**Intergovernmental Oceanographic Commission**

Workshop Report No. 278

# Tsunami Hazard in Central America: Historical Events and Potential Sources

San Jose, Costa Rica
23–24 June 2016

**UNESCO**

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# TABLE OF CONTENTS

**ANNEXES**

## EXECUTIVE SUMMARY

Central America lies between two oceans, the Pacific and the Atlantic through the Caribbean Sea. Although it has no records of great earthquakes (~8.0 to 9.0), a tsunami catalogue based on historical references for Central America lists more than 50 entries. Tsunamis caused damage and casualties in 1882 off the Caribbean coast of Panama, in 1991 in Costa Rica and Panama and in 1992 in the Pacific coast of Nicaragua. Coastal population has vastly increased in recent decades, along with tourism, increasing total exposure to tsunami.

The outcomes of this meeting, organized by UNESCO's Intergovernmental Oceanographic Commission (IOC), are initially intended to contribute with sound science inputs to the project "Building resilient communities and integrated Early Warning Systems for tsunamis and other ocean related hazards in Central America", funded by the European Commission's Civil Protection and Humanitarian Aid Operations department (ECHO) implemented by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and national counterparts in El Salvador, Guatemala, Honduras and Nicaragua, in close cooperation with Panama and Costa Rica.

The invited experts analyzed credible tsunami sources, for which they identified the following groups in the Pacific Ocean and Caribbean Sea, with potential impact for Central America's coasts:

- Pacific margin tectonic sources
  - Near-field tectonic sources (less than 500 km from impact zone):
    - Middle America Trench MAT1 (GUANICA) – $M_w$ 8.6
    - Middle America Trench MAT2 (NICOBA) – $M_w$ 8.0
    - Middle America Trench MAT3 (DOM1) –$M_w$ 7.5
    - Middle America Trench MAT4 (OSA) – $M_w$ 7.6
  - Far-field tectonic sources
    - Colombia-Ecuador South American margin SAM1 (COLEC) – $M_w$ 8.7
- Caribbean tectonic sources
  - Near-field tectonic sources (less than 500 km from impact zone):
    - Northern Panama Deformed Belt NPDB1 - Limón (LIMON) – $M_w$ 7.9
    - Northern Panama Deformed Belt NPDB2 - 1882 (1882) – $M_w$ 8.5
    - Northern Panama Deformed Belt NPDB3 - Panama (PAN) – $M_w$ 8.5
  - Far-field tectonic sources
    - West branch of the South Caribbean Deformed Belt (WSCDB) – $M_w$ 8.6
    - Full South Caribbean Deformed Belt (FSCDB) - $M_w$ 8.9

## 1. BACKGROUND

Central America lies between two oceans, the Pacific and the Atlantic through the Caribbean Sea. Although it has no records of great earthquakes (~8.0 to 9.0), a tsunami catalogue based on historical references for Central America lists more than 50 entries (Molina, 1997) (Figure 1). Furthermore, a couple of tsunamis at both shores have caused damage and casualties at the end of the 20th century: 1991 in Costa Rica-Panama and 1992 in Nicaragua. At least two "tsunami earthquakes" have happened at the Pacific shores of Central America: 1992 in Nicaragua (Kanamori and Kikuchi, 1993) and 2012 in El Salvador-Nicaragua (Borrero et al., 2014). In 1882 a $M_w$ 7.9 earthquake off the Caribbean coast of Panama generated a tsunami that caused upwards of 100 deaths on the San Blas Archipelago.

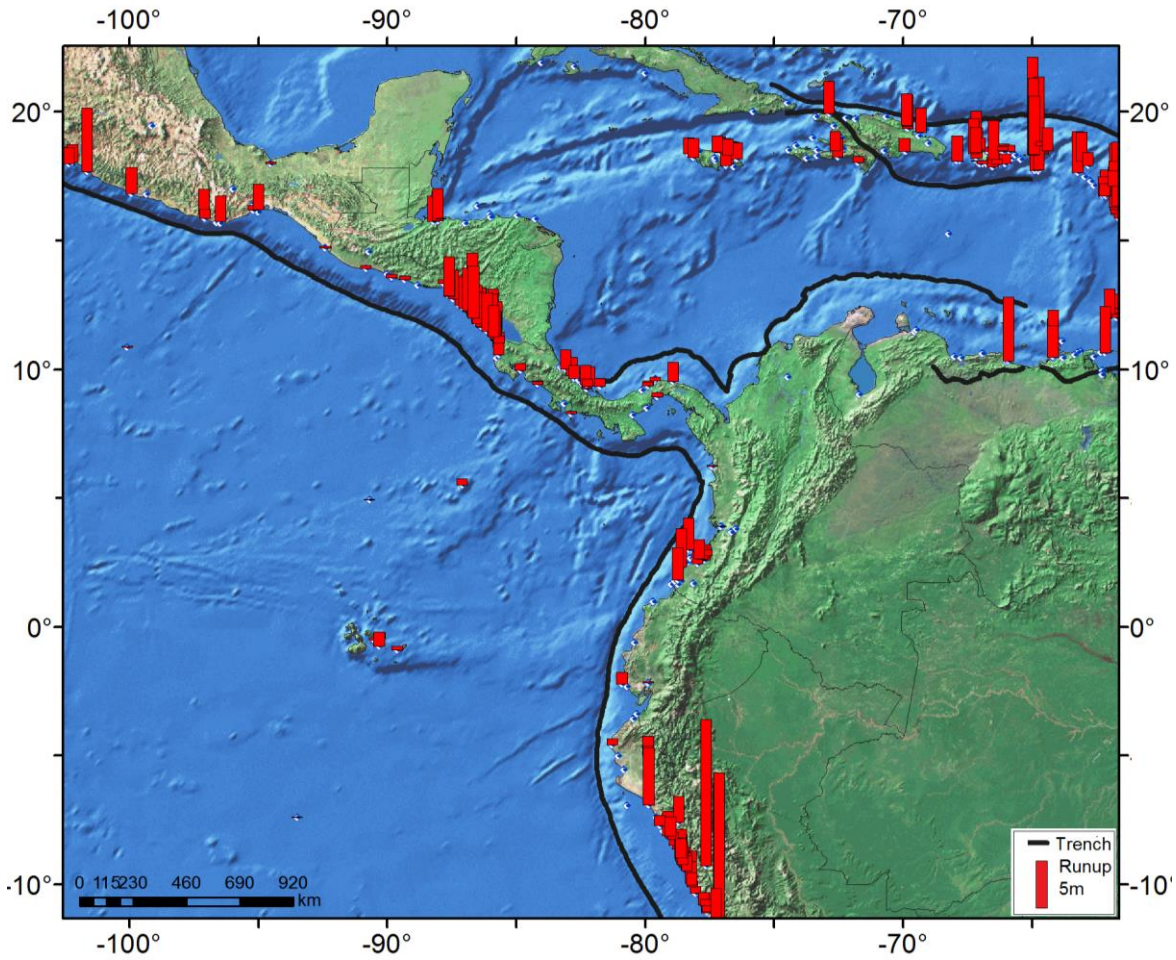


Figure 1. Run-up and tsunamigenic earthquakes along CAM in 500 years.
Source modified from Fernández et al. (2000) and NGDC/WDS (2015).

The coastal population along the region has vastly increased in the past decades, along with tourism, increasing the number of persons exposed to tsunami risk.

Central America tsunami preparedness is improving with different degrees of development, some of the Central American countries have National Tsunami Warning Systems. Also, a Central America Tsunami Advisory Centre (CATAC) at INETER (Nicaraguan Institute of Territorial Studies) in Nicaragua is under development, deployment of tidal gauges is improving and the region was chosen by the Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System (ICG/PTWS) for the 2015–2017 pilot course on Tsunami Evacuation Maps, Plans and Procedures (TEMPP).

While the potential for tsunamis with larger amplitude than documented historically has not been established for either shore, the relatively short span of historical tsunami records does not allow excluding it upfront.

Objective:

Identification of credible sources of tsunamis that could significantly impact the Pacific and Caribbean coasts of Central America and that can be used for tsunami modelling, evacuation mapping, planning and exercises.

Leading questions for the discussion:

a. Which sources of tsunamis should be used for tsunami inundation modelling, hazard assessment, evacuation mapping, planning and exercises for the Caribbean and Pacific coasts of Central America?

b. What is the potential for "tsunami earthquakes" in the Pacific coast of Central America?

c. Is there a chance for a $M_w$>8.0 event along the Middle America Trench (MAT)?

d. Is there a chance of the MAT rupturing as a whole?

e. What is the seismic potential of the North Panama Deformed Belt (NPDB)? Is it possible that it ruptures as a whole?

f. Is there any risk of a major earthquake in other sections of the Central America Caribbean coast?

g. Should regional sources (like Colombia or Mexico) also be considered as local sources due to travel time and directivity (both for Pacific and Caribbean shores)?

## 2. SEISMIC SOURCES WITH TSUNAMIGENIC POTENTIAL AFFECTING CENTRAL AMERICA

Over 20 experts attended the meeting, including representatives of Costa Rican institutes and international experts. The agenda and list of speakers is available under Annex I. The list of participants can be found in Annex IV.

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

The Experts Meeting was divided in three technical sessions. The 23 June 2016 researchers presented the main aspects of the tectonics, seismicity and tsunamigenic sources along Central America and Northern South America including the Pacific and Caribbean margins. The 24 June 2016 talks addressed tsunami modelling, followed by technical discussions. The latter were divided into two Working Groups (WG). The numerical modelling group (WG1) was in charge of discussing the main challenges of tsunami modelling in the region. The second Working Group (WG2) defined the tsunamigenic seismic sources that could affect Central America. During the three technical sessions, the state of the art was presented, whereas during the second part, experts defined the most likely tsunami sources that might strike Central America.

Figure 2. Kick-off meeting group picture

## 2.1 TECHNICAL DISCUSSION SESSIONS

Technical discussion sessions from Working Group 2 largely focused on discussing fault plane parameters for each of the proposed feasible tectonic sources for tsunamis.

Working Group 1 (tsunami modellers) discussed requirements for numerical modelling and assisted Working Group 2 by showing results of previously modelled tsunami sources for the region. Also, during breaks they modelled some of the proposed sources allowing refinement of the fault parameters.

Figure 3.Dr Eduardo Camacho (Panama), Dr Wilfried Strauch (Nicaragua), Mr Néstor Luque (Panama) and Dr Emile Okal (USA) during the working session.

Figure 4. Prof. Emile Okal summarizing the main aspects discussed by WG2

Ten sources were defined, some of them involving several fault segments, four near-field sources extending throughout Guatemala to Panama in the Pacific margin, and three sources from Costa Rica to Panama along the Caribbean margin. In the far field, one source has been suggested along the Colombia-Ecuador subduction zone, and two sources in the Colombia-Venezuela South Caribbean Deformation Belt.

## 3. TECTONIC SETTING OF CENTRAL AMERICA AND SURROUNDINGS

Central America (CAM) lies in the Western part of the Caribbean plate. It is bounded by the Middle America Trench (MAT) along the Pacific margin, and the Northern Panama Deformation Belt (NPDB) in the south Caribbean side. Five tectonic areas have been considered in this study as potential contributors to tsunami hazard in CAM: (i) Middle America Trench, (ii) Southern Panama Convergence Zone, (iii) Colombia-Ecuador margin, (iv) Northern Panama Deformation Belt (NPDB), and (v) Southern Caribbean Deformation Belt (Figure 5).

### 3.1 PACIFIC MARGIN: TECTONICS AND TSUNAMIGENETIC SOURCES ALONG MIDDLE AMERICA, COLOMBIA AND ECUADOR

The Middle America subduction zone has generated most of the large earthquakes in this region. The interaction of the Cocos plate, Caribbean plate, Panama block and Nazca plate (offshore Panama) has triggered mainly local tsunamis. There is great variability in the characteristics of seismic ruptures and seismic rates along this margin, which are related partly to its tectonic structure and to physical properties such as interplate coupling and fluids supply (i.e. Audet and Schwartz, 2013; Ye et al., 2013).

