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The Caribbean Disaster Emergency Management Agency

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TSUNAMI SMART

Tsunami and Other Coastal Hazards Information Kit for the Caribbean Media

Tsunami & Other Coastal Hazards Warning System Project

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This document and any updates to it are available at www.cdema.org, www.weready.org and www.uwiseismic.com.

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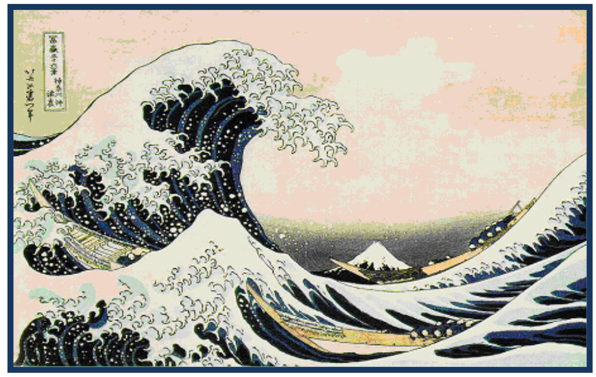
TABLE OF CONTENTS

Frequently Asked Questions on Tsunamis

WHAT IS A TSUNAMI?



A tsunami is an ocean wave or series of waves caused by a sudden disturbance of the ocean floor that displaces a large amount of water. Tsunami waves are different from large waves brought by storms. They usually look like a surge of sea inland rather than breaking waves. Tsunamis bring many surges that can last for hours, arriving every ten to sixty minutes.[1]

Are tsunamis and tidal waves the same thing? No. Strictly speaking, a tidal wave is related to ocean tides while a tsunami is triggered by earthquakes, landslides or volcanic events.

How are tsunamis formed? Tsunamis are caused generally by earthquakes, less commonly by submarine landslides, infrequently by submarine volcanic eruptions and very rarely by large meteorite impacts in the ocean.

Do all earthquakes cause tsunamis? No, all earthquakes do not cause tsunamis. There are four conditions necessary for an earthquake to cause a tsunami:

(1) The earthquake must occur beneath the ocean or cause material to slide into the ocean.

(2) The earthquake must be strong, at least magnitude 6.5.

(3) The earthquake must rupture the Earth's surface and it must occur at shallow depth – less than 70km below the surface of the Earth.

(4) The earthquake must cause vertical movement of the sea floor (up to several metres).

How do volcanic eruptions cause tsunamis? Although relatively infrequent, violent volcanic eruptions can displace a great volume of water and generate extremely destructive tsunami waves in the immediate source area. According to this mechanism, waves may be generated by the sudden displacement of water caused by large volumes of volcanic material entering the sea.

What are some effects of a tsunami? A tsunami is usually a series of waves and the first wave is often not the largest. Tsunami waves are powerful and capable of moving dangerous

[1] "Preparing Your Community for Tsunamis." Samant, L.D., Tobin, L.T., Tucker, B. (2008). GeoHazards International

debris such as trees, boats, cars and small structures. They can flood (inundate) hundreds of metres inland past the typical high water level and even beyond areas flooded by storm surge.

How do tsunamis behave? Tsunamis tend to be small – even imperceptible – when travelling over open water, and do not 'size up' until they approach shallow water nearer to the coast. As a tsunami approaches shore, it begins to slow while increasing in height. Often at this point the shoreline begins to recede, drastically exposing the seafloor – reefs, rocks and stranded fish may be seen on the sand. They approach the coast with tremendous amounts of energy as they attain great height upon reaching the continental shelf – the part of the Earth's crust that slopes or rises from the ocean floor up to the land. Tsunamis may attain maximum vertical heights onshore of up to 30 metres.

Can tsunamis occur in the Caribbean? Tsunamis have impacted the region in the past and are therefore, expected to occur in the future. In the past 500 years there have been at least ten confirmed earthquake-generated tsunamis in the Caribbean Basin with four causing fatalities. An estimated number of more than 3000 persons were killed by these events.

Since the islands of the Caribbean lie in an area of relatively high earthquake activity, earthquake triggered tsunamis are the most likely tsunamis to affect the region. The recurrence rate for tsunamis in the Caribbean is approximately: 1 destructive tsunami per 200 years for distant earthquakes, i.e. earthquakes occurring outside of the Caribbean.

Is there a tsunami early warning system in the Caribbean? Currently, there is no comprehensive Caribbean tsunami early warning system. Scientists at various monitoring agencies and other technical experts in the Caribbean and adjacent areas (Central America and South America) are in the process of developing a tsunami warning system for the region but it may be several years before this is complete. This system is being coordinated by the ICG/CARIBE the Caribbean chapter of UNESCO's Intergovernmental Oceanographic Commission (IOC).

In the mean time, if an earthquake occurs that can or has triggered a tsunami that may affect the Caribbean, the Pacific Tsunami Warning Center (PTWC), which currently provides interim services, will send a warning to specific agencies in the Caribbean except Puerto Rico and the Virgin Islands. Though a Caribbean Tsunami Warning Centre with specific responsibility for issuing tsunami bulletins for the Caribbean is to be established, communicating this warning within countries, however, is the responsibility of key local agencies including the National Disaster Management Organisation.

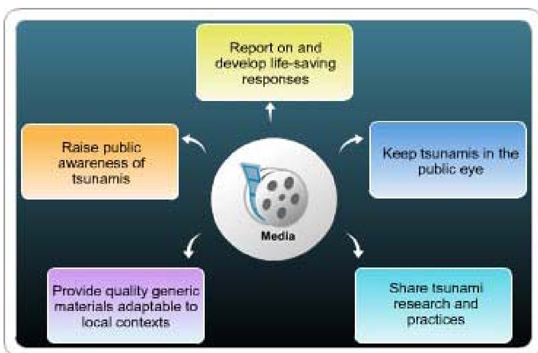
The Media

The Media's Role

Media professionals provide a vital link between politicians, experts and communities. The media can help save lives and protect communities as it plays a critical role in reporting on tsunamis that threaten – or have struck – countries and regions.

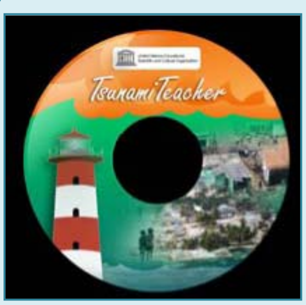
The media can also provide the public with important information on tsunami preparedness. For instance, the media can highlight designated safe areas during a tsunami or the media can educate parents on appropriate responses to maximize family safety during a tsunami.

A UNTV cameraman in Mullaitivu, a town in Northeastern Sri Lanka ravaged by the tsunami of 26th December 2004.



Journalists can usefully question local and national authorities about tsunami and other emergency strategies and businesses about systems in place to warn clients and prepare staff for a tsunami event. The media can also investigate disaster relief and reconstruction plans that the public and private sectors may (or may not) have developed.

The media is crucial to the rapid dissemination of tsunami warnings as development of a tsunami warning system for the Caribbean progresses. The media is encouraged to adopt policies which ensure that the bulletins which are provided by local authorities are issued to the public immediately, and the content is disseminated in the manner it was received. After a disaster has struck, news media can provide effective communication channels and can assist in rapidly providing a picture of how a tsunami has affected impacted areas thus helping to more efficiently direct aid and rescue efforts to survivors.



***Tsunami Teacher* Media Module** provides accurate, verified information for media professionals to improve their knowledge of tsunamis. The objective is to encourage the production of quality articles and programmes that promote public awareness and understanding of tsunami events and to help to develop responses that have the potential to save lives. It can be found at: http://ioc3.unesco.org/TsunamiTeacher/

Graphic Courtesy: *Tsunami Teacher*, UNESCO IOC
International Tsunami Information Center (2006)

The media can support tsunami safety by keeping the public up-to-date on information and research so as to promote tsunami public awareness. In the aftermath of an event the media also plays an important role in monitoring relief efforts and the performance of authorities in rebuilding areas that tsunamis may have devastated.

