Community tsunami inundation maps for selected ICG/CARIBE EWS member states

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Introduction

The Intergovernmental Coordination Group for the Tsunami and other Coastal Hazards Warning System for the Caribbean and Adjacent Regions, IOC/UNESCO, as part of its Tsunami Programme is currently implementing major initiatives aimed at reducing the vulnerability of its Member States in the Caribbean and adjacent regions to tsunamis and other coastal hazards. This project focuses on supporting the CARIBE EWS, coordinated by ICG/CARIBE, to develop accurate products towards the reduction of the tsunami vulnerability and the advance of the global tsunami preparedness in the area.

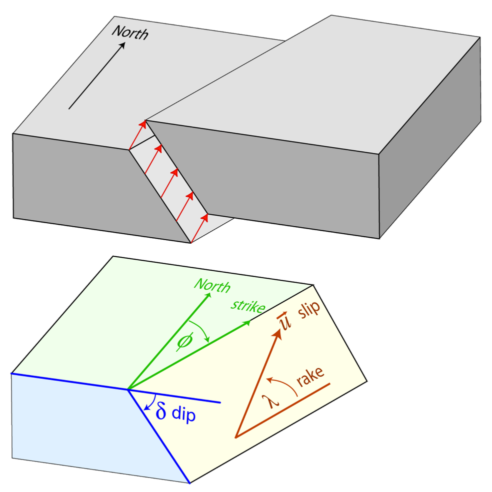
- Strengthen the capacities of early warning and response for tsunamis in the Caribbean
- Develop of **community-level tsunami inundation maps** for select coastal communities
- Support communities preparation for and response to tsunamis

Tsunami-HySEA model implements in the same code the three phases of an earthquake generated tsunami: **generation** (Okada deformation model), **propagation and coastal inundation** (non-linear shallow-water system).

Tsunami-HySEA numerical model

Okada deformation model

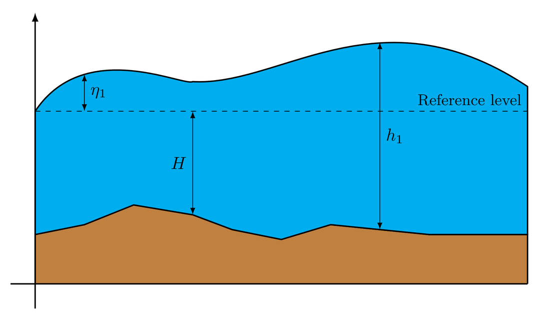
- In the generation stage, Okada's fault deformation model (Okada, 1985) is used to predict the initial bottom deformation that is transmitted to the sea surface.
- Assumes that an earthquake can be regarded as the rupture of a single fault plane.
- The fault is described by a series of parameters, comprising dip angle, strike angle, rake angle, fault width, fault length, and fault depth.
- Tsunami-HySEA can combine several fault planes to model the complete seafloor deformation and each fault could be applied at different time steps to simulate the full rupture time.



Shallow Water System Equations

- Uses the well known 2D nonlinear one-layer shallow water system.

$$
\begin{aligned}
h_t + (q_x)_x + (q_y)_y &= 0\\
(q_x)_t + \left(\frac{q_x^2}{h} + \frac{g}{2}h^2\right)_x + \left(\frac{q_x q_y}{h}\right)_y &= ghH_x + S_x\\
(q_y)_t + \left(\frac{q_x q_y}{h}\right)_x \left(\frac{q_y^2}{h} + \frac{g}{2}h^2\right)_y &= ghH_y + S_y
\end{aligned}
$$



- $h(x,t)$ denotes the thickness of thewater layer at pointx $\in D \subset \mathbb{R}^2$ at time t, being D the horizontal projection of the 3D domain where the tsunami takes place.
- $H(x)$ is the depth of the bottom at point(x)measured from a fixed level of reference.
- $\eta(x,t) = h(x,t) - H(x)$ corresponds to the free surface of the fluid.
- $q(x,t) = (q_x(x,t), q_y(x,t))$ is the mass-flow of the water layer at point x at time t.
- S_x and S_y parametrizes the friction effects

$$
\begin{cases}
S_x(U) = -gh\dfrac{n^2}{h^{4/3}}u_x u\\
S_y(U) = -gh\dfrac{n^2}{h^{4/3}}u_y u
\end{cases},
$$

where $n > 0$ is the Manning coefficient.

