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Evaluation of Intensity of Recent Seismogenic Tsunamis in the World Ocean from 2000 to 2014

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Abstract—Tsunami intensity on the Soloviev–Imamura scale is one of the most important parameters for characterizing the overall size of a tsunami generated by submarine earthquakes. Consequently, this parameter is included in both global tsunami databases maintained by the National Centers for Environmental Information/World Data Service (NCEI/WDS) and the Novosibirsk Tsunami Laboratory of the Institute of Computational Mathematics and Mathematical Geophysics (NTL/ICMMG). S. Soloviev made the initial evaluation of the intensities of a large number of destructive historical tsunamis while compiling his two historical catalogs of tsunamis in the Pacific. The Novosibirsk Tsunami Laboratory under the Expert Tsunami Database Project made further determinations of tsunami intensity for the events after 1975. These intensities have been periodically incorporated into the NCEI/WDS tsunami database under the Global Tsunami Database Joint ICG/ITSU-IUGG/TC Project. In the on-line version of the NCEI/WDS Tsunami Database, the data on tsunami intensity are available only for the events prior to 2003. The main purpose of this paper is to extend the temporal coverage of this important parameter for characterizing tsunamigenic events to the present in order to provide researchers with more data for analyzing the temporal and spatial tsunami occurrence. However, of the 164 tsunamigenic events in the World Ocean from 2000 to the present, we could determine the intensity value for only 44 events that is less than 27 % of the total. For the rest of the events (that is, 73 %), the intensity value cannot be determined due to the lack of data on wave heights from the nearest coast. This shows that despite a great improvement in the tsunami-recording network in the Pacific and other oceanic basins during the last two decades, the data for reliable estimates of tsunami intensity are still problematic.

Key words: Tsunami, submarine earthquakes, earthquake magnitude, tsunami intensity, tsunami warning.

1. Introduction

One of the main problems in cataloging historical tsunamis is to measure the overall “size” or “force” of an event. To compare different tsunamigenic events, we need some scale for their measurement. A number of descriptive and quantitative scales were proposed for quantification of historical tsunamis (their survey can be found in Gusiakov 2009), however, only one of them, the Soloviev–Imamura intensity scale I became *de facto* the most widely used scale for measuring the size of tsunamis. This scale is incorporated into both global historical tsunami databases maintained by NOAA’s National Centers for Environmental Information/World Data Service (NCEI/WDS 2015) and the Novosibirsk Tsunami Laboratory (NTL) of the Institute of Computational Mathematics and Mathematical Geophysics of the Siberian Division, Russian Academy of Sciences (ICMMG SD RAS) (HTDB/WLD 2015). What is more important, the intensity I is now determined for more than 90 % of all significant historical tsunamis worldwide; thus, allowing us to rank the main tsunamigenic regions by their tsunamigenic potential and different tsunamigenic events by their overall size.

The first quantitative scale to compare the Pacific tsunamis was introduced by (Iida 1963) who connected the grade number m of Imamura’s descriptive scale, proposed in 1942 in Japan (Imamura 1942) with a maximum observed run-up value at the coast $H_{\max}$ by the formula:

$$m = \log_2 H_{\max}. \tag{1}$$

Imamura called it a tsunami magnitude scale, but it is a typical example of intensity scale, since it is based on coastal tsunami effects and does not contain

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any correction for distance from source. Soloviev (1972) made an important modification of this scale proposing to use the average height H_{av} over some extended part of the nearest coast for calculation of tsunami intensity I by the formula:

$$I = {}^{1}\!/_{2} + \log_2 H_{av}. \tag{2}$$

Soloviev argued that this value is a more reliable characteristic of a tsunami and is most closely related to the total tsunami energy radiated from a source. In his original paper, Soloviev did not quantify the notion of "extended part of the nearest coast," noting only that the stronger the earthquake the longer the part of the coast that should be considered. This uncertainty is one of the main reasons why the procedure of intensity calculation cannot be completely formalized. A simple "rule of thumb" is that the extent of the coast considered should be about double the size of the earthquake source length, that is to be approximately 200 km for sources with $M_{\mathrm{w}} = 7.8$, 400 km for sources with $M_{\mathrm{w}} = 8.4$ and 800 km for mega-events with $M_{\mathrm{w}} = 9.0$.