Key Tsunami Smart messages for the public

1) Tsunamis have occurred in the Caribbean in the past and can occur in the future.
2) If you are at the coast and you feel a very strong shaking leave immediately and head inland or to high ground.
3) If you are at the beach and the sea withdraws drastically exposing the seafloor, leave immediately and head inland or to high ground.
4) Recognizing these natural warning signs could save your life.
5) Do not wait for all the natural warning signs to occur before moving inland or to high ground.
6) Do not wait for an official warning before evacuating as there may not be enough time to issue one.
7) If a Tsunami Warning is issued, **NEVER** go down to the beach to watch the waves.
8) A tsunami is a series of waves that can come ashore for hours and the first wave is not necessarily the largest or most deadly.
9) After the tsunami, stay out of the danger area until an "all-clear" is issued by the competent authority.

Preparedness Actions

Before a Tsunami

- Find out if your home, school or office is in a danger area by knowing the distance it is from the coast.
- If you live or work in a low-lying area – for instance near to the beach – learn the quickest way to get to high ground. A safe area would be at least 30m (~100feet) above sea level and 3km (~ 2miles) inland. Teach and practice your evacuation plan with all family members and work colleagues.
- Ensure that all family members and work colleagues know how to detect natural tsunami signs.
- Discuss tsunamis with your family, friends and work colleagues.
- **Gather disaster supplies:**
  - o Flashlight and extra batteries
  - o Portable, battery-operated radio and extra batteries
  - o First Aid kit and manual
  - o Emergency food and water
  - o Medication for chronic conditions

o Cash and credit cards

- Develop an emergency plan in the event that family members are separated (e.g. during the workday when adults are at work and children are at school). Agree on a close friend or relative that should be contacted if children cannot reach their parents and vice-versa.

During a Tsunami

Sensing a tsunami

Tsunamis are often accompanied by natural signs that can be sensed by an alert person. Recognizing **any** of these tsunami warning signs at the beach may save your life.

FEEL

Do you FEEL the ground shaking strongly?

Strong earthquakes at the coast may cause tsunamis. If you feel a strong earthquake **RUN** to high ground after the shaking stops. Do not wait for an official warning to be issued. You may have less than 10 minutes before the first tsunami wave arrives.

SEE

Do you SEE an abnormal withdrawal of water?

As a tsunami approaches land, the ocean may pull back a long way from the shore, exposing the ocean floor, reefs and fish. **RUN** to high ground if the sea withdraws an abnormal distance away from the shore.

HEAR

Do you HEAR a strange roar?

A roaring sound from the ocean is sometimes heard before a tsunami arrives. **RUN** to high ground if you hear the roar.

- Sometimes tsunamis may occur without the initial withdrawal of the sea.
- A tsunami may be seen as a massive wall of water approaching land.
- If you are unable to move to higher ground go to an upper floor (3rd storey or higher) or roof of a building. As a last resort, climb a strong tree if trapped on low ground.
- If swept up by a tsunami, look for something to use as a raft.
- Abandon belongings. Save your life, not your possessions.
- **Never** go down to the beach to watch for a tsunami. If you can see the wave, you are already too close to outrun it.
- **A tsunami is not a single wave**, but a series of waves that can come ashore for hours. **The first wave may not be the largest**. During the 2004 Indian Ocean tsunami it was the second wave that killed people, not the first.
- Play it safe and heed official warnings. Even if you think the danger has passed.

- Stay out of danger zones until an "all-clear" is issued by a recognized authority e.g. your National Disaster Organisation.
- If possible, listen to the radio for official updates and instructions.
- Have the telephone number for your National Disaster Organisation at hand.

After a tsunami

- Stay tuned to a battery-operated radio for the latest emergency information.
- Help injured or trapped persons and persons requiring special assistance (infants, elderly people and persons with disabilities).
- Do not move seriously injured persons unless they are in immediate danger of fatal injury.
- Stay out of damaged buildings. Return home only when authorities say it is safe to do so.
- Shovel mud while it is still moist to give walls and floors an opportunity to dry.
- Check for electrical shorts and live wires. Never attempt to move live wires.
- Check for gas leaks.
- Keep out of stagnant water.
- Open windows and doors to help dry buildings.
- Check for damage to sewer and water lines.
- Check food supplies and have tap water tested by the local health department if possible.
- Fresh food that has come in contact with flood water may be contaminated and should be discarded.

- Expect the waves to leave debris. A tsunami will leave behind sand, the remains of houses and bodies.
- Expect earthquakes to lower coastal land. A large earthquake can leave nearby coastal areas lowered, allowing tidal water to flood them.

TSUNAMI WARNING MESSAGES

In the event of a potential tsunami threat in the Caribbean (except for Puerto Rico and the Virgin Islands), the Pacific Tsunami Warning Center (PTWC) may issue the messages below to regional Tsunami Warning Focal Points (specific agencies designated by each government to receive tsunami warnings from tsunami warning centers) in each country. Although a Caribbean Tsunami Warning Centre with specific responsibility for issuing tsunami bulletins for the Caribbean is to be established, communicating this warning within countries, however, is the responsibility of key agencies within the National Disaster Management System and the National Disaster Organisation.

TSUNAMI INFORMATION BULLETIN/STATEMENT advises of major earthquakes and gives general information about tsunami threats. In most cases, it indicates there is no threat of a destructive tsunami, and is used to prevent unnecessary evacuations as the earthquake may have been felt in coastal areas.

A TSUNAMI ADVISORY is issued when there is the threat of a tsunami which may produce strong currents or waves dangerous to those in or near the water.

A TSUNAMI WATCH is the second highest level of alert. Watches are issued based on seismic (earthquake) information without confirmation that a destructive tsunami is underway. It is issued as a means of providing an advance alert to areas that could be impacted by destructive tsunami waves.

A TSUNAMI WARNING is the highest level of alert. It is issued where there is imminent threat of a tsunami from a large underwater earthquake or following confirmation that a potentially destructive tsunami is underway. The danger may continue for several hours after the arrival of the initial wave.

A CANCELLATION BULLETIN is issued to ensure that the population knows that the wave threat is no longer there.

Understanding Tsunamis and Other Coastal Hazards

Introduction

The Indian Ocean tsunami of 26th December 2004, which exerted a devastating toll in human suffering and destruction in affected coastal areas, was a harsh reminder that coastal communities are vulnerable to natural events that can produce massive unforeseen effects.

Coastal hazards are those natural and manmade hazards that occur where the ocean meets the coastline. Most notable of the natural hazards are the high winds, waves and floods generated by atmospheric disturbances such as tropical storms, hurricanes and geologic events such as earthquakes and tsunamis. Such events have led in some cases to coastal real estate and infrastructure being threatened and/or destroyed by the sea. Unfortunately, coastal hazards often go unaddressed until the sea is lapping at the front door. These periodic and episodic hazards include not only natural events that threaten the health and stability of coastal ecosystems and communities, but also effects induced by human activity.

Oblique aerial photo of the coastal city of Port of Spain Trinidad
Photo: A. Maharaj www.panoramio.com/photo/2205141

Coastal areas around the world are experiencing an unprecedented rate of change due to population growth, human induced vulnerability, and global climate change. In the Caribbean, coastal areas are increasingly being settled, with 60% of the population now living within an area extending less than 100 km from the coast. This includes capital cities, industrial complexes, trade centre's and resort tourism enclaves. In addition the resident population is swelled every year by the influx of over 40 million tourists nearly all of whom converge on the region's beaches.

