Modeling the Tsunami Potential along the Pacific Coast of Central America

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1. Introduction

Along the Pacific coast of Central America, the Cocos plate subducts beneath the Caribbean plate, at the Middle America Trench (MAT). There are no records of mega earthquakes originated there; probably associated to the low coupling in some sections and the presence of seismic barriers. However, moderate ruptures have caused important tsunami runups in the region in 1992 (Ide et al. 1993) and in 2012 (Borrero et al. 2014).
Scenarios presented here were defined as worst-case-scenario by 20 experts on seismology, tsunamis and tsunami modeling (Fig 1.1), based on historical events and/or tectonic and geodetic data. They met in 2016 under the coordination of IOC/UNESCO to discuss the tsunami potential at Central America. Although some scenarios have a low probability of occurrence, they should be taken into account for preparedness purposes.
We present the coseismic deformation and deep-water propagation (energy plots) for the five Pacific scenarios (Fig. 1.2, Fig 1.3 and Table 1), whereas the Caribbean scenarios were published in Chacón Barrantes et al. (2016).
The purpose is to dimension the tsunami size and energy directivity of each scenario. The results can assist countries in hazard assessment and increasing preparedness.

More information about the meeting at http://www.ioc-tsunami.org/index.php?option=com_oe&task=viewEventRecord&eventID=1840

2. Methods

The propagation of the Pacific scenarios was modeled using NEOWAVE numerical model (Yamazaki et al., 2010), which solves Shallow Water Equations (SWE). Only linear equations were employed over a 1 arcmin grid, therefore the tsunami heights given here are referred to deep-ocean and no coastal tsunami heights were calculated. The bathymetry was composed from GEBCO (IOC/UNESCO, 2003) and digitized nautical charts. The co-seismic deformation was simulated within NEOWAVE using Okada (1985).