Along the Pacific margin of Central America the Cocos plate is subducting beneath the Caribbean plate and the Panama block at a rapid convergence rate that increases from North to South from 7.5 to ~ 9.0 cm/yr (DeMets et al., 2010). It has been pointed out that the ocean bottom along the Middle America Trench (MAT) changes considerably along-strike

(Barckhausen et al., 1998; Hey, 1977), which is related to a diversity in the origin of the Cocos plate. These variations change from smooth bathymetry from offshore Guatemala to the Nicoya Peninsula in Costa Rica, to rougher bathymetry from South of the Nicoya Peninsula towards Osa Peninsula, arising from the presence of seamounts and of the Cocos ridge, which are subducting beneath the Caribbean plate (Figure 5).

The Southeastern end of the Cocos Plate is overlain by the aseismic Cocos Ridge, where a 20-km thick buoyant crust could have been subducting for 1 to 5 Ma (de Boer et al., 1995, 1988; Lonsdale and Klitgord, 1978; Sallarès, 2003). This subduction of the Cocos ridge beneath the Panama microplate causes strong coupling (Sitchler et al., 2007), strong forearc shortening (Sak et al., 2009; Sitchler et al., 2007) and shallowing of seismicity along the Benioff zone (Protti et al., 1994) possibly increasing steepness towards the edge (Dzierma et al., 2011).

Such bathymetric imprints could be playing a major role in seismicity and tsunami generation (Bilek et al., 2003; Wang and Bilek, 2014) and have been related to the potential for triggering tsunami earthquakes (Kanamori, 1972). Another related factor that could be influencing the seismicity is the coupling between the Cocos and Caribbean plates. Predominantly low coupling has been suggested along the MAT, except at the Nicoya and Osa peninsulas and in the shallow part of the mega-thrust along Nicaragua and El Salvador. These regions appear to be strongly coupled, as are deeper patchy zones of strong seismic coupling identified along Guatemala (Álvarez-Gómez et al., 2008; Correa-Mora et al., 2009; Feng et al., 2012; LaFemina et al., 2009; Ye et al., 2013).

Offshore the Pacific margin along Panama, the Panama Fracture Zone separates the Cocos plate from the Nazca plate. Here, the Southern Panama Convergence Zone is the main tectonic feature, where the Nazca plate subducts under the Panama block (Adamek et al., 1988; Kolarsky and Mann, 1995).

Further South, the Nazca plate subducts beneath the South American plate at a convergence rate of 5.5 cm/yr along the Colombia-Ecuador margin. The Grijalva Fracture Zone (GF) and the Carnegie Ridge (Figure 5) are important features that could be influencing the deformation patterns along the margin (Collot et al., 2002). In the last century, at least six great earthquakes have ruptured along the North Andean plate boundary between South Colombia and North Ecuador (Herd et al., 1981; Kanamori and McNally, 1982; Swenson and Beck, 1996). The Northern part of this plate is capable of generating tsunamis, as exemplified by the earthquake that occurred on 31 January 1906 (Bilek, 2010) with magnitude $M_w$~8.6 (Okal, 1992).

It is interesting to note that no large earthquakes, and in particular no tsunamigenic events, are known before 1906 for Southern Colombia and Northern Ecuador, even though written archives document such events starting in the XVI$^{th}$ century A.D., in other parts of the former Spanish colonies, e.g., in present-day Mexico, Peru and Chile. This remark emphasizes that essentially nothing is known of the duration of seismic cycles in Ecuador and Colombia.

It is important to note that local tsunamis seem to represent most of the hazard for CAM. There have been suggested different earthquake rupture mechanisms along-strike the MAT, where coupling ratios could partly explain the lack of giant earthquakes along the interplate (Wang and Bilek, 2014; Ye et al., 2013). Despite the absence of giant earthquake records, tsunami earthquakes (Kanamori, 1972) have caused large local tsunamis. The highest recorded tsunamis along CAM have been triggered by the 1992 $M_w$ = 7.6 Nicaragua earthquake, that generated a 10 m run-up (Satake et al., 1993), and the 2012 $M_w$ = 7.3 El Salvador earthquake that caused a 6 m run-up (Borrero et al., 2014). These two events have been characterized as 'tsunami earthquakes' according to the definition from Kanamori (1972). Magnitudes disparities characterize tsunami earthquakes such as the 1992 Nicaragua event ($m_b$=5.3, $M_s$=7.2;

$M_w$=7.6) and are attributed to low frequencies, with slow ruptures and unusually long durations (Kikuchi and Kanamori, 1995; Newman and Okal, 1998; Satake, 1994).

The 1992 Nicaragua earthquake occurred in a region where sediments are sparse but where high pore pressure could allow shallow rupture propagation (Von Huene and Scholl, 1991). Subducted seamounts whose location coincides with the large seismic moment release and seafloor deformation have been proposed as asperities of the 1992 earthquake (McIntosh et al., 2007). They agree with a model that states that unstable regions (prone to rupture) are surrounded by conditional stable material, precluding the up-dip rupture propagation of the mega-thrust (Bilek and Lay, 2002).

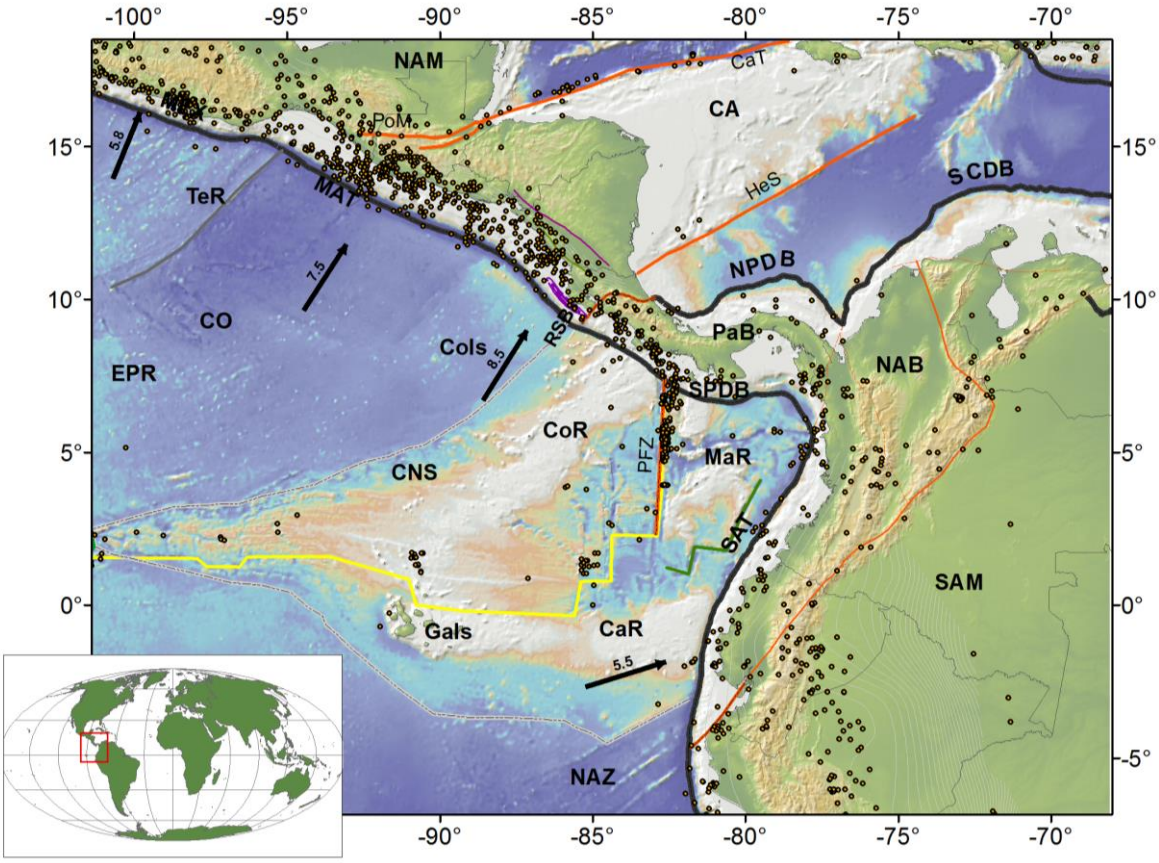


Figure 5. General overview of main tectonic structures. Source of the digital elevation model (Ryan et al., 2009). CA: Caribbean plate; CaR: Carnegie ridge; CNS: Cocos-Nazca Spreading Center origin; CO: Cocos plate; CoR: Cocos ridge; EPR: East Pacific Rise; Gals: Galapagos Islands; HeS: Hess Escarpment; NAB: Northern Andean Block; NAM: North American plate; NAZ: Nazca plate; PaB: Panama Block; PFZ: Panama Fracture Zone; PoM: Polochic Motagua Fault Zone RSB: rough-smooth ocean floor boundary (Hey, 1977); SAM: South American plate; SAT: South American Trench. Arrows show convergence rate in cm/yr. Yellow dots show seismicity $M_w$>5. Inset map shows the area of study on a global view.

## 3.2 CARIBBEAN MARGIN: TECTONICS AND TSUNAMIGENIC SOURCES ALONG SOUTHERN CENTRAL AMERICA, COLOMBIA AND VENEZUELA

The main tsunamigenic source along the Central American Caribbean tectonic margin is the Northern Panama Deformed Belt, whereas the Southern Caribbean Deformed Belt has been considered as an important tsunamigenic source that could potentially affect Central America.

The Northern Panama Deformed Belt (NPDB) expresses the convergence between the Caribbean plate and the Panama block, at a rate of 7 mm/yr (Trenkamp et al., 2002). This deformation zone extends from Costa Rica to Northwestern Colombia (Silver et al., 1990). Most of the seismicity in this region occurs along the over-thrusting system. The over-thrusting subduction limits remain a scientific debate; however, it has been recognized that along central Panama (Eastern segment of the NPDB) there is clear evidence of a Wadatti-Benioff zone demonstrating an active subduction beneath the Panama block (Camacho et al., 2010). Due to distinct seismicity patterns, it has been separated in three seismo-tectonic areas, mostly on the account of crustal seismicity; however, offshore central Panama, focal mechanisms distinctly show inverse mechanisms as pointed by Camacho et al. (2010), that could trigger tsunamigenic events. The NPDB is divided following approximately at the Costa Rica-Panama border (Camacho and Víquez, 1993). For the western area, the earthquake epicenters appear to rupture mostly inland, even though most of the tsunami records are located there, as opposed to along the eastern segment, which has only one tsunami record.

The largest documented earthquake along the Costa Rica sub-segment of western NPDB occurred in 1991 ($M_w$ = 7.7) (Plafker and Ward, 1992), with an associated 2–3 m tsunami runup. The 1991 earthquake ruptured along an inverse fault that dips ~30°. Coastal terraces indicate earthquake recurrence of 200–1100 years (Denyer et al., 1995; Plafker and Ward, 1992). There is a tsunami record in 1798 along the Costa Rica central Caribbean coast, associated with an earthquake of unknown magnitude and epicenter (Camacho and Víquez, 1993). The 20 December 1904 an earthquake ($M_s$ = 7.0) was felt in Costa Rica and Panama, but there is an open controversy about whether this earthquake originated in the Pacific (Kobayashi et al., 2014; Pacheco and Sykes, 1992) or on the Caribbean shore(Camacho and Víquez, 1993). In favour of the Caribbean shore location there is a reported uplift of coastal reefs close to Limon hospital on the Costa Rica Caribbean shore, although there is no specific report of a related tsunami. The 1822 earthquake was initially located at the South Pacific coast as well, until a tsunami record was associated (Camacho and Víquez, 1993). Sediment deposits from the 1822 tsunami are very similar to those of 1991, suggesting a similar earthquake magnitude (Camacho and Víquez, 1993). The only tsunami that has been triggered by earthquakes documented along the western segment of the NPDB occurred on 25 April 1916 (Magnitude 7). There are reports of three other earthquakes without associated tsunamis: 26 November 1867, 21 December 1910 ($M_s$=6.5), and 24 April1916 ($M_s$=7.3). Subsidence of Zapodilla Island was reported for the 1867 event; however, no clear tsunami records are available.

