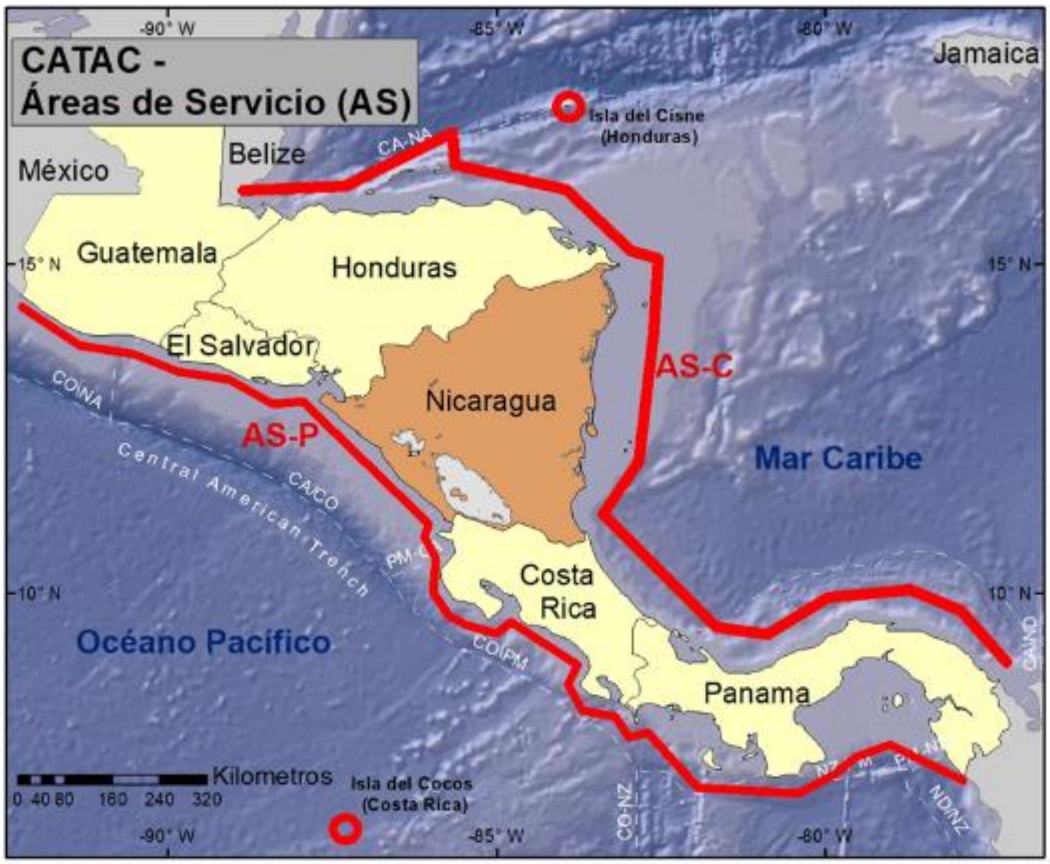
User's Guide
Central America Tsunami Advisory Center (CATAC) established at INETER/Nicaragua
- 2021 version, experimental phase completed

Draft vs. 20211125 -



Managua, Nicaragua

November 2021

Nicaraguan Institute of Territorial Studies (INETER)

Tsunami Advisory Center for Central America (Centro de Asesoramiento de Tsunamis para América Central)

Central America Tsunami Advisory Center (CATAC) User's Guide established at INETER/Nicaragua - Version 2021, pilot phase completed - Draft vs. 20211127 -

Prepared by: Wilfried Strauch, with input from the CATAC team.
Date: 27/11/2021
Managua, Nicaragua

Photo 1. CATAC team, 2019

Note: Please send comments and corrections to wilfried.strauch@yahoo.com.

This User's Guide has been written with reference to the User's Guide for the Pacific Tsunami Warning Center (PTWS) Enhanced Products, IOC Technical Series No 1 05, revised edition. UNESCO / IOC 2014 (English; Spanish) and the Operational Users Guide for the Pacific Tsunami Warning and Mitigation Center (PTWS). IOC Technical Series No 87, Second Edition. UNESCO / IOC 2009, the Users' Guides for the NTWAC (2018), and the SCSTAC Guide (2019).

Content

Summary

In 2016, the Central America Tsunami Advisory Center (CATAC) has been established. The Nicaraguan Institute of Territorial Studies in Managua, Nicaragua has implemented the Tsunami Advisory services for Central America in its role as the sub-regional Tsunami Service Provider (TSP) for the Pacific Tsunami Warning and Mitigation System (PTWS) and the Caribbean Tsunami Warning System (CARIBE TWS). CATAC was then under development from 2016-2019 through projects that INETER was implementing for its strengthening in cooperation with JICA/Japan and IOC/UNESCO. Following the successful launch of the Pacific Tsunami Warning Center (PTWC) Enhanced Products and a series of ICG / PTWS recommendations, CATAC homologated its products in 2019 to provide recipient countries with the greatest utility through detailed tsunami hazard assessments for local coastal areas. Following the approval of ICG/PTWS XVIII (04/2019) and confirmation by the 30th [va]IOC General Assembly (06/2019), CATAC starts issuing the products in a pilot phase from 18:00 UT on 22 August 2019 via email, Whatsapp and TELEGRAM, and with its website catac.ineter.gob.ni. The introductory and familiarization pilot period of about 2 years duration was intended to: 1) To increase CATAC's capacity for earthquake and tsunami processing and especially the training of 8 seismologists that INETER additionally assigned for 24x7 service; 2) To support training on the products and implementation of the necessary updates of the Standard Operating Procedure (SOP) in the recipient countries and Central America; 3) To improve the instrumental capacity of the seismic networks in the region through the project for Earthquake Warning in Nicaragua and Central America (EWARNICA) with Swiss cooperation. In November 2021, CATAC proposes to the Central America Working Group to start with the full and routine mode of work.

This User Guide describes CATAC products and provides related examples. In addition to the text-based products, additional graphical products with more information and levels of detail are also available. These include maps showing deep ocean tsunami amplitude forecasts, tsunami travel time forecasts, and expected maximum wave amplitudes in coastal areas.

1. Overview

1.1 Tsunami Hazard Situation

The Pacific Coast of Central America is very prone to tsunamis (Figure 1) due to the high seismicity (Figure 2) at the margins of the Cocos and Caribbean tectonic plates; while the Caribbean Sea Coast of this region has a considerably lower tsunami threat (Molina, 1996; Fernández et al., 2001; IOC 2018). The largest known tsunami impact in history was caused by the September 1, 1992 event on the Pacific coast of Nicaragua with runup of up to 10 meters.

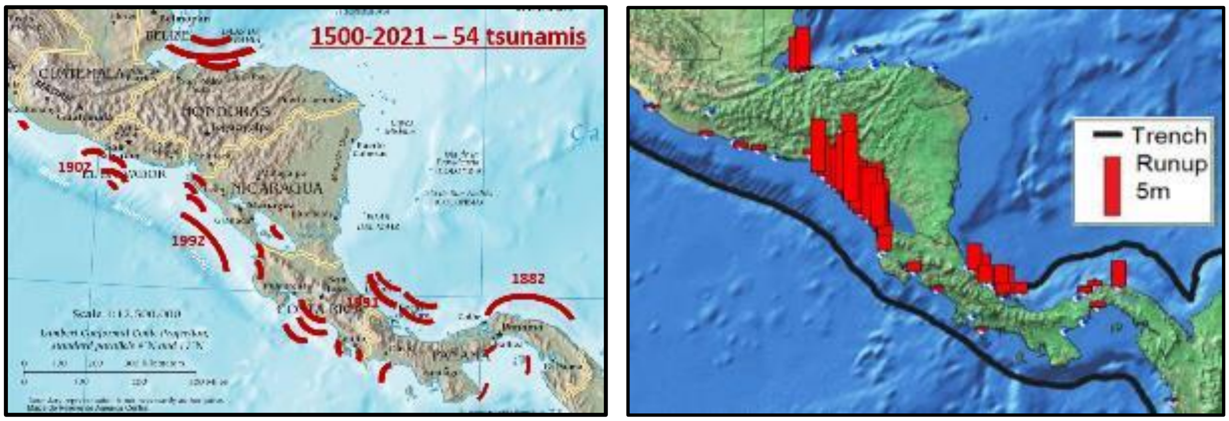


Figure 2. a) Seismicity in Central America according to NEIC/USA (left) and b) Major sources contributing to the tsunami hazard for Central America (right, red rectangles). According to IOC (2018), IOC (2020).

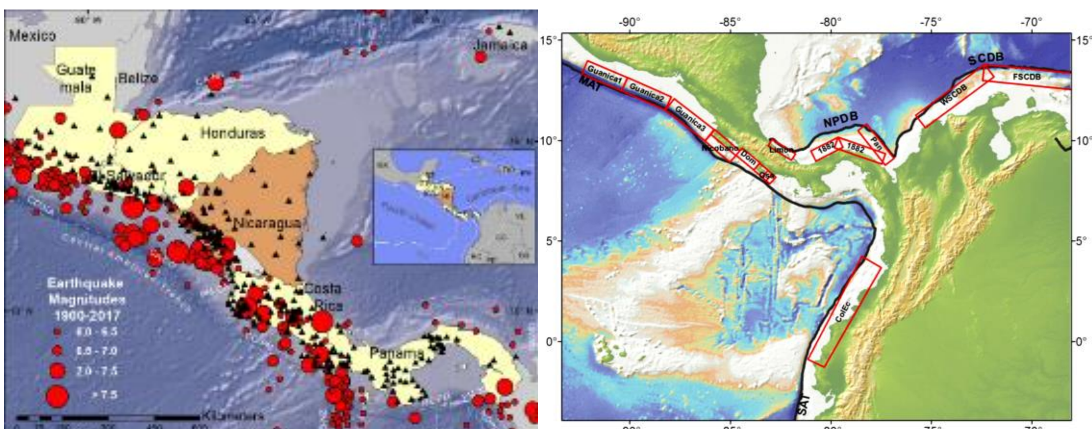


Figure 3. Location of tsunamis (left) and runup (right) in Central America since 1500. Source: Molina, 1996; Fernández et al.,2000); NGDC/WDS, 2015; modified.

In the Pacific, Guatemala, El Salvador and Nicaragua have a very broad continental shelf with shallow sea depth, which reduces wave speed and increases the time tsunamis need to reach the coast. On these coasts, tsunamis would enter within 30 to 60 minutes after the local earthquake.

However, in some coastal areas, the minimum time of impact of local tsunamis is very short, which forces CATAC to send warning messages within a few minutes.

Areas in Central America with a reduced local

Zones with reduced time to tsunami impact exist where

1) The source area is very close to the coast: Cisne Islands in Honduras, Nicoya and Osa in Costa Rica; Chiriqui Gulf, Azuero and Darien in Panama).
2) The source fault enters the coast: Northern Guatemala, San Juan del Norte in Nicaragua, El Limon in Costa Rica).
3) Between the coast and the source zone there are very deep waters (Gulf of Chiriqui in Panama).
4) There is a deeper sea channel that connects the source zone with the coast (southern Guatemala).

O. Combined.

tsunami first impact time of less than 10 minutes.

1.2 Emergence of the CATAC proposal

Tsunami advisory services for both coasts of Central America are currently provided by the Pacific Tsunami Warning Center (PTWC). The Intergovernmental Oceanographic Commission (IOC) of UNESCO adopted Resolution EC-XLI.6, for Member States around the regional seas, as appropriate, to actively promote the development, establishment and sustained operation of National and Sub-regional Tsunami Warning and Mitigation Systems. The six Central American countries and the Coordination Center for the Prevention of Natural Disasters in Central America (CEPREDENAC), during a meeting held in Managua, Nicaragua on September 3, 2003, decided to initiate the development of a Regional Tsunami Warning System, and requested the International Coordination Group for the Tsunami Warning System in the Pacific (in 2003: ICG/ITSU, today: ICG/PTWS) to provide support in this regard.

Currently, Nicaragua, El Salvador and Costa Rica already operate National Tsunami Warning Systems (NTWS). But, other countries in the region have had slower progress, although there have been considerable improvements in terms of capabilities applicable to the requirements of a regional tsunami warning system such as real-time seismic data exchange between countries, availability of sea level data, tsunami hazard mapping and personnel training. Therefore, Nicaragua proposed, in 2015, to establish CATAC in Nicaragua covering both the Pacific and Caribbean coasts within the framework of PTWS and CARIBE-EWS.

The operation of CATAC, as well as its improvement, is a complex and ongoing process that involves the active participation and commitments of Member States through their respective agencies and institutions. The provision of CATAC tsunami advisory products is intended to enable the target countries (Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica and Panama) to take appropriate actions against local and regional hazards, in collaboration with the Pacific-wide service provided by PTWC. The development of tsunami advisory products that take into account regional characteristics and the particular requirements of CATAC Member States is crucial for an effective regional tsunami warning and mitigation system. In this regard, strong involvement of all Member States in the development of CATAC regional products during the design period is very important.

CATAC's tsunami advisory products incorporate state-of-the-art forecasting skills, such as the tsunami scenario database, as well as real-time numerical modeling based on the fast CMT seismological solution. Numerical model benchmarking and validation of prediction results are essential. The CATAC tsunami advisory products serve as the basis for CATAC operation from 2019 onwards.

1.3 Service and Monitoring Areas and Geographic Emission Criteria

CATAC's objective is to support Central American countries in the prevention and mitigation of tsunami disasters. Therefore, the service areas (SA) for which CATAC issues products are the coasts of Central American countries and the islands of these countries in the Pacific Ocean (Pacific Service Area, SA-P) and in the Caribbean Sea (Caribbean Service Area, SA-C), see map in figure 3.

CATAC - Pacific Ocean and Caribbean Sea Service Areas Figure 4.

Figure 5. CATAC - Monitoring Areas in the Pacific Ocean and the Caribbean Sea

CATAC Advisory information is issued when CATAC detects an earthquake of magnitude 6.5 or greater in its Monitoring Areas (MA) (see Figure 4).

To fulfill its duty CATAC must monitor not only the areas near the coasts of Central America but also more remote areas. As CATAC's Monitoring Areas (MA) are characterized as those areas that contain tsunami sources from which waves can reach some point in the Service Areas (SA), i.e. the coasts of Central America, within one hour after being generated, see Figure 2:

1) The Pacific part (Pacific Monitoring Area, AM-P) consisting of the South Coast of Mexico, the Pacific Coast of Central America, the Pacific Coast of Colombia and Ecuador to the North of South America.
2) The Caribbean part (Caribbean Monitoring Area, AM-C), which consists of the area between the Yucatan Coast (Mexico) and Belize, the Caribbean Coast of Central America, the northwestern Caribbean coast of South America, the western Caribbean Sea south of Cuba and Haiti and the Dominican Republic.

Governance and Approval

2.1 Establishment of CATAC

The Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System (ICG/PTWS) at its XIX Session decided to assist Central American countries in this process and established for this purpose the Regional Working Group on the Tsunami Warning and Mitigation System for the Pacific Coast of Central America (WG-CA). ICG/PTWS-XXV.1 recommended to determine whether El Salvador or Nicaragua (or both countries in cooperation) could establish an Interim Tsunami Warning Center to disseminate warnings to all Central American countries and the implementation of a Technical Committee for the Development of a Regional Tsunami Warning and Mitigation System.

The following ICG/PTWS-WG-CA meetings have developed the idea for a Central American Regional Tsunami Advisory Center (CATAC): The first meeting held in Managua, Nicaragua, 04-06/11/2009; The second meeting held in San Salvador, El Salvador, 28-30/09/2011; The third meeting held in Managua, Nicaragua, 29/11/2014; The fourth meeting held in Managua, Nicaragua, 11/02/2019. The efforts for the establishment of a Central American Regional Seismic Network are documented in the Third Meeting of the ICG/PTWS-WG-CA.

The Center for the Coordination of Natural Disaster Prevention in Central America (CEPREDENAC) is the corresponding agency for disaster prevention within the Central American Integration System (SICA). The Council of Representatives of CEPREDENAC at its meeting of February 6, 2015, decided to "recognize within CEPREDENAC's priorities the development of the Central American Tsunami Warning Center (CATAC) and the creation of a Regional Seismic Network to be established in the Republic of Nicaragua and to elevate it to SICA".

Nicaragua formalized at PTWS-XXVI in 2015 the proposal to establish CATAC in Nicaragua and to cover both the Pacific and Caribbean coasts under PTWS and CARIBE-EWS. Recognizing Nicaragua's remarkable progress in its National Tsunami Warning and Mitigation System and noting Nicaragua's offer to host and develop CATAC at the Nicaraguan Institute of Territorial Studies (INETER) in Managua, Nicaragua, ICG/PTWS - through Recommendation ICG/PTWS-XXVI.2. - accepted Nicaragua's offer to host and develop CATAC under the guidance of ICG/PTWS-WG-CA, within the framework of ICG/PTWS, ICG/CARIBE-EWS and TOWS-WG,

Appendix I of the Recommendation ICG / PTWS-XXVI.2 defines the Terms of Reference for a Central American Sub-regional Working Group on the Establishment of a Tsunami Advisory Center for Central America (TT-CATAC) for the purpose of "Assisting the Central American Working Group in the establishment of the CATAC until it has the capacity to provide operational services and the mandate "Under the guidance of the ICG/PTWS-WG-CA, the task team will strengthen coordination and cooperation among the CA countries to establish the CATAC".

The Intergovernmental Coordination Group for the Tsunami and Other Coastal Hazards Warning System for the Caribbean and Adjacent Regions (ICG/CARIBE-EWS) also accepted, in 2015, Nicaragua's offer to host and develop CATAC as a Subregional Tsunami Service (TSP) under the leadership of the PTWS Regional Working Group for Central America Pacific Coast and within the framework of ICG/PTWS, ICG/CARIBE-EWS and TOWS-WG.

The 28th UNESCO/IOC General Assembly in 2015 noted Nicaragua's offer to host and develop a Tsunami Advisory Center for Central America (CATAC) under the guidance of the ICG/PTWS TT-CATAC, ICG/ CARIBE-EWS and TOWS-WG.
Nicaragua requested technical support from Japan for the development of CATAC and in March 2015 JICA delivered the final report of a detailed analysis of the situation of the tsunami hazard and capabilities of seismological monitoring and tsunami warning in Central America with concrete proposals for the implementation of CATAC, (JICA, 2015). After receiving the green light from the different IOC/UNESCO agencies and national and regional institutions involved in Central America, Nicaragua signed, in 2015, an

agreement with Japan on 3-year technical assistance for the strengthening of CATAC, including training of personnel, transfer of experience and knowledge and the acquisition of equipment such as seismic stations, computer equipment and seismological software. The project implementation started in October 2016 and ended in October 2019, successfully.

In 2016, Nicaragua signed an agreement with Switzerland on the medium-term development of a program for the development of earthquake early warning for Nicaragua and Central America, including improvements of seismic networks and methods for rapid estimation of strong earthquake magnitudes that is important for tsunami warning. The first stage of the program was implemented in 2016-2017, the second stage was implemented in 2018-2021, and the third stage will be implemented in 2022-2024.

2.2 CATAC's institutional basis

The Nicaraguan Institute of Territorial Studies (INETER), located in Managua, Nicaragua, is the institution responsible for the operation of CATAC. To meet the operational and organizational requirements necessary to establish and maintain a sub-regional center, INETER concentrated efforts in its Seismology Directorate and allocated from 2016 a significant amount of budget to support the increase of observational resources, service personnel and operational facilities. INETER has also requested international support and established cooperation with Japan, the United States, Switzerland, and Germany regarding tsunami warning and other related topics. CATAC benefits greatly from the long-standing and intense cooperation of Central American countries in seismology and seismic data exchange. To support the strengthening of tsunami warning and mitigation capacity in the CATAC region, INETER also focuses on regional collaboration and training by organizing training workshops on tsunami modeling and risk assessment and standard operating procedures.

CATAC's operation is included in INETER's budget and in its development plans.

The most important parts of CATAC's operating system are duplicated in case of partial malfunction. However, the possibility of catastrophic failure cannot be eliminated even by a giant earthquake affecting CATAC facilities. If A-CATAC products are not issued in an emergency, CATAC user countries/organizations should take appropriate measures with reference to PTWC products and/or use their own or alternate means to estimate the effects of a strong earthquake possibly generating tsunami.

2.3 Mission and duties of CATAC

Mission

CATAC's primary mission is to provide timely warnings of potentially destructive tsunamis to the National Tsunami Warning Centers (NWWCs) and Tsunami Warning Focal Points of the WG-AC Member States 24 hours a day, 7 days a week. To fulfill this mission, CATAC is prepared to continuously receive and process seismic and sea level monitoring data from within and outside the region and assess tsunami threats for CATAC member countries.

Duties

More specifically, CATAC's duties consist of the following elements:

Continuously acquire continuous seismic records from multiple sources in real time; Detect and locate and determine the magnitude of all detectable earthquakes in and around the Monitoring Area.

2. Characterize earthquake source parameters through automatic and interactive processes;

3. Decide on the basis of seismological information whether the earthquake could have generated a dangerous tsunami for Central America.

4. Calculate the estimated time of arrival (ETA) and tsunami amplitudes for the designated forecast points defined by the Central American countries;

5. Disseminate seismological and tsunami messages and bulletins to NTWCs and NTFPs;

4. Receive real-time sea level monitoring data from multiple sources to confirm tsunami generation and severity;

6. Conduct routine and unannounced communication tests with NTWCs and NTFPs;

7. Provide opportunities for education, outreach and training activities in the region;

8. Prepare a summary report each time a destructive tsunami occurs and warnings are issued; Also prepare an annual report on CATAC activities for WG-CATAC; prepare publications in INETER's monthly and annual seismology bulletins. Develop and maintain the website catac.ineter.gob.ni.