The intensity I in the Soloviev–Imamura scale is based on the coastal tsunami effect (run-up heights), therefore, it is clearly an intensity-type scale. However, in practice it is widely used as a magnitude-type scale allowing a direct comparison of different tsunamigenic events. This is possible because most tsunamis occur in subduction zones where their sources are located at nearly the same distance from the nearest coast (50–100 km).

With this scale, Soloviev evaluated the intensity for a large number of the Pacific tsunamis when compiling his catalogs (Soloviev and Go 1974, 1975; Soloviev 1978). Further determinations of tsunami intensity were made by the Novosibirsk Tsunami Laboratory under the ETDB (Expert Tsunami Database) Project (Gusiakov *et al.* 1997) and periodically have been incorporated into the NCEI/WDS tsunami database under the GTDB (Global Tsunami Database) Joint ICG/ITSU- IUGG/TC Project (Gusiakov 2003). In the current on-line version of the NCEI/WDS Tsunami Database, the tsunami intensity data are available only for the events prior to 2003. The main purpose of this paper is to extend the temporal coverage of this important parameter for characterizing historical tsunamigenic events to the present in order to provide researchers with more data for analyzing their temporal and spatial occurrence. Due to a continuous extension and technical improvement of the tsunami observation network in the Pacific and elsewhere, the amount and quality of data on tsunami measurements have been drastically improved for the events during the XXI century as compared with earlier historical events (Mofjeld 2009; Rabinovich and Eblé 2015). It is also interesting to evaluate the recent and older historical tsunamis in terms of the accuracy and reliability of their intensity determination.

2. *Data*

The data retrieval from the NCEI/WDS database was made for tsunamigenic events from 2000 to 2014 with a validity index from 1 to 4, thus excluding from consideration the events with validity −1 (erroneous entry) and 0 (disturbance in inland rivers). The retrieval returned a list of 164 tsunamigenic events or, on average, almost 11 tsunamis annually occurring in the World Ocean. The geographical distribution of their sources is shown in Fig. 1: 128 events occurred in the Pacific, 21 in the Indian Ocean, 10 in the Atlantic, and 5 in the Mediterranean region. Among the 164 events, 146 had a seismogenic origin, 6 events resulted from volcanic eruptions and associated failures of volcanic slopes, 8 were generated by submarine or coastal landslides, and the remaining 4 events had a non-tectonic origin (meteotsunamis or freak waves, their actual number might be much greater). Only 15 of 164 events (that is less than 10 %) were accompanied by fatalities, all the rest were non-fatal events despite some having great maximum run-ups (up to 50 m, as in the case of the Greenland landslide tsunami of 21 November 2000). The total death toll due to tsunami during the last 15 years is great: 248,085 fatalities, but it is important to note that 99.3 % of them resulted from just two transoceanic mega-tsunamis—the 2004 Sumatra tsunami (227,899 deaths) and the 2011 Tohoku tsunami (18,482 deaths). The remaining 13 fatal events are responsible only for 0.7 % of all tsunami fatalities.

Both global tsunami databases, maintained by the NCEI/WDS and the NTL/ICMMG, consist of two

