

Tsunami generation potential of different tsunamigenic regions in the Pacific

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Abstract

The historical tsunami catalog collected within the Historical Tsunami Database (HTDB)/PAC Project contains the most complete parametric tsunami data covering the whole Pacific and the full historical period of the available observations (from 47 BC to present). The collected data provide a possibility to study variability of the tsunami potential of submarine earthquakes over the main tsunamigenic regions in the Pacific. For each region, the tsunami efficiency (TE) is calculated as the ratio between the number of tsunamis of tectonic, landslide and unknown origin and the total number of the coastal and the submarine earthquakes with magnitude $M \geq 7.0$ and focus depth $h < 100$ km. The tsunami efficiency, calculated in the above manner, varies from 84% for the South America region to 36% for the New Zealand–Tonga region. The correlation of variability of the TE value with the position of the main sedimentation zones in the Pacific shows that the regions located within the equatorial humid zone (New Guinea, Indonesia, Philippines) have a larger TE value as compared to the regions located in other zones. The circum-continental zoning in the sedimentation rate has resulted in the highest TE value for the South America region, where tsunamigenic sources are located close to the land. A higher sedimentation rate results in a higher potential for submarine slumping, which, according to the results of many recent studies, considerably increases efficiency of tsunami generation mechanism. Earthquakes in the marginal seas (the Japan Sea, the Okhotsk Sea, the Bering Sea) have a higher tsunami efficiency as compared to the earthquakes in the Pacific Ocean. A similar feature takes place for the Indonesia region, where the tsunami efficiency of the earthquakes occurring in the Indian Ocean (within the Java trench) is almost 95%, while the rest of the region has this value at the level of 62%.

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1. Introduction

This research on the tsunamigenic potential of submarine earthquakes in the Pacific is extensively

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based on the tsunami database collected within the Historical Tsunami Database (HTDB) Project initiated in 1995 as a joint project of the IUGG Tsunami Commission and the International Coordination Group of the IOC/UNESCO for the Tsunami Warning System in the Pacific (Gusiakov, 2001). The HTDB project is intended for improving the situation with cataloguing historical tsunamis in the Pacific by means of organizing them in the form of a parametric tsunami catalog and a database. The database consists of two main parts: the catalog of tsunamigenic events with their basic source parameters and the catalog of the observed run-up heights provided with geographical coordinates of observational sites. The current version of the database (3.8 of December 31, 2002) covers the period from 47 BC to 2002 and contains data on 1305 historical tsunamigenic events of different origin (tectonic, volcanic, landslide, meteorological, etc.) and almost 7500 run-up heights. As a supplementary part, the database contains the global earthquake catalog from ancient times up to the present counting almost 230,000 events. This seismic catalog was compiled from several sources, mainly the NGDC Catalog of Significant Earthquakes (Dunbar et al., 1992), USGS/NEIC digital catalog PDE (http://www.neic.cr.usgs.gov/neis/epic/epic_global.html) with some additions from regional seismic catalogs (such as the JMA, the Kuril–Kamchatka and the South America catalogs) for different areas. The quality and completeness of the combined earthquake catalog vary over time and space, but one can hope that, for the events exceeding a certain magnitude threshold (for instance, 7.0), the catalog is nearly complete for the last 100 years. The basic set of quantitative parameters collected within the HTDB Project (the event and run-up catalogs) is available on the Web site at the following URL: <http://tsun.sccc.ru/htdbpac>. The full version of the database also includes textual descriptions of tsunami manifestation and some additional and reference information related to the tsunami problem in the Pacific. It is distributed on the CD-ROM that contains the GIS-type graphic shell running under Windows 95, 98, 2000, NT 4.0 and XP. The shell provides options for easy data retrieval, visualization and processing, some of them being essentially used in this study.

2. Tsunami efficiency of submarine earthquakes

The main question in the present study can be formulated as follows: what fraction of the submarine earthquakes are tsunamigenic, and how does this fraction vary over the main tsunamigenic regions in the Pacific? The data collected within the historical database and the options provided by the HTDB graphic shell are readily available to answer this question in detail. The historical tsunami catalog collected within the HTDB Project contains the most complete parametric tsunami data covering the whole Pacific and the full historical period of the available observations (from 47 BC to 2002). The collected data present a possibility to study the variability of the tsunami potential of submarine earthquakes over the main tsunamigenic regions of the Pacific. As the completeness and accuracy of the earthquake catalog are of great importance for this kind of study, we confine the time period for our investigation to the last century (from 1901 to 2000) when instrumental data for determining the earthquake magnitude are available.

