Tsunami Information Sheet

Prof. Peter Bormann

Please note: The following information and recommendations have been prepared to the best of our knowledge. Nevertheless, the GFZ cannot be made responsible or accept any liability whatsoever for losses incurred as a result of following the advice given below.

1. Causes and characteristics of tsunamis

Tsunami is a Japanese word. "tsu" means harbour and "nami" means wave – i.e. "harbour wave". A tsunami is therefore a wave, which has particularly marked characteristics in harbours and bays where it often causes extensive devastation. Such a wave is caused by sudden rising or lowering of the ocean floor or by large masses of earth falling or sliding into the water and propagates as consecutive, very long period ocean waves over long distances.

Tsunamis are mostly (around 90%) triggered by **strong earthquakes** below the ocean floor. One of the largest tsunamis in the 20th century, with a water front of up to 70 m arose during the Alaska earthquake of 28 March 1964. During this quake the earth's surface shifted within an area of around 500,000 km^2, i.e. an area larger than Germany; rising by up to 12 m at the coast and lowering by up to 2.3 m inland.

Tsunamis resulting from **volcano eruptions** and due to submarine **landslides** are rarer, but are often no less vast. For example, around 8000 years ago a flood wave up to 30 m high flooded parts of Great Britain, Norway and Iceland. This tsunami was probably triggered by a large slip off the coast of Norway, in which rocky masses from the surface of Iceland fell 2000 m deep into the North Atlantic. During the explosion of the Krakatoa volcano in 1883, around 18 km^3 of ash and slag were ejected into the Sunda Strait between Java and Sumatra. After the eruption, the previously 900 m high volcanic island collapsed and formed an over 200 m deep crater (caldera) in the sea. At the same time, a tsunami resulted, reaching heights of up to 35 m in several coastal bays, flooding flat coastal areas 2 to 10 km inland and claimed 36,000 lives.

Large **cosmic projectiles** impacting the sea can also cause enormous tsunamis; however, these events are extremely rare. The extinction of many dinosaur species around 65 million years ago is attributed to a meteorite impacting the area of the present day Gulf of Mexico.

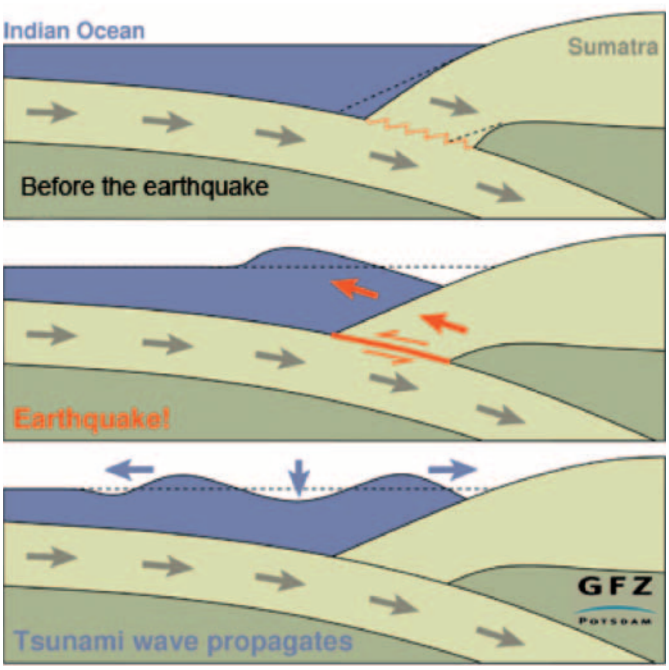
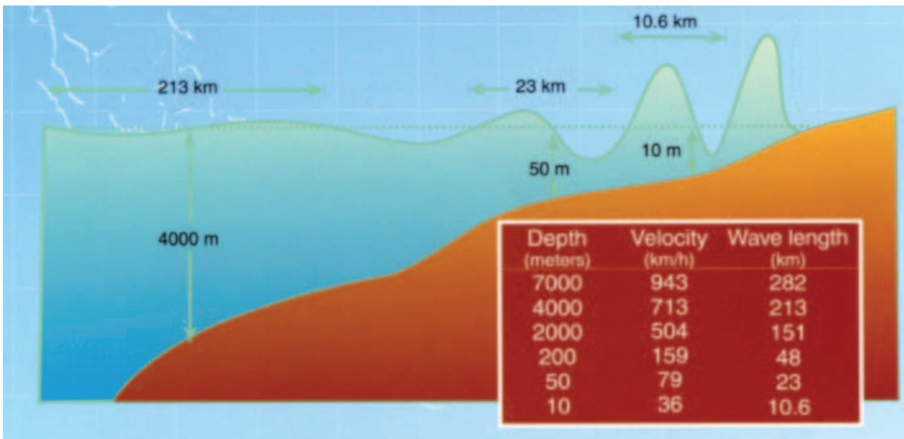


Fig. 1: Schematic diagram of the development of the tsunamis on 26.12.2004.

Fig. 1 shows a schematic of how the devastating tsunami formed in the Indian Ocean as a result of the strong Sumatra earthquake on 26.12.2004. In this area, the oceanic crust moves from the west (left) to the east, collides with the Sumatra crustal plate and dives under it. This is called **subduction**. But it does not occur uniformly. In the area of contact, the two rock places collide and get hooked on each other. This caused the crustal plate of Sumatra to be flexed downwards and to the east (right) and a deep-sea trench was formed off the coast of Sumatra. On 26.12.2004, the enormous stresses accumulated over decades suddenly caused the plate contact to rupture over an area of more than 100,000 km2. The Sumatra plate sprung back to the left (west) and upwards by around 13 m. The resulting earthquake with a strength of Mw = 9.3 on the Richter scale was the second strongest to occur in the past one hundred years. The ocean floor in the area of the Sumatra plate was raised by 2 to 3 m and caused asymmetrical upheaval and sinking of the water column above it (Fig. 1, centre). This began to vibrate and to propagate in all directions with several wave crests and troughs (Fig. 1, bottom). In total, this tsunami claimed around 300,000 lives, destroyed several hundred thousand homes and left behind around 3 million homeless.

