TSUNAMIGENIC POTENTIAL OF SUBMARINE EARTHQUAKES IN DIFFERENT REGIONS IN THE PACIFIC

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ANNOTATION

The historical tsunami catalog collected within the 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 the 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 ratio between the number of tsunamis of tectonic, landslide and of unknown origin and the total number of the coastal and the submarine earthquakes with magnitude $M \geq 7.0$ and 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 comparison of the variation of the TE value with the position of the main sedimentation zones in the Pacific [Lisitsyn, 1974] shows that the regions located within the equatorial humid zone (New Guinea, Indonesia, Philippines) have the increased number of tsunamigenic events as compared to the regions located in other zones. The circum-continental zonation in the sedimentation rate has resulted in the highest TE value for the South America region, where the tsunamigenic sources are located most closely to the land. The higher sedimentation rate results in a higher potential for submarine slumping that, according to the results of many recent studies, considerably increases the efficiency of tsunami generation mechanism. The 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 situation takes place for the Indonesia region, where the tsunami efficiency of the events occurred within the Java trench is almost 95% while the rest of the region has this value at the level of 62%.

This study is extensively based on the Historical Tsunami Database collected within the HTDB Project that was 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 project is directed to improve the situation with catalogization of historical tsunamis in the Pacific by means of organizing them in the form of the parametric tsunami catalog and the database. The database consists of the two main parts: the catalog of tsunamigenic events with their basic source parameters and the catalog of the observed run-up heights provided with the geographical coordinates of observational sites. The current version of the database (3.8 of July 31, 2002) covers the period from 47 B.C. to present time and contains the data on 1305 historical tsunamigenic events of different origin (tectonic, volcanic, landslide, meteorological, etc.) and almost 7500 run-up heights. As its supplementary part, the database contains the global earthquake catalog from ancient times up to the present that contains almost 230000 events. This catalog was compiled from several sources, mainly, the NGDC Catalog of Significant Earthquakes [Dunbar *et al.*, 1992], NEIC catalog (after 1973) with some additions from regional seismic catalogs (such as JMA, Kuril-Kamchatka of South America catalogs) for different areas. The quality and completeness of the combined earthquake catalog vary over the time and space, but we can hope that for the events above certain magnitude threshold (for instance, 7.0) the catalog is nearly complete for, at least, the last one hundred 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.sscc.ru/htdbpac.** The full version of the database also includes the 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 were essentially used in this study.

The main question for the present study was: to find what fraction of the submarine earthquakes are tsunamigenic and how this fraction varies over the main tsunamigenic regions in the Pacific? The data collected within the HTDB database and the options provided by the HTDB graphic shell are readily available to investigate 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 present). 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. Because the completeness and accuracy of the earthquake catalog are of vital importance for this kind of a study, we confine the time period for our investigation to the last one hundred years (from 1901 to 2000), where the instrumental data for determining the earthquake magnitude are available.

Fig. 1 shows the positions of 10 main tsunamigenic regions in the Pacific. In identification of the boundaries of these regions we basically followed (with some miner modifications) the zonation used in the well-known NGDC map "Tsunamis in the Pacific Basin, 1900 – 1983" [Lockridge, 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).

For each region we determine some quantitative value conventionally called the Tsunami Efficiency (TE) coefficient. The TE coefficient is calculated as ratio between the number of tsunamis of tectonic, landslide and of unknown origin and the total number of the coastal and the submarine earthquakes with magnitude $Ms \geq 7.0$ and depth $h < 100$ km occurred within a certain region during the last one hundred years (from 1901 to 2000). The term «coastal» means that we also take into account also earthquakes located within 100 km «in-land» for the events with $7.0 \leq Ms \leq 8.0$ and 200 km "in-land" for the events with $Ms > 8.0$. We should note that according to this definition, the TE value may exceed 1, if this is a case, it means that some part of tsunamigenic events was generated by the earthquakes with magnitude less than 7.