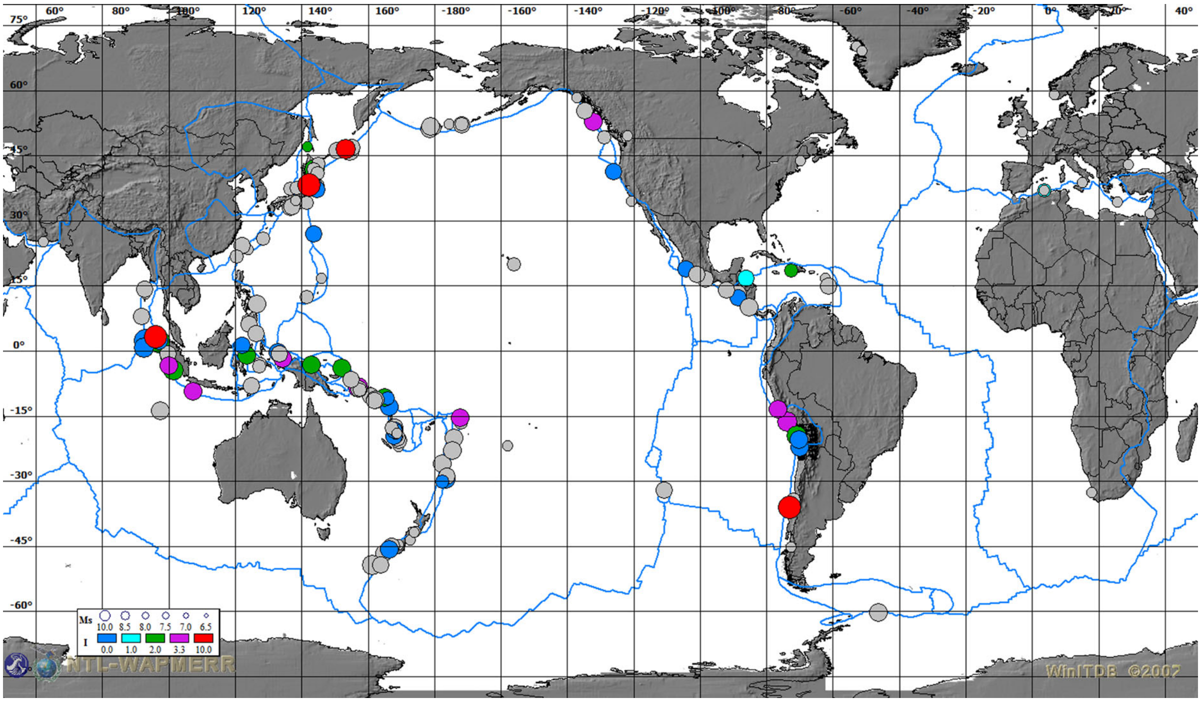


Figure 1

A source map of 164 tsunamigenic events in the World Ocean from 2000 to 2014. The *size of circles* is proportional to the event magnitude; the *color* represents the tsunami intensity on the Soloviev–Imamura scale. *Gray color* shows the events for which the tsunami intensity is not determined. *Solid blue lines* are the main plate boundaries

main parts: tsunami source event data containing basic parameters of a source event and tsunami run-up data listing available wave heights for a particular event. For this study, the most important is the second part of the database, containing the data on water height measurements at a particular location: run-up height, inundation depth, maximum amplitudes on tide gage records, etc. (the full list of parameters available in the NCEI/WDS database includes 10 different types of height measurements).

The NCEI/WDS database has 11,761 height measurements for these 164 recent historical events. On average, there are 72 heights per event that in principle allows a reliable determination of the tsunami intensity. However, the actual distribution of height measurements over events is highly inhomogeneous and by far is dominated by two transoceanic tsunamis generated by the M9 class earthquakes on March 11, 2011 in Tohoku, Japan (6054 measurements) and on December 26, 2004 in the Indian Ocean (1507 measurements). These two mega-tsunamis give on the whole nearly 65 % of all the measurements available in the database for this period. Eleven events have more than 100 measurements and 22 events have more than 10 measurements (Fig. 2). Thus, on the whole, we can expect obtaining more or less reliable estimates of the tsunami intensity for only 35 events out of 164, provided that the measurements are mainly represented by the coastal run-up heights. Of the remaining 129 events, having a small number of wave measurements, the vast majority were weak local or regional tsunamis recorded only by coastal and ocean bottom instruments.

In this study, calculation of the intensity *I* was made with the help of a special built-in procedure available in the WinITDB graphic shell (WinITDB 2009) that is used for visualization and handling of the HTDB/WLD data. The procedure is based on formula (2) and consists of the selection of a historical event from the list, selection of a geographical area around the source, plotting available heights, editing them, if necessary (e.g., by deleting some values closely distributed within a small distance

