Numerical Simulation of Several Tectonic Tsunami Sources at the Caribbean Basin

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A subgroup of the WG2 members of the ICG/CARIBE-EWS

Introduction

According to the NGDC/WDS Global Historical Tsunami Database, the Caribbean Sea has experienced more than 100 historical tsunamis. The most recent tsunami observed in this basin was caused by the 2010 Haiti Mw 7.0 earthquake with up to 3.2 m runup (Fritz et al. 2013). Still, as tsunamis are not frequent in this basin, tsunami awareness represents a challenge even more because of population increase, tourism, infrastructure and development along the coastal area.

The Intergovernmental Coordination Group of the Early Warning System for Tsunamis and Other Coastal Threats in the Caribbean Sea and Adjacent Regions (ICG/CARIBE-EWS) seeks to increase tsunami preparedness in the region. Its Hazard Assessment Working Group (WG2) has been assigned the task of identifying potential tsunami sources. During 2016, IOC/UNESCO sponsored three Experts Meetings on Tectonic Tsunami Sources focusing on Honduras, Central America and the Dominican Republic southern coast. The work presented here is part of the results the WG2 has obtained by modeling the credible worst-case scenarios defined on those meetings. The ultimate goal is to develop tsunami evacuation maps using those scenarios among others, as well as provide future scenarios for CaribeWave exercises.

Methods

Three numerical models were used for the simulations: (a) MOST (Titov et al., 2011), (b) NEOWAVE (Yamazaki et al. 2009) and (c) Tsunami-HySEA (Macías et al., 2016). In all models the initial condition was calculated using Okada et al. (1985). Scenarios from Honduras region were modeled with ComMIT and scenarios from North Panamá Deformed Belt (NPDB) were modeled with NEOWAVE, both using the grid from López et al. (2016) with extension -89º to -60ºW and 7º to 22.95ºN, at 1 arc-minute resolution, shown in Figure 6. Scenarios from South Caribbean Deformed Belt (SCDB), Muertos Trough (MT) and Northeastern Caribbean (NEC) were modeled using Tsunami-HySEA on a 1 arc-min resolution grid from -90º to -55ºW and 6º to 25ºN, built with GEBCO bathymetry.

The seismic parameters employed are listed at Table 1. Those parameters were defined at the three Experts Meetings held during 2016, considering the worst credible scenario. Some of these scenarios are related to historical events.

Conclusions

- Highest tsunami heights were obtained for sources along NPDB, where historic tsunamis have struck in the past.
- Sources at Honduras Gulf presented smallest tsunami amplitudes.
- None of the resulting tsunamis modeled here would present a basin-wide threat.
- There are still large gaps on the knowledge of potential tsunamigenic earthquakes within the Caribbean.
- Non-tectonic tsunamis have also been recorded in the past in the Caribbean Basin, such as volcanic and landslide triggered tsunamis. Those sources should also be considered for hazard assessment in future research.

References

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Acknowledgement

The authors summarized and modeled the sources proposed at three Experts Meetings on Tsunamis Sources held during 2016. Reports, documents and list of experts participating in those meetings can be found at the meetings websites:
Honduras: http://www.ioc-tsunami.org/index.php?option=com_oe&task=viewEventRecord&eventID=1803
Dominican Republic: http://www.ioc-tsunami.org/index.php?option=com_oe&task=viewEventRecord&eventID=1842
Central America: http://www.ioc-tsunami.org/index.php?option=com_oe&task=viewEventRecord&eventID=1840

