User's Guide of the
Central American Tsunami Advisory Center (CATAC)
established at INETER/Nicaragua – 2023
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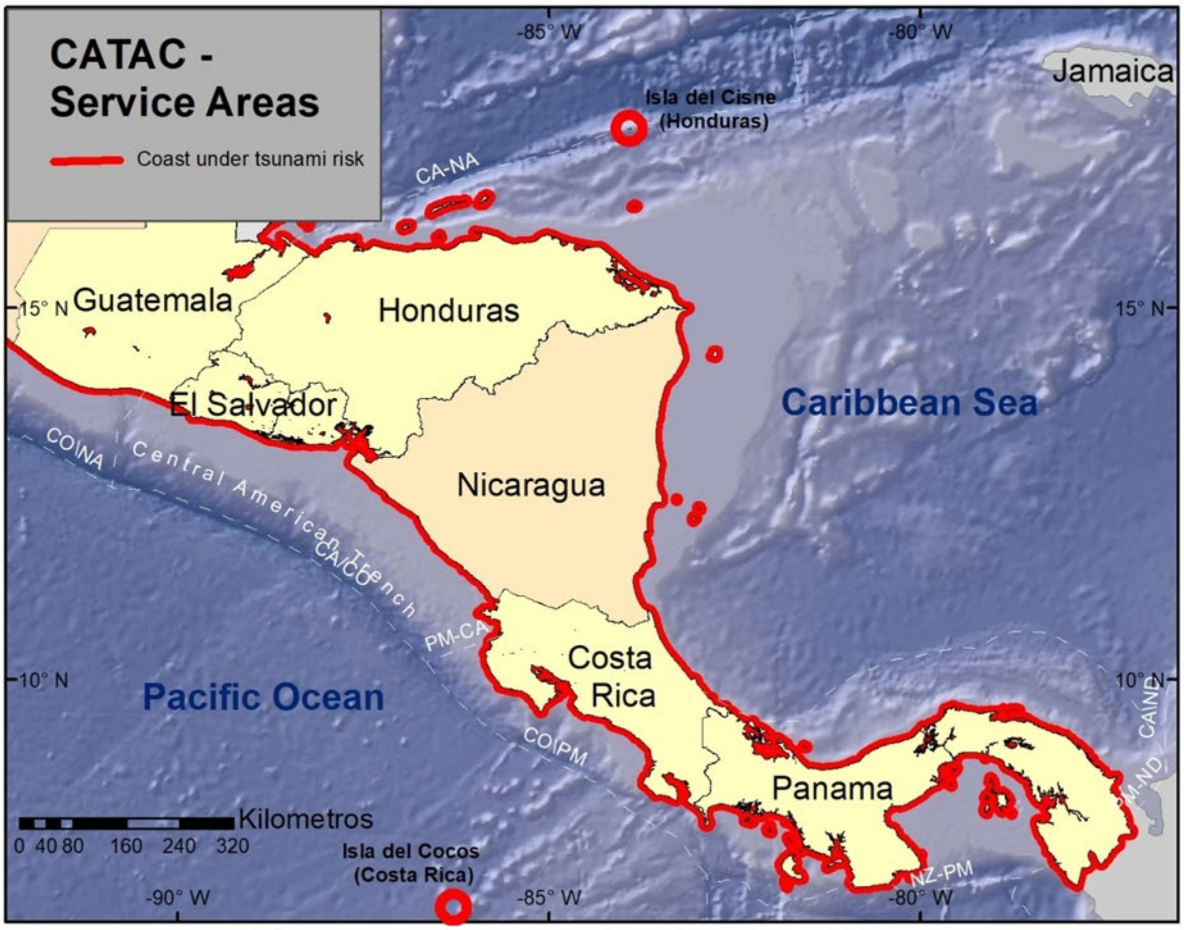

Managua, Nicaragua
September 2023

Nicaraguan Institute of Territorial Studies (INETER)
Central American Tsunami Advisory Center (CATAC

User's Guide of the Central American Tsunami Advisory Center (CATAC) - established at INETER/Nicaragua - 2023

Version: 09/2023

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NOTES

CATACV´s User´s Guide can be downloaded from
http://catac.ineter.gob.ni/doc/CATAC%20Guia%20de%20usuario%20SPANISH%2020190710.pdf

Comments and corrections

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

Earlier versions

The first version of the *User´s Guide was elaborated in 1919. It was updated in December 2021.*

This present version of 2023 of the User's Guide has a new structure and has been written with reference to the ***Common PTWS TSP Users' Guide Table of Contents*** *as prepared by the WG2 Task Team of TSPs in August, 2023; the TOWS-WG Global Services Definition Document from 2016 and the User's Guide for the Pacific Tsunami Warning Center (PTWS) Enhanced Products, IOC Technical Series No 1 05, revised edition. IOC 2014 are considered in the contents of this document.*

Limitations of this draft:

- This is a work in progress. This version is for discussion in ICG/PTWS XXX
- Many figures are still from the previous version and were taken from a low resolution copy to maintain the size of the document small during editing, so they might exist quality problems in this draft which will be corrected in the final version
- In September 2023, CATAC will introduce version 5 of the seismological software package SeisComP. In the present draft, figures corresponding to the data processing process and of the graphical products were still made with SeisComP 3 which CATAC uses since 2019. This will be corrected in the final version
- CATAC has tested new
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Additions, details or extended information in the present version, about:

- Nicaragua and the Instituto Nicaragüense de Estudios Territoriales where CATAC is established including the organization of CATAC
- the regional context of CATAC
- the tsunami hazard in Central America including volcanic and meteorologic sources
- the way how CATAC accelerated the computation of the tsunami impact to generate its text and graphical products in a shorted time
- how and to whom CATAC sends its products
- the efforts to Introduce GPS/GNSS in CATAC´s data processing system
- efforts to develop capacities of new sources of data
- information about how CATAC works on the capacitation of its users, overcoming the strong limitations during the period of the pandemic of COVID-19
- CATAC´s plans for further improvements

Contents

Executive Summary

This document was prepared for the use of the Civil protection agencies and the scientific institutions in Central America related with tsunami warning. They are the principal users of CATAC´s products, but User´s Guide might be useful also for other institutions or persons engaged in Tsunami hazard and risk mitigation and tsunami warning. This User´s Guide is pretended to serve the users of the CATAC products to understand their contents and possible applications.

The Central America Tsunami Advisory Center (CATAC) has been established, in 2016, by the Nicaraguan Institute of Territorial Studies (INETER) in Managua, Nicaragua. The Seismological Directorate of INETER implemented the Tsunami Advisory services for the Pacific and Caribbean coasts of Central America in its role as a sub-regional Tsunami Service Provider (TSP) withing the Pacific Tsunami Warning and Mitigation System (PTWS) and the Caribbean Tsunami Warning System (CARIBE TWS).

The concrete addressees of CATAC messages are at least those contacts contained in the list of recipients of tsunami messages maintained by the Tsunami Resilience Section at IOC/UNESCO in Paris. But CATAC sends its messages also to some additional addressees in the countries of Central America and CATAC´s products are available on its website catac.ineter.gob.ni.

CATAC was under development from 2016-2019 through projects that INETER was conducting for its strengthening in cooperation with JICA/Japan and IOC/UNESCO. In parallel, Seismology of INETER in cooperation with Swiss Seismological Service also executed, 2016-2023, a project on the development of the Earthquake Early Warning (EEW) System for Nicaragua which later was extended to other countries of Central America and strengthened the seismic networks of Nicaragua, El Salvador and Guatemala. The experience, methods and products of these EEW systems can be used by CATAC for the fast evaluation of strong earthquakes.

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 IOC General Assembly (06/2019), CATAC started on 22 August 2019 issuing the products in a pilot phase via email and TELEGRAM, and with its website. 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 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 received the green light from by the ICG/PTWS and in April, 2023, from ICG/CARIBE -EWS to start an interim phase with the full and routine mode of work on both coast of Central America. the full operation of CATAC is to be discussed and endorsed at the ICG/PTWS-XXX in Tonga where to will present a report about the full operation of CATAC and propose a start date for the full operation of CATAC. Final confirmation is expected by the IOC ion 2024.

This User´s Guide contains short descriptions of the tsunami hazard and risk in Central America, about CATAC´s methods for earthquake detection and the related tsunami prediction, its 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 of Central America.

1. Overview

1.1 Background

1.1.1 CATAC's institutional basis

In 2015, the Nicaraguan government made the Nicaraguan Institute of Territorial Studies (INETER) responsible for the creation and operation of the CATAC. INETER, subordinated to the Presidency of Nicaragua, is the largest geosciences institution in Central America (founded in 1982, around 400 co-workers, www.ineter.gob.ni). Its main offices are located in Managua, Capital of Nicaragua. INETER comprises the Departments of Geology and Geophysics, Meteorology, Water Resources, Geodesy and Cartography, Land Use Planning, Physical Cadaster, and Geoinformatics. The Geophysical Department of INETER combines the Seismology, Volcanology and Geology sections. The Seismology section works on earthquake and tsunami hazard studies, risk mitigation and early warning systems, maintains the Nicaraguan Seismic Network and the Center for Monitoring and Early Warning of Earthquakes and Tsunamis. The function of CATAC is directly subordinated to the director of INETER and supervised by an advisor to the director. CATAC's operation is included in INETER's budget and in its development plans. Due to the experience with the disastrous 1992 tsunami on the Nicaraguan Pacific coast, population and institutions of the country are much interested in the mitigation measures for tsunamis. Nicaragua integrated the ICG/PTWS in 1993 and INETER is the National Tsunami Warning Focal Point. The seismology section comprises the National Tsunami Warning Center (NTWC) and is also National Center of CTBTO. A National Tsunami Warning System was established in Nicaragua in 1996 combining 1) the efforts of INETER for seismic monitoring and tsunami characterization; 2) the warning and rescue capacities of the Civil Defense of the Nicaraguan Army; Today an additional factor is: 3) the National System for the Prevention of Disasters (SINAPRED, created in 1999), a network of all institutional and territorial structures relevant for disaster prevention and mitigation.

To meet the operational and organizational requirements necessary to establish and maintain CATAC as 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.

1.1.2 The regional context of CATAC

The 1991 disastrous tsunami on the Nicaraguan Pacific coast was a wake-up call for Central America to include the tsunamis risk in their efforts for disaster mitigation and prevention measures. Numerous scientific studies carried out in the first years after this tsunami shed light on the hazards, risks, vulnerabilities and the total lack of detection and early warning facilities for the phenomenon in the region.

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.

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 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, expressed the need to reduce or mitigate tsunami risk in the region and decided to initiate the development of a Regional Tsunami Warning System. They 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. In subsequent meetings a proposal was developed to establish a TSP in Nicaragua. In 2015. the Nicaraguan government offered in a SICA meeting to establish CATAC at INETER in Nicaragua. This offer was supported by the civil protection agencies of Central America as was expressed in a letter of CEPOREDENAC to IOC. Also, the scientific or seismological institutions of all central American countries related to tsunami warning expressed their support for this proposal. Previously, two JICA fact finding missions to Central America had found that INETER in Nicaragua was the most adequate organization in the region where to place a TSP.

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 provided by PTWC for the Pacific and the Caribbean Sea. 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.

1.1.3 The establishment of CATAC

The ICG/PTWS in its XIX Session decided to assist the 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 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 2015, Nicaragua signed also 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 was implemented in 2022 and will finish at the end of 2023.

1.1.4 Mission and duties of CATAC

Mission

CATAC's primary mission is to provide timely technical information on 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

CATAC's duties consist of the following elements:

1. Continuously acquire continuous seismic records from multiple sources in real time;
2. Detect and locate and determine the magnitude of all detectable earthquakes in and around the Monitoring Area.
3. Characterize earthquake source parameters through automatic and interactive processes;

4. Decide on the basis of seismological and geophysical information whether the earthquake could have generated a dangerous tsunami for Central America.
5. Calculate the estimated time of arrival (ETA) and tsunami amplitudes for the designated forecast points defined by the Central American countries;
6. Disseminate seismological and tsunami messages and bulletins to NTWCs and NTFPs;
7. Receive real-time sea level monitoring data from multiple sources to confirm tsunami generation and severity;
8. Conduct routine and unannounced communication tests with NTWCs and NTFPs;
9. Provide opportunities for education, outreach and training activities in the region;
10. Prepare a summary report each time a destructive tsunami occurs and messages 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.