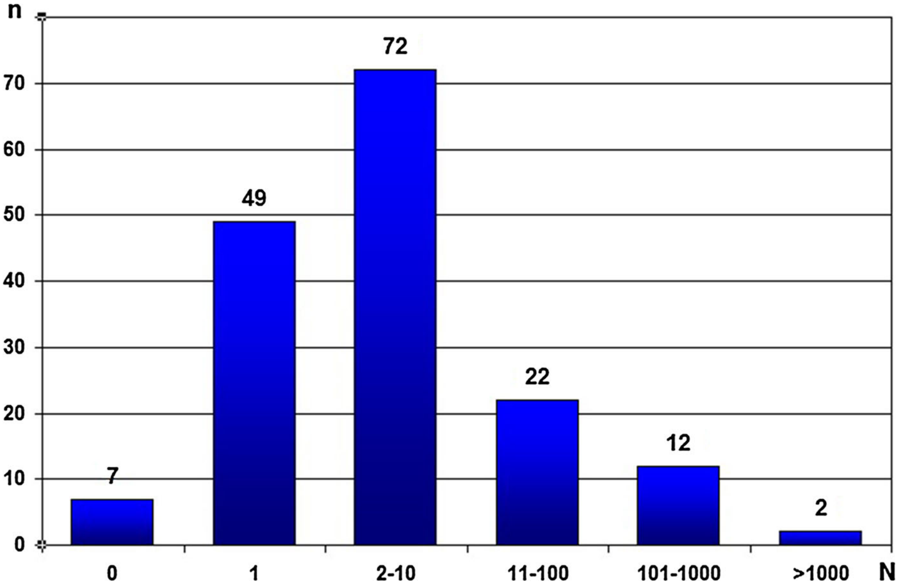


Figure 2

Distribution of number of tsunamigenic events *n* for the period from 2000 to 2014 over the number of height measurements *N* available in the NCEI/WDS database

along the coast). Upon obtaining the final list of heights, by pressing just a single button, one can obtain a number of statistical parameters for the selected heights including the *I* value.

However, practical application of this procedure faces several problems. Certain tsunamigenic earthquakes occur within island archipelagos (like Micronesia or Indonesia), where the coastal geometry is rather complex and the coastline is not straight. For these events, one must be sure to use the heights measured at different azimuths and covering a certain range (10–200 km) of epicentral distances.

The evaluation of intensity for tsunamigenic events in the island arc regions creates another problem. In these areas, the height measurements are available only from the nearest islands with large spatial gaps between them. Examples of these events are the Simushir tsunami of 15 November 2006 and the Haida Gwaii tsunami of 28 October 2012. If we formally apply the above procedure to the available heights for these events, we will obtain an artificially increased *I* value, as the average will be shifted to greater heights measured on the nearest islands due to the dearth of or the absence of smaller heights in the dataset. For these events we have to introduce some correction to the calculated *I* value, based on the attenuation of tsunami heights along the coast.

The availability of only tide gage records from remote locations along with the absence of run-up heights from the nearest coast is a typical situation for weak tsunamis. Being non-fatal and non-damaging, these events are rarely followed by a field survey, so the coastal height measurements for them are scarce or absent. However, a correct quantification of them is important for the rational selection of threshold magnitudes for the early tsunami warning. For these events, only expert estimates are possible and they must be based on some correlation between the near-field run-up heights and the far-field wave amplitudes as extrapolated from larger events having both run-up and mareograph data.

All of these factors mean that the process of tsunami intensity determination, despite the availability of data in digital and computer-readable form and the presence of specialized retrieval and visualization software (like WinITDB graphic shell), cannot be completely computerized and therefore requires some expert knowledge.

The final results of intensity determination for the recent tsunamigenic events are presented in Table 1.

Table 1

Tsunamigenic events in the World Ocean from 2000 to 2014 that have a sufficient number of height measurements in the NCEI/WDS tsunami database to calculate tsunami intensity I