The results of the calculations of the TE ratio for 10 main tsunamigenic regions are summarized in Table 1, where the regions are listed in the decreasing order of their tsunami activity, i.e. the number of tsunamis occurred during the last century within each region. As one could expect, the top line is taken by the Japan region, that can be explained not only by its high tsunamigenic activity but also by the better monitoring conditions. Since this region has also the highest number of earthquakes, its TE ratio is only 48%, that is lower than the average value for the whole Pacific (58%). The bottom line is taken by the Hawaiian region with 13 tsunamis having local sources, among them, however, there were only 3 earthquakes with magnitude above the selected threshold (7.0).

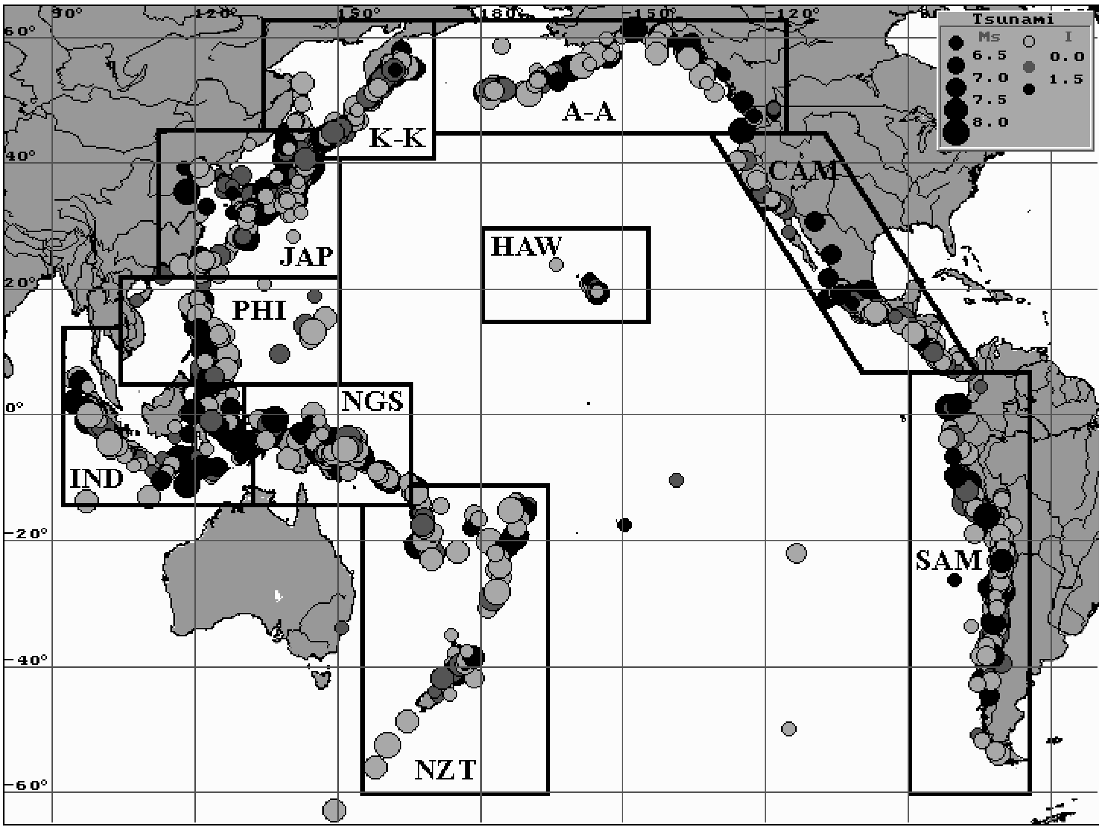


Fig.1. Boundaries of the main tsunamigenic regions in the Pacific. Circles show source positions of the tsunamigenic events occurred in the Pacific from 1901 to 2000.

Fig. 2 shows the same data as a chart diagram, where each column corresponds to a particular region. Based on their TE ratio, we have conventionally divided all the regions into three categories, conditionally named as “red”, “green” and “blue”, that roughly corresponds to the increased (compared to the average for the whole Pacific), normal and decreased level of the this ratio. With selected windows 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.