1.1.5 Implementation timeline

Date	Actor (s)	Activity
1992-09-01	Nicaragua	Experience with the disastrous Tsunami at the Nicaraguan Pacific coast
1993	INETER	Membership to ITSU (later renamed to ICG/PTWS)
1996	INETER, Civil Defense	Creation of Nicaraguan Tsunami Warning Systema
1998	INETER	Proposal for a Central American Tsunami Warning System
2003	ICG/PTWS	Creation of ICG/PTWS-WG-CA)Working Group for Central America)
2004-2014	ICG/PTWS-WG-CA	Meetings to discuss the prospects of a regional TWS
2014	Nicaraguan President at SICA meeting	Proposal for the creation of CATAC at INETER
2014	CEPREDENAC, Central American Civil Protection Agencies	Letter to IOC on support for the creation of CATAC at INETER
2012, 2014	JICA	JICA missions in Central America JICA find that INETER is the most favorable institution to establish CATAC
2015	ICG/PTWS-XXVII Hawaii	Accepts Nicaragua's proposal to establish CATAC at INETER
2016	Government of Nicaragua	Establishes CATAC at INETER/Managua
2016 Nov	Governments of Japan and Nicaragua	Start the cooperation project at INETER for strengthening CATAC
2015-2016	INETER/University UNAN, Managua	1-year postgraduate seismology course for 30 participants from INETER and other Nicaraguan institutions
2016 Oct	INETER/JICA (JMA, Univ. Hokkaido)	Start with technical efforts of CATAC project
2017	ICG/PTWS-XXVII	

2017-2019	INETER/CATAC	Instrumental/computational/software base strengthening measures
2019-Apr	ICG/PTWS XXVIII, Nicaragua	Approval for experimental operation of CATAC
2019-Apr	ICG/CARIBE-EWS, Costa Rica	Approval for experimental operation of CATAC
2019-Jun	IOC 30, Paris	confirms CATAC as regional tsunami services provider under experimental operation
2019-Aug	INETER-CATAC	Start of experimental operation of CATAC
2019-Aug	INETER-CATAC	First CATAC Regional Exercise
2019-Sep	INETER-CATAC	Evaluation of the first regional exercise
2019-Oct	INETER/JICA	Completion of the project with JICA
2019-2021	INETER-CATAC	CATAC's experimental phase
2021-Nov-15	ICG/PTWS-WG-CA	Discussion on the progress of CATAC in the pilot phase and recommendations on the start of full operation.
2021-Dec	ICG/PTWS-XXIX (virtual)	Discussion on the progress of CATAC in the pilot phase and decisions on the start of interim full operation.
2023-Apr	ICG/PTWS-WG-CA VI	Discussion on the progress of CATAC in the pilot phase and recommendation on the start of full operation.
2023-Apr	ICG/CARIBE-EWS-XVI	Discussion on the progress of CATAC in the pilot phase and decisions on the start of interim full operation.
2023-Sep	ICG/PTWS-XXX	Draft of new version of User´s Guide presented

1.1.6 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) Expansion of Shift Staff to two watch standers in the 24x7 service; 2) Enhanced Processing Speed and Accuracy due to experience gathered; 3) Accelerated Earthquake and Tsunami Processing according the needs for local tsunamis; 4) Seismic Network Strengthening in Nicaragua and Central America, much more and better stations; 5) Novel Approach to Magnitude Determination taking into account slow earthquakes; 6) Acceleration of Tsunami Simulation with TOAST; 7) Fast Product Dissemination according experience with Earthquake Early Warning 8) Innovative Communication Methods in development (cellphone applications and social networks) 9) Additional Siren Installation for Tsunami Warnings in Nicaragua (Total of 80 now); 10 Siren installation in other countries has started; 11) Establishment of CATAC's Website; 12) Shakemap Website Development; 13) Collaboration with MARN on the creation of a CATAC Backup center; 14) GPS/GNSS Integration initiated

A more complete report on the progress of CATAC in the pilot phase can be obtained from http://catac.ineter.gob.ni/docs/pilotphase.pdf .

1.2 Area of Service

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

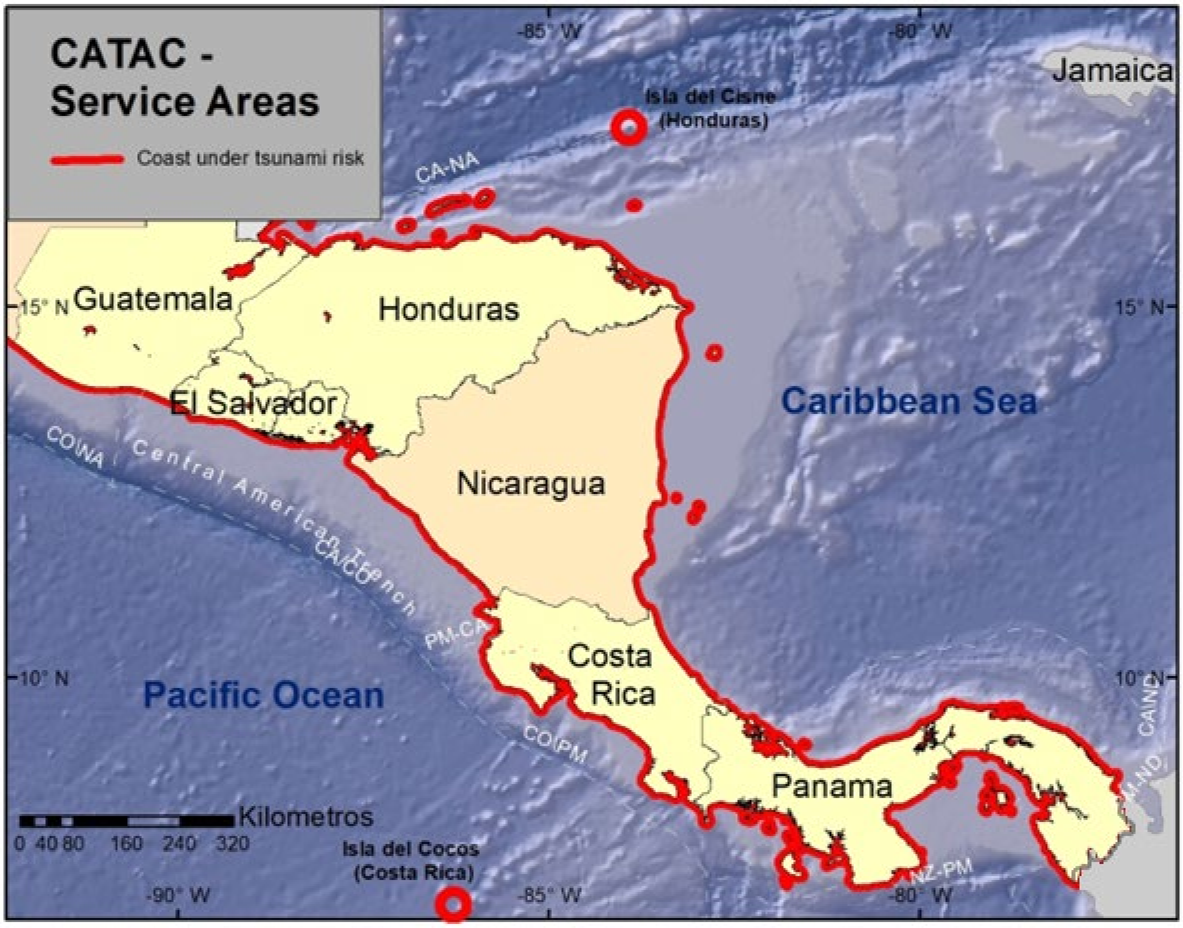

Figure 3. CATAC´s Service Areas on the Central American coasts of the Pacific Ocean and the Caribbean Sea

1.3 Earthquake Source Zone

CATAC Advisory information is issued when CATAC detects an earthquake of magnitude 6.5 or greater in its Monitoring Areas (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 are characterized as those areas that contain tsunami sources from which waves can reach some point in the Service Areas, i.e. the coasts of Central America, within about one hour after being generated. These areas are limited by polygons as follows:

1) The Pacific zone: starting from the border of the Mexican states of Guerero and Oaxaca along the coasts of Oaxaca, Central America, Colombia and Ecuador, then from the border of Ecuador

with Peru a line to the Southern tip of Galapagos Islands, from there continuing a line back to starting point at the coast of México.

2) The Caribbean zone: starting from Cancun (Mexico) along the coasts of Mexico, Belize, Central America, Colombia, Venezuela until the town of Coro (Venezuela), then a polyline passing Santo Domingo (Dominican Republic), Inagua Islands (West Indies), Trinidad (Cuba), and back to Cancun (México).

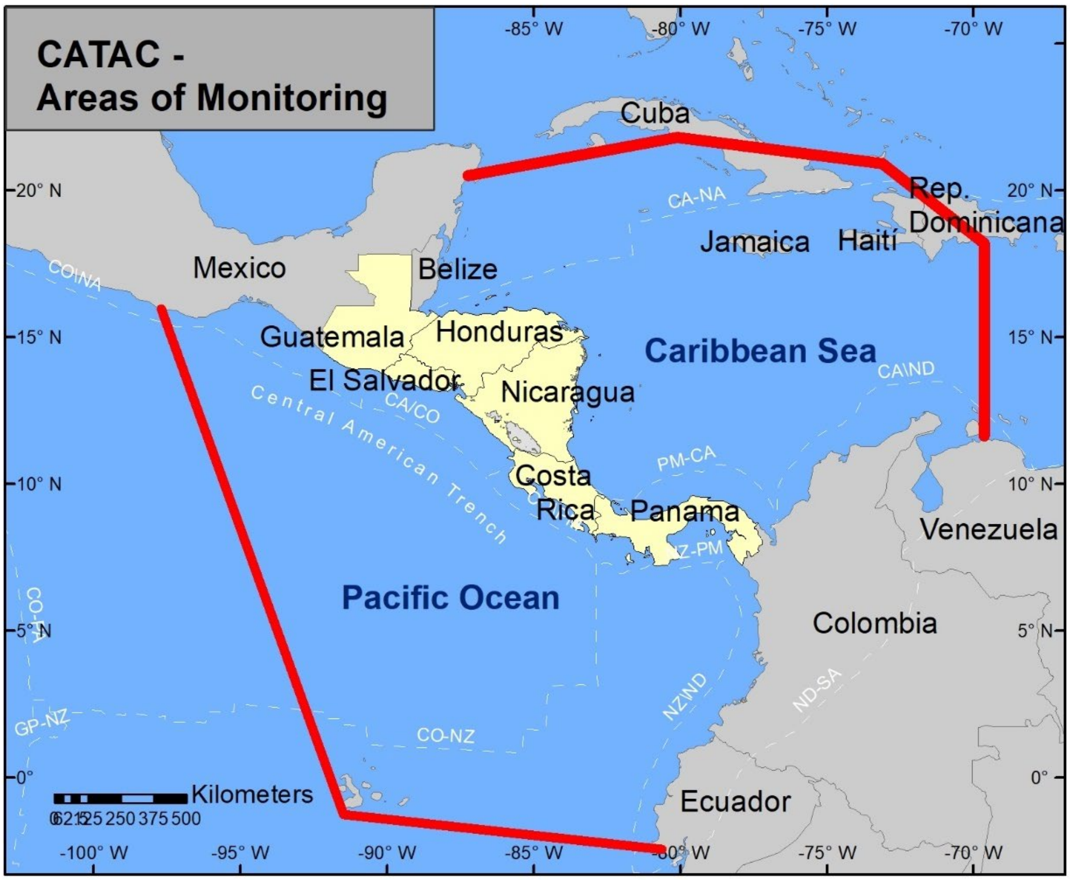

Figure 4. CATAC´s Monitoring Areas in the Pacific Ocean and the Caribbean Sea

Seismicity of Central America

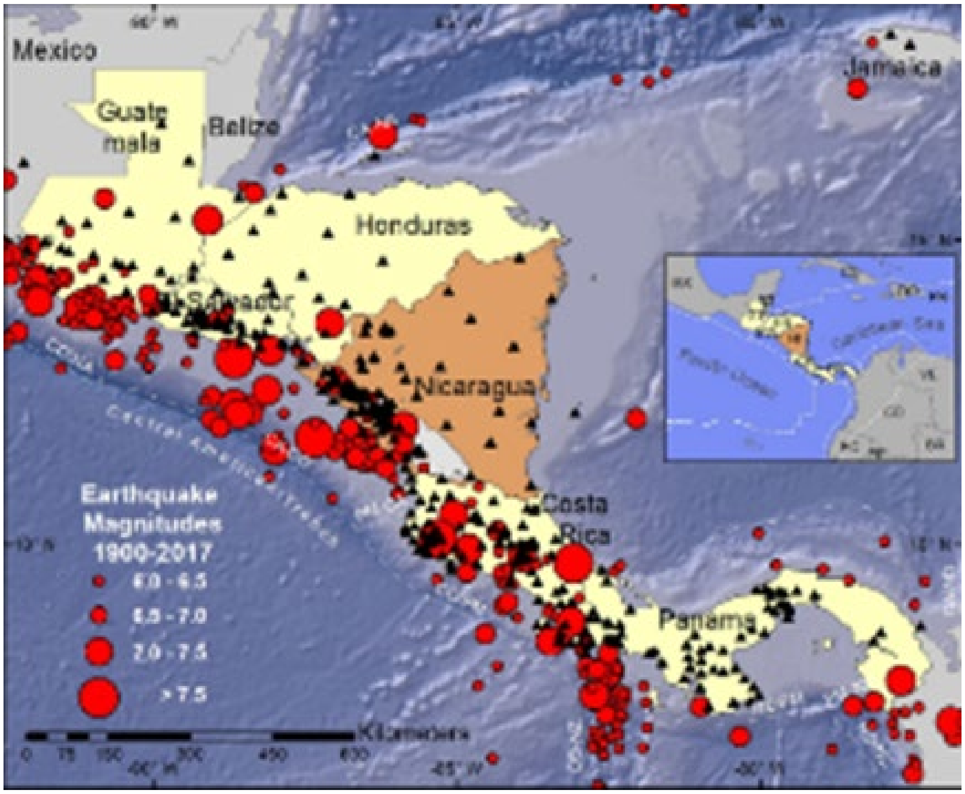

Figure . Seismicity in Central America according to NEIC/USA

Large earthquakes occur mainly in the Central American subduction zone from Guatemala to Southern Costa Rica

Volcanoes in Central America

The volcanic Hazard is high in Guatemala, El Salvador, Nicaragua and Costa Rica but much smaller in Honduras and Panama.