Fig. 1 shows the positions of 10 main tsunamigenic regions in the Pacific. In identifying the boundaries of these regions, we basically followed the zoning used in the well-known NGDC map *Tsunamis in the Pacific Basin, 1900–1983* (Lockridge and Smith, 1984). These regions are Alaska–Aleutians (A–A), Central America (CAM), South America (SAM), New Zealand–Tonga (NZT), New Guinea–Solomon I (NGS), Indonesia (IND), Philippines (PHI), Japan (JAP), Kuril–Kamchatka (K–K) and Hawaii (HAW).

Fig. 2 shows how these regions are distributed geographically. It can be seen that their geographical distribution forms a certain pattern that can be interpreted in terms of geographical zoning in the oceanic sedimentation described in Lisitsyn (1974). Namely, three of five regions are located within the equatorial humid zone that has the highest sedimentation rate and accumulates up to 76% of the total bulk of sediments delivered to the ocean by rivers, winds and glaciers (Lisitsyn, 1988). A higher sedimentation rate results in a higher potential for submarine slumping, which considerably increases the efficiency of the tsunami generation mechanism (Garder and Poplavsky, 1990; Heinrich, 1992; Melekestsev, 1995; Murty, 1979).

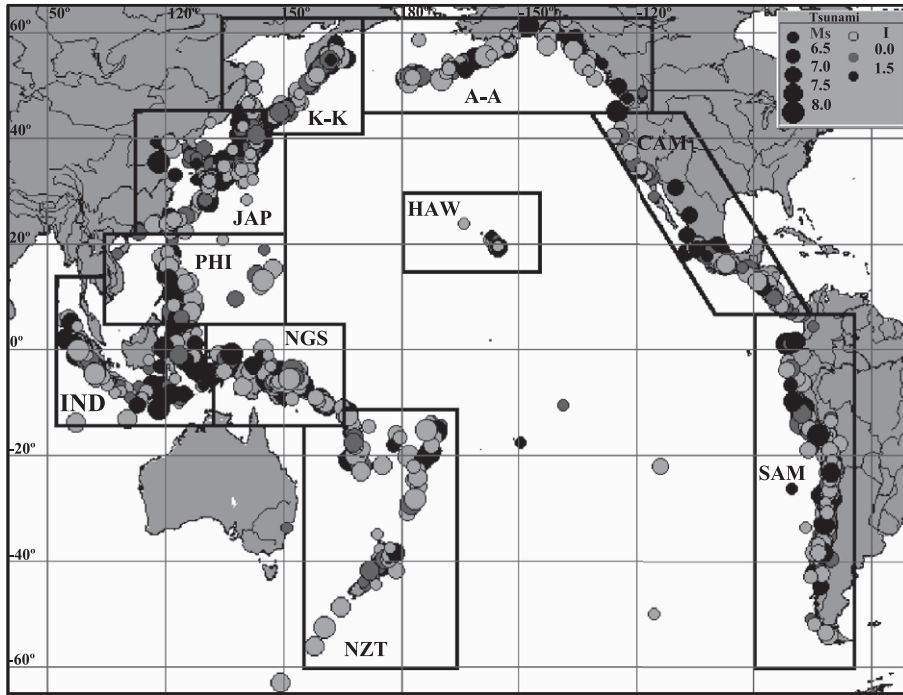


Fig. 1. Boundaries of the main tsunamigenic regions in the Pacific. Circles show source positions of the tsunamigenic earthquakes that occurred in the Pacific from 1901 to 2000. The size of circles is proportional to the magnitude M_s , density of grey tone—to the tsunami intensity I .