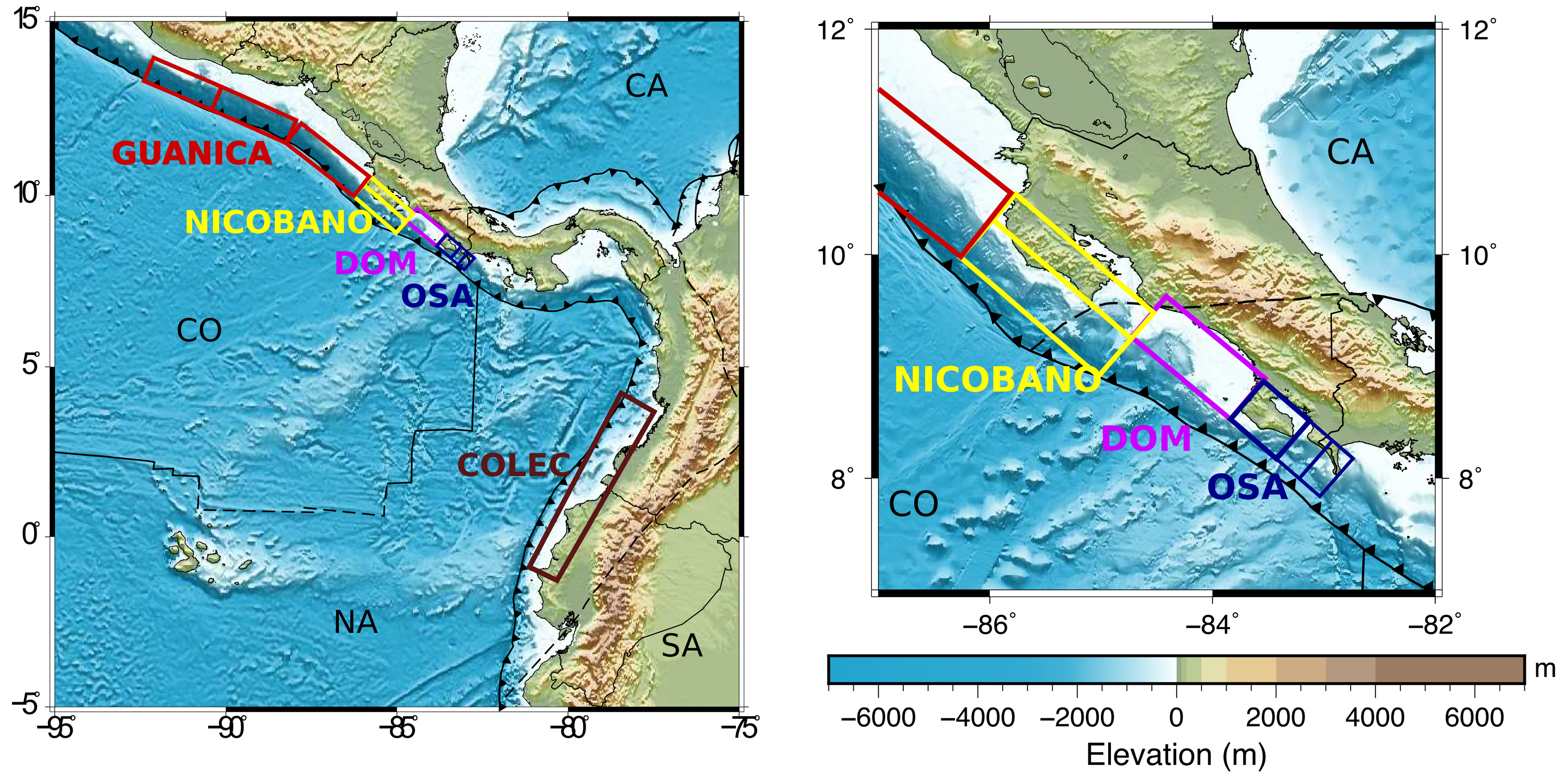

Fig. 1.1 (up) Rupture planes of scenarios modeled here: GUANICA, NICOBANO, DOM, OSA and COLEC. (down) Rupture planes offshore Costa Rica. CO: Cocos Plate, CA: Caribe Plate, NA: Nazca Plate, SA: South America Plate.

Scenario	Planes	Slip Av. (m)	L (km)	W (km)	Mo (N·m)	Mw	μ (GPA)	maximum modeled uplift (m)	maximum modeled subsidence (m)	maximum modeled tsunami height (m)
GUANICA	3	5	769	80	1.08E+22	8.6	35	2.38	0.77	3.5
NICOBANO	2	2.8	180	83	1.46E+21	8.0	35	1.10	0.25	2.5
DOM	1	3	127	53	7.07E+20	7.8	35	1.29	0.50	2.4
OSA	3	2	117	50	3.51E+20	7.6	30	0.74	0.53	0.8
COLEC	1	5	650	125	1.22E+22	8.7	30	2.48	0.74	3.9

Table 1.1 Summary of tsunami scenarios modeled here

RONMAC-UNA Program and NOAA/NCEI created the Caribbean and Adjacent Regions Tsunami Sources and Models (CATSAM) interactive map viewer which includes also the scenarios presented here. This map viewer shows the faults parameters, historical tsunami data and tsunami energy plots for some of the scenarios. CATSAM is available at: https://maps.ngdc.noaa.gov/viewers/CATSAM/

3. GUANICA

This was the largest scenario proposed within the MAT. It is composed by three ruptures along strike that might also break independently. The 80 km width assumed along GUANICA is 'conservative', as the rupture width of 1992 Nicaragua and the coupling constraints (i.e. low geodetic coupling) may be better reconciled with ~40 km coupling width.
The modeling of this scenario indicates some subsidence along the coasts of the mentioned countries, except inside Fonseca Gulf (Fig 3.1). The tsunami would affect largely the coast between Chiapas, Mexico, to Guanacaste, Costa Rica, and Galápagos Islands; and to a lesser extent Cocos Island (Fig. 3.2). The effect of such a tsunami inside Fonseca Gulf should be studied in more detail, with a finer bathymetric grid to account for possible resonance effects.