Interactive map available at http://arcg.is/2gbsg2k

	HON		NEC		MT				SCDB			NPDB			
#	1	2	1	2	1	2	3	4	1	2w	2e	1	2w	2e	3
Name	ROA	HON	MEF	PRT	WMT	SMT1	SMT2	MS	WSCDB	FSCDB		LIM	1882		PAN
Mw	7.43	7.60	7.60	8.71	7.98	7.63	7.65	7.65	8.63	8.86		7.93	8.48		8.47
Lon	-86.39	-87.39	-67.80	-66.50	-69.50	-70.00	-68.70	-69.80	-73.70	-73.70	-69.30	-82.43	-80.21	-78.54	-77.80
Lat	16.45	15.97	18.30	19.30	17.60	17.60	17.40	17.70	12.30	12.30	13.10	9.54	9.60	9.53	9.80
Depth (km)	11.5	11	10	20	2.5	3.8	3.7	3.5	25	25	20	15	22.5	22.5	25
L (km)	100	150	80	500	290	140	150	190	500	500	500	150	166	274	243
W (km)	50	20	20	110	30	25	25	20	90	90	90	45	70	70	80
Slip (m)	1	3	6	8	4	3	3	3	7.4	7.4	8	4.2	6	6	10
Strike	70.64	216	290	86	100	105	95	99	53	53	96	122	63	109	142
Dip	15	70	70	20	9	11	10	14	17	17	20	25	30	30	40
Rake	90	-90	270	23	90	90	90	90	90	90	90	90	65	110	90
Historical tsunamis		1539	1918	1787 1943	1751							1798 1822 1916 1991	1882		1882

Table 1. Seismic parameters employed for the 16 tsunami scenarios

1. Honduras

1.1 Roatán (ROA) Mw 7.4

This source was suggested as the largest seismic event that could take place along the Swan fault system in the proximity of the Honduras Caribbean coast. The source was designed as specified in the ComMIT Propagation Database with slip amount of 1 m and located along the island of Roatán. Most of the energy from this tsunami is directed at northern Belize and the Yucatán peninsula.

1.2 Honduras Gulf (HON) Mw 7.6

A Mw 7.6 earthquake rupture following a fault along the Honduras Depression has been proposed as a tsunamigenic source. The normal fault of this source has been suggested as the offshore extension of the graben that has formed the valley where San Pedro Sula is located. The resulting tsunami given the orientation and parameters of this source would probably affect a limited area near Honduras, Guatemala, and Belize. A tsunami was reported in this region in 1539.

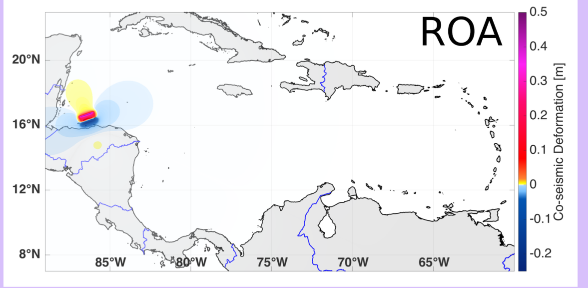

Figure 1.1. Co-seismic deformation in meters caused by Roatán scenario.

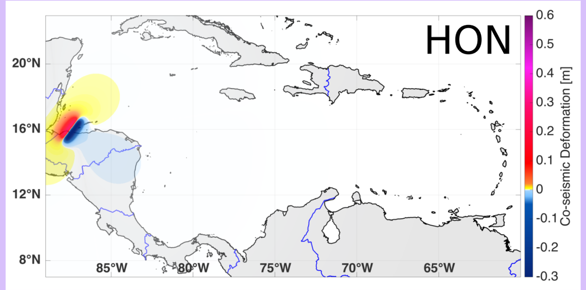

Figure 1.2. Co-seismic deformation in meters caused by HON scenario.