Numerical Scheme

- Solves the two-dimensional shallow-watersystem using a high-order (second and third order) path-conservative finite volume method.
- The numerical scheme is conservative for both mass and momentum in flat bathymetries, and, in general, is mass preserving for arbitrary bathymetries.
- Implementation of Tsunami-HySEA has been performed on GPU clusters and it handles nested grids.
- These facts allows to speedup the computations, being able to perform complex simulations, in huge domains, much faster than real time

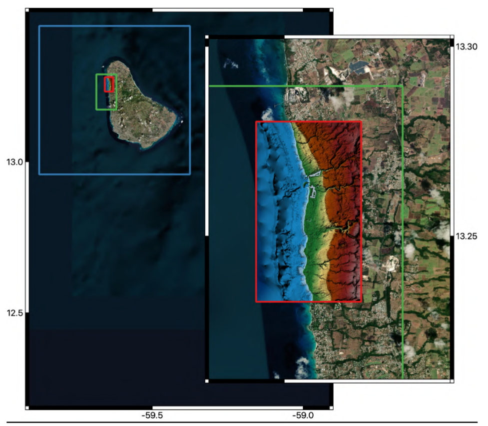
Topobathymetric data

Collected data

	Saint John s (Antigua & Barbuda)	Speightstown (Barbados)	Puerto Plata (Dom. Rep)	Union Island (SVG)	Carenage (Trinidad & Tobago)
Bathymetry	SCB Data provided by Department of Environment. Digitization of nautical charts	Lidar data. Resolution 1m, provided by the Coastal Zone Management Unit. Digitization of Nautical charts	Provided by UNESCO from a previous project in the area. Bathymetric contours	Provided by NOAA resolution 30m	Digitization of Nautical Charts
DEM	Satellite data provided by Department of Environment Resolution: 1m	Lidar data. Resolution 1m, provided by the Coastal Zone Management Unit	Provided by UNESCO from a previous project in the area. Resolution 30 m	Provided by NOAA Resolution 5m; Some uncertainties found	Provided by ODPM. Resolution 30m

Nested meshes

COMMUNITIES	Level	NESTED GRIDS	# OF CELLS	RESOLUTION (meters)
DOM. REP	0	Caribbean Sea	4231x2078	1820
	1	Approximation 1	324x126	960
	2	Approximarion 2	432x316	240
	3	Puerto Plata	1464x1088	30
ANTIGUA & BARBUDA	0	Caribbean Sea	1927x986	2048
	1	Antigua	208x176	128
	2	Saint John's	944x672	8
BARBADOS	0	Caribbean Sea	4561x2237	900
	1	Barbados	480x472	120
	2	West Coast	512x896	15
	3	Speightstown	1704x2920	2
TRINIDAD & TOBAGO	0	Caribbean Sea	4561x2237	960
	1	North Trinidad	468x200	240
	2	West Trinidad	628x336	60
	3	Carenage	572x428	15
SVG	0	Caribbean Sea	1591x770	2600
	1	Saint Vincent	468x200	330
	2	Union Island	628x336	40
	3	Local Detail	572x428	5