Tsunami waves oscillate very slowly. Their **period**, i.e. the time interval between consecutive crests, varies between several minutes up to around two hours, depending on the **water depth** and the type, size and spatial orientation of the initiation process in the area of origin. The tsunami's **propagation velocity** depends on the water depth. In the deep sea it equals that of a jet liner, and in shallow water it is roughly the speed of a fast cyclist or sprinter. The **wavelength**, i.e. the spatial distance between consecutive wave crests and the **wave height** (amplitude) therefore also vary with the water depth (sketch and table in Fig. 2). The shallower the water, the shorter the distances between the waves and the greater their amplitudes, as the water masses are concentrated in an increasingly smaller space. The literature references therefore speak of so-called run-up heights at the coast. The tsunami wavelengths therefore vary within a wide range of between around 10 km and 700 km.



Depth (meters)	Velocity (km/h)	Wave length (km)
7000	943	282
4000	713	213
2000	504	151
200	159	48
50	79	23
10	36	10.6

Fig. 2: Schematic diagram of the relationship between the wavelengths and amplitudes of a tsunami and water depth. (Taken from [1]).

One consequence of this tsunami characteristic is that on high seas, even large tsunamis with amplitudes of mostly only a few decimetres cm are not registered due to the enormous wavelengths of several 100 km. They therefore cause no risk to ships on high seas. It is only in the shallow waters of the coastal areas that the dangerous water fronts build up to several 10 m.

The wave periods, lengths and run-up heights of tsunamis are also influenced by the horizontal coastal outline, the vertical profile in shallow waters and by the water's natural oscillation in the shallow continental shelf and in bays into which the tsunami runs. Ebb and flow conditions at the time the tsunami reaches the coast also play a role. The dominating influence of coastal shape and shallow water profile on the observed run-up heights are also made clear by detailed observations of the tsunami of 12 July 1993 in the Sea of Japan following an earthquake near the coast with a magnitude of M=7.8. On the coast of Hokkaido and the island of Okushiri just off the coast, around 50 to 200 km from the earthquake epicentre, different run-up heights of between 1 m and 32 m were measured! Severe devastation can also occur on (peninsular) island coasts on the side facing away from the tsunami, as a result of diffraction or refraction of the long period tsunami waves in the shallow water fringe (e.g. on the SW coast of Sri Lanka around Galle during the tsunami of 26.12.2004).

These diverse influences make it very difficult to precisely predict the height and timing of tsunami waves and the size of the flood areas on coasts at risk. Such scenarios can only be approximately calculated for specific and precisely known or assumed tsunami sources and coastal situations. The possible flood areas, according to which the evacuation zones and refuge areas are to be defined by disaster managers, should therefore not be assumed to be too small.

Most tsunamis do not penetrate the flat coastal hinterland by more than several hundred metres; however, distances of several kilometres can be reached by the strongest. For example, 18th, 19th and 20th century tsunamis repeatedly caused flooding of 2 to 3 km of several coastal areas of Chile and in the Sumatra quake of 2004 caused flooding 2 to 7 km inland along the coast of Thailand, the Nikobar islands and North Sumatra. The tsunami caused by the Krakatoa eruption of 1883 penetrated the Pepper Bay of Java by up to 10 km inland. Tsunami effects were detected even further inland in the estuary of wide rivers, among other things due to backwater, e.g. up to 30 km along the Imperial River in Chile following the earthquake of 1960.

On the other hand, the **propagation time of tsunamis** through areas of deep seas and oceans can be calculated very quickly and precisely, as soon as the origin (the **epicentre**) is known. Fig. 3 shows the result of such a calculation by the Pacific Tsunami Warning Center (PTWC) in Honolulu for a quake off the coast of North Chile. Fig. 4 shows an analogous illustration of GFZ Potsdam for the tsunami of 26.12.2004 in the Indian Ocean. Both diagrams clearly show that there is adequate early warning time, at least for distant coastal areas, if the causative seismic centre and resulting tsunami can be localised and more precisely described quickly enough (cf. also Section 6.).

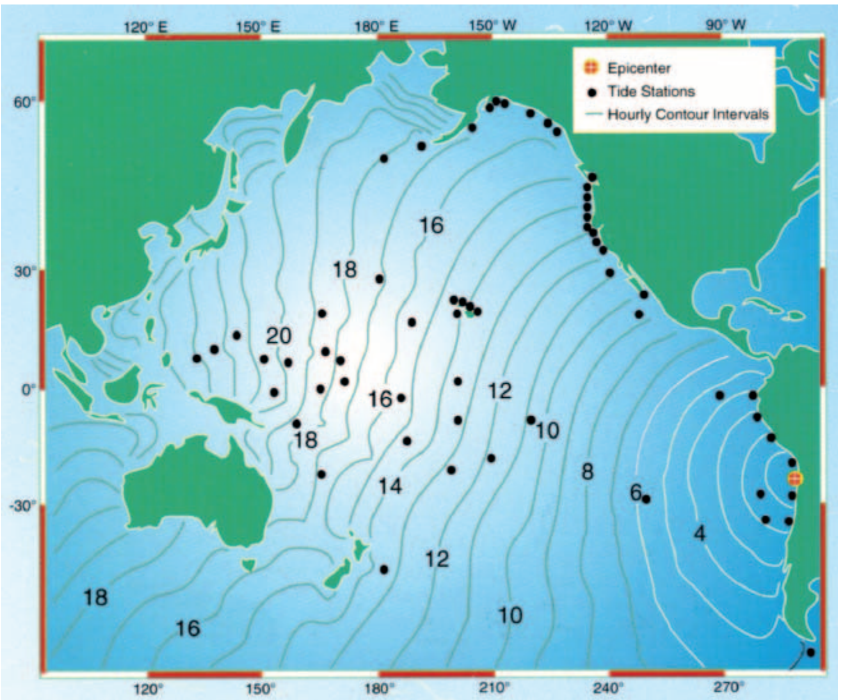


Fig. 3: Calculated propagation time for the first wave of a tsunami, which was triggered by an earthquake off the coast of North Chile. The numbers on the isolines give the propagation time in hours. The dots mark the position of tidal stations in the Pacific, which record fluctuations in the sea surface levels and send them to PTWC by satellite (taken from [1]).