No.	Date (YYYY, MM, DD)	Time (UTC)	Source area	M_w	N	H_{max}	N_{nf}	H_{max_NF}	H_{min_NF}	H_{av_NF}	I
1	2000.05.04	04:21:18.0	Sulawesi, Indonesia	7.50	2	6.00	2	6.00	1.00	3.50	2.0
2	2000.11.16	04:54:59.3	Papua New Guinea	8.00	9	3.00	8	3.00	1.00	1.50	1.08
3	2001.06.23	20:33:15.4	Peru	8.39	143	8.77	42	8.77	1.29	3.74	2.40
4	2002.09.08	18:44:25.3	Papua New Guinea	7.59	87	5.50	67	5.50	1.00	1.86	1.39
5	2003.01.22	02:06:36.4	Colima, Mexico	7.48	3	0.61	3	0.61			−0.5
6	2003.05.21	18:44:21.3	Boumerdes, Algeria	6.81	13	3.00	1	1.00			0.5
7	2003.09.25	19:50:08.4	Tokachi-oki, Japan	8.26	262	4.40	210	4.40	1.0	2.44	1.77
8	2004.12.26	00:58:53.7	Sumatra, Indonesia	9.00	1508	50.90	495	50.90	2.00	12.95	4.19
9	2005.03.28	16:09:37.5	Sumatra, Indonesia	8.62	61	4.20	42	4.20	0.50	2.37	1.74
10	2005.06.15	02:50:54.8	Nothern California, USA	7.20	4	0.40	4	0.40	0.07	0.20	−1.8
11	2005.08.16	02:46:28.5	Honsu, Japan	7.20	5	0.13	5	0.13	0.05	0.08	−3
12	2006.07.17	08:19:27.6	Java, Indonesia	7.70	196	20.90	155	20.90	1.00	6.20	2.95
13	2006.11.15	11:14:16.7	Kuril Islands	8.30	254	21.90	114	21.90	1.30	10.24	3.36
14	2007.04.01	20:39:58.0	Solomon Islands	8.10	234	12.10	169	12.10	1.00	3.38	2.26
15	2007.08.02	02:37:43.4	Nevelsk, Sakhalin	6.19	22	3.20	16	3.20	0.70	1.64	1.21
16	2007.08.15	23:40:57.9	Peru	8.00	136	10.05	69	10.05	1.00	3.15	2.16
17	2007.09.12	11:10:27.7	Sumatra, Indonesia	8.49	47	5.00	25	5.00	1.20	2.32	1.71
18	2007.11.14	15:40:50.5	Chile	7.73	6	0.13	3	0.13			−3
19	2008.11.16	17:02:33.7	Sulawesi, Indonesia	7.35	3	0.13	1	0.13			−3
20	2009.01.03	19:43:54.9	Papua, Indonesia	7.67	24	0.39	1	0.39			−2
21	2009.05.28	08:24:46.9	Honduras and Belize	7.35	2	4.00	2	4.00			1
22	2009.07.15	09:22:32.6	NewZealand	7.78	9	0.47	4	0.47	1.12	0.22	−1.7
23	2009.09.29	17:48:10.9	Samoa Islands	8.09	622	23.35	404	23.35	2.00	5.33	2.92
24	2009.10.07	22:03:15.1	Vanuatu	7.62	37	0.31	2	0.31	0.10	0.20	−2
25	2010.01.12	21:53:10.0	Haiti	7.10	7	3.00	3	3.00	1.00	2.33	1.7
26	2010.02.27	06:34:14.0	Chile	8.80	600	29.00	415	29.00	2.00	7.93	3.49
27	2010.04.06	22:15:02.0	Sumatra, Indonesia	7.80	5	0.44	5	0.44	0.07	0.19	−2
28	2010.10.25	14:42:22.0	Mentawai, Indonesia	7.70	89	9.30	69	9.30	1.20	4.56	2.69
29	2010.12.21	17:19:40.0	Bonin Islands	7.40	4	0.13	4	0.13	0.03	0.07	−3
30	2010.12.25	13:16:37.0	Vanuatu	7.30	4	0.15	4	0.15	0.02	0.06	−3.5
31	2011.03.09	02:45:18.0	Honsu, Japan	7.50	11	0.60	11	0.60	0.20	0.33	−1.1
32	2011.03.11	05:46:23.0	Tohoku	9.10	6051	40.57	1476	40.57	2.00	13.61	4.22
33	2011.07.06	19:03:18.2	Kermadec Islands	7.60	23	1.20	4	1.20	0.22	0.66	0
34	2011.08.20	16:55:02.5	Vanuatu Islands	7.10	4	0.18	4	0.18	0.07	0.12	−2.5
35	2011.08.20	18:19:23.5	Vanuatu Islands	7.10	4	0.18	1	0.18			−3
36	2012.04.11	08:38:36.7	Sumatra, Indonesia	8.60	20	1.08	3	1.08	0.24	0.56	−0.5
37	2012.04.11	10:43:10.8	Sumatra, Indonesia	8.20	4	0.22	1	0.22			−2
38	2012.08.27	04:37:19.4	Salvador	7.30	11	0.36	5	0.36	0.03	0.18	−2.0
39	2012.10.28	03:04:10.0	Haida Gwaii, Canada	7.80	176	12.98	62	12.98	2.50	5.83	2.54
40	2013.02.06	01:12:25.8	Solomon Islands	7.90	129	11.0	7	11.00	0.51	2.63	1.9
41	2013.02.08	15:26:38.4	Solomon Islands	7.00	1	0.09	1	0.09			−4
42	2013.10.25	17:10:18.0	Honsu, Japan	7.10	9	0.40	6	0.40	0.20	0.30	−1.3
43	2014.04.01	23:46:46.0	Chile	8.20	164	4.40	8	4.40	0.57	1.78	1.2
44	2014.04.03	02:43:13.0	Chile	7.70	5	0.74	5	0.74	0.19	0.48	−1