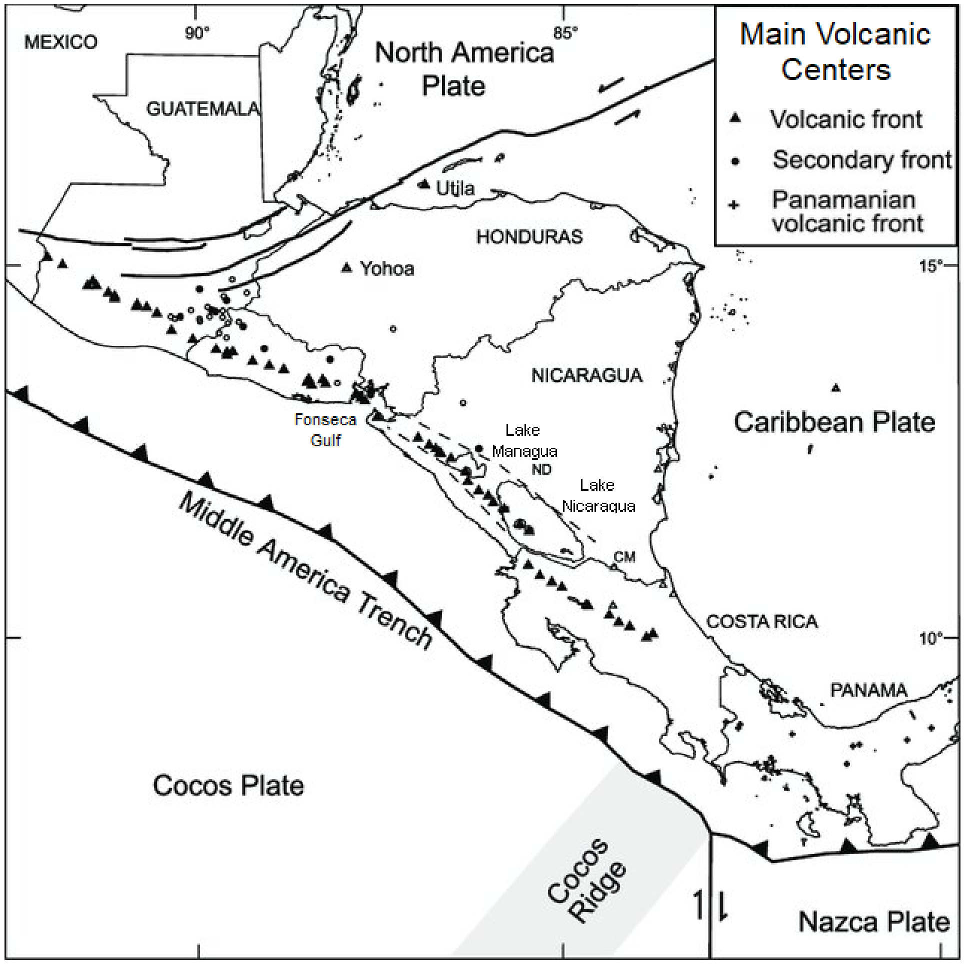

Figure . Location of principal volcanic centers in Central America. (Carr, 2006).
Volcanoes can cause tsunamis the Fonseca Gulf and in the big lakes of Nicaragua.

1.4 Tsunami Hazard

General tsunami hazard

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 disastrous event on the Pacific coast of Nicaragua with a runup of up to 10 meters.

Figure . Historical tsunami occurrence in Central America

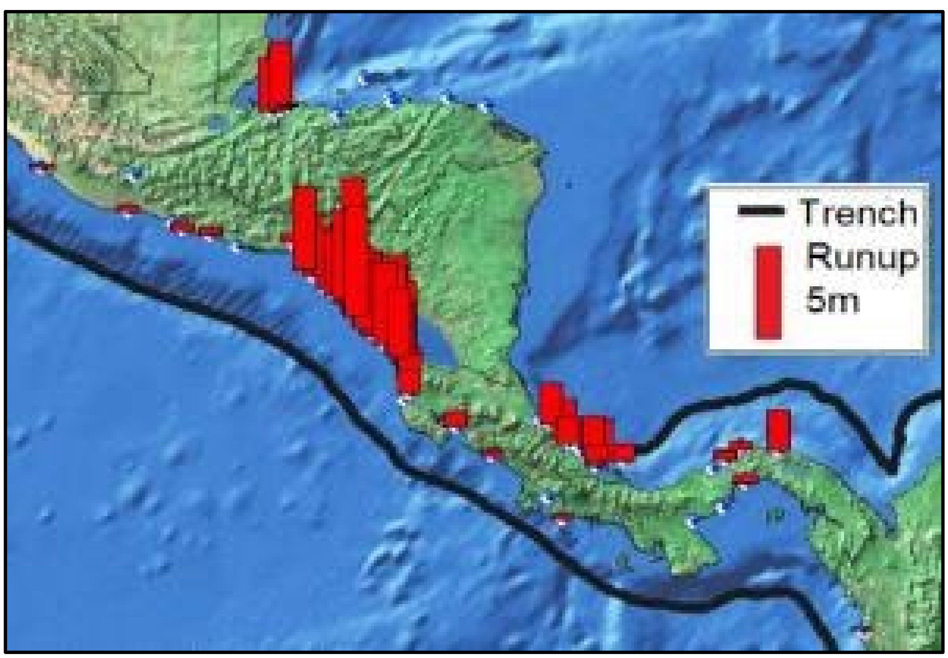

Figure 3. Location of tsunamis (left) and runup (right) in Central America since 1500. Source: Molina, 1996; Fernández et al.,2000); NGDC/WDS, 2015; modified.

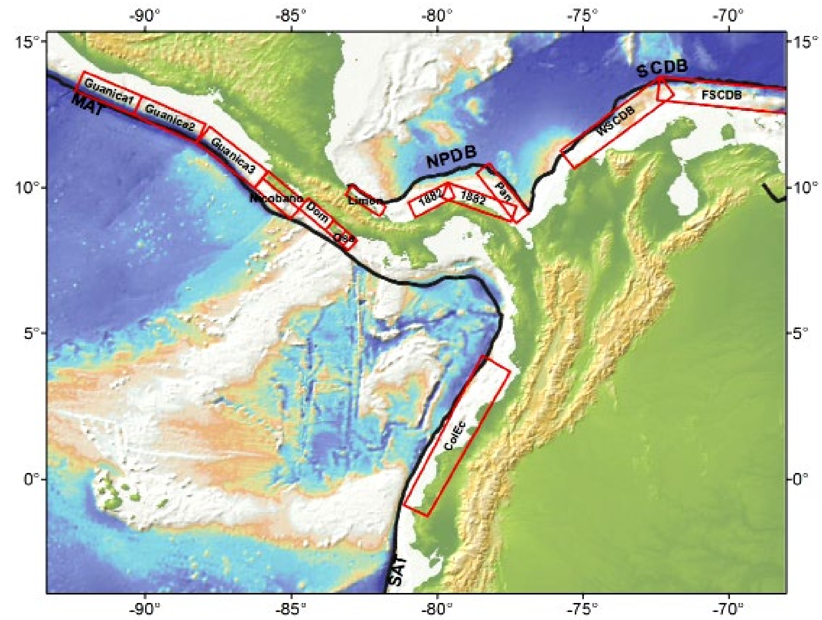

Figure . Major earthquake sources contributing to the tsunami hazard for Central America (red rectangles). According to IOC (2018), IOC (2020).

In the Pacific Ocean, 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 much shorter, which forces CATAC to send warning messages within a few minutes.

Coastal areas with reduced tsunami first impact time

In many parts of the Pacific and Caribbean coasts of Central America there exists a wide shelf area between the main earthquake source area and the coast. In these area the delay between the earthquake occurrence and the tsunami impact is rather large, between 30 or 60 minutes or even larger.

But there exist coastal zones with reduced time to tsunami impact exist due to:
1) The source area is very close to the coast: Swan 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 (se.g. Southern Guatemala, Gulf of Chiriquí in Panama).
These conditions exist also combined in some areas.

Figure . Areas where the tsunami impact time can be less than 10 minutes (red lines)

Tsunami hazard in the big lakes of Nicaragua

There exist geological and historical information on the occurrence of tsunamis or seiches in the big lakes in Nicaragua caused by earthquakes or volcanic processes. The tsunami catalogue of Central America (Molina, 1997) mentions that in May, 1844 an earthquake with a magnitude between 7 and 7.8 with epicenter in the southernmost part of Lake Nicaragua of Nicaragua caused a tsunami o seiches in the Lake.

CATAC has carried out tsunami simulations of large earthquakes in the area between Nicaragua and Costa Rica and for earthquakes in the Pacific Ocean which confirmed that tsunamis or seiches with amplitudes of several meters can occur in Lake Nicaragua due to these events.

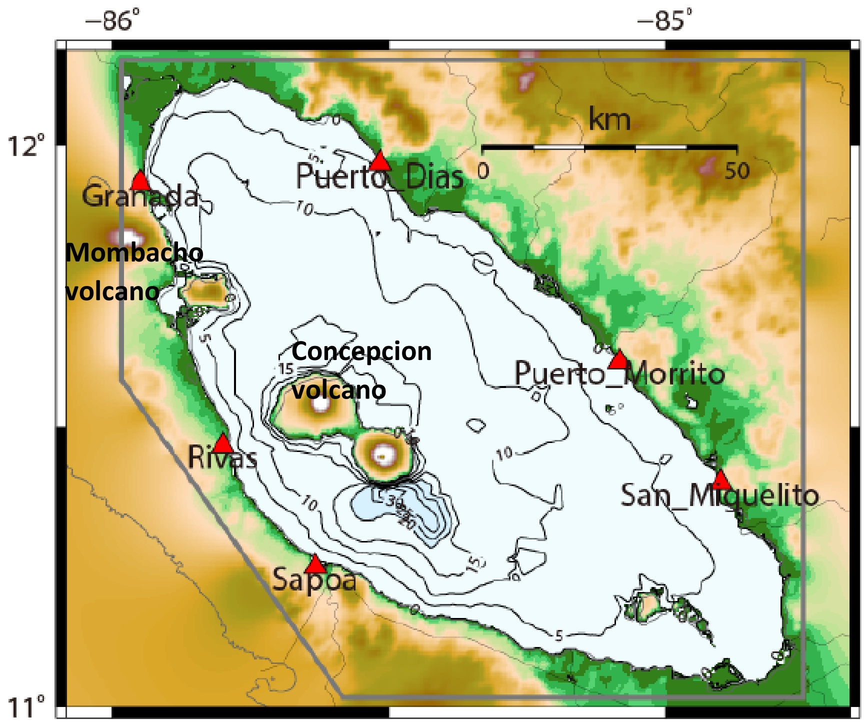

Figure . Map of Lake Nicaragua. Red triangles indicate coastal sites used for tsunami modelling Bathymetry in meters.

For Mombacho, a steep volcano located at the coast of Lake Nicaragua very near the city of Granada, there exist geological and topographic evidences for a large collapse of its Eastern flank. The landslide entered directly into lake Nicaragua and created a peninsula and hundreds of small islands. Certainly, this event caused a tsunami in the lake. At this volcano another collapse is known which also might have entered the lake (Shea et al, 2008). Concepción, a steep active volcano on Ometepe Island in Lake Nicaragua, could also be the origin tsunamis caused by landslides, pyroclastic flows or volcanic explosions. Perez (2019) has carried out numeric simulation of tsunamis caused by a debris avalanches at Concepción and Mombacho. It was shown that destructive tsunamis could not only affect the vicinity of these volcanoes but also at other densely populated coasts.

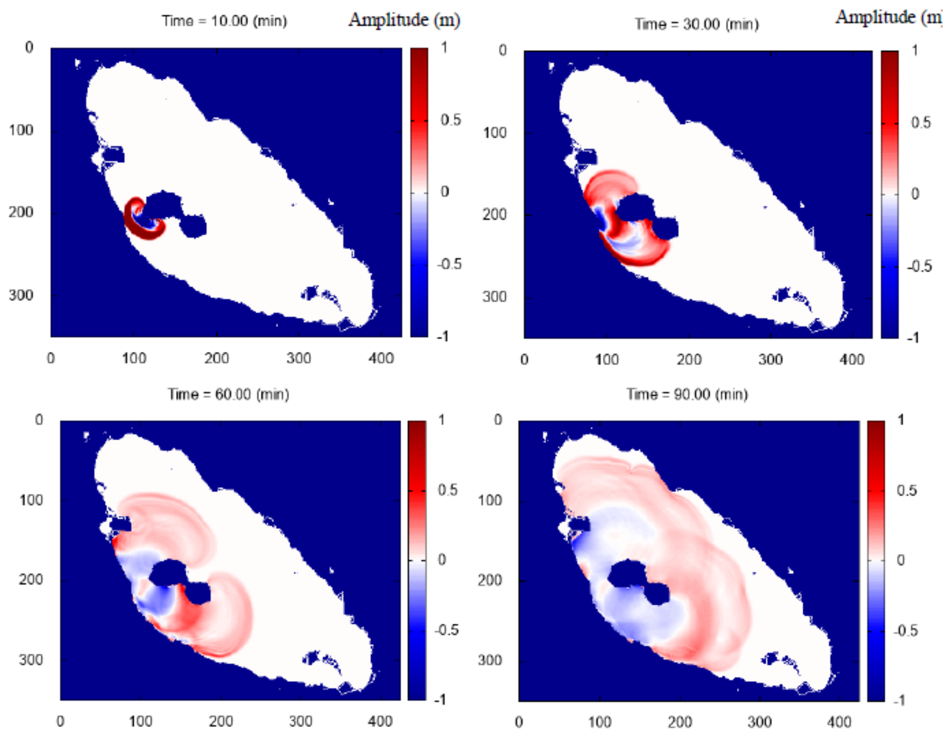

Figure . Snapshots of tsunami propagation from a debris avalanche at Concepcion volcano in Lake Nicaragua, from Perez (2019).