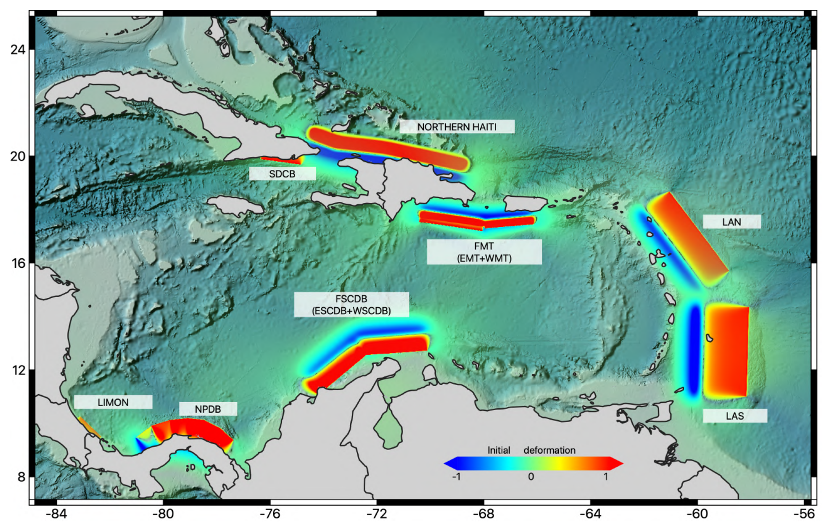


EVENT	Simulation time	# of GPUs*	Runtime
CARIBE_LAS	8 hours	1	2 min
CARIBE_LAN	8 hours	1	2 min
CARIBE_NORTHERNHAITI	8 hours	1	2 min
DO_NORTHERNHAITI_4L	2 hours	1	9 min
AG_LAN_3L	3 hours	1	4 min
BB_LAS_4L	2 hours	4	48 min
SVG_LAS_4L	2 hours	1	9 min
TT_LAS_4L	2 hours	1	5 min

* Tesla V100 graphic cards (2018 Volta architecture, released 7 Dec 2017)

Tsunamigenic sources characterization

- A specific **seismotectonic study** was carried out, based on the tsunami **historical events** and the available catalogue of tsunami scenarios.
- Numerous scenarios were simulated.



- **Worst-case** scenarios were selected to proceed with a deterministic analyses of the tsunami hazard.

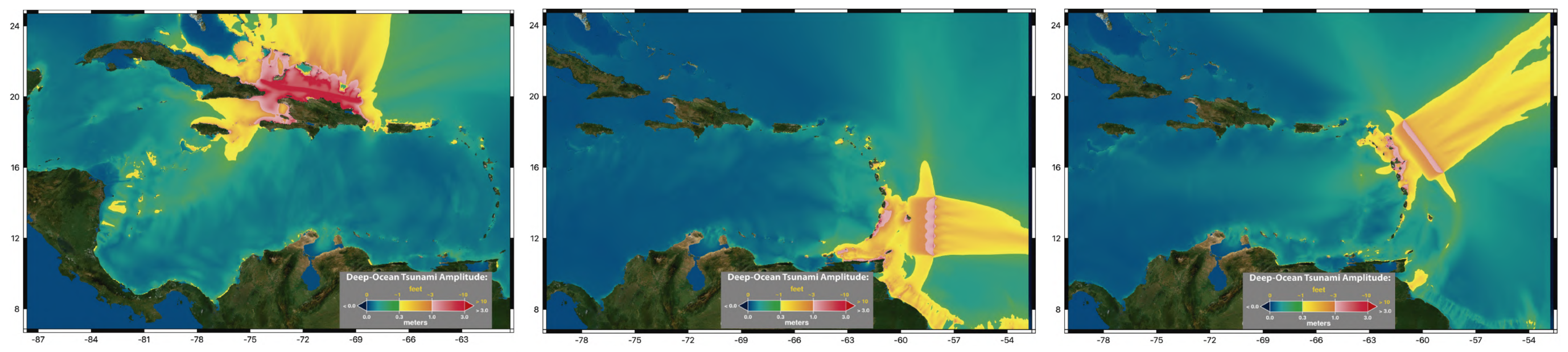
Communities	Source
St. John's (capital)	LAN
Speightstown	LAS
Puerto Plata	NORTHERN HAITI
Union Island	LAS
Carenage	LAS