N is the total number of height measurements available for a particular event, N_{NF} is the number of near-field heights, H_{max_NF} is the near-field maximum height (m), H_{min_NF} is the near-field minimum height (m), H_{av_NF} is the average height (m) that is used in I calculations. Earthquake parameters (origin time and magnitude M_w) are taken from the ISC-GEM catalog (Storchak *et al.* 2015)

It contains a list of 44 tsunamigenic events in the World Ocean from 2000 to 2014 that have a sufficient number of height measurements in the NCEI/WDS tsunami database. The events in Table 1 are characterized by their date, source time, source location, moment-magnitude M_w, and the maximum reported wave height H_{max}. In addition to the main calculated value, that is the tsunami intensity I, the table contains several additional parameters, summarizing the data available for the intensity calculation. These parameters are the total number of height measurements (N), available for a particular event, the number of near-field heights (N_{NF}), near-field maximum height $H_{\mathrm{max\_NF}}$ (in all but one case $H_{\mathrm{max\_NF}}$ coincides with the H_{max} value), the near-field minimum height $H_{\mathrm{min\_NF}}$ and the average height $H_{\mathrm{av\_NF}}$, that is used in the I calculation.

In Table 1, the values of tsunami intensity I are listed with different accuracy that depends on the value N_{NF} used in the calculation. For the events with $N_{\mathrm{NF}} > 10$, the value I is listed as it comes from the calculation, with 2 digits after the decimal point, for the events with $N_{\mathrm{NF}} = 6$–10 it is listed with 1 digit after the decimal point, for the events with $N_{\mathrm{NF}} = 1$–5 it is rounded to the nearest half of grade (0.5), and to the integer value for the events with no height measurements on the nearest coast. The latter values represent the expert estimates based on the correlation between the near-field run-up heights and the far-field wave amplitudes.

3. *Discussion*

Table 1 lists 44 recent tsunamigenic events for which we could calculate or somehow estimate the tsunami intensity on the Soloviev–Imamura scale. It represents only 27 % of the total number of tsunamigenic events available in the NCEI/WDS database for 2000–2014. For the remaining 120 events even a rough estimation of the tsunami intensity is not possible. Some of these events were non-seismic (volcanic, meteorological, resulting from slope failure, harbor seiches), for which this scale is not applicable. They can only be quantified with a scale based on their overall energy, for instance, ML scale, proposed by (Murty and Loomis 1980). However, nearly 100 events occurring between 2000 and 2014 were generated by submarine earthquakes and their absence in Table 1 results from the dearth of near-field height measurements. Quantification of these events in terms of their intensity is important both for studying the temporal tsunami recurrence in the different tsunamigenic regions and for the rational selection of magnitude thresholds for issuing operational tsunami warnings.

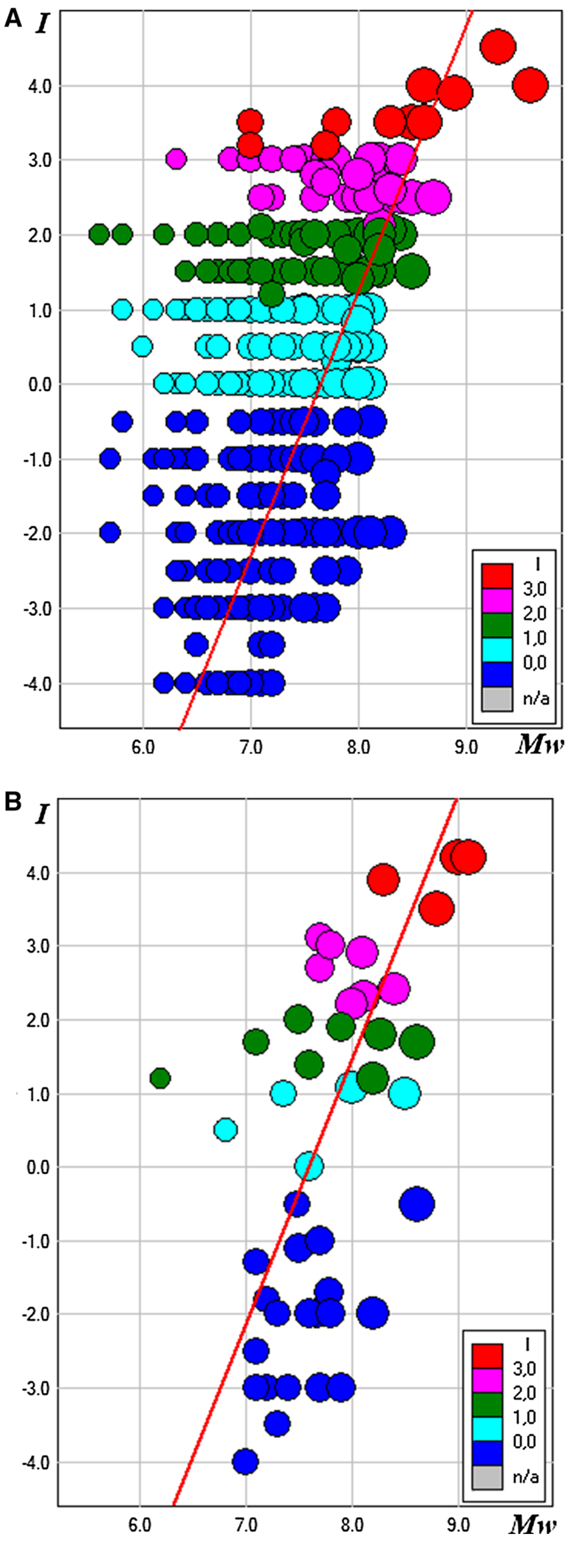
The most important issue about seismogenic tsunamis is how their overall size or energy depends on the source magnitude of the parent seismic event. As was stated in "Introduction," in the absence of practical methods of estimating the total tsunami energy, the intensity I on the Soloviev–Imamura scale is a parameter that most closely relates to the overall size of a tsunami. For seismogenic tsunamis, the best parameter for quantification of a source event is, of course, its moment-magnitude M_{w} that is now routinely being determined for all earthquakes above magnitude threshold 5.5 or so with an accuracy about ±0.1 (Storchak *et al.* 2015).