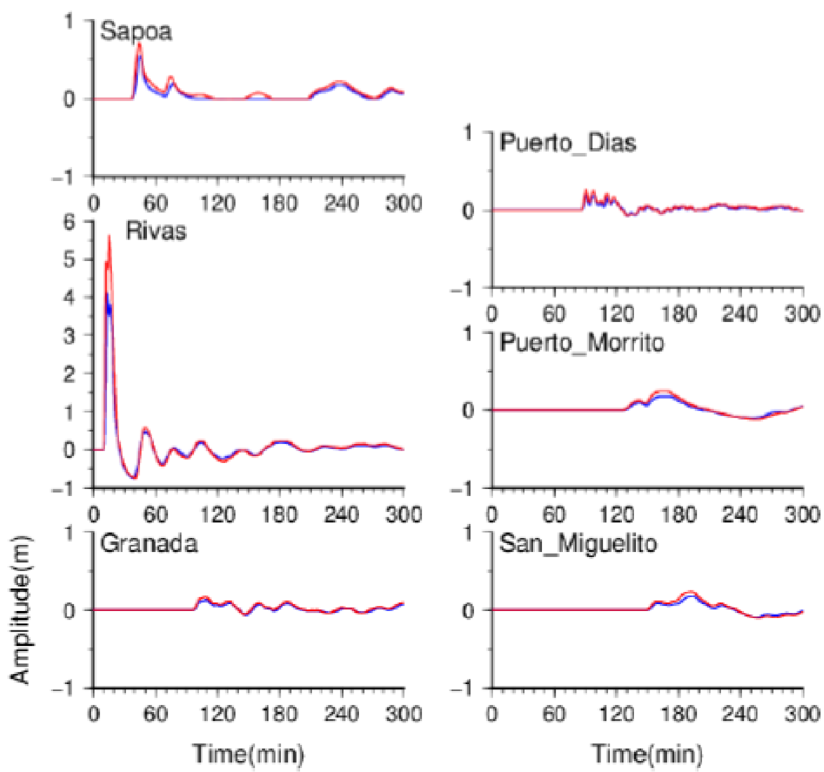

Figure . Numeric simulation of the tsunami impact at the coasts of Lake Nicaragua. From Perez (2019)

Freundt et al (2006ª, 2006[b]), documented geologic evidence about a tsunami generated by a volcanic explosion near Apoyeque volcano located at the shore of Lake Managua, only 8 km from the Nicaraguan capital, Managua. Freundt et al (2007) discuss the possibilities of tsunamis generated by volcanoes. Momotombo, another volcano in Lake Managua, could also cause tsunamis.

Volcanic tsunami hazard in the Gulf of Fonseca, Pacific coast

The Gulf of Fonseca, shared by Nicaragua, El Salvador and Honduras, seems to be the only place along the Pacific Coast of the Americas - besides Alaska and Southern Chile - where volcanoes are situated at the very coast and thus with the possibility to generate tsunamis due to flank collapses, landslides, lahars, pyroclastic flows and volcanic explosions. (Not to count volcanoes Barcena and Evermann on the Revillagigedo Archipelago more than 600 km west of the Mexican Pacific coast (Puerto Vallarta) or other Volcano islands far from the main land) The huge eruption in 1835 of Cosiguina volcano, Gulf of Fonseca, Nicaragua, possibly caused tsunamis, but there are no direct evidences. In this time the population density in this area was very low. Besides Cosiguina there is Conchagua, a large inactive volcano on the coast of El Salvador. Both, Cosiguina and Conchagua, could cause tsunamis due to flank collapse or lahars. In the Gulf there are several volcanic islands and earthquakes with magnitudes up to 6 have occurred, also seismic swarm activity is frequent. In

The Gulf of Fonseca is included in CATAC´s area of monitoring and area of responsibility. CATAC/INETER is in discussion with the seismic networks of El Salvador and Honduras to improve the seismic monitoring for the Gulf and to develop also the capacity for tsunami warning in the case of volcanic sources.

Meteorological tsunamis

The Caribbean coast of Central America is affected by hurricanes and other meteorological phenomena which can swell the surface of the sea which then propagate to the coast similar as tsunamis and can reach several meters height on the beach. Also, the large lakes in Nicaragua can be affected by these meteorological tsunamis, when strong air pressure disturbances travel over the lakes with velocities similar as the tsunami propagation speed corresponding to the shallow water depths in these lakes, mainly 10 to 20 meters, in smaller areas up to 40 meters. Resonance=

In the moment CATAC has no capacities monitor and process these phenomena.

Not to be confused with the tsunamis are the strong surfs which affect frequently certain places on the Pacific coasts of Central America (e.g. Cedeño/Honduras, Corinto/Nicaragua) and which are caused by distant storms or hurricanes in the Ocean from where the generated waves travel to the coasts. The monitoring of theses waves and predictions of possible impact are done by the for oceanographic groups in some countries of Central America as for instance at MARN in El Salvador.

2. Operations

2.1. CATAC´s Capacities and Facilities

Monitoring and warning room

Within INETER, CATAC is part of the Seismology Directorate that manages the Monitoring and Warning Center for earthquakes, tsunamis, seismological evaluation of volcanic phenomena and landslides. This unit occupies an area of 250 square meters divided in a monitoring and warning room, a meeting room, a server and seismograph bunker, the electronics/seismometry lab for maintenance of the data center and Nicaraguan seismic network , an IT room, and 6 offices where the

CATAC´s staff

INETER/Seismology currently has a team of 18 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 intensely trained in in the JICA project 2017-2019 and later on. Both watch standers are restricted to the facilities of CATAC, during office hours there is also support at INETER for the case of emergency. Four key positions were designated, namely the CATAC Coordinator, CATAC Director (Director of Seismology section), 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, local network 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.

Technical facilities

CATAC is 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 concrete bunker of about 40 square meters in the basement of the building where there are also the seismometers, accelerometers for routine and instrument tests. There is also a battery backup unit with a capacity of 20kWh which

Around the processing facilities the is ample room for meetings, capacitation and emergency work (situation room). That way the watch standers - to some extend - can participate in meetings or capacitation measures, while there are no important events occurring.

Computing facilities

The main workstation for automatic seismological and tsunami processing including tsunami is a Workstation which has a Intel Processor Xeon (LGA2011-3 2.60G 35M Proc E5-2697V3 14C DDR4 Up to 2133MHZ) and a GPU Nvidia TESLA M40 GPU 12GB GDDR5 Accelerator Processing Card (GPU), acquired in 2017. This system will be updated in September 2023 with a NVIDIA RTX 4090 GPU to increase the

Photo 2. CATAC, Processing and Alerting Room

Photo 3. CATAC, Situation and Meeting Room

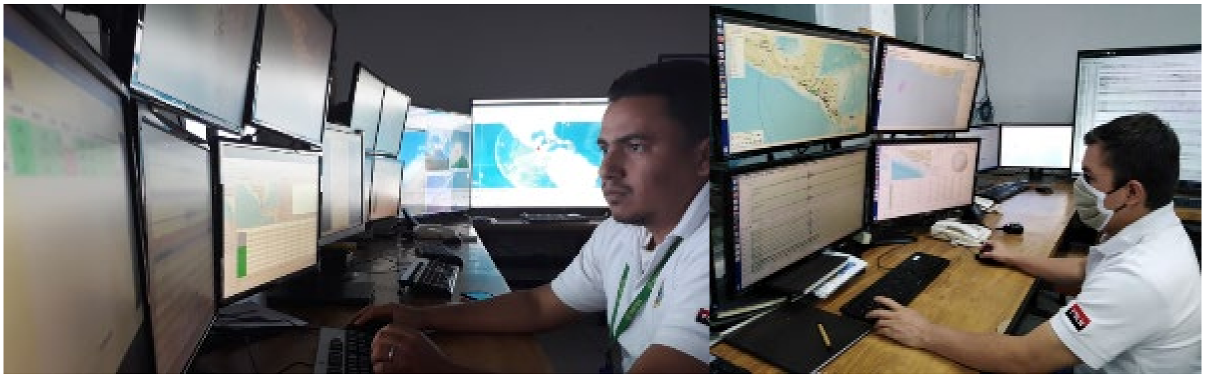

Photo 4. The seismologists of the 24x7 service revise the automatic results perform the manual processing and must publish first results within 2 minutes after the detection of the earthquake.

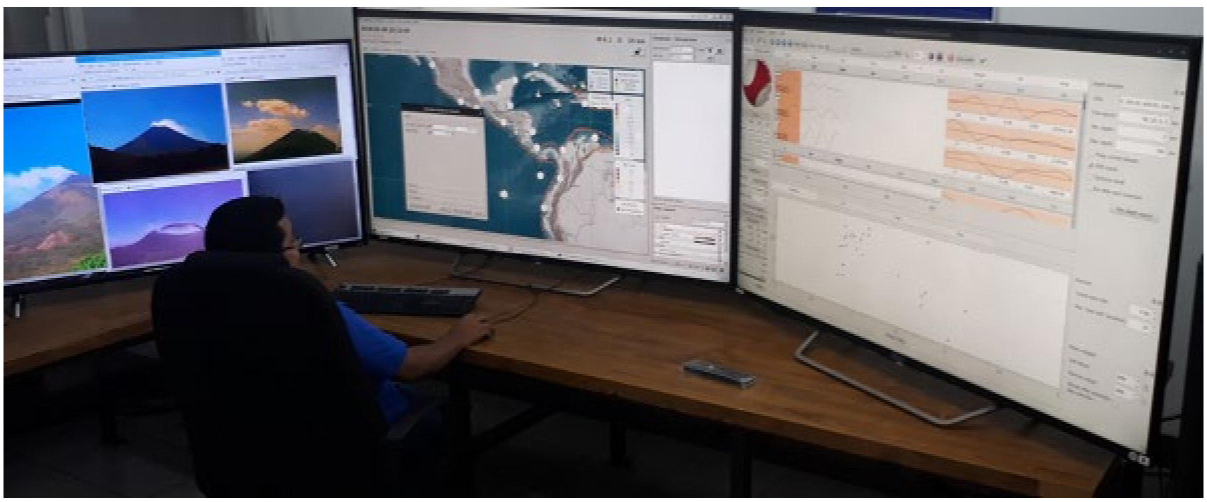

Photo 5. Moment Tensor calculation and numerical tsunami simulation are important tasks of the CATAC seismologist on duty.

Backup facilities of CATAC

The most important parts of CATAC's operating system - as the workstation for earthquake and tsunami processing and the terminals for manual processing and the electric power backup systems - are duplicated in case of partial malfunction. However, the possibility of catastrophic failure cannot be eliminated; a giant distant earthquake or a local earthquake in Managua might affect CATAC facilities. If CATAC products cannot be 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 advisory services for both coasts of Central America are currently provided by the Pacific Tsunami Warning Center (PTWC).

CATAC has a plan for the implementation for a backup center in Nicaragua. The under consideration is located in a facility of the Nicaraguan Electric Power Transmission Company ENATREL in the town of Sébaco, about 100 km N of Managua, 1.5 hours drive . This place is distant to the volcanic chain of Nicaragua, has much lower seismic hazard, would not be seriously affected by earthquakes in Managua or in the Nicaraguan subduction zone. ENATREL provides access to their optical fiber network which transports large part of the data of the Nicaraguan seismic network. ENATREL is also an INTERNET provider and would facilitate the access to the regional and international seismological data centers. The used

Another backup plan is under discussion with the Seismological Center at the Ministry of Environment in El Salvador (MARN). INETER and MARN are cooperating closely and MARN is the NTWC of El Salvador. They dispose to similar facilities and software system as CATAC and their organization of earthquake and Tsunami processing is similar. MARN does not use the complete suite of SeisComP as CATAC but has elaborated own solutions for the most important functions. In talks between CATAC and MARN a closer integration of both centers was agreed, including direct exchange of the products of both centers using the corresponding modules of SeisComP.

2.2 Seismological and Geophysical Monitoring Networks

2.2.1 Seismic stations

Seismic Network of NETER in Nicaragua

Seismology/CATAC is responsible to develop and to maintain the Nicaraguan seismic network which currently (2023) has around 140 accelerometric, short period and broad band seismic sensors. The data are received by direct streaming with the seedlink protocol and is fed into several SeisComP systems for archiving and for real time automatic and manual processing. About 70 % of these stations were installed since 2016 that means with the direct consideration to be used for the reinforcement of CATAC and the development of the earthquake early warning system in Nicaragua. The network uses many low cost instruments (for example Raspberry Shake) according the limited budget of INETER. But there are also sufficient broad band sensors suited for some tsunami specific processing methods.

Other seismic networks in Central America

Obviously, it is the responsibility of the countries interested in 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 especially for local events near its coasts.

CATAC receives real time data from nearly all seismological data centers in the countries of the Central America. These data obtained via direct transmission via seedlink from the corresponding network centers are characterized by a low delay of the data transmission from the station to CATAC, normally less than a few seconds.

Table . Direct streaming from Central America, low delay (several seconds)

Country	Institution	Type of sensors	Number of seismic stations
Nicaragua*	CATAC/INETER*, Gob.	ac, sp, bb	140
El Salvador*	MARN*, Gob.	ac, sp, bb	70
Guatemala	INSIVUMEH*, Gob.	ac, sp, bb	60
Honduras*	COPECO*, Gob.	sp, 1 bb	15
Honduras*	UNAH*, Univ.	Sp	16
Costa Rica	OVSICORI, Univ.	ac, sp, bb	10
Costa Rica	UCR, Univ.,	sp, bb	22
Panamá*	Panama Canal*, Gob.	ac, sp, bb	10
Panama*	Baru Network, Priv.	sp	8
Panama*	IG-UPA*, Univ.	ac, sp, bb	6
*) All existing networks in the country participate	*) Facilitates complete network Gob-Government, Univ.-University, Priv.-Private		**Total 357 (sep 2023)**

Table . Direct streaming from countries in the greater region,

Country	Institution	Type of sensors	Number of Seismic stations
Mexico (Southern part)	UNAM, Univ.	bb	14
Venezuela	FUNVISIS, Gob.	bb	11
Colombia	SGC, Gob	bb	21

Other broad band seismic data from South America, North America, the Caribbean and the World come in through EarthScope (previously IRIS)/USA or GEOFON (GFZ, Potsdam, Germany).

The density of seismic stations in Central America is generally very high, which facilitates the rapid and accurate elaboration of CATAC products for local earthquakes occurring in the region. The governmental seismological institutions in Nicaragua, El Salvador, Guatemala and Honduras facilitate the data of 100% of their networks. However, in Honduras and Panama there is still insufficient coverage for high quality products especially there is a lack of broad band sensors and there are currently no stations near the plate border North of Honduras which produces the major seismic hazard for the country. Honduras was strongly affected by the Covid-2019 pandemic and the COPECO seismic network was almost completely down due to the lack of maintenance but this situation is now rapidly improving. As for Panama, CATAC is in the process of establishing an agreement with the University of Panama (UPA) to receive more seismic data from its Geosciences Institute.