The central segment of the NPDB has very low seismicity rates and apparently, it does not pose any tsunami threat. Along the eastern segment of the NPDB a large event occurred in 1882 with magnitude M 7.9 causing a tsunami. Here the Caribbean plate subducts beneath the Panama microplate with a dip angle of 50° (Adamek et al., 1988). A Wadati-Benioff zone has been determined with seismological records for this segment of the NPDB (Camacho et al., 2010) but not yet for the western or central segments. There are reports of moderate (M<7.2) earthquakes in this segment in 1873, 1909, 1914, 1930, and 2000, with no associated tsunami records. Reverse mechanisms with strike-slip components prevail in this region.

The second tsunamigenic source considered for the Caribbean margin is the South Caribbean Deformation Belt offshore Colombia-Venezuela. This region, also known as the South Caribbean marginal fault, is a deformation belt of an accretionary wedge where under-thrusting of the Caribbean plate and the sedimentary basin overlap the South American plate (Mann, 1999). This segment is a tectonically complex region that extends between the NPDB and limited in the southwestern Caribbean-South American plates by fault zones along the Venezuelan Andes (i.e. Bocono fault). As these crustal faults zones appear only inland, they are not described here.

There is a right-lateral transpression with slow abduction of the southern Caribbean plate onto South America at 2 cm/yr (Speed 1985; Trenkamp et al. 2002). Pindell and Dewey (1982) proposed that the Panama collision towards South America is driving the North Andean Block escape. This North Andean detachment could be driven by the oblique Nazca convergence (Kelllog and Mohriak 2001), or the arrival of the Carnegie ridge at the Ecuador trench (Gutscher et al., 1999), whereas the eastward collision of Panama towards North Andes may have been driven by oblique subduction of the Cocos Ridge and the Nazca and Cocos plates (Mann and Kolarsky, 1995). Two tsunamis appear in the databases for this region; one struck in 1825 and another occurred in the Maracaibo Lake in 1961. The largest earthquakes in the seismic catalogues are in the range of M ≈ 6–6.5.

## 4. TSUNAMI SOURCES AGREEMENT

The objectives of the meeting were met to a largely extent. A consensus on tsunami sources was reached followed by further discussions via email. These discussions were supported by numerical tsunami simulations using the NEOWAVE tsunami code (Yamazaki et al. 2010). The simulations led to more accurate parametrization of the sources. It was proposed to include lower rigidity (i.e. 20 GPa) at shallow parts, which was not considered in this report, but might be included in future simulations. Only seismic tsunamigenic scenarios were identified and divided into near-field and far-field sources as follows.

### 4.1 PACIFIC MARGIN TECTONIC SOURCES

#### 4.1.1 Near-field tectonic sources (less than 500 km from impact zone)

Tsunami sources in this category are located near the area of study (less than 500 km), so that first arrival waves of the tsunami will reach coastal zones in less than 20 minutes. Discussions among experts agreed on four main sources:

- Middle America Trench MAT1 (GUANICA) – $M_w$ 8.6
- Middle America Trench MAT2 (NICOBA) – $M_w$ 8.0
- Middle America Trench MAT3 (DOM) – $M_w$ 7.5
- Middle America Trench MAT4 (OSA) – $M_w$ 7.7

#### 4.1.2 Far-field tectonic sources

Sources in this category are located farther than 500 km from the area of study so that first tsunami waves are expected to arrive more than 60 minutes after origin time.

- Colombia-Ecuador South American margin SAM1 (COLEC) – $M_w$ 8.7

### 4.2 CARIBBEAN TECTONIC SOURCES

#### 4.2.1 Near-field tectonic sources (less than 500 km from impact zone):

- Northern Panama Deformed Belt - Limon (NPDB1) – $M_w$ 7.9
- Northern Panama Deformed Belt– Historical 1882 (NPDB2) – $M_w$ 8.5
- Northern Panama Deformed Belt - Panama (NPDB3) – $M_w$ 8.5

### 4.2.2 Far-field tectonic sources

- West branch of the South Caribbean Deformed Belt (WSCDB) – $M_w$ 8.6
- Full South Caribbean Deformed Belt (FSCDB) - Mw 8.8

All the sources are included in a Webmap available at: http://arcg.is/2qkmnlO

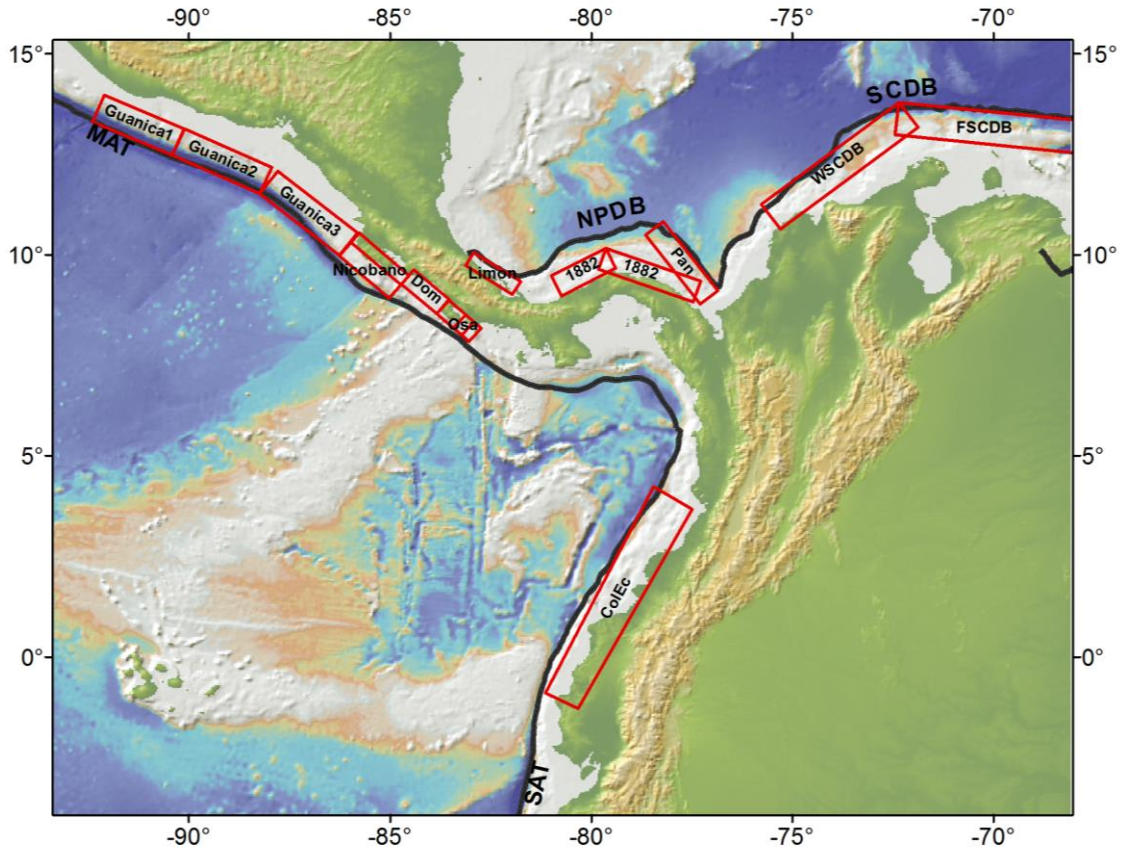


Figure 6. Seismic sources (projected fault planes) considered as important contributors to tsunami hazard for CAM.

| | | Geometrical centre | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Source** | **#** | **Lon** | **Lat** | **Depth (km)** | **Slip Av (m)** | **L (km)** | **W (km)** | **Mo (N·m)** | **$M_w$** | **μ (GPa)** |
| GUANICA | 1 | -91.26 | 13.23 | 12.5 | 5.0 | 234 | 80 | 3.28E+21 | 8.6 | 35 |
| | 2 | -89.17 | 12.33 | 12.5 | 5 | 259 | 80 | 3.63E+21 | | |
| | 3 | -87.01 | 11.04 | 12.5 | 5 | 276 | 80 | 3.86E+21 | | |
| NICOBANO | 1 | -85.49 | 9.61 | 15 | 2.8 | 180 | 49 | 8.64E+20 | 8.0 | 35 |
| | 2 | -85.23 | 9.91 | 27.5 | 2.8 | 180 | 34 | 6E+20 | | |
| DOM | 1 | -84.22 | 9.08 | 17.5 | 1.6 | 100 | 40 | 1.92E+20 | 7.5 | 30 |

| | | Geometrical centre | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Source** | **#** | **Lon** | **Lat** | **Depth (km)** | **Slip Av (m)** | **L (km)** | **W (km)** | **Mo (N·m)** | **$M_w$** | **μ (GPa)** |
| OSA | 1 | -83.48 | 8.52 | 4.25 | 2.0 | 60 | 50 | 1.80E+20 | 7.6 | 30 |
| | 2 | -83.17 | 8.2 | 4.25 | 2 | 30 | 50 | 9E+19 | | |
| | 3 | -82.97 | 8.09 | 4.25 | 2 | 27 | 50 | 8.1E+19 | | |
| COLEC | 1 | -78.94 | 1.19 | 12 | 5.0 | 650 | 125 | 1.22E+22 | 8.7 | 30 |

Table 1. Rupture parameters for seismic sources along the Pacific margin

| | | | Geometrical centre | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Region** | **Source** | **#** | **Lon hypo** | **Lat hypo** | **Depth (km)** | **Slip Av (m)** | **L (km)** | **W (km)** | **Mo (N·m)** | **$M_w$** | **μ (GPa)** |
| NPDB | Limon | 1 | -82.43 | 9.54 | 15 | 4.2 | 150 | 45 | 9.92E+20 | 7.9 | 35 |
| | PARC | 1 | -78.53 | 9.53 | 22.5 | 6 | 274 | 70 | 4.03E+21 | 8.5 | 35 |
| | | 2 | -80.21 | 9.59 | 22.5 | 6 | 166 | 70 | 2.44E+21 | | |
| | Panama | 1 | -77.8 | 9.8 | 25 | 10 | 243 | 80 | 6.42E+21 | 8.5 | 33 |
| SCDB | WSCDB | 1 | -73.83 | 12.21 | 25 | 7.4 | 467 | 90 | 1.03E+22 | 8.6 | 33 |
| | FSCDB | 1 | -73.83 | 12.21 | 25 | 7.4 | 467 | 90 | 1.03E+22 | 8.9 | 33 |
| | | 2 | -69.67 | 13.18 | 25 | 8 | 585 | 90 | 1.39E+22 | | |

Table 2. Rupture parameters for seismic scenarios along the Caribbean margin

## 4.3 MODELING RESULTS

### 4.3.1 Pacific Nearfield Sources

#### *4.3.1.1 GUANICA: Middle America Trench 1 (MAT1) from Guatemala to Nicaragua (Fig. 7a and 7b)*

This is the largest source proposed within MAT with $M_w$ = 8.6. It has a total length of 769 km and extends from Guatemala to Nicaragua. It is composed of three fault planes that might also break independently; however, here a joint rupture is considered as a worst-case scenario.

The modelling of this source indicates some subsidence along the coasts of the mentioned countries, except inside Fonseca Gulf. The tsunami would vastly affect the coast, from southern Mexico to northern Costa Rica. 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.

The 80 km width assumed along Guanica is 'generous', as the rupture width of the 1992 Nicaragua event and coupling constraints from geodesy may be better reconciled with a ~40 km coupling width. Should a total rupture occur, it might drive slip further down-dip more than has been the case with isolated ruptures, along the weakly coupled seismogenic zone between the Cocos and Caribbean plates (T. Lay, written comm.).

This scenario is settled to magnitudes $M_w$ = 8.6 as a reasonable bound, given the low coupling along GUANICA, although it might have very low probability and thus likely constitute a worst-case scenario (T. Lay, written comm.).

Realistic aspect ratio constraints are assumed based on other historical large events (J.A. Álvarez, pers. comm.).