The increased TE ratio for the South America region fits very well to another law-governed feature of sediment distribution, the circum-continental zoning. In this region, sources of tsunamigenic earthquakes are located very close to the land with many sources of great tsunamis situated partly within the land. This feature of the South America earthquakes was noted by Gutenberg (1939) who was probably the first to link tsunamigenic earthquakes with submarine slumping. A high slope gradient between the nearby mountain ridge (Cordilleras) and the deep-water ocean (Peru–Chile trench) results in an increased level of land erosion and sediment transport. This region is also characterized by a high level of coastal wave erosion that gives an additional input of terrestrial sediments coming into the seawater from the continent.

As far as the Hawaiian region is concerned, the main factor here is a huge amount of volcanic material delivered by numerous Hawaiian volcanoes resulting in a high level of instability of submarine volcano cones. Being located far away from the main sources

of the terrestrial sediments, the Hawaiian region experiences, however, a high load of explosive volcanogenic material, forming an underwater volcanic edifice of all Hawaiian islands, resulting in frequent slumping on the underwater skirts of the Hawaiian volcanoes.

For more detailed consideration, all the tsunamis were divided into three categories in terms of their intensity I on the Soloviev–Imamura scale (Soloviev, 1972) and of the average run-up heights H_{av} :

Damageable	$I > 1.5 (H_{av} > 3m)$
Perceptible	$-0.5 \leq I \leq 1.5$ ($0.5m \leq H_{av} \leq 3m$)
Observable	$I < -0.5 (H_{av} < 0.5m)$ and without any I value.

From the chart diagram shown in Fig. 3, the same law-governed feature in the distribution of the TE value over the regions can be seen in each separate category of tsunamigenic events; that is, the highest

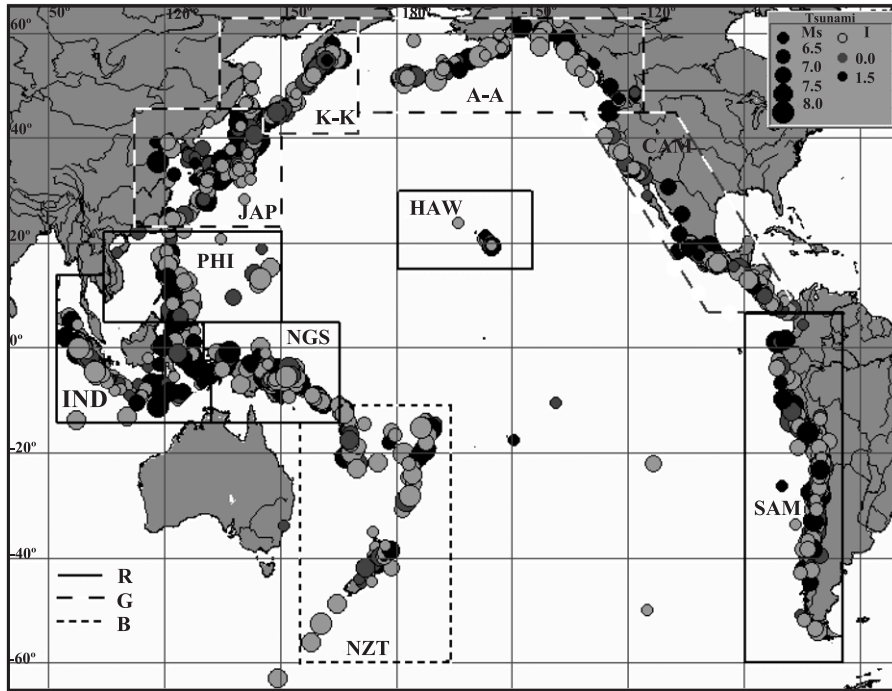


Fig. 2. “Red” (R), “green” (G) and “blue” (B) tsunamigenic regions in the Pacific. Circles show source positions of the tsunamigenic events that occurred in the Pacific from 1901 to 2000. The size of circles is proportional to the magnitude M_s and the density of grey tone to the tsunami intensity I .

fraction of perceptible and damaging tsunamis takes place for the same regions, namely, Hawaii, South America, Indonesia and Philippines.