2.4 Implementation timeline.

Table 1. Activities carried out

Date		Activity
2015	ICG/PTWS	accepts Nicaragua's proposal to establish CATAC at INETER
2016	Government Nicaragua	CATAC established at INETER/Managua
2016 Nov	Governments Japan and Nicaragua	Start of the cooperation project for strengthening CATAC
2015-2016	University UNAN/ INETER	1-year postgraduate course in seismology for 30 participants
	JICA/ INETER	
2017-2019	INETER	Instrumental/computational/software base strengthening measures
2019 Apr	ICG/PTWS XXVIII	Approval for experimental operation of CATAC
2019 Apr	ICG/CARIBE EWS	Approval for experimental operation of CATAC
2019 Jun	IOC 30	confirms CATAC as regional tsunami services provider
2019-Aug	INETER	Start of experimental operation of CATAC
2019-Aug	CATAC	First CATAC Regional Exercise
2019-Sep	CATAC	Evaluation of the first regional exercise
2019-Oct	INETER/JICA	Completion of the project with JICA
2019-Nov	INETER	CATAC's 24x7 seismologists on duty increased to 2
2019-Nov	CATAC	Training of 8 people for this job begins
2019-2021	CATAC	Participation in PTWS and Caribbean TWS exercises
2020-Feb	CATAC	Second regional exercise conducted
2020-Feb	CATAC	Evaluation of the Second Regional CATAC Exercise
2021-Feb-Nov	EWARNICA	Installation of 70 accelerographs in Central America

2020-21	INETER-EWARNICA-JICA	Development of facilities to send earthquake and tsunami warning messages via digital television in Central American countries.
2021-Nov to Jan-2022	INETER/CATAC	Massive experiment for the use of digital TV to send warning messages to the population.
2021-Nov-15	ICG/PTWS-WG-CA	Meeting of the Central America Regional Working Group. Discussion on the progress of CATAC in the pilot phase and recommendations on the start of full operation.
2021-Dec-1-8	ICG/PTWS XXIX	ICG/PTWS meeting. Discussion on the progress of CATAC in the pilot phase and decisions on the start of full operation.

2.5 CATAC progress in the pilot phase of operations from 2019 to 2021.

An experimental introductory and familiarization period of about 2 years duration, 2019-2021, was conducted. During this time, only seismological messages were routinely sent. Tsunami advisory was conducted in a less formal manner via social media communications with alert recipients in the region immediately after the earthquake.

In the experimental phase, CATAC achieved the following advances:

1. The 24x7 shift staff was doubled, employing 2 people per shift. Staff was trained, especially the 8 new people on the shift that INETER additionally assigned for the 24x7 service.

2. The accuracy and speed of earthquake and tsunami processing in general was improved. Experience was gained with the processing of strong earthquakes that occurred in the region: 5 earthquakes with magnitudes greater than M=7; 8 earthquakes with magnitudes between 6.5 and 7, and a large number of earthquakes with M less than 6.5.

3. In Central America, the greatest tsunami threat comes from local and regional sources, and areas along the Central American coasts have been identified where tsunamis can impact in less than 10 minutes after the earthquake or tsunami generator. For this reason, CATAC was dedicated to accelerate the processing of earthquakes and tsunamis. To reduce the processing time and improve the

reliability of the products, a series of concrete measures were taken, which are detailed in the following.

4. The seismic networks in Nicaragua, El Salvador, and Guatemala were greatly densified through the EWARNICA project with Switzerland, while improving the accuracy of earthquake locations. With the CATAC earthquake early warning methods, CATAC obtains a first location and magnitude of the earthquakes occurring in Central America within a few seconds after the start of the event and also accelerated the calculations of the Moment Tensor and the Mw magnitude.

5. CATAC finalized the development of the tsunami database, which yields tsunami parameters within a few seconds after establishing earthquake parameters.

6. In Central America, slow earthquakes can occur, which means that conventional methods of determining earthquake magnitude are not reliable. Therefore, CATAC introduced the routine use of the CMT calculation to determine the Mw magnitude. The configuration of the modules for the calculation of the Moment Tensor was optimized (with the SCAUTOMT and SCMTV modules of SeisComP), allowing the use of data from accelerographic stations that are not saturated by strong shaking near the epicenter. Thus, it is possible to obtain in less than 10 minutes the focal parameters of the earthquake and the Mw magnitude, which accelerates the tsunami simulation in real time and the generation of tsunami products.

7. CATAC optimized the configuration of the TOAST module for tsunami simulation in its SeisComP system.

8. CATAC also worked to improve the rapid dissemination of products in Nicaragua and the other Central American countries. It cooperated with various foreign (especially Switzerland, Japan, Central American countries) and national institutions and worked intensively to develop and introduce in practice methods for mass dissemination of earthquake and tsunami warning messages. In Nicaragua, the dissemination of messages via digital television has already started. Through the EWARNICA project, CATAC also promoted the application of this method in other countries of the region in the coming years.

9. In Nicaragua, 40 additional sirens were installed in communities along the Caribbean coast. Together with the 60 sirens already in place since 2015 Nicaragua now has a total of 100 of these devices for tsunami warning and other emergencies. Thus, the vast majority of the entire population under tsunami danger can receive

CATAC warnings by this means. The installation of sirens has also begun in the other Central American countries.

Figure 6. Location of mermaids on the Pacific and Caribbean coasts of Nicaragua.

10. CATAC has also worked on the development of other methods for sending messages to the population through social networks, smart phone applications and direct communication between computers. An experimental phone application developed by CATAC allows the user located in a community on the Pacific coast to know the status of the tsunami warning and evacuation routes.

11. CATAC established its website catac.ineter.gob.ni and continues to develop it. This site provides information on earthquakes and tsunamis for the target audience of CATAC products as well as for the general public.

12. CATAC in cooperation with ETHZ/Switzerland developed the Shakemaps website (http://shakemapcam.ethz.ch/) of strong earthquakes recorded by CATAC that shows the impact of earthquakes which is important when assessing the situation of the coastal population after an event.

13. As CATAC can be temporarily affected by adverse circumstances and lose its ability to work partially or completely, a closer cooperation with MARN/El Salvador was developed with the objective of having MARN act as a backup for CATAC.

14. CATAC with other seismological institutions in Central America is preparing the new KUK-AHPAN project together with Spanish Universities. The project aims to investigate in the coming years the seismic hazard and crustal structure in northern Central America. Particular studies were proposed that will have beneficial results in the medium term for the tsunami warning theme, for example: a regional model of seismic velocities, improvement of the seismic monitoring of Honduras.

15. CATAC initiated the use of GPS/GNSS in the process of seismological monitoring and characterization of large earthquakes. In 2021, Nicaragua established real-time transmission of high frequency data sampling from 25 GPS/GNSS stations to CATAC, retransmitted these data to UNAVCO and is working to implement software that allows the data to be used routinely.

3. CATAC's scientific-technical and instrumental basis

3.1 Network of seismic stations used by CATAC

CATAC currently (2021) uses the 140 seismic stations of INETER/Nicaragua and the following number of stations provided by the countries of the region: 60 from MARN/El Salvador, 18 from INSIVUMEH/Guatemala, 14 from COPECO/Honduras, 5 from OVSICORI and 22 from UCR of Costa Rica, 1 from A. Rodriguez/Panama and 9 from the Panama Canal. In addition, it receives data directly from 14 stations of UNAM/Mexico, 22 of the Seismic Network of the Colombian Geological Service. These data by direct transmission are characterized by a great speed of data transmission from the station to CATAC, normally in less than 10 seconds. Other seismic data from South America, North America and the Caribbean come in through IRIS/USA.

The density of seismic stations in Central America is generally very high, which facilitates the rapid and accurate acquisition of CATAC products. However, in Honduras and Panama there is currently insufficient coverage for high quality products. Honduras was affected by the Covid-2019 pandemic and the COPECO seismic network was almost completely down due to lack of maintenance. But it is assumed that this is temporary and that the situation will improve soon. As for Panama, CATAC is in the process of establishing an agreement with the University of Panama (UPA) to receive seismic data from its Geosciences Institute.

Obviously, it is the responsibility of the countries receiving CATAC's tsunami advisory to provide the necessary data. If a country does not provide sufficient data it will not be able to receive the products quickly and in good quality specifically for local events near its coasts.

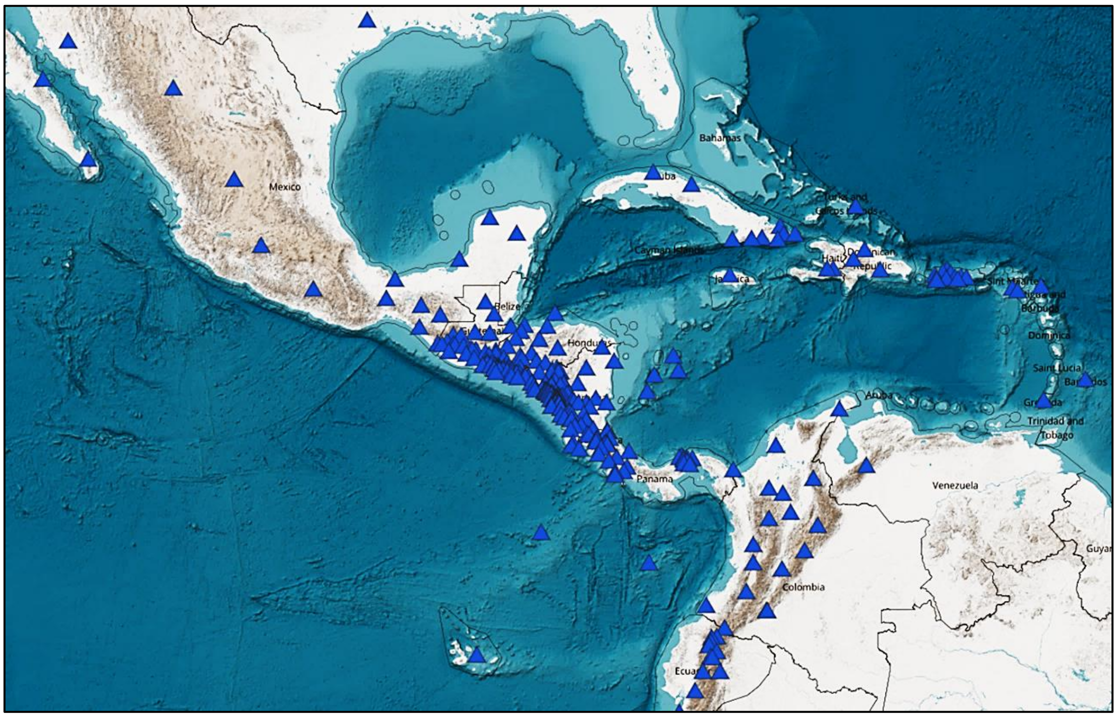
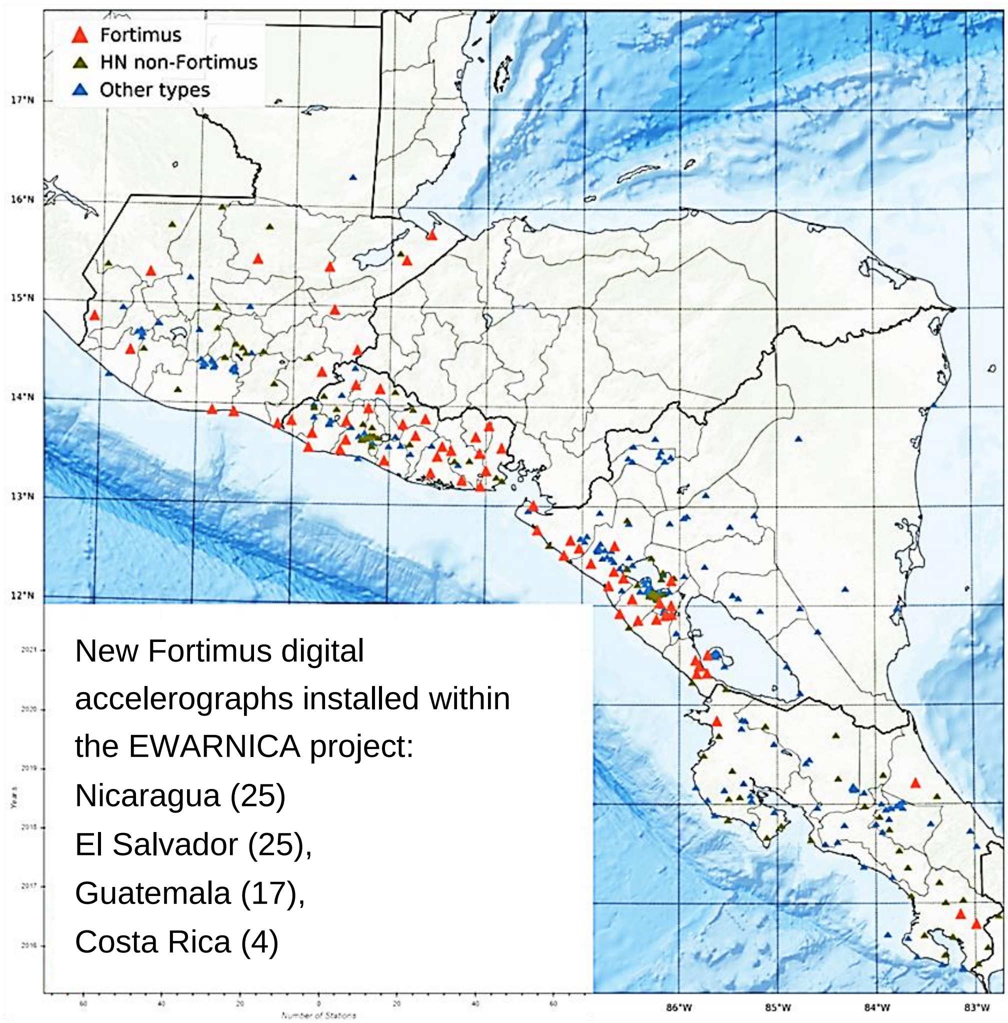


Figure 7. Location of seismic stations in and around Central American countries used by CATAC in 2021.



Location of new accelerometer stations installed in 2021 for earthquake early warning and tsunami warning (red triangles).

CATAC maintains another SeisComP system for global earthquake monitoring. This system provides locations and magnitudes of earthquakes with magnitudes above 5.5 worldwide. This system is useful when seismic waves emitted by these earthquakes are recorded in Central America. It also facilitates a global awareness of seismicity and zones close to CATAC monitoring areas, such as South America, Eastern Caribbean.

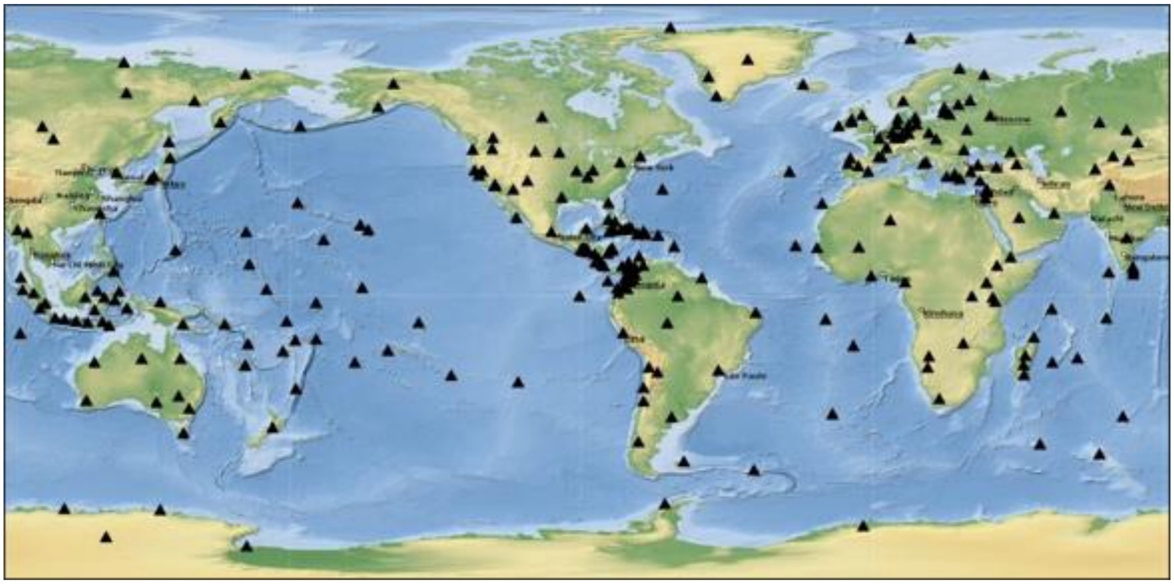
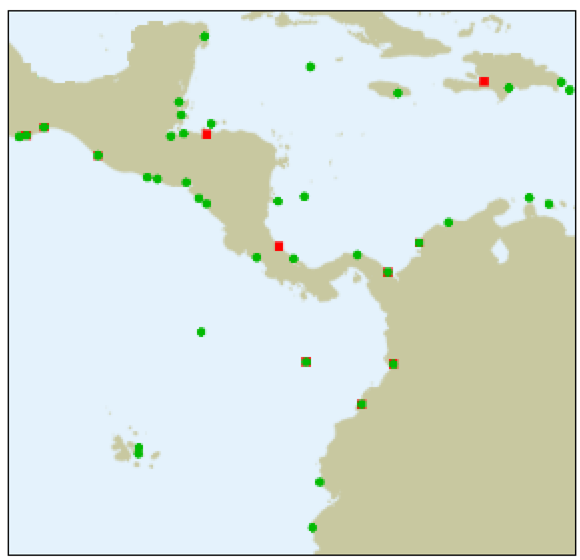


Figure 9. Location of the international seismic network stations used by the CATAC global locator.

3.2 Tide gauge networks used

If the tsunami is generated by an earthquake it can be confirmed by tide stations or deep water tsunami buoys. INETER has 5 tide stations on the Pacific Ocean coast of Nicaragua and 3 on the Caribbean coast. Through the Internet (http://www.ioc-sealevelmonitoring.org/map.php) data are received from Mexico (4), El Salvador (3), Costa Rica (2), Colombia (3), Ecuador (3), Peru (1) located on the Pacific coasts. From the sea Tidal data are received from Mexico (1), Belize (2), Guatemala (1), Honduras (3), Cayman Island (1), Jamaica (1), Haiti (1), Costa Rica (1), Dominican Republic (1), Panama (2), Colombia (3), Aruba (1), Curacao (1). Data are received via SeisComP3. Tide data are also received via TideTool.



Tide gauges in Central America and surrounding areas registered by CATAC.

3.4 GPS/GNSS networks

INETER has 25 GPS/ GNSS stations with continuous on-line recording in Nicaragua and CATAC intends to develop the methodology to use the real-time data for tsunami advisory. Data with a sampling frequency of 1 Hz are input in real time and transferred to UNAVCO. INETER maintains a regional mirror system to access UNAVCO GPS stations in Central America and the Caribbean.

Figure 8. UNAVCO GPS Stations in Central America and the Caribbean registered in INETER

3.5 CATAC Facilities

Within INETER, CATAC is part of the Seismology Directorate that manages the Monitoring and Warning Center for Geological Phenomena (earthquakes, tsunamis, volcanic phenomena, landslides). This unit occupies an area of 250 square meters equipped with high performance computer servers, workstations, communication hardware, as well as decision support systems (DSS), facilities for the development and maintenance of equipment at the central and monitoring stations throughout Nicaragua. Critical equipment and facilities have multiple safety redundancy in case of fatal failure. Most of the servers are located in a space of about 40 square meters in the basement of the building.

Photo 2. CATAC, Processing and Alerting Room

Photo 3. CATAC, Situation and Meeting Room

Photo 4. The seismologists of the 24x7 service perform the manual processing and must publish the results within 2 minutes after the occurrence of the earthquake.

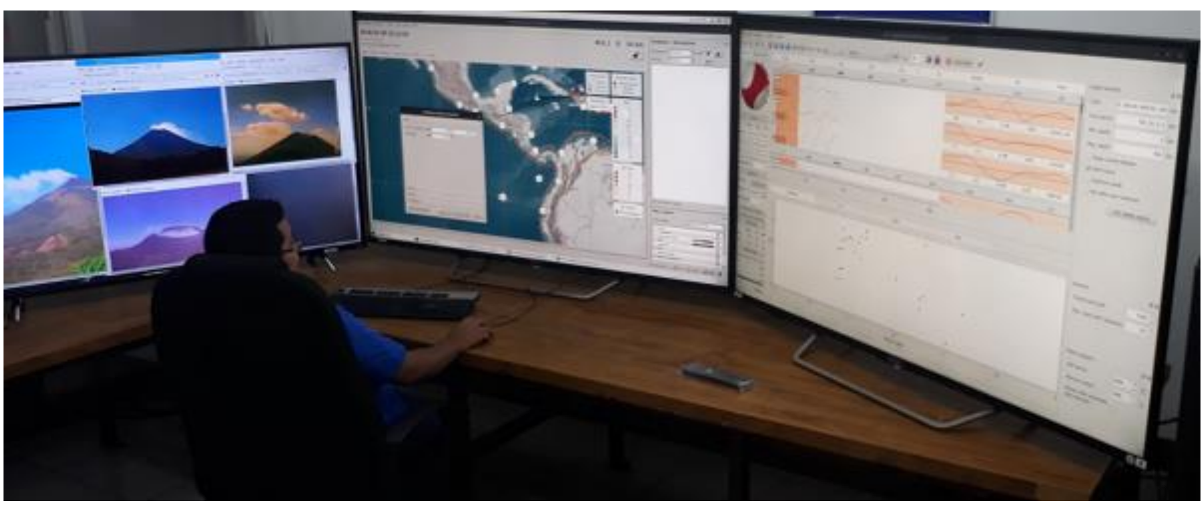


Photo 5. Moment Tensor calculation and numerical tsunami simulation are important tasks of the CATAC seismologist on duty.