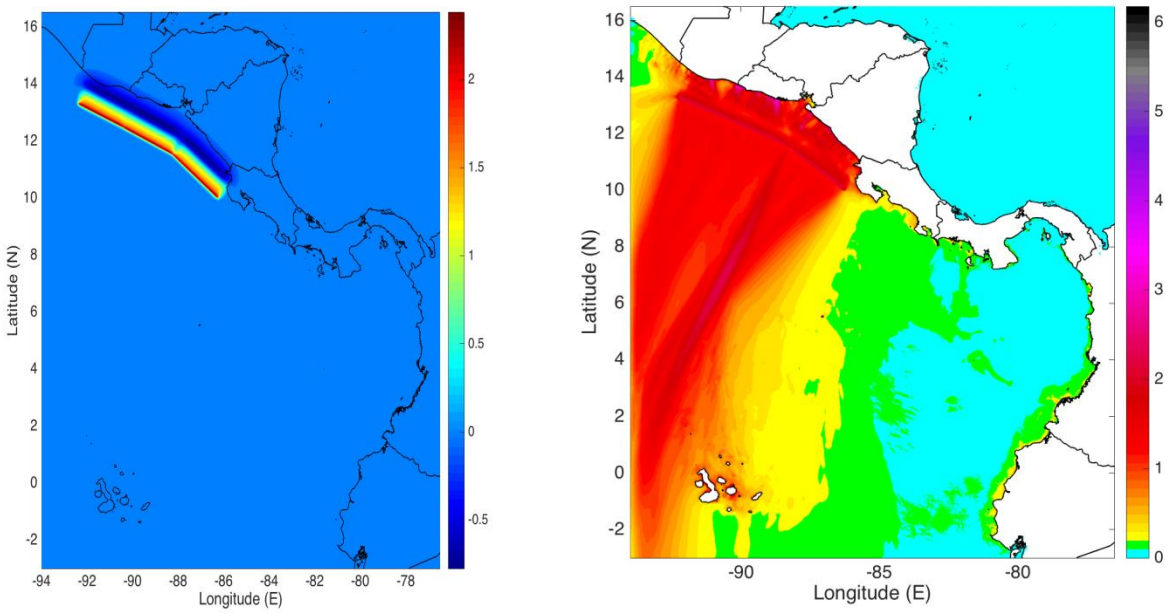


Figure 7. a. Surface deformation of the GUANICA scenario (left).
b. Tsunami propagation resulted from GUANICA scenario (right).

### *4.3.1.2 NICOBA: Middle America Trench 2 (MAT2), Nicoya and Cóbano segment, Costa Rica (Fig. 8a and 8b)*

This source involves the Nicoya segment and the rupture extent of the 1990 earthquake at the entrance of Nicoya Gulf, for a total length of 180 km and $M_w$ = 8.0. The joint rupture of these two segments is an extreme case, as differences in coupling might not support it.

This source is divided in two rupture planes: shallow and deep, as the subduction angle changes in this region to a steeper dip for the deep plane. These setup causes uplift of the western coast of the Nicoya Peninsula and subsidence of the Nicoya Gulf.

The subsequent tsunami would impact Costa Rica and the Southern coast of Nicaragua. The directivity of this source would imply a considerable amount of tsunami energy focusing on the Cocos and Galapagos Islands. Further simulations with finer grids are recommended to study the effect of this source within Nicoya Gulf.

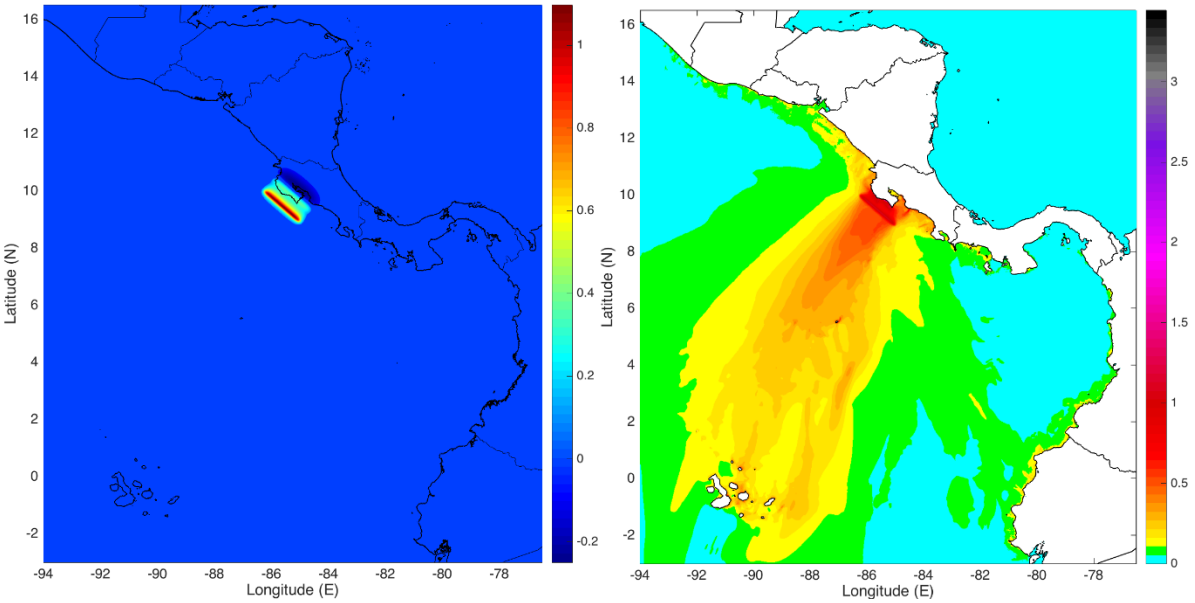


Figure 8. a. Surface deformation of the NICOBA scenario (left).
b. Tsunami propagation resulted from NICOBA scenario (right).

#### *4.3.1.3 DOM: Middle America Trench 3 (MAT3) Costa Rican Central Pacific (Fig. 9a and 9b)*

The DOM scenario involves the rupture of the remaining part along the Cóbano-Herradura segment together with the Quepos-Sierpe segment within the Costa Rican subduction zone. DOM represents the rupture of most of seismogenic zone (Figure 9a) as shown in Arroyo et al. (2014), and here we estimated it as an event of $M_w$ 7.8. The extent and the slip deficit could lead to such an event, even if it would be very unlikely due to the low coupling (M. Protti, pers. comm.). This tsunami directs most of its energy to the Cocos and Galapagos Islands (Figure 9b). Within Central America this scenario would affect only Puntarenas province, Costa Rica.

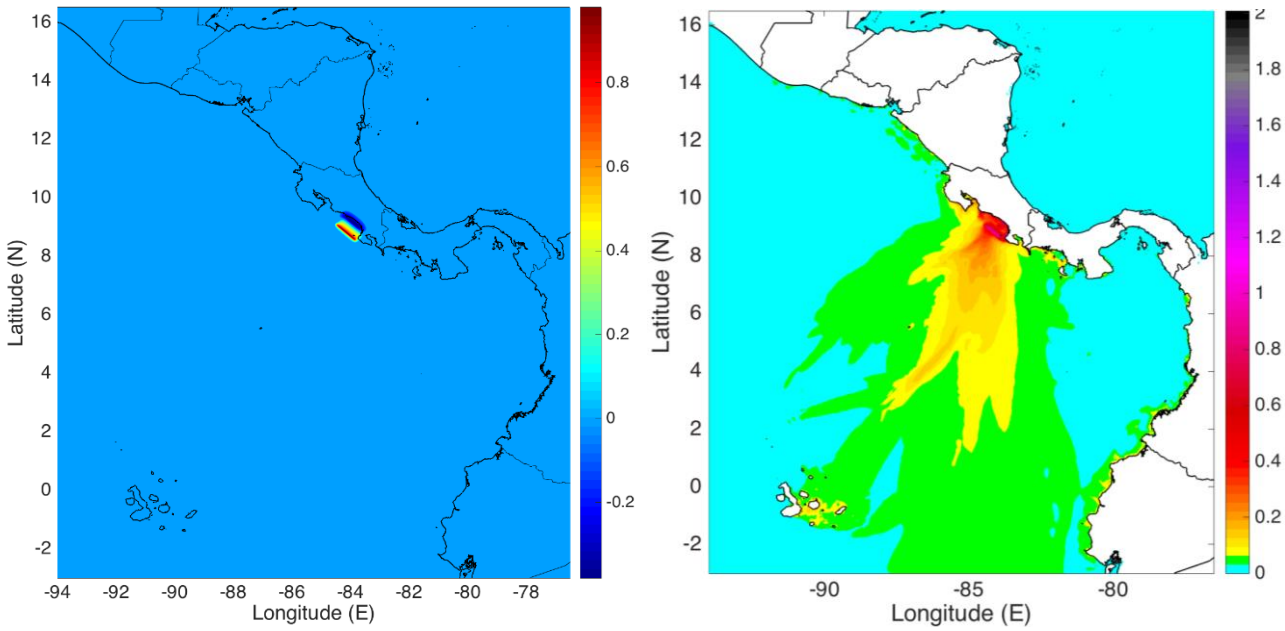


Figure 9. a. Surface deformation of the DOM scenario (left).
b. Tsunami propagation resulted from DOM (right)

*4.3.1.4 OSA: Middle America Trench 4 (MAT4), Osa-Burica segments, Costa Rica-Panama. (Fig. 10a and 10b)*

The Osa segment of the Costa Rica subduction zone has a recurrence time of about 40 years (M. Protti, personal communication) and the last event was in 1983; therefore there is a strong probability of an earthquake there within the next ten years. The source presented here consists of three fault planes that should not be considered separately. The results presented correspond to the rupture of the three planes together for a total length of 117 km representing the worst-case scenario with $M_w$ = 7.6; smaller scenarios can be simulated considering only segment 1 or segment 1 and 2. The use of segments 2 or 3 alone is not advised.

This source would provoke uplift on Osa Peninsula and subsidence of Dulce Gulf. The tsunami would affect the central and South coast of Costa Rica and the Chiriqui province of Panama. The directivity of this source would also affect the Cocos and Galápagos Islands, although it has a smaller magnitude than the Nicobano and Dom sources.

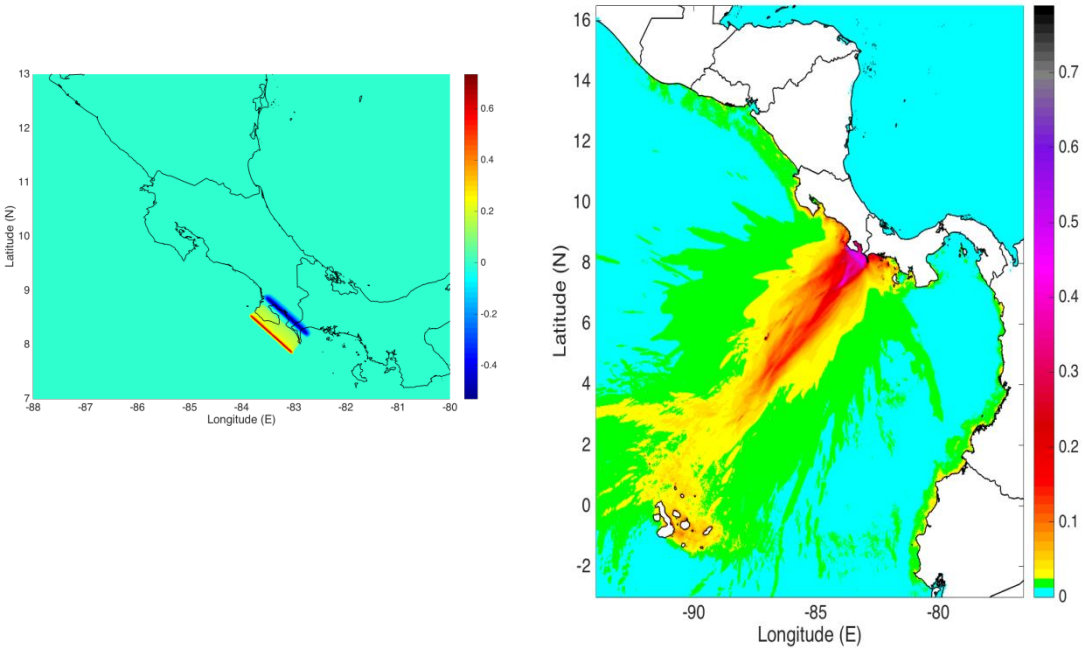


Figure 10. a. Surface deformation of the OSA scenario (left).
b. Tsunami propagation resulted from OSA scenario (right).