The relationship between the tsunami intensity on the Soloviev–Imamura scale and the source magnitude was first studied by (Chubarov and Gusiakov 1985) and later, using more complete data by (Gusiakov 2011). The main feature of this relationship is a large scattering of I values, exceeding six grades on the intensity scale, for events with a given magnitude M_{w} in the magnitude range 7.0–8.0, where most tsunamigenic earthquakes occur. This fact makes the operational prediction of tsunami heights at the coast, based solely on seismic data to be a difficult, if at all possible, task.

Figure 3a reproduces Fig. 3 from Gusiakov (2011) modified for the period from 1900 to 1999 and represents the $I(M_{\mathrm{w}})$ dependence for tsunamigenic events of the XX century having estimates for I and M_{w}. A similar $I(M_{\mathrm{w}})$ relationship for the last 15 years (2000–2014) is shown in Fig. 3b. As one can see, increasing the accuracy of intensity determination for recent tsunamis (in particular, for those that were followed by post-event field surveys) does not narrow the scattering in $I(M_{\mathrm{w}})$ dependence. In fact, looking at Fig. 3a, one can conclude that this dependence actually does not exist. There is only a general tendency for an increase in the tsunami intensity with an increase in the source magnitude. This tendency pretty well fits the predicted dependence I on M_{w}.

$$I = 3.55M_{\mathrm{w}} - 27.1, \qquad (3)$$

obtained in (Chubarov and Gusiakov 1985) on the basis of numerical simulation of tsunami generation



◀ Figure 3

a Tsunami intensity *I* on the Soloviev–Imamura scale versus magnitude M_w for tsunamigenic earthquakes in the World Ocean from 1900 to 1999. Events are shown as *circles with the color* depending on tsunami intensity and size proportional to the earthquake magnitude. *Solid red line* shows the dependence *I* on M_w as obtained in (Chubarov and Gusiakov 1985). **b** Tsunami intensity *I* on the Soloviev–Imamura scale versus magnitude M_w for tsunamigenic earthquakes in the World Ocean from 2000 to 2014. Events are shown as *circles* with the *color* depending on tsunami intensity and size proportional to the earthquake magnitude. *Solid red line* shows the dependence *I* on M_w as obtained in (Chubarov and Gusiakov 1985)

and propagation on a model relief typical for island arc regions.

The reasons for this large scattering are multifold. First, there are differences in the focus depth and the source mechanisms. Second, there are differences in the source location (marginal seas, subduction zones, deep-water oceanic plate, etc.). Third, and possibly the most important, is the degree of involvement of secondary mechanisms (foremost being submarine slides and slumps) in the tsunami generation process. In greater details, with examples for specific historical tsunamigenic events, including the known tsunami-earthquakes which occurred from 1896 to 2006, this subject is discussed in two earlier publications (Gusiakov 2001, 2011).