The high density of seismic stations and the small delays of the data from the very region entering CATAC permit the use of alternative methods for the rapid evaluation of the seismic magnitude as the module FINDER from the Earthquake Early Warning software package provided by the Swiss Seismological Service to the countries of Central America. This method uses the high frequency spectrum of the recordings contrary to the very long period signals which are preferred normally for the evaluation of seismological parameters relevant for tsunami evaluation.

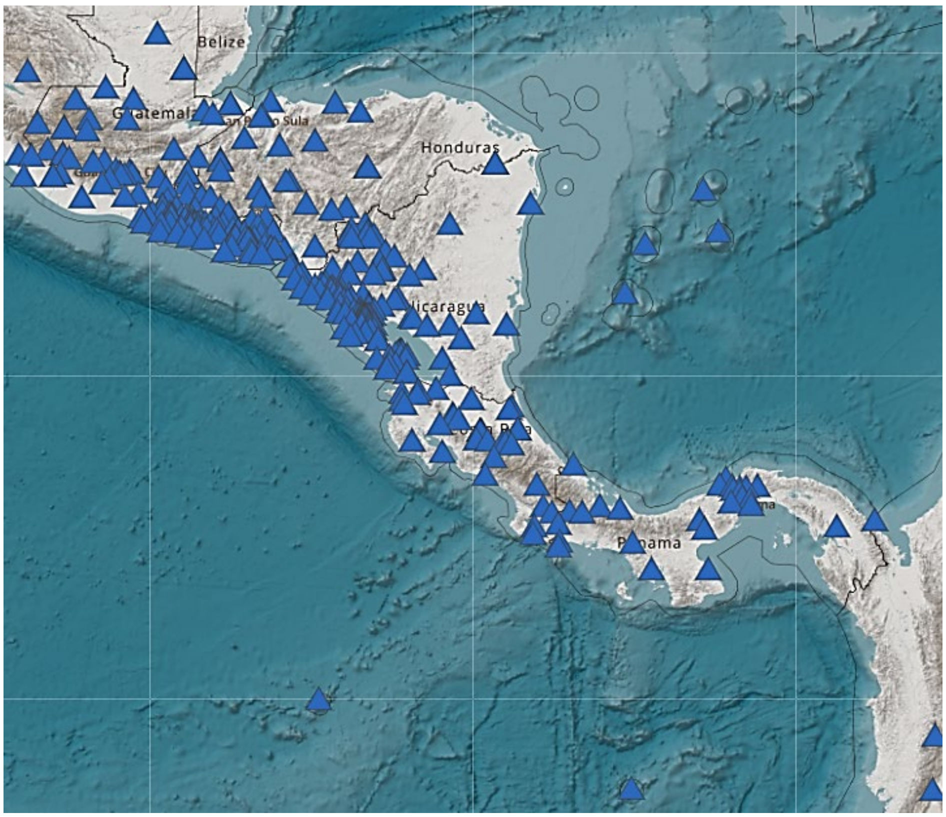

Figure 7. Location of seismic stations in Central American countries used by CATAC.

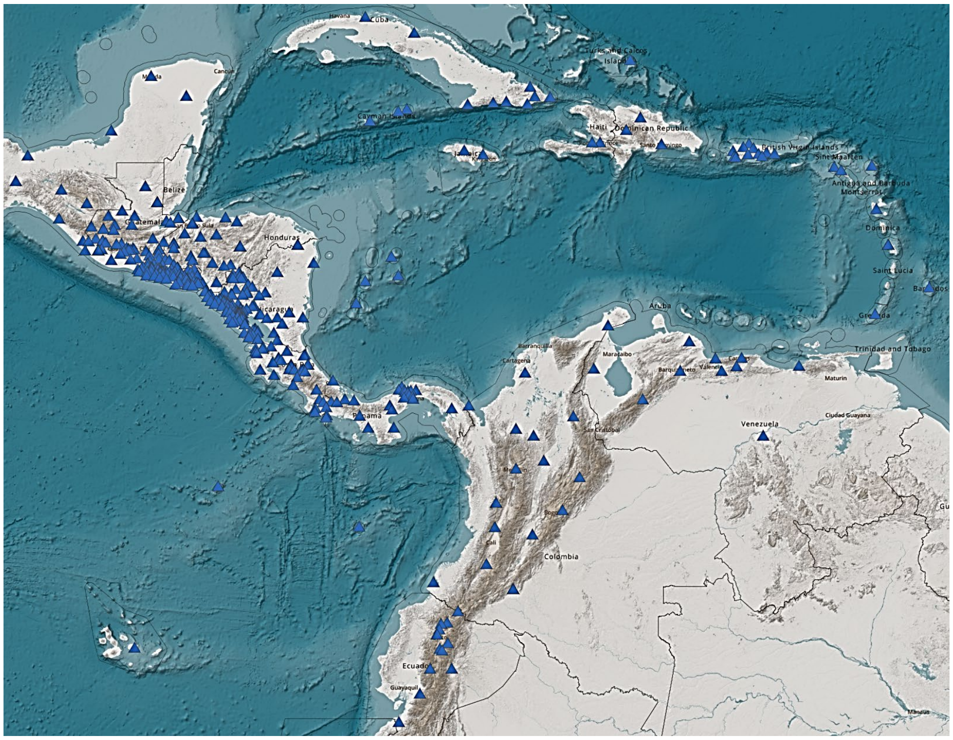

Figure 8. Location of seismic stations in the larger region used by CATAC.

Improvement of seismic networks

The seismic networks in Nicaragua, El Salvador, and Guatemala were greatly densified in 2021 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

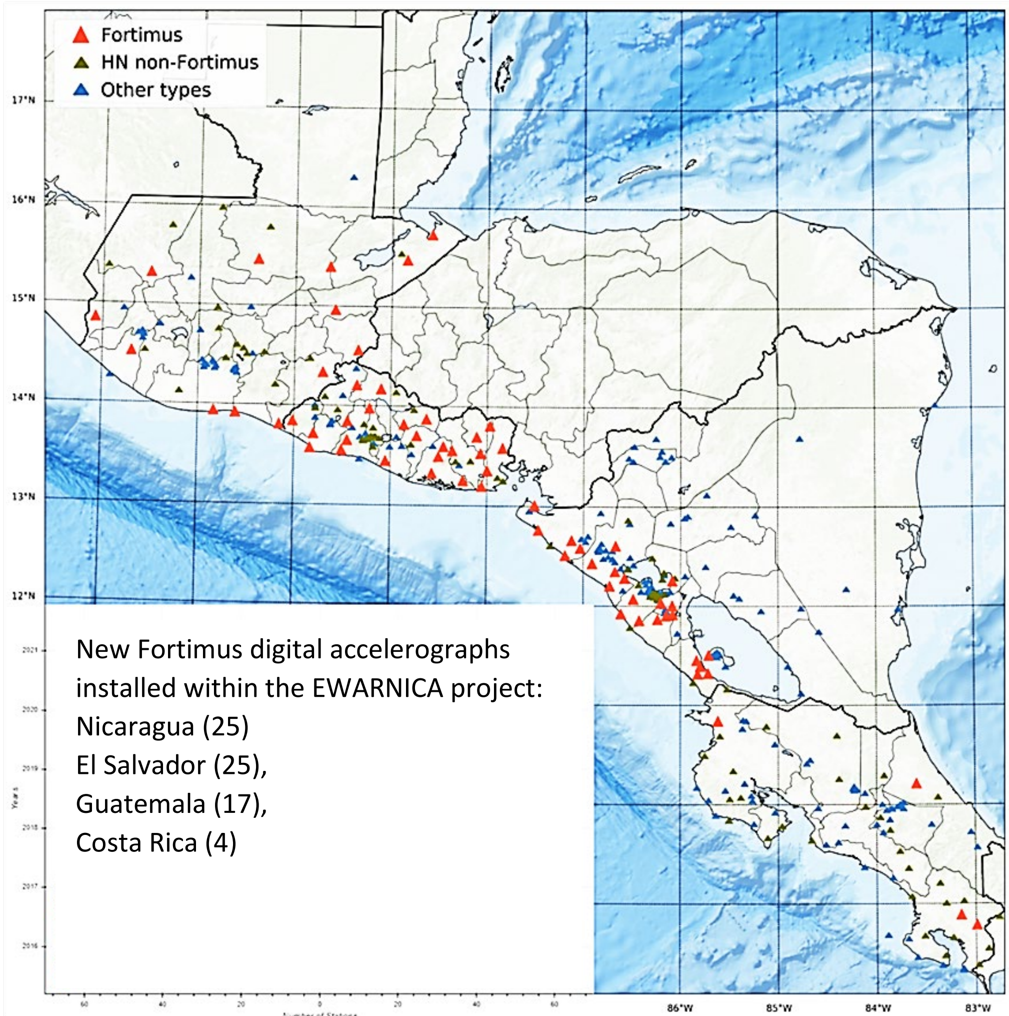

Figure . Location of new accelerometer stations installed in 2021 for earthquake early warning and tsunami warning (red triangles).

Global

CATAC maintains a special 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 awareness global of seismicity and zones close to the CATAC monitoring areas, such as South America and Eastern Caribbean. For big global earthquakes the CATAC SeisComP system also performs the calculation of the mmoment tensor and

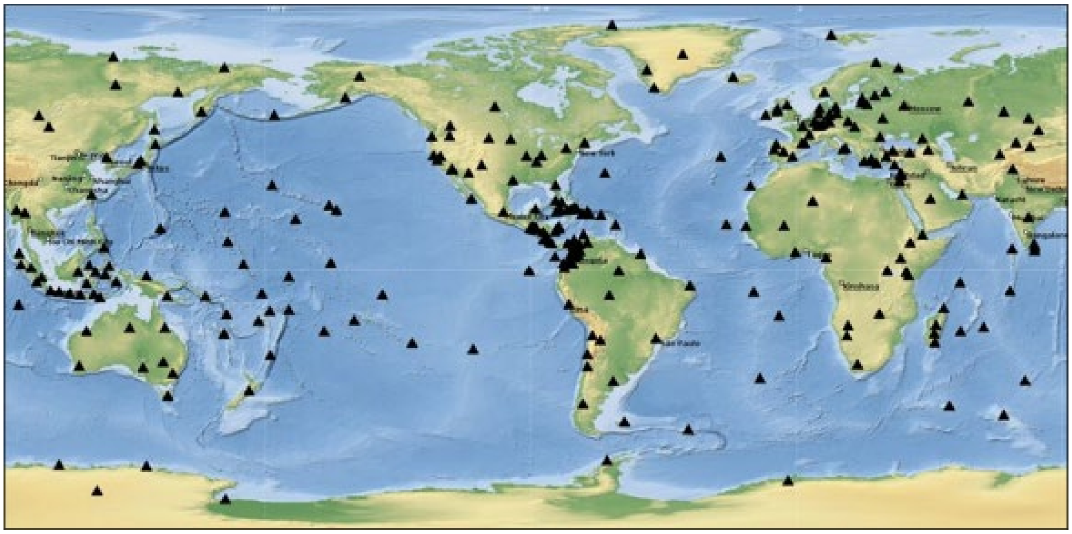

Figure 9. Seismic stations used by the CATAC global locator.

2.2.2 GPS/GNSS networks

In the last years methods were developed internationally to use displacement data obtained from GPS/GNSS for the characterization of large earthquakes. Magnitudes, moment tensors or event slip distributions can be obtained much faster than with the data from seismographs.

The INETER departments of Geophysics and Geodesy maintain In Nicaragua a total of 33 GPS/GNSS stations from which data with a sampling frequency of 1 Hz are streamed with the BKG Caster software to CATAC to be converted into displacement and fed to the SeisComP system. CATAC is recently working to develop the capacity for the use of these real-time data for tsunami advisory. In the near future CATAC expects to receive also GPS/GNSS data streams from other Central American Geophysical Institutions.