Fig. 3 shows how these regions are distributed geographically. From this map one can see that their geographical distribution forms some pattern that can be interpreted in terms of geographical zonation 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 76% of the total bulk of sediments delivered to the ocean mainly by rivers [Lisitsyn, 1988]. The higher sedimentation rate results in a higher potential for the submarine slumping that considerably increases the efficiency of the tsunami generation mechanism [Garder and Poplavsky, 1990; Melekestsev, 1995].

The increased TE ratio for the South America region fits very well to another law-governed feature of sediments distribution – circum-continental zonation. In this region, sources of tsunamigenic earthquakes are located most closely to the land and source areas of many tsunamis are located partly within the land. This feature of the South America earthquakes was noted by Gutenberg [Gutenberg, 1939] who was probably the first to link tsunamigenic earthquakes with submarine slumping. High vertical difference in the level of the mountain ridge (Cordilleras) and the nearby deep-water trench results in the increased number of sediments transport. This region is also characterized by a high level of wave erosion that gives an additional amount of the terrestrial sediments coming into the water.

Table 1

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

Japan	123	255	48%
South America	102	122	84%
New Guinea–Solomon	86	134	66%
Indonesia	68	86	79%
Kurile-Kamchatka	68	148	46%
Central America	62	110	56%
New Zealand–Tonga	62	162	38%
Philippines	55	73	75%
Alaska-Aleutians	49	108	46%
Hawaii	13	3	433%
All Pacific	736	1271	58%
Japan	123	255	48%

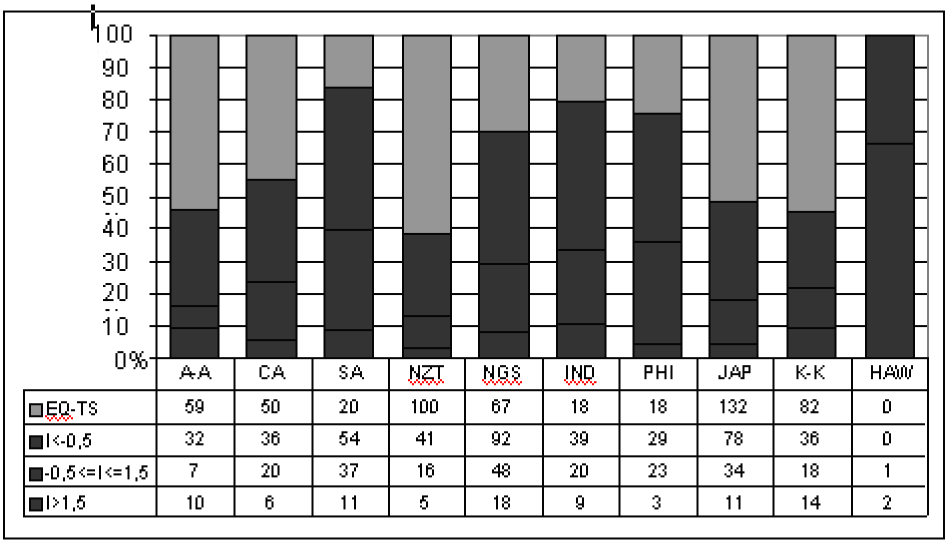


Fig.2. Chart diagram showing fractions of the tsunamigenic earthquakes (black color) in the total number of submarine earthquakes with Ms≥7.0 and h<100 km occurred in the main tsunamigenic regions of the Pacific from 1901 to 2000.

As far as the Hawaiian region is concerned, the main factor here is the huge amount of volcanic material delivered by numerous Hawaiian volcanoes that resulted 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, bringing about frequent slumping on the underwater skirts of the Hawaiian volcanoes.

For a 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 the average run-up heights Hav:

- damageable I>1.5 (Hav >3m)
- perceptible –0.5≤I≤1.5 (0.5m≤Hav≤3m)
- observable I<-0.5 (Hav <0.5m) and without I value.