Initial deformation of the selected sources. They are all depicted in the same figure although they were considered separately for the analysis and definition of tsunamigenic sources

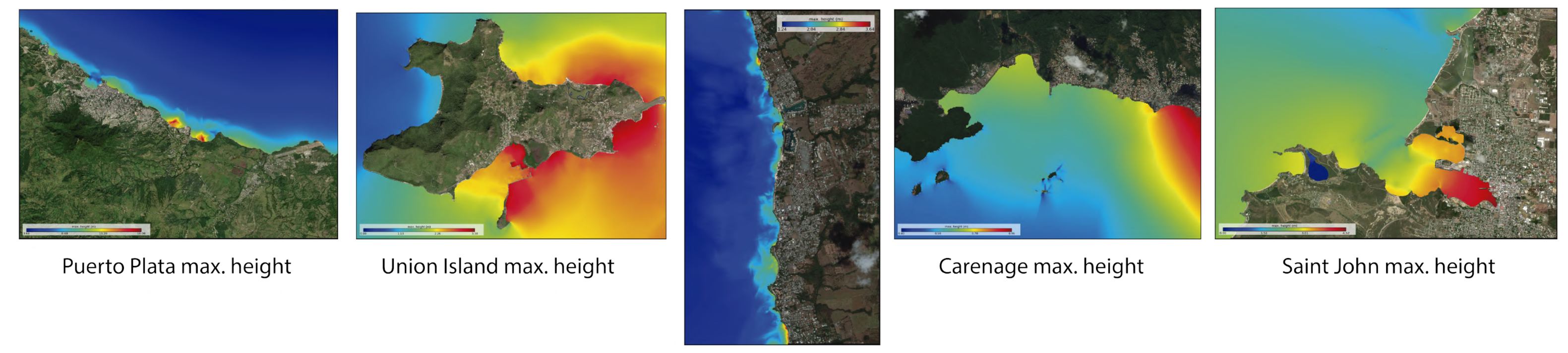
EVENT	LONGITUDE	LATITUDE	DEPTH	LENGTH	WIDTH	STRIKE	DIP	RAKE	SLIP
LAS	-59.0817	12.70847	15.25	370.933	211.966	181.5	8	90	5.96
LAN	-60.4487	16.82799	15.25	406.692	141.887	143.943	12	90	4.28
NORTHERN HAITI	-74.0091	20.5871	20	109	59	111	21	90	10
	-72.60172	20.3025	20	193	59	97	21	90	10
	-70.2080	19.8761	20	317	59	103	21	90	10