Detection characteristics of tsunamis

Although destructive waves and extensive flooding of flat coastal areas are the main characteristic of **large tsunamis**, their arrival at the coast – compared to the sea tides – is often preceded by a very **rapid rise or even fall in the water level** within a few minutes. This is an important, mostly unknown or ignored, early warning sign. Whether the sea level rises or falls, depends on the type and spatial orientation of the triggering process, the propagation direction of the waves, the orientation of coastal bays, and other influences. For example, on 26.12.2004, the water level off the coast of Thailand fell by several metres before the arrival of the first tsunami wave. If this relationship had been commonly known, and had the people on the coast immediately fled to the higher areas of the hinterland, many thousands of lives would have been spared.

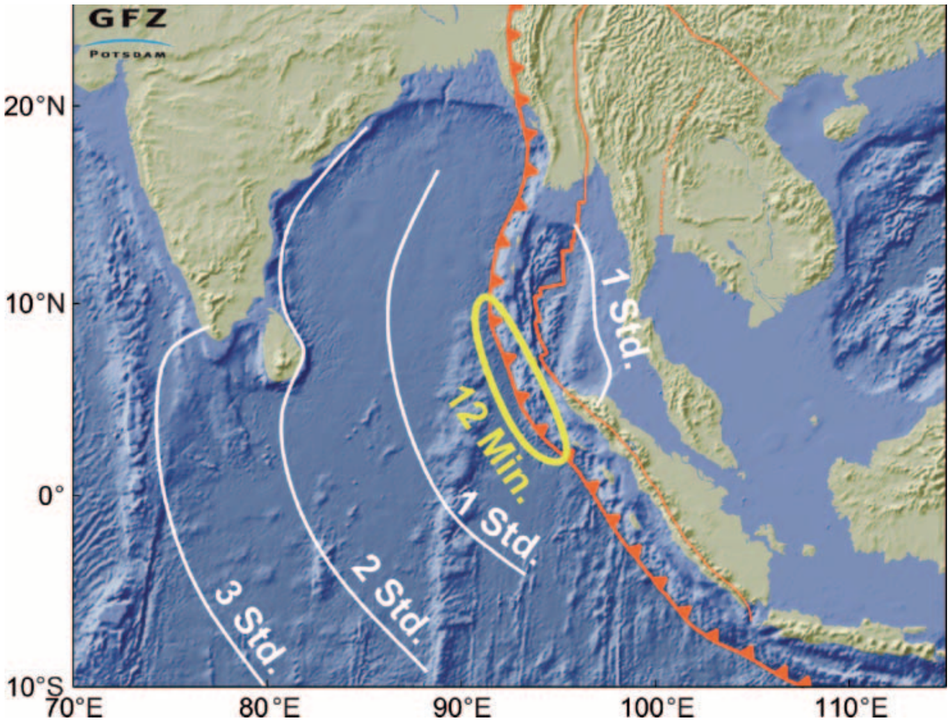


Fig. 4: Propagation times of the first wave front of the tsunami of 26.12.04 through the north-eastern part of the Indian Ocean.

Fig. 5 shows registrations of the seal level in Antofagasta (Chile) and Kaimaisi (Honshu, Japan) between 22 and 24 May 1960. The around 12-hour period of the sea tides (ebb and flood) can be clearly seen. It is superimposed by substantially faster fluctuations with periods between around 18 and 55 minutes and at times much larger amplitudes. These are tsunami waves, which were triggered by the Chile earthquake of 22 May 1960, the strongest earthquake to date to be recorded by instruments (magnitude 9.5 on the Richter scale). The level gauge in Antofagasta was approximately 1,800 km from the earthquake's epicentre and the one in Kaimaisi was around 18,000 km away. Fig. 5 shows further important tsunami characteristics:

- The periods of a tsunami can vary considerably, not only in various directions and distances from the origin, but also for consecutive wave crests at the same location;
- In most cases, the first tsunami wave is not the largest. Subsequent waves, sometimes the fifth or sixth, can be many times stronger. As these late waves often do not arrive until many hours after the first wave, refuges should never be left after the first wave(s) has/have receded! (see Section 7).
- Even at very large distances from the area of origin, tsunamis can still be dangerous. During the Chile tsunami of 1960, more than 250 people were killed in Japan.