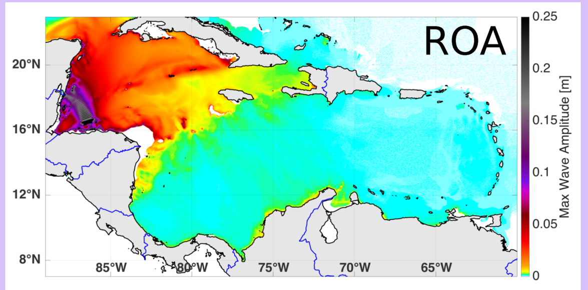

Figure 1.3 Maximum tsunami heights in meters caused by Roatán scenario

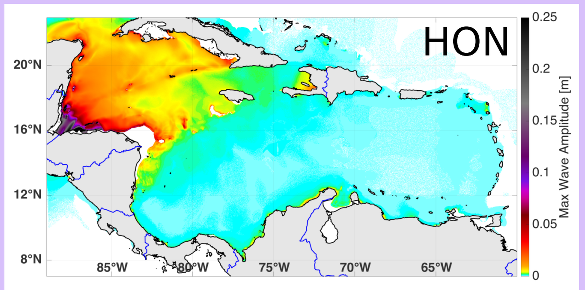

Figure 1.4 Maximum tsunami heights in meters caused by HON scenario

2. Northeastern Caribbean (NEC)

2.1 Mona Extension Fault (MEF) Mw 7.6

Recent studies by Chaytor and ten Brink (2010) have identified systematic normal faults oriented NW-SE throughout the sea-floor of the Mona Passage, between the islands of Hispaniola and Puerto Rico. Fault evidence there has been used to suggest a potential tsunami-triggering south-verging normal fault in the region. This region is the location of the Mw 7.2 October 11, 1918 earthquake and tsunami that resulted in 140 casualties.

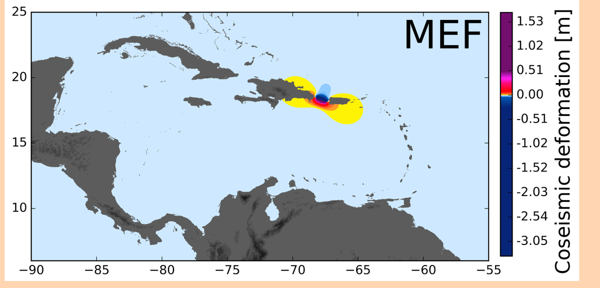

Figure 2.1. Co-seismic deformation in meters caused by MEF scenario.

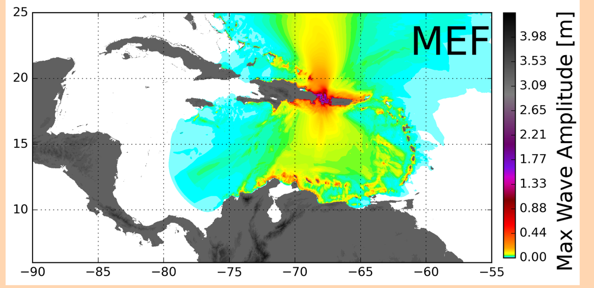

Figure 2.2. Maximum tsunami height in meters caused by MEF scenario.

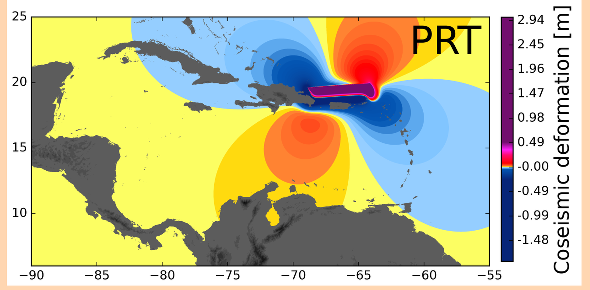

Figure 2.3. Co-seismic deformation in meters caused by PRT scenario.

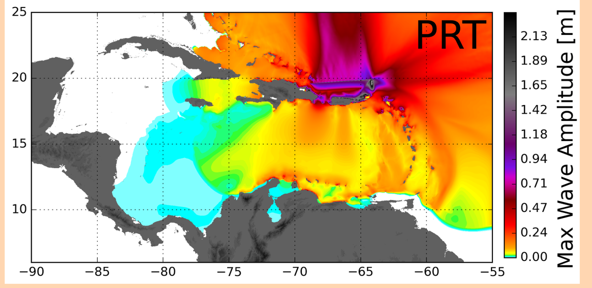

Figure 2.4. Maximum tsunami height in meters caused by PRT scenario.