### 4.3.2 A2. Pacific Regional Sources

#### *4.3.2.1 COLEC: South America Margin (SAM), Colombia-Ecuador margin. (Fig. 11a and 11b)*

This source is not a local source for Central America, but was considered here due to proximity and directivity.

The subduction zone offshore Colombia and Ecuador has a higher seismic potential than the MAT. In 1906 a magnitude $M_w$ = 8.6 earthquake (Okal, 1992) was triggered, which might have had important consequences for Central America; unfortunately there are no historical reports to confirm it.

The tsunami corresponding to this source would affect the whole Central America, as opposed to the local sources proposed above. According to the propagation simulation, the tsunami would have its greater heights at Cocos Island, Panama, Costa Rica and El Salvador shores. Tsunami inundation modelling is strongly advised to analyze in detail the effects of such a tsunami for the Central American countries, considering that arrival time would be on the order of one hour for the nearest countries.

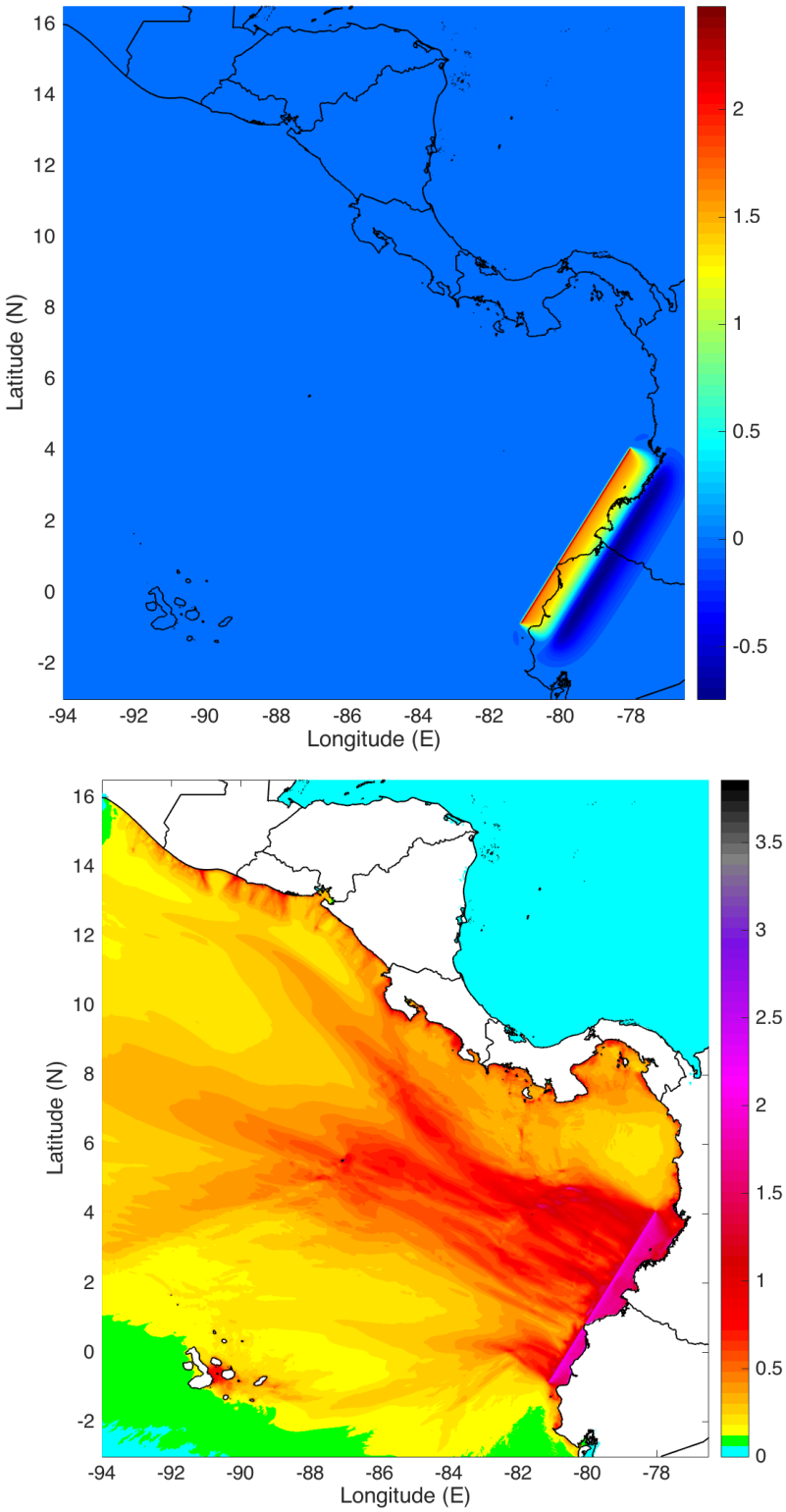


Figure 11. a. Surface deformation of the COLEC scenario (top).
b. Tsunami propagation resulted from COLEC (bottom).

## 4.4 CARIBBEAN

### 4.4.1 Caribbean Near Field Sources

#### *4.4.1.1 LIMON: Northern Panama Deformation Belt 1 (NPDB1), Western Subsegment of the Western Segment of the NPDB, Costa Rica and Panama. (Fig. 12a and 12b)*

This source is based on historical events with $M_w$ = 7.9. It would cause uplift of the shore at the Costa Rican side and Changuinola and subsidence deep inland in both countries and at Chiriquí Lagoon.

The tsunami will impact both countries, as well as Nicaragua and San Andres archipelago (Colombia). Some of the tsunami energy might reach southeast Jamaica and western Colombian shores.

Tsunami inundation modelling with a finer grid is recommended for Chiriquí Lagoon.

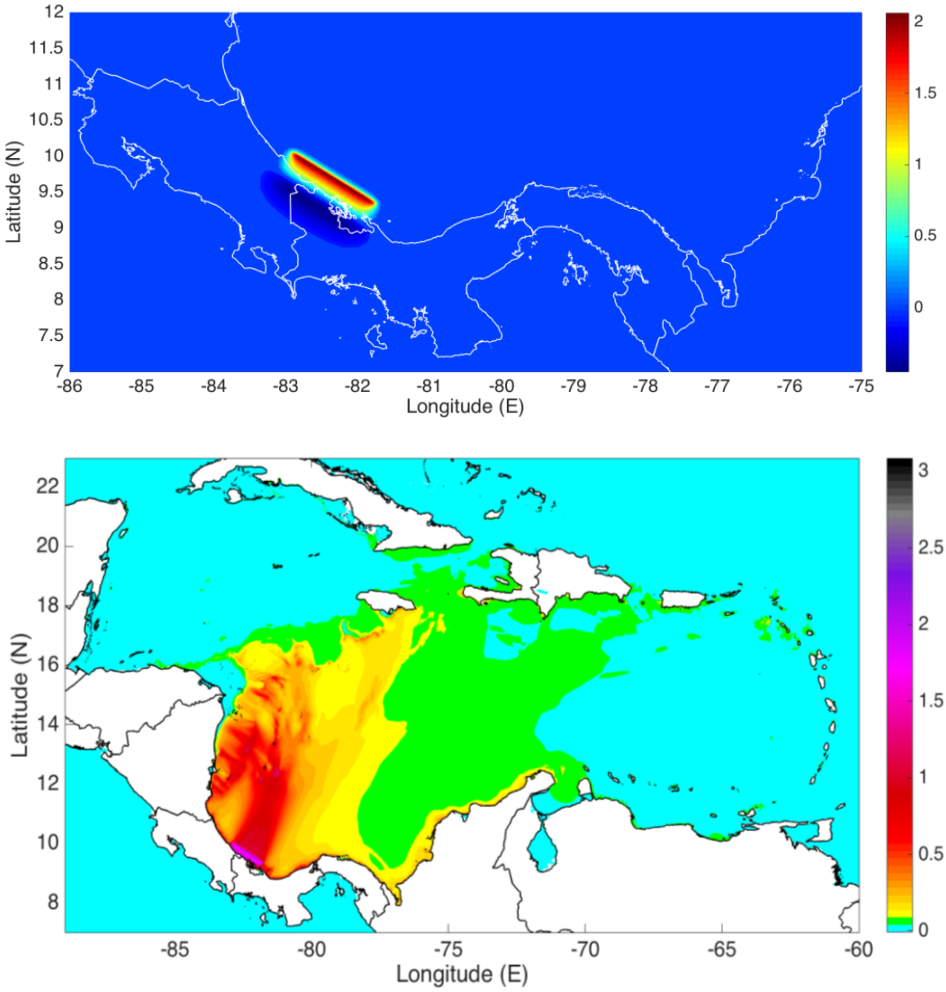


Figure 12. a. Surface deformation of the NPBD1 scenario (top).
b. Tsunami propagation resulted from NPBD1 scenario (bottom).

*4.4.1.2 PARC: Northern Panama Deformation Belt 2 (NPDB2), Central and Eastern Segment of the NPDB, Panama. (Fig. 13a and 13b)*

This source involves two fault planes following the arcuate morphology of the North Panama Deformed Belt (NPDB), with $M_w$ = 8.5. The tsunami would affect Nicaragua, Costa Rica and Panama. It would have two main directions of maximum energy toward Nicaragua and towards southern Cuba, but it would also affect Jamaica, Hispaniola and Colombia.

Tsunami inundation modelling with a finer grid is recommended for Chiriquí Lagoon and San Blas archipelago, as well as for Nicaragua.

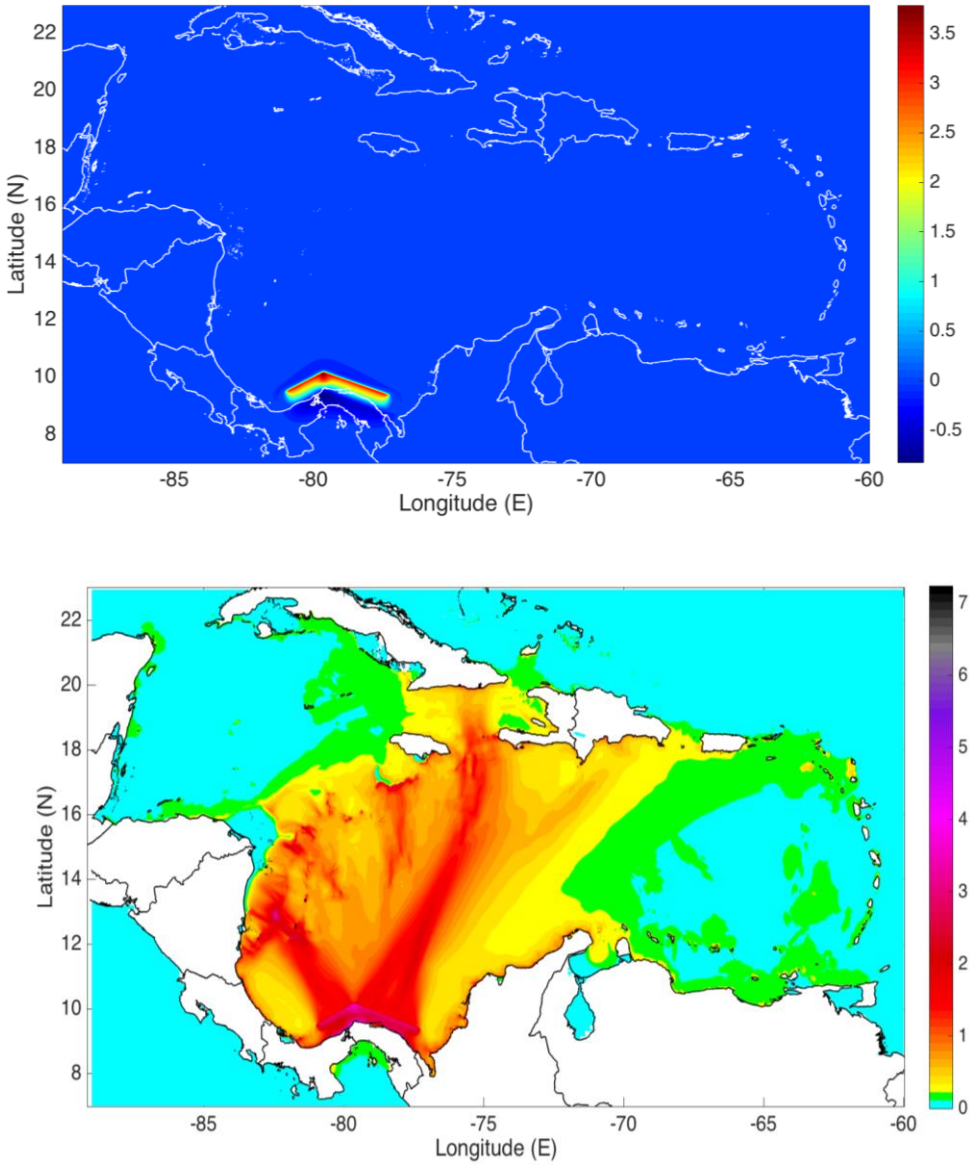


Figure 13. a. Surface deformation of the NPBD2 scenario (top).
b. Tsunami propagation resulted from NPBD2 scenario (bottom).