In this paper, we have confined our analysis to the 164 tsunamigenic events in the World Ocean from 2000 to 2014. However, the actual number of recent tsunamis may be higher. Table 2 lists submarine earthquakes with magnitude $M_w \geq 7.5$ and a source depth less than 100 km for which the occurrence of tsunami is still unknown. This magnitude is equal to or well above the threshold value for immediate issuing of a tsunami warning for all the main tsunamigenic regions in the Pacific and elsewhere. Normally, such strong submarine earthquakes generate at least a weak tsunami whose signature is clearly visible on coastal or deep-water records. The absence of these events in the tsunami databases means either the absence of recording instruments in the vicinity of the source area or that the routine search for tsunami signals on the instrumental records was not made carefully enough. More progress in both cases will further facilitate the work on improvement of tsunami cataloging.

Table 2

List of strong ($M_w \geq 7.5$) shallow (depth <50 km) submarine earthquakes in 2000–2014 having no entries in the NGDC tsunami database

Date (YYYY, MM, DD)	Time (UTC)	Lat.	Long.	Depth (km)	M_w	Source region
2000.06.04	16:28:28	−4.61	102.06	35	7.9	Sumatra, Indonesia
2000.06.04	16:39:48	−4.64	102.01	35	7.6	Sumatra, Indonesia
2000.11.16	07:42:20	−5.20	153.14	32	7.8	New Ireland region
2000.11.17	21:01:59	−5.54	151.94	37	7.8	New Ireland region
2001.07.07	09:38:43	−17.50	−71.76	10	7.6	Peru
2003.07.15	20:27:53	−2.60	68.35	10	7.5	Carlsberg Ridge
2003.08.04	04:37:24	−60.56	−43.52	22	7.6	Scotia Sea
2007.09.12	23:49:04	−2.57	100.76	35	7.9	Sumatra, Indonesia

Earthquake parameters (origin time in UTC and magnitude M_w) are taken from the ISC-GEM catalog (Storchak *et al.* 2015)

4. Conclusion

1. Based on the available run-up and tide gage measurements, the tsunami intensity on the Soloviev–Imamura scale has been determined for 44 seismogenic tsunamis that occurred in the World Ocean during the last 15 years. Among them there were two transoceanic mega-tsunamis (the 2004 Indian Ocean and 2011 Tohoku) and ten destructive tsunamis, which resulted in considerable damage and human fatalities. The rest were non-fatal regional and local events, even though some of them resulted from submarine earthquakes with great source magnitude ($M_w = 8.0$ or higher).
2. Even for the most recent events, the accuracy of intensity values is quite different and varies from ±0.1 up to ±1 depending on the number of available wave heights at the nearest coast. An accurate and reliable intensity determination is possible for the major tsunamis, having more than 10 near-field height measurements. Most of these tsunamis (17 of 18) were followed by post-tsunami field surveys carried out by national and international survey teams.
3. The determination of intensity for non-destructive events is typically based on a small number (1–10) of height measurements, some of them being non-instrumental (witness accounts) or made far away from a source area. The accuracy of these determinations is about ±0.5. The most problematic are intensity estimates for weak tsunamis recorded only by coastal or ocean bottom instruments. For these events, only expert estimates are possible based on an approximation (in the area of small amplitudes) of the rough correlation between the near-field run-up heights and the far-field wave amplitudes obtained for larger events provided both with the run-up and instrumental data. The accuracy of these intensity estimates is of order ±1.
4. Increasing the accuracy of the intensity determination for many recent tsunamis (in particular, for those that were the subject of post-event field surveys) does not narrow the scattering in the $I(M_w)$ dependence. This shows that in addition to the source magnitude, there are some other parameters controlling the tsunami generation process (i.e., source mechanism, source depth, depth of water in the generation area). Another important factor responsible for the absence of direct correlation of the tsunami intensity with the earthquake magnitude is the degree of involvement of secondary generation mechanisms such as submarine slumping. As was shown in (Gusiakov 2001), slumping could significantly augment the tsunami potential of nearly 30 % of all tsunamigenic earthquakes that occurred in the Pacific in the XXth century.
5. Despite the great improvement in the tsunami-recording network of coastal tide gages and deep-water instruments during the last two decades, the data for reliable estimates of the tsunami intensity are still problematic. Moreover, for 8 strong ($M_w > 7.5$) submarine earthquakes, which occurred during the last 15 years, there are no entries in the global tsunami databases that would provide evidence for the occurrence of any tsunami.

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