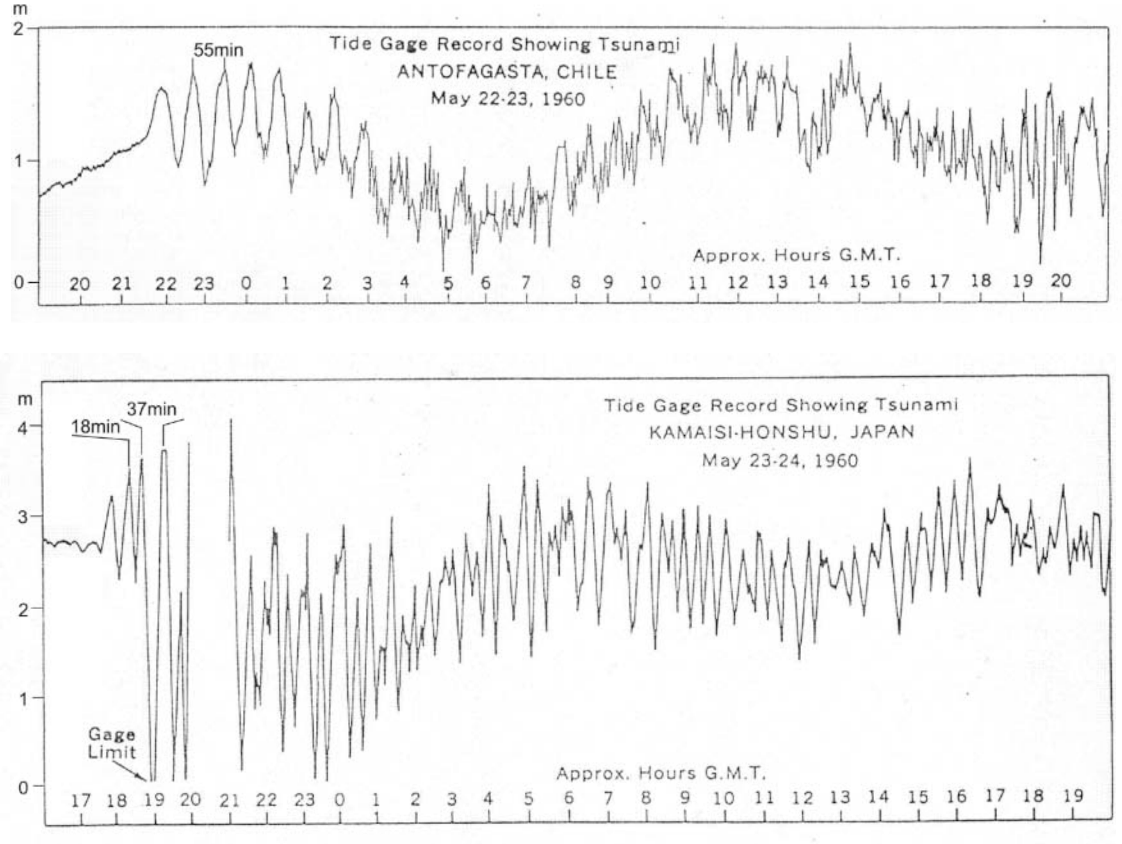


Fig. 5: Level gauge registrations of ebb and flood in Antofagasta, Chile (top) and Kamaishi, Japan (bottom), superimposed by the shorter periods of tsunami waves of the Chile earthquake, 1960.

2. Where do tsunamis originate and where can they cause damage?

Most strong earthquakes occur in so-called **subduction zones** ("forcing underneath" or "engulfing" zones). This is where the earth's oceanic crust collides with a thicker continental crust or with another, younger oceanic crust plate, is pushed under it and sinks into the earth's hot mantle. During this process, stresses permanently develop in the earth's crust, which are released by – at times strong – earthquakes. Almost the whole Pacific edge, in which around 80% of the worldwide energy triggered by earthquakes is released, consists of subduction zones. This is why the most tsunamis occur there. Yet devastating tsunamis can also occur in other oceans and seas such as the Atlantic, the Indian Ocean and the Mediterranean. However, only around 10 to 20% of the strong earthquakes with Richter magnitudes of over 6.5 in the area of the seas and oceans trigger tsunamis, and at magnitudes $M < 7.5$ these usually only have regional effects within a radius of a few 100 km from the causal epicentre.

Fig. 6 shows the worldwide distribution of the **most important** earthquake, volcano and **tsunami zones of the earth**. Above all, these are the tectonically active edges of the large continental and oceanic earth's crustal plates. These plates float on the viscous, hot molten magma of the upper mantle and slowly drift (a few cm per year). They slide past each other, shift on top of each other, get hitched onto each other and then tear apart again. Within the plate collision zones, new mountains pile up on the continents or island chains form off the continents, and submarine mountain ranges and volcanoes form along the major oceanic fault zones (so-called rift zones); identifiable by the beaded-like arrangement of earthquake epicentres in the oceans. These processes are called global pate tectonics. They have been occurring on the earth for more than 3.5 billion years and constantly change the face of our planet. They cannot be influenced by man and will continue to act for billions of years to come. The resulting risks for human society must be identified and counteracted through deliberate action.

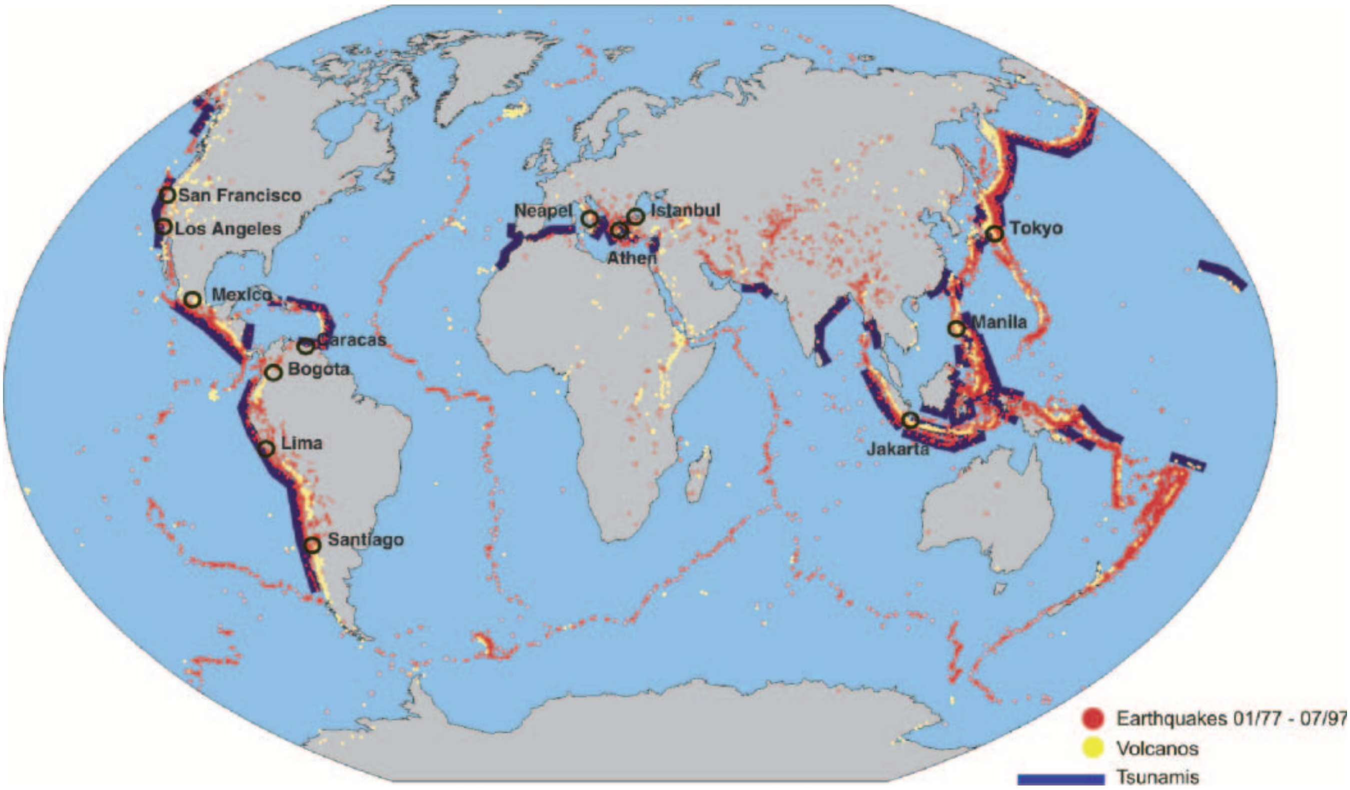


Fig. 6: Worldwide distribution of the most important earthquake, volcano and tsunami zones, compiled by GFZ Potsdam (2000). However, isolated large tsunamis can also arise or have effects in other locations, like the Sumatra–tsunami of 26.12.04 on the coast of Somalia, Kenya and Tanzania.

