Dr. Matthieu Péroche

Dr. Marion Le Texier

Lecturer, Université de Montpellier Paul-Valéry, LAGAM (France)

- Geographer specialized in natural hazards
- Active contributor to the work of the Intergovernmental Coordination Groups (ICG) on tsunami risk management
- Developer of participatory approaches to evacuation planning and mapping with local authorities and communities
- Contributor to the design of decision-making tools integrated into Standard Operating Procedures (SOPs) and organiser of crisis management exercises
- Creator of multi-scale spatial risk GeoIndicators

- Geographer specialized in data processing and modelling applied to human mobility, land use and natural risk media coverage (publications in diverse scientific journals: Cartography and Geographic Information Science, Applied Geography, Environment and Planning B, Journal of Environmental Management, Geoscience Communication, …)
- Deputy Vice President for Ecological Transition of University Paul Valéry Montpellier
- Member of the French National Council of Universities

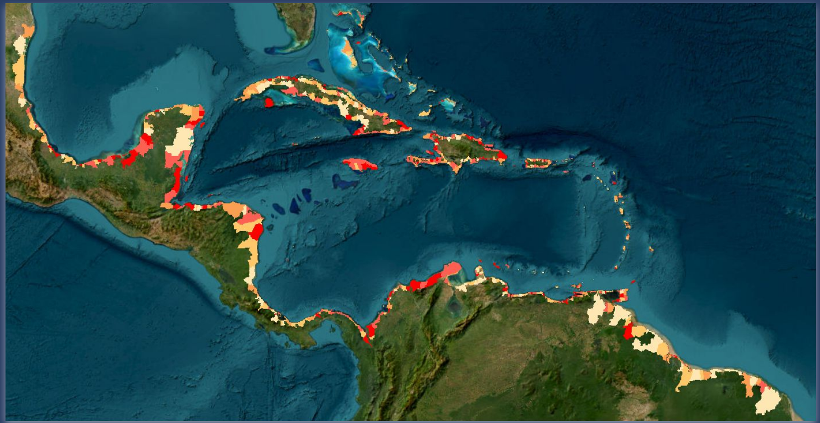
ODTP-SC Meeting

UNESCO Paris - January 16, 2025

Methodological Protocol for Tsunami Risk Ranking at the Community Level in the Caribbean Basin

Dr. Matthieu Péroche

Dr. Marion Le Texier



Caution: This presentation is a working document.

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Objectives

- Identify Eligible Communities
- Rank Evacuation Needs
- Rank Tsunami Hazard Exposure
- Rank Tsunami Risk

Objectives

- **Identify Eligible Communities:** determine the number of communities that could apply for IOC-UNESCO Tsunami Ready recognition
- Rank Evacuation Needs
- Rank Tsunami Hazard Exposure
- Rank Tsunami Risk

Objectives

- Identify Eligible Communities
- **Rank Evacuation Needs:** assess the number of people who would need to be evacuated locally (communities), nationally (countries), and regionally (Caribbean basin) in the event of an anticipated tsunami.
- Rank Tsunami Hazard Exposure
- Rank Tsunami Risk

Objectives

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- Identify Eligible Communities
- Rank Evacuation Needs
- **Rank Tsunami Hazard Exposure:** Identify the communities most exposed to tsunami hazards based on numerical simulation results.
- Rank Tsunami Risk

Objectives

- Identify Eligible Communities
- Rank Evacuation Needs
- Rank Tsunami Hazard Exposure
- **Rank Tsunami Risk:** identify priority communities for the implementation of prevention and crisis management measures by crossing evacuation needs and hazard exposure ranks.

Objectives

- Identify Eligible Communities
- Rank Evacuation Needs
- Rank Tsunami Hazard Exposure
- Rank the level of tsunami risk

Methodological protocol **applicable to the entire Caribbean basin** and further **replicable at the global scale**

Reproducibility & transparency

Criteria for data selection:

- Available and homogeneous at global scale
- Accurate (both in terms of quality and temporality)
- Open access

Criteria for data modelling:

- Open source programming language (R)
- Code delivered alongside the study results

Communities delineation

A **community** is defined by **territorial boundaries** to associate tsunami risk metrics.

- Data from OpenStreetMap (shared territorial ontology on a global scale), downloaded in 2024
- Administrative level from 2 to 8 (equivalent to French municipalities)
- Eligibility rule: hosting an evacuation zone

Data source:
OpenStreetMap

Study area - 41 small states or territories bordering the Caribbean Sea (7 694 territorial boundaries), excluding the United States and Brazil.

Communities delineation

➢ **Obtaining territorial boundaries in vector format for the entire Caribbean region**

Main technical steps

- **Identify administrative level :** determine the appropriate administrative level for each country using the OSM Wiki table.
- **Download boundaries :** Obtain terrestrial administrative boundaries from the OSM-boundaries website.
- **Visual verification :** Conduct a visual check of entities and manually adjust geometries if necessary.
- **Complete attribute table :** Populate the attribute table according to the metadata file provided.
- **Merge boundaries:** Combine the boundaries of each state into a single unified file.

Main Challenges

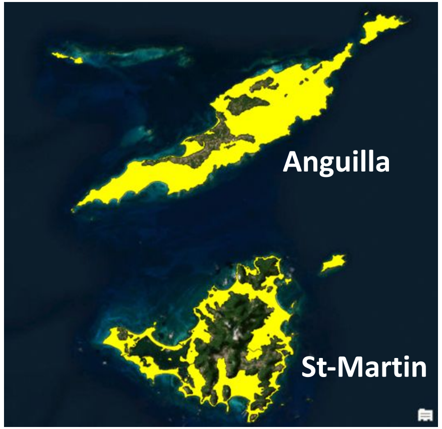
- Variations in administrative levels across countries and regions
- Topological issues in the data
- Missing data for small islands
- Difficulty accounting for barrier islands and lagoons

Evacuation zones delineation

A **evacuation zones** defined by a **maximum distance from coastlines** (3KM) **AND** the presence of areas located between **0 and 15 meters a.s.l.** and **0 and 30 meters a.s.l**

Elevation grids - GLO-30 Data Advantages

- Copernicus Digital Elevation Model (DEM)
- Global coverage at a resolution of 30 metres
- Absolute vertical accuracy: < 4m (90% linear error). Relative Vertical Accuracy: < 2m for slopes below or equal 20%;
- Derived from multiple sources, including **TanDEM-X**, providing reliable data



→ THE EUROPEAN SPACE AGENCY

Evacuation zones dataset

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Task #1 : Map the baseline coastline in order to map the maximum evacuation zone inland

Main Steps

- **Coastline Definition:** Use OSM terrestrial boundaries, refining generalization with GIS.
- **Manual Adjustments:** Apply photo-interpretation for complex areas (ponds, estuaries) and extend the coastline several kilometers inland along major rivers, particularly in South America, to account for tsunami risks.
- **Buffer Zone:** Generate a 3 km inland buffer using GIS tool

Main Challenges

- **Complex coastal configurations**: Estuaries, lagoons, and lido coasts require special attention.
- **Manual certification** needed for areas with ponds, channels, and large rivers.

Evacuation zones dataset

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Task #2 : Mapping Elevations Below 30 and 15 Meters a.s.l.

Main Technical Steps

- **Select and download**: Access GLO-30 data for the 3 km coastal zone from the dedicated server.
- **GIS processing**: Apply a GIS workflow to map areas below **30 m and 15 m**, smoothing boundaries, filling micro-reliefs, and removing non connected topographic depressions.

Main Challenges

- **Data management**: the large number of files to be downloaded in the form of tiles
- **Data management**: the weight of the files to be processed

Evacuation zones dataset

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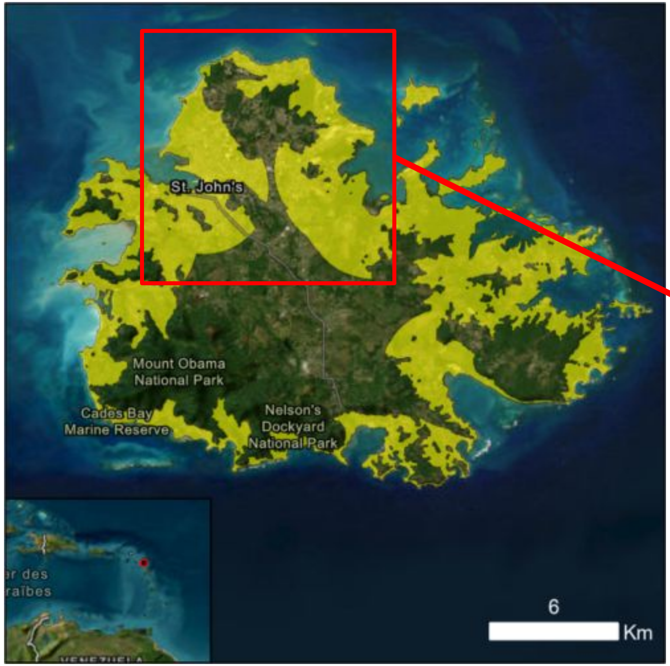
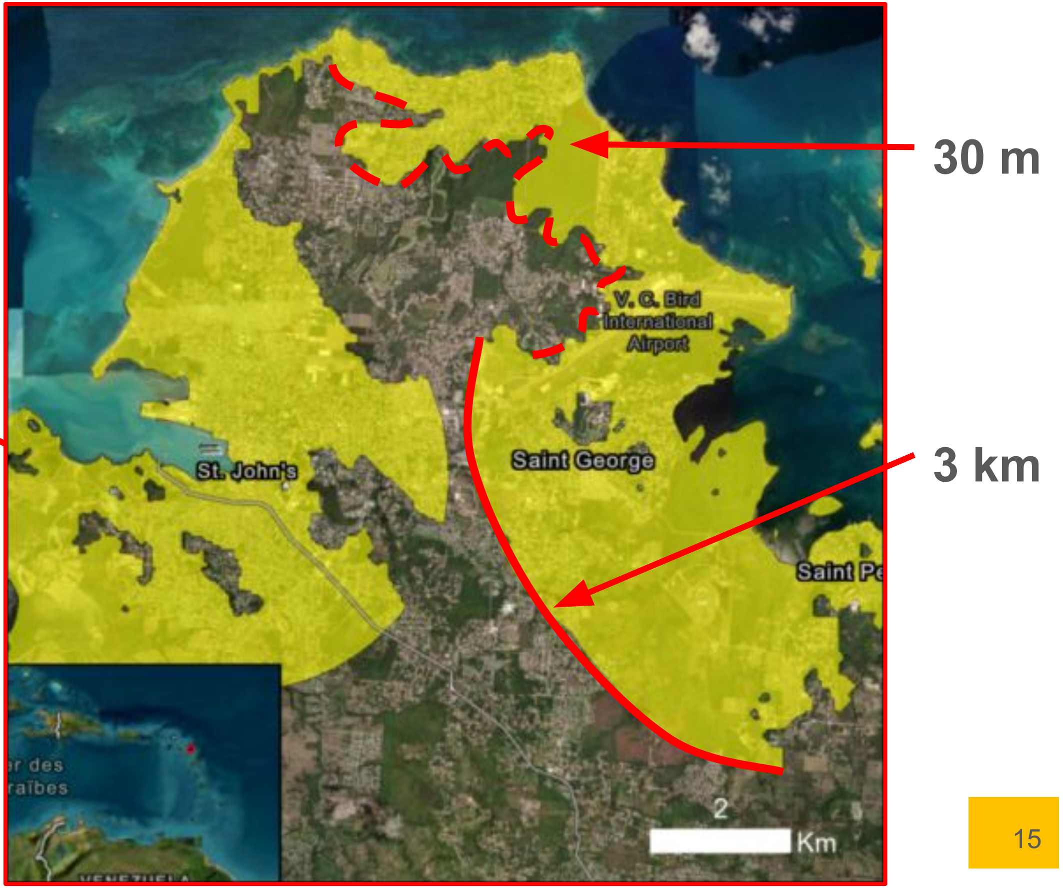
Example of the "30m" Evacuation Zone (Antigua)