*4.4.1.3 Panama: Northern Panama Deformation Belt (NPDB3), Eastern NPDB segment, Panama. (Fig. 14a and 14b)*

This source, also with $M_w = 8.5$, is located in the same region as the eastern segment of the 1882 source but offshore, and aligned with the front of the NPDB. This source was based on several data, among them GPS velocity vectors from published literature and predicted motion at the NPDB trace, with an angular vector clearly suggesting left-lateral strike-slip motion along the western segment and pure thrust along the Eastern one (A. López, personal communication).

The tsunami would affect Panama and Nicaragua, and as well as Colombia. Tsunami inundation modelling with a finer grid is recommended for San Blas archipelago and Nicaragua.

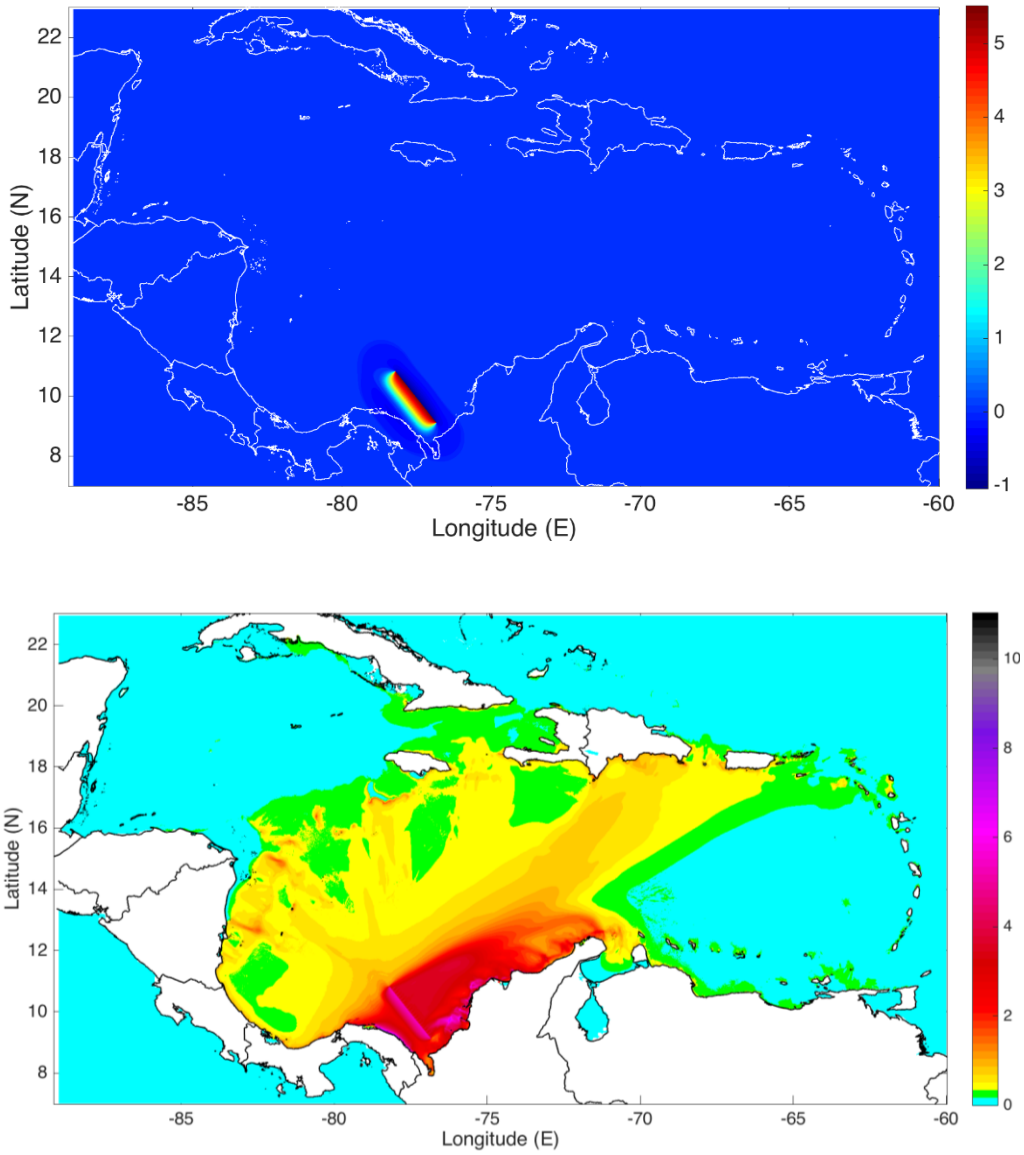


Figure 14. a. Surface deformation of the NPBD3 scenario (top).
b. Tsunami propagation resulted from NPBD3 scenario (bottom).

### 4.4.2 CARIBBEAN REGIONAL SOURCES

#### *4.4.2.1 WSCDB: Western segment- Southern Caribbean Deformation Belt. (Fig. 15a and 15b)*

This source is not a local source for Central America, but was considered here due to proximity and directivity. It involves rupture of the western segment of the South Caribbean Deformed Belt (SCDB) offshore north Colombia, with $M_w$ = 8.6.

The tsunami would affect mostly Nicaragua, and in a smaller extent Costa Rica and Panama, and its travel time would be about one hour for the nearest shores.

Tsunami inundation modelling with a finer grid is recommended for San Blas archipelago and Nicaragua.

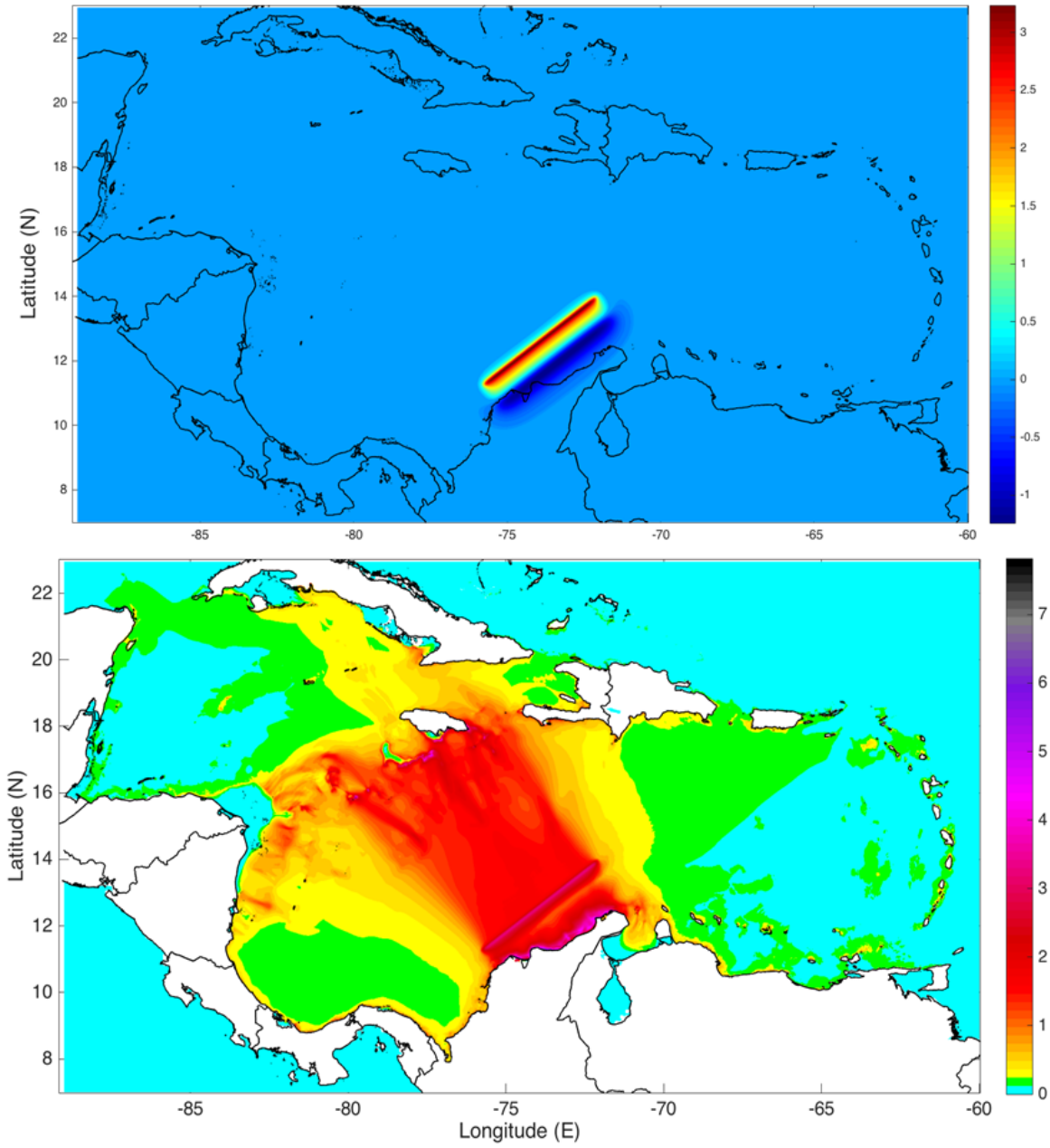


Figure 15. a. Surface deformation of the WSCDB scenario (top).
b. Tsunami propagation resulted from WSCDB scenario (bottom).

*4.4.2.2 FSCDB: Full rupture along Southern Caribbean Deformation Belt. (Fig. 16a and 16b)*

This source is not a local source for Central America, but was considered here due to its proximity and probable directivity. It represents the full rupture of the South Caribbean Deformed Belt (SCDB) offshore Colombia and Venezuela, with $M_w$ = 8.8. This source was proposed at the Experts Meeting on Sources of tsunamis in the Caribbean with possibility to impact the southern coast of the Dominican Republic, Santo Domingo, Dominican Republic, 6–7 May 2016. Details can be found in the Meeting Report.

This source would affect mostly the Greater Antilles and Colombia and Venezuela. The consequences for Central America would be comparable to those of the source WSCDB.

