<td>17428.3</td>
<td>0.5</td>
</tr>
<tr>
<td>St. Lucia</td>
<td>353.8</td>
<td>40</td>
<td>57316.2</td>
<td>9.7</td>
<td>715929.1</td>
<td>778.2</td>
</tr>
<tr>
<td>St. Martin</td>
<td>220.4</td>
<td>22</td>
<td>4174.2</td>
<td>0.0</td>
<td>681697.3</td>
<td>12.9</td>
</tr>
<tr>
<td>Sint Maarten</td>
<td>23.5</td>
<td>954</td>
<td>479.7</td>
<td>0.0</td>
<td>59074.0</td>
<td>1.2</td>
</tr>
<tr>
<td>Martinique</td>
<td>3267.0</td>
<td>30</td>
<td>491427.2</td>
<td>38.3</td>
<td>6571833.0</td>
<td>3205.1</td>
</tr>
<tr>
<td>Montserrat</td>
<td>0.1</td>
<td>5161</td>
<td>0.0</td>
<td>0.0</td>
<td>116.1</td>
<td>0.0</td>
</tr>
<tr>
<td>St. Vincent and the Grenadines</td>
<td>123.3</td>
<td>62</td>
<td>29458.4</td>
<td>3.9</td>
<td>227916.0</td>
<td>196.9</td>
</tr>
</tbody>
</table>

Among the two-island state Antigua & Barbuda, Barbuda is more hazard-prone due to its significantly lower elevation of mostly less than 50m. However, Barbuda inhabits only about 1600 people and thus has only minor exposure. Antigua has a much more pronounced elevation, yet due to its exposed location, the whole states faces tsunami loss rather frequently and thus loses about 1% of its GDP about every 50 years. Almost the same situation faces St. Barthelemy however with just a tenth of the available exposure, but a similar AAL ratio. On the other side, Dominica, located in the centre of the Lesser Antilles benefits from its steep coasts and low exposure. Same holds for the island of Montserrat where low exposure and steep coasts are reducing the potential tsunami impact. St. Kitts & Nevis can also be considered fairly protected from tsunami impacts. Being location in a second row of islands, most tsunami waves are likely to have lost a significant part of their energy before they reach the coast, in addition, a steep coastline is also beneficial avoid most tsunami damage.

In contrast, Barbados is a very interesting case, it is located well further East compared to the other states. It could be expected that due to its exposed location its tsunami risk is increased. But it is aligned with the area of earthquake ruptures and is thus either perpendicular to the tsunami direction and thus less affected, and in case the rupture occurs within its vicinity, it is often part of the direct uplift which is also decreasing the tsunami threat leading to a rather moderate tsunami risk compared to the other island states.

Guadeloupe and Martinique face the highest average annual death toll since both country have also the highest exposure, in addition, Martinique faces a 1% GDP loss about every 30 years, while for Guadeloupe it takes more than twice as long. This mostly because both countries have a lot of exposure located in low-lying coastal areas. Similarly, considering the total population of the
countries, St. Lucia and Grenada are high on the fatalities, but also losing an equivalent of 1% of GDP every 40 years.

Even though Saint Martin and Sint Maarten share the same island, their tsunami risk is quite different. The AAL is almost 10 times higher in Saint Martin and the PML10000 is equivalent to almost 140% of its GDP. In Sint Maarten, this value is just about 3%. The huge difference originates from a different exposure distribution with respect to topography. Considering the used digital elevation model, the towns of Green Cay and Sandy Ground in Saint Martin are very low lying while in Sint Maarten the exposure is mostly located on grounds higher than 10m. However, the exposure model does not very accurate around the Juliana Airport and Port Blanche, this may lead to an underestimation of loss there.

The occurrence of fatalities during tsunami events in the Caribbean based on the model using Japanese observations may underestimate the actual numbers, but no empirical data can currently validate that. Several islands are low-lying and whether people will reach high ground in time is open. This is also of special importance since the evacuation time is directly linked to the early warning time. Depending on island and epicentre, the tsunami waves reach almost any place of in the Lesser Antilles within much less than 2h, while some islands may be affected within less than 20min.

In this study, the economic loss is considered as the reconstruction cost after the tsunami event, comparing these numbers with the total GDP, the average annual loss is almost negligible being well small than 0.01% in most cases. However, the loss is here dominated by long-term events, and individual disasters are likely to cause a major disruption for most of the Lesser Antilles island states. Even though being under debate, a maximum magnitude of $M_w = 9.1$ within 10,000 years introduces a significant risk for the whole region and on a trans-oceanic level. Among all assessed countries, such an event will cause a loss equivalent to 35-40% of GDP in average, while some countries may face even more than twice that value.

4. CONCLUSIONS

This study introduced a modelling frame for the assessment of probabilistic tsunami risk on global scale. Compared to other studies, it provides an efficient way to compute risk in terms of expected loss for a specific time. Advantage is here the use of GPUs to simulate tsunami wave propagation. However, the assessment of tsunami return periods is similar to previous approaches. The loss component builds on empirical vulnerability equations of the last decade and is also thus limited to the affected exposure of those previous tsunamis. Same holds for the estimation of fatality ration which is completely resolved from the observations of the 2011 Tohoku tsunami. In addition, limitations in the quality of the topography and bathymetry models affect the results introducing additional uncertainties together with the general earthquake source variability which is of high importance especially for larger earthquakes.

First results are provided for the Caribbean area of the Lesser Antilles. Here, clear differences in loss can be correlated with the islands location, distribution of exposure and topography, which are a crucial component for the country’s tsunami risk. The methodology has been built from globally available data and is thus applicable anywhere in the world where tsunami risk is of relevance like in South East Asia or the Americas. Future studies will focus on a global country-by-country tsunami risk assessment. Using the same methodological framework globally makes it possible to compare tsunami risk quantitatively all over the world.

In conclusion, this study provides a probabilistic tsunami risk assessment model, which is efficient enough to operate independent of supercomputing environments for tsunami wave simulation, but which also depends highly on the empirical data from the recent tsunami observations since 2004.

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