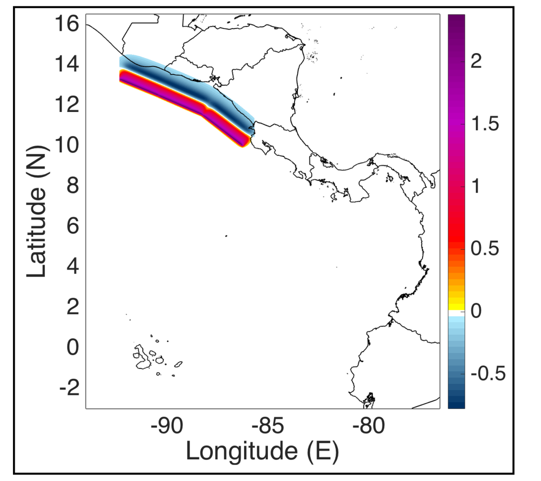

Fig. 3.1. Coseismic deformation (m)

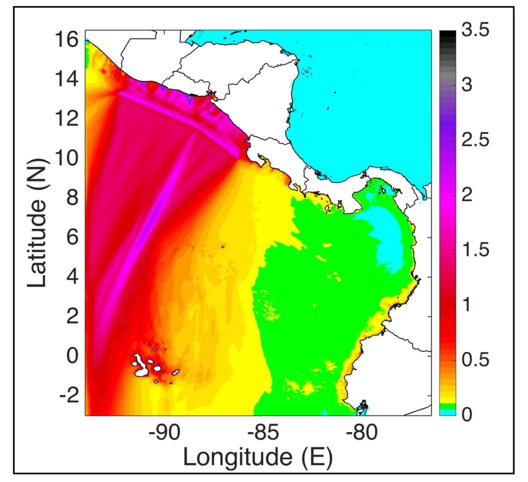

Fig. 3.2. Max. tsunami heights (m)

#	Geometrical center Lon	Geometrical center Lat	Depth (km)	Slip Av (m)	L (km)	W (km)	Strike	Mo (N·m)	Mw	combined Mw
1	-91.2595	13.23	12.5	5	234	80	293	3.28E+21	8.3	8.6
2	-89.1765	12.334	12.5	5	259	80	294	3.63E+21	8.3	
3	-87.0189	11.0426	12.5	5	276	80	308	3.86E+21	8.3	

Table 3.1 Seismic Parameters for GUANICA scenario

4. NICOBANO

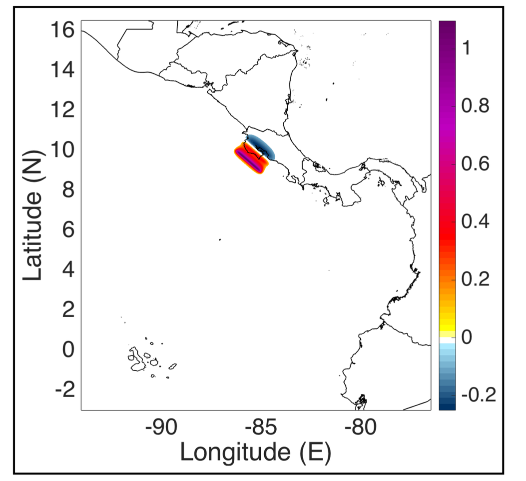

Fig. 4.1. Coseismic deformation (m)