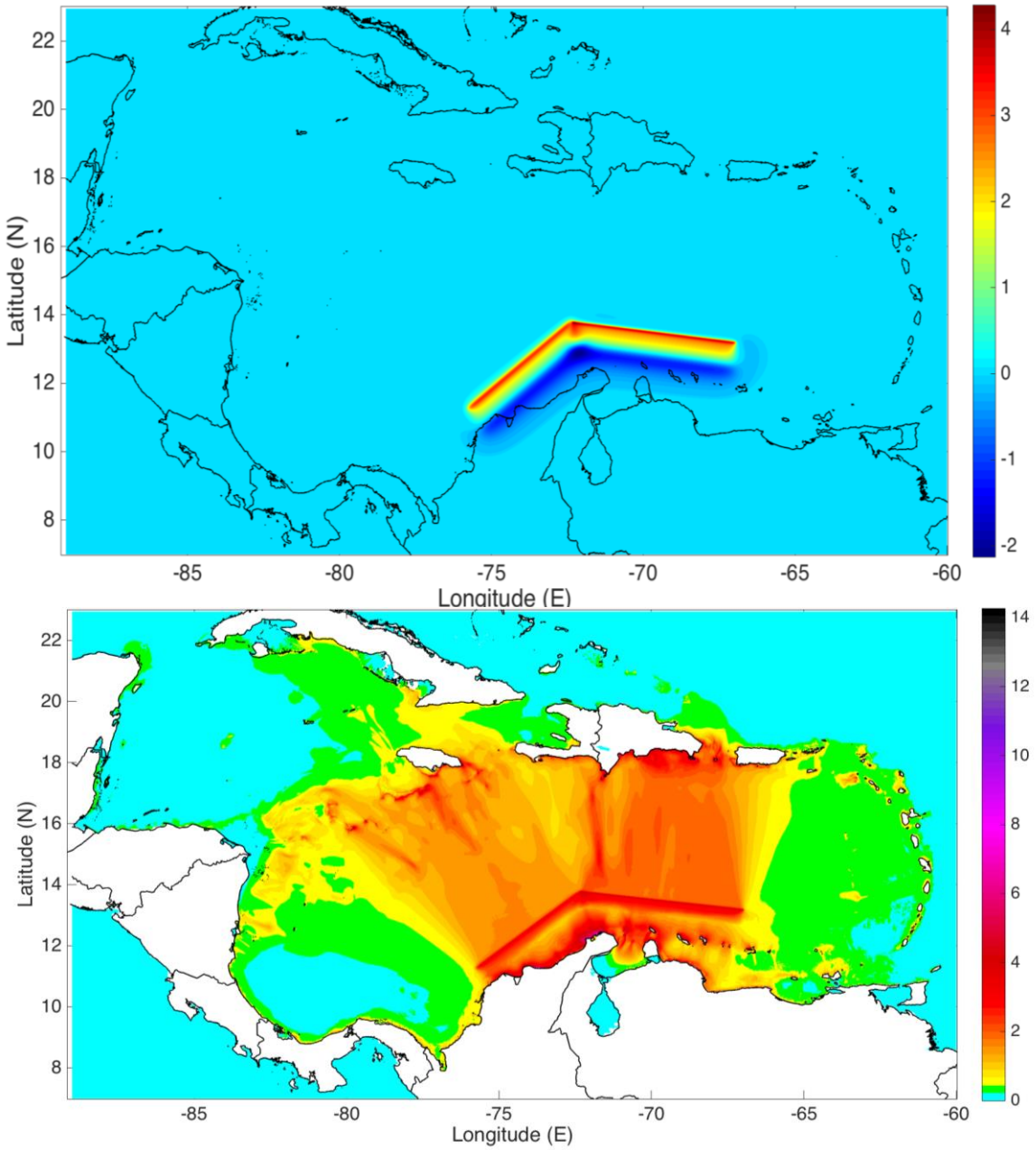


Figure 16. a. Surface deformation of the FSCDB scenario (top).
b. Tsunami propagation resulted from FSCDB scenario (bottom).

ANNEX I

**AGENDA**

| **DAY 1** | |
|---|---|
| **14.00** | **Opening** |
| **14.15 PM** | **Historical events in the Central America region and adjacent areas [Moderator:Bernardo Aliaga]** |
| 14.15–14.45 | Wilfried Strauch Historical background: Central America Pacific Coast earthquakes and tsunamis |
| 14.45–15.15 | Emile Okal, Tsunami Earthquakes: the ultimate challenge in real-time tsunami mitigation |
| **15.15–15.30** | **Pause** |
| **15.30–16.00** | Thorne Lay, Modeling Tsunami Earthquakes and Slip to the Trench in Great Events |
| **16.00–16.30** | Hans Jürgen Meyer & Diana Mendoza, Possible evidence of prehistoric tsunami impact on San Andrés Island, Colombia and Preliminary evaluation of tsunami potential on the northern segment of the Colombian subduction zone (presented by D. Mendoza) |
| **16.30–17.00** | Emile Okal, Tsunami earthquakes, Landslides and Terraces: the contribution of rogue events to tsunami risk in Central America |
| **DAY 2** | |
| **8.30** | **Seismic studies and potential tsunamigenic sources in the Central America region [Moderator: Dr. Emile Okal]** |
| **8.30–9.00** | Jose Antonio Alvarez-Gomez, Tsunamigenic sources in the Middle America Trench off Central America |
| **9.00–9.30** | Eduardo Camacho, Seismotectonics and Tsunamis in the North Panama Deformed Belt |
| **9.30–10.00** | Marino Protti, South Central America sources (presented by S. Chacón) |
| **10.00** | **Technical/Scientific development of tsunami modelling for the Central America region, including key parameters [Moderator: Dr. Vasily Titov]** |
| **10.00–10.15** | Vasily Titov, Tsunami model forecast approaches |
| **10.15–10.30** | **Pause** |
| **10.30–10.45** | Nestor Luque, Tsunami modeling of the September 7, 1882 tsunami in the Province of Colon, Panama. |

| | |
|---|---|
| **10.45–11.00** | Silvia Chacon, Modeling of local tsunami sources for Costa Rica, Pacific and Caribbean shores |
| **11.00–11.15** | Natalia Zamora, Major challenges of the probabilistic tsunami hazard assessment along Central America |
| **11.15** | **Break-out Groups**<br>Round-up of the three sessions and general guidance discussion chaired by moderators [Bernardo Aliaga, Emile Okal, Vasily Titov]. Then separate groups would discuss the two objectives below.<br>1. Earthquake based scenarios – key parameters and geometry of the faults<br>2. Tsunami modelling – datasets inventory for topography and bathymetry, priority gaps |
| **12.30–14.00** | **Lunch break** |
| **14.00–15.00** | **Break-out Groups – continued** |
| **15.00** | **Summary session – breakout groups report and recommendations** |
| **16.30** | **Close of the meeting** |

ANNEX II

## FAULT PLANE DATA

Pacific Side

| | | | |
|---|---|---|---|
| **REGION** | **MAT** | | |
| **NAME** | **GUANICA** | | |
| Hypocenter Lon | 13,8 | | |
| Hypocenter Lat | 268 | | |
| Hypocenter Depth | 20 | | |
| **EQ Mw** | **8,62** | | |
| Shear modulus (GPa) | 35 | | |
| Seismic moment (N*m) | 1,08E+22 | | |
| Corner Point A | **segment 1** | **segment 2** | **segment 3** |
| Lat | 13,13 | 12,17 | 10,55 |
| Lon | 269,87 | 272,05 | 274,19 |
| | -90,13 | -87,94 | -85,81 |
| Depth (km) | 20 | 20 | 20 |
| Corner Point B (NEOWAVE) | | | |
| Lat | 12,47 | 11,51 | 9,98 |
| Lon | 269,58 | 271,75 | 273,74 |
| | -90,42 | -88,24 | -86,26 |
| Depth (km) | 5 | 5 | 5 |
| Corner Point C | | | |
| Lat | 13,3 | 12,47 | 11,51 |
| Lon | 267,6 | 269,6 | 271,75 |
| | -92,4 | -90,42 | -88,24 |
| Depth (km) | 5 | 5 | 5 |
| Corner Point D | | | |
| Lat | 13,96 | 13,13 | 12,08 |
| Lon | 267,89 | 269,88 | 272,21 |
| | -92,11 | -90,11 | -87,79 |
| Depth (km) | 20 | 20 | 20 |
| Deep Center (MOST) | | | |
| Lat | 13,54 | 12,64 | 11,31 |
| Lon | 268,88 | 270,96 | 273,19 |
| | -91,12 | -89,03 | -86,81 |
| Depth (km) | 20 | 20 | 20 |
| Other Fault Parameters | | | |
| Strike (phi) | 293 | 294 | 308 |
| Dip (delta) | 20 | 20 | 20 |
| Rake (lamda) | 90 | 90 | 102 |
| L (km) | 234 | 259 | 276 |
| W (km) | 80 | 80 | 80 |
| W map view (km) | 75,2 | 75,2 | 75,2 |
| Slip (m) | 5 | 5 | 5 |
| Seismic moment (N*m) | 3,28E+21 | 3,63E+21 | 3,86E+21 |
| $M_w$ | 8,28 | 8,31 | 8,33 |

| **REGION** | **MAT** | |
|---|---|---|
| NAME | **NICOBANO** | |
| Hypocenter Lon | -86,26 | |
| Hypocenter Lat | 9,98 | |
| Hypocenter Depth | 2 | |
| **EQ Mw** | **8,05** | |
| Shear modulus (GPa) | 35 | |
| Seismic moment (N*m) | 1,46E+21 | |
| Corner Point A | **segment 1** | **segment 2** |
| Lat | 9,25 | 9,48 |
| Lon | 275,27 | 275,47 |
| | -84,73 | -84,53 |
| Depth (km) | 20 | 35 |
| Corner Point B (NEOWAVE) | | |
| Lat | 8,91 | 9,25 |
| Lon | 274,98 | 275,27 |
| | -85,02 | -84,73 |
| Depth (km) | 10 | 20 |
| Corner Point C | | |
| Lat | 9,97 | 10,31 |
| Lon | 273,74 | 274,03 |
| | -86,26 | -85,97 |
| Depth (km) | 10 | 20 |
| Corner Point D | | |
| Lat | 10,31 | 10,54 |
| Lon | 274,03 | 274,23 |
| | -85,97 | -85,77 |
| Depth (km) | 20 | 35 |
| Deep Center (MOST) | | |
| Lat | 9,78 | 10,01 |
| Lon | 274,65 | 274,85 |
| | -85,35 | -85,15 |
| Depth (km) | 20 | 35 |
| Other Fault Parameters | | |
| Strike (phi) | 311 | 311 |
| Dip (delta) | 12 | 29 |
| Rake (lamda) | 90 | 90 |
| L (km) | 180 | 180 |
| W (km) | 49 | 34 |
| W map view (km) | 47,9 | 29,7 |
| Slip (m) | 2,8 | 2,8 |
| Seismic moment (N*m) | 8,64E+20 | 6,00E+20 |
| $M_w$ | 7,89 | 7,79 |

| **REGION** | **MAT** | | |
|---|---|---|---|
| **NAME** | **OSA** | | |
| Hypocenter Lon | | | |
| Hypocenter Lat | | | |
| Hypocenter Depth | | | |
| **EQ Mw** | **7,63** | | |
| Shear modulus (GPa) | 30 | | |
| Seismic moment (N*m) | 3,51E+20 | | |
| | **segment 1** | **segment 2** | **segment 3** |
| Corner Point A | | | |
| Lat | 8,51 | 8,34 | 8,18 |
| Lon | 276,87 | 277,08 | 277,26 |
| | -83,13 | -82,92 | -82,74 |
| Depth (km) | 6,5 | 6,5 | 6,5 |
| Corner Point B (NEOWAVE) | | | |
| Lat | 8,17 | 7,99 | 7,84 |
| Lon | 276,57 | 276,78 | 276,96 |
| | -83,43 | -83,22 | -83,04 |
| Depth (km) | 2 | 2 | 2 |
| Corner Point C | | | |
| Lat | 8,53 | 8,17 | 7,99 |
| Lon | 276,16 | 276,57 | 276,78 |
| | -83,84 | -83,43 | -83,22 |
| Depth (km) | 2 | 2 | 2 |
| Corner Point D | | | |
| Lat | 8,87 | 8,51 | 8,34 |
| Lon | 276,46 | 276,87 | 277,08 |
| | -83,54 | -83,13 | -82,92 |
| Depth (km) | 6,5 | 6,5 | 6,5 |
| Deep Center (MOST) | | | |
| Lat | 8,69 | 8,42 | 8,26 |
| Lon | 276,66 | 276,97 | 277,17 |
| | -83,33 | -83,02 | -82,83 |
| Depth (km) | 6,5 | 6,5 | 6,5 |
| Other Fault Parameters | | | |
| Strike (phi) | 311 | 311 | 311 |
| Dip (delta) | 5 | 5 | 5 |
| Rake (lamda) | 90 | 90 | 90 |
| L (km) | 60 | 30 | 27 |
| W (km) | 50 | 50 | 50 |
| W map view (km) | 49,8 | 49,8 | 49,8 |
| Slip (m) | 2 | 2 | 2 |
| Seismic moment (N*m) | 1,80E+20 | 9,00E+19 | 8,10E+19 |
| $M_w$ | 7,44 | 7,24 | 7,21 |