3.6 CATAC Staff

INETER/Sismology currently has a team of 20 people (see list in Annex 6) to support CATAC's 24/7 operational shifts and monitoring and warning for the other phenomena, with 2 shifts of 12 hours in a day. CATAC since November 2019 is actually required to have two people on duty at all times. The staff has been trained in 2017-2021. The lead watch manager is restricted to the duty room, and support staff must remain in the same building in case of emergency. Four key positions were designated, namely the CATAC Coordinator, CATAC Director, Monitoring and Warning Center Manager, and CATAC IT Specialist, who are responsible for SOP development, detection/forecasting tools, and monitoring and warning organization. To support a sustained operation, INETER's Computer and Network Division provides CATAC with some computer, cable and INTERNET technical support when CATAC's capacity is not sufficient.

In order to enhance regional collaboration, CATAC Member States are strongly encouraged to nominate seismologists or tsunami specialists to be assigned to CATAC on a temporary basis. Bilateral cooperation can thus be undertaken to facilitate the exchange of personnel.

4. Operational Procedures

4.1 CATAC Performance Indicators

At its meeting (Managua, March 2017), the WG-CATAC approved CATAC's key performance indicators (KPIs) and their target values in its initial phase of operation. According to the latest monitoring networks CATAC has access to (September 2016), the KPI target values can be consistently improved in the near future by upgrading SOPs and warning facilities.

CATAC Performance Indicators and the values to be achieved in its initial/experimental operation phase and in the fully implemented phase.

Performance indicators	Values to be achieved during preliminary operations	Values to be achieved after final implementation

Time elapsed from earthquake to emission of initial tsunami products with preliminary earthquake parameters 2.	5 minutes	2 minutes
2. Probability of detection of earthquakes with magnitude Mw>=6.0.	100%	100%
3. Accuracy of preliminary earthquake parameters in: hypocenter location/magnitude/depth.	0.3degree/0.3/<30 km	0.2degree/0.2/<20km
5. Accuracy of Estimated Time of Arrival in the event of a tsunami	10% of travel time	10% of travel time
6. Percentage of Member States receiving products shipped by CATAC	100%	100%
7. Percentage of time that CATAC is operating and able to respond to a tsunami event.	100%	100%
8. Frequency of regular communication tests	Twice a year	Four times a year

4.2 Types of messages and criteria

At the 25th ICG/PTWS meeting held on 11-13 September 2013, all Member States agreed to change the PTWC products and establish New Enhanced Products as of 1 October 2014. Since each Member State is sovereign and responsible for taking measures to ensure the safety of its population, the PTWC New Enhanced Products no longer use alert levels (e.g., watch and warning) to define tsunami bulletins but instead provide threat levels based on numerical models. Threat levels are now provided as the maximum expected tsunami wave amplitudes with respect to the tide within four categories which are 1) less than 0.3 m, 2) 0.3 to less than 1 m, 3) 1 m to 3 m, and 4) greater than 3 m.

CATAC's Tsunami Advisory Products adhere to PTWC's practice of providing a quantitative tsunami threat assessment to receivers, rather than warning alert levels that are more meaningful for domestic warnings. According to numerical studies conducted in the CATAC region, local tsunamis triggered on the Pacific coast of Central America will impact the nearest coast within 30 minutes in the case of Guatemala, El Salvador, Honduras, Nicaragua and with much less time in the case of Costa Rica and Panama, where waves arrive in only 5-10 minutes after the earthquake. Therefore, there is not much time left for emergency response. Basically, CATAC will send out the Initial Bulletin as soon as possible, based mainly on the preliminary earthquake parameters, such as location, magnitude and focal depth. Whether a portion of a Member State's coastline is placed in the "threat area" depends on the relatively conservative output from 1) the tsunami scenario database or 2) the result of the real-time numerical simulation.

The Centroid Moment Tensor (CMT - SCMTV module in SeisComP) is normally available at CATAC about 5-10 minutes after the earthquake to trigger the numerical model. Importantly, the CMT can now produce a more accurate initial condition which is critical to the modeling result. It is especially important for identifying slow earthquakes that may occur in Central America. While CMT analysis is appropriate for distant tsunamis, for regional and local tsunamis in the CATAC region, in certain situations such as giant earthquakes of magnitudes above 8 it could take too long to provide quantitative forecasts using this technique. Therefore, a tsunami scenario database based on the preliminary earthquake parameters, in combination with fast tsunami models, was also adopted to quantitatively assess the coastal hazard levels in the subsequent bulletin that appears 3-5 minutes after the first one. Thereafter, supplemental bulletins may be issued when a major revision of the earthquake magnitude occurs. CATAC will also run the high-resolution regional model when the WCMT analysis becomes available, however, the primary purpose is to update and validate previous forecast results.

Table 3. Criteria adopted by CATAC

Type of Newsletter		**Criteria**	**Content**	**Weather**
Tsunami Information	Only one bulletin	Magnitudes 6.0-6.4; or underground; o depth≥100km	EQ earthquake parameters and 'No Tsunami Hazard' statement	1-5 min
	Only one bulletin if no minor reportable waves observed	Magnitudes 6.5-7.0	Earthquake parameters and 'No Tsunami Hazard' statement	5-10 min

	Bulletin with cantitative prediction		Earthquake parameters and quantitative prediction of hazard level and estimated time of arrival (ETA).	3-5 min
Tsunami Hazard Message	Supplementary with remarks	7.1 and above	Earthquake parameters, quantitative prediction and tide gauge observations.	When there is a revision of the earthquake or tsunami prediction, or of observations
	Final bulletin		Declaration of 'Tsunami not confirmed or threat terminated'.	Dangerous waves have passed or there are no significant tsunami observations.

In the Tsunami Information or Tsunami Threat Message, the tsunamigenic potential is provided based on preliminary earthquake parameters as follows:

Table 4. Potential Gene Tsunami adopted by CATAC

Magnitude (Mw)	Tsunami Potential Description
$4.5 \leq M_w \leq 7.0$	There is no tsunami threat from this earthquake.
$7.1 \leq M_w \leq 7.5$	Possibility of a destructive local tsunami confined to distances of 100-300 km from the epicenter.
$M \geq 7.6_w$	Possibility of a destructive tsunami along the entire coast.

5. Main Decision Support Systems for CATAC Operations

5.1 SeisComP package

Origin

CATAC uses the SeisComP software (GFZ/Potsdam, GEMPA) in the PRO variant for both real-time and post-processing of seismic data. SeisComP was initially developed for the GEOFON network and extended in the MEREDIAN project under the direction of GEOFON/GFZ-Potsdam and ORFEUS. SeisComP was designed as a real-time data processing and fully automatic data acquisition tool, including quality control, event and location detection, as well as event alert dissemination. Also, additional functionalities were implemented to meet the requirements of 24/7 early warning centers. SeisComP is currently being developed by the GEMPA Company based in Potsdam, Germany.

SixComP as a decision support system adapted for CATAC

Tsunami advisory procedures begin with rapid transmission and processing of Earth observation data streams, and end with successful dissemination of advisory products to recipients. All procedures require the incorporation of seismic and sea level data, historical earthquake catalogs, tsunami scenario database, numerical models, and text processing module into user-friendly analysis software to help observers make rapid decisions and produce accurate and concise products. An effective decision support system must be tailored to the requirements of TSP's operating procedures and available resources.

Basically, a Decision Support System should achieve the following functions (modules):
Collection, archiving, processing and visualization of seismic and sea level data, international earthquake and tsunami products in real time;
2. Automatically or interactively calculate earthquake parameters that could be derived from the observed data and trigger alarm in case of exceeding the criteria thresholds;
3. Retrieval and visualization of the historical and scenario database to inform the proctor of an appropriate decision or action;
4. Produce and disseminate text and graphic products to TWFPs and NTWCs.

Since 2014, INETER was continuously developing software packages to help watchstanders work through the entire warning chain in an effective and efficient manner. The system is designed for the watchstander to make decisions in terms of Standard Operating Procedures and warning criteria. CATAC text bulletins and graphical products can be ultimately generated through a series of functional modules including: seismic module, tsunami observation module, tsunami modeling module and tsunami database.

The system collects earthquake data from multiple resources and assists the decision maker in choosing the most appropriate parameters by incorporating the Slab 1.0 and Harvard CMT 50-year models. The system is also capable of visualizing global sea level data to quickly confirm tsunami generation. The system is based on a pre-calculated scenario database and rule-based decision support that is delivered to the observer through sophisticated graphical user interfaces.

5.2 Seismological processing

5.2.1 Quality Control

Other important modules are *SCQCV* which monitors the quality of seismic data,

5.2.2 Automatic and manual seismological standard processing

Automatic processing

Standard automatic seismological processing includes the detection of seismic waves generated by earthquakes with the SeisComP *SCAUTOPICK* module. The SCEVENT module groups chopped phases into events that are localized with *SCAUTOLOC* and/or *SCANLOC*. SC

Magnitude

Automatic processing yields initial results within about 30 seconds and then improves the solutions when new data from different seismic stations appear.

Manual processing

The seismologists on duty immediately review the results of the automatic processing with interactive programs that allow viewing the seismograms and preliminary results on the graphic displays of the workstations.

A key interactive module of SeisComP3 is *SCOLV*, a graphical user interface that allows: Interaction with and management of the event catalog; Access to all sources comprising each event; Manual re-phasing; Manual event relocation; Magnitude review using the processed waveforms; Quick visualization of the solution, such as plotting time residuals for each station, displacement curves and polarity plots. Other GUIs are available that show summaries of more recent events, real-time waveforms and data quality summaries.

5.2.3 Automatic and Interactive Moment Tensor Calculation

The Moment Tensor is a physical description of the process of fault rupture that generates the displacement of the blocks under the seafloor that cause the tsunami and that emit the seismic waves that are recorded remotely and that allow the detection of the earthquake and the prediction of the tsunami before it reaches the coast. The determination of the Moment Tensor also makes it possible to determine the magnitude of the earthquake Mw with a higher precision than that allowed by simple methods that use the amplitude value of certain seismic waves to estimate the magnitude ML, Mb with certain formulas.

Automatic Moment Tensor Calculation

After detecting and locating the earthquakes automatically the *SCAUTOMT* Module evaluates the seismic waveforms recorded at the different stations and compares them with the numerically simulated shapes with a certain model of the earthquake focal mechanism. By testing a large number of possibilities for hypocenter depth and varying the location and parameters of the fault it arrives at a result where the recorded data optimally matches the model. The SCAUTOMT module is configured to include near and far stations in the processing. Distant stations have the advantage that their records are not saturated which would make the determination of the Moment Tensor impossible.

Automatic Moment Tensor Calculation

The *SCMTV* module is used for the interactive calculation of the Moment Tensor. The operator can adapt the program to the specific situation of the event. By limiting the distance of the stations involved in the processing, the work can be accelerated.

The SCAUTOMT and *SCMTV* modules of SeisComP PRO use P-wave, S-wave, surface waveforms and W-waves to determine the Moment Tensor. CATAC previously used only broadband seismic station records for this process. However, broadband records located near the epicenter are often saturated by the high amplitudes of seismic waves and cannot be used for magnitude and Moment Tensor calculations. That is why CATAC also uses on a large scale the high quality accelerographic stations located in Central America for these purposes.

The W phase is a long-period phase that arrives before the S wave. Because of the fast group velocity of the W phase, most of the energy of the W phase is contained within a short time window after the arrival of the P wave. The amplitude of the long-period waves best represents the tsunami potential of an earthquake. By extracting the W phase from the vertical component of seismic waves, the Mw magnitude and source mechanism can be deduced for large earthquakes using the linear inversion algorithm. Previous studies (e.g. Argüello, 2016; Argüello et al, 2018)) show that W-phase inversion produces reliable and consistent CMT solutions that are necessary for numerical tsunami modeling. With the current CATAC-initiated enhanced seismic networks in Central America, the initial solution can be produced within 5-8 min after the occurrence of earthquakes of magnitude greater than 5.5 including data from stations up to 1000 km epicentral distance. Central America is a very narrow region and sometimes solution stability problems can occur due to insufficient azimuthal coverage. In this case it is possible to increase the distance of stations up to 1500 or 2000 km and repeat the calculation (Cabrera et al., 2021).

5.2.4 Exploitation of Earthquake Early Warning (ATT) Results

Since 2016, INETER/Sismología has been developing together with the Swiss Seismological Service (SED) at the ETH Zurich University an earthquake early warning system (Earthquake Early Warning - EEW) for Nicaragua. This project was extended from 2018 also to other Central American countries and largely supported in the development of CATAC (Massin et al, 2018).

A primary objective for EEW is the immediate estimation of the location and magnitude of the seismic event within seconds after or even during the rupture of the earthquake fault. The fast magnitude estimation algorithms created for EEW can be useful for

Tsunami Warning. Also the fast location of the seismic event provided by EEW is important for tsunami thematic, especially in those coastal regions where tsunamis may arrive a few minutes after the crustal rupture process ends.

Tsunami mitigation efforts can be seriously affected by the seismic impact of the earthquake that generated the waves. NTWC and Civil Protection institutions should have an estimate of the level of impact or destruction as soon as possible to adapt mitigation measures (e.g., evacuation) accordingly. The ATT requires very rapid methods to alert large numbers of people of the impending impact by an earthquake and the same methods serve the tsunami warning.

CATAC will continue to investigate the usefulness of ATT for tsunami warning in Central America and promote its application for tsunami warning.

5.2.5 Earthquake Impact Scenarios, Shakemaps

In the aforementioned EEW project with SED / ETH, procedures to generate and distribute Shakemaps in near real time for Nicaragua and Central America were also installed in March 2017 (Cauzzi et al, 2018). When planning for tsunami response, it is important to consider the potential seismic impact in areas near the source, as these impacts can affect tsunami response and increase tsunami impact by hindering evacuation and contributing to wave-borne debris. For earthquake impact, the USGS has developed ShakeMap and the rapid assessment of global earthquakes for response (PAGER). The primary purpose of ShakeMap is to show the ground shaking levels produced by the earthquake. The levels of shaking events in the region are studied as a function of earthquake magnitude, distance from the earthquake source, rock and soil behavior in the region, and the propagation of seismic waves through the earth's crust. Based on ShakeMap output, PAGER estimates the population exposed to earthquake shaking, fatalities and economic losses.

CATAC creates Shakemaps in a few minutes after the earthquake impact and provides them through its website to NTWCs and TWFPs in Central America.

5.3 Tsunami Forecast Models

CATAC uses for quantitative tsunami warnings -

1) A pre-calculated base of tsunami forecasts; together with
2) A real-time numerical simulation technique.

5.3.1 Tsunami Forecast Database

The tsunami scenario database covering the Pacific and Caribbean monitoring regions was developed with the objective of using the preliminary earthquake parameters to retrieve pre-calculated scenarios and provide real-time forecast of the tsunami amplitude near the beach (Gonzalez, Acosta, Strauch; 2021).

Each scenario covers the entire monitoring area in the Pacific and Caribbean, respectively. The simulation length is 8 hours. The linear momentum equation was adopted which is not suitable for very shallow waters. Therefore, the coastal forecast points are selected along the 200-meter isobath, and the coastal amplitudes along the 5, 10, 20 and 50-meter isobath are scaled by Green's Law. Each coastal forecast point is spaced with a 12-minute interval (approximately 20 km) covering the CATAC edge countries. The maximum wave amplitude, ETA at each coastal forecast point are stored in the database for rapid retrieval. Each time an earthquake occurs, the scenarios closest to the event are extracted from the database and then interpolated to obtain a coastal amplitude forecast.

Tsunami propagation scenarios based on various fault types/locations were simulated in advance, and data on calculated tsunami arrival times and amplitude were stored in a database along with information on magnitudes and hypocenter locations. The assumed epicenter locations are shown in Figure 2. For each, faults with four magnitudes (M8.5, 8.0, 8.0, 7.5 and 7.0) and six depths (0, 20, 40, 60, 80 and 100 km) are determined. Once an earthquake occurs and its hypocenter and magnitude are determined, the closest scenario is retrieved for the formulation of CATAC advisories. Specifically, the scenario with the closest fault location is selected and tsunami amplitudes are estimated by interpolation or extrapolation related to magnitude and depth. For tsunami propagation simulation, the model described in 8.2 is used.

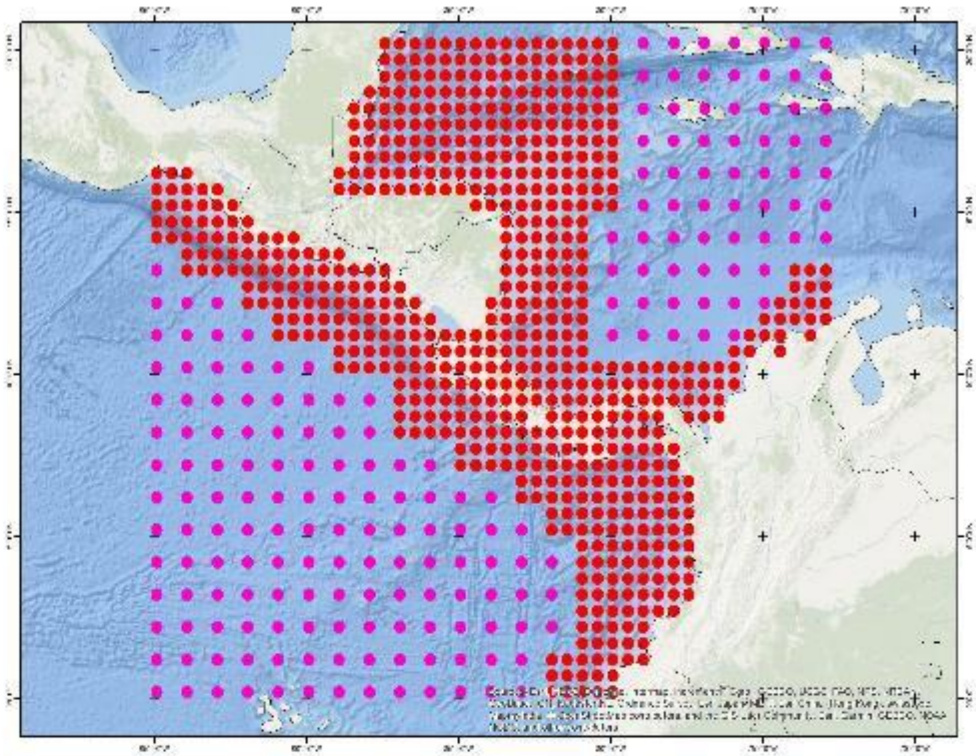


Figure 11. Assumed fault locations for the pre-calculated base. CATAC tsunami forecast data.

This database contains for 829 locations of faults in the Pacific Ocean and the Caribbean Sea at 0.5 or 1 degree separation a total of 16,580 simulation cases with 4 magnitudes (6.5, 7.0, 7.5, 8.0) and 5 depths (10, 30, 60, 80, 100km). The strike from the database of earthquakes occurred in the area. The dip is 45 degrees, the slip angle (rake) is 90 degrees. If an earthquake with a magnitude greater than 8 occurs, an extrapolation is made based on the existing values in the database.

In calculating tsunami propagation for tsunami forecast database information and real-time forecasts, CATAC uses a numerical tsunami simulation model based on nonlinear long-wave theory. This model incorporates the effects of Coriolis force and seafloor friction, and has a grid resolution of 1 arc-min (e.g., Satake (2002)).

The long wave theory can be applied when the wavelength of a tsunami is considered to significantly exceed the sea depth and when the wave amplitude is considered to be much smaller than the sea depth. However, these conditions are not applicable for tsunamis heading towards coastal areas in shallow water. Therefore, the estimation of tsunami amplitudes at coastal points is based on the simulated value for a corresponding offshore point several to several tens of kilometers offshore using Green's Law (e.g., Satake (2002). The depth of the coastal ocean is set to 1 m.

Meanwhile, the tsunami arrival time at the coastal point determined from the numerical simulation is considered as the corresponding coastal point without conversion. The arrival time is defined as the point at which the initially estimated amplitude exceeds 5 cm.

It should be noted that actual tsunami arrival times and amplitudes may differ from the predicted data depending on coastal and seafloor topography, especially in coastal areas where fine-mesh bathymetric data are not used in the numerical simulation of tsunamis. Consequently, although the estimated arrival times for each forecast point are given to the nearest minute, the data are not necessarily accurate to the order of a minute. Tsunamis may arrive somewhat earlier or later than the A-CATAC estimated times.

Tsunami travel times.

The calculation of tsunami travel times shown on the tsunami travel time maps is based on long wave theory, which means that the wave speed is calculated from the square root of the amount of water depth multiplied by the acceleration of gravity. Consequently, the times shown on these maps may not accurately match the times in the CATAC Tsunami Advisory text messages.

5.3.2 Real-time tsunami forecast model

SEISCOMP PRO, the seismological software package used at CATAC for earthquake detection, location and magnitude determination also has a real-time tsunami forecast model based on the *TOAST* module (Tsunami Observation and Simulation Terminal; GEMPA, https://www.gempa.de/products/toast/). *TOAST is a* tsunami simulation and verification software for rapid hazard assessment. The results can be verified by oceanographic sensors such as tide gauges or buoys. *TOAST* is the complement to SeisComP3 for the implementation of a fully functional tsunami warning system. In addition to this in-flight simulation the *TOAST* interface for flexible simulation also allows the integration of existing pre-calculated scenario databases.