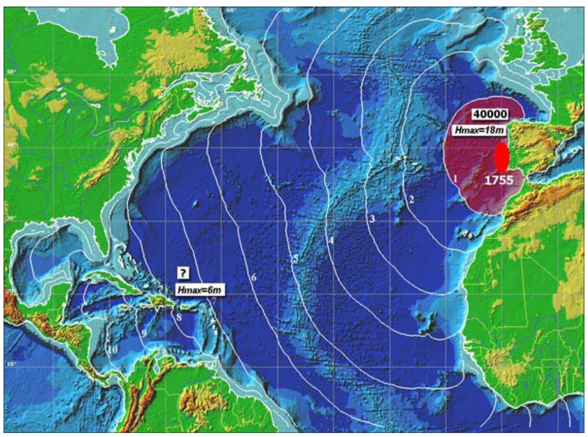
When compared to other natural disasters, the tsunami risk in the Caribbean is "minor"[2] however the impact could be "major"[3]. Between 1690 and 2004 there were at least 360 deaths from tsunamis in the Caribbean compared to 43,120 for hurricanes. There were six destructive tsunamis compared to 28 destructive hurricanes. The most people killed by a single tsunami was 200 compared to 15,600 by a single hurricane. With the increase in population and affluence concentrated in vulnerable coastal areas today, the threat has increased. There are

[2] "UWI Seismic Research Centre comments on proposed tsunami early warning system" – http://www.cdera.org/cunews/news/article_879.php
[3] "On the role of IOCARIBE in a Caribbean tsunami system: Science, Engineering, management, and Education" by George Maul

approximately 2 million people vulnerable to a tsunami and 18 million for a hurricane. However, with improved early warning systems in place for hurricanes and none for tsunamis the forecast for the biggest credible loss of life in a future Caribbean event is 40,000 fatalities for a tsunami against 20,000 fatalities for a hurricane.[4]

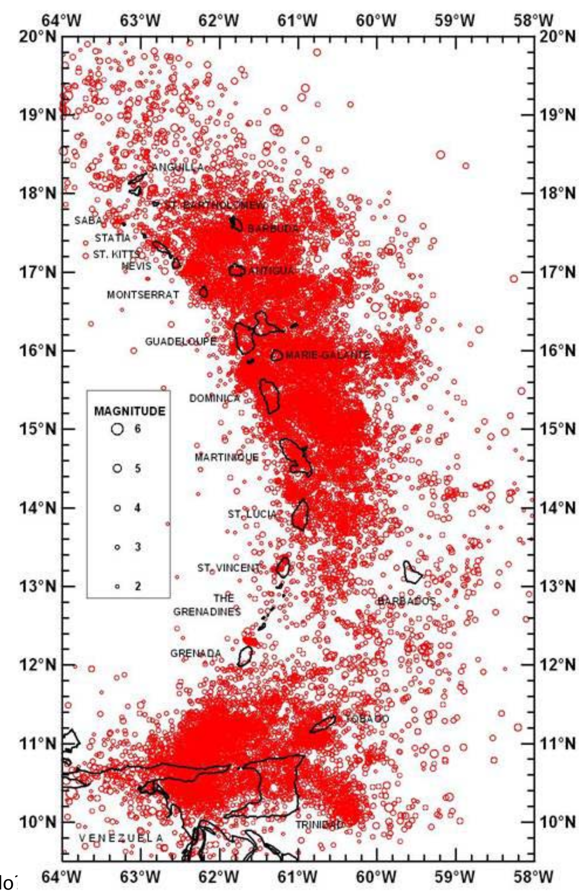
Tsunami Risks in the Caribbean

The Caribbean region is an area of moderate seismicity and, although tsunamis are not a frequent natural hazard in the Caribbean, their impact can be as devastating as hurricanes, earthquakes or volcanic eruptions. Infrequent events with limited predictability pose the greatest risk of disaster with an associated extended period of disaster recovery. Large tsunamis can be devastating to life and property in coastal areas. They can travel at speeds up to 800km/hour (the speed of a jet airliner) in the deep ocean, where the waves are barely noticeable, but as they enter shallow water they slow down and grow in height tremendously.



Tsunami travel time chart for the 1755 Lisbon tsunami. Solid ellipse marks position of the earthquake source. Red color shows the area within 1-hour propagation time. Source: tsun.sscc.ru/TTT_rep.htm

All known tsunami generating mechanisms are found to occur within the Caribbean, these include earthquakes, volcanic eruptions and landslides. In addition to which, there is the potential for tele-tsunamis from sources across the Atlantic.



Since the Caribbean islands lie in an area of moderate earthquake activity, the most likely tsunamis to affect the Caribbean would be those triggered by shallow (less than 70km depth) earthquakes of magnitude greater than 6.5 within the region. Tsunamis can also be caused by large volcanic eruptions at or below sea level. In the Eastern Caribbean the submarine volcano, Kick-'em-Jenny located 9 km north-west of Grenada, erupts on average every 11 years. Two of those eruptions, in 1939 and 1965, are known to have generated small tsunamis that were witnessed on

[4] "Tsunami risk in the Caribbean: How big are they and what should we do'

Earthquake epicenters <35km deep in the eastern Caribbean subduction zone (1955-2006/09). Source: The UWI Seismic Research Centre the north coast of Grenada. However, detailed studies of the physical structure of Kick 'em Jenny conducted in 2002-2004 suggest that the volcano does not currently pose an immediate tsunami threat, but it is possible that future eruptions could change this picture.

Earthquake Generated Tsunamis in the Caribbean

Date	Location	Cause	Mag	Effects
1690 April 6	Leeward Islands	Earthquake between Antigua and Guadeloupe	7.5-7.8	Separate tsunamis generated by landslides into the sea in Antigua and Nevis. Extensive earthquake damage but no reported damage or casualties attributed to tsunamis
1692 June 7	Jamaica Cuba	Earthquake	7.5	Tsunami generated with run-up of 1.8 m. Of the 2-3000 casualties, most were attributed to the earthquake.
1843 Feb 8	Leeward Islands	Earthquake	8+	Tsunamis generated by landslides into the sea in Antigua, Montserrat and Nevis. Extensive earthquake damage but no reported damage or casualties attributed to tsunamis *(investigations are ongoing).*
1867 Nov 18	Virgin Islands	Earthquake between St. Thomas and St. Croix	7.5	Tsunami possibly generated by submarine landslide generated in the Virgin Islands causing 23 deaths. Travelled west to Puerto Rico, east to Barbuda and south to Grenada. Robson (1964) quotes, "a wave 60 feet high and 3 miles broad inundated the beaches and entered houses in Guadeloupe."
1918 Oct 11	Puerto Rico	Earthquake between Puerto Rico and Dominican Republic	7.5	Tsunami up to 4m high generated on the west coast of Puerto Rico, inundated 100m inland, causing 29 deaths and extensive damage. Observed on the east coast of Dominican Republic and Virgin Islands.
2010	Haiti	Earthquake South-West of Port au	7.0	Devastating earthquake 25km SW of Port au Prince, Haiti (~222,570 fatalities). 4 people killed by a local tsunami in the Petit Paradis area near Leogane.