Of the very reliably recorded tsunamis that have occurred during the past 140 years, almost 25% occurred in Japan. The west coasts of South America, North and Central America, Indonesia, the Philippines and New Guinea and the Solomon Islands were each equally affected by around 10% of the events. They are followed by Kurile-Kamchatka, Alaska and New Zealand with around 6% of the events each. During this period, only around 2 to 3% of the recorded tsunamis occurred in the Mediterranean region, Hawaii and the coastal areas of the Atlantic and Indian Ocean.

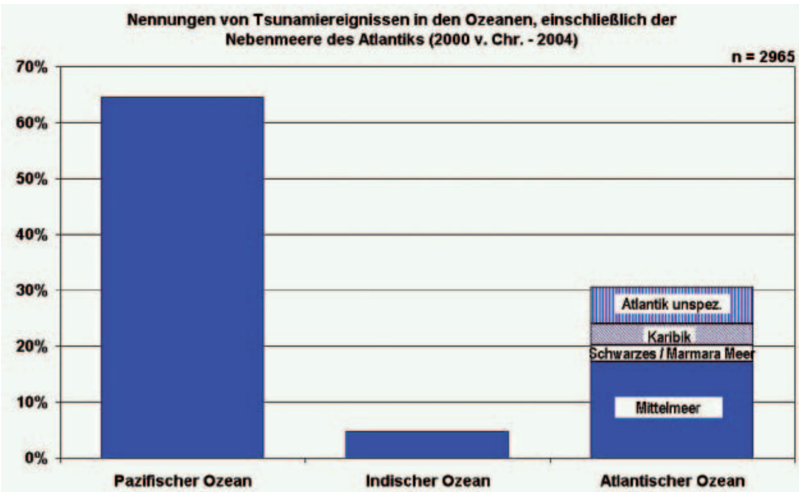


Fig. 7: All currently recorded tsunami events (partly uncertain) from a compilation of different international databases (according to [2]).

Fig. 7 shows all tsunamis documented in international tsunami databases **since 2000 BC** for the Pacific, the Indian Ocean (Indic) and the Atlantic (including its intracontinental seas). Of the events recorded with deaths, 79% are in the Pacific, 14% in the Atlantic and 7% in the den Indic. However, due to the different cultural development of the regions during the history of man, these frequencies are neither complete nor representative for the actual long-term frequency of the occurrence of large tsunamis. Around 70% of all those named occur during the past 200 years alone. They also say nothing about their potential dangerousness. This is proven by the earthquake of 26.12.04 when the tsunami claiming the most lives in history occurred in the Indic.

3. Frequency of the occurrence of dangerous tsunamis

Compared to earthquakes, volcanic eruptions and landslides/avalanches, tsunamis are rare events. A compilation of different databases gives almost 3000 entries worldwide for the period from 2000 BC until today, many with the comment "erroneous" or "questionable" to "very questionable" tsunamis. Over 2000 of these entries occurred during the past 200 years alone, not because the frequency of tsunamis has increased, but because of a rise in their recording and documentation. Less than half these events are listed as "definitive" or "probable" tsunamis. Of these, since 1562, around 100 tsunamis have reached maximum run-up heights of 10 m and more and 26 tsunamis have reached heights of over 30 m (up to maximum 500 m during an enormous landfall in Lituya Bay, a fjord in Alaska). More complete frequency statistics since 1868 show that in the long-term average, over a period of 10 years dangerous maximum run-up heights of > 2 m were observed 23 times, >8 m eight times and >32 m only once ([2]).

Fig. 8: Number of von tsunamis with and without damage in the decades of the 20th century (compiled according to information from the National Geophysical Data Center and the National Oceanic and Atmospheric Administration (NOAA) of the USA)