Results

Propagation maps



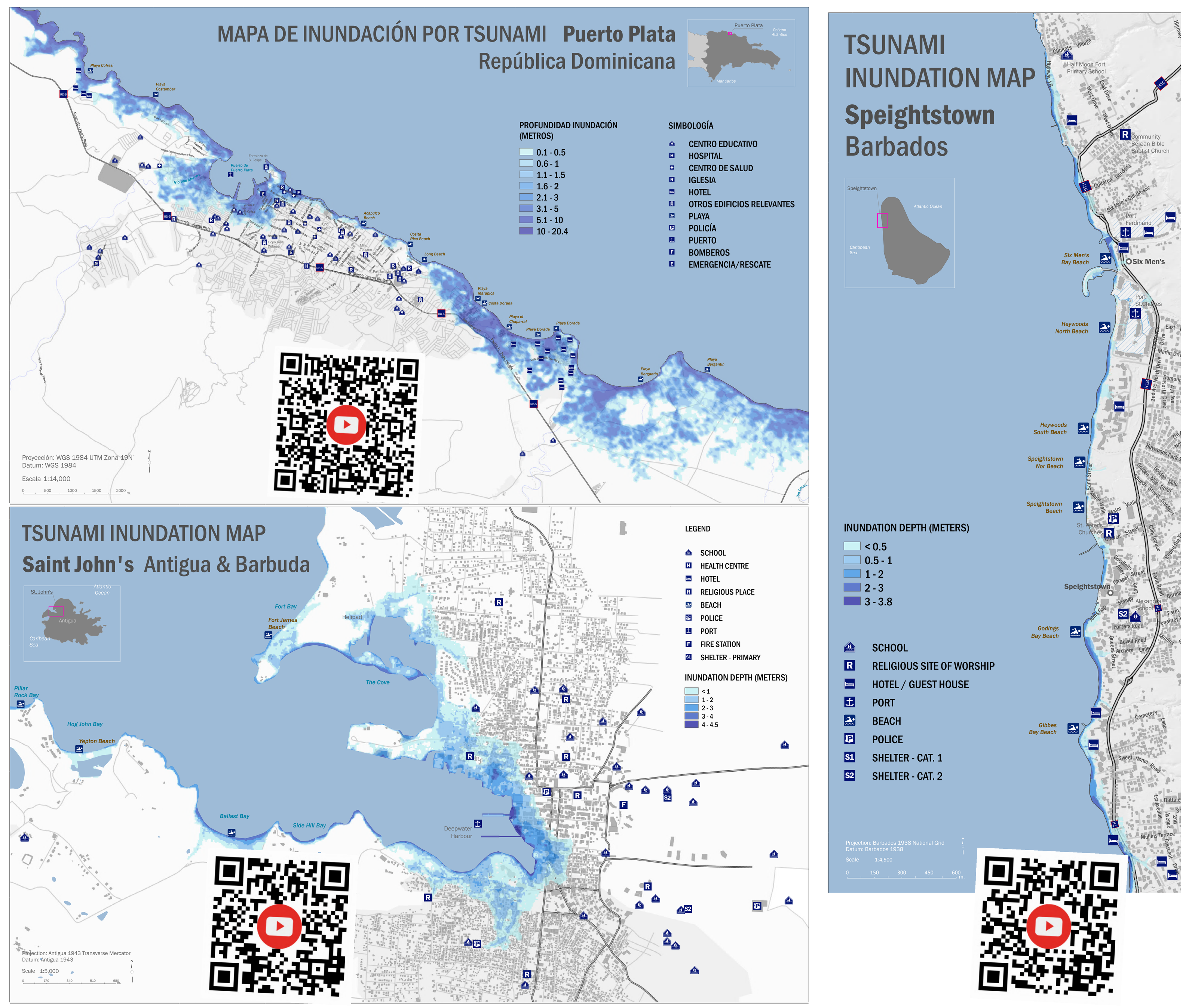
NORTHERN HAITI event max. height — Lesser Antilles South (LAS) event max. height — Lesser Antilles North(LAN) event max. height



Puerto Plata max. height — Union Island max. height — Speightstown max. height — Carenage max. height — Saint John max. height

Maximum height in selected events and locations using coarsest level in Caribbean and high resolution level in local communities

Inundation maps



Inundation maps presented during the workshops at each community

References

- Macías, J., Mercado, A., González-Vida, J.M., Ortega, S., and Castro, M.J. (2016). Comparison and numerical performance of Tsunami-HySEA and MOST models for LANTEX 2013 scenario. Impact assessment on Puerto Rico coasts. Pure and Applied Geophysics, 173(12), 3973–3997
- Macías, J., Castro, M.J., Ortega, S., Escalante, C. and González-Vida, J.M. (2016). NTHMP Benchmarking of Tsunami-HySEA model for propagation and inundation. The 2011 NTHMP Model Benchmarking Workshop. [DOI: 10.13140/RG.2.2.35077.76001]
- Macías, J. (2014). Tsunami Numerical Simulations: HySEA model. A GPU approach to tsunami modeling and case studies. Experts Meeting Workshop on Tsunami Modeling and Mitigation. Cartagena de Indias (Colombia), 1-3 December, 2014.