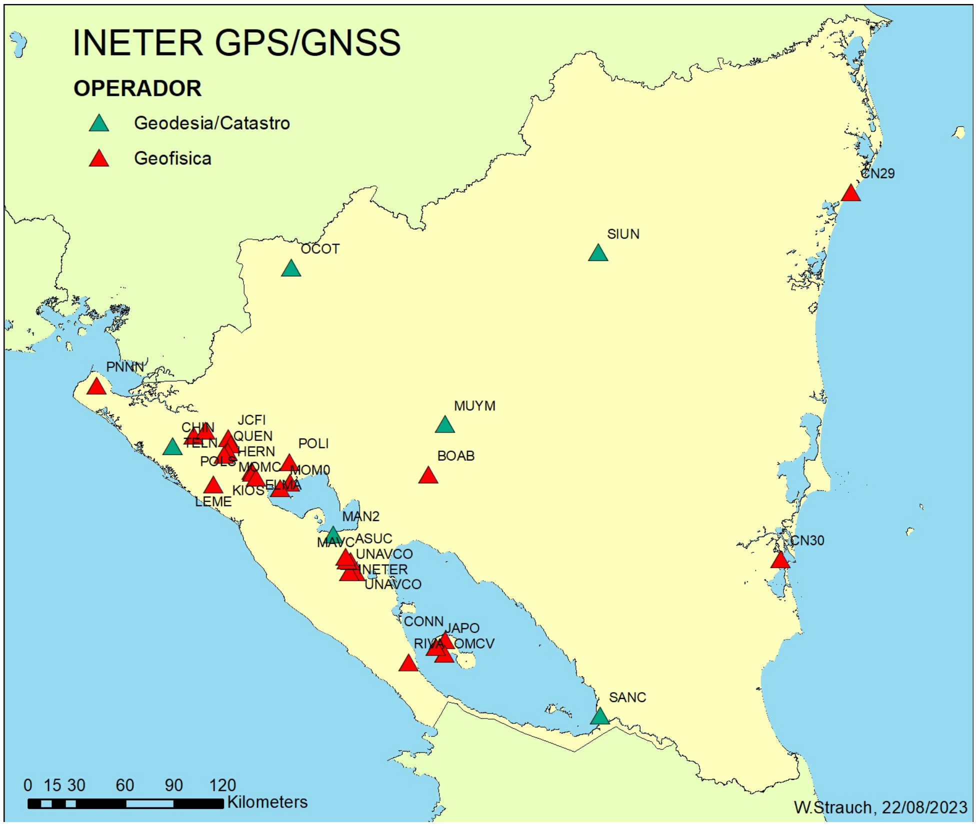

Figure . INETER GPS/GNSS network

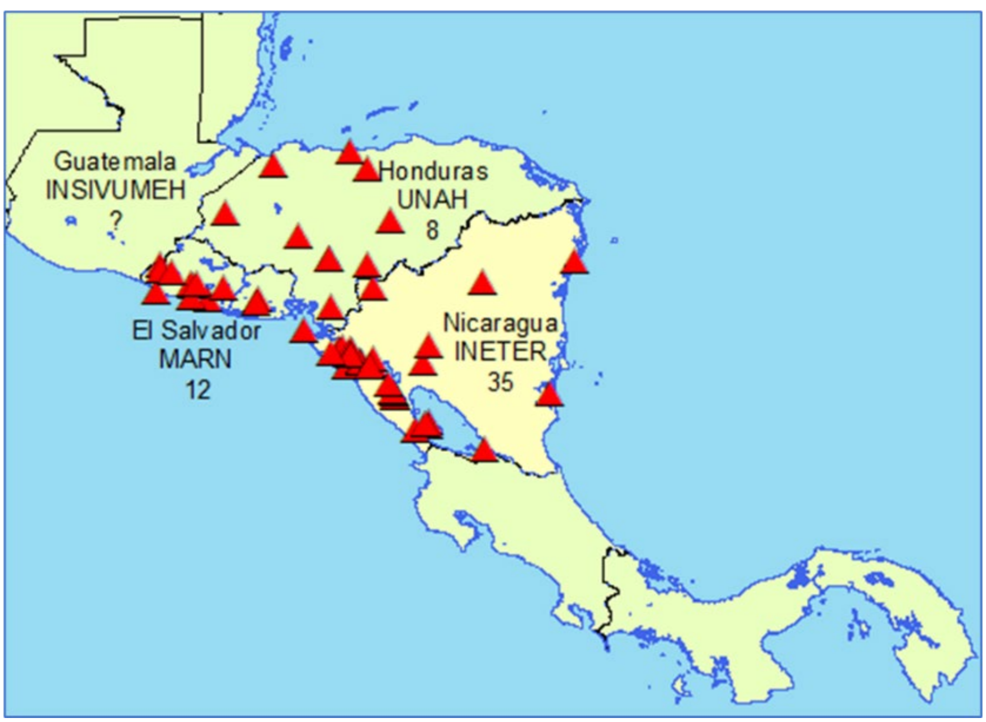

Figure . GPS/GNSS stations in geophysical institutions of Northern Central America

In Central America and the Caribbean there are many GPS/GNSS stations installed the data of which were exchanged freely during the project COCONET (with UNAVCO, now). INETER maintains since 2015 a regional mirror system of UNAVCO GPS stations in Central America and the Caribbean and expects to convert this system in a real time acquisition system for CATAC. maintained a server as a regional mirror for GPS/GNSS data from Central America and the Caribbean. CATAC pretends to make use of this experience and establish a real time download from these stations and use them (or a number of them for tsunami warning).

Figure . GPS/GNSS stations received at the Coconet mirror at INETER

2.2.3 Mareographic facilities

In case a tsunami is caused by an earthquake or any other event, its occurrence can be verified or measured using sea gauges located along the coast, deep water tsunami buoys, GPS/GNSS installed on large ships, GPS/GNSS or ocean radars located on the coast, or other appropriate methods.

CATAC´s SeisComP system receives data directly from INETER´s own sea gauges, or from foreign sea gauges via the COI/UNESCO sea level site (https://www.ioc-sealevelmonitoring.org/) operated by VLIZ. SeisComP´s TOAST module is used to visualize and process the data. Mareographic data are also received and visualized with TideTool (PTWC).

Mareographic stations in Nicaragua

INETER (both CATAC and Water Resources Department) has installed 6 mareographic stations on the Pacific Ocean coast of Nicaragua and 4 on the Caribbean coast. In some sites 2 stations are operating in parallel. In the last years the network was strongly affected by hurricanes and ship accidents and is in a process of restructuring.

A list and access to data of sea gauges in Nicaragua and the other countries of Central America can be obtained from http://catac.ineter.gob.ni/mareo.html.

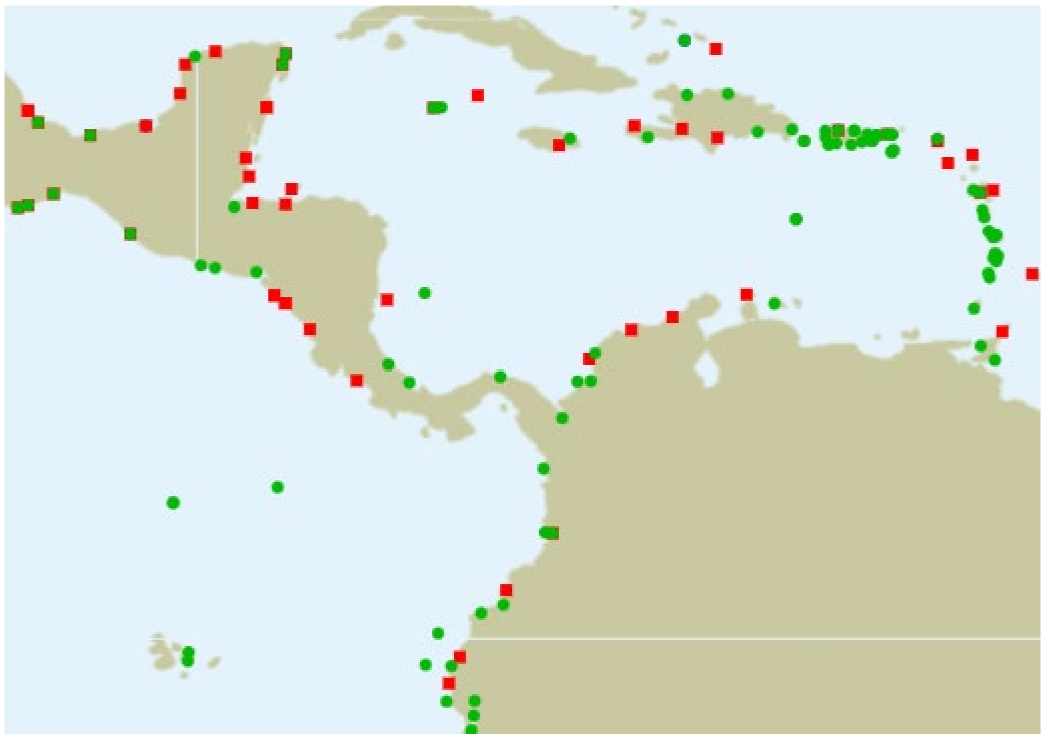

Figure . Sea level stations available to CATAC
(via www.ioc-sealevelmonitoring.org/map.php. Green squares - functioning stations; red squares - not operating stations at the moment of accessing the website.
(page accessed on 28/08/2023)

Volcano monitoring capacities for possible tsunami warning

CATAC/Seismological uses the seismic stations for volcano monitoring in Nicaragua and cooperates with INETER´s Volcanological section which maintains other sensors in the volcanic chain of Nicaragua.

2.3 Operational Tools and Procedures

CATAC uses the SeisComP software package (GFZ/Potsdam, GEMPA) in the PRO variant for both automatic real-time and manual post-processing of seismic data and tsunami analysis. 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.

2.3.1 Seismological Tsunami Source Characterization

Automatic and manual seismological standard processing

Automatic processing

Event detection and location

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

Magnitude

Automatic standard 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.

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).

Exploitation of Earthquake Early Warning 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 the the tsunami topic, 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 EEW for tsunami warning in Central America and promote its application.

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.

2.4 Tsunami Forecasting

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.

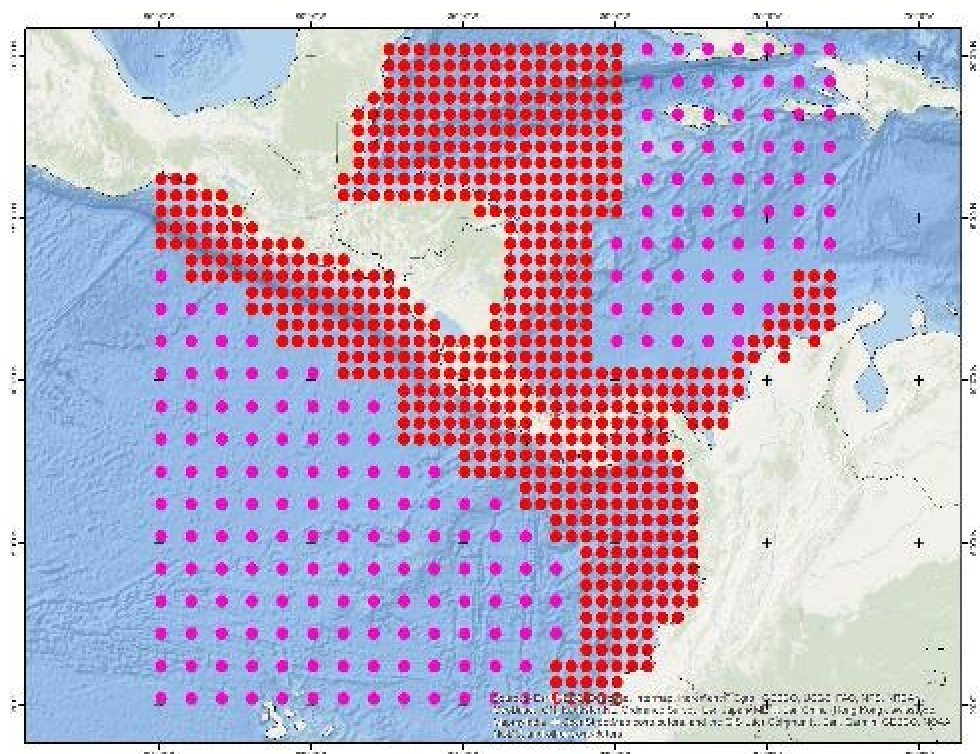

Figure 11. Assumed fault locations for the pre-calculated base. CATAC tsunami forecast data.

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.

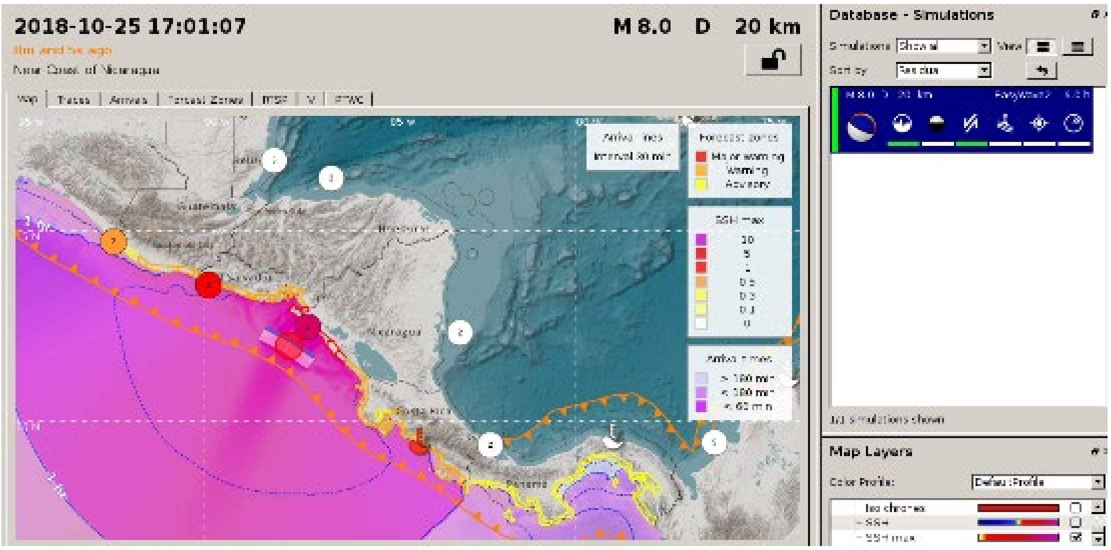

Figure 12 TOAST simulation of tsunami propagation of a magnitude 8.0 event off the Pacific coast of Nicaragua

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.