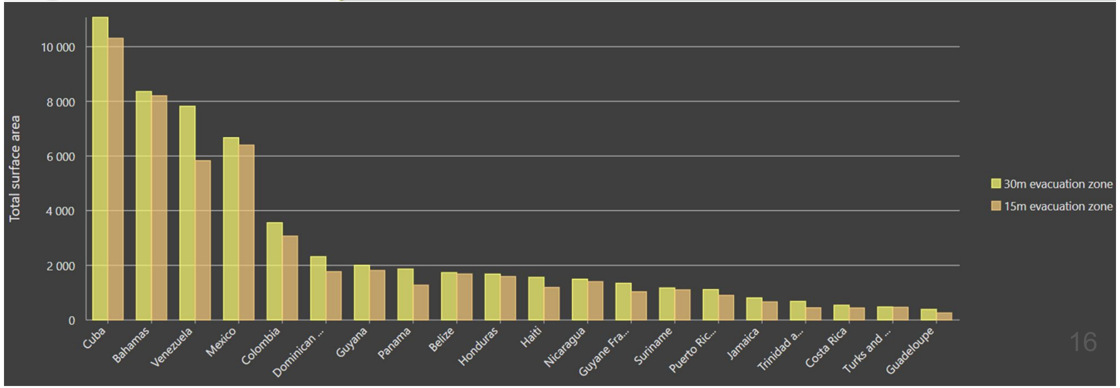




Intermediary results

The area to be evacuated defined at 30 m a.s.l. (limited to 3 km inland) has an estimated surface area of **59,000 km²**

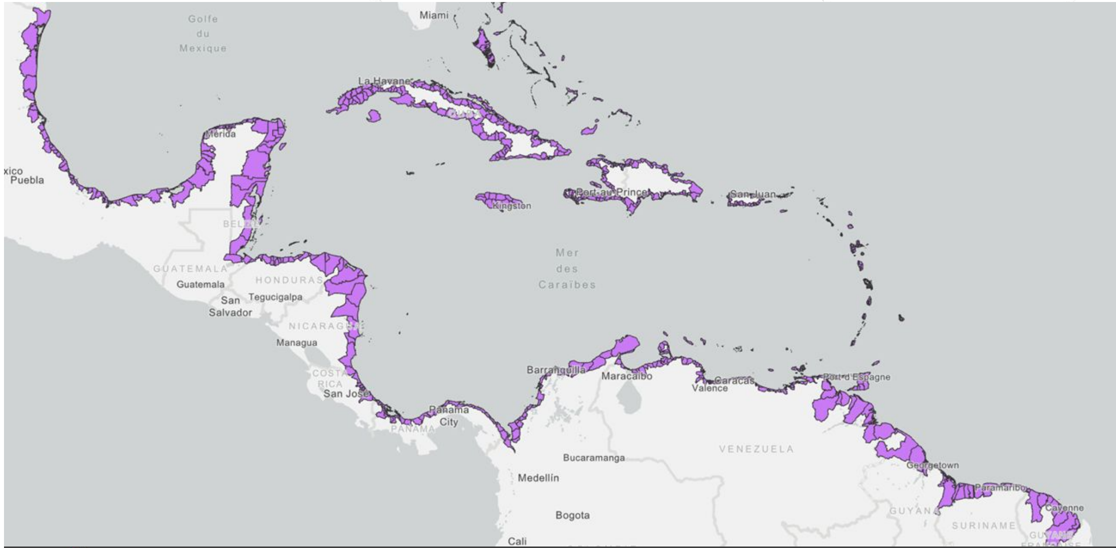
The area to be evacuated defined at 15 m a.s.l. (limited to 3 km inland) has an estimated surface area of **51,000 km²**

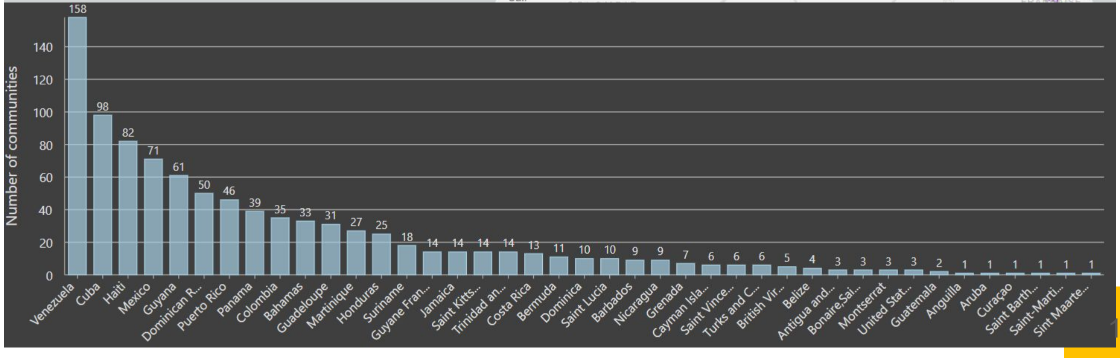


RESULT 1: eligible communities

A total of **946 communities** are included in the evacuation zone at an altitude of 15 or 30 meters

35 of these are without direct access to the sea (still need to be checked manually)



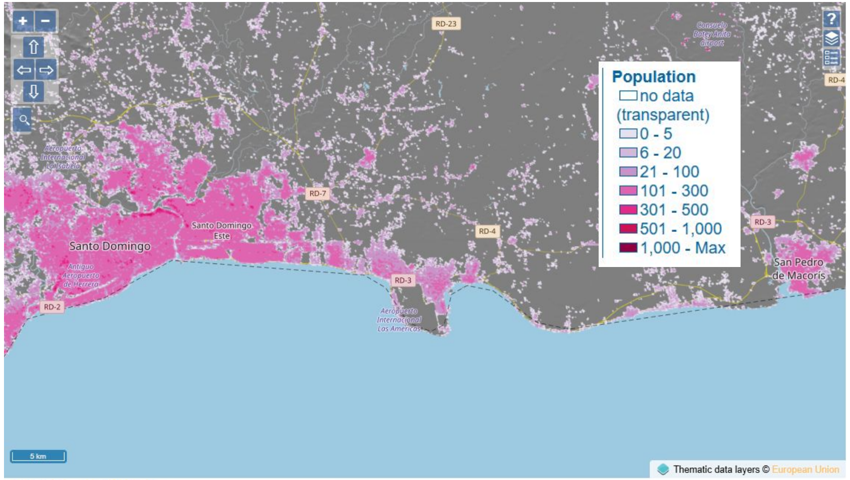


Evacuation needs estimation

Evacuation needs are defined by the **size of the population living in the evacuation zones.**

Population grids

- Copernicus Global Human Settlement Layer (GHSL)
- Residential population in 2020 expressed as the number of people per cell
- Data derived from the raw global census data harmonized by CIESIN for the Gridded Population of the World, version 4.11 (GPWv4.11)
- Spatial resolution: 100 m

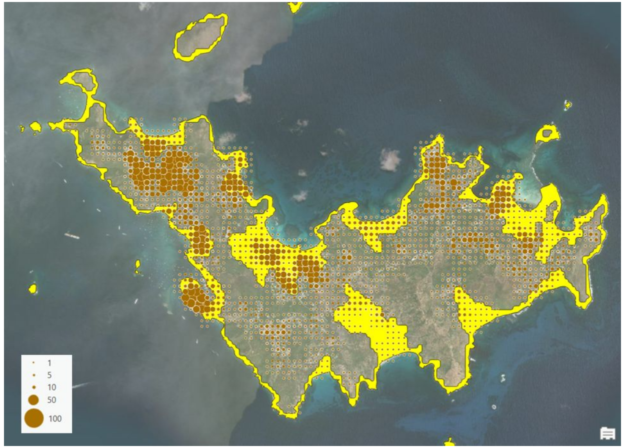


Layers selected:
Population - P2023 (res.: 100m): 2020

GHSL - Global Human Settlement Layer

Evacuation needs dataset

To estimate the population within the evacuation zone, **Global Human Settlement Layer (GHSL)** data were chosen, specifically the **GHSL-POP R2023 version**, due to its high resolution and wide temporal coverage.



Main Technical Steps

1. **Selection of GHSL Data**
   - Download **2020 GHSL data** for the **3 km coastal zone**.
2. **GIS Processing Chain**
   - Apply a GIS workflow to extract population data for municipalities and evacuation zones.

