Tsunami risk of earthquakes at the coast of Japan for the Far East of Russia

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Abstract. Possibility of a tsunami as a result of an earthquake is estimated by magnitude and geographical criterion now. The earthquake is considered tsunami-danger if his epicentre gets to a tsunamigenic zone, and intensity exceeds the set threshold value of magnitude. The solution of such task as specification of magnitude and geographical criterion for the announcement of alarm of a tsunami in the Sea of Japan and in the water area of the Pacific Ocean to the east of the Japanese islands is extremely relevant. For the purpose of specification of magnitude and geographical criterion of tsunami risk of earthquakes in these areas the author executed a series of computing experiments. During the computing experiments the centres of real historical tsunami in these water areas were modelled. At creation of the model centres of a tsunami the Okada model was used. Based on the analysis of statistics of historical tsunami and results of numerical modelling by the author the redundancy now in use by Service of warning of a tsunami in the Far East of Russia magnitude a tsunami risk threshold is shown.

1. Introduction

One of the natural hazards in the Far East of Russia is the tsunami. Now the main working method applied by Tsunami Warning Service in the Far East of Russia (TWS) at making decision on the announcement of alarm of a tsunami is the seismic method based on registration of the advancing tsunami of seismic waves. Possibility of a tsunami as a result of an earthquake is estimated by magnitude and geographical criterion now. The earthquake is considered tsunami-danger if his epicentre gets to a tsunami-risk zone, and intensity exceeds the set threshold value of magnitude. For earthquakes in the Sea of Japan and in the Sea of Okhotsk the threshold value of magnitude for the Far East of Russia is 7.0, for earthquakes to the east of Kuril Islands – 7.0 to the east of the island of Hokkaido – 7.5, and to the east of the island of Honshu ¬ 8.0 [1, 2].

The efficiency of this magnitude and geographical criterion of tsunami risk can be estimated by means of the analysis historical data on manifestation of the tsunami which arose in these water areas on coast of Sea of Japan of the Far East of Russia and on coast of the Kuril Islands.

2. Historical data on manifestation of a tsunami in the Far East of Russia

The main tsunamigenic zone of the Far East of Russia in which the epicentres of most of a tsunami are located coincides with the western slope of the Kurilo-Kamchatsky Trench. Continuation of the Kurilo-Kamchatsky Trench is Japan Trench to the oceanic hollow in the west of the Pacific Ocean to the east from the island of Honshu, to the south from Hokkaido and to the north from the Bonin Islands. The bottom and slopes of Japan Trench also often become epicentres of earthquakes some of which cause

the tsunami dangerous not only for Japan, but also for the Far East of Russia (in particular, for the Kuril Islands).

In the suburban seas of the Pacific Ocean washing the Far East coast of Russia, tsunami arise less often. Most dangerously in this regard Sea of Japan. The tsunamigenic zone of the Sea of Japan passes along east coast of Korea, the western coast of Japan and the southwest coast of the island of Sakhalin (figure 1).