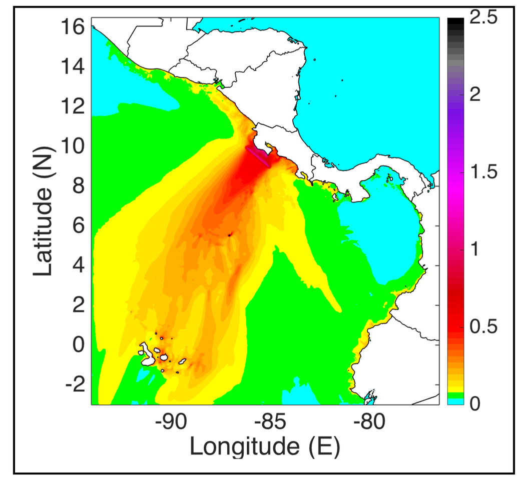

Fig. 4.2. Max. tsunami heights (m)

Table 4.1 Seismic Parameters for NICOBANO scenario

#	Geometrical center Lon	Geometrical center Lat	Depth (km)	Slip Av (m)	L (km)	W (km)	Strike	Mo (N·m)	Mw	combined Mw
1	-85.4937	9.6161	15	2.8	180	49	311	8.64E+20	7.9	8.0
2	-85.2363	9.9086	27.5	2.8	180	34	311	6.00E+20	7.8	

NICOBANO scenario comprises the Nicoya segment and the rupture extent of the 1990 earthquake at the entrance of Nicoya Gulf. The joint rupture of these two segments of MAT is an extreme case, as the differences on the coupling might not support it.
This scenario is divided in two rupture planes: shallow and deep (Fig. 1.3), as the subduction angle changes in this region: steeper for the deep plane. The rupture of those planes separately might be considered. These setup causes uplift of the western coast of the Nicoya Peninsula and subsidence of the Nicoya Gulf (Fig. 4.1). The subsequent tsunami would impact Guanacaste and Puntarenas provinces of Costa Rica and to a lesser extent Rivas department, Nicaragua (Fig. 4.2). The directivity of this scenario would imply a considerable amount of tsunami energy focusing in Cocos and Galapagos Islands. Further simulations with finer grids are recommended to study the effect of this scenario within Nicoya Gulf.

5. DOM

DOM scenario comprises the rupture of the remaining part along the Cóbano-Herradura segment together with the Quepos-Sierpe segment within the Costa Rican subduction zone (Fig. 5.1). The most reasonable scenario assumes a narrower rupture plane with an smaller rupture length, given the "width of the seismogenic zone is very narrow because the forearc has been chewed up by tectonic erosion" (M. Protti, pers. Com). DOM directs most of its energy to Cocos and Galapagos Islands (Fig. 5.2), although the magnitude of the scenario is much smaller than NICOBANO. Within Central America this scenario would affect only Puntarenas province, Costa Rica.

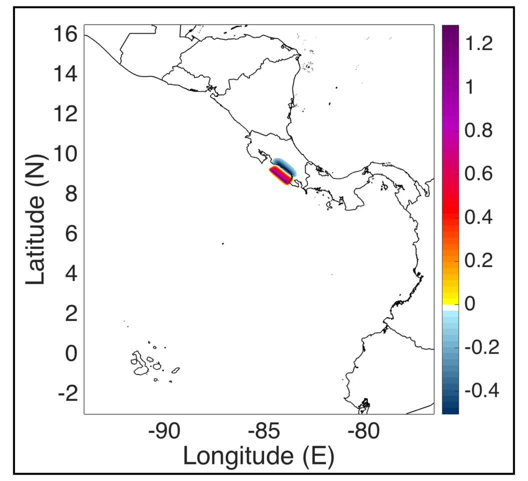

Fig. 5.1. Coseismic deformation (m)

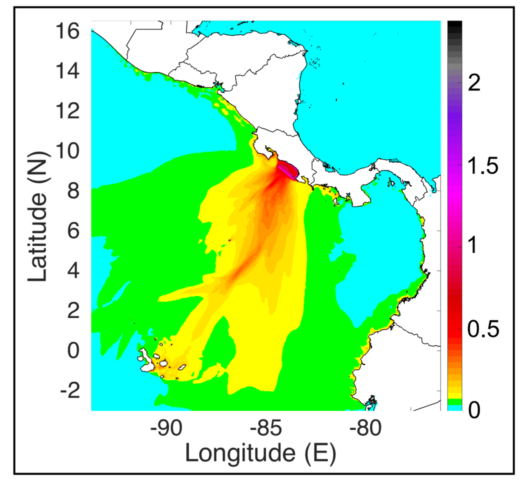

Fig. 5.2. Max. tsunami heights (m)