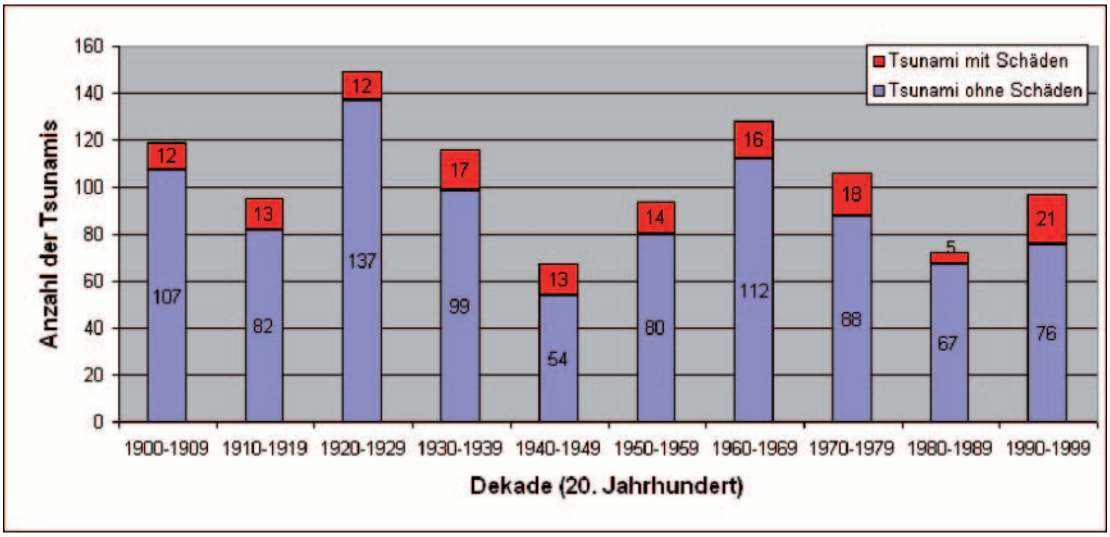


Fig. 8 shows the **frequency of tsunamis with and without damage** in the decades of the 20th century. Accordingly, during the past century, on average only around 10 tsunamis occurred per year, of which no more than 1 to 2, sometimes only one every 2 years, caused damage. Almost 90% of the tsunamis were triggered or initiated by earthquakes. The condition is that the earthquakes are sufficiently shallow and strong enough to fracture the earth's crust up to the ocean floor. However, this is only the case for earthquakes with magnitudes M (strength on the Richter scale) higher than 6. In the long-term average, around 200 quakes of this strength occur on the earth each year. But only around 10 to 20% of these quakes also generate a sufficiently strong vertical movement of the ocean floor in order to trigger a tsunami. Only tsunamis with run-up heights of 2 m and more cause noteworthy damage. Apart from a few exceptions, these are usually generated by earthquakes with M>7. Of these, on average there are around 17 quakes per year worldwide (fluctuated in the 20th century between around 5 to 40 per year). Only around one in every tenth of them also generated a noteworthy tsunami. However, occasionally comparatively weak or very slowly occurring earthquakes, which are not perceived at nearby coasts or are registered as weak tremors only, can cause large submarine landslides or ocean floor displacements and thus result in tsunamis. This was, e.g. the case in the two tsunamis of 1992 in Nicaragua (run-up max. 9 m) and 1998 in Papua New Guinea (run-up max. 15 m) with severe damage and numerous deaths.

4. Tsunami damage and risk

Compared to direct damage resulting from earthquakes, volcanic eruptions or landslides/rock avalanches, most of which only occur locally or in spatially limited areas, tsunamis can cause devastation and claim lives on coasts thousands of kilometres away. The intention of this section is to highlight special features, which are important for decisions with respect to living, working and relaxation in areas at risk of tsunamis and what to do after such a disaster.

Reefs and sandbanks/shallow water areas off a coast can reduce the destructive force of tsunami waves, and sometimes special wave-breaking structures, such as those built along several coastal sections of Japan at particular risk. Examples also exist where necessary culvert/throughway areas in such protective structures caused dangerous local increases in the flow velocity and wave height of the tsunami and therefore increase the damage in the area that should be protected.

Experience from Japan shows tsunami amplitudes below 1.5 m do not usually pose any risk to people and structures. However, there are cases, such as the night-time inrush of the tsunami of 1992 in Nicaragua where above all children, asleep on the floor in fishermen's huts on the beach, were drowned in the water, rising in some places by only 1 to 1.5 m.

If wave heights are over 2 m, most lightweight buildings made from wood, sheet metal, mud/clay, etc. are totally destroyed, if the waves are > 3 m high, concrete block buildings are also destroyed. If the wave heights exceed 4 m the number of deaths also rises drastically. Well-built reinforced concrete structures on the other hand can withstand tsunami waves at least 5 m high. Therefore, the upper storeys of reinforced concrete high-rise buildings/hotels can also be used as refuges in case of very short early warning times and small chances of escaping outdoors.

Tsunamis often penetrate hundreds of metres into flat coastal regions, particularly high waves can even penetrate several kilometres, and not only destroy human settlements but also make agricultural land and wells unusable due to salination and sanding. As the water masses penetrate and flow back several times, the flood areas are covered with mud and sand, shattered objects and parts of buildings. Ships in harbours are thrown on land (Fig. 9), roads are blocked and railway tracks are washed away, and are therefore unusable. Low-lying harbour areas and fishermen settlements often stand under water for a long time and become uninhabitable (Fig. 10). In addition, there are risks caused by leaking barrels full of fuels and chemicals, flooding of waste-water treatment works or cesspits and often hundreds or even thousands of human and animal corpses. Especially in tropical regions, the acute risk of drinking water contaminations, the breakout of epidemics, etc. Direct tsunami damage is often intensified by the outbreak of fires resulting from broken gas pipes and electrical short circuits, often in conjunction with leaking fuel from stranded ships and vehicles or leaking tanks in harbours (Fig. 10).

Fig. 9: Heaps of debris in Kodiak harbour, Alaska, after the tsunami on 27 March 1964 (Photo: R. Kachadorian, USCGS; taken from [3])

Fig. 10: Devastation and fires in the harbour of Niigata on Honshu, Japan, after the tsunami and earthquake of 16 June 1964.

Coastal biotopes (mangrove forests, coral reefs, etc.) can also be severely damaged and permanently destroyed by tsunamis.

5. Tsunami early detection and warning

The possibilities for early detection and warning grow with the distance of a coast at risk from the origin of the tsunami. If local monitoring networks exist in the area of origin (as is currently the case in Japan, Kamchatka and Alaska; such systems are currently being developed for several other areas), locating and estimating the strength and dangerousness of a tsunami and subsequent immediately initiated automatic warnings are possible within 5 to 10 min, depending on the development status of the technology used. For coastal sections further than 50 to 100 km (depending on the water depth and therefore tsunami propagation time, see Fig. 2) from the epicentre, there is therefore a real opportunity for early warnings. Coastal inhabitants then have several minutes to reach a safe place.

If regional tsunamis occur, e.g. in intracontinental and inland seas such as the Mediterranean, Black Sea, Sea of Japan, the Caribbean, the Gulf of Bengal, etc. warnings for more further away coasts at distances of several hundred up to 2000 km are possible in principle 1 to 3 hours before the tsunami reaches them (cf. Fig. 4). However, no technical early warning systems exist yet for the Atlantic and Indic and their intracontinental seas. Existing regional earthquake systems can be used for setting up such systems, specifically developed and supplemented with pressure sensors on the ocean floor and other oceanographic monitoring systems. Ocean sensors enable tsunami waves propagating from an excitation source to be recorded, their height determined and their propagation through the sea to be tracked.

Apart from a large number of modern sensors for obtaining the necessary data, the prerequisites for a functioning early warning system are their immediate transfer (e.g. via satellites), processing virtually in real time and immediate infeed of the resulting findings into national and international, worldwide open information systems and forwarding to warning centres.