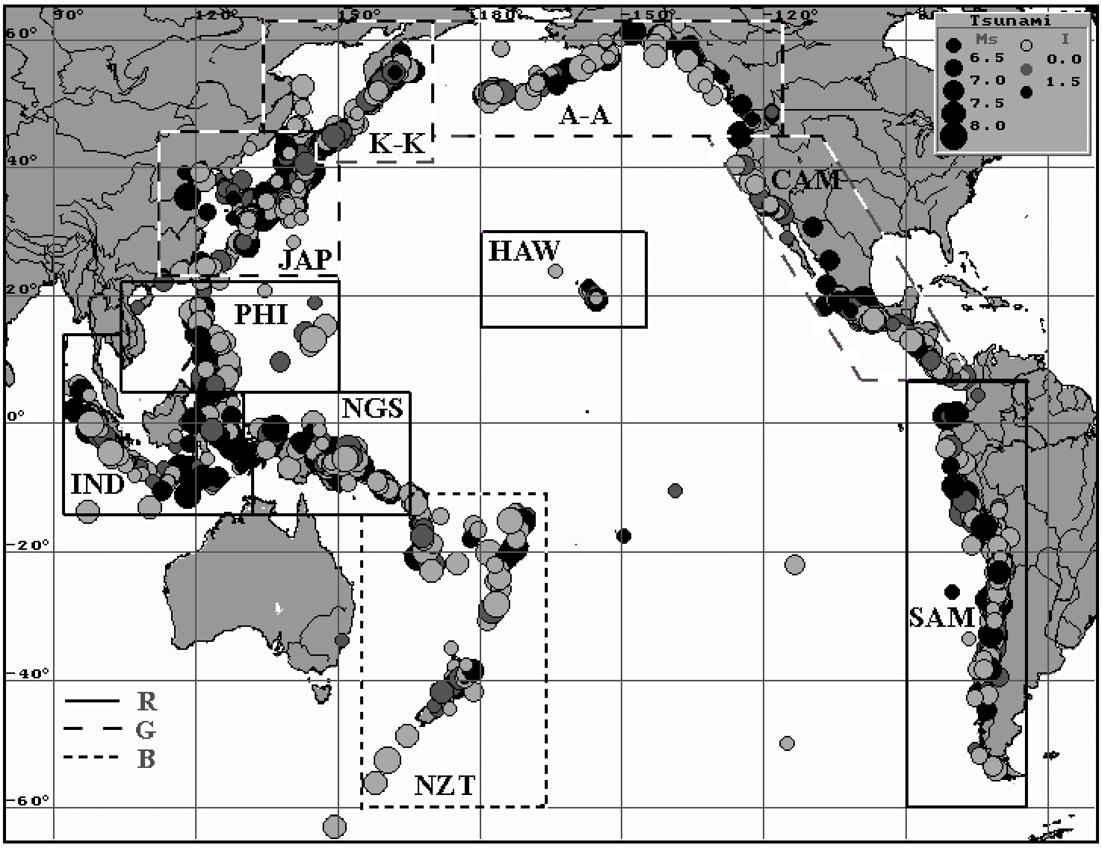
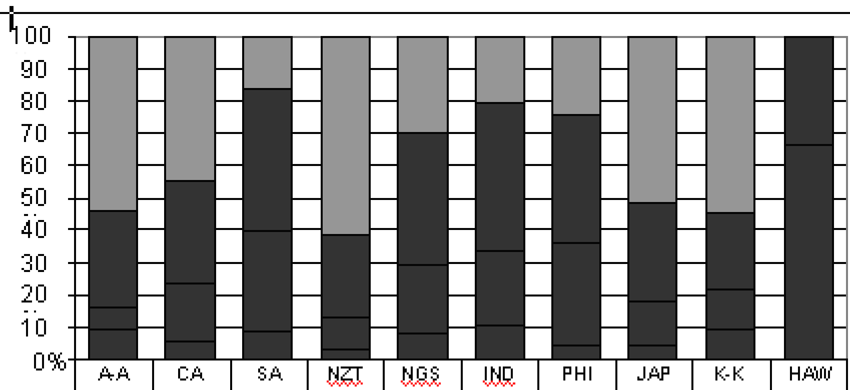


Fig.3. “Red” (R), “green” (G) and “blue” (B) tsunamigenic regions in the Pacific. Circles show source positions of the tsunamigenic events occurred in the Pacific from 1901 to 2000.