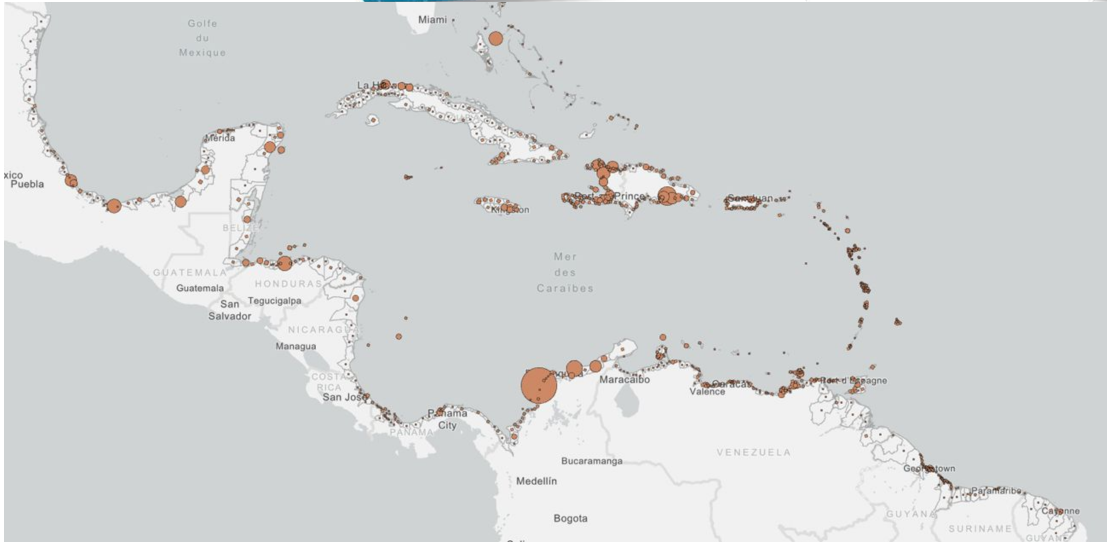
Main challenges

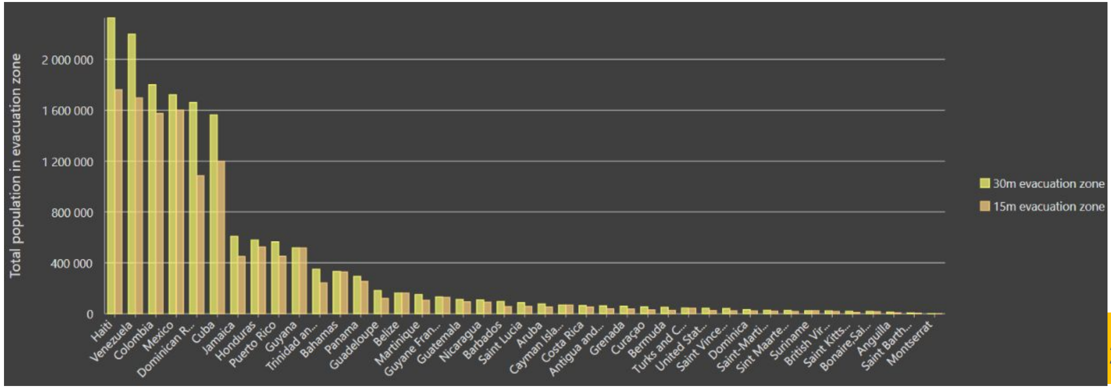
- Demographic data come from global census-based datasets.
- Redistribution issues may occur in sparsely populated areas (e.g., industrial zones).
- Results include only resident populations, excluding workers or transient groups.
- Provides an estimated range of people to evacuate rather than exact numbers.

Intermediary results

Nearly 47,030,000 people were detected as living in coastal communities.

It was estimated that around **16,300,000 (35%)** people would live in the 30m evacuation zone and **13,000,000 (28%)** in the 15m evacuation zone.





TENI - Tsunami Evacuation Needs Index

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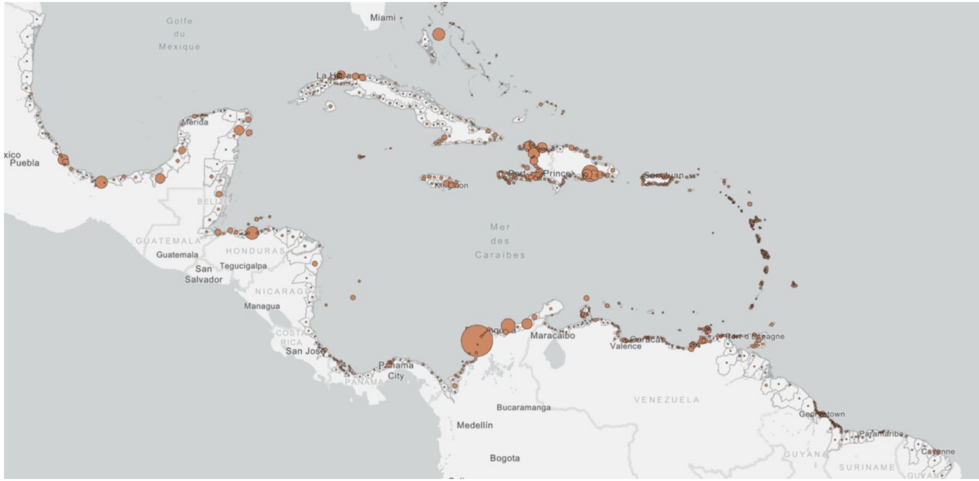
Composite index

1. **Percentile of number of the community inhabitants living in the evacuation zone**
2. …
3. …



TENI - Tsunami Evacuation Needs Index

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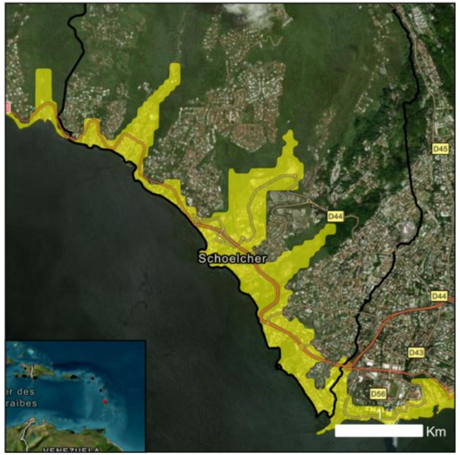
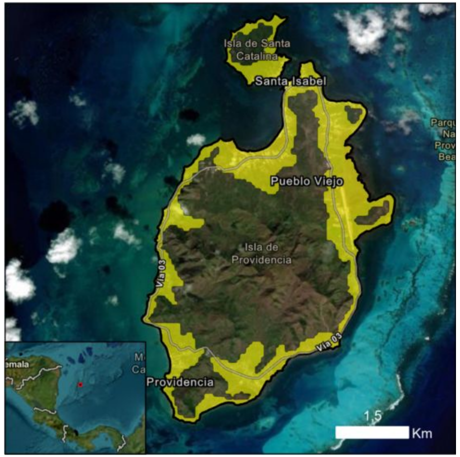
Composite index

1. Percentile of number of the community inhabitants living in the evacuation zone
2. **Percentile of share of the community inhabitants living in the evacuation zone**
3. **...**



Schoelcher municipalitiy (Martinique, France)



Archipelago of Saint Andrew, Providence and Saint Catherine (Colombie)

Total popualtion 20 893
5 123 (24,52%)

5 091
4 859 (95,46 %)

TENI - Tsunami Evacuation Needs Index

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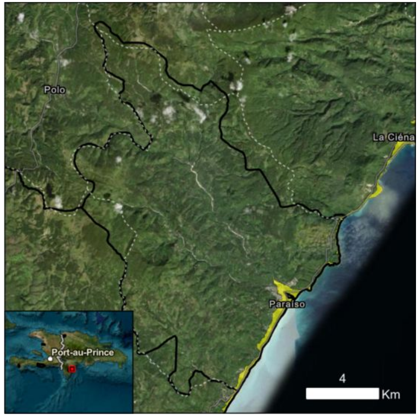
Composite index

1. Percentile of number of the community inhabitants living in the evacuation zone
2. Percentile of share of the community inhabitants living in the evacuation zone
3. **Percentile of share of the community area included in the evacuation zone**



Paraíso (Dominican Republic)	Útila (Honduras)
136.32 km²	41,41 km²
2.872km²	41,407
0,021	0,998

TENI - Tsunami Evacuation Needs Index

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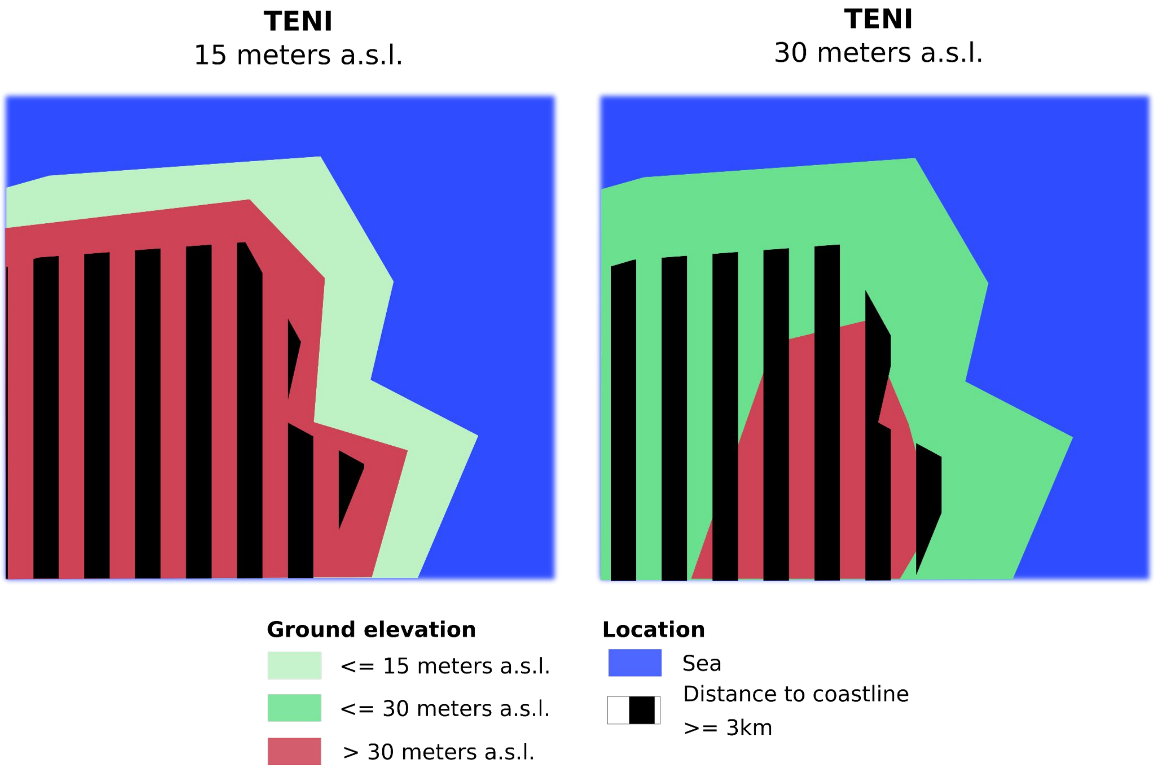
Weights defined through a structured expert elicitation process)