The Pacific tsunami warning system for the Pacific Ocean has existed since 1965 and has an operative centre in Honolulu, Hawaii (PTWC – Pacific Tsunami Warning Center). It is supplemented by an international information centre (ITIC – International Tsunami Information Center). More detailed information is available from the ITIC's web portal (http://www.prh.noaa.gov/itic/; with links to the Alaska Tsunami Warning Center and events in the Indic). If a tsunami risk exists for remote pacific coastal zones with adequate warning times, the PTWC issues a tsunami alarm level. If you receive such information through the media, strictly follow the official instructions.

Organised responses and evacuations are no longer possible for local tsunamis, which occur directly off the coast and also not for the arrival of tsunamis originating from distant locations for which there are no official early warnings. Even then, you still have a good chance of saving your own life and those of others, if you attentively observe nature and know how to interpret unusual phenomena.

How can you identify an imminent tsunami risk, which requires **immediate response** by each individual?

- If official early warning systems exist, then a tsunami is signalled via agreed siren signals, messages via coastal radio or other media;
- If you are in a coastal area and notice strong earth tremors, then this is an acute warnings that a tsunami is POSSIBLE and immediate action is appropriate (cf. Item 7even if only a few of the strong quakes actually trigger a dangerous tsunami;
- It is important to know that earth tremors travel considerably faster than tsunami waves. This is why the earthquake of 26.12.2004 off Sumatra was felt in the province of Aceh 15 minutes before the tsunami wave arrived. This would have been sufficient time for correct tsunami response by the coastal inhabitants. In the event of tsunamis resulting from remote earthquakes or even (under certain circumstances even nearby) submarine earth slides and volcanic eruptions, however, in most cases there is no prior registration of tremors. In almost all tsunamis, however, the first large breaker wave is preceded by a relatively fast – compared to ebb and flood – RISE or FALL of the water level, often by several metres within 5 to 10 minutes. Both are **unmistakeable signs** that the first large wave front will soon reach the coast (less than 30 minutes; depending on the period of the subsequent tsunami waves).

Attentive observation of nature and immediate responsible response by each individual can therefore save lives. All people on the beach or the coast who either feel strong earth tremors or observe unusual behaviour of the sea level should bring this to the attention of all people around them and tell them to immediately leave the beach and all other flat coastal areas therefore at risk of flooding (cf. Section 7).

6. Which questions should one ask in regions in which there is a tsunami risk?

People who temporarily stay or live in coastal areas of the regions of the earth most at risk from tsunamis (Fig. 5) should ask the following questions and obtain information from the hotel management, local authorities, the police, or disaster or civil defence organisations, etc:

- Is the hotel/house/work building, etc. within a flood area within the event of a large tsunami?
- If yes, in what building class respect to its height, stability and strength of the foundations, is the building in which you are to live or work classified?
- Can the upper storeys of high (more than 3–storeyed) buildings with credible stability in an emergency be used as a refuge **(cf. Section 4.)**?
- Does a plan of the areas at risk from tsunamis exist for the location/bay, etc. (designated maximum impact and flood zones) with recommended evacuation routes, collection points, emergency shelters?
- How far away is the nearest high ground and other suitable refuges?
- Does a functioning early warning system and tsunami management exist for the location/beach/coastal area and if yes, what alarm signals apply and what action should be taken? (If applicable, request leaflet)?
- Is the hotel management/building management prepared to warn the residents at night in the event of an emergency and to give competent instructions on what to do? What type and through which media?

You should be aware that to date it was not usual to ask such questions. You will therefore probably be met with a lack of understanding and often even displeasure, especially as in most countries all the aforementioned bodies cannot yet provide any useful information. Don't let that put you off asking. Only questions repeatedly asked of these bodies by tourists, business people, politicians, etc. will produce the necessary moral, political and even economic pressure in order to make substantial disaster prevention and precaution progress within the next few years and decades. Several official bodies will even be grateful that they can refer to YOUR urgent questions, in their own efforts to obtain help, clarification and decisions from higher-ranking bodies.

7. Preventive and pressing rules for action in tsunami areas

- **Knowledge is safety!** Pass on your knowledge about tsunamis to others. This can help to save lives during future events.
- Although tsunamis can be very dangerous and devastating, they nevertheless occur very rarely. You should therefore not spoil your pleasure in experiencing the sea and beaches even in countries at risk of tsunamis, but at the same time, you should be an attentive and knowledgeable observer of nature, even if nothing unusual happens for decades.

7.1 What to do if you are outdoors

- If you are in low-lying coastal areas or a river bank near the estuary and feel a severe earthquake, then warn the other people near you and hurry as quickly as possible to **higher ground** in the hinterland or on the coast.
- Remember that tsunami waves can often reach heights of over 10 m at the coast, and in rare, extreme cases, more than 30 to 50 m. Tsunami waves dissipate quickly in the hinterland, but they can flood flat coastal areas several hundred metres up to several kilometres inland. Hills more than 10 m high at a distance of several hundred metres from the coast can provide a safe refuge. But: the higher and further away you can get within the warning time the safer you are.
- If suitable outdoor refuges are too far away from your location, if possible, seek protection in the higher storeys of a well-built, modern high-rise building/hotel.
- A tsunami consists of a series of high waves, sometimes more than 10. They follow each other at intervals of around 10 to 60 minutes (occasionally up to 2 hours). The first wave is rarely the strongest; this sometimes does not come until the sixth. Therefore, the tsunami risk exists for many hours after the arrival of the first wave. Returning to the flat coast too early can be fatal! You should therefore patiently remain in your safe refuge until the police of civil defence services give an official all clear!
- The same applies if you are on the beach or coast and observe an unexpected, non-tidal (6-hourly) but relatively fast **rise or fall** in the sea level during the course of minutes. Both are an **unmistakeable early warning** of an imminent first large tsunami wave. Never follow inquisitive persons who run into dry bays after the sea has retreated to look for fish or seashells! Instead, urgently warn these people and **immediately escape to higher ground inland**. You only have a few minutes head-start before the wave arrives!
- The same applies if you are on the beach or outdoors within the flood zone and are warned of the **imminent** arrival of a **tsunami** by an **alarm signal**.
- If you are on the open sea in your boat or ship when a tsunami warning arrives for your coastal area, do not return to a harbour or bay. Apart from breaking ways and dangerous sudden fluctuations in the water level, a tsunami can also cause unpredictable dangerous currents there. Stay at least a few kilometres away from the coast and do not return to the harbour until the harbour authorities have re-released it for safe navigation and anchoring.
- If you are in a harbour when a tsunami warning is given, you should note the following: Most large harbours are under the control of a harbour authority of a guide system for shipping. Immediately contact this authority as, in the event of alarm status, you are obliged to follow all instructions issued by the harbour authorities, if necessary even the instruction to leave the harbour.