Jan 12		Prince		Recorded wave heights (peak-to-trough) of 12 cm at Santo Domingo, Dominican Republic and 2 cm at Christiansted, US Virgin Islands. Investigations are continuing for this event. (Source: USGS)

Tele-tsunamis that have affected the Caribbean

Date	Cause	Mag	Effects
1755 Nov 1	Great Lisbon Earthquake in the Azores fracture zone (near Portugal)	8.7	Tsunami generated crossed the Atlantic and observed throughout the region from Barbados to Antigua and as far west as Cuba. 2-10 m high waves were generated and continued to arrive for many hours. No damage or casualties reported.
1761 March 31	Earthquake in the Azores fracture zone (near Portugal)	8+	Tsunami waves observed in Barbados (from European sources) but no damage information available.
1929 Nov 18	Earthquake off the Grand banks of Newfoundland, Canada	7.2	Generated by landslide slumping. Reports suggest that tsunami reached the Eastern Caribbean but no damage information available

Volcanic Tsunamis Generated in the Caribbean

Date	Location	Cause	Effects
1902 May 7	Martinique, St. Vincent	Volcanic eruption of Soufriere (St. Vincent) and Mt. Pelée (Martinique)	Entry of pyroclastic flows into the sea in St. Vincent created disturbances of the sea with tsunami waves 2-3 m high in Grenada, Barbados and Saint Lucia. Reports from harbour-masters confirm the event. Submarine telecommunication cables from Martinique were cut that day.

1997 Dec 26	Montserrat	Volcanic eruption of Soufriere Hills	Major pyroclastic flow entering the sea in southwestern Montserrat generated minor tsunami at Montserrat and Guadeloupe.

Characteristics of a Tsunami and Natural Warning Signs

Characteristics

A tsunami is a series of waves and the first wave is not necessarily the largest. Since tsunamis can travel very far without losing much energy, they can affect places that are a great distance from their source. Generally, tsunamis that are the result of water displacement from above (e.g. landslides, meteor strikes) tend to dissipate quickly and have little impact on faraway coastlines.

According to wave physics, tsunamis tend to be small – almost imperceptible – while travelling in the open water and do not "size up" until they approach the coast. As a tsunami approaches shore, it begins to slow and often the sea recedes abnormally. Tsunamis reach the coast with tremendous amounts of energy and their height increases as they approach the continental shelf – the part of the earth's crust that slopes or rises from the ocean floor up to the land. Tsunamis have been known to attain a vertical height onshore above sea level of 30 m.

The Pacific Ocean hosts a greater number of large, destructive tsunamis than elsewhere because of the many major earthquakes along the margins of the Pacific Ocean and also because dip-slip earthquakes (which involve vertical rather than lateral ground motion) are more common in the Pacific than elsewhere.

With waves capable of inundating (flooding) hundreds of metres inland past the typical high-water level, the fast-moving water associated with the incoming tsunami can crush homes and other coastal structures. Tsunamis can sweep boats inland, they can drown people and animals and strip beaches of sand that may have taken years to accumulate. The powerful waves can also undermine trees and other coastal vegetation.

Sri Lanka, 26th December 2004 Image shows "drawback" or withdrawal of water exposing ~150 meters of temporary beach. Photo: www.digitalglobe.com

Natural Warning Signs

An **earthquake** is one of nature's tsunami warning signs. If you are at the beach and the ground shakes so strongly that *standing is difficult* – a tsunami may have been generated.

Tsunamis may be preceded by a **rapid fall in sea level** as the ocean retreats *exposing fish and rocks on the sea floor*. In such a situation, to protect life, immediate evacuation to higher ground is essential. This is because a tsunami from a local earthquake can strike within minutes, long before an official tsunami warning can be issued. Sometimes, however, there is **no withdrawal of the sea** *even though the earthquake may have generated a tsunami.* Tsunami survivors have also remarked that **a strange roar,** similar to a jet plane or train, is often heard as the tsunami approached land. If **intense ground shaking** is observed, as a precaution those near shore should **quickly move to higher ground** when the shaking stops.

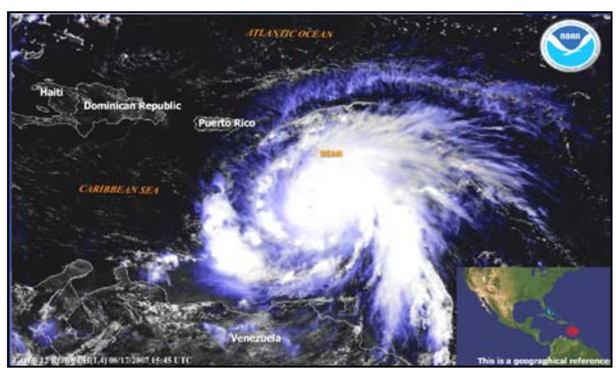
Other Coastal Hazards

Tuvalu, a group of nine coral atolls has started to evacuate it's population to New Zealand. 75 people are moving annually. This picture shows the centre of the island flooding during a very high tide. Photo source: http://www.coolkidsforacoolclimate.com/Causes&Effects/RisingSeaWorld.htm

The Caribbean region faces a variety of coastal hazards every year. These range from coastal erosion to Tropical Hurricanes e.g. Hurricane Ivan which devastated Grenada in 2004. These potential hazards are exacerbated by the rapid coastal development occurring in the Caribbean region, in addition to phenomenon such as Global Climate Change.

In the south Pacific, Papua New Guinea's Carteret islands are being drowned by rising sea levels which are a result of Global climate change. Over the past 20 years the inhabitants of these islands have watched as their homes were slowly washed away by waves and have witnessed the demise of their forests as the groundwater becomes contaminated by rising sea levels. In 1999, the Kiribati islands, Tebua, Tarawa and Abanuea, disappeared underwater. All three islands had experienced severe flooding by storms and high tides. Other islands that are still inhabited experience those same effects. This may be a glimpse into the future for the Caribbean, perhaps a hundred years from now.

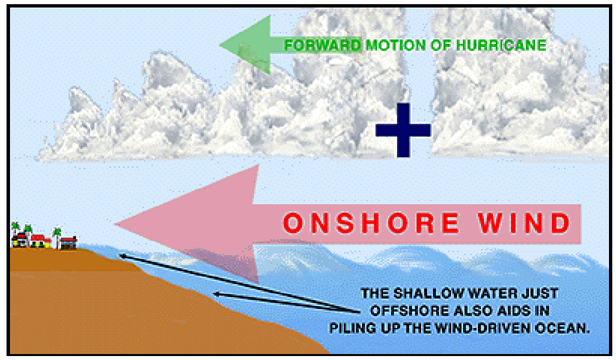
Global climate change is expected to cause an increase in the frequency and strength of hurricanes and storm events. Hurricanes and storms play an important role in global climate and their formation, intensity and track are influenced by the heat balance and rotation of the Earth. Hurricanes and storms transport excess heat and moisture from the Tropics to Temperate latitudes as they form over warm ocean waters with temperatures of at least 26˚C.



Satellite image of Hurricane Dean moving west through the Caribbean in August 2007

The interaction between atmospheric disturbances, human activity and climate is important in understanding global climate change and its potential feedback impact; hurricanes and storms may produce more damaging surface winds and storm surges in coastal areas. While winds may cause significant structural damage, storm surges are frequently the most devastating element of a hurricane.

A storm surge is the unusual rise in sea level caused by low pressure, high winds, and waves associated with hurricanes and tropical storms prior to and during landfall. Unlike seismically generated tsunamis which are caused by movement of the ocean floor, storm surges are caused primarily by high winds pushing on the ocean's surface. This causes the water to pile up higher than the normal sea level. A wide gently sloping continental shelf or a large bay may also promote inordinately large storm surges.