Composite index

1. Percentile of number of the community inhabitants living in the evacuation zone	**80 %**
2. Percentile of share of the community inhabitants living in the evacuation zone	**10 %**
3. Percentile of share of the community area included in the evacuation zone	**10 %**

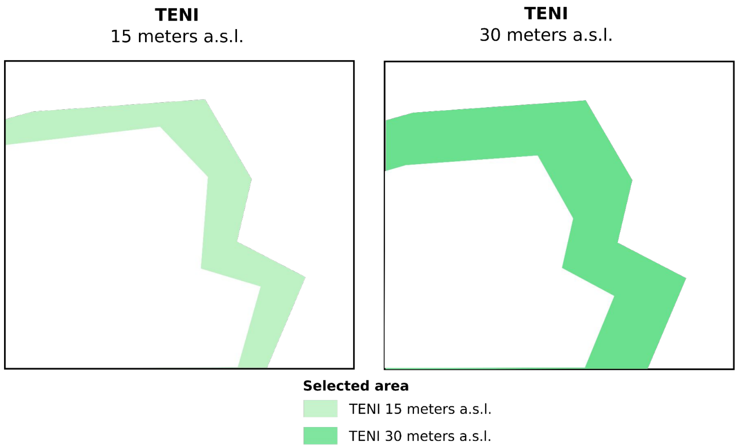
TENI - Calculation for the two evacuation zones

Schematic Representation of the Two Evacuation Zones used for TENI calculations

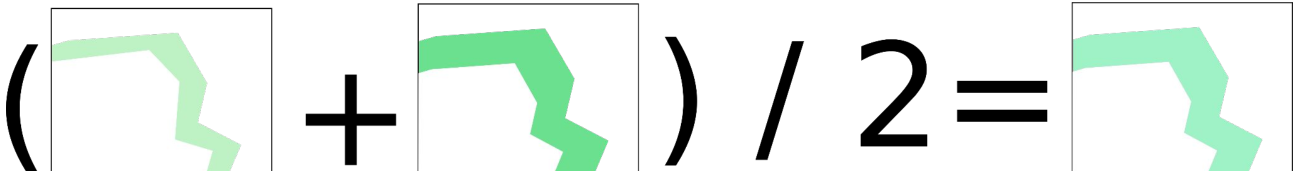


TENI - Calculating an average value

Deriving a global TENI by averaging the values from the two evacuation zones



TENI
Global



Objective:

- Facilitate comparisons on a basin-wide scale without favoring one evacuation scenario over another.
-
- This weighting highlights the higher vulnerability of **communities with concentrated issues at lower altitudes** in large-scale evacuation scenarios.

RESULT 2 - Tsunami Evacuation Needs Index

Key Results:

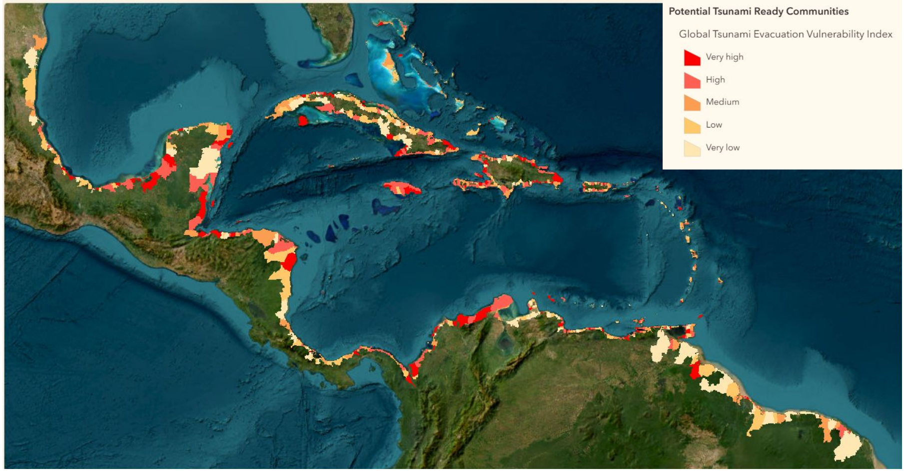
- **130+ communities** have a **very high vulnerability index**.
- **223 communities** have a **high vulnerability index**.

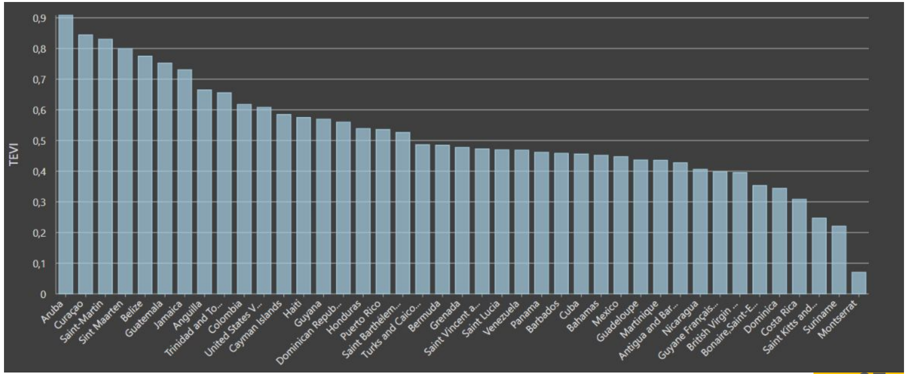
Communities with the Highest Vulnerability (TEVI_GL):

1. **New Providence, Bahamas** – 0.9655
2. **Boca del Río, Mexico** – 0.9575
3. **Cité Soleil, Haiti** – 0.9565

Country with the Most High-Vulnerability Communities:

- **Venezuela** – 23 communities





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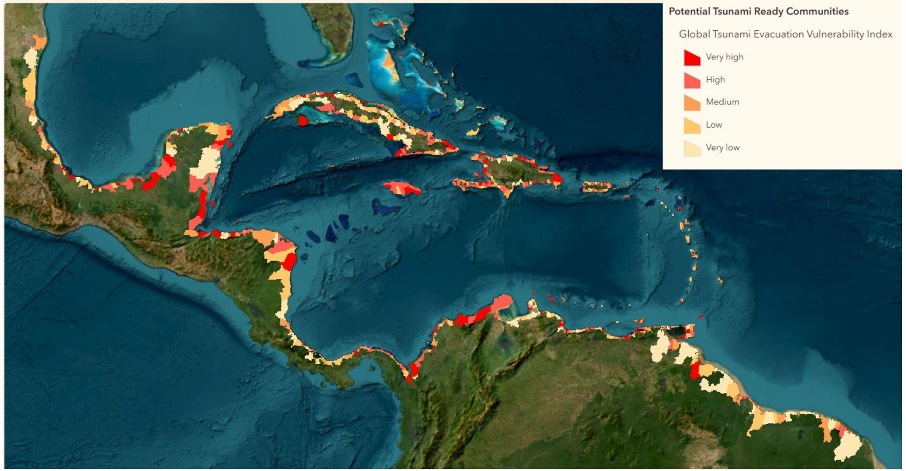

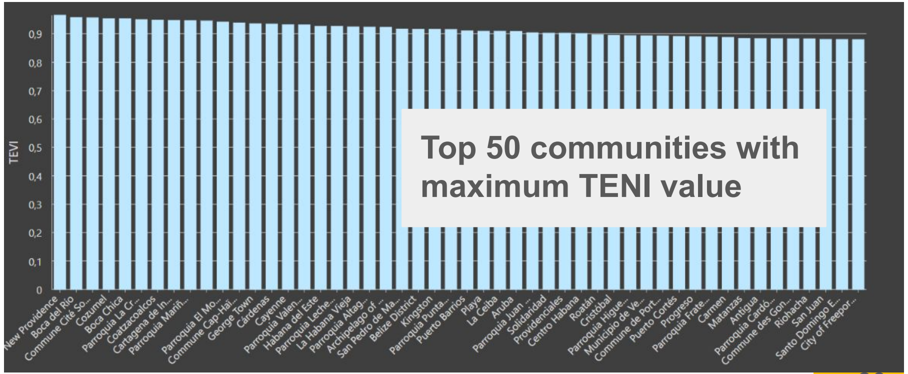

RESULT 2 - Tsunami Evacuation Needs Index

Access the online map via this link :

https://www.arcgis.com/apps/dashboards/a2d4b82b96524321bed19abd3b13ac0a

Tsunami Hazard Exposure

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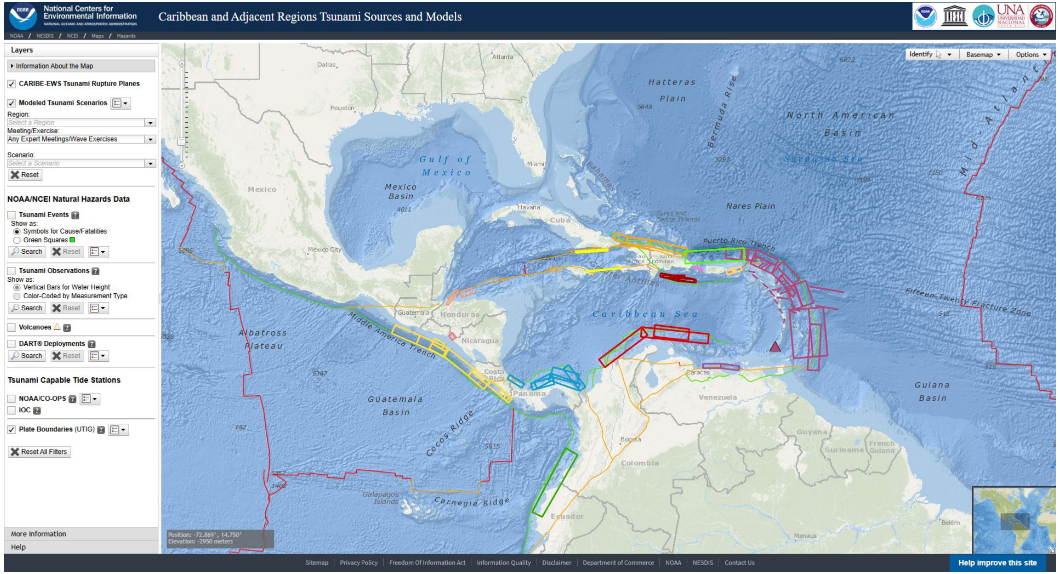
Tsunami hazard exposure is defined by a **generalized measure** of **wave amplitudes at the coast**.