Geometrical center Lon	Geometrical center Lat	Depth (km)	Slip Av (m)	L (km)	W (km)	Strike	Mo (N·m)	Mw
-84.4157	9.627	18.7	3	127	53	310	7.07E+20	7.8

Table 5.1 Seismic Parameters for DOM scenario

6. OSA

Osa segment of Costa Rica subduction zone has a recurrence period of about 40 years, and the last event was in 1983 (Protti, 2014). This worst-case-scenario consists in three fault planes. Smaller scenarios can be simulated considering only segment 1 or segment 1 and 2. The segments 2 or 3 alone would not represent realistic scenarios. OSA scenario would generate uplift of Osa Peninsula and subsidence of Dulce Gulf (Fig. 6.1). The tsunami would affect central and south of Puntarenas province, Costa Rica, and Chiriqui province of Panamá (Fig. 6.2). The directivity of this tsunami scenario would also affect Cocos and Galápagos Islands, although it has a smaller magnitude than NICOBANO and DOM scenarios.

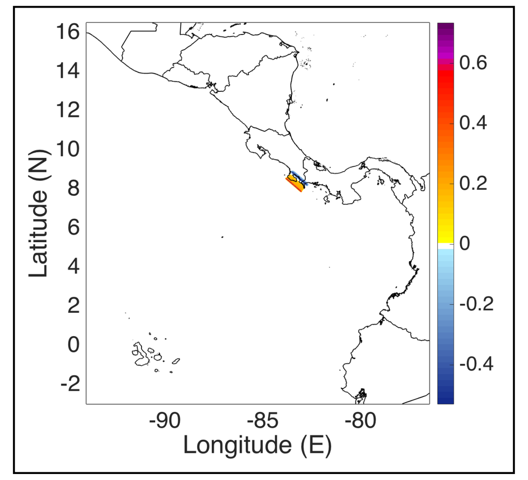

Fig. 6.1. Coseismic deformation (m)

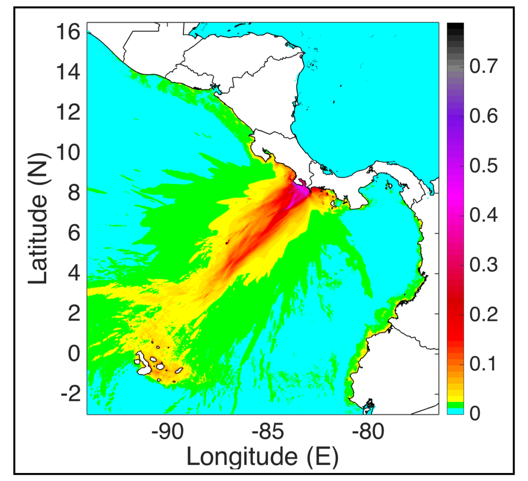

Fig. 6.2. Max. tsunami heights (m)

#	Geometrical center Lon	Geometrical center Lat	Depth (km)	Slip Av (m)	L (km)	W (km)	Strike	Mo (N·m)	combined Mw
1	-83.4834	8.5216	4.25	2	60	50	311	1.80E+20	7.6
2	-83.1747	8.2561	4.25	2	30	50	311	9.00E+19	
3	-82.9796	8.0879	4.25	2	27	50	311	8.10E+19	