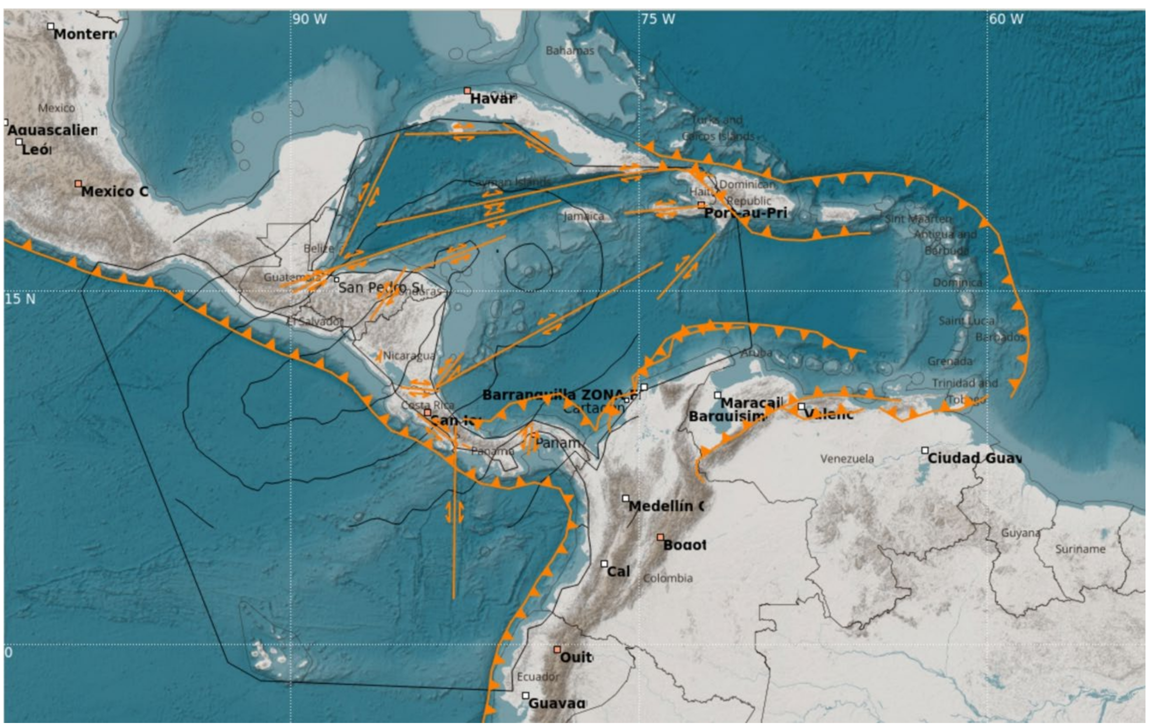

Figure . Plate boundaries with subduction process (yellow line with triangles) and other main faults (yellow line) in the CATAC monitoring area. When CMT is not yet known, TOAST uses a database of parameters of these faults as input for initial tsunami simulation

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 picking
- Observations of tsunami wave heights/periods by manual picking
- 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 sea 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, and 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.

2.4.3 Decision Support

2.4.4 Product Creation and Dissemination

CATAC tsunami advisory products are issued when an earthquake with moment magnitude 6.5 or greater is detected in one of the CATAC Monitoring Areas.

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

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.

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.

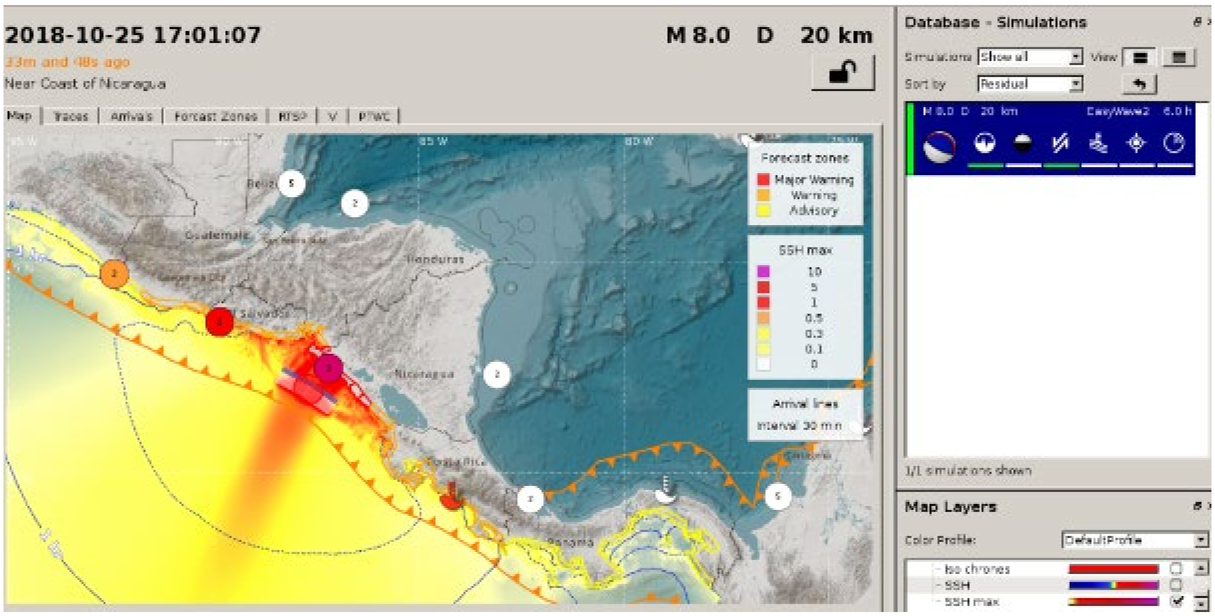

Figure . Tsunami energy radiance of a simulated event of magnitude 8.0 off the Coast of Nicaragua, created with TOAST.

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.

2.4.5 Timeline

Time/ minutes	Occurrence / Action
00	An earthquake rupture initiates in CATAC Monitoring Areas
0-0.3	The P waves leaving from the hypocenter are detected by at least 4 seismic stations
0.1-0.3	An earthquake early warning message is generated and sent out - only to recipients in Nicaragua
0.5-2	P waves are detected at 15 or more stations, the hypocenter is located. As soon the magnitude can be determined – an automatic message with seismological information is sent to all recipients, if the magnitude is 5 or bigger,
	A real time tsunami simulation is carried out with TOAST based on the initial earthquake parameters. The tsunami propagation is limited to 2 hours to reduce calculation time to about 20 seconds.
3	**The first CATAC tsunami text product** based on information from real-time simulation and is issued along with updated preliminary earthquake parameters.
	Another ATAC text product is issued if the earthquake parameters are updated .
8	**The automatic CMT solutions** are obtained and revised manually; The simulation in real time is recalculated again using CMT results with 2 hours propagation time

10	**The second CATAC text product and graphical products** based on real-time numerical simulation using CMT are issued.
10	An initial text product from PTWC CATAC arrives at CATAC and are compared with CATAC´s products. Eventual corrections are made. Possible interaction CATAC-PTWC
15	A real time tsunami simulation is carried out again with 4 hours tsunami propagation time and the text and graphical products are sent to the recipients.
20	A real time tsunami simulation is carried out again with 8 hours tsunami propagation time and the text and graphical products are sent to the recipients.
30	First tsunami arrivals are detected at sea gauges and informed to the recipients. Possibly a reinterpretation has to be carried out and product to be sent to the recipients
60	Tsunami arrivals are detected at sea gauges and informed to the recipients. Possibly a reinterpretation has to be carried out and product to be sent to the recipients
120 or more	Final product with text and graphical products with a possible cancellation of the tsunami threat.

3 Products

3.2 Product Types and Criteria

3.2.3 Informational

3.2.4 Threat

3.3 Product Content

3.3.3 Text Products

3.3.4 Graphical Products

4 Dissemination

4.1 Methodologies

4.1.1 Dissemination of Products

Nicaragua

In Nicaragua, sirens are the main system to disseminate the warnings of CATAC to the coastal population. Since 1915 there are 60 sirens installed in the communities at the Pacific coast. Twenty additional sirens were installed in 2022 in communities along the Caribbean coast that means there are now in total 80 sirens installed on both coasts. Most of the coastal population is in reach of the acoustic signals emitted from this system as typical siren sound or speech "Alerta de tsunami!". Thus, the vast majority of the entire population under tsunami danger can receive CATAC warnings by this means. The sirens are controlled by the Civil Defense organization of the Nicaraguan Army via a digital VHF radio system. After receiving a warning message, they activate by pressing a single switch or using a computer all sirens of a coast or part of them. While the system was installed for tsunamis warning the sirens can also be used for other emergencies. Each siren can also be activated locally if necessary. The sirens a completely independent from commercial electrical power as each device has a solar panel and a battery.

The installation of sirens has also begun in the other Central American countries but up to the moment no other country has reached the completeness of the siren system as in Nicaragua.

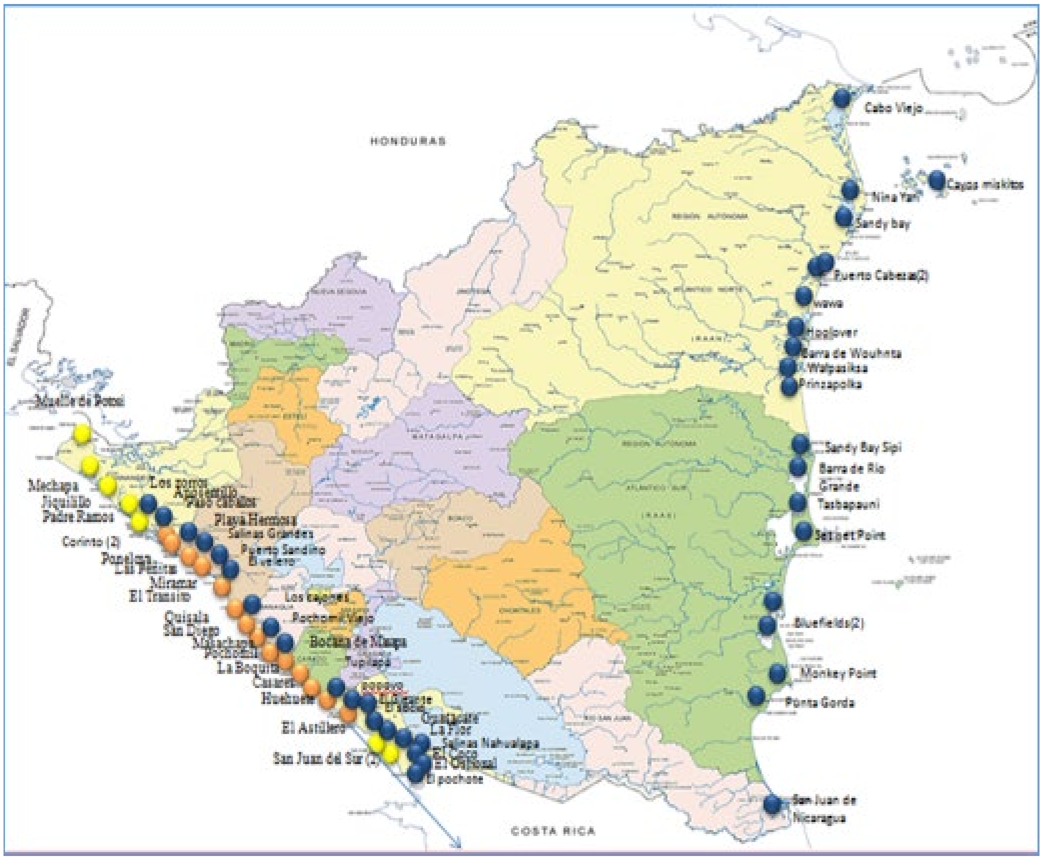

Figure 6. Location of sirens on the Pacific and Caribbean coasts of Nicaragua.

Delivery to other countries

4.1.2 Customer Decision Support

To be completed.

4.2 Communication Testing

To be completetd

Conducting Regional Tsunami Exercises

CATAC is participating

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".

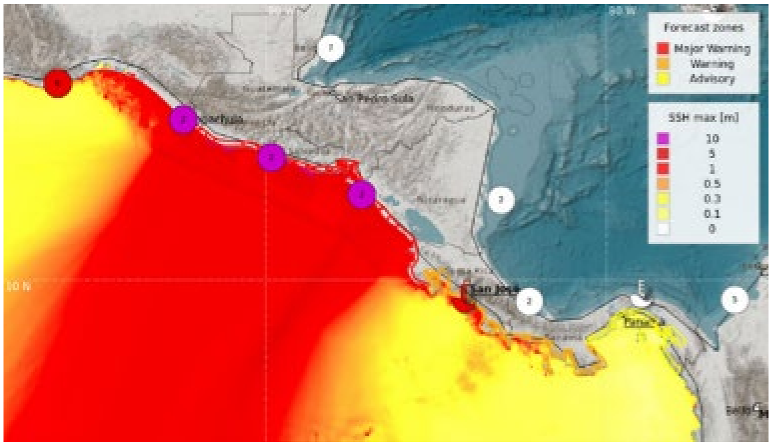

Figure 14. Tsunami map of exercise 1.

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.

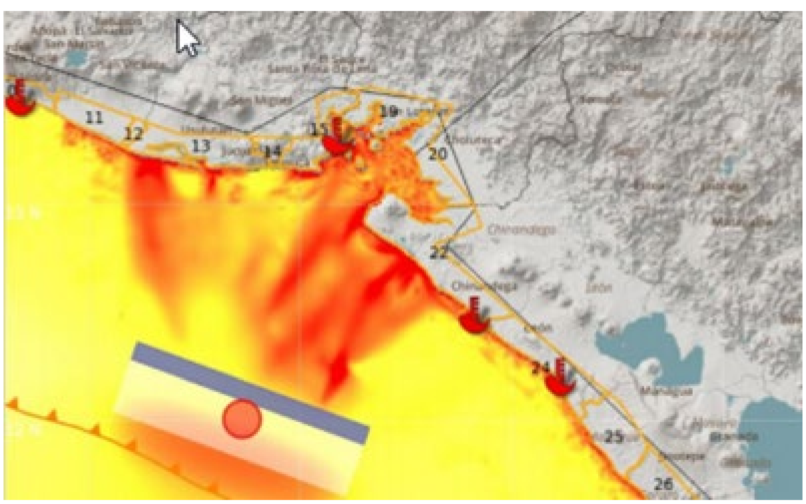

Figure 15. Tsunami map of exercise 2.

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

4.3 Capacitation

During the reinforcement of CATAC in 2016-2019 several efforts went on to capacitate CATAC´s future customers i.e. the scientific institutions or NTWC and the civil protection agencies or TWFP. Especially two UNESCO projects on the elaboration of Standard Operation Procedures SOP in the countries of Central America are to be mentioned in which participated both the NTWC as well the TWFP. But, as CATAC was not yet officially established as a Tsunami Service Provider it was not included in the SOPs but only the PTWC remained as the source of tsunami information.

Unfortunately, the capacitation process was interrupted due to the pandemic COVID-2019. While CATAC continued operating normally most related institutions suffered heavy restrictions of their activities. It was impossible to visit the countries and institutions. The virtual meetings

In March-June 2023, CATAC with the help of JICA and CEPREDENAC carried out 17 webinars of 2 hours duration, to discuss in each of the 6 countries of Central America, Belize and Dominican Republic with its customers about CATAC´s procedures and products. The topics presented and discussed were: Tsunami Hazard country specific; Minimum dangerous tsunami height; Zones with small impact times; CATAC procedures; Tsunami simulation; Warning products; Warning messages; Warning methods (social networks); Recipients of messages; Country protocols; Proposals.