For each region, we determine some quantitative value conventionally called the Tsunami Efficiency (TE) coefficient. The coefficient TE is calculated as

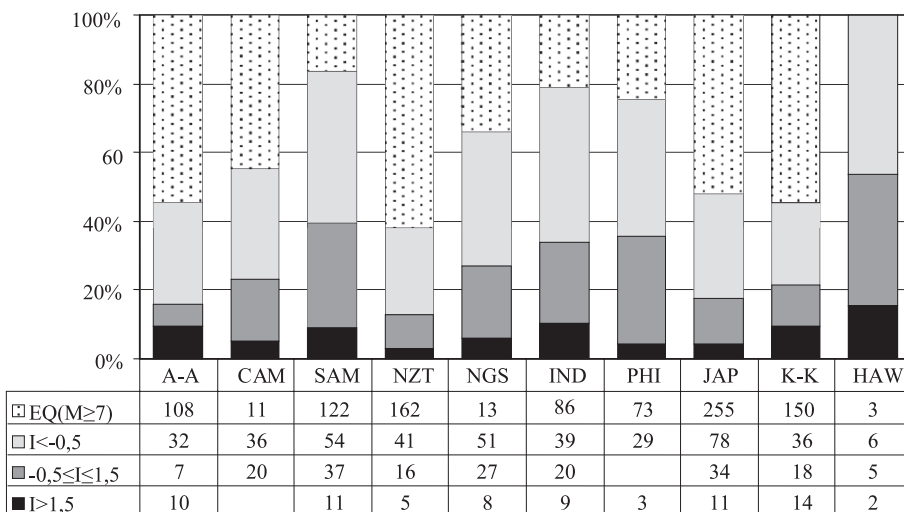


Fig. 3. Chart diagram showing fractions of damaging (black), perceptible (dark grey) and observable (light grey) tsunamigenic events in the total number of submarine earthquakes with $M_s \geq 7.0$ and $h < 100$ km that occurred in the main tsunamigenic regions of the Pacific from 1901 to 2000.

Table 1

Number of tsunamis (TS) and submarine earthquakes (EQ) that occurred in the main tsunamigenic regions of the Pacific from 1901 to 2000 and their TE ratio

Regions	TS	EQ	TE (%)
Japan	123	255	48
South America	102	122	84
New Guinea–Solomon	86	130	64
Indonesia	68	86	79
Kuril–Kamchatka	68	150	45
Central America	62	112	55
New Zealand–Tonga	62	162	38
Philippines	55	73	75
Alaska–Aleutians	49	108	46
Hawaii	13	3	433
All Pacific	688	1201	57

the ratio between the number of tsunamis of tectonic, landslide and unknown origin and the total number of the coastal and the submarine earthquakes with magnitude $M_s \geq 7.0$ and depth $h < 100$ km that occurred within a certain region during the last 100 years (from 1901 to 2000). The term «coastal» means that we also take into account the earthquakes located within 100 km «in-land» for the events with $7.0 \leq M_s \leq 8.0$ and 200 km «in-land» for the events with $M_s > 8.0$. One can note that according to this definition, the TE value may exceed 1; in this case, it simply means that some part of tsunamigenic events was generated by the earthquakes with magnitude less than 7.

3. Variation of tsunami efficiency over the Pacific region

The results of the calculations of the TE ratio for the 10 main tsunamigenic regions are summarized in Table 1, where the regions are listed in decreasing order of their tsunami activity, i.e., the number of tsunamis that occurred during the last century within each region. As one could expect, the Japan region is on the top of this list, which can be explained not only by its high tsunamigenic activity but also by better cataloguing traditions and by the existence of a dense monitoring network. Since this region has also the highest number of submarine earthquakes, its TE ratio is only 48%, which is lower than the average value for the whole Pacific (57%). The bottom line is taken by the Hawaiian region, with 13 tsunamis having local sources. Among them, however, there are only three seismotectonic events generated by the earthquakes with magnitude above the adopted threshold (7.0). The rest of events are marked as landslides or unknown. Part of these events is marked as “meteorological” (Lander and Lockridge, 1989), which simply means that, in these cases, unusual waves were not clearly associated with seismic or volcanic activity. The data presented in Table 1 are also shown in Fig. 4 as a chart diagram, where each column corresponds to a particular region.