2.2 Puerto Rico Trench (PRT) Mw 8.7

The Puerto Rico Trench is the main plate boundary between the Caribbean and North America plates along the northeastern Caribbean. It is the eastward continuation of the Northern Hispaniola Deformed Belt north of the Dominican Republic to the beginning of the Lesser Antilles Trench. Parameters for this source are taken from López et al. (2015) describing a tsunami generated from a purely thrust mechanism equivalent to a Mw 8.7 earthquake along the Puerto Rico Trench. This scenario would mostly affect the northern coasts of Puerto Rico and the Dominican Republic but some waves would be expected to travel south through the Mona Passage and refract towards the area southern Dominican Republic.

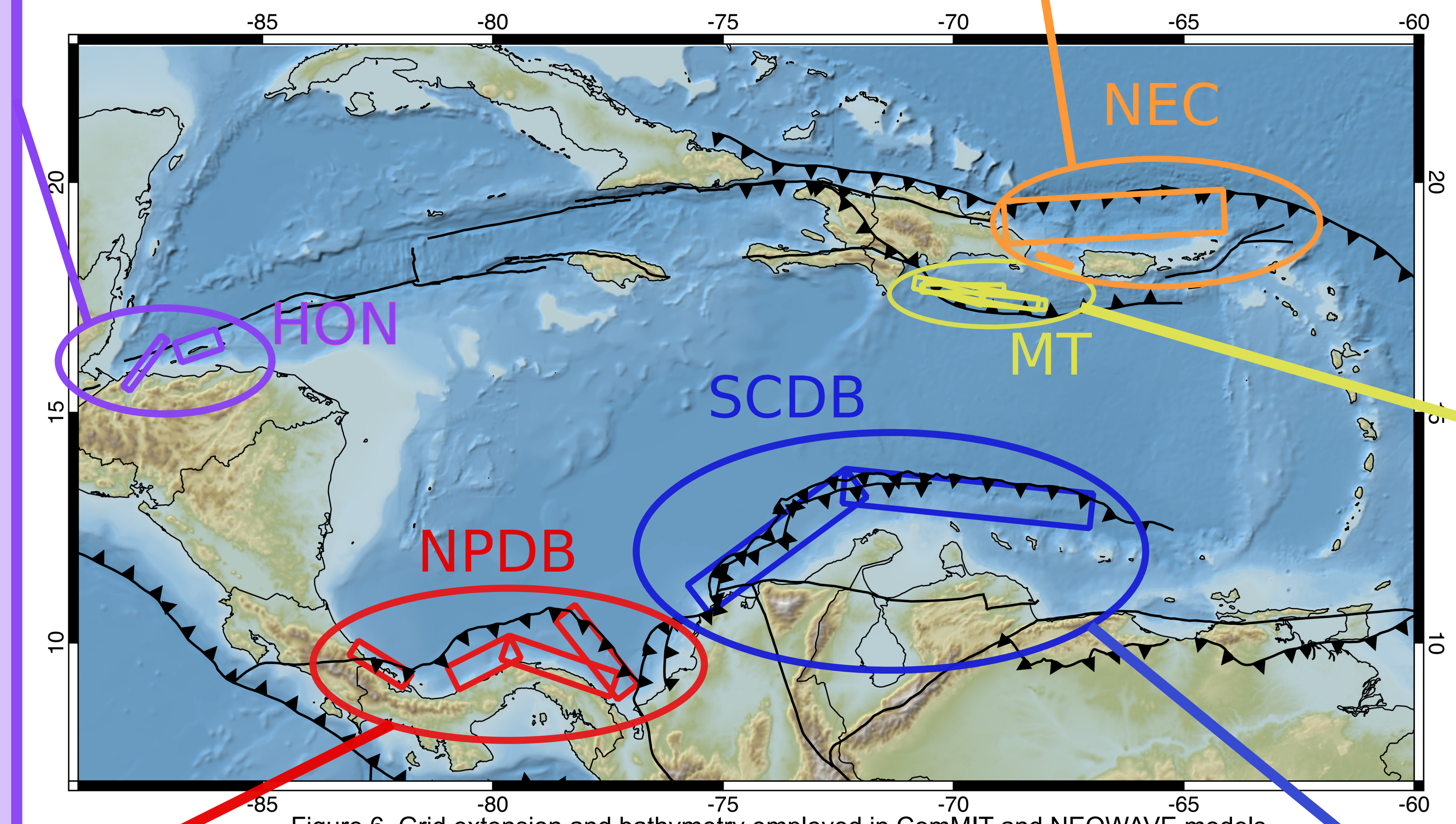

Figure 6. Grid extension and bathymetry employed in ComMIT and NEOWAVE models. Modeled rupture planes are shown with rectangles