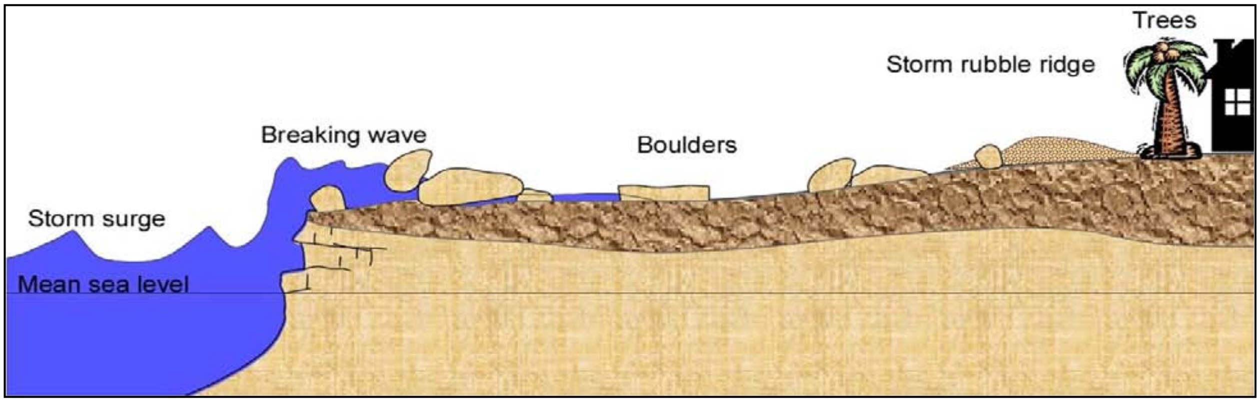
The main force creating the storm surge at the time the centre of the hurricane or tropical storm makes landfall is the wind driving the ocean ashore. The ocean creates frictional drag for the wind and therefore piles up against the coastline. Source: http://www.hurricanetrack.com/ncstormsurge/srginf.html

In addition to damage caused by storms and hurricanes, the slow rise in sea level attributed to global climate change and rising atmospheric and sea surface temperatures, means that the oceans are gradually encroaching on the land, and the beaches are retreating landwards as a result. The amount of retreat varies with local conditions and on very low-lying shores the rate of retreat can be very high. With the prospect of the rate of sea level rise accelerating in the future it is certain, that beach erosion and coastline retreat will continue, possibly at a faster rate.

Coastal Set-back

The elevation of the coastline significantly influences the kind of damage to buildings. In low-lying coastal areas with beaches, damage from storms is likely to result from breaking waves causing beach erosion that undermines foundations. On a cliff coastline, the force of the storm waves surging against the cliff can generate breaking waves that overtop the cliff and damage structures near the edge. The level and rate of erosion that is being observed may be used to inform the "safe" distance from the coastline, up to which buildings may be, in this context, safely constructed.

While climate change may not influence earthquakes and their propensity to generate tsunamis, rising sea-level will make coastal buildings increasingly vulnerable to sudden flooding events. Coastal set back limits should thus cater for the occurrence of such events.



The calculation of setbacks for permanent structures on coastlines needs to be site-specific. The assessment of waves and associated boulders and debris encroachment inland can be used to assist in assigning site specific setbacks for shoreline construction. Diagram courtesy: Rowe, D-A., Khan, S.A. & Robinson, E., The University of the West Indies Marine Geology Unit.

Residents already living in coastal areas threatened by tropical storms and hurricanes should understand the dangers these events pose to their families and properties. When a tropical storm or hurricane threatens the area, the Meteorological Service forecasts expected storm surge heights. Residents should use these forecasts, the elevations of their houses and properties together with advice from local emergency management officials to guide their evacuation decisions.

In the coming decades, risks from tsunamis and other coastal hazards will increase as coastal development and population centres continue to grow. However these natural phenomena need not become disastrous, if measures are taken to reduce their impact. Therefore, it is critical that sound risk reduction techniques be incorporated into emergency response and decision-making policies that affect the development of coastal communities. This will foster the reduction of risks and costs of these natural phenomena to society.

Case Studies

APPENDICIES

The 2004 Indian Ocean Tsunami

On 26th December, 2004, trillions of tons of rock were moved along hundreds of kilometres within the Earth causing the planet to shudder with a 9.1-magnitude earthquake off the coast of Sumatra, the largest earthquake in forty years. The movement generated devastating tsunami waves that struck twelve countries around the Indian Ocean. Within hours, waves radiating from the earthquake source slammed into coastlines, snatching people out to sea, drowning others in their homes or on beaches, and demolishing property from Sumatra to Africa.

The tsunami traveled as much as 5,000 km from Sumatra to Africa, with waves as high as 15 m in some places. In many other places, witnesses described a rapid surging of the ocean, similar to an extremely powerful river or flood. Witnesses said the approaching tsunami sounded like three freight trains or the roar of a jet. In several places the tsunami announced itself in the form of a rapidly receding ocean before advancing as a torrent of foaming water. Many reports quoted survivors as saying that they had never seen the sea withdraw such a distance, exposing seafloor never viewed before, stranding fish and boats on the sand. Tragically the novelty of the sight stoked the curiosity of many people who ran out onto the exposed seafloor. Ignorant of the natural warning signs, tourists in Thailand were seen wandering around photographing the scene.

Survivors who knew what the receding ocean portended, rounded up family and friends and tried to warn people who were drawn to the water's edge to run for high ground. A receding ocean may give people as much as five minutes warning to escape to high ground. That may have been enough time for many of the people to save themselves, if only they had understood the signals and knew what to do.

Photo: Peter Lemieux

In the aftermath of the tsunami, over 220,000 people lost their lives, and 2.3 million people were left homeless. Tens of thousands remain unaccounted. Estimated property damage and economic losses were in the tens of billions of dollars, making it perhaps the most destructive tsunami in history.

A day that had started like any other had unfolded into one where millions of people were struggling with the reality of tens of thousands of dead or missing relatives, destroyed homes, and shattered lives. Post disaster research studies with tsunami survivors revealed that many people were fearful about future tsunami threats. They did not have a sound understanding of the warning signs of a tsunami, how to evacuate or how tsunamis form.

Across the world the magnitude of the disaster and the scale of the suffering prompted a new wave—one of education, information, awareness and the call for early warning systems. Education and information can help alleviate the anxiety and fear of tsunami threats as people understand the tsunami-triggering mechanisms and learn to recognize natural warning signs. Public education coupled with a tsunami warning system could provide ample time for evacuation and ultimately could save lives.

The 2009 Samoan Tsunami

First wave arriving at Pago Pago Harbour, American Samoa during the tsunami after the mag 8 earthquake.
Photo Courtesy: Gordon Yamasaki, NOAA.

On 29th September 2009, a magnitude 8.0 earthquake occurred in the Samoan Islands region and generated a tsunami which caused substantial damage and loss of life in Samoa, American Samoa, and Tonga. More than 189 people were killed, most of them in Samoa.

In some ways, the geological conditions were even worse for this tsunami than they were during the Indian Ocean tsunami that claimed more than 220,000 lives in 2004. This time, however, there were fewer people in harm's way.

The earthquake was shallow, striking just below the ocean floor with very little energy being lost. It also occurred in deep water producing bigger waves that raced toward the island territories at speeds approaching 851 km/h or as fast as a jet airliner.

The earthquake shaking at the meteorological office in Pago Pago, the capital of American Samoa, was so intense that officials immediately alerted the tsunami warning center to activate the warning system. The Pacific Tsunami Warning Center in Hawaii issued its first alert 18 minutes after the earthquake but there was not enough time. Less than 25 minutes after the ground shaking, the first tsunami wave swamped Samoa and the warning system had little effect. Four sets of waves 5-6 m high followed leaving a death toll well over 100. By that time the first wave had crashed into villages and resorts in Samoa, those who would survive had already fled to higher land, rattled by powerful earth tremors lasting several minutes.