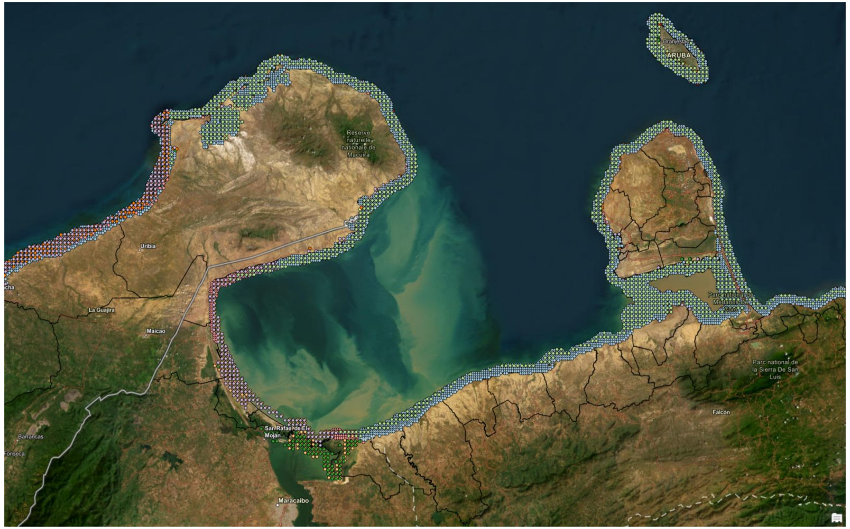
- Amplitude grid with a spatial resolution between 900m and 1800m
- CATSAM (Caribbean and Adjacent Regions Tsunamis Sources and Models)
- Scenarios based on historical events and/or tectonic and geodetic data
- 56 scenarios were used (including 15 used in CaribeWave Exercises)



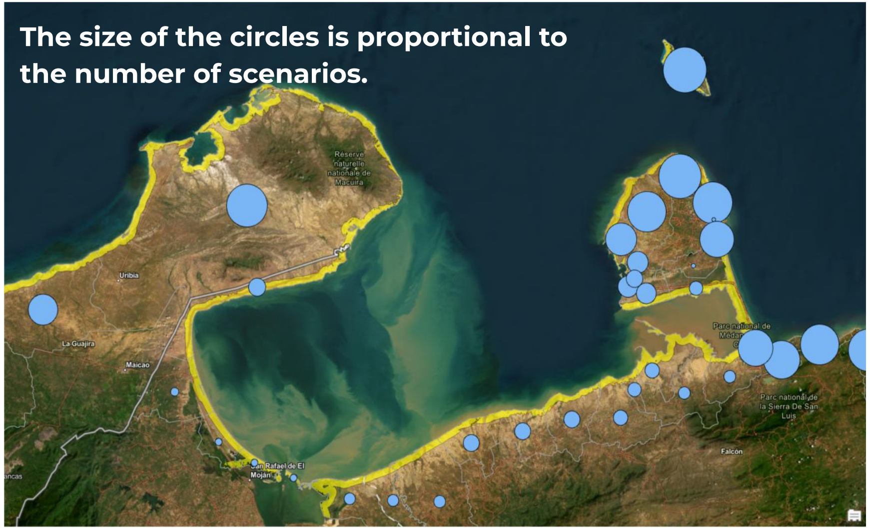
Tsunami Hazard Exposure database

Main challenges:

We assign tsunami amplitude values to the nearest communities (euclidean distance)



For specific scenarios, certain communities lack associated values.



THI - Tsunami Hazard Index

THI quantifies the **degree of exposure** of each municipality to tsunami hazard by calculating a **score based on the number of scenarios within each of the five wave amplitude classes used by PTWC**

Values	**Classes**
0	scen0
] 0 ; 0.3]	scenC1
] 0.3 ; 1]	scenC2
] 1 ; 3]	scenC3
> 3	scenC4

THI - Tsunami Hazard Index

THI represents the weighted average value class, calculated as follows:

THI = $[(scen0 \times 0) + (scenC1 \times 1) + (scenC2 \times 2) + (scenC3 \times 3) + (scenC4 \times 4)]/nbScen$

where scen0, scenC1, scenC2, scenC3, scenC4 are the value classes, and nbScen is the total number of scenarios

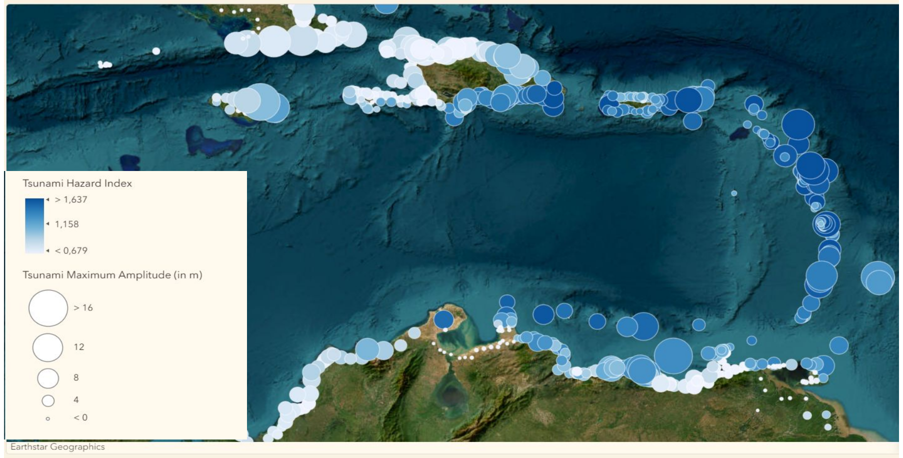
Theoretically, the index is confined within an interval between 0 and 4

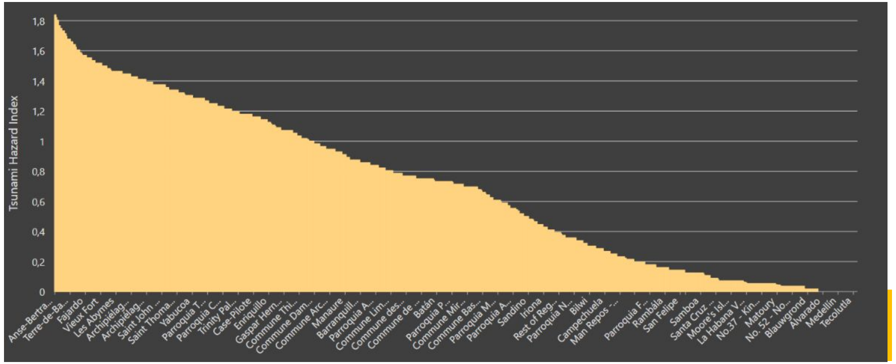
Territory	scen0	scenC1	scenC2	scenC3	scenC4	THI
A	56	0	0	0	0	0,00
B	0	56	0	0	0	1,00
C	0	0	56	0	0	2,00
D	0	0	0	56	0	3,00
E	0	0	0	0	56	4,00
F	16	10	10	10	10	1,79
G	12	30	10	3	1	1,13
H	24	24	0	3	5	0,95

RESULT 3 - Tsunami Hazard Index (THI)

Distribution Analysis:

- **No community reaches the maximum theoretical THI score of 4**.
- The middle **50% of communities (between the 1st and 3rd quartiles)** have THI values between **0.21 and 1.18**, indicating **heterogeneous local situations** within the basin.
- **A significant number of communities** experience tsunami scenarios where the **average maximum amplitude exceeds the first “PTWC” threat level threshold (THI ≥ 1)**.





RESULT 3 - Tsunami Hazard Index (THI)

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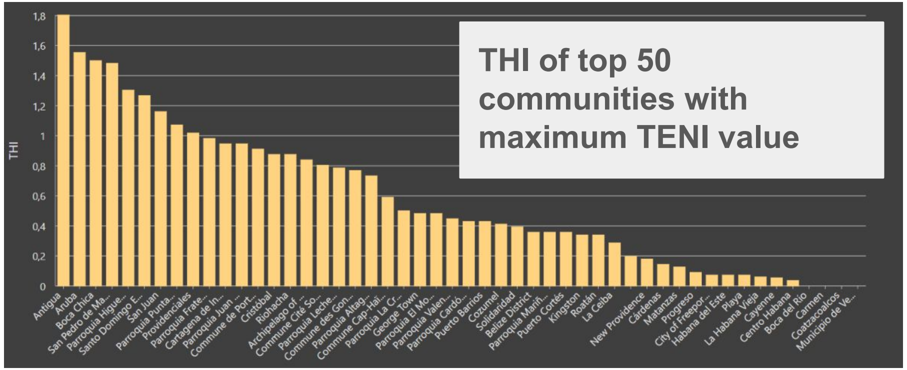
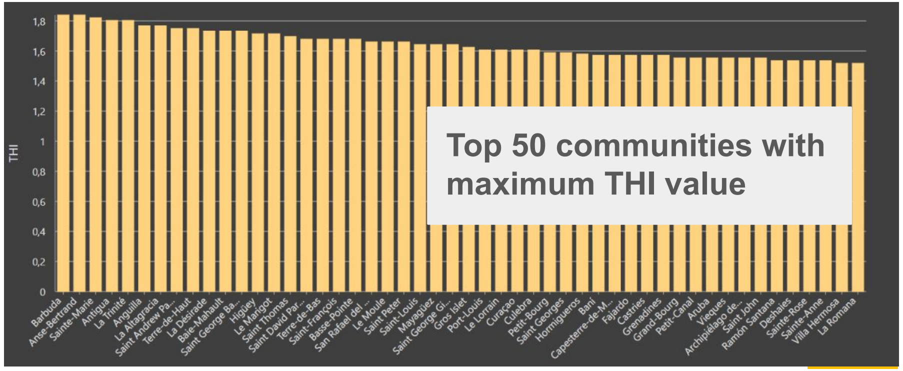
Communities with the Highest THI Scores:

1. **Barbuda, Antigua and Barbuda** – THI of 1.84
2. **Anse-Bertrand, Guadeloupe** – THI of 1.84
3. **Sainte-Marie, Martinique** – THI of 1.82
4. **Antigua, Antigua and Barbuda** – THI of 1.80
5. **La Trinité, Martinique** – THI of 1.80



General Trends:

- The **mean and median THI values** are around **0.73**, indicating **relatively low maximum amplitudes** for most scenarios.
- Even low composite index values can include **one or more high-impact events**.