3. Muertos Trough MT

The Muertos Trough is a tectonic feature observed south of the islands of Hispaniola and Puerto Rico, which nowadays is considered a retro-arc backstop (ten Brink et al., 2009; Granja-Bruña et al., 2014). The October 18, 1751 earthquake and tsunami may have originated in this area.

3.1 Western Muertos Trough (WMT) Mw 8.0

The western portion of the Muertos thrust belt defined here consists of a 290 km long rupture area oriented parallel to the strike of the Muertos thrust belt and shallowly dipping towards the north at 9 degrees.

3.2 & 3.3 Small Muertos Trough: SMT1 Mw 7.6 & SMT2 Mw 7.7

The WMT source has been further subdivided into two smaller sources: SMT1 and SMT2 with shorter rupture lengths. SMT1 scenario is characterized by the western part of the WMT found at the western terminus of the Muertos Thrust Belt where the deformation and relief is more prominent. SMT2 is located east of SMT1.

3.4 Muertos Trough Mega-splay (MS) Mw 7.7

A mega-splay has been identified by Granja-Bruña et al. (2014) along the western terminus of the Muertos Thrust Belt. The same authors have suggested this mega-splay can pose a significant tsunami threat to the southern Dominican Republic. According to multi-channel seismic lines, the mega-splay dips 14 degrees to the north, and meets the detachment fault at depth. The MS tsunami source corresponds to a Mw 7.7 event with slightly similar fault dimensions to WMT.