- Small harbours or bays do not have such authorities. If you receive a tsunami warning and it leaves you enough time to manoeuvre your ship or boat into deep water, then you should immediately do this in an orderly way, paying attention to the safety of other water vehicles around you. Because in deep water a tsunami is hardly dangerous or its waves can still be manoeuvred at a distance from the coast and before they break, similar to waves on stormy seas.
- For the captains or helmsman of small boats, especially in the event of local tsunamis with a very short warning period or in case of dangerous stormy seas outside the harbour, it may be safer to leave the boat at the pier, to go on land and look for higher ground.
- In all the above cases with short warning times, you should never try to rescues property or return to buildings if they lie within a possible flood area. All healthy adult persons should run away or go by bike/moped. Car driving among hundreds or thousands of people in panic-stricken flight on blocked roads can have worse consequences than the tsunami itself. Cars should therefore only be used to take (small) children and disabled or elderly people to safety.
- If you are outdoors in a coast area and receive a tsunami warning by mobile phone, radio or from other people, with a **long warning period** of hours, then if the time allows, go to your apartment or hotel first and immediately notify your family, acquaintances and friends there. See the section on “what to do if you are in a building” for further information.
- If a long warning time is available, the local authorities will usually arrange orderly evacuations within the expected flood area and direct people to safe collection points or emergency shelters. In such a situation, buses and other vehicles are used or their private use is tolerated. Follow any instructions given by the law enforcement officers.
- If there is insufficient warning time or a lack of more recent instructions without an all clear, act as described above and look for refuge in a higher location or building within the expected impact and flood area. Remain there until the all clear is given.

7.2 What to do if you are in a building

- If you are in a building near the coast and within a potential tsunami flood area and feel a strong earthquake, immediately flee under a stable desk/table or door frame in a load-bearing internal wall and remain there for as long as the tremors last. For more information, you can refer to the *Earthquake leaflet*. After the tremors have subsided, leave the building immediately if it is in a flat coastal area, is a low building or the building substance is in a poor condition. Experience from Japan has shown that cheap, lightweight buildings made from wood, mud/clay or concrete blocks are destroyed by tsunami waves more than 2 to 3 m high. They therefore do not provide any chance of survival if they are near the beach and a powerful tsunami occurs.
- Well-build structures with sound foundations and reinforced construction methods on the other hand can withstand tsunami waves at least 5 m high. If such buildings/hotels are high enough (more than 3 storeys), corridors in the upper storeys may provide a safe refuge, even if they are near the beach or in low-lying coastal areas. As the arrival of the first tsunami wave can be expected within minutes, immediately after strong earthquake tremors have subsided in a coastal area, it is preferable to stay on the upper storeys of the building rather than to flee to higher ground.
- Switch your mobile phone, radio or television to reception in expectation of precise messages from the early warning service and instructions from the disaster management body, the police or other official agencies. Unless explicitly instructed otherwise by an official body, remain in your refuge until the all clear is given. Never leave a building after the first or second tsunami wave!
- If fleeing people inform you that a sudden fall or rise in water on the coast indicates the imminent arrival of a strong tsunami and you are in a low or not well-built building within the potential flood zone, you

should leave it immediately. Look for the shortest route to a refuge on higher ground and/or further away from the coast. If you are on the higher storeys of a very well built building when the warning is given, remain there, unless you are explicitly instructed otherwise by civil defence authorities.

- In the event of a tsunami warning issued through official media with a warning time of more than one hour for your coastal area, you must act prudently and stay calm. Switch on the radio, TV, mobile phone, etc. and wait for up-to-date information and instructions from the disaster/civil defence agency or the police. Inform the members of your family, fellow residents and friends where you are and immediately switch off all master switches/valves for electricity, gas and water (risk of accidents and fire!). Immediately issue yourself and your dependents with emergency supplies and clothing and take your cash, valuables, important personal documents, portable radio, mobile phone, etc. with you. Wait for possible evacuation instructions.
- If no evacuation instructions are given up to around half an hour before the expected arrival of the tsunami, you should immediately leave the building you are in, if it is located in a flat area near the coast, or is a low and/or lightweight building and look for a safe location. If, on the other hand, you are in a well-built high-rise building (more than 3 storeys) made of reinforced concrete or a steel skeleton structure, go to the corridors in the upper storeys as a place of refuse. Otherwise, join other people fleeing outdoors. You should only use cars if sufficient time is remaining and there is no panic or traffic jams on the roads (e.g. traffic control by police or civil defence offices) or if children, elderly, sick and/or disabled people need to be taken to safety.
- If your apartment/hotel/workplace is located within the flood area of a tsunami and orderly evacuation is required, always follow the instructions of the official bodies. However, if no further instructions or an all clear is give after a pressing tsunami warning, you should not take any risks or loose any time. Act responsibly, taking into account the general rules about what to do given above.
- If you have left the evacuation zone in a vehicle, do not return to the devastated area with it after the tsunami has passed (or only with the explicit approval of the disaster protection bodies!). Otherwise you can hinder clearance and rescue work.

Further reading/references

[1] **Anonymous (2002):** Tsunami – the great waves. Revised edition, drawn up by the U.S. National Oceanic & Atmospheric Administration (NOAA), UNESCO/Intergovernmental Oceanographic Commission (IOC), International Tsunami Information Center (ITC), Laboratoire de Geophyssique, France (LDG)

[2] **Römer, H.(2005):** Eine internationale Tsunamidatenbank – Erstellung und erste Auswertungen. Practical training work produced at GFZ Potsdam

[3] **Bolt, B. (1984):** Erdbeben. Eine Einführung. Springer–Verlag Berlin–Heidelberg–New York–Tokyo. 236 p.