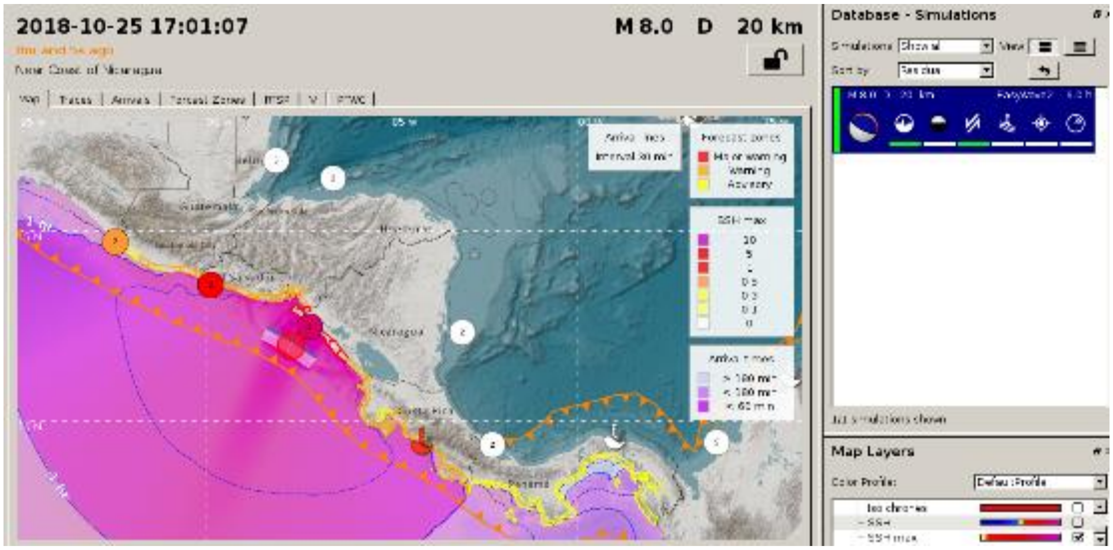


Figure 12 TOAST simulation of tsunami propagation of a magnitude 8.0 event off the Gulf of Fonseca, between El Salvador and Nicaragua.

TOAST module workflow

TOAST connects to the SeisComP3 system and listens for internal system messages with parameters of the incoming earthquake. In case a hypocenter and magnitude arrive, TOAST uses a formula from Wells & Coppersmith (1984) to generate the rupture size based on the magnitude. By default, the rupture area is centered around the epicenter, and strike and dip information are derived from preconfigured fault information. Once the rupture area is generated, the simulation plug-ins are activated.

EasyWave application for tsunami simulation

By default TOAST uses the EasyWave program (https://gitext.gfz-potsdam.de/id2/geoperil/easyWave) an application used to numerically simulate tsunami generation and propagation in the context of early warning (Babeyko, 2012). It makes use of Graphics Processing Units (GPU) to considerably speed up the calculations. The rupture area can be placed at several preconfigured positions with respect to the hypocenter and simulations for several positions can be computed on the fly in parallel. As the earthquake information is changing over time, with each relevant update new simulations are automatically triggered. But rupture areas can also be generated manually and simulations can be started using these.

TOAST provides different perspectives showing the simulation results. The following features are shown:

- Simulated as a function of time Sea Surface Height
- Simulated sea surface height
- Simulated isochrones
- Simulated tsunami travel times
- Estimated tsunami arrivals
- Tsunami coastal wave height estimation.
- Observations of tsunami arrival through manual initiation chopping
- Observations of tsunami wave heights/periods by hand chopping
- Points of interest and oceanographic sensors
- Failure information
- Rupture area
- Seismic parameters

- Simulation progress
- Simulation quality
- Newsletter

To verify the simulation results, *TOAST* provides a manual tsunami onset selector, which allows selection of arrivals, amplitudes and periods based on real-time tide gauge observations. The observed information is then used to calculate the quality of a scenario that represents the agreement between the simulated and observed values.

For example, the quality of oceanographic sensors is indicated by the color of the tide gauge symbol in the simulation widget. The simulation widget displays these quality parameters not only for tide gauge data, but also for epicenter location, depth, magnitude, comparison with preconfigured rupture mechanisms, and existing moment tensors. The quality information may change over time as it compares the simulation information with the actual information.

5.4 Interpretation of database and model results

The uncertainties associated with the tsunami propagation scenario database and numerical models come from the CMT solution, interpolation between neighboring scenarios, numerical modeling of the propagation, as well as Green's law extrapolation. Each uncertainty can result in large errors. For example, numerical forecasts can easily vary by a factor of two due to uncertainties in earthquake magnitude, depth and assumed mechanism; Green's Law is very sensitive to local topography and bathymetry, the coastal amplitude could be over or underestimated by a factor of 2-3 depending on coastal features; the effect of wave dispersion is significant for distant tsunami propagation.

Therefore, the ability to understand numerical forecasts is very important for national receivers to correctly recognize tsunami hazards. Basically, the major tsunami service providers such as PTWC and NWPTAC interpret the numerical results by classifying them into various categories. NWPTAC categorizes the tsunami amplitude into 0.5 m; 1 m; 2 m; 3 m; 4 m; 6 m; 8 m; and over 10 m. In the PTWC New Enhanced Products, the coastal amplitude forecast at each forecast point is categorized into four threat levels of <0.3 m; 0.3-1 m, 1-3 m and above 3 m, which are illustrated with different colors along the coasts.

The uncertainties associated with the tsunami propagation scenario database and numerical models come from the CMT solution, interpolation between neighboring scenarios, numerical modeling of the propagation, as well as Green's law extrapolation. Each uncertainty can result in large errors. For example, numerical forecasts can easily vary by a factor of two due to uncertainties in earthquake magnitude, depth and assumed mechanism; Green's Law is very sensitive to local topography and bathymetry, coastal amplitude could be over or underestimated by a factor of 2-3 depending on coastal features; The effect of wave dispersion is not negligible for distant tsunami wave propagation.

Therefore, how to understand the numerical forecasts is very important for national receivers to correctly recognize tsunami hazards. Basically, CATAC interprets the numerical results by classifying them into several categories. In CATAC's Tsunami Advisory Products, the coastal amplitude forecast at each forecast point is classified into four threat levels of <0.3 m; 0.3-1 m, 1-3 m and above 3 m, which are illustrated with different colors along the coasts. The practice is exactly the same as that of the PTWC New Enhanced Products.

6. CATAC Tsunami Advisory Products

CATAC tsunami advisory products are issued when an earthquake with moment magnitude 4.5 or greater is detected in one of the CATAC Monitoring Areas.

6.1 Text bulletin

The Text bulletin is available to the public and NTWCs. Typically, the CATAC text product contains earthquake parameters, tsunami genic potential, tsunami amplitude and ETA forecasts for Coastal Forecast Points, tsunami observations and recommended actions.

6.2 Coastal Forecast Points

Tsunami amplitude and estimated time of arrival (ETA) are provided for coastal forecast points in the CATAC region. These coastal forecast points are points chosen by CATAC Member States. They correspond to coastal cities and tide gauge station sites. In the tsunami threat message, all forecast points with maximum amplitude greater than 0.3

meters are listed in groups according to Member States. Tsunami amplitude estimates are grouped into four clusters of <0.3 m; 0.3 to less than 1 m; 1 to 3 m; and greater than 3 m.

6.3 Tsunami Energy Map

The tsunami energy map gives the distribution of the maximum tsunami amplitude in the CATAC region color coded. The direction of the tsunami energy beam and the threatened areas can be easily identified by the different color scale. The tsunami travel time (TTT) contours are shown in light gray lines and are superimposed on the tsunami energy map.

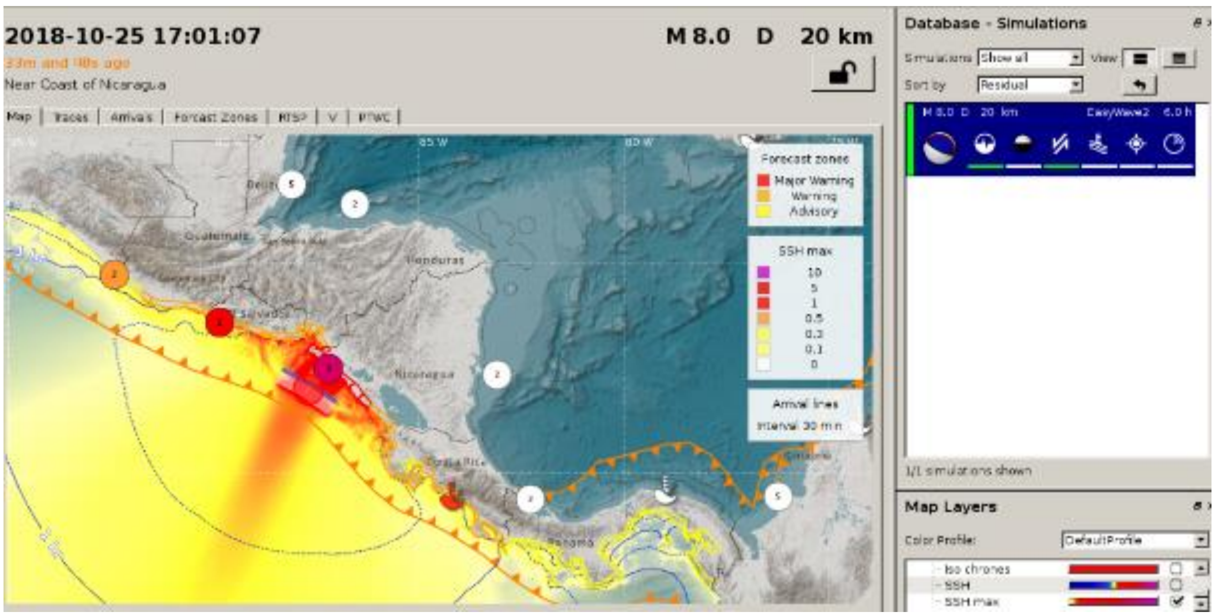


Figure 13. Tsunami energy radiance of a simulated event of magnitude 8.0 off the Gulf of Fonseca, between El Salvador and Nicaragua, performed with TOAST.

6.4 Coastal Prediction Map

The coastal forecast map provides a detailed view of the tsunami threat along the coasts of the CATAC region. It divides the CATAC coastlines into a series of modeling output sites. Each site is colored according to the tsunami amplitude corresponding to the model grid points closest to the site. The tsunami energy map is also overlaid in gray shading style with illuminated effect and in addition there are TTT contour lines placed.

7. Dissemination and Services

7.1 Computer Basis

Messages are generated with *GDS, QuakeLink and GIS*, which are SeisComP3 modules that collect event information and disseminate template-based messages through various communication channels such as SMS, email, fax and web. Using plug-in technology, they import and filter seismic information from different sources before dissemination. *GDS, QuakeLink and GIS* complement SeisComP and *TOAST* functionalities in the area of notification and alert dissemination.

- Text messages and graphic products including tsunami energy maps, coastal forecast maps are sent to NTWC/TWFPs in Central America via email, SMS, Whatsapp and the password protected CATAC website.
- Short text messages are disseminated in Nicaragua through the EWBS system of digital TV to many institutions and the general public, starting December 2021. In the other countries of the region, TWFPs could follow this example.
- The messages are additionally disseminated also with an Apple / Android app (still under development).
- The text messages are posted on CATAC's website for the general public, together with graphic material on the earthquake tsunami generator.

7.2 CATAC website

The CATAC website www.catac.ineter.gob.ni (under development since 2019) is designed for both NTWC/TWFPs in Central America and the general public. For the public, only the basic earthquake newsletter and text bulletin can be accessed, while NTWC/TWFPs, can obtain with restricted access more specialized information on seismic parameters (CMT solutions), graphical tsunami advisory products and real-time data. Further coverage can be developed at the request of WG-CA Member States. In the long term, the CATAC web site can serve as a sub-regional capacity building protocol for tsunami exercises, training and tsunami hazard mitigation.

8. CATAC Products

The successful launch of the Pacific Tsunami Warning Center (PTWC) Enhanced Products in October 2014 demonstrated the mature capability of Member States to use advanced graphics products.
In recognition of the importance of providing conventional, concise and easy-to-understand text messages containing forecast amplitude information for selected individual forecast points (FP), CATAC also decided to issue its text products along with graphical products.
Appendix II lists the FPs for which data are reported in CATAC products. The list has been compiled taking into account those used for PTWC products and requests from Central American countries.
To avoid public confusion, CATAC products are provided exclusively to national authorities responsible for national tsunami warnings in the CATAC Area of Service (AoS).
Text messages and seismological information are published on the CATAC website catac.ineter.gob.ni.

8.1 CATAC product scheme

CATAC products are differentiated into seismological products and tsunami products.
Seismological products consist of seismological data such as time of origin, location, hypocenter depth, earthquake magnitude, focal mechanism, moment tensor.
1) Automatic immediate seismological information generated with the earthquake early warning system, sent about 10 seconds after the onset of earthquakes with magnitudes above 4.5.
2) Immediate seismological information on manually confirmed earthquakes with magnitudes above 4.5 that occurred in the monitoring zone.

CATAC-tsunami's products consist of initial text messages compiled from
1) Initial tsunami assessment based solely on an outline of earthquake location, depth, and magnitude.
2) Tsunami assessment based on tsunami simulation by immediately accessing a preset tsunami simulation database;
3) Tsunami information based on a numerical simulation with the TOAST program running in real time,

8.2 Product distribution policy

CATAC follows the example of PTWC and publishes seismological and tsunami text messages on its website catac.ineter.gob.ni. The messages contain subsequent text messages accompanied by graphic products.

The products will be distributed exclusively to the national authorities of the user countries.

8.3 Product specifications

8.3.1 Text products

- Forecast method.
    - First message (and second message in the case of an earthquake parameter update) from 1) the tsunami forecast database using a preliminary determined hypocenter and magnitude; or 2) tsunami forecast based on real-time numerical simulation.
    - Subsequent real-time simulation messages using the CMT solution.
- Content
    - Earthquake parameters (time of origin, location, magnitude).
    - Tsunamigenic potential
    - Coastal blocks.
    - Extent of forecast and arrival time.
    - Observed amplitude and time of arrival.
- Distribution channels.
    - e-mail, TELEGRAM, (mobile application in preparation),
    - Digital TV EWBS

b. Graphic products (maps).

- Forecast method
    - Real-time simulation.
- Content
    - Tsunami amplitude prediction map of the offshore tsunami.
    - Tsunami travel time map.
    - Coastal tsunami amplitude prediction map.
- Distribution channels.
    - E-mail, TELEGRAM, (Mobile application in preparation), Web

Appendix I provides examples of CATAC enhanced products.

Seismological details of text messages.

Earthquake information.

a. Time of origin.
b. Epicenter coordinates (latitude and longitude).
c. Location (geographical area).
d. Depth
e. Magnitude (at the moment

Tsunamigenic Potential.

The potential generic tsunami is initially evaluated based on the magnitude M of the earthquake, and the location and depth of the hypocenter.

M	**Probability and Affectation**
6.5-7.0	Very small possibility of destructive local tsunami
7.1-7.5	Possibility of destructive local tsunami within 100 km of the epicenter.
7.6-7.8	Possibility of destructive regional tsunami within 1,000 km of epicenter
7.9-	Possibility of destructive tsunami in the whole ocean

No potential generic tsunami is associated with earthquakes with epicenters far inland or at depths of 100 km or more.

8.3.2 Estimation of the estimated tsunami amplitude and arrival time.

PP forecast points

Along the Pacific and Caribbean coasts the relevant scientific institutions of the countries in cooperation with CATAC have defined PP forecast points for which the tsunami time and amplitude and arrival time and amplitude are estimated - with the following criteria:

Location of tide stations,
2. Points for in coastal blocks reflecting political and administrative boundaries,
2. Communities at risk on the coast,
3. Topographic features,
4. Points from which the apparent tsunami velocity at the coast varies greatly. I.e. entry into a bay, beginning of a zone of low sea speed, etc..

A tsunami amplitude and arrival time is estimated for each forecast point in coastal areas (Appendix II). This information is included in CATAC advisory messages with the names of forecast points and their latitudes/longitudes in coastal block groups.
Here, **amplitude is defined as the maximum distance between tsunami wave crests and undisturbed sea level.** The estimated tsunami amplitude is shown only for forecast points expected to experience tsunami heights 0.3 m or greater. **The classifications are 0.3 - 1 m, 1 - 3 m, greater than 3 meters.** If a tsunami with an amplitude of 0.3 m or more is not expected for any forecast point, the A-CATAC message reads "Estimated forecast points: no tsunami waves with an amplitude of 0.3 m or more are expected at any forecast point."

8.3.4 Tsunami Observation

Information on the amplitude of the largest wave (to the nearest 0.1 m) and other tsunami wave data observed at tide stations with telemetry links to CATAC are provided as needed.

8.3.5 Limitations of CATAC Products

a) Tsunami travel time map.

This shows the estimated travel time according to the location of the earthquake (hypocenter or centroid) and the magnitude determined.

Limitations:
Actual arrival times may differ from expected times for reasons including:

- Uncertainty of tsunami source (the area of seafloor deformation is assumed from the location and magnitude of the earthquake.)
- Bathymetry uncertainty around the observation point and elsewhere.
- Non-linear effects on tsunami propagation that are not considered in the travel time estimation (such effects may be more significant in shallow water).
- Difficulty in determining first wave arrival times from sea level observation data.

b) Coastal tsunami amplitude forecast map.

This displays individual coastal points with colors based on the predicted tsunami amplitude at each point.
The larger of the two forecast amplitudes based on a set of conjugate faults determined through CMT analysis is used for each point.

Limitations:
Actual coastal amplitudes may differ from forecasts for reasons that include:
- Tsunami source uncertainties (two rectangular faults are assumed from CMT analysis).

- Uncertainties regarding tsunami/coastal interaction (Green's Law is used as a general approximation).
Results can easily vary by a factor of two due to these uncertainties.

c) Offshore Tsunami Amplitude Forecast Map

This map shows the maximum tsunami amplitude at each location in the deep ocean. It shows how the tsunami 1) propagates directionally from the tsunami source; 2) is focused and defocused by the shape of the seafloor, and 3) is dissipated due to distance.
Two maps are provided based on a set of conjugate faults determined through CMT analysis.

Limitations:
Actual tsunami amplitudes in the deep ocean may differ from forecasts due to uncertainties in the tsunami source (two rectangular faults are assumed from the CMT analysis) and other factors.
This map should not be used to estimate coastal tsunami amplitudes or impacts.

8.3.6 Product issuance timeline

The A-CATAC issuance schedule, shown below, is typical but approximate and conservative.

Time/ minutes	**Occurrence / Action**
00	An earthquake occurs in CATAC Monitoring Areas
0.5	An automatic message with seismological information is sent to the recipients.
3	**The first CATAC text product** based on information from a tsunami forecast database or real-time simulation is issued along with data on preliminary earthquake parameters.

	Another A-CATAC text product is issued if the earthquake parameters are updated.
8	The CMT solution is obtained and recalculates the simulation in real time.
9	The simulation is completed in real time.
10	The second A-CATAC text product and graphical products based on real-time numerical simulation are issued.
10	CATAC receives an initial text product from PTWC.

Communications Test

CATAC conducts communication tests or drills approximately twice a year on liaisons to user organizations. Advance notice of the test is provided through an IOC Circular Letter. In the test, users are asked to acknowledge receipt of a test message using a report form provided with the Circular.

9. Exchange of CATAC products with PTWC, NTWCs and other tsunami suppliers.

Starting in 2022, CATAC will also send its products through the GTS, which will allow PTWS, NWPTAC and other tsunami service centers to receive them. In this way CATAC supports these centers and the recipients of its products to receive rapid information on earthquakes and tsunamis occurring in Central America.

Earthquakes off the coasts of Mexico and Colombia can cause tsunamis that reach Central America in an hour or less. Therefore, it is important for CATAC to receive NTWC products from these countries. The seismological and tsunami results obtained in these countries can help to avoid serious errors in CATAC's seismic and tsunami hazard assessment. CATAC communicated with the NTWCs of these countries and agreed on a routine exchange of information. From 2020 CATAC will receive products from the Mexico Tsunami Warning Center and from 2022 it will send its official products to this center. Likewise, CATAC intends to exchange its products with the NTWC of Colombia.

CATAC Advisory Products are provided to Central American countries in parallel with PTWC's tsunami products to assist user countries in taking timely and appropriate action against tsunami hazards. However, it is important to note that the products are recommendations to support the Central American countries' own efforts to warn people of the hazards; the issuance of evacuation warnings is the responsibility of the countries themselves.

The accuracy of tsunami arrival/amplitude estimation times and the timing of forecast issuance depend on the quantity and quality of seismic and tide gauge data that the countries themselves provide to CATAC and on the technology used for the determination of the hypocenter/CMT and quantitative tsunami forecast. Consequently, it is strongly recommended that Central American countries improve and/or expand their seismic networks, provide sufficient data, and use CATAC products with careful consideration of the technological background described in this User's Guide.

CATAC makes every effort to provide its products as quickly as possible. However, people may need to be alerted prior to the issuance of A-CATAC in the event of large earthquakes in coastal areas, as tsunamis can reach land quickly.

CATAC advisory products do not explicitly include cancellation of warnings in subsequent issues because CATAC does not issue warnings. The authorities of the countries concerned should issue and cancel them officially, since the tsunami characteristics depend on the coastal terrain. To facilitate this process, CATAC, after issuing the first warnings, will perform tsunami simulations for the next 8 to 12 hours after the earthquake and provide the results to the countries.

In the event of any difference in tsunami severity assessment between PTWC and CATAC products, the more severe one should be adopted.