	A-A	CA	SA	NZT	NGS	IND	PHI	JAP	K-K	HAW
EQ-TS	59	50	20	100	67	18	18	132	82	0
I<-0,5	32	36	54	41	92	39	29	78	36	0
-0,5<=I<=1,5	7	20	37	16	48	20	23	34	18	1
I>1,5	10	6	11	5	18	9	3	11	14	2

Fig.4. Chart diagram showing fractions of the damaging (black), perceptible (dark gray) and observable (light gray) tsunamigenic events in the total number of submarine earthquakes with Ms≥7.0 and h<100 km occurred in the main tsunamigenic regions of the Pacific from 1901 to 2000.

From the chart diagram shown in Fig. 4, 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 fraction of perceptible and damaging tsunamis takes place for the same regions, namely, Hawaii, South America, Indonesia and Philippines.

Some of the 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 (Java Sea, Flores Sea, Banga Sea). The level of sedimentation rate in these two parts of both regions is quite different, therefore we can expect a difference in their TE value. The Japan Sea is a marginal sea with the increased (as compared to the Pacific ocean) level of sedimentation rate. The tsunamigenic events in the Indian part occur in the area covered with the long tongue of high concentration of sediments originated near the mouths of great Indian rivers Gang and Brahmaputra that deliver in the Indian ocean the 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 we could expect, the events in the internal basins have the increased TE value as opposed to the Pacific events and, especially, a great difference exists for the major (damageable) tsunamis.

Table 2

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

	TE	TE for damaging events
Japan region		
Japan Sea part	58%	18%
Pacific part	49%	4%
Indonesia region		
Indian Ocean part	95%	17%
Pacific part	63%	5%

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 zonation 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 a preliminary estimation of the long-term tsunami risk.

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REFERENCES

Garder O. I., and Poplavsky A. A., 1990: Can slumps generate tsunamis? Issledovaniya Tsunami, Moscow, Nat. Geophys. Committee Publ., 5, 38-49 (in Russian).

Dunbar P. K., Lockridge P. A., and Whiteside L. S., 1992: Catalog of significant earthquakes, 2150 B.C. – 1991 A.D., NOAA/NGDC Report SE-49, Boulder, Colorado, 320p.

Gusiakov V. K., 2001: Basic Pacific tsunami catalogs and database, 47 BC – 2000 AD: results of the first stage of the project. Proceedings of the International Tsunami Symposium, August 7-9, 2001, Seattle, USA, PMEL/NOAA, P.263-272.

Gutenberg B. Tsunamis and earthquakes. *Bull. Seis. Soc. Am.*, 1939, **29**, 4, P.517-526.

Lisitsyn A. P., 1974: Sedimentation in oceans. Moscow, Nauka, 425 pp. (in Russian).

Lisitsyn A. P., 1988: Avalanche sedimentation and breaks in the sediment deposition in seas and oceans. Moscow, Nauka, 309 pp. (in Russian).

Lockridge P. A., and Smith R. H., 1984: Tsunamis in the Pacific Basin, 1900-1983 (map), Boulder, Colorado, NOAA/NGDC.

Melekestsev I. V., 1995: On the possible source of the November 23, 1969 Ozernoy tsunami in Kamchatka. *Vulkanologiya i Seismologiya*, 3, 105-108 (in Russian).

Soloviev S. L., 1972: Earthquake and tsunami recurrence in the Pacific ocean. Volny Tsunami, Trudy SAKHNII, v.29, Yuzhno-Sakhalinsk, 7-47 (in Russian).