RESULT 3 - Tsunami Hazard Index (THI)

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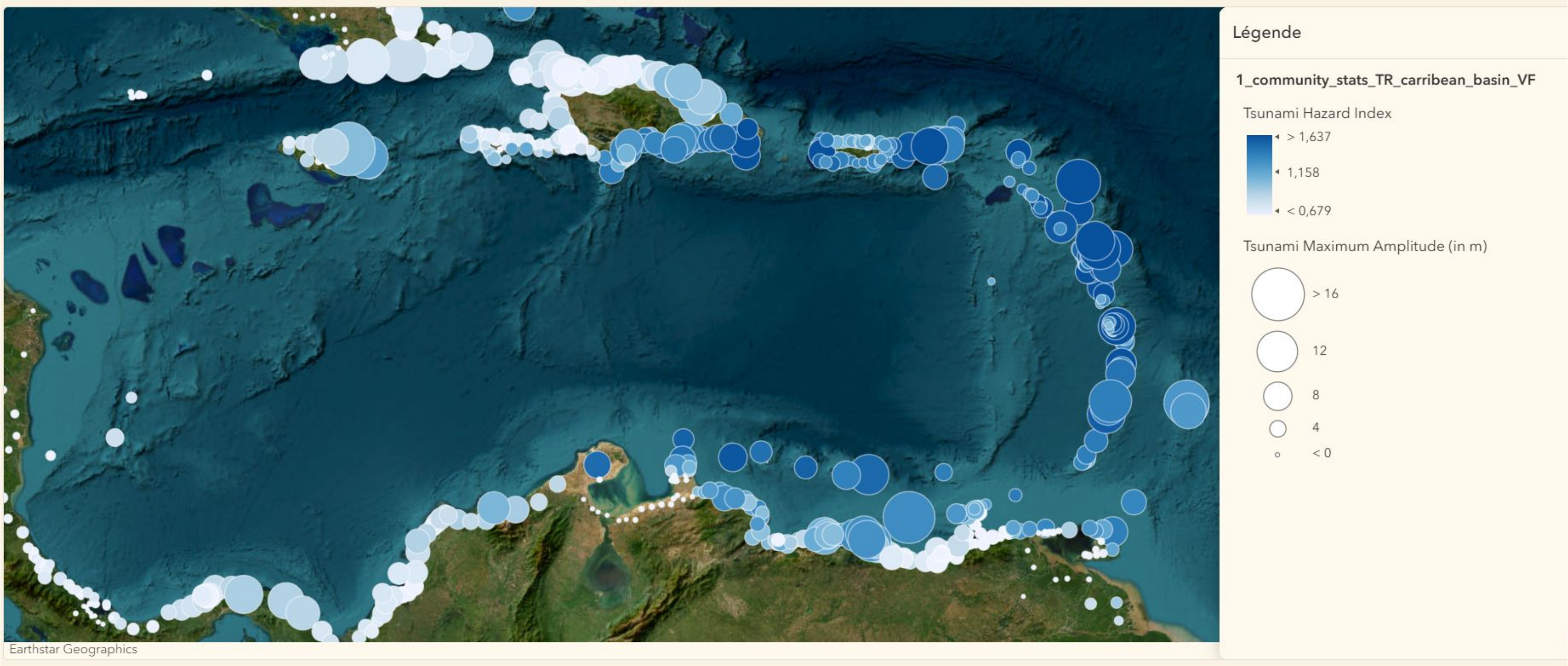


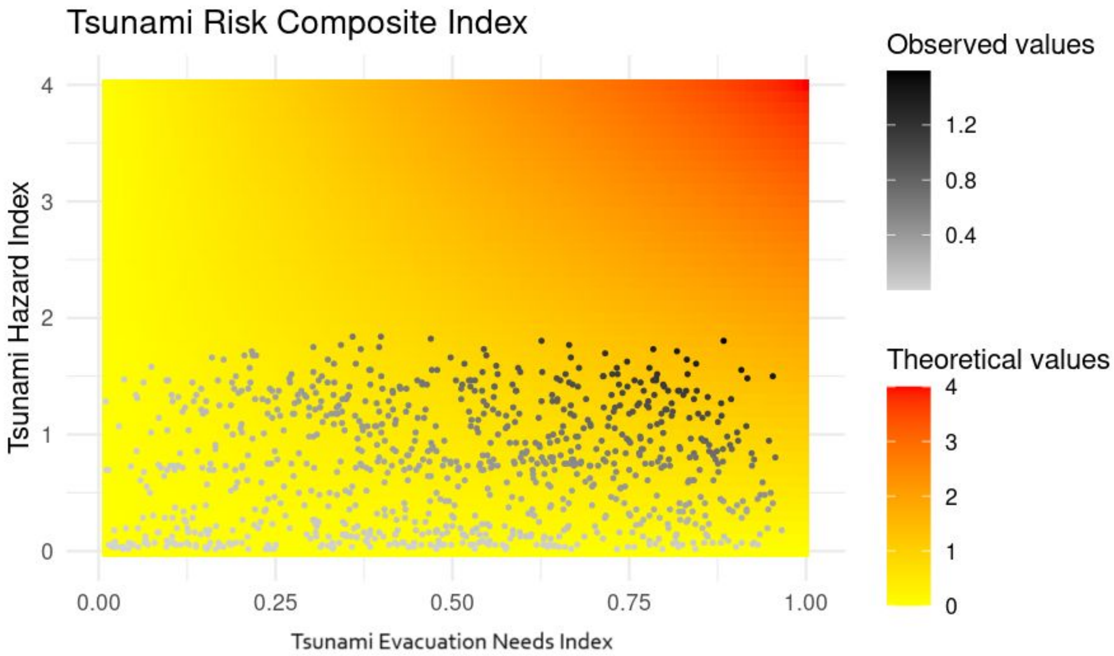
Access the online map via this link :

https://www.arcgis.com/apps/dashboards/a2d4b82b96524321bed19abd3b13ac0a

Tsunami Risk Composite Index

Tsunami risk is defined by the **product of evacuation needs and tsunami hazard exposure**:

Tsunami Risk Composite Index (TRCI) = TENI * THI



RESULT 4 - Tsunami Risk Composite Index

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Key Findings:

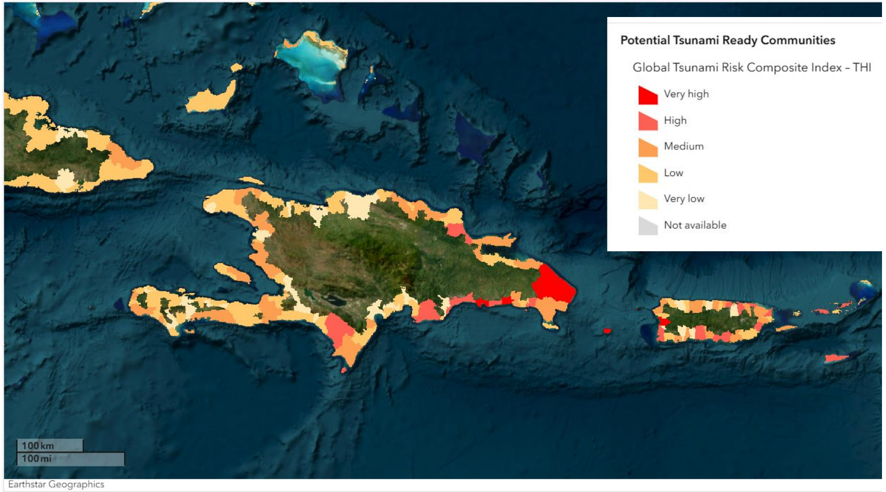
- **8 communities** have a **very high tsunami risk** index.
- **64 communities** have a **high tsunami risk** index.

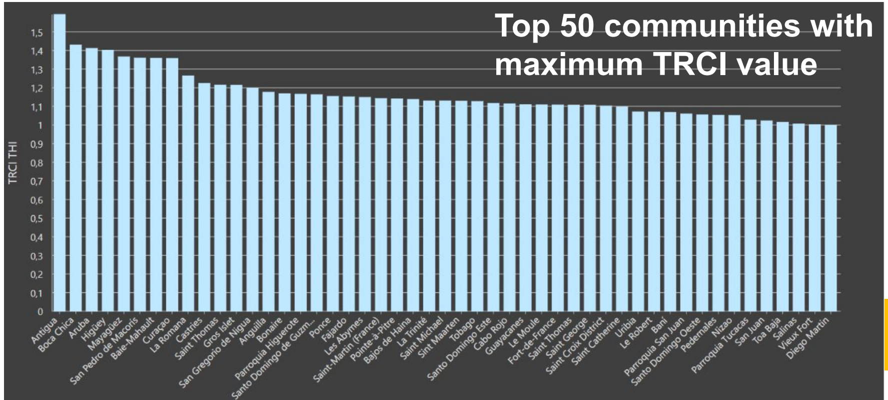
Communities with the Highest Risk Values:

1. **Antigua (TRCI_THIGL = 1.593455)**
2. **Boca Chica, Dominican Republic (TRCI_THIGL = 1.4295)**
3. **Aruba (TRCI_THIGL = 1.41142)**