REFERENCES

Gerzon Gonzalez, Norwin Acosta Wilfried Strauch (2021) A real-time application for tsunami warning and evacuation route information in the Pacific coastal areas of Nicaragua, INETER and Taiwan technical cooperation, Managua, Nicaragua.

JICA (2015) Data Collection Survey on the Observation Capacity of Earthquakes and Tsunami In Central America, Final Report, March 2015, Japan International Cooperation Agency, Oriental Consultants Global Co., Ltd, Japan Meteorological Business Support Center.

Satake, K. 2002. Tsunamis. International Handbook of Earthquake Seismology and Engineering, Part A, III-28. Academic Press.

UNESCO-IOC (2009) Technical Series No. 87 "Operational Users' Guide for the Pacific Tsunami Warning and Mitigation System (PTWS)", Second Edition, Annex II, 2011.

UNESCO-IOC (2014) User's Guide for the Pacific Tsunami Warning Center (PTWS) enhanced products, IOC Technical Series No 105, revised edition. UNESCO / IOC 2014 (English; Spanish)

UNESCO/IOC. 2019. User's Guide for the South China Sea Tsunami Advisory Center (SCSTAC) products for the South China Sea Tsunami Warning and Mitigation System. Paris, UNESCO, IOC Technical Series No 149.

Intergovernmental Oceanographic Commission. 2018. Tsunami Hazard in Central America: Historical Events and Potential Sources. San Jose, Costa Rica, June 23 and 24, 2016. Paris, UNESCO, 50 pp (IOC/2018/WR/278).

Freundt, Armin , Kutterolf, Steffen , Wehrmann, Heidi, Schmincke, Hans-Ulrich and Strauch, W. (2004) Tsunami in Lake Managua, Nicaragua, triggered by a compositionally zoned plinian eruption. [Talk] In: IAVCEI General Assembly. , 14.-20.11, Pucon, Chile

Armin Freundt, Wilfried Strauch, Steffen Kutterolf, and Hans-Ulrich Schmincke (2007) Volcanogenic Tsunamis in Lakes: Examples from Nicaragua and General Implications, Pure appl. geophys. 164 (2007) 527-545, 0033-4553/07/030527-19
DOI 10.1007/s00024-006-0178-z

Strauch, Wilfried (2019) EXERCISE TSUNAMI-CA 19. A Mega tsunami drill for Central America - August 19, 2019, IOC/UNESCO Technical Series #148, CATAC-INETER.

Strauch, Wilfried (2020) Exercise TSUNAMI-CA-20. Central America Tsunami Exercise - November 11, 2020 - A slow earthquake and tsunami off the Gulf of Fonseca. Participants' Manual, IOC/UNESCO Technical Series #XXX, Central American Tsunami Advisory Center (CATAC/INETER), Managua, Nicaragua.

Greyving J. Arguello M., Yuichiro Tanioka, Wilfried Strauch (2018) Reliability of the W-PhaseInversion
for earthquakes with MW > 6.0 to be used by the Central American Tsunami AdvisoryCenter [CATAC], Abstract, Joint Conference of the Latin American and Caribbean SeismologicalCommission
[LACSC] and the Seismological Society of America [SSA], 14-17 May 2018, Miami, Florida.

Strauch W. and Weber B (2018) New SeisComP3 Installation for Tsunami Early Warning at the Central American Tsunami Advisory Center [CATAC] in Managua, Nicaragua, Abstract, IOC/UNESCO SYMPOSIUM on Advances in Tsunami Warning to Enhance Community Responses, Paris, 12 - 14, February 2018, IOC Brochure 2018-1.

Nobuo Furukawa, Yu Kumagai, Wilfried Strauch, Emilio Talavera, Virginia Tenorio, Javier

Ramírez, Greyving Argüello, Martha Herrera, Norwin Acosta, Allan Morales (2018) Project for Strengthening the Capacity of the Central American Tsunami Advisory Center [CATAC], Abstract, IOC/UNESCO SYMPOSIUM on Advances in Tsunami Warning to Enhance Community Responses, Paris, 12 - 14 February 2018, IOC Brochure 2018-1 [IOC/BRO/2018/1 Add].

Wilfried Strauch, Bernd Weber, Marit Moeller, Faustino Blanco, Javiér Ramirez, Emilio Talavera (2018) First Experience with SeisComP3 Based tsunami software for the Central American Tsunami Advisory Center [CATAC] at INETER, Nicaragua, Joint Conference of the Latin American and Caribbean Seismological Commission [LACSC] and the Seismological Society of America [SSA], 14-17 May 2018, Miami, Florida.

Carlo Cauzzi, John Clinton, Frédérick Massin, Wilfried Strauch and Javier Ramirez (2018). ShakeMaps for Nicaragua and Central America based on SeisComP3 at INETER, Joint conference of the Latin American and Caribbean Seismological Commission [LACSC] and the Seismological Society of America [SSA], 14-17 May 2018, Miami, Florida

Massin F., Strauch W., Clinton J.F., Ramirez J. (2018) Building EEW in Nicaragua: Performance and Perspectives, Joint conference of the Latin American and Caribbean Seismological Commission [LACSC] and the Seismological Society of America [SSA], 14-17 May 2018, Miami, Florida.

Strauch W. , Clinton J. , Massin F., Ramirez J. (2018) Towards Earthquake Early Warning in Central America, Joint Conference of the Latin American and Caribbean Seismological Commission [LACSC] and the Seismological Society of America [SSA], 14-17 May 2018, Miami, Florida.

Javier Ramirez and Wilfried Strauch (2018) Coconet mirror data center at INETER, Nicaragua, and Early Warning in Central America, Joint Conference of the Latin American and Caribbean Seismological Commission [LACSC] and the Seismological Society of America [SSA], 14-17 May 2018, Miami, Florida.

A. G. Cabrera R. (2017). Tsunami Characteristics of Outer-Rise Earthquakes Along the Pacific Coast of Nicaragua - A Case Study for the 2016 Nicaragua Event, Master Thesis, GRIPS/ IISEE/ BRI, Tsukuba/TokyoJapan, August 2017.

Massin, F., J. Clinton, and W. Strauch (2017). Project proposal to COSUDE, Managua: Earthquake Early Warning in Nicaragua and Central America [EWARNICA]-Phase II, Zurich and Managua, 4 October 2017.

Lindholm, C.; Strauch, W.; Fernández, M. (2017). Tsunami hazard in Central America: history and future, Geological Society, London, Special Publications, 456, SP456. 2, Geological Society of London.

Namendi, D. (2017). Rapid Magnitude Determination for Tsunami Warning Using Local Data in and Around Nicaragua, Master Thesis, GRIPS/ IISEE/ BRI, Tsukuba/Tokyo Japan, August 2017.

Y. Tanioka, G. J. Arguello Miranda, A. R. Gusman, Y. Fujii (2017) Method to Determine Appropriate Source Models of Large Earthquakes Including Tsunami Earthquakes for Tsunami Early Warning in Central America, Pure and Applied Geophysics, August 2017, Volume 174, Issue 8, pp 3237-3248,

Wilfried Strauch (2017) Report on the Progress in the Development of the Central AmericanTsunami
Advisory Center [CATAC], Meeting of the ICG/PTWS-XXVII, Tahiti France, 2-31 March, 2017.

Wilfried Strauch (2017) Progress in the Establishment of the Central American Tsunami Advisory Center CATAC) at INETER, Nicaragua, Presentation, Meeting of the ICG/CARIBE EWS-XII, Punta Leona, Costa Rica, 10-12 May 2017.

G.J. Argüello M. (2016). W Phase Inversion Analysis and Tsunami Simulation for Tsunami Warning for Large Earthquake [Mw>7.0] in Nicaragua, Master Thesis, GRIPS/ IISEE/ BRI, Tsukuba/Tokyo Japan, Japan August 2016.

Herrera, M. V. J. (2016). Tsunami modeling of the 2012 El Salvador earthquake along the Pacific Coast of El Salvador and Nicaragua, Master Thesis, GRIPS/IISEE/BRI, Tsukuba/Tokyo, Japan.

Massin, F; Clinton, JF; Behr, Y; Strauch, W; Cauzzi, C; Boese, M; Talavera, E; Tenorio, V; Ramirez, J (2016). Assessing the Applicability of Earthquake Early Warning in Nicaragua, AGU Fall Meeting Abstracts,2016.

Talavera, E. (2015) Tsunami Simulation for the 1992 Nicaragua Earthquake, Master Thesis, GRIPS/IISEE/BRI, Tsukuba/Tokyo Japan, August 2015.

Strauch, W. (2014) Automatic Seismic Datacenters and Tsunami Warning in Central America [in Spanish], GEO-NETWORK OF LATINAMERICAN-GERMAN ALUMNI [GOAL], Newsletter No 1 March 2014.

Strauch, Wilfried (2013) Phase 1 - Analysis and Modeling of Geophysical, Seismological and Hydrometeorological Data
for the Implementation of Automated Risk Management Systems that Strengthen the OSOP and the Disaster Prevention System of Panama.OSOP/Senacyt, Volcan, Panama.

Flores, P. (2013). Moment Tensor Analysis of Middle and Large Earthquakes in Nicaragua, Master Thesis, NGIPS/BRI, Tsukuba/Tokyo, Japan, September 2013.

Tenorio, Virginia; Strauch, Wilfried (2012) Evaluation of the earthquake of August 26, 2012, in the Pacific Ocean between El Salvador and Nicaragua, in: Editor V. Tenorio, Boletín Mensual Sismos y Volcanes de Nicaragua, year 2012 month August, pp. 22-48.

Strauch, Wilfried (2012) Guía para la implementación y sostenibilidad de Sistemas de AlertaTempiertaTemprana
ante Deslizamientos [SATD] en América Central, Proyecto Fortalecimiento de losSistemas de Alerta Temprana en América Central, UNESCO San José Office for Central America and Mexico.

Strauch, Wilfried; Norwin, Acosta (2010) Tsunami hazard maps for the Gulf of Fonseca - El Salvador, Honduras, Nicaragua; Central American Geohazard Mitigation Project, Bundesanstalt für Geowissenschaften und Rohstoffe BGR, Managua,

Strauch, Wilfried (2010) Análisis de desempeño del SAT Tsunami Chileno en el Terremoto y Tsunami de 2010 - Diagnostico brechas sobre el Sistema de Alerta Temprana
Tsunami of 2010 - Gap diagnosis on the Early Warning System, Monitoring,
Procedures and Protocols for Data Transmission and Issuance / Activation of Warnings, ONEMI / IDB, Santiago de Chile.

Strauch, Wilfried; Norwin, Acosta (2010) Tsunami hazard maps for the Gulf of Fonseca El Salvador, Honduras, NicaraguaProyecto de Mitigación de Georiesgos en Centroamérica, Bundesanstalt für Geowissenschaften und Rohstoffe BGR, Managua,

Strauch, Wilfried (2010) Geo-Hazards and Geo-Hazards in Central America, in: Manual for the Evaluation of Risk Exposure to Natural Hazards in Central America - El Salvador, Guatemala, Honduras and Nicaragua, 121 pages, 26 images, 44 tables, 35, Technical Cooperation Project - Geo-Hazards Mitigation in Central America, BGR Bundesanstalt für Geowissenschaften und Rohstoffe BGR, Hannover, Managua,

N., Acosta; W, Strauch; A., Castellón; A., Larreynaga; G., Funes (2009)GIS based Tsunami Hazard Mapping in Nicaragua, El Salvador and Honduras and Application to Disaster Prevention Measures, Lateinamerika-Kolloquium, Gottingen, Germany, 07- 09 April, 2009

ANNEXES

ANNEX 1. Construction details of CATAC products

1. **Tsunamigenic potential**

The evaluation of the tsunami potential generated by earthquakes located in the CATAC Monitoring Area is based on the location, depth and magnitude of the earthquake as follows:

CATAC criteria for the assessment of tsunamigenic potential

Criteria	**Potential gene tsunami**
- Epicenter well on the mainland - Deep underwater epicenter (greater than 100 km)	There is no possibility of a tsunami
- Shallow submarine earthquake, - M6.5 - 7.0	Very small chance of a destructive local tsunami
- Shallow submarine earthquake. - M7.1 - 7.5	Possibility of a destructive local tsunami near the epicenter.
- Shallow submarine earthquake- M7.6 - 7.8	Possibility of a destructive regional tsunami.
- Shallow submarine earthquake. - M greater than 7.9	Possibility of a destructive ocean-wide tsunami.

CATAC's initial messages are based on this assessment which requires only the location and magnitude of the earthquake.

Coastal blocks

If a tsunami with an amplitude of 0.3 m or greater is expected for any PP Forecast Point, the **Coastal Blocks** containing the relevant PPs are shown in this part. If a tsunami of this scale is not expected at any PP, the report says: "Estimate at Forecast

Points: no tsunami waves with an amplitude of 0.3 m or greater are expected at any Forecast Point." (Addition), (Revision) or (Cancellation) is specified as described below (Section 7.6) in subsequent information issued due to updates to earthquake parameters or observation of an unexpectedly significant tsunami.

3. Forecast amplitude and arrival time.

Tsunami amplitude and arrival time are estimated for each coastal PP. The estimated amplitudes (AMPL in meters) and arrival times **(hhmm DD MMM in Central American or Panama Local Time**) are listed with names **(FP1-1**, etc.) for each PP along with its latitude and longitude in coastal block groups.

Here, **amplitude is defined as the maximum distance between tsunami wave crests and undisturbed sea level**. It is estimated in categories of 0.3-1 m, 1-3 m, greater than 3 m, and is shown only for PPs expected to experience tsunamis with heights of 0.3 m or greater. If a tsunami of this scale is not expected in any PP, this part is not shown in the message.
If new FPs need to be added or the expected tsunami arrival time/amplitude needs to be changed in a revised problem due to updates of earthquake parameters or observation of an unexpectedly significant tsunami, (Addition) or (Revision) is specified in the relevant FPs line. For FPs that appeared in the previous A-CATAC message, but must be removed due to the revision, (Cancellation) is indicated in the revised publication.

3. Tsunami Watch Messages.

Tsunami wave information recorded at sea level stations with telemetry links to **CATAC** is provided as needed. The amplitude **(AMPL** in meters) of the largest wave to the nearest 0.1 m and the time of arrival (**hhmmZ DD MMM**) are listed along with the station name (STATION-1, etc.) and its latitude and longitude **(LL.L [N] [S] LLL.L [E] [W]**.
To minimize confusion among user countries/organizations, CATAC generally adopts the Maximum Tsunami Height values (measured with respect to the normal tide level) for PTWC products in correspondence with those of the maximum tsunami wave amplitude in CATAC products.

4. Qualitative expressions for giant earthquakes.

In the case of a giant earthquake (M greater than 8) near Central America, the qualitative terms "Giant", "Large" or "----" and the magnitude expression "MAG GREATER than 8" may be used in CATAC Advisories. Such expressions may be shown when A-CATAC the earthquake is so massive that it is impractical to estimate the appropriate magnitude value in the few minutes available until national tsunami warnings are issued. In such cases, the tsunami scale estimate is based on a predefined maximum possible magnitude.

Mw values can generally be determined within approximately 8 minutes of an earthquake in time for the initial A-CATAC broadcast. Otherwise, CATAC issues initial messages using qualitative expressions with a note specifying that the warning is based on predefined magnitude values.

ANNEX 2. CATAC Product Examples

Annex 2.1 First text product (when coastal tsunamis with heights of 0.3 m or more are expected)

CATAC - Tsunami Advisory Center for Central America
===

NOTICE : This message is issued for information purposes only in support of Central American countries. National authorities are responsible for determining the level of alert and for taking the appropriate measures for their country.

Tsunami Bulletin No. 01

Published 2019-08-19 10:03:00 Central American Time
2019-08-19 11:03:00 Panama Time

An earthquake has occurred with the following preliminary parameters:

Magnitude : 7.5
Date : 08/19/2019
Time : 10:00:00 Central American Time, 11:00:00:00 Panama Time
Latitude : 13.26 North
Longitude : 90.51 West
Depth : 20 Km
Location Near the Pacific coast of Guatemala

Evaluation:
There is a high possibility of tsunami considering the magnitude, depth of the hypocenter and location of the earthquake.

Recommended actions:
It is urgent to take immediate action for the protection of the population on the Pacific coasts of Guatemala and El Salvador.
More information will be provided in the next few minutes.
****

Annex 2.2 First text product (when coastal tsunamis with heights of 0.3 m or more are not expected)

CATAC - Tsunami Advisory Center for Central America
===
NOTICE : This message is issued for information purposes only in support of Central American countries. National authorities are responsible for determining the level of alert and for taking the appropriate measures for their country.

Tsunami Bulletin No. 01

Publicado2019-08-19 10:03:00 Central American Time
2019-08-19 11:03:00 Panama Time

An earthquake has occurred with the following preliminary parameters:

Magnitude : 6.3
Date : 08/19/2019
Time : 10:00:00 Central American Time, 11:00:00:00 Panama Time
Latitude : 13.26 North
Longitude : 90.51 West
Depth : 20 Km
Location : Near the Pacific coast of Guatemala.

Evaluation:
There is a high possibility of tsunami considering the magnitude, depth of the hypocenter and location of the earthquake.

Recommended actions:
According to its location and magnitude, this earthquake will not cause a tsunami with dangerous waves above 0.3 meters.
It is recommended to observe the behavior of the ocean in the areas near the epicenter.

More information will be provided in the next few minutes.
****

Annex 2.3 First text product (when depth is 100 km or more)

CATAC - Tsunami Advisory Center for Central America
==
NOTICE : This message is issued for information purposes only in support of Central American countries. National authorities are responsible for determining the level of alert and for taking the appropriate measures for their country.

Tsunami Bulletin No. 01

Publicado2019-08-19 10:03:00 Central American Time
2019-08-19 11:03:00 Panama Time

An earthquake has occurred with the following preliminary parameters:

Magnitude : 7.3
Date : 08/19/2019
Time : 10:00:00 Central American Time, 11:00:00:00 Panama Time
Latitude : 13.26 North
Longitude : 90.51 West
Depth : 110 Km
Location : Near the Pacific coast of Guatemala.

Evaluation:
There is no possibility of a tsunami considering the great depth of the hypocenter.

Recommended actions:
It is recommended to observe the behavior of the ocean in the areas near the epicenter.

More information will be provided in the next few minutes.
****

Annex 2.4 Second text product (with tsunami observations)

Tsunami Advisory Center for Central America - CATAC
==
NOTICE :

This message is issued for information purposes only in support of Central American countries. National authorities are responsible for determining the level of alert and taking appropriate action for their country.

Tsunami Bulletin No. 02

Published: 2019-08-19 10:05:00 Central American Time.
2019-08-19 11:05:00 Panama Time

A tsunami warning is in effect for the coastal areas of Central American countries.

An earthquake has occurred with the following parameters:

Magnitude : 7.5
Date : 2019-08-19
Time : 10:00:00 Central America, 11:00:00:00 Panama
Epicenter : 13.26 N 90.51 O
Depth : 20 Km
Location 68 Km southwest of Las Brisas, Guatemala

Evaluation:

Due to the magnitude, depth and location of the earthquake, there is a possibility that a tsunami may have been produced, which would affect the nearest coasts with greater intensity, about 100 kilometers from the epicenter of the earthquake.
Authorities should take actions corresponding to their response plans.

Tsunami simulation results:
Estimated Time of Arrival (ETA), in local time and Maximum Height (AM) of the tsunami at different forecast points:

Site	*Country*	*ETA*	*Threat(m)*
Santa Rosa	*Guatemala*	*2019-08-19 10:*	*310.93*
Jutiapa	*Guatemala*	*2019-08-19 10:371*	*.52*
Sonsonate	*El Salvador*	*2019-08-19 10:*	*390.84*
Achuapán	*El Salvador*	*2019-08-19 10:421*	*.77*
La Libertad	*El Salvador*	*2019-08-19 11:*	*110.84*

La Paz	*El Salvador*	*2019-08-19 11:*	*320.62*

Graphic result:
Please review the color-coded forecast zones for the Pacific Ocean coastal areas of Central America in the attachment to this message.

Upgrades:
More information will be provided in the next few minutes.

Countries may additionally receive messages from the Pacific Tsunami Warning Center (PTWC). In case of differences between CATAC and PTWC results, we recommend conservatively preferring the estimates that correspond to a higher hazard.

Additional information

Detailed information on the earthquake and tsunami can be found on the following web site www.catac.ineter.gob.ni
****

Annex 2.5 Third text product after correcting location and magnitude of the earthquake using CMT results

Tsunami Advisory Center for Central America - CATAC
===

NOTICE :
This message is issued for information purposes only in support of Central American countries. National authorities are responsible for determining the level of alert and taking the appropriate measures for each country.

Tsunami Bulletin No. 03

Published: 2019-08-19 10:09:00 Central American Time
2019-08-19 11:09:00 Panama Time

A tsunami warning is in effect for the Pacific coasts of Central American countries.

An earthquake has occurred with the following parameters:

Magnitude : 8.6
Date : 2019-08-19
Time : 10:01:00 Central America, 11:01:00 Panama
Centroid : 12.10 N 88.23 O
Depth : 20 Km
Centroid location : In front of the Gulf of Fonseca

Evaluation: The Centroid was determined, which represents the point of greatest release of seismic energy during the rupture that originates the earthquake.
Due to the magnitude, depth and location of the earthquake, there is a possibility that a tsunami may have been produced, which would affect the nearest coasts with greater intensity.
Severe effects are forecast for Guatemala, El Salvador, Honduras, Nicaragua and Costa Rica.
There are also dangers for the Pacific coast of Panama.
There is also the possibility of tsunamis/seiches in Lake Managua and Lake Nicaragua.