Table 6.1 Seismic Parameters for OSA scenario

7. COLEC

COLEC scenario was considered here due to proximity and directivity, even when corresponds to the South America Trench (SAT) (Fig. 7.1). 1906 Colombia-Ecuador Mw 8.6 tsunami (Okal, 1992) was witnessed in Costa Rica, El Salvador and Panamá, with no important consequences (NGDC/NCEI, 2018), very likely due to sparsely populated coasts at that time.
This scenario would affect the whole Central America (Fig. 7.2). The tsunami would have higher heights at Cocos Island, Costa Rica, El Salvador and Panamá. Tsunami inundation modeling is strongly advised to analyze in detail the effects of such a tsunami along Central America, considering that arrival time would be on the order of one hour for the nearest countries.

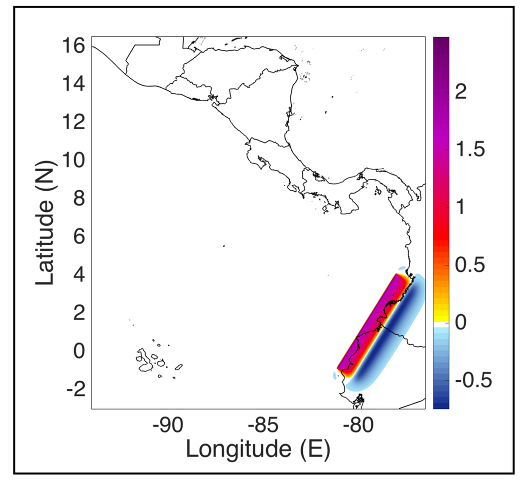

Fig. 7.1. Coseismic deformation (m)

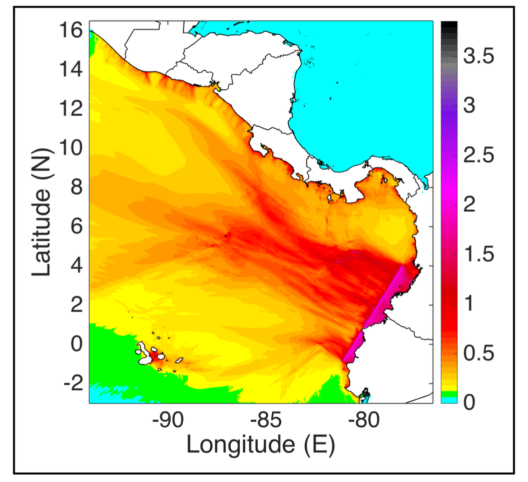

Fig. 7.2. Max. tsunami heights (m)

Geometrical center Lon	Geometrical center Lat	Depth (km)	Slip Av (m)	L (km)	W (km)	Strike	Mo (N·m)	Mw
-78.9418	1.19	12	5	650	125	32	1.22E+22	8.7

Table 7.1 Seismic Parameters for COLEC scenario

8. Conclusions

Here were considered five worst-case tsunami scenarios for Central America. These scenarios were defined for tsunami hazard assessment purposes:

1. Only one of the five scenarios considered here affected the complete Central America region, and this was not originated within the region but along the South American Trench (SAT).

2. Energy plots showed that tsunamis originated along the Middle American Trench (MAT) very likely would be mild and localized. However, they could still pose a threat for coastal regions, particularly considering the high touristic visitation in the region during all seasons. The local hazard for each country, including numerical inundation modeling, should be estimated in future studies.

3. All tsunami scenarios modeled here show important energy beams toward Cocos Island. Even when this island is a very low populated national park, authorities and visitors should be prepared.

9. Future Work

- Use a varying rigidity to account for areas where coupling could be lower, yet slip could occur, as in the Nicaragua 1992 "tsunami earthquake".
- Incorporate seismic scenarios considering heterogeneous slip distributions, to account for large uncertainties that could be derived from the complexity of ruptures, not always considered in regional studies.
- Model tsunami inundation. This has been carried in some particular cases. However, high-resolution bathymetry coverage is still quite limited in the region, hindering numerical modeling.

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