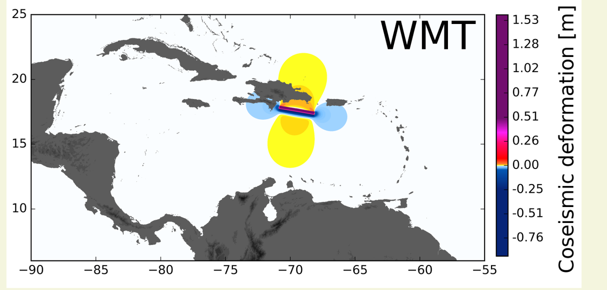

Figure 3.1 Co-seismic deformation in meters caused by WMT scenario

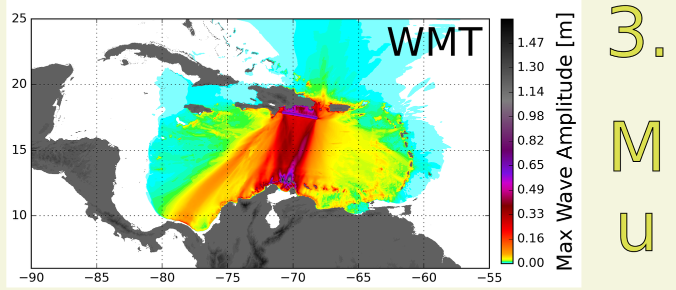

Figure 3.2 Maximum tsunami height in meters caused by WMT scenario

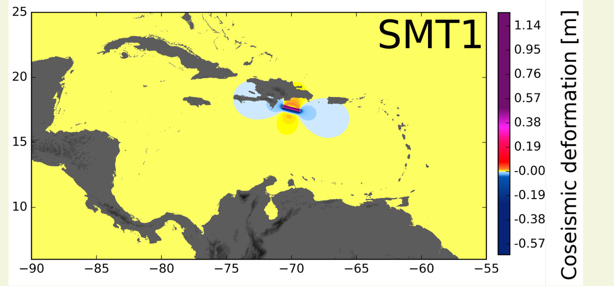

Figure 3.3 Co-seismic deformation in meters caused by SMT1 scenario

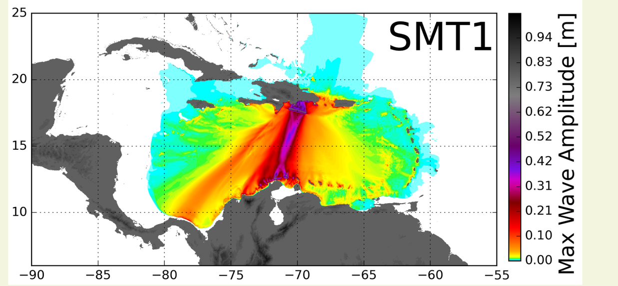

Figure 3.4 Maximum tsunami height in meters caused by SMT1 scenario

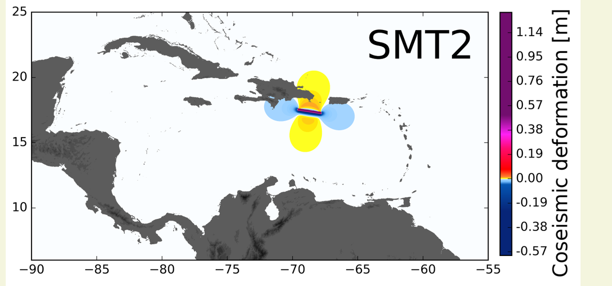

Figure 3.5 Co-seismic deformation in meters caused by SMT2 scenario

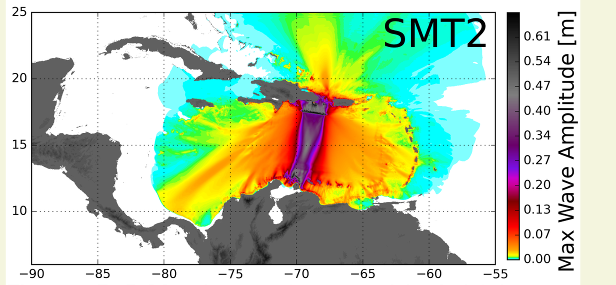

Figure 3.6 Maximum tsunami height in meters caused by SMT2 scenario

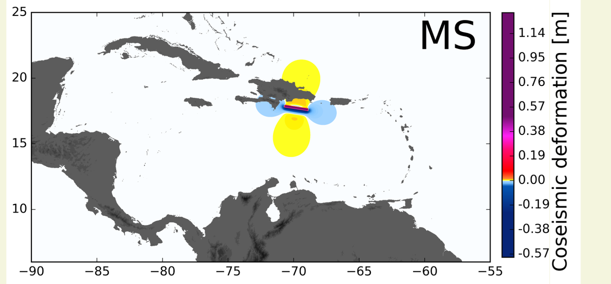

Figure 3.7 Co-seismic deformation in meters caused by MS scenario

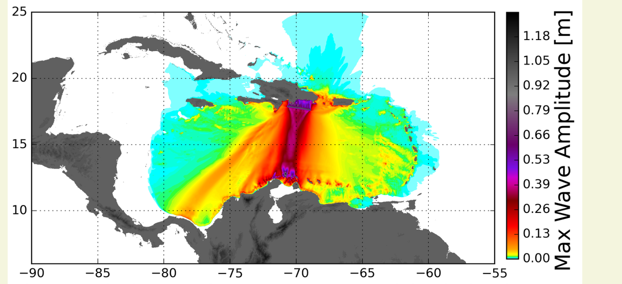

Figure 3.8 Maximum tsunami height in meters caused by MS scenario

5. North Panamá Deformed Belt (NPDB)

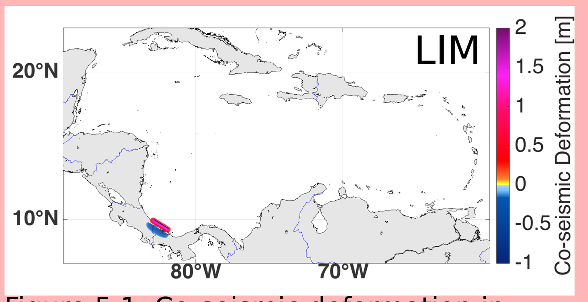

Figure 5.1. Co-seismic deformation in meters caused by Limón scenario.