Authorities should take actions corresponding to their response plans.

Tsunami simulation results:

Estimated Time of Arrival (TOA) and Maximum Height (MA) of the tsunami at different forecast points:

Central America Time

ZONES	COUNTRY	ETA	AM(meters)
Escuintla	Guatemala	2019-08-19 10:28	greater than 3
Santa Rosa	Guatemala	2019-08-19 10:30	over 3
San Marcos	Guatemala	2019-08-19 10:36	greater than 3
Suchitepequez	Guatemala	2019-08-19 10:35	greater than 3
Champerico	Guatemala	2019-08-19 10:35	greater than 3
Jutiapa	Guatemala	2019-08-19 10:36	greater than 3
Retalhuleu	Guatemala	2019-08-19 10:36	greater than 3
Sonsonate	El Salvador	2019-08-19 10:36	greater than 3
Ahuachapan	El Salvador	2019-08-19 10:36	greater than 3
La Libertad	El Salvador	2019-08-19 10:44	greater than 3
San Vicente	El Salvador	2019-08-19 10:49	greater than 3
La Paz	El Salvador	2019-08-19 10:48	greater than 3
Rusulutlan	El Salvador	2019-08-19 10:53	greater than 3
San Miguel	El Salvador	2019-08-19 10:56	greater than 3

La Union	*El Salvador*	*2019-08-19 10:57*	*greater than 3*
Conchaguita	*El Salvador*	*2019-08-19 11:19*	*greater than 3*
Meanguera del Golfo	*El Salvador*	*2019-08-19 11:29*	*greater than 3*
Isla del Tigre	*Honduras*	*2019-08-19 11:29*	*greater than 3*
Choluteca	*Honduras*	*2019-08-19 11:46*	*greater than 3*
Managua	*Nicaragua*	*2019-08-19 10:40*	*greater than 3*
Carazo	*Nicaragua*	*2019-08-19 10:42*	*greater than 3*
Leon	*Nicaragua*	*2019-08-19 10:46*	*greater than 3*
Chinandega	*Nicaragua*	*2019-08-19 11:05*	*greater than 3*
Rivas	*Nicaragua*	*2019-08-19 11:06*	*greater than 3*
Farallones Cosiguina	*Nicaragua*	*2019-08-19 11:10*	*greater than 3*
Guanacaste	*Costa Rica*	*2019-08-19 10:34*	*greater than 3*
Puntarenas North	*Costa Rica*	*2019-08-19 10:23*	*greater than 3*
Puntarenas South	*Costa Rica*	*2019-08-19 15:31*	*greater than 3*
Tortuga Island	*Costa Rica*	*2019-08-19 10:41*	*1 a 3*
Cano Island	*Costa Rica*	*2019-08-19 10:39*	*1 a 3*
Cocos Island	*Costa Rica*	*2019-08-19 10:52*	*1 a 3*

Panama Time

Coiba Island	*Panama*	*2019-08-19 12:14*	*1 a 3*
Veraguas-Pacifico	*Panama*	*2019-08-19 12:24*	*1 a 3*
Darien	*Panama*	*2019-08-19 12:54*	*1 a 3*
Chiriqui	*Panamá*	*2019-08-19 16:33*	*greater than 3*
Los Santos	*Panama*	*2019-08-19 17:08*	*1 a 3*
King's Island	*Panama*	*2019-08-19 19:59*	*1 a 3*
Coclé	*Panamá*	*2019-08-19 20:25*	*1 a 3*
Tobaguilla Island	*Panama*	*2019-08-19 20:31*	*0.5 a 1*
Panama	*Panama*	*2019-08-19 20:33*	*1 a 3*
Herrera	*Panama*	*2019-08-19 21:27*	*1 a 3*

Graphical result: Check in the attached file to this message, the forecast zones.
color-coded according to hazard, for coastal areas
Pacific Ocean of Central America.

Updates: More information will be provided in the next few minutes.

PTWC messages: Countries may additionally receive messages from the Pacific Tsunami Warning Center (PTWC). In case of differences between CATAC and PTWC results, we recommend conservatively preferring the higher hazard estimates.

Additional information: Detailed information on the earthquake and tsunami can be found on the following web site

www.catac.ineter.gob.ni

****

ANNEX 3. Examples of CATAC graphic products

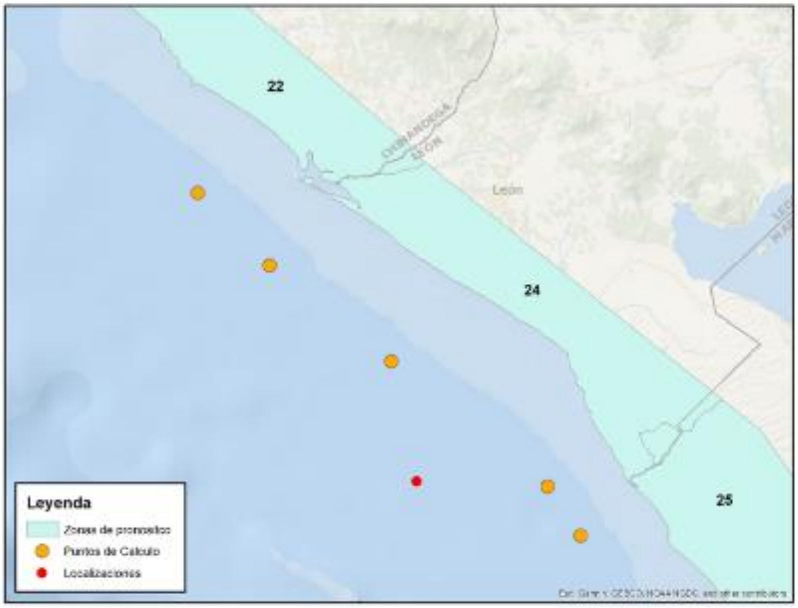


Figure 16. Coastal blocks and forecast points on the coast. Forecast points at 50 m depth. Definition of forecast zones at departmental level. Maximum values obtained for 70 forecast zones. For 130 forecast points on the Pacific and Caribbean coast.

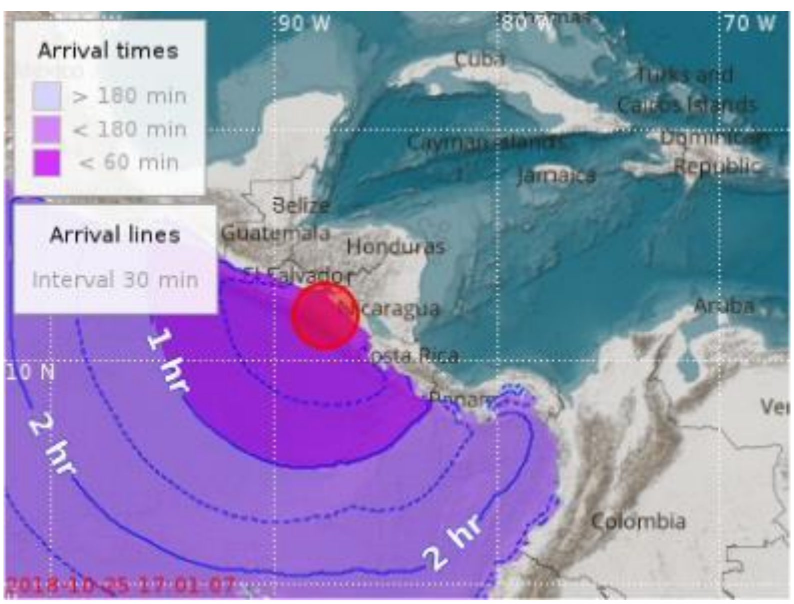


Figure 17. CATAC Tsunami arrival time forecast.

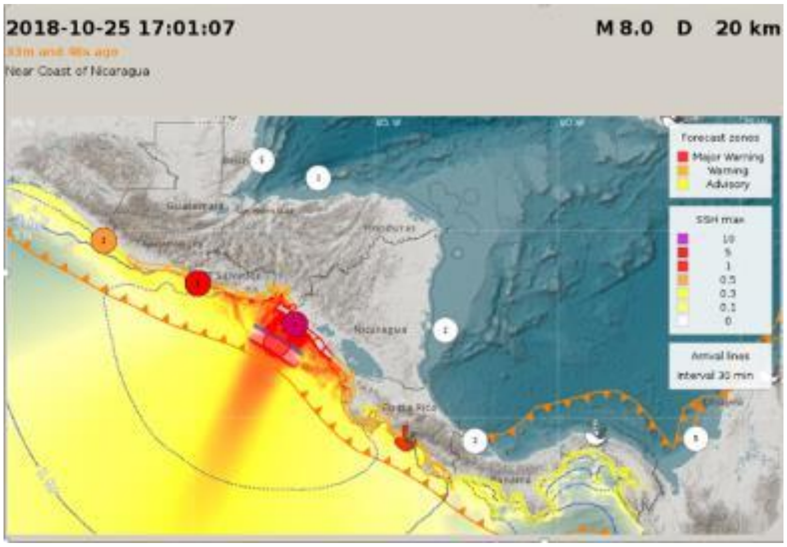


Figure 18. CATAC Tsunami coastal amplitude forecast.

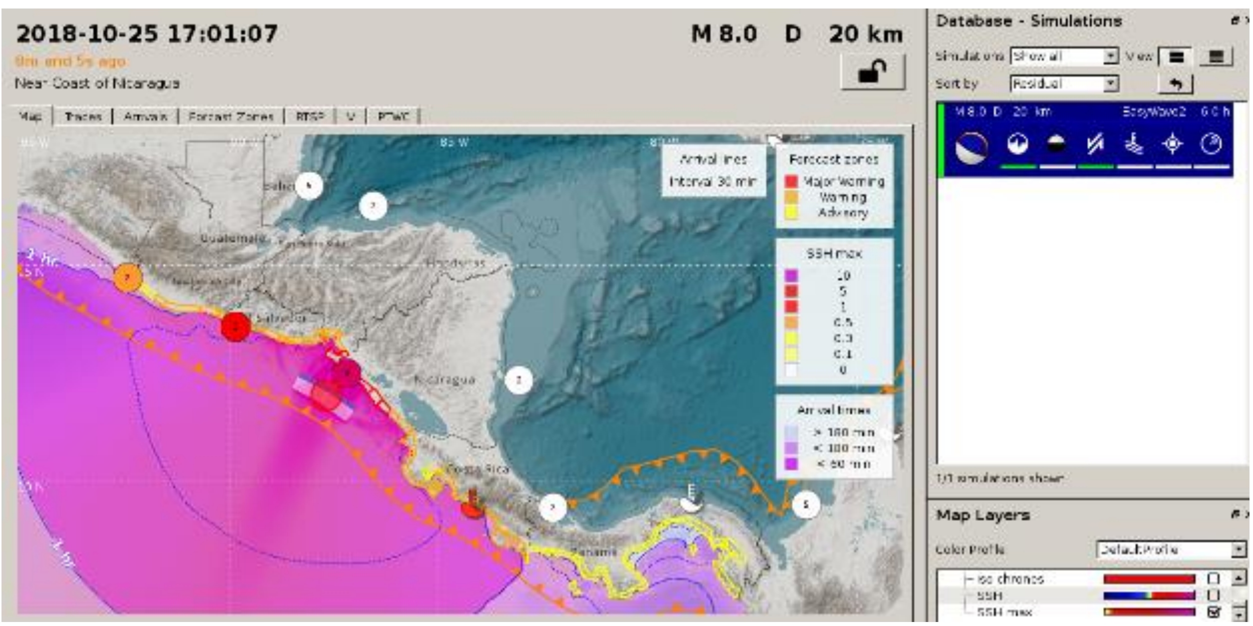


Figure 19. CATAC Deep-sea tsunami amplitude forecast.

ANNEX 4. Conducting Regional Tsunami Exercises

In the experimental phase, CATAC conducted two exercises for Central American countries:

1. Mega earthquake in the subduction zone between Guatemala, El Salvador and Nicaragua.

Date of exercise 1: 08/19/2019

Earthquake parameters:
Magnitude 8.6, with a complex source that would generate a maximum possible tsunami in Central America of more than 20 m in height.

The modeling was done with SeisComP TOAST, in "real time".

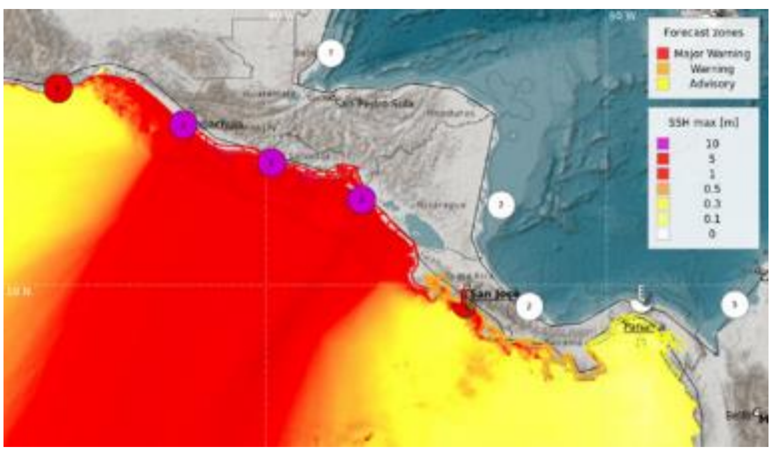


Figure 14. Tsunami map of exercise 1.

2 Slow earthquake of magnitude 7.6 off the Gulf of Fonseca

Exercise date 2: 11/11/2020
Earthquake parameters
M 7.6, slow earthquake and tsunami impacting El Salvador, Honduras and Nicaragua, Honduras, Nicaragua)
Modeling with SeisComP TOAST

This exercise was conducted under COVID-2019 conditions.

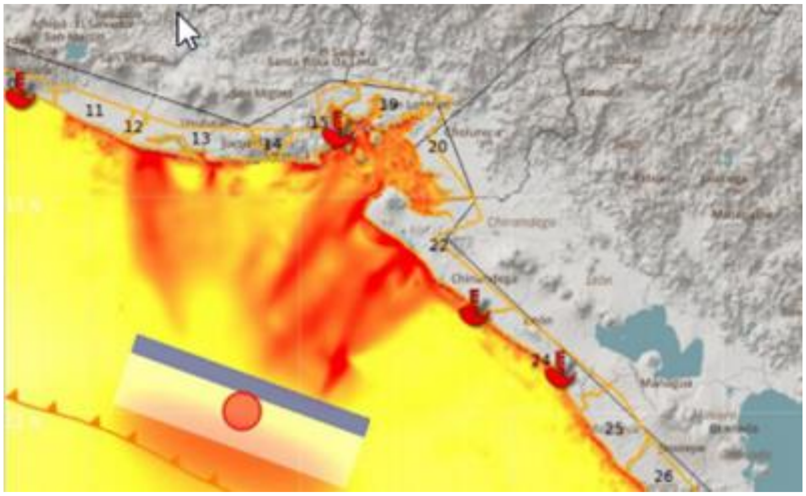


Figure 15. Tsunami map of exercise 2.

2 other scheduled exercises were not conducted due to COVID-2019 conditions.

ANNEX 5. NTWC and TWFP in Central America

NTWC o Institutions responsible for scientific monitoring

1) Nicaragua: INETER, CATAC/Dirección de Sismología

For Nicaragua, CATAC acts as NTWC issuing messages to the Government of Nicaragua, the Emergency Operations Center (CODE) of the National System for Disaster Prevention, Mitigation and Response (SINAPRED) and Civil Defense of the Nicaraguan Army according to the national SOPs of Nicaragua. From 2022 onwards, INETER will directly send Earthquake and Tsunami messages to the population.

2) El Salvador: Ministry of Environment and Natural Resources (MARN), General Directorate of the Environmental Observatory (MARN-DGOA).

(3) Guatemala: National Institute of Seismology, Volcanology, Meteorology and Hydrology (INSIVUMEH).

4) Honduras: Permanent Contingency Commission (COPECO). In Honduras there is no scientific institution with the capacity to evaluate the tsunami threat. COPECO maintains the seismic network of the country.

5) Costa Rica: Tsunami Monitoring Room of the National University (SINAMOT)

6) Panama: Institute of Geosciences of the University of Panama (IGC-UPA)

TWFP or Organizations in charge of issuing Tsunami Warnings to the population:

1) Nicaragua: National System for Disaster Prevention, Mitigation and Response (SINAPRED) / Nicaraguan Army Civil Defense.

It is intended that, as of 2022, INETER will directly send Earthquake and Tsunami messages to the population.

2) El Salvador: Ministry of the Interior, General Directorate of Civil Protection and Disaster Prevention and Mitigation (DGPC).

(3) Guatemala: National Coordinator for Disaster Reduction (CONRED)

4) Honduras: Permanent Contingency Commission (COPECO)

5) Costa Rica: National Commission for Risk Prevention and Emergency Attention (CNE).

6) Panama: National Civil Protection System (SINAPROC）.

Regional civil protection institution

1) CEPREDENAC; Center for Disaster Prevention in Central America

ANNEX 6. List of CATAC staff, November 2021

#	First and last name	24x7	Function / experience
1	Dr. Wilfried Strauch	-	Advisor INETER, CATAC Coordinator
2	MSc Emilio Talavera	X	Director Seismology/CATAC
3	Virginia Tenorio	-	Director of the Central Monitoring Center, seismology, tsunami, volcanic seismology, volcanic seismology
4	Miguel Flores	X	Computer science, digital systems, Seismology, Tsunami
5	Eng. Norwin Acosta	-	Tsunami Modeling, GIS
6	MSc Greyving Argüello	X	Seismology, Geophysics, Tsunami
7	MSc Amilcar Cabrera	X	Seismology, Mathematics, Tsunami
8	MSc Petronila Flores	X	Seismology, Geology, Tsunami,
9	MSc Martha Herrera	X	Seismology, Electronics, Tsunami, Digital Communication, Seismometry
10	MSc Domingo J. Ñamendi	X	Seismology, Electronics, Tsunami, Digital Communication, Seismometry
11	MSc Ulbert Grillo	X	Seismology, Tsunami, Electronics, Digital Communication, Seismometry
12	Fernando García	X	Seismology, Tsunami, Electronics, Digital Communication, Seismometry
13	Jaqueline Sanchez	X	Seismology, Tsunami, Computer Science
14	Juan Carlos Guzmán	X	Seismology, Tsunami, Computer Science
15	Tec. Allan Morales	X	Seismometry, Tsunami, Electronics
16	Tec. Antonio Acosta	X	Seismometry, Tsunami, Electronics
17	Ana Rodriguez	X	Seismology, Tsunami, GIS
18	Milton Espinoza	X	Seismology, Tsunami, GIS
19	Wesly Rodríguez	X	Geophysics, Seismology, Tsunami

X - serves as a 24x7 on-call seismologist
In addition: Consultant: Eng. Gerzon González (programming, IT)

ANNEX 7. Example of Test Message generated by TOAST in CATAC

Magnitude : 8.0 SR

Date : 10/25/2018

Time : 17:01:07 UTC

Latitude : 11.98 N

Length : 87.69 W

Depth : 20 Km

Event ID toast2018vamnlx M

Location : Near Coast of Nicaragua

Evaluation:

There is a Tsunami Possibility in the Following Areas:

T2 T1 T3 T4 Status Height

COUNTRY LOCATION

2018-10-25 17:46:37 2018-10-25 17:01:07 2018-10-25 17:54:07 2018-10-25 23:01:07 Tsunami 5.08m
NICARAGUA LEON

2018-10-25 17:47:37 2018-10-25 17:01:07 2018-10-25 21:44:37 2018-10-25 23:01:07 Tsunami 3.49m
NICARAGUA CARAZO

2018-10-25 17:50:37 2018-10-25 17:01:07 2018-10-25 20:28:37 2018-10-25 23:01:07 Tsunami 3.03m
NICARAGUA MANAGUA

2018-10-25 17:52:07 2018-10-25 17:01:07 2018-10-25 18:06:07 2018-10-25 23:01:07 Tsunami 3.03m
NICARAGUA CHINANDEGA

2018-10-25 17:55:07 2018-10-25 17:01:07 2018-10-25 20:05:07 2018-10-25 23:01:07 Tsunami 2.51m
NICARAGUA RIVAS

2018-10-25 18:55:07 2018-10-25 17:01:07 2018-10-25 22:53:07 2018-10-25 23:01:07 Tsunami 2.24m
HONDURAS TIGER ISLAND

2018-10-25 18:19:37 2018-10-25 17:01:07 2018-10-25 18:46:07 2018-10-25 23:01:07 Tsunami 2.13m
EL SALVADORCONCHAGUITA

2018-10-25 18:32:37 2018-10-25 17:01:07 2018-10-25 19:19:37 2018-10-25 23:01:07 Tsunami 2.11m
EL SALVADORLA UNION

2018-10-25 17:42:37 2018-10-25 17:20:29 2018-10-25 21:16:07 2018-10-25 23:01:07 Tsunami 2.08m
COSTA RICA GUANACASTE

2018-10-25 19:22:37 2018-10-25 17:08:23 2018-10-25 19:54:07 2018-10-25 23:01:07 Tsunami 2.01m
HONDURAS VALLEY

2018-10-25 18:04:07 2018-10-25 17:01:07 2018-10-25 19:53:37 2018-10-25 22:37:07 Tsunami 1.97m
EL SALVADORUSULUTLAN

2018-10-25 18:20:37 2018-10-25 17:01:07 2018-10-25 18:50:07 2018-10-25 22:45:37 Tsunami 1.95m EL SALVADORMEANGUERA DEL GOLFO

2018-10-25 17:53:37 2018-10-25 17:01:07 2018-10-25 21:43:37 2018-10-25 22:52:37 Tsunami 1.92m EL SALVADORSAN MIGUEL