Currently it takes scientists 5-20 minutes to analyze essential earthquake data including its magnitude, depth, precise location and faulting mechanism. So, if the quake strikes close to shore, as it did on this occasion, communities are unlikely to receive, far less respond to, an official alert in the time before flooding (inundation). The Samoan tsunami demonstrated a challenge for early warning systems as massive waves crashed ashore before researchers could analyze the earthquake and sound the alarm. Even as relief teams confront the aftermath of the tsunami – which threw successive walls of water up to 198 m inland - the disaster is drawing attention to how much warning residents could have received ahead of time. This event illustrates the challenges of an early warning system proving that they are important, potentially fatal limitations.

It is often assumed that an early-warning system solves the problem of tsunamis but it is only one mitigation measure. Education continues to be as important as technology and increased awareness of a tsunami's natural indicators or warning signs – strong earthquake, sea withdrawal - has saved lives in the past and will continue to save lives in the future.

The 1929 Newfoundland Submarine Landslide

On 18th November 1929, a magnitude 7.2 earthquake, with an epicentre about 250 kilometres south of Newfoundland, Canada generated an extremely large submarine landslide. This slide triggered a tsunami that struck the southern coast of Newfoundland. Later studies by seismologists confirmed that the tsunami was not generated by the earthquake, but rather was triggered by the subsequent large submarine landslide[5].

Newspaper accounts of the Grand Banks Earthquake and Tsunami. Source: http://earthquakescanada.nrcan.gc.ca

It is believed that a massive slab of sediment about 1,610km long slid off the edge of the continental shelf, down the steep continental slope in a broad flow and into the deep ocean basin beyond. As the sediment started moving, it mixed with the ocean, allowing the material to move as a fluid. This huge mass of mobile, water-logged sediment plunged into the deep ocean at around 80 km/h. The landslide flowed across several transatlantic telegraph cables, major lines of communication between Europe and North America at the time, snapping them off one by one. The locations of the cables were precisely known, so the exact timing of the disconnection of the cables made it possible to determine that the speed of the landslide was ~ 80 km/h. Although the disconnection of the cables disrupted communication, it proved useful in alerting people that something significant had happened to the ocean floor.

A landslide occuring at the bottom of the sea may seem minor but events that occur in remote and inaccessible places on the planet usually affect us, sometimes directly, more often

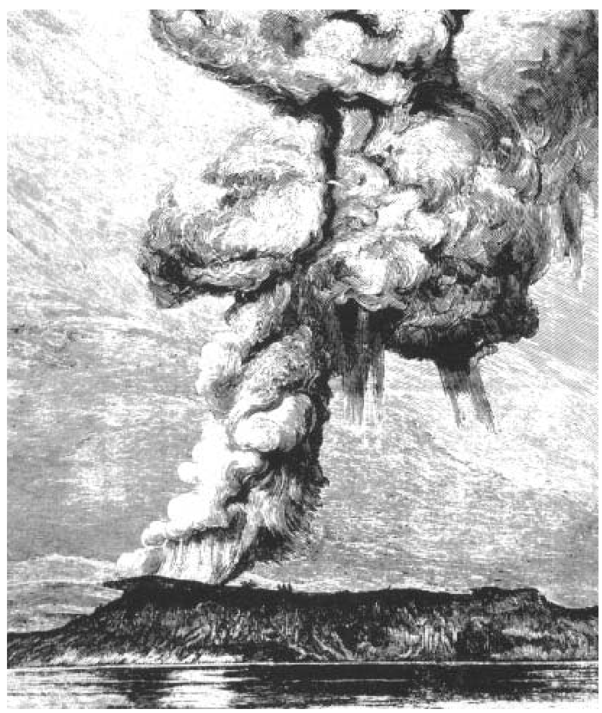
[5] The Atlas of Canada. http://atlas.nrcan.gc.ca/site/english/maps/environment/naturalhazards/tsunami/tsunami/1

indirectly. The Newfoundland seabed landslide displaced so much ocean water that it generated a tele-tsunami with waves being recorded as far south as South Carolina, USA and across the Atlantic Ocean in Portugal[6]. The landslide-generated tsunami in 1929 was given little publicity at the time as there were few witnesses in the sparsly populated areas of the Newfoundland and Nova Scotia coastline. The Newfoundland tsunami was nevertheless a major phenomenon; with waves attaining amplitudes of 12 m high and claiming the lives of at least 28 people.

Although the Newfoundland landslide was a major event, it was still only one-tenth of the size of the world's biggest landslides. The largest and most dangerous landslide generated tsunamis in the world are caused on the flanks of volcanic islands where the landslides begin on land and end up in the ocean displacing substantial volumes of water. Volcanic islands are particulary vulnerable because they often have unstable slopes built up of lava and loose ash – and they are relatively prone to being jolted and vibrated by earthquakes. The movement of magma may also cause the volcano to inflate and develop networks of cracks on its flanks. Fortunately such large scale landslides and associated tsunamis are very rare, but as with other large scale and infrequent events, when they do occur the results may be catastrophic.

The 1883 Eruption of Krakatau

The island of Krakatau lies in the Sunda Strait bewteen Sumatra and Java, Indonesia. Prior to the great eruption of 1883, the original island lay in an area of deep water surrounded by a broken ring of islands which marked the outer flanks of the original volcanic mountain. At the centre of the little cluster of islands was an island with a large volcano rising to height of 762 m.



The smoldering remains of the still erupting Rakata, on Krakatau, after the main eruption destroyed the island.
Source: http://www.earlham.edu/~bubbmi/krakatoa.htm

A long series of minor earthquakes begining in 1877 marked the stirrings of the mountain as magma began to make its way to the surface. The activity escalated in the early months of 1883, and by May 1883 eruptions had started. The small eruptions intensified on 24th August, 1883 and culminated in a violent eruption on 27th August, 1883 (Verbeek, 1886; Judd, 1888, Simkin, Fiske, 1983).

[6] The 1929 Magnitude 7.2 "Grand Banks" earthquake and tsunami". Natural Resources Canada. www.nrcan.gc.ca

This was the greatest eruption since the bronze age and the explosion was heard nearly 4,828 km away. The extreme violence of the eruption emptied the lava chamber beneath the island, leaving a huge hollow and very hot vault. Unsupported, the chamber collapsed. Cold seawater rushed repeatedly into the hot chamber, turned instantly into steam, and caused four violent explosive blasts. Since these blasts were on the seabed, large tsunamis were generated rolling out from the gaping hole where Krakatau had stood. Some waves reached as high as 40 m slamming into the nearby coastlines, and could be recorded on tide gauges over 7,000 km away.

Many small coastal islands were completely submerged and as the wave hit the mainland islands of Java and Sumatra it ravaged towns and villages while stripping away nearly all vegetation. In some cases, whole towns of several thousands of people were washed away in a flash destroying any sign of their existence. Accounts of villagers scrambling up inland hills to escape the waves can be found. Often only the small top of a hill would be spared by the huge waves. One hundred and sixty-five villages were devastated, leading to the death of over 36,000 people. According to Dutch authorities, 90% of these fatalities were attributed to the devastating tsunamis. Bodies lined the coasts for weeks and thousands of livestock were found throughout the Sunda Strait. The Krakatau eruption provides an excellent example of how an eruption can cause a tsunami. Waves were said to have reached Cape Horn and were recorded by tide gauges as far away as the English Channel and the southern coast of the Arabian Peninsula - more than 7,000 km from the source in Krakatau (Simkin and Siebert, 1994).

More Frequently Asked Questions on Tsunamis

Why is it called a tsunami?

The word tsunami is taken from two Japanese words which mean **harbour** (tsu) **wave** (nami). Tsunamis are quite common in Japan.

How are tsunamis different from normal ocean waves?