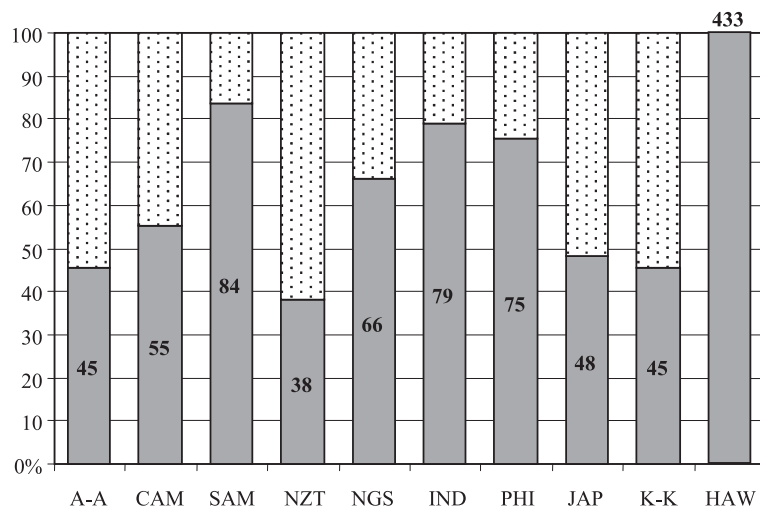


Fig. 4. Chart diagram showing fractions of the tsunamigenic events (TS) in the total number of submarine earthquakes (EQ) with $M_s \geq 7.0$ and $h < 100$ km that occurred in the main tsunamigenic regions of the Pacific from 1901 to 2000.

Table 2
The TE ratio for different parts of the Japan and the Indonesia regions

	TE for all tsunamis (%)	TE for damaging events (%)
<i>Japan region</i>		
Japan Sea part	58	18
Pacific part	49	4
<i>Indonesia region</i>		
Indian Ocean part	95	17
Pacific part	63	5

Based on the TE ratio for each tsunamigenic region, we have divided the regions into three categories, conditionally named “red”, “green” and “blue”, that roughly corresponds to the increased (as compared to the average for the whole Pacific), the normal and the decreased levels of this ratio. With windows selected for the TE value in each category (0–40%, 40–60% and above 60%), we have five regions in the “red” category, four regions in the “green” category and one region in the “blue” category.

Some of the Pacific tsunamigenic regions can be divided into two parts that belong to different sea basins. They are, for instance, the Japan region, having tsunamigenic events originating both in the Japan Sea and in the Pacific, and the Indonesian region, having tsunamis in the Indian Ocean and in the Pacific marginal seas (the Java Sea, the Flores Sea, the Banga Sea). Since the level of sedimentation rate in these two parts of both regions is quite different, we can expect a difference in their TE value. The Japan Sea is a marginal sea with an increased (as compared to the Pacific Ocean) level of sedimentation rate. The tsunamigenic events in the western part of the Indonesian region (the Java trench) occur in the area covered with a long tongue of high concentration of sediments originating near the mouths of the great Indian rivers Gange and Brahmaputra. These rivers deliver to the Indian ocean a tremendous amount of sediments eroded by water from the Tibet mountain area. The results of the calculation of the TE value for separate parts of these two regions are shown in Table 2. As one could expect, the events in the internal basins have an increased TE value as opposed to the Pacific events, and especially, a great difference exists for the major (damageable) tsunamis.

4. Conclusions

The main conclusion of this study can be formulated as follows. Variation of the tsunami efficiency, calculated in the above-defined manner, over the main tsunamigenic regions in the Pacific shows its clear spatial correlation with the geographical and the circum-continental zoning in the distribution of oceanic sediments. This means that a landslide component in the tsunami generation mechanism also varies regionally, and this fact should be taken into account in operational warning procedures and preliminary estimation of the long-term tsunami risk. The results of this study demonstrate the existence of a close relationship between oceanic sedimentation zones and tsunamigenic potential of submarine earthquakes. In spite of greater efforts made in recent years for studying the slumping mechanism as a significant contributing factor in tsunami generation, this factor is almost completely overlooked by the operations of tsunami warning systems, and it is not taken into account in calculation of the long-term tsunami risk. At present, most efforts are focused mainly on the seismotectonic aspects of tsunami generation, on the improvement of operational methods for source mechanism and magnitude determinations, while conditions of sedimentation of the ocean floor in the source area are almost completely ignored. The present study illustrates that conditions of oceanic sedimentation are of extreme importance in the understanding of the tsunami generation mechanism.

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