2018-10-25 18:08:07 2018-10-25 17:04:07 2018-10-25 18:15:07 2018-10-25 22:57:37 Tsunami 1.90m EL SALVADORSAN VICENTE

2018-10-25 18:11:07 2018-10-25 17:12:35 2018-10-25 22:41:07 2018-10-25 23:01:07 Tsunami 1.90m EL SALVADORLA PAZ

2018-10-25 19:24:37 2018-10-25 17:01:07 2018-10-25 22:27:07 2018-10-25 23:01:07 Tsunami 1.87m HONDURAS CHOLUTECA

2018-10-25 18:34:07 2018-10-25 17:01:07 2018-10-25 18:39:37 2018-10-25 23:01:07 Tsunami 1.62m EL SALVADORISLA PUNTA ZACATE

2018-10-25 18:12:07 2018-10-25 17:01:07 2018-10-25 18:57:37 2018-10-25 22:54:07 Tsunami 1.48m NICARAGUA FARALLONES OF COSIGUINA

2018-10-25 18:00:37 2018-10-25 17:35:43 2018-10-25 22:08:37 2018-10-25 22:51:07 Tsunami 1.45m EL SALVADORLA LIBERTAD

2018-10-25 19:46:07 2018-10-25 17:48:29 2018-10-25 21:32:07 2018-10-25 23:01:07 Tsunami 1.25m GUATEMALA SANTA ROSA

2018-10-25 18:10:37 2018-10-25 17:59:35 2018-10-25 18:17:37 2018-10-25 22:48:37 Tsunami 1.16m GUATEMALA JUTIAPA

2018-10-25 18:11:37 2018-10-25 17:57:59 2018-10-25 18:15:07 2018-10-25 22:03:07 Tsunami 1.04m EL SALVADORAHUACHAPAN

2018-10-25 20:25:37 2018-10-25 18:13:05 2018-10-25 20:17:07 2018-10-25 23:01:07 Tsunami 1.03m GUATEMALA SUCHITEPEQUEZ

2018-10-25 18:00:07 2018-10-25 17:48:44 2018-10-25 22:46:37 2018-10-25 23:01:07 Tsunami 1.00m EL SALVADORSONSONATE

2018-10-25 18:20:07 2018-10-25 17:48:13 2018-10-25 22:56:37 2018-10-25 23:01:07 Tsunami 0.71m GUATEMALA ESCUINTLA

2018-10-25 18:12:37 2018-10-25 17:58:53 2018-10-25 18:43:37 2018-10-25 21:18:07 Tsunami 0.64m COSTA RICA COCOS ISLAND

2018-10-25 17:44:37 2018-10-25 17:35:17 2018-10-25 20:37:07 2018-10-25 23:01:07 Tsunami 0.64m COSTA RICA PUNTARENAS

2018-10-25 22:49:37 2018-10-25 18:15:35 2018-10-25 22:57:37 2018-10-25 22:54:37 Tsunami 0.58m GUATEMALA SAN MARCOS

2018-10-25 22:22:07 2018-10-25 17:47:29 2018-10-25 22:51:07 2018-10-25 23:01:07 Tsunami 0.56m COSTA RICA PUNTARENAS

2018-10-25 20:02:37 2018-10-25 17:49:13 2018-10-25 22:36:37 2018-10-25 23:01:07 Tsunami 0.54m COSTA RICA TURTLE ISLAND

ANNEX 8. List of Forecast Points

Costa Rica Abangaritos 10.1167 -85.0167 4
Costa Rica Agua Buena 8.4167 -83.3833 4
Costa Rica Agujas 9.7167 -84.6500 4
Costa Rica Ballena 9.1000 -83.7000 4
Costa Rica Bananito Sur 9.8667 -83.0000 4
Costa Rica Barmouth East 10.1167 -83.2333 4
Costa Rica Bonifacio 9.7833 -82.9167 4
Costa Rica Brasilito 10.4167 -85.7833 4
Costa Rica Brasilito 10.9833 -85.6833 4
Costa Rica Cabo Blanco 9.9333 -85.0000 4
Costa Rica Cabuya 9.6000 -85.0833 4
Costa Rica Cahuita 9.7333 -82.8500 4
Costa Rica Carrillo 9.8333 -85.3333 4
Costa Rica Catorce Millas 10.0833 -83.2000 4
Costa Rica Coco 10.5500 -85.7000 4
Costa Rica Colorado 10.1833 -85.1167 4
Costa Rica Colorado 10.7833 -83.6000 4
Costa Rica Comadre 9.7167 -82.8333 4
Costa Rica Conventillos 11.0833 -85.6833 4
Costa Rica Coronado 9.0500 -83.6167 4
Costa Rica Corozal 9.9833 -85.1667 4
Costa Rica Corralillo 9.8833 -84.7167 4
Costa Rica Culebre 10.6500 -85.6500 4
Costa Rica Curu 9.7833 -84.9333 4
Costa Rica Sunday 9.2500 -83.8667 4
Costa Rica El Tigre 10.7167 -85.6167 4
Costa Rica Esterillos East 9.5167 -84.5167 4
Costa Rica Garza 9.9000 -85.6500 4
Costa Rica Golfito 8.6333 -83.1667 4
Costa Rica Goschen 10.1667 -83.3167 4
Costa Rica Guerra 8.7667 -83.6167 4
Costa Rica Hacienda Santa Elena 10.9333 -85.8333 4
Costa Rica Hatillo 9.3000 -83.9000 4
Costa Rica Islita 9.8500 -85.4000 4
Costa Rica Jabilla 9.8167 -85.3000 4
Costa Rica Jaco 9.6167 -84.6333 4
Costa Rica La Abuela 9.7000 -85.0167 4
Costa Rica La Palma 8.6667 -83.4667 4
Costa Rica Las Mantas 9.7000 -84.6667 4
Costa Rica Lepanto 9.9333 -85.0333 4
Costa Rica Los Organos 9.8167 -84.9000 4
Costa Rica Madrigal 8.4500 -83.5167 4
Costa Rica Bad Country 9.6167 -85.1500 4
Costa Rica Manzanillo 9.7000 -85.2000 4
Costa Rica Marbella 10.0833 -85.7667 4
Costa Rica Matapalo 9.3333 -83.9667 4
Costa Rica Mexico 9.9833 -83.1333 4
Costa Rica Moin 10.0000 -83.0833 4
Costa Rica Montezuma 9.6500 -85.0667 4
Costa Rica Muneco 9.5500 -84.5500 4
Costa Rica Naranjo 9.9333 -84.9667 4
Costa Rica New Castle 9.9167 -83.0500 4
Costa Rica Nuevo Colon 10.5167 -85.7333 4
Costa Rica Palo Seco 8.6000 -83.4167 4
Costa Rica Paquera 9.8167 -84.9333 4
Costa Rica Paraiso 10.1833 -85.8000 4
Costa Rica Parismina 10.3000 -83.3500 4
Costa Rica Pigres 9.7833 -84.6333 4
Costa Rica Pital 9.7333 -84.6333 4
Costa Rica Pochotal 9.5833 -84.6167 4
Costa Rica Pochota 9.7500 -85.0000 4
Costa Rica Pochote 10.1500 -85.2833 4
Costa Rica Puerto Carazo 10.2167 -85.2500 4
Costa Rica Puerto Coyote 9.7833 -85.2667 4
Costa Rica Puerto Jimenez 8.5333 -83.3000 4
Costa Rica Puerto Limon 9.9833 -83.0333 3
Costa Rica Puerto Manzanillo 9.6333 -82.6500 4
Costa Rica Puerto Quepos 9.4167 -84.1500 4
Costa Rica Puerto Thiel 10.0333 -85.2000 4
Costa Rica Puerto Viejo 9.6333 -82.7500 4
Costa Rica Puerto Vlejo 10.3833 -85.8167 4
Costa Rica Punta Trinidad 10.0333 -85.7500 4
Costa Rica Puntarenas 9.9667 -84.8500 3
Costa Rica Quebrada Nando 9.7667 -85.2333 4
Costa Rica Quebrada Seca 9.8500 -85.3500 4
Costa Rica Quepos 9.4500 -84.1500 4
Costa Rica Refundores 10.3333 -85.8500 4
Costa Rica Rincon 8.6833 -83.4833 4
Costa Rica Rio Crande 9.6833 -85.0333 4
Costa Rica Rio Madre 10.0000 -83.1500 4
Costa Rica San Andres 9.8500 -82.9667 4
Costa Rica San Pedro 9.9667 -85.1500 4
Costa Rica San Rafael 10.2167 -83.3333 4
Costa Rica San Vicenta 9.7333 -85.0167 4
Costa Rica Santa Marta 9.9667 -85.6667 4
Costa Rica Santa Teresa 9.6500 -85.1833 4
Costa Rica Santiago 9.6667 -85.1833 4
Costa Rica Tarcoles 9.7667 -84.6167 4
Costa Rica Tigre 8.5500 -83.3667 4
Costa Rica Tuba Creek 9.7667 -82.9000 4
Costa Rica Uvita 9.1500 -83.7500 4
Costa Rica Venado 10.1667 -85.8167 4
Costa Rica Villalta 9.7333 -85.2000 4
Costa Rica Zancudo 8.5333 -83.1333 4
Costa Rica Zapotal 10.5000 -85.8000 4
Costa Rica Parismina 10.3156 -83.3515 0
Costa Rica Limon 9.9969 -83.0237 0
Costa Rica Puerto Viejo de Talamanca 9.6589 -82.7532 0
Costa Rica Manzanillo 9.6340 -82.6625 0
Guatemala Agua Caliente 15.6833 -88.5833 4
Guatemala Shipyard 13.8500 -90.3500 4
Guatemala Barra de la Gabina 13.7667 -90.1833 4
Guatemala Barra del Jiote 13.7833 -90.2167 4
Guatemala Barra Madre Vieja 14.0167 -91.4333 4
Guatemala Cabeza de Vaca 15.8833 -88.9500 4
Guatemala Cambalache 15.9167 -88.5667 4
Guatemala Champerico 14.2833 -91.9167 3
Guatemala Chapeton 13.8333 -90.3333 4
Guatemala Chicago 14.0833 -91.6000 4
Guatemala Churirin 14.1167 -91.6667 4
Guatemala El Arrenal 13.9167 -90.5833 4
Guatemala El Carrizal 13.9167 -90.9667 4
Guatemala El China 14.4167 -92.0500 4
Guatemala El Gariton 13.9167 -90.6000 4
Guatemala El Pumpo 13.9000 -90.5000 4
Guatemala El Semillero Barra Nahual. 14.0500 -91.5167 4
Guatemala Estero Lagarto 15.9333 -88.6000 4
Guatemala Hawaii 13.8667 -90.4000 4
Guatemala La Barrita 13.9167 -90.9167 4
Guatemala La Barrita 13.7667 -90.1667 4
Guatemala La Graciosa 15.8667 -88.5333 4
Guatemala La Isla 13.9167 -90.5167 4
Guatemala La Muerte 13.8500 -90.3667 4
Guatemala La Pimienta 15.8333 -88.4667 4
Guatemala La Romana 15.7167 -88.6000 4
Guatemala La Verde 14.1833 -91.7500 4
Guatemala Las Escobas 15.6833 -88.6333 4
Guatemala Las Lagunas 13.9833 -91.3500 4
Guatemala Las Lisas 13.8000 -90.2667 4
Guatemala Las Quechas 13.9000 -90.5167 4
Guatemala Livingston 15.8167 -88.7500 4
Guatemala Machacas 15.7667 -88.5333 4
Guatemala Macho Creek 15.7667 -88.7167 4
Guatemala Mangrove 15.8833 -88.5000 4
Guatemala Nueva Venecia 14.0500 -91.5333 4
Guatemala Papaturro 13.9333 -90.6000 4
Guatemala Pato Creek 15.9167 -88.6000 4
Guatemala Pioquinto 15.7833 -88.5667 4
Guatemala Puerto Barrios 15.7167 -88.6000 3
Guatemala Puerto San Jose 13.9333 -90.8333 4
Guatemala Puerto Viejo 13.9333 -90.7000 4
Guatemala Punta del Cabo 15.9500 -88.5667 4
Guatemala Punta Herreria 15.8167 -88.7333 4
Guatemala Quehueche 15.8500 -88.7833 4
Guatemala Rio Blanco 15.8167 -88.7667 4
Guatemala Rio Salado 15.8000 -88.7167 4
Guatemala Rio San Carlos 15.7333 -88.6833 4
Guatemala San Francisco Madre Vieja 14.0333 -91.4500 4
Guatemala San Francisco del Mar 15.8333 -88.4167 4
Guatemala San Jose Buena Vista 13.8167 -90.3167 4
Guatemala San Jose Rama Blanca 13.9333 -91.2333 4
Guatemala San Juan 15.8500 -88.8833 4
Guatemala San Manuel 15.7000 -88.5833 4
Guatemala San Pedro 13.8167 -90.2833 4
Guatemala Santa Maria 15.7833 -88.6833 4
Guatemala Santa Rose 13.9333 -90.8000 4
Guatemala Sarstun 15.8833 -88.9167 4
Guatemala Sipacate 13.9333 -91.1500 4
Guatemala Tahuexco 14.1000 -91.6167 4
Guatemala Tecojate 13.9667 -91.3500 4
Guatemala Tulate 14.1500 -91.7000 4
Guatemala Livingston 15.7453 -88.6172 0
Guatemala Puerto Barrios 15.7453 -88.6172 0
Guatemala Punta de Manabique 15.7453 -88.6172 0
Honduras Agua Dulce 15.7833 -86.6333 4
Honduras Alligator Nose 16.4333 -86.2833 4
Honduras Amalapa 13.2667 -87.6500 4
Honduras Amapala 15.8500 -85.5500 4
Honduras Auaspani 15.2333 -84.8667 4
Honduras Auasta 15.2667 -84.8167 4
Honduras Aurata 15.4000 -84.1500 4
Honduras Awijiaratora 15.2500 -84.6000 4
Honduras Baja Mar 15.8833 -87.8500 4
Honduras Balfate 15.7667 -86.3833 4
Honduras Banda del Norte 16.0167 -85.9333 4
Honduras Barra 15.3833 -83.7167 4
Honduras Barra de Aguan 15.9667 -85.7500 4
Honduras Barra del Cruta 15.2333 -83.4167 4
Honduras Barra del Motagua 15.7000 -88.2333 4
Honduras Barra Patuca 15.8000 -84.2833 4
Honduras Barra Ulua 15.9167 -87.7167 4
Honduras Boca Cerrada 15.7667 -87.2000 4

Honduras Boca del Toro 15.7500 -87.0500 4
Honduras Bruner 15.9500 -84.9500 4
Honduras Bruner 15.9333 -84.9000 4
Honduras Burgoc 15.7500 -86.9667 4
Honduras Cabo de Homos 15.7667 -86.8167 4
Honduras Casautara 15.0333 -83.2167 4
Honduras Cauquira 15.3167 -83.5833 4
Honduras Cayos Arriba 16.4833 -85.8667 4
Honduras Cedeno 13.1667 -87.4333 4
Honduras Chachaguala 15.7167 -88.1000 4
Honduras Close 15.6167 -84.0833 4
Honduras Clubquimuna 15.0333 -83.2667 4
Honduras Cocal Tusi 15.8333 -84.5500 4
Honduras Cocobila 15.9000 -84.8000 4
Honduras Colorado 15.8167 -87.3000 4
Honduras Leather 15.7500 -87.1167 4
Honduras Dapat 15.3333 -83.6167 4
Honduras Diamond Rock 16.4167 -86.3000 4
Honduras Dixon's Cove 16.3500 -86.5000 4
Honduras El Benk 15.1000 -83.3167 4
Honduras El Cacao 15.7833 -86.5333 4
Honduras El Naranjo 13.3833 -87.7333 4
Honduras El Ojochalito 13.1333 -87.3667 4
Honduras El Paraiso 15.7500 -87.6500 4
Honduras El Peru 15.7833 -86.7500 4
Honduras El Porvenir 15.8333 -87.9333 4
Honduras El Saldado 16.4833 -85.9167 4
Honduras El Triunfo de la Cruz 15.7667 -87.4333 4
Honduras El Zapone 15.8000 -86.5500 4
Honduras El Zapone 15.8667 -86.9000 4
Honduras First Bight 16.3833 -86.4000 4
Honduras Flowers Bay 16.2833 -86.6167 4
Honduras Gallinero 13.3167 -87.7500 4
Honduras Guanaja 16.4500 -85.8833 4
Honduras Guasita 15.5333 -83.5333 4
Honduras Guipo 13.1167 -87.4000 4
Honduras Huarta 15.8500 -84.6167 4
Honduras Iriona 15.8833 -85.2167 4
Honduras Ivas 15.8500 -84.8500 4
Honduras Jonesville 16.4000 -86.3667 4
Honduras Kanko 15.2000 -83.3667 4
Honduras Karasunta 15.1000 -83.3167 4
Honduras Kaski 15.3667 -83.6833 4
Honduras Kiaskira 15.3500 -83.7167 4
Honduras Kokota 15.2833 -84.8500 4
Honduras La Auencia 15.7333 -86.8833 4
Honduras La Ceiba 15.7833 -86.8000 3
Honduras La Laguna 15.9500 -85.9167 4
Honduras La Laguna 16.4667 -85.9167 4
Honduras La Negra 13.3667 -87.6000 4
Honduras La Virgen 15.2833 -83.5000 4
Honduras Landa 15.8667 -85.5833 4
Honduras Las Palmas 13.4500 -87.5833 4
Honduras Liano Largo 13.3833 -87.7500 4
Honduras Limon 15.8500 -85.4667 4
Honduras Masca 15.6667 -88.1333 4
Honduras Middgeton 16.4000 -86.4333 4
Honduras Miranda 15.8333 -86.2333 4
Honduras Mokobila 15.8167 -84.4333 4
Honduras Mud Hole 16.3333 -86.5667 4
Honduras Nakunta 15.2000 -84.7833 4
Honduras Nuevo Armenia 15.8000 -86.5167 4
Honduras Oak Ridge 16.4000 -86.3500 4
Honduras Omoa 15.7667 -88.0333 4
Honduras Pakwi 15.1333 -83.3500 4
Honduras Palkaka 15.3167 -84.8667 4
Honduras Palmerson Point 16.4000 -86.4500 4
Honduras Palmira 15.7333 -86.9000 4
Honduras Unemployment 15.9000 -84.8167 4
Honduras Pital 15.9000 -86.0333 4
Honduras Prumnitara 15.3333 -83.6667 4
Honduras Pueblo Nuevo 15.9667 -84.9833 4
Honduras Puerto Castilla 16.0167 -86.0333 4
Honduras Puerto Cortes 15.8500 -87.9500 3
Honduras Puerto Lempira 15.2500 -84.7833 3
Honduras Pulpito 16.4167 -86.2333 4
Honduras Punta Blanca 16.4333 -86.3500 4
Honduras Pusuaya 15.4333 -83.8500 4
Honduras Quiancan 15.3000 -83.5667 4
Honduras Quienquita 15.7500 -86.9167 4
Honduras Ras 15.8667 -84.7000 4
Honduras Ratlaya 15.5333 -83.9833 4
Honduras Raya 15.0667 -83.3000 4
Honduras Roatan 16.3333 -86.5167 3
Honduras Salado Barra 15.7500 -87.0333 4
Honduras Salatu 15.7667 -86.4500 4
Honduras San Juan 15.7333 -87.5000 4
Honduras San Lorenzo 13.4165 -87.4500 4
Honduras San Luis 15.0000 -83.2167 4
Honduras Sandy Bay 16.3500 -86.5833 4
Honduras Santa Rosa de Aguan 15.9500 -85.7167 4
Honduras Tauwanta 15.3000 -84.8500 4
Honduras Tela 15.7667 -87.4667 3
Honduras Titi 15.0833 -83.3167 4
Honduras Tocamacho 15.9833 -85.0167 4
Honduras Tomabe 15.7500 -87.5500 4
Honduras Travesia 15.8667 -87.9000 4
Honduras Trujillo 15.9167 -85.9667 3
Honduras Tusidaksa 15.1167 -83.3333 4
Honduras Twimawala 15.2833 -83.4833 4
Honduras Uhibila 15.4833 -83.9167 4
Honduras Usibila 15.2167 -83.3667 4
Honduras Venus 15.7833 -86.5167 4
Honduras Veracruz 15.6833 -88.1167 4
Honduras Vienna 15.9333 -85.8500 4
Honduras Vuelta Grande 15.9500 -85.7667 4
Honduras Walpatara 15.2167 -83.4000 4
Honduras West End 16.3000 -86.6137 4
Honduras Yahurabila 15.4000 -83.8000 4
Honduras Yamanta 15.2667 -83.4333 4
Honduras Zacate 15.7500 -86.9833 4
Honduras Omoa 15.7814 -88.0511 0
Honduras Puerto Cortez 15.8232 -87.9403 0
Honduras Tela 15.7841 -87.4807 0
Honduras El Triunfo de La Cruz 15.7841 -87.4807 0
Honduras La Ceiba 15.7841 -87.4807 0
Honduras Utila Island/Pumpkin Hill 16.1229 -86.8825 0
Honduras Utila/Utila Island 16.0968 -86.8968 0
Honduras Roatan Island/West Bay 16.2767 -86.6003 0
Honduras Roatan/Roatan Island 16.2767 -86.6003 0
Honduras Roatan Island/Sandy Bay 16.3317 -86.5673 0
Honduras Roatan Island/Punta Gorda 16.4164 -86.3658 0
Honduras Roatan/Oakridge Island 16.3900 -86.3533 0
Honduras Roatan Island/Camp Bay Beach 16.4293 -86.2907 0
Honduras Roatan Island/Barbareta Island 16.4303 -86.1425 0
Honduras Guanaja Island/Jim Bodden 16.4532 -85.9162 0
Honduras Guanaja Island/Airport 16.4532 -85.9162 0
Honduras Bonacca Island 16.4420 -85.8857 0
Honduras Guanaja Island/ Mangrove B. 16.5008 -85.8685 0
Honduras Guanaja Island/ Savannah B. 16.4841 -85.8444 0
Honduras Swan Island 17.4014 -83.9436 0
Honduras Cayos Cochino Grande 15.9702 -86.4718 0
Honduras Trujillo 15.9349 -85.9652 0
Honduras Limón 15.8675 -85.5006 0
Honduras Punta Piedra 15.8891 -85.2406 0
Honduras Iriona 15.8891 -85.2406 0
Honduras Lempira(Kaski) 15.3796 -83.6849 0
Nicaragua Amerisco 11.1833 -83.8667 0
Nicaragua Aposentillo 12.6333 -87.3667 0
Nicaragua Ariswatla 13.4000 -83.5833 0
Nicaragua Auastara 14.3833 -83.2333 0
Nicaragua Banco Brown Abajo 12.4500 -83.7333 0
Nicaragua Barra de Wawa 13.8833 -83.4667 0
Nicaragua Barra del Rio 11.2833 -83.8833 0
Nicaragua Bismuna Tara 14.7500 -83.4167 0
Nicaragua Bluefields 12.0167 -83.7667 0
Nicaragua Bluefields 12.0400 -83.7700 0
Nicaragua Brito 11.3500 -85.9667 0
Nicaragua Cabo Gracias a dios 14.9833 -83.1667 0
Nicaragua Cayos Misquitos 14.3665 -82.7433 0
Nicaragua Cano Mocho 12.1167 -83.8167 0
Nicaragua Casares 11.6500 -86.3500 0
Nicaragua Corinto 12.4833 -87.1833 0
Nicaragua Corn Island 12.1766 -83.0317 0
Nicaragua Little Corn Island 12.2898 -82.9759 0
Nicaragua Dakura 14.4000 -83.2167 0
Nicaragua El Carmen 12.3500 -86.9667 0
Nicaragua El Chaparral 12.2833 -86.8833 0
Nicaragua El Corali 12.0167 -83.8167 0
Nicaragua El Naranjo 11.0833 -85.7167 0
Nicaragua El Ostional 11.1000 -85.7667 0
Nicaragua El Porvenir 14.9833 -83.2000 0
Nicaragua El Realejo 12.5333 -87.2000 0
Nicaragua El Soccoro 11.2167 -85.8167 0
Nicaragua El Transito 12.0500 -86.7000 0
Nicaragua Escameca 11.1667 -85.8000 0
Nicaragua Fatima 12.5667 -87.2333 0
Nicaragua Greystown 14.4500 -83.2833 0
Nicaragua Haulover 13.7000 -83.5167 0
Nicaragua Haulover 12.3167 -83.6667 0
Nicaragua Jiquilillo 12.7333 -87.4333 0
Nicaragua Kakabila 12.4000 -83.7333 0
Nicaragua Karawala 12.8833 -83.5833 0
Nicaragua Krukira 14.1667 -83.3167 0
Nicaragua Kuanwalta 13.3167 -83.6000 0
Nicaragua Kukra Hill 12.1333 -83.7000 0
Nicaragua La Aldina 11.4667 -86.1167 0
Nicaragua La Barra 12.9000 -83.5333 0
Nicaragua La Fe 12.4667 -83.7500 0
Nicaragua La Flor 11.1333 -85.7833 0
Nicaragua Pearl Lagoon 12.3333 -83.6833 0
Nicaragua Lamlaya 14.0167 -83.4167 0
Nicaragua Li-Dakira 14.4667 -83.2667 0
Nicaragua Linda Vista 12.4500 -87.1667 0
Nicaragua Maderas Negras 12.5833 -87.2833 0
Nicaragua Masachapa 11.7833 -86.5167 0