• Ocean waves are related to changes in the atmosphere while tsunamis are related to changes within the Earth.
• Tsunami waves are distinguished from ordinary ocean waves by their long wavelengths (distance between two crests or highest point of the wave), often exceeding 100 km in the deep ocean and by the long amount of time between the arrivals of these crests, ranging from five minutes to an hour.
• Most tsunami waves do not break like normal surf waves at the beach that curl over as they approach shore rather they come in much like a very strong and very fast wall of water. Those that do break often form vertical walls of turbulent water called bores.

Is it safe to surf a tsunami wave?

Absolutely not! Tsunami waves should not be surfed as they possess tremendous destructive power from BOTH the strength and size of the waves. The large amount of seafloor material (mud and sediment) caught up in the wave makes them very dangerous for surfing.

Can an earthquake from outside of the Caribbean region cause a tsunami?

Yes, a tsunami may be generated from earthquakes occurring both within and outside of the region. In 1755 the Great Lisbon earthquake near Portugal caused a tsunami “as high as the upper storey’s of houses” on the east coast of Martinique. Waves 2 m high were also observed at the east coast of Barbados.

Can an eruption of the Kick 'em Jenny submarine volcano cause a tsunami?

Kick ‘em Jenny is a submarine (underwater) volcano located 9 km northwest of Grenada. Currently, scientists believe that there is a very small chance that an eruption of the volcano would trigger a tsunami. Although likely to be minor, tsunamis triggered by underwater eruptions are a potential hazard for neighbouring islands.

Can tsunamis be predicted?

Currently, scientists cannot say when and where an earthquake might occur and so they cannot predict when an earthquake-generated tsunami might occur. Tsunamis that are triggered by volcanic activity – like submarine volcanic eruptions or pyroclastic flows - can be forecast if the volcano is carefully monitored as is the case with volcanoes in the Eastern Caribbean.

If a tsunami is detected by scientists how much time will they have to warn the public?

Following an earthquake, scientists need 5 – 20 minutes before a tsunami warning can be issued. However, if you live in Antigua and a local tsunami is generated by an earthquake near Nevis, waves could impact your island in less than 15 minutes with little or no time for an official warning. This means that coastal residents must be able to recognise a tsunami’s natural warning signs. Alternatively, if an earthquake were to occur off the west coast of Africa, a tsunami generated by that earthquake (tele-tsunami) would take several hours before reaching the Caribbean, allowing ample time to issue an official warning.

Is it possible for a tsunami of similar amplitude and strength to the one that occurred in the Indian Ocean to occur here in the Caribbean?

The magnitude 9.1 earthquake which occurred on 26th December, 2004 off the west coast of northern Sumatra, was one of the top five largest earthquake events in the world since 1900. The tsunami triggered by that earthquake killed over 220,000 people in at least eleven countries. While it is possible for a similar tsunami to occur in the Caribbean, scientists currently believe that there is a very small chance of this happening. As far as we know, the largest tsunami to affect the Caribbean in the past 500 years was 8 m in height.

Is it true that there is a volcano in the Canary Islands that can cause a mega-tsunami in the Caribbean?

The Cumbre Vieja Volcano is on the Island of La Palma in the Canary Islands (off the west coast of Africa). There are some scientists who think that if the western flank (side) of the volcano were to collapse and drop 150 to 500km^3 of rock into the sea, massive tsunamis could be generated which could devastate islands in the Caribbean as well as coastal areas in North America.

While this may be possible, this is in fact a worst case scenario and it is not the most likely scenario. Scientists at the UWI Seismic Research Centre believe that there is a very small chance of this ever happening and so, planning for such a rare event should not be a priority at this time. Instead, attention should be placed on the dangers posed by immediate natural hazards in the region such as hurricanes, earthquakes and volcanic events. It should be noted, however, that the planning currently taking place to cater for tsunamis in the region will also cover the most likely event that might occur at Cumbre Vieja.

What can we do to prepare for a tsunami?

If you live in a low-lying area make yourself familiar with the quickest way to get to higher ground. Make sure all family members know the evacuation plan. **If you are close to the sea and the water retreats or pulls back by an abnormal amount, move to high ground at once.**

For more answers to frequently asked questions and information on tsunamis in the Caribbean, visit:

www.weready.org

www.cdema.org

www.uwiseismic.com

Tsunami Glossary

ARRIVAL TIME

Time the first the tsunami waves arrive.

CREST LENGTH

The length of a wave along its crest. Sometimes called crest width.

ELAPSED TIME

Time between the maximum level arrival time and the arrival time of the first wave.

ESTIMATED TIME OR ARRIVAL (ETA)

Time of tsunami arrival at some fixed location, as estimated from modeling the speed and refraction of the tsunami waves as they travel from the source. ETA is estimated with very good precision if the bathymetry and source are well known (less than a couple of minutes).

HISTORICAL TSUNAMI

A tsunami identified as having occurred through eyewitness or instrumental observation within the historical record.

INITIAL RISE

Time of the first minimum of the tsunami waves.

INTENSITY

Extreme strength, force, or energy.

INUNDATION

The horizontal distance inland that a tsunami penetrates, generally measured perpendicularly to the shoreline.

INUNDATION (MAXIMUM)

Maximum horizontal penetration of the tsunami from the shoreline. A maximum inundation is measured for each different coast or harbour affected by the tsunami.

INUNDATION AREA

Area flooded with water by the tsunami.

INUNDATION LINE

Inland limit of wetting, measured horizontally from the mean sea level (MSL) line. The line between living and dead vegetation is sometimes used as a reference. In tsunami science, the landward limit of tsunami run up.

LEADING WAVE

First arriving wave of a tsunami. In some cases, the leading wave produces an initial depression or drop in sea level, and in other cases, an elevation or rise in sea level. When a drop in sea level occurs, sea level recession is observed.

LOCAL TSUNAMI

A tsunami from a nearby source for which its destructive effects are confined to coasts within 100 km of the source. A local tsunami is usually generated by an earthquake, but can also be caused by a landslide, or a pyroclastic flow from a volcanic eruption.

MEAN HEIGHT

Average height of a tsunami measured from the trough to the crest after removing the tidal variation.

OVERFLOW

A flowing over; inundation.

PALEOTSUNAMI

Tsunami occurring prior to the historical record or for which there are no written observations. Paleotsunami research is based primarily on the identification, mapping, and dating of tsunami deposits found in coastal areas, and their correlation with similar sediments found elsewhere locally, regionally, or across ocean basins. As work in this field continues it may provide important new information about past tsunamis to aid in the assessment of the tsunami hazard.

POST-TSUNAMI SURVEY

Tsunamis are relatively rare events and most of their evidence is phemeral. Therefore, it is very important that reconnaissance surveys be organized and carried out quickly and thoroughly after each tsunami occurs, to collect detailed data valuable for hazard assessment, model validation, and other aspects of tsunami mitigation.

RECESSION

Drop in sea level prior to tsunami flooding. The shoreline moves seaward, sometimes by a kilometre or more, exposing the sea bottom, rocks, and fish. The recession of the sea is a natural warning sign that a tsunami is approaching.

REGIONAL TSUNAMI

A tsunami capable of destruction in a particular geographic region, generally within about 1,000 km of its source. Regional tsunamis also occasionally have very limited and localized effects outside the region.

Most of the destructive tsunamis can be classified as local or regional, meaning their destructive effects are confined to coasts within a hundred km, or up to a thousand km, respectively, of the source -- usually an earthquake. It follows that many tsunami related casualties and considerable property damage also comes from such tsunami.

RISE

The upward change or elevation in sea level associated with a tsunami, a tropical cyclone, storm surge, the tide, or other long term climatic effect.