The institutions were asked about the established SOPs in the different countries and institutions and it was found that with exception of Nicaragua CATAC, though it is known, it is still not considered in the official procedures.

Thus, CATAC, JICA and CEPREDENAC developed the idea of a capacitation effort to change this situation. A project proposal was elaborated to be funded by JICA and to be executed from 2023 till 2025. It foresees the execution of a virtual meeting of

On September 1st, 2023, JICA published a call for the "Third Country Course for the Strengthening in the use of the Earthquake and Tsunami Warning products of the Central American Tsunami Advisory Center (CATAC)", to be held in two phases. The first phase in virtual mode, from November 13 to 17, 2023 and the second phase in face-to-face mode, from November 20 to 24, 2023 in Nicaragua. The objective of this course is to train key personnel on CATAC methods and products for earthquake and tsunami warning and their proper application by civil protection institutions in Central American countries, as well as to promote the exchange of experiences and knowledge among participants. In this regard, the excellent efforts of CEPREDENAC are requested in order to share the information of the course to the civil protection institutions of the Central American region. An invitation was extended for the participation of a CEPREDENAC official during both phases. In addition, on November 20, 2023, an inauguration ceremony will be held with international participants and Nicaraguan authorities.

This course will be repeated in November 2024 and 2025, additionally visits of CATAC personnel to the countries are also programmed. That way CATAC will be able to stay in direct contact with its customers.

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 Advisory Center [CATAC], Abstract, 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. 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. (English: 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, Nicaragua, Proyecto 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

I. Example Products

I.1 Text products

IV.

IV.2. Examples of CATAC graphic products

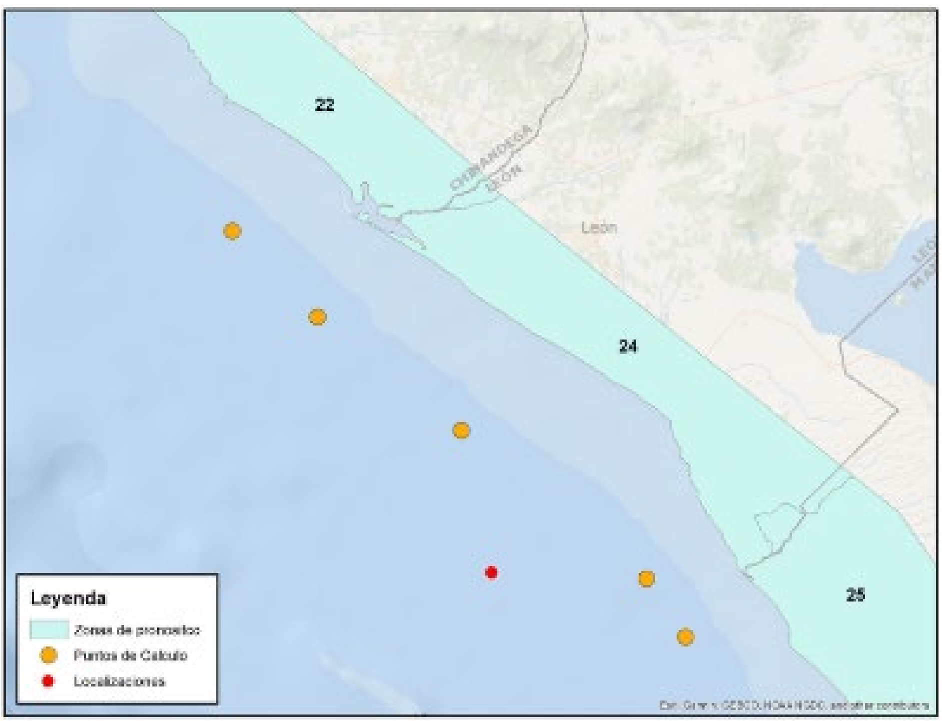

Figure 16. Coastal blocks and forecast points on the coast. Forecast points at 50 m depth. Definition of forecast zones at departmental level. Maximum values obtained for 70 forecast zones. For 130 forecast points on the Pacific and Caribbean coast.

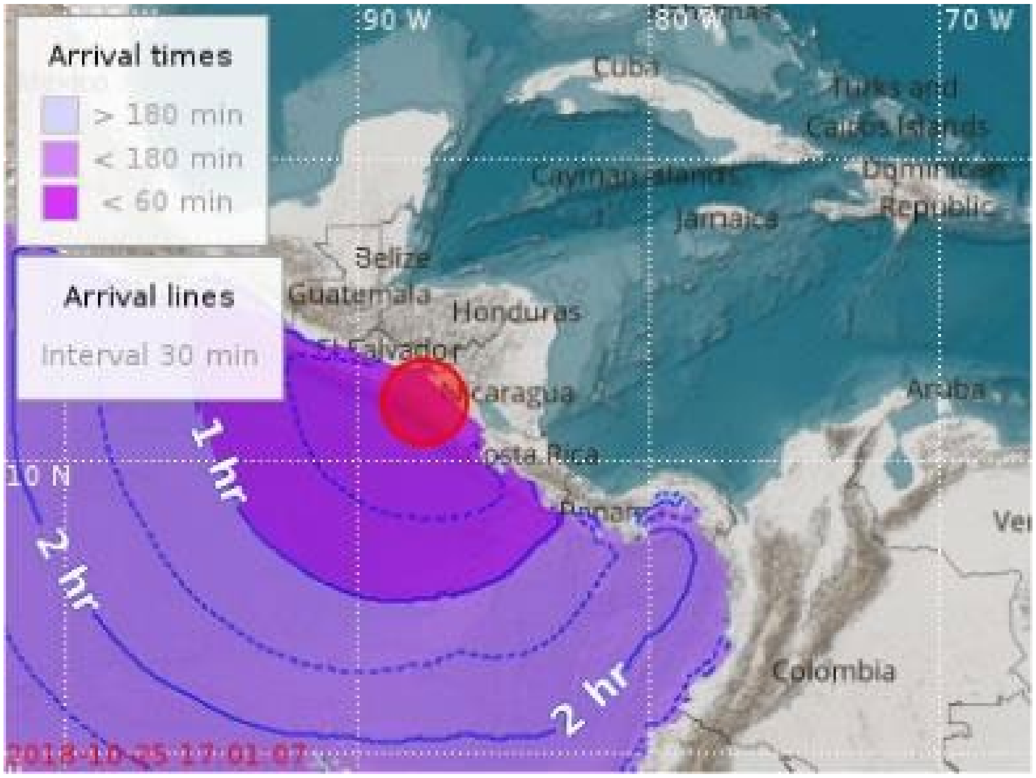

Figure 17. CATAC Tsunami arrival time forecast.

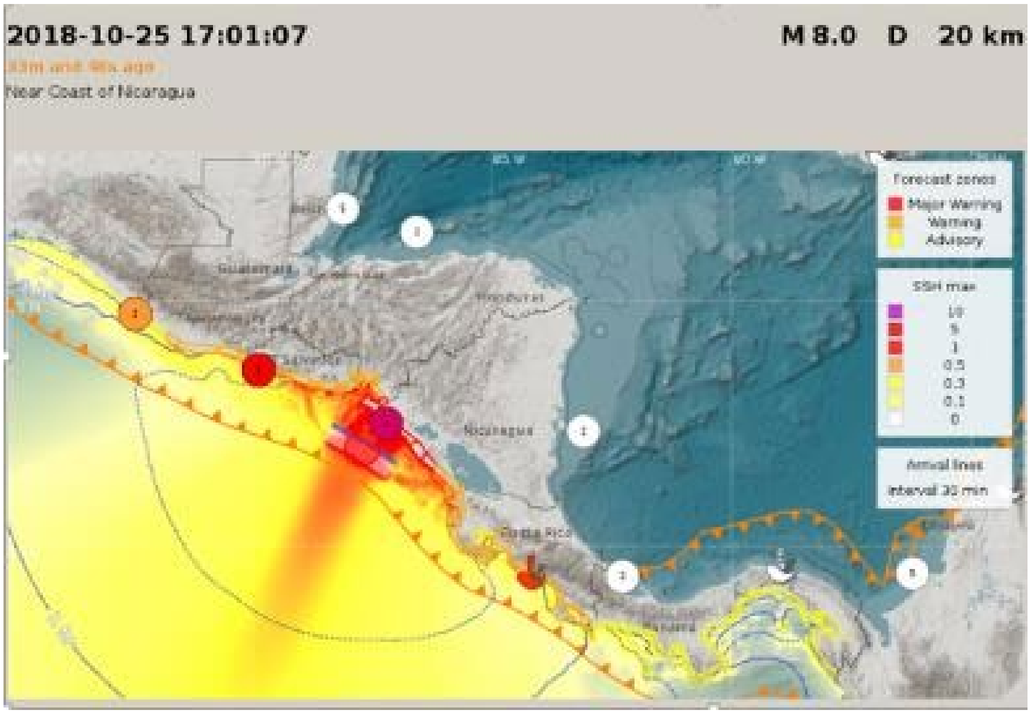

Figure 18. CATAC Tsunami coastal amplitude forecast.

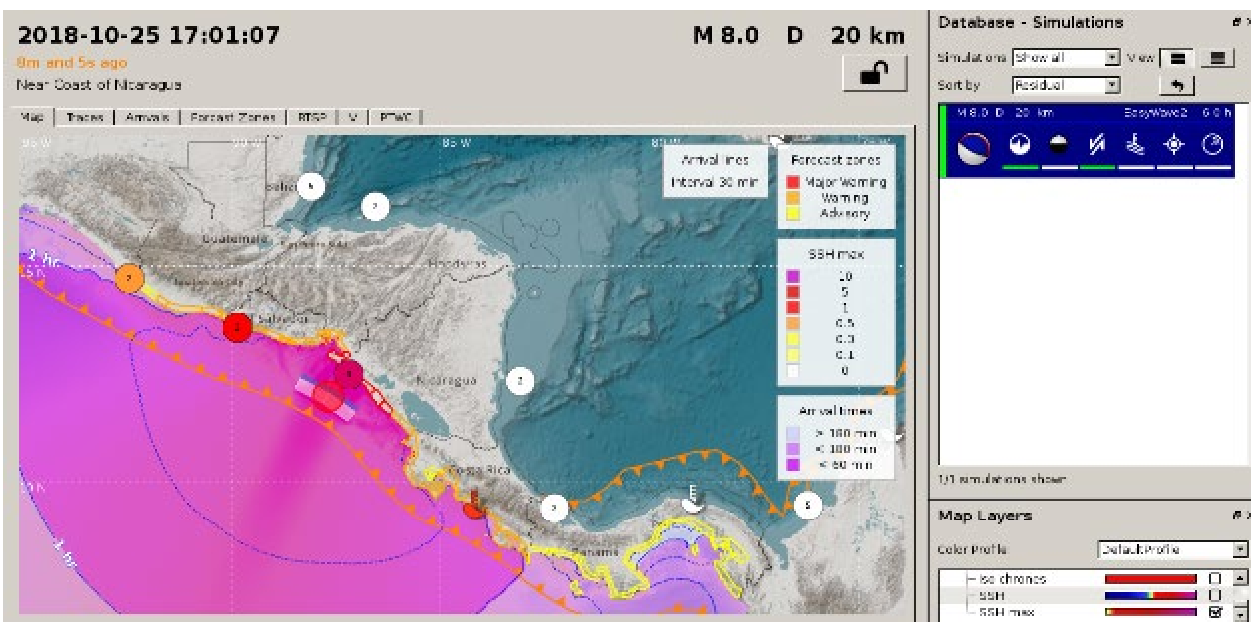

Figure 19. CATAC Deep-sea tsunami amplitude forecast.

Example of Text Message generated by TOAST at 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 0:02:37 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
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II. Forecast Points

Map of Forecast points

List of Forecast Points

Country, Sitename. Latitude, Longitude

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
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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
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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
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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
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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
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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
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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
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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

III. Observation Sites

Reference to a table at CATAC´s webpage

IV. NTWC and TWFP in Central America

CATAC is cooperating with the following institutions

NTWC o Institutions responsible for scientific monitoring, CATAC receives seismic and geophysical data from

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 2023 onwards, INETER will directly sends 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:

- **a)** 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.
- **b)** Geophysical Institute, University of Honduras. Maintains the seismic network of UNAH

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

6) Panama:

- **a)** Institute of Geosciences of the University of Panama (IGC-UPA)
- b) Panama Canal
- c) Baru seismic network

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

1) Nicaragua:

- **a)** National System for Disaster Prevention, Mitigation and Response (SINAPRED)
- b) Civil Defense of the Nicaraguan Army.

It is intended that, as of 2023, 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 institution related to Disaster prevention including tsunamis

1) **CEPREDENAC;** Center for Disaster Prevention in Central America

   Coordination of disaster prevention measures and the establishment of a common politics on disaster prevention and mitigation

V. Current list of addressees for the messages of CATAC

ANNEX 6. List of CATAC staff, September 2023

#	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	Eng. 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	Eng. Jaqueline Sanchez	X	Seismology, Tsunami, Computer Science
13	Eng. Juan Carlos Guzmán	X	Seismology, Tsunami, Computer Science
14	Tec. Allan Morales	X	Seismometry, Tsunami, Electronics
15	Tec. Antonio Acosta	X	Seismometry, Tsunami, Electronics
16	Lic. Ana Rodriguez	X	Seismology, Tsunami, GIS
17	Eng. Milton Espinoza	X	Seismology, Tsunami, GIS
18	Lic. Wesly Rodríguez	X	Geophysics, Seismology, Tsunami
19	N.N. free position (sep 2023)		

X - serves as a 24x7 on-call seismologist

In addition: Consultant: Eng. Gerzon González (programming, IT)