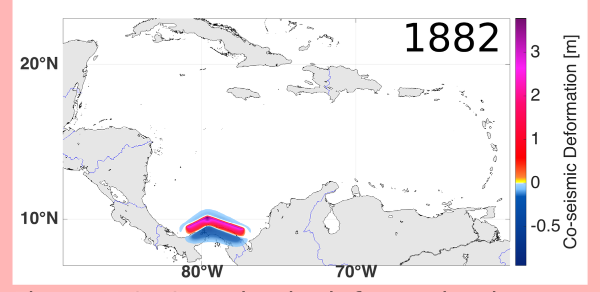

Figure 5.2. Co-seismic deformation in meters caused by 1882 scenario.

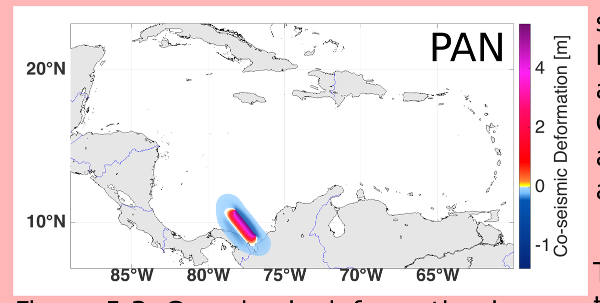

Figure 5.3. Co-seismic deformation in meters caused by Panamá scenario.

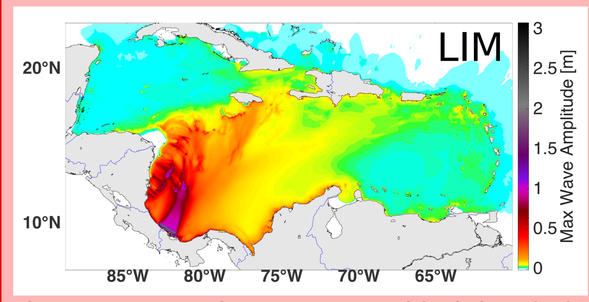

Figure 5.4. Maximum tsunami heights (m) for Limón scenario

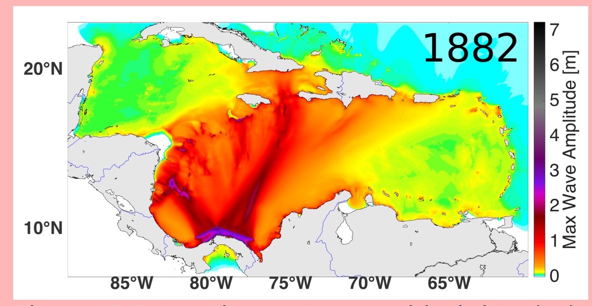

Figure 5.5. Maximum tsunami heights (m) for 1882 scenario

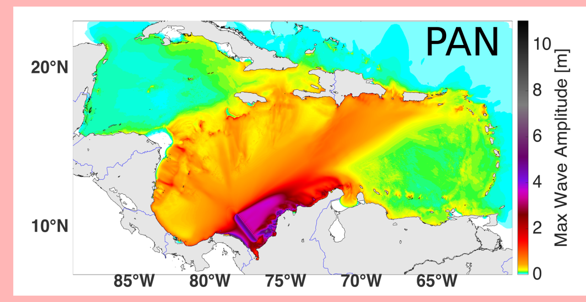

Figure 5.6. Maximum tsunami heights (m) for Panamá scenario

5.1 Limón (LIM) Mw 7.9

The scenario is located at the western end of the North Panamá Deformed Belt (NPDB), a subduction margin under development. It is based on historical events (1798, 1822, 1991) and it would cause uplift of the shore along the Costa Rica - Panamá border. The tsunami would also impact Nicaragua and San Andrés archipelago (Colombia).