RUN-UP

1) Difference between the elevation of maximum tsunami penetration (inundation line) and the sea-level at the time of the tsunami.
2) Elevation reached by seawater measured relative to some stated datum such as mean sea level, mean low water, sea level at the time of the tsunami arrival, etc., and measured ideally at a point that is a local maximum of the horizontal inundation.

RUN-UP DISTRIBUTION

Set of tsunami run-up values measured or observed along a coastline.

SEICHE

A seiche is the term used to describe oscillations in a partially or fully enclosed body of water. It may be initiated by long period seismic waves (an earthquake), wind and water waves, or a tsunami.

SEISMIC SEA WAVE

Tsunamis are sometime referred to as seismic sea waves because they are most often generated by earthquakes.

SIGNIFICANT WAVE HEIGHT

The average height of the one-third highest waves of a given wave group. Note that the composition of the highest waves depends upon the extent to which the lower waves are considered. In wave record analysis, the average height of the highest one-third of a selected number of waves, this number being determined by dividing the time of record by the significant period. Also called characteristic wave height.

TELE-TSUNAMI OR DISTANT TSUNAMI

A tsunami originating from a far away source, generally more than 1,000 km away.

Less frequent, but more hazardous than regional tsunamis, are ocean-wide or distant tsunamis. Usually starting as a local tsunami that causes extensive destruction near the source, these waves continue to travel across an entire ocean basin with sufficient energy to cause additional casualties and destruction on shores more than a 1,000 km from the source. In the last 200 years, there have been at least 21 destructive ocean-wide tsunamis.

The worst tsunami catastrophe in history occurred in the Indian Ocean on the 26th December, 2004, when a magnitude 9.1 earthquake off of the northwest coast of Sumatra, Indonesia produced a ocean-wide tsunami that also hit Thailand and Malaysia to the east, and Sri Lanka, India, the Maldives, and Africa to the west as it traversed across the Indian Ocean. Over 225,000 people lost their lives, and more than 1 million people were displaced, losing their homes, property, and their livelihoods. The magnitude of death and destructiveness caused immediate response by the world's leaders and led to the development of the Indian Ocean tsunami warning and mitigation system in 2005.

TIDAL WAVE

1. The wave motion of the tides.

2. Often incorrectly used to describe a tsunami, storm surge, or other unusually high and therefore destructive water levels along a shore that are unrelated to the tides.

TRAVEL TIME

Time required for the first tsunami wave to propagate from its source to a given point on a coastline.

TSUNAMI AMPLITUDE

Usually measured on a sea level record, it is:

1) The absolute value of the difference between a particular peak or trough of the tsunami and the undisturbed sea level at the time,

2) Half the difference between an adjacent peak and trough, corrected for the change of tide between that peak and trough. It is intended to represent the true amplitude of the tsunami wave at some point in the ocean. However, it is often amplitude modified in some way by the tide gauge response.

TSUNAMI BORE

A steep, turbulent, rapidly moving tsunami wave front, typically occurring in a river mouth or estuary.

TSUNAMI GENERATION

Tsunamis are most frequently caused by earthquakes, but can also result from landslides, volcanic eruptions, and very infrequently by meteorites or other impacts upon the ocean surface. Tsunamis are generated primarily by tectonic dislocations under the sea which are caused by shallow focus earthquakes along areas of subduction. The upthrusted and downthrusted crustal blocks impart potential energy into the overlying water mass with drastic changes in the sea level over the affected region. The energy imparted into the water mass results in tsunami generation, i.e. energy radiating away from the source region in the form of long period waves.

TSUNAMIGENIC

Having generated a tsunami: a tsunamigenic earthquake, a tsunamigenic landslide.

TSUNAMI IMPACT

Although infrequent, tsunamis are among the most terrifying and complex physical phenomena and have been responsible for great loss of life and extensive destruction to property. Because of their destructive potential, tsunamis have important impacts on the human, social and economic sectors of societies. Historical records show that enormous destruction of coastal communities throughout the world has taken place and that the socio-economic impact of tsunamis in the past has been enormous.

TSUNAMI PERIOD

Amount of time that a tsunami wave takes to complete a cycle. Tsunami periods typically range from five minutes to two hours.

TSUNAMI PREPAREDNESS

Readiness of plans, methods, procedures and actions taken by government officials and the general public for the purpose of minimizing potential risk and mitigating the effects of future tsunamis. The appropriate preparedness for a warning of impending danger from a tsunami requires knowledge of areas that could be flooded (tsunami inundation maps) and knowledge of the warning system to know when to evacuate and when it is safe to return.

TSUNAMI SOURCE

Point or area of tsunami origin, usually the site of an earthquake, volcanic eruption, or landslide that caused large-scale rapid displacement of the water to initiate the tsunami waves.

TSUNAMI WARNING CENTRE (TWC)

Centre that issues timely tsunami information messages. The messages can be information, watch, or warning messages, and are based on the available seismological and sea level data as evaluated by the TWC, or on evaluations received by the TWC from other monitoring agencies. The messages are advisory to the official designated emergency response agencies. Regional TWC monitor and provide tsunami information to Member States on potential ocean-wide tsunamis using global data networks, and can often issue messages within 20 minutes of the earthquake. Local TWC monitor and provide tsunami information on potential local tsunamis that will strike within minutes. Local TWC must have access to continuous, real-time, densely-spaced data networks in order to characterize the earthquakes within seconds and issue a warning within minutes.

An example of a Regional Tsunami Warning Centre is the Pacific Tsunami Warning Center which provides international tsunami warnings to the Pacific. After the 26th December 2004 tsunami, the PTWC and JMA have been acting as an Interim Regional TWC for the Indian Ocean.

Examples of sub-regional TWC are the NWPTAC operated by the Japan JMA, WC/ATWC operated by the USA NOAA NWS, and CPPT operated by France. These centres, along with Russia and Chile, also act as national TWC providing local tsunami warnings for their countries.

WATER LEVEL (MAXIMUM)

The difference in elevation between the highest local water mark and that of the sea-level at the time of the tsunami. This is different from maximum run-up because the water mark is often not observed at the inundation line, but maybe halfway up the side of a building or on a tree trunk.

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Resources/ Links

Caribbean Disaster Emergency Management Agency (CDEMA) ……………………….http://www.weready.org
http://www.cdema.org

UWI Seismic Research Centre…………………………………………………………………..http://www.uwiseismic.com/

United States Geological Survey (USGS) ……………………… http://walrus.wr.usgs.gov/tsunami/basics.html
http://vulcan.wr.usgs.gov

International Tsunami Information Centre (ITIC) ………………………………………..http://ioc3.unesco.org/itic/
http://ioc3.unesco.org/itic/files.php?action=viewfile&fid=424&fcat_id=75
ioc3.unesco.org/itic/files/how_smart_family_survived_tsunami.pdf
http://ioc3.unesco.org/itic/contents.php?id=332

United Nations Scientific and Cultural Organization (UNESCO) …………………..http://www.ioc-tsunami.org/

National Oceanic and Atmospheric Administration…………http://www.tsunami.noaa.gov/education.html
wcatwc.arh.noaa.gov/deadlywaters.pdf

Global Volcanism Program (Smithsonian Institute) ………………………………………http://www.volcano.si.edu

Intergovernmental Panel on Climate Change…………………………… http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf

North Carolina Storm Surge ………………………http://www.hurricanetrack.com/ncstormsurge/mainpg.html

Government of New Zealand……………….http://www.getthru.govt.nz/web/GetThru.nsf/web/BOWN-7GZVAT?OpenDocument
http://www.mfe.govt.nz/publications/climate/coastal-hazardsclimate-change-guidance-manual/html/index.html

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