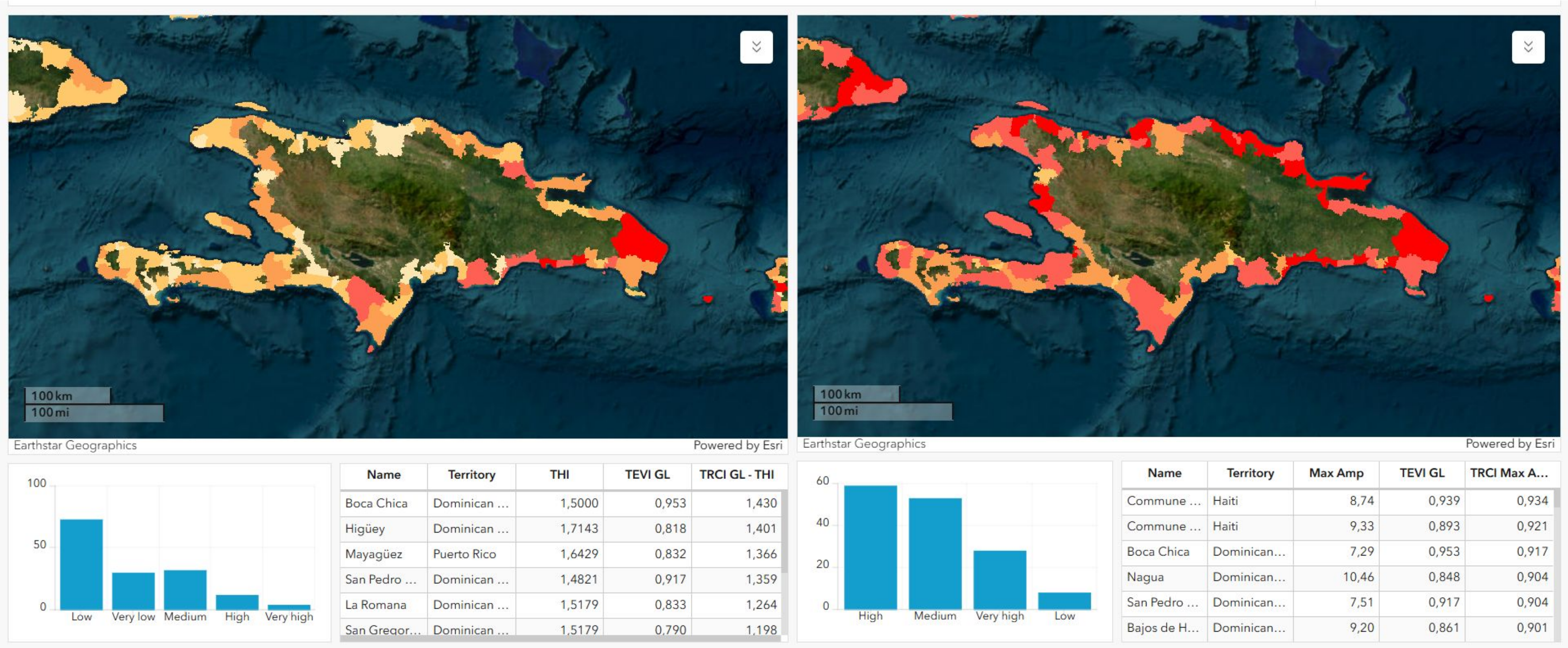
Countries with the Most High-Risk Communities:

- **Dominican Republic** – 14 high-risk communities
- **Puerto Rico** – 10 high-risk communities
- **Venezuela** – 7 high-risk communities





Delivrable - Interactive web-based mapping of indicators :



Access the online map via this link :

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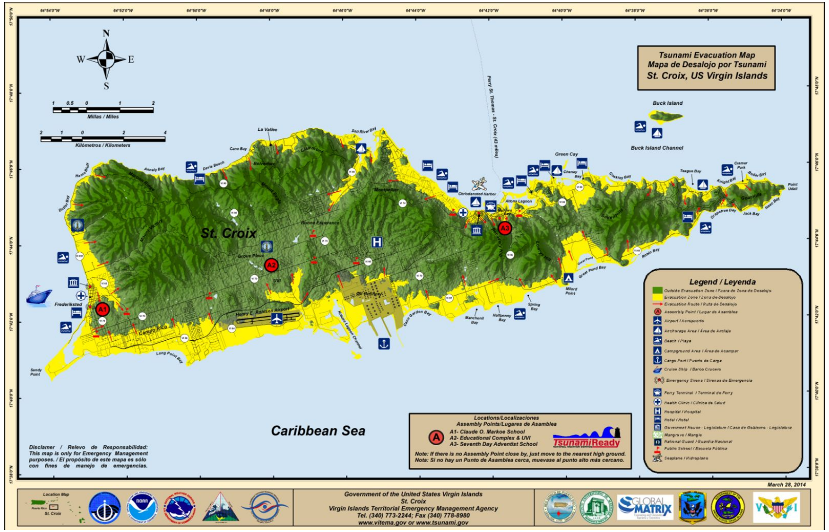
Discussion & Perspectives

Delimitation of Evacuation Zones

- Current hypothesis: The evacuation zone is defined based on altitudes of 30 and 15 meters and a maximum inland distance of 3 km.

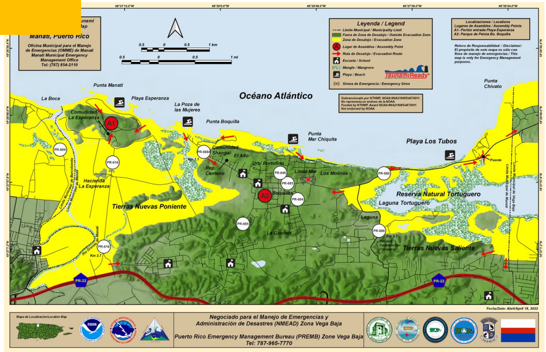
- **Question for discussion:** Are these hypotheses relevant? Is it appropriate to maintain multiple zones?

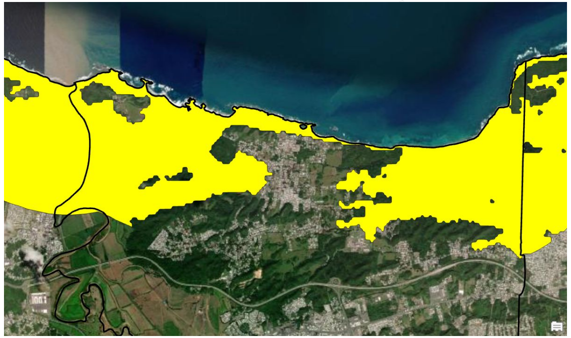
Discussion & Perspectives

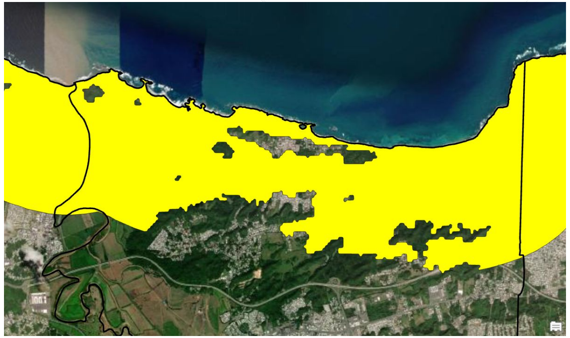


Discussion & Perspectives

Discussion & Perspectives







	15 m a.s.l.	30 m a.s.l.
Population in Evacuation Zone	538	3 931
Percentage of Population Evacuation Zone	1,43	10,44
Evacuation Zone Area (in km²)	15,891	23,131
Population Density in Evacuation Zone	33,88	169,94
Tsunami Evacuation Vulnerability Index	0,23 (low)	0,428 (medium)
Global Tsunami Evacuation Vulnerability Index	0,329 (low)	
Tsunami Risk Composite Index – THI	0,271 (very low)	0,504 (low)
Global Tsunami Risk Composite Index – THI	0,388 (very low)	
Tsunami Risk Composite Index – Max. Amplitude	0,37 (low)	0,469 (medium)
Global Tsunami Risk Composite Index – Max. Amplitude	0,419 (medium)	

Discussion & Perspectives

TENI improvement

- **Built-Up Areas as a Proxy for Human Activity**
  - **Current practice:** Evacuation needs are currently assessed solely based on the resident population.
  - **Proposition:** Use built-up areas (e.g., businesses, infrastructure, tourism) as a complementary indicator to estimate evacuation needs.

GHS-BUILT-S - R2023A

GHS-BUILT-S R2023A - GHS built-up surface grid, derived from Sentinel2 composite and Landsat, multitemporal (1975-2030)

GHS-BUILT-S

JRC Data catalogue

GHS-BUILT-S

The spatial raster dataset depicts the distribution of built-up surfaces, expressed as number of square metres. The data report about the **total built-up surface** and the **built-up surface allocated to dominant non-residential** (NRES) uses.
Data are spatial-temporal interpolated or extrapolated from 1975 to 2030 in 5 years intervals.
For the temporal anchor point of 2018 the data is published at 10m as observed from the S2 image data.

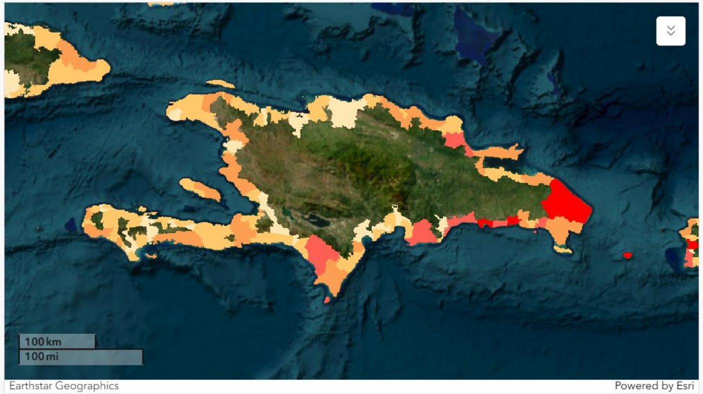
The main characteristics of this dataset are listed below.
The complete information about the GHSL main products can be found in the GHSL Data Package 2023 report (14.44 MB)

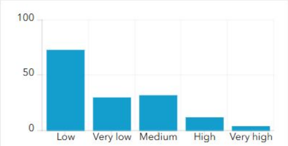
You can a look at the interactive visualisation of the GHS-BUILT-S data.