| **NAME** | **COLEC** |
|---|---|
| Hypocenter Lon | -79,39 |
| Hypocenter Lat | 1,47 |
| Hypocenter Depth | 22 |
| **EQ Mw** | **8,66** |
| Shear modulus (GPa) | 30 |
| Seismic moment (N*m) | 1,22E+22 |
| Corner Point A | **segment 1** |
| Lat | -1,28 |
| Lon | 279,68 |
| | -80,32 |
| Depth (km) | 22 |
| Corner Point B (NEOWAVE) | |
| Lat | -0,89 |
| Lon | 278,87 |
| | -81,13 |
| Depth (km) | 2 |
| Corner Point C | |
| Lat | 4,23 |
| Lon | 281,55 |
| | -78,45 |
| Depth (km) | 2 |
| Corner Point D | |
| Lat | 3,68 |
| Lon | 282,51 |
| | -77,49 |
| Depth (km) | 22 |
| Deep Center (MOST) | |
| Lat | 1,47 |
| Lon | 280,61 |
| | -79,39 |
| Depth (km) | 22 |
| Other Fault Parameters | YeEtAl & JA-G |
| Strike (phi) | 32 |
| Dip (delta) | 20 |
| Rake (lamda) | 90 |
| L (km) | 650 |
| W (km) | 125 |
| W map view (km) | 117,5 |
| Slip (m) | 5 |
| Seismic moment (N*m) | 1,22E+22 |
| $M_w$ | 8,66 |

| **REGION** | **NPDB** |
|---|---|
| **NAME** | **LIMON** |
| Hypocenter Lon | -82,54 |
| Hypocenter Lat | 9,37 |
| Hypocenter Depth | 19 |
| **EQ Mw** | **7,93** |
| Shear modulus (GPa) | 35 |
| Seismic moment (N*m) | 9,92E+20 |
| Corner Point A | **segment 1** |
| Lat | 9,73 |
| Lon | 276,88 |
| | -83,12 |
| Depth (km) | 25 |
| Corner Point B (NEOWAVE) | |
| Lat | 10,05 |
| Lon | 277,08 |
| | -82,92 |
| Depth (km) | 5 |
| Corner Point C | |
| Lat | 9,33 |
| Lon | 278,25 |
| | -81,75 |
| Depth (km) | 5 |
| Corner Point D | |
| Lat | 9,02 |
| Lon | 278,04 |
| | -81,96 |
| Depth (km) | 25 |
| Deep Center (MOST) | |
| Lat | 9,37 |
| Lon | 277.46 |
| | -82,54 |
| Depth (km) | |
| Other Fault Parameters | |
| Strike (phi) | 122 |
| Dip (delta) | 25 |
| Rake (lamda) | 90 |
| L (km) | 150 |
| W (km) | 45 |
| W map view (km) | 40,8 |
| Slip (m) | 4,2 |
| Seismic moment (N*m) | 9,92E+20 |
| $M_w$ | 7,93 |

Caribbean Side

| **REGION** | **NPDB** |
|---|---|
| **NAME** | **PAN** |
| Hypocenter Lon | -77,75 |
| Hypocenter Lat | 9,8 |
| Hypocenter Depth | 25 |
| **EQ Mw** | **8,47** |
| Shear modulus (GPa) | 33 |
| Seismic moment (N*m) | 6,42E+21 |
| **Corner Point A** | **segment 1** |
| Lat | 10,49 |
| Lon | 281,35 |
| | -78,65 |
| Depth (km) | 50,7 |
| **Corner Point B (NEOWAVE)** | |
| Lat | 10,83 |
| Lon | 281,79 |
| | -78,21 |
| Depth (km) | 0 |
| **Corner Point C** | |
| Lat | 9,11 |
| Lon | 283,15 |
| | -76,84 |
| Depth (km) | 0 |
| **Corner Point D** | |
| Lat | 8,77 |
| Lon | 282,71 |
| | -77,29 |
| Depth | 50,7 |
| **Deep Center (MOST)** | |
| Lat | 9,63 |
| Lon | 282,03 |
| | -77,9707 |
| Depth(km) | |
| **Other Fault Parameters** | |
| Strike (phi) | 142 |
| Dip (delta) | 40 |
| Rake (lamda) | 90 |
| L (km) | 243 |
| W (km) | 80 |
| W map view (km) | 61,3 |
| Slip (m) | 10 |
| Seismic moment (N*m) | 6,42E+21 |
| $M_w$ | 8,47 |

| **REGION** | **NPDB** | |
|---|---|---|
| **NAME** | **1882** | |
| Hypocenter Lon | -79,64 | |
| Hypocenter Lat | 10,16 | |
| Hypocenter Depth | 25 | |
| **EQ Mw** | **8,48** | |
| Shear modulus (GPa) | 35 | |
| Seismic moment (N*m) | 6,47E+21 | |
| **Corner Point A** | **segment 1** | **segment 2** |
| Lat | 9,64 | 8,98 |
| Lon | 280,18 | 279,26 |
| | -79,82 | -80,74 |
| Depth (km) | 40 | 40 |
| **Corner Point B (NEOWAVE)** | | |
| Lat | 10,16 | 9,48 |
| Lon | 280,36 | 279,01 |
| | -79,64 | -80,99 |
| Depth (km) | 5 | 5 |
| **Corner Point C** | | |
| Lat | 9,35 | 10,16 |
| Lon | 282,72 | 280,36 |
| | -77,28 | -79,64 |
| Depth | 5 | 5 |
| **Corner Point D** | | |
| Lat | 8,83 | 9,67 |
| Lon | 282,54 | 280,61 |
| | -77,46 | -79,39 |
| Depth (km) | 40 | 40 |
| **Deep Center (MOST)** | | |
| Lat | 9,25 | 9,32 |
| Lon | | |
| | -78,64 | -80,07 |
| Depth (km) | | |
| **Other Fault Parameters** | | |
| Strike (phi) | 109 | 63 |
| Dip (delta) | 30 | 30 |
| Rake (lamda) | 110 | 65 |
| L (km) | 274 | 166 |
| W (km) | 70 | 70 |
| W map view (km) | 60,6 | 60,6 |
| Slip (m) | 6 | 6 |
| Seismic moment (N*m) | 4,03E+21 | 2,44E+21 |
| $M_w$ | 8,34 | 8,19 |

| **REGION** | **SCDB** |
|---|---|
| **NAME** | **WSCDB** |
| Hypocenter Lon | -73,7 |
| Hypocenter Lat | 12,3 |
| Hypocenter Depth | 25 |
| **EQ Mw** | **8,63** |
| Shear modulus (GPa) | 33 |
| Seismic moment (N*m) | 1,10E+22 |
| **Corner Point A** | **segment 1** |
| Lat | 10,64 |
| Lon | 365 |
| | 5 |
| Depth (km) | 38,2 |
| **Corner Point B (NEOWAVE)** | |
| Lat | 11,26 |
| Lon | 284,22 |
| | -75,78 |
| Depth (km) | 11,8 |
| **Corner Point C** | |
| Lat | 13,96 |
| Lon | 287,90 |
| | -72,10 |
| Depth (km) | 11,8 |
| **Corner Point D** | |
| Lat | 13,34 |
| Lon | 288,38 |
| | -71,62 |
| Depth (km) | 38,2 |
| **Deep Center (MOST)** | |
| Lat | 11,98 |
| Lon | 286,53 |
| | -73,46 |
| Depth (km) | 38,2 |
| **Other Fault Parameters** | |
| Strike (phi) | 53 |
| Dip (delta) | 17 |
| Rake (lamda) | 90 |
| L (km) | 500 |
| W (km) | 90 |
| W map view (km) | 86,1 |
| Slip (m) | 7,4 |
| Seismic moment (N*m) | 1,10E+22 |
| $M_w$ | 8,63 |

| **REGION** | **SCDB** | |
|---|---|---|
| **NAME** | **FullSCDB** | |
| Hypocenter Lon | | |
| Hypocenter Lat | | |
| Hypocenter Depth | 25 | |
| **EQ Mw** | **8,84** | |
| Shear modulus (GPa) | 33 | |
| Seismic moment (N*m) | 2,26E+22 | |
| **Corner Point A** | **segment 1** | **segment 2** |
| Lat | 10,64 | 12,96 |
| Lon | 284,70 | 287,91 |
| | -75,30 | -72,09 |
| Depth (km) | 38,2 | 35,4 |
| **Corner Point B (NEOWAVE)** | | |
| Lat | 11,26 | 13,76 |
| Lon | 284,22 | 287,99 |
| | -75,78 | -72,00 |
| Depth (km) | 11,8 | 4,6 |
| **Corner Point C** | | |
| Lat | 13,60 | 13,19 |
| Lon | 287,40 | 293,05 |
| | -72,59 | -66,95 |
| Depth (km) | 11,8 | 4,6 |
| **Corner Point D** | | |
| Lat | 12,96 | 12,39 |
| Lon | 287,91 | 292,94 |
| | -72,09 | -67,06 |
| Depth (km) | 38,2 | 35,4 |
| **Deep Center (MOST)** | | |
| Lat | 11,81 | 12,73 |
| Lon | 286,29 | 290,43 |
| | -73,71 | -69,57 |
| Depth (km) | 38,2 | 35,4 |
| **Other Fault Parameters** | | |
| Strike (phi) | 53 | 96 |
| Dip (delta) | 17 | 20 |
| Rake (lamda) | 90 | 90 |
| L (km) | 434 | 550 |
| W (km) | 90 | 90 |
| W map view (km) | 86,1 | 84,6 |
| Slip (m) | 7,4 | 8 |
| Seismic moment (N*m) | 9,54E+21 | 1,31E+22 |
| $M_w$ | 8,59 | 8,68 |

ANNEX III

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ANNEX V

## LIST OF ACRONYMS

| | |
|---|---|
| **CA** | Caribbean plate |
| **CAM** | Central America |
| **CaR** | Carnegie Ridge |
| **CATAC** | Central America Tsunami Advisory Centre |
| **CNS** | Cocos-Nazca Spreading Center origin |
| **CO** | Cocos plate |
| **CoR** | Cocos ridge |
| **ECHO** | European Commission's Civil Protection and Humanitarian Aid Operations department |
| **EPR** | East Pacific Rise |
| **FSCDB** | Full South Caribbean Deformed Belt |
| **GaIs** | Galapagos Islands |
| **GF** | Grijalva Fracture Zone |
| **HeS** | Hess Escarpment |
| **ICG/PTWS** | Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System |
| **INETER** | Nicaraguan Institute of Territorial Studies |
| **IOC** | Intergovernmental Oceanographic Commission |
| **MAT** | Middle America Trench |
| **NAB** | Northern Andean Block |
| **NAM** | North American plate |
| **NAZ** | Nazca plate |
| **NPDB** | North Panama Deformed Belt |
| **PaB** | Panama Block |
| **PFZ** | Panama Fracture Zone |
| **PoM** | Polochic Motagua Fault Zone |
| **RSB** | Rough-smooth ocean floor boundary |

| | |
|---|---|
| **SAM** | South American plate |
| **SAT** | South American Trench |
| **SCDB** | South Caribbean Deformed Belt |
| **TEMPP** | Tsunami Evacuation Maps, Plans and Procedures |
| **UNESCO** | United Nations Educational, Scientific and Cultural Organization |
| **WG** | Working Group |