Nicaragua Mokey Point 11.6000 -83.6667 0
Nicaragua Nandairne 11.2667 -85.8667 0
Nicaragua Ninayeri 14.4667 -83.2833 0
Nicaragua Orinoco 12.5500 -83.7167 0
Nicaragua Pahara 14.3833 -83.3000 0
Nicaragua Paredones 12.5500 -87.2333 0
Nicaragua Playa Grande 12.2167 -86.7333 0
Nicaragua Petacaltepe 12.7000 -87.3833 0
Nicaragua Pochomil 11.7667 -86.5000 0
Nicaragua Potosi 13.0167 -87.5333 0
Nicaragua Prinzapolka 13.3167 -83.6167 0
Nicaragua Puerto Arturo 12.8500 -87.5000 0
Nicaragua Puerto Cabezas 14.0333 -83.3833 0
Nicaragua Puerto Cabezas 14.0800 -83.3800 0
Nicaragua Puerto Isabel 13.3667 -83.5667 0
Nicaragua Punta Gorda 11.4667 -83.8833 0
Nicaragua Punta Marshall 12.5667 -83.7000 0
Nicaragua Salinas Grandes 12.2500 -86.8500 0
Nicaragua San Antonio 12.0667 -83.8833 0
Nicaragua San Juan de Nicaragua 10.9167 -83.7167 0
Nicaragua San Juan del Sur 11.2500 -85.8667 0
Nicaragua San Luis 11.8833 -86.5833 0
Nicaragua San Miguel 12.5833 -87.2667 0
Nicaragua Sandy Bay Sirpi 12.9667 -83.5333 0
Nicaragua Santa Emilia 11.4500 -86.0667 0
Nicaragua Set Net 12.4333 -83.5000 0
Nicaragua Tasbapauni 12.6833 -83.5500 0
Nicaragua Tawantara 13.3833 -83.5667 0
Nicaragua Tuapi 14.1000 -83.3333 0
Nicaragua Tupilapa 11.6167 -86.3333 0
Nicaragua Waingka Laya 14.4500 -83.3167 0
Nicaragua Walpa 12.9333 -83.5333 0
Nicaragua Walpasiksa 13.4667 -83.5500 0
Nicaragua Wankluma 13.2167 -83.5833 0
Nicaragua Wounta 13.5500 -83.5500 4
Nicaragua Uskira 14.4833 -83.2833 0
Panama Aguadilla 7.4500 -78.1167 4
Panama Alligator Creek 8.8333 -81.5667 4
Panama Almirante 9.2833 -82.4000 4
Panama Anachukuna 8.7000 -77.5500 4
Panama Ancon 8.7833 -79.5500 4
Panama Armila 8.6667 -77.4667 4
Panama Bahia Azul 9.1667 -81.9000 4
Panama Bajo del Pueblo 8.4333 -80.0333 4
Panama Bajo Grande 8.3833 -78.1500 4
Panama Balboa 8.9333 -79.5500 4
Panama Batipa 8.3167 -82.2500 4
Panama Belen 8.8667 -80.8667 4
Panama Bella Vista 9.2167 -82.3000 4
Panama Berlanga 8.6833 -79.7833 4
Panama Big Creek 9.3667 -82.2500 4
Panama Bique 8.9000 -79.6667 4
Panama Boca de Daria 8.9500 -82.0167 4
Panama Boca de Parita 8.0167 -80.4500 4
Panama Boca del Drango 9.4167 -82.3167 4
Panama Bocas del Toro 9.3333 -82.2500 3
Panama Boquita 8.2833 -82.3333 4
Panama Brujas 8.5667 -78.5167 4
Panama Buena Vista 9.2000 -82.1333 4
Panama Buena Vista 8.3833 -78.2333 4
Panama Buenaventura 9.5333 -79.6667 4
Panama Cacique 9.6000 -79.6167 4
Panama Calabacito 7.5500 -81.2167 4
Panama Can Can 9.5167 -79.6833 4
Panama Cana Blanca 8.1500 -82.9000 4
Panama Cana Brava 7.7167 -81.1167 4
Panama Cana Chiriquicito 8.9833 -82.1500 4
Panama Cangrejal 8.3167 -82.2000 4
Panama Carreto 8.7833 -77.5833 4
Panama Carrizales 8.3167 -82.6333 4
Panama Cascajal 8.6667 -77.4000 4
Panama Cativa 9.3500 -79.8500 4
Panama Cayo de Coco 9.2833 -82.2667 4
Panama Chepillo 8.3833 -78.8500 4
Panama Chiman 8.7000 -78.6167 4
Panama Chiriqui Grande 8.9500 -82.1333 4
Panama Cilico Creek 9.0667 -82.2833 4
Panama Chuchecal 8.2167 -82.1667 4
Panama Cocalito 7.3167 -77.9833 4
Panama Colon 9.3667 -79.9000 4
Panama Concholon 8.2333 -78.9167 4
Panama Corocita 7.7333 -81.4833 4
Panama Cruces 8.7167 -79.7500 4
Panama Cusapin 9.1667 -81.8833 4
Panama Don Bernardo 8.4000 -79.0833 4
Panama El Atrocho 8.1000 -82.8833 4
Panama El Barquito 8.3000 -78.9500 4
Panama El Cano 8.9333 -81.9833 4
Panama El Cedro 8.2333 -82.2333 4
Panama El Chacarero 8.1333 -81.7167 4
Panama El Charco 8.9667 -79.0167 4
Panama El Chumico 7.4333 -80.1000 4
Panama El Coco 7.7833 -81.2167 4
Panama El Espino 8.4000 -80.1000 4
Panama El Nance 8.5167 -79.9333 4
Panama El Peru 8.1000 -81.6833 4
Panama El Porvenir 9.5500 -78.9833 4
Panama El Rompio 7.9667 -80.3500 4
Panama El Salto 7.4333 -80.9000 4
Panama El Tapao 9.1000 -82.2833 4
Panama El Torno 8.0000 -81.6000 4
Panama El Trapiche 7.4833 -81.7333 4
Panama El Suspiro 8.3500 -78.9500 4
Panama El Viejito 9.1500 -80.2500 4
Panama Finca Pino 8.3333 -82.7667 4
Panama Finca Sesenta y Uno 9.4500 -82.4833 4
Panama Finca Uno 9.4667 -82.5000 4
Panama Fish Creek 9.0167 -82.2667 4
Panama Fuerte Kobbe 8.9167 -79.5833 4
Panama Garachine 8.0667 -78.3667 4
Panama Garza 9.1167 -82.3000 4
Panama Gonzalo Vasquez 8.4167 -78.4500 4
Panama Goyo Diaz 8.7000 -78.6000 4
Panama Guacalito 8.2333 -82.2000 4
Panama Guanabano 8.2500 -82.9000 4
Panama Guera 8.6000 -78.5167 4
Panama Hope Well 9.1833 -82.2333 4
Panama Icacal 9.2000 -80.1500 4
Panama Grande Island 9.6333 -79.5667 4
Panama Mamey Island 8.4333 -78.8667 4
Panama Tiger Island 9.4333 -78.5500 4
Panama Jaque 7.5167 -78.1667 4
Panama Jim Creek 9.3000 -82.1167 4
Panama Juan Franco 8.9833 -79.5167 4
Panama Jutica 9.3333 -82.1667 4
Panama Kuba 8.9167 -77.7167 4
Panama La Albina 8.3333 -80.1833 4
Panama La Arena 7.9167 -81.5833 4
Panama La Barqueta 8.3000 -82.5667 4
Panama La Boca de Chame 8.6000 -79.7667 4
Panama La Boca de Rio Viejo 9.4167 -79.8000 4
Panama La Calzada 7.8333 -80.3167 4
Panama La Candelaria 7.7333 -80.1500 4
Panama La Carretera 9.3667 -82.2667 4
Panama La Catina 8.3833 -78.3833 4
Panama La Chumicosa 8.4333 -80.0167 4
Panama La Concepcion 7.6667 -80.1000 4
Panama La Concepcion 9.5667 -79.0667 4
Panama La Corocita 7.7333 -81.1333 4
Panama La Esmeralda 8.2667 -78.9333 4
Panama La Estancia 7.9500 -81.5833 4
Panama La Garita 7.5167 -80.0000 4
Panama La Isleta de Esteban 8.6833 -78.6167 4
Panama La Josefa 8.3667 -78.3833 4
Panama La Miel 7.4333 -80.0833 4
Panama La Miel 8.6667 -77.3833 4
Panama La Mina 8.4833 -79.0000 4
Panama La Palma 8.4000 -78.1500 4
Panama La Paz 8.4000 -78.3667 4
Panama La Playa 8.1667 -81.8333 4
Panama La Playa 7.4333 -80.8333 4
Panama La Quebrada 8.4833 -78.1667 4
Panama La Seca 7.3333 -80.8833 4
Panama Lagarto 7.4667 -78.1500 4
Panama Lagua 8.3667 -78.1667 4
Panama Las Cucharitas 7.8000 -80.2333 4
Panama Lima 9.6167 -79.5667 4
Panama Limoncito 7.3833 -80.4000 4
Panama Limones 7.6167 -80.9500 4
Panama Loma Mojica 8.8500 -79.7667 4
Panama Loma Partida 9.1500 -82.1833 4
Panama Los Alpes 9.3500 -82.2667 4
Panama Los Chiricanos 8.9667 -82.2167 4
Panama Los Guabitos 7.8167 -81.0167 4
Panama Los Hatillos 8.8000 -79.7833 4
Panama Los Llanos 8.5167 -79.9500 4
Panama Los Ranchitos 7.3000 -80.8833 4
Panama Macca Bite 9.2500 -82.1500 4
Panama Maguegandi 9.3500 -78.4167 4
Panama Majagual 8.3167 -82.7667 4
Panama Maje 8.6667 -78.5833 4
Panama Mamey 7.7667 -81.4833 4
Panama Mamey 8.4000 -78.9667 4
Panama Mamimulo 8.9833 -77.7833 4
Panama Mamitupo 9.1833 -77.9833 4
Panama Man Creek 8.9167 -82.0667 4
Panama Mandinga 9.4500 -79.0667 4
Panama Mansukum 9.0333 -77.8167 4
Panama Maranon 8.2833 -82.1667 4
Panama Maria Chiquita 9.4500 -79.7500 4
Panama Maria Grande 9.4500 -79.7667 4
Panama Mariabe 7.5833 -80.0667 4
Panama March 8.3667 -78.8500 4
Panama Mateo 7.4833 -80.0167 4
Panama Medina del Este 8.4000 -78.8667 4
Panama Mellicite 8.1667 -82.9000 4
Panama Miguel de la Borda 9.1500 -80.3167 4
Panama Mimitimbi Bluff 9.4333 -82.2833 4
Panama Miramar 9.0000 -82.2500 4
Panama Mogocenega 8.3167 -78.1667 4
Panama Muturi 9.1167 -81.9167 4
Panama Navagandi 9.0167 -77.8000 4
Panama New Guinea 9.3167 -82.1667 4
Panama No Tolente 8.9333 -81.9000 4
Panama Nuevo Chagres 9.2333 -80.0833 4
Panama Nuri 8.9167 -81.8167 4
Panama Otoque Oriente 8.6000 -79.6000 4
Panama Paja Verde 8.3167 -80.4000 4
Panama Pajonal 8.6167 -79.8667 4
Panama Palenque 9.5833 -79.3667 4
Panama Palo Grande 8.8667 -79.2167 4
Panama Panama 8.9700 -79.5300 0
Panama Patino 8.2500 -78.2833 4

Panama Paunch 9.3833 -82.2500 4
Panama Pedasi 7.5333 -80.0333 4
Panama Pena Blanca 8.8967 -79.7833 4
Panama Perrecenega 8.3500 -78.1667 4
Panama Pigeon Creek 9.2500 -82.2667 4
Panama Pilon 9.1833 -80.2000 4
Panama Piloncito 9.1833 -80.2167 4
Panama Pito 8.6833 -77.5333 4
Panama Pitshis Creek 9.1833 -82.3333 4
Panama Pixvae 7.8333 -81.5833 4
Panama Playa Bugori 9.1167 -81.9000 4
Panama Playa Colorada 9.0500 -81.7667 4
Panama Playa Colorada 8.6667 -78.6167 4
Panama Playa Floral 8.4167 -78.9667 4
Panama Playa Gallinaza 9.1333 -81.9167 4
Panama Playa Mananti 8.9500 -82.0000 4
Panama Playon Chico 9.3000 -78.2333 4
Panama Portobelo 9.5500 -79.6500 4
Panama Porvenir 9.3500 -82.2333 4
Panama Pueblo Viejo 9.1833 -80.1833 4
Panama Puerto Armuelles 8.2833 -82.8667 3
Panama Puerto Barrero 7.8833 -81.1500 4
Panama Puerto Escondido 8.0167 -78.4167 4
Panama Puerto Escondido 8.9833 -81.7667 4
Panama Puerto Mariato 7.6667 -81.0000 4
Panama Puerto Naranjo 7.2667 -80.9167 4
Panama Puerto Obaldia 8.6667 -77.4167 4
Panama Puerto Pilon 9.3667 -79.7833 4
Panama Puerto Pina 7.5833 -78.1833 4
Panama Puerto Ventura 9.4500 -82.4500 4
Panama Punta Alegre 8.2833 -78.2500 4
Panama Punta Chame 8.6500 -79.7000 4
Panama Punta de Burica 8.0333 -82.8833 4
Panama Punta del Medio 9.2500 -80.0667 4
Panama Punta Laurel 9.1500 -82.1333 4
Panama Punta Mala 7.4667 -80.0000 4
Panama Punta Robalo 9.0333 -82.2500 4
Panama Quebrada de Tallo 8.0833 -82.8833 4
Panama Quebrada Grande 9.1333 -80.3667 4
Panama Quebrada la Yeguada 7.6833 -80.1167 4
Panama Rafaelito 8.2500 -78.9167 4
Panama Rio Alejandro 9.3833 -79.7833 4
Panama Rio Azucar 9.4333 -78.6333 4
Panama Rio Canaveral 9.0167 -81.7167 4
Panama Rosarito 7.8500 -81.5667 4
Panama Saboga 8.6167 -79.0667 4
Panama San Carlos 8.4833 -79.9667 4
Panama San Buenaventura 8.5000 -78.5000 4
Panama San Miguel 8.4500 -78.9333 4
Panama San Miquelito 9.0333 -79.5000 2
Panama Santa Ana Arriba 7.9333 -80.3667 4
Panama Santa Catalina 7.6333 -81.2667 4
Panama Santa Catalina 8.7667 -81.3333 4
Panama Santa Clara 8.3833 -80.1167 4
Panama Santa Isabel 9.5333 -79.1833 4
Panama Secretary 9.0500 -81.8500 4
Panama Senon 8.4167 -78.1500 4
Panama Sevilla 8.2500 -82.4000 4
Panama Shark Hole 9.2167 -82.2167 4
Panama Short Cut 9.3333 -82.1833 4
Panama Sukunya 8.8333 -77.6333 4
Panama Taimati 8.1500 -78.2333 4
Panama Tarascon 9.2500 -80.0500 4
Panama Tembladera 8.6833 -79.7667 4
Panama Plan Terminal 9.1833 -80.2000 4
Panama Ticantiqui 9.4000 -78.4667 4
Panama Tubuala Numero Uno 8.9167 -77.7333 4
Panama Ustupo 9.1333 -77.9333 4
Panama Ustupo Yantupo 9.1167 -77.9333 4
Panama Varadero 7.2833 -80.9000 4
Panama Veraguas 8.8667 -80.9000 4
Panama Viento Frio 9.5833 -79.4000 4
Panama Playa Boca del Drago 9.4178 -82.3322 0
Panama Bocas del Toro 9.4178 -82.3322 0
Panama Kusapin 9.1834 -81.8866 0
Panama Veraguas 8.8735 -80.9050 0
Panama Cocle del Norte 9.0784 -80.5715 0
Panama Palmas Bellas 9.2333 -80.0880 0
Panama Colon 9.3558 -79.9068 0
Panama Puertobelo 9.5553 -79.6570 0
Panama Grande Island 9.6369 -79.5635 0
Panama Viento Frio 9.5857 -79.4073 0
Panama Palenque 9.5742 -79.3603 0
Panama El Porvenir 9.5597 -78.9477 0
Panama Porvenir Islands 9.6056 -78.7000 0
Panama Tiger Island 9.4345 -78.5211 0
Panama Playon Chico 9.3098 -78.2328 0
Panama Achutupu 9.2001 -77.9875 0
Panama Ustupo 9.1370 -77.9249 0
El Salvador Acajutla 13.5833 -89.8333 3
El Salvador Conchaguita 13.2333 -87.7667 4
El Salvador Condadillo 13.2000 -87.9333 4
El Salvador El Limon 13.2500 -88.4167 4
El Salvador El Majahual 13.5000 -89.3667 4
El Salvador El Naranjo 13.1833 -88.2500 4
El Salvador El Porvenir 13.7167 -90.0500 4
El Salvador El Sunzal 13.5000 -89.3833 4
El Salvador Garita Palmera 13.7333 -90.0833 4
El Salvador La Libertad 13.8167 -89.3333 3
El Salvador La Union 13.3333 -87.8500 3
El Salvador Las Piedras 13.5333 -89.6333 4
El Salvador Los Jiotes 13.4500 -87.8500 4
El Salvador Mejicanos 13.7333 -89.2000 2
El Salvador Metalio 13.6167 -89.8833 4
El Salvador Monte Verde 13.4167 -87.8833 4
El Salvador Montecristo 13.2500 -88.8000 4
El Salvador Punta Remedios 13.5333 -89.8000 4
El Salvador Salinas de Sisiguayo 13.2833 -88.6833 4
El Salvador Sitio de Santa Lucia 13.2833 -88.5500 4