Discussion & Perspectives

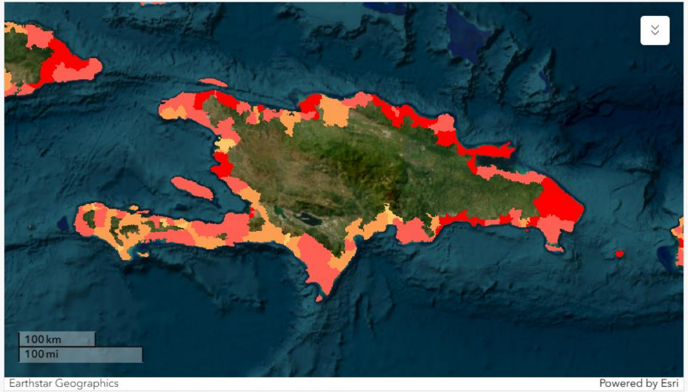
Comparison between the Tsunami Risk Composite Index, THI, and Maximum Amplitudes

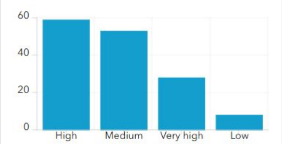
- **Key question:** Should the analysis rely solely on the THI, which incorporates multiple dimensions of risk, or should it also consider the maximum amplitude (Hmax), which is more sensitive to the simulation results of a single scenario?





Name	Territory	THI	TEVI GL	TRCI GL - THI
Boca Chica	Dominican ...	1,5000	0,953	1,430
Higüey	Dominican ...	1,7143	0,818	1,401
Mayagüez	Puerto Rico	1,6429	0,832	1,366
San Pedro ...	Dominican ...	1,4821	0,917	1,359
La Romana	Dominican ...	1,5179	0,833	1,264
San Gregor...	Dominican ...	1,5179	0,790	1,198





Name	Territory	Max Amp	TEVI GL	TRCI Max A...
Commune ...	Haiti	8,74	0,939	0,934
Commune ...	Haiti	9,33	0,893	0,921
Boca Chica	Dominican...	7,29	0,953	0,917
Nagua	Dominican...	10,46	0,848	0,904
San Pedro ...	Dominican...	7,51	0,917	0,904
Bajos de H...	Dominican...	9,20	0,861	0,901

Discussion & Perspectives

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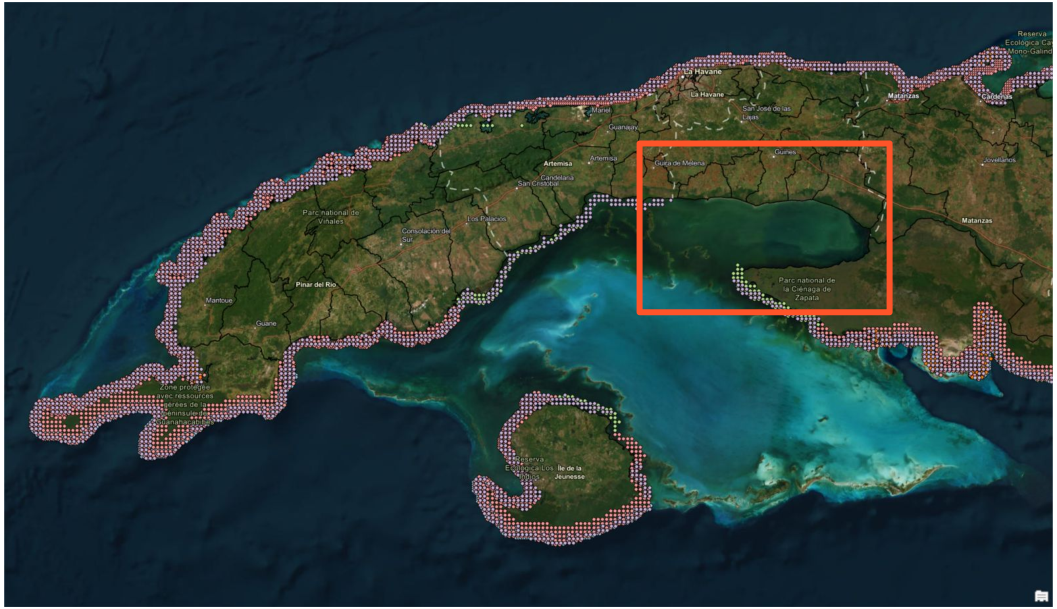
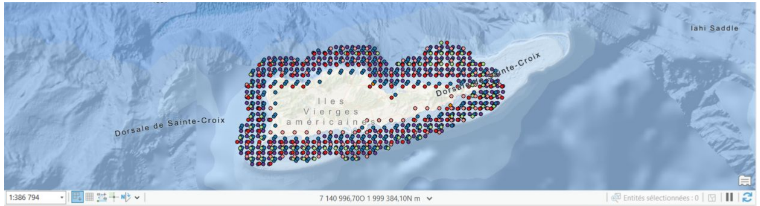
Generalizing the THI in Contexts with Missing Data

- **Problem:** Some regions lack data on wave amplitudes.
- **Question for discussion:** How can the Tsunami Hazard Index (THI) be generalized in such cases?



Other perspectives

Taking into account Green's Law …

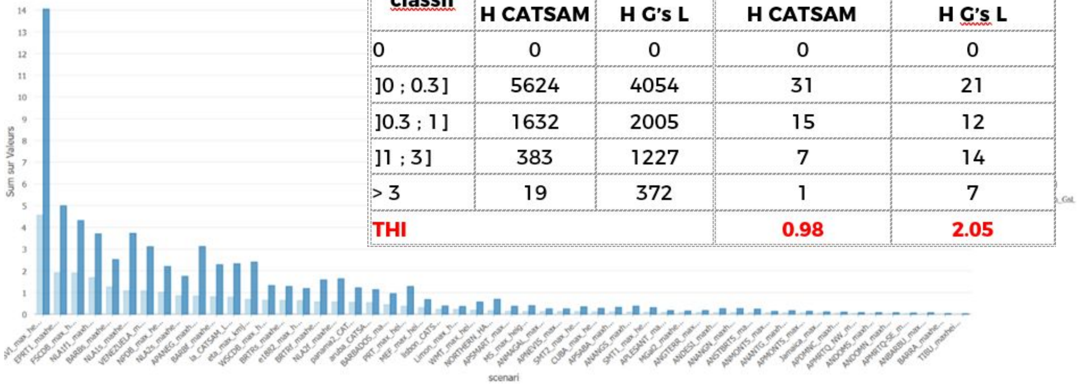


with GEBCO Dataset, the only database available worldwide

Characteristics

- **Global Bathymetry Database** providing **seafloor elevation data** with a spatial resolution of up to **15 arc-seconds (~500 m)**.

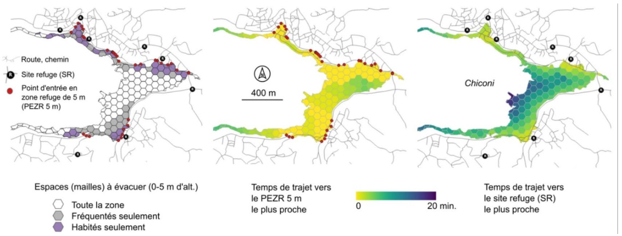
Value classif	St Croix All point H CATSAM	St Croix All point H G's L	St Croix Max scenario H CATSAM	St Croix Max scenario H G's L
0	0	0	0	0
]0 ; 0.3]	5624	4054	31	21
]0.3 ; 1]	1632	2005	15	12
]1 ; 3]	383	1227	7	14
> 3	19	372	1	7
THI			0.98	2.05

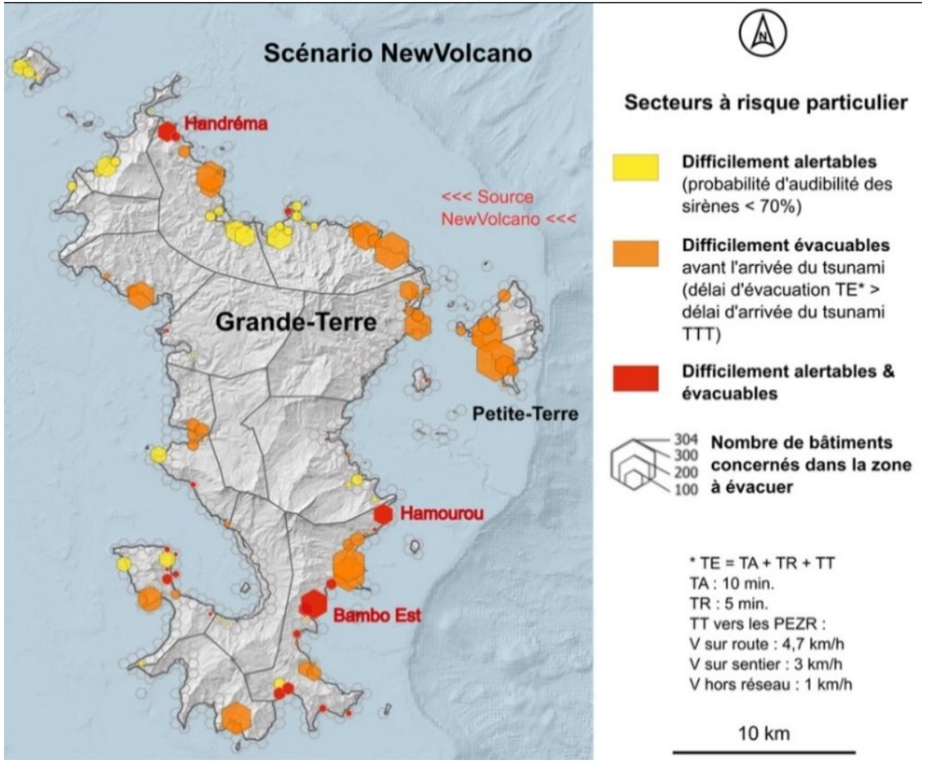


Other perspectives

Shift from a **community-based approach** to a more detailed analysis using **"infra-municipality" divisions**.

- Apply **grid-based zoning** or **coastal segment** to improve accuracy.
- This approach allows for **better identification of local exposition** within large administrative areas.
- Provides **more precise data** by focusing on smaller, more homogeneous zones.





https://journals.openedition.org/echogeo/25078

Leone et al., 2023

THANK YOU

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