5.2 1882 Mw 8.5

This scenario follows the arcuate morphology of the North Panamá Deformed Belt (NPDB). It is one possible solution of the 1882 tsunami. It would have two main directions of maximum energy toward Nicaragua and the south of Cuba, impacting also Jamaica, La Hispaniola and Colombia.

5.3 Panamá (PAN) Mw 8.5

This source is located in the same region of the eastern segment of 1882 source but offshore, and aligned with the front of the NPDB. It is an alternative solution for the 1882 historical event. The tsunami would affect Panamá, Nicaragua and Colombia.

4. South Caribbean Deformed Belt (SCDB)

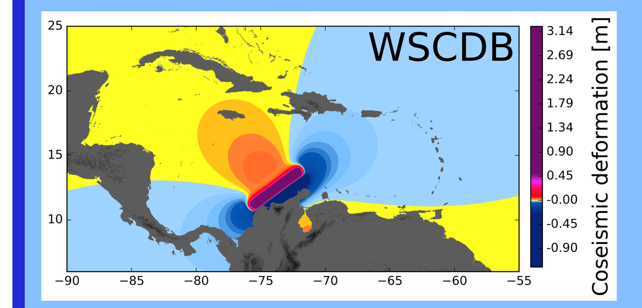

Figure 4.1 Co-seismic deformation in meters caused by WSCDB scenario

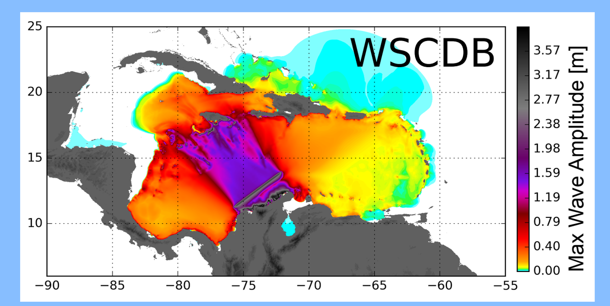

Figure 4.3 Maximum tsunami heights in meters caused by WSCDB scenario

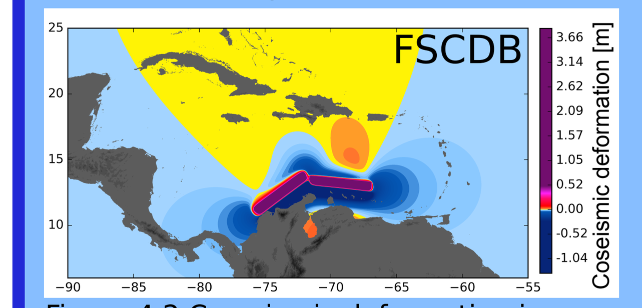

Figure 4.2 Co-seismic deformation in meters caused by FSCDB scenario

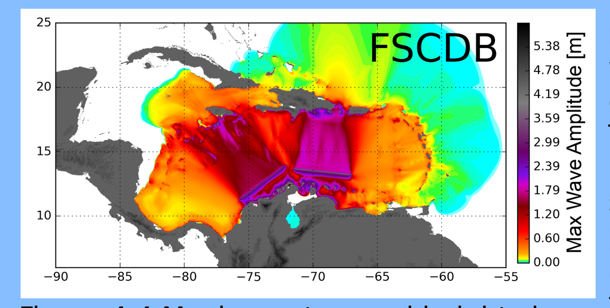

Figure 4.4 Maximum tsunami heights in meters caused by FSCDB scenario

4.1 Western SCDB Mw 8.6

Recent geodynamic studies have suggested considerably locking occurs at the western section of the SCDB. Although minimal seismic and paleotsunami evidence has been found that would suggest significant risk, the fact that current plate motion places full thrust along the deformation front makes this geologic feature worth studying to mitigate its tsunami potential.

4.2 Full SCDB Mw 8.9

The full SCDB segment is a composite source rupturing a total of 1000 km starting at the western segment mentioned above through the eastern portion of the SCDB north of Venezuela. The chances for the entire source rupturing are unknown and very unlikely to occur given that such an earthquake has not been identified in the past, and provided that the interplate motion is mostly accommodated along the northern margin of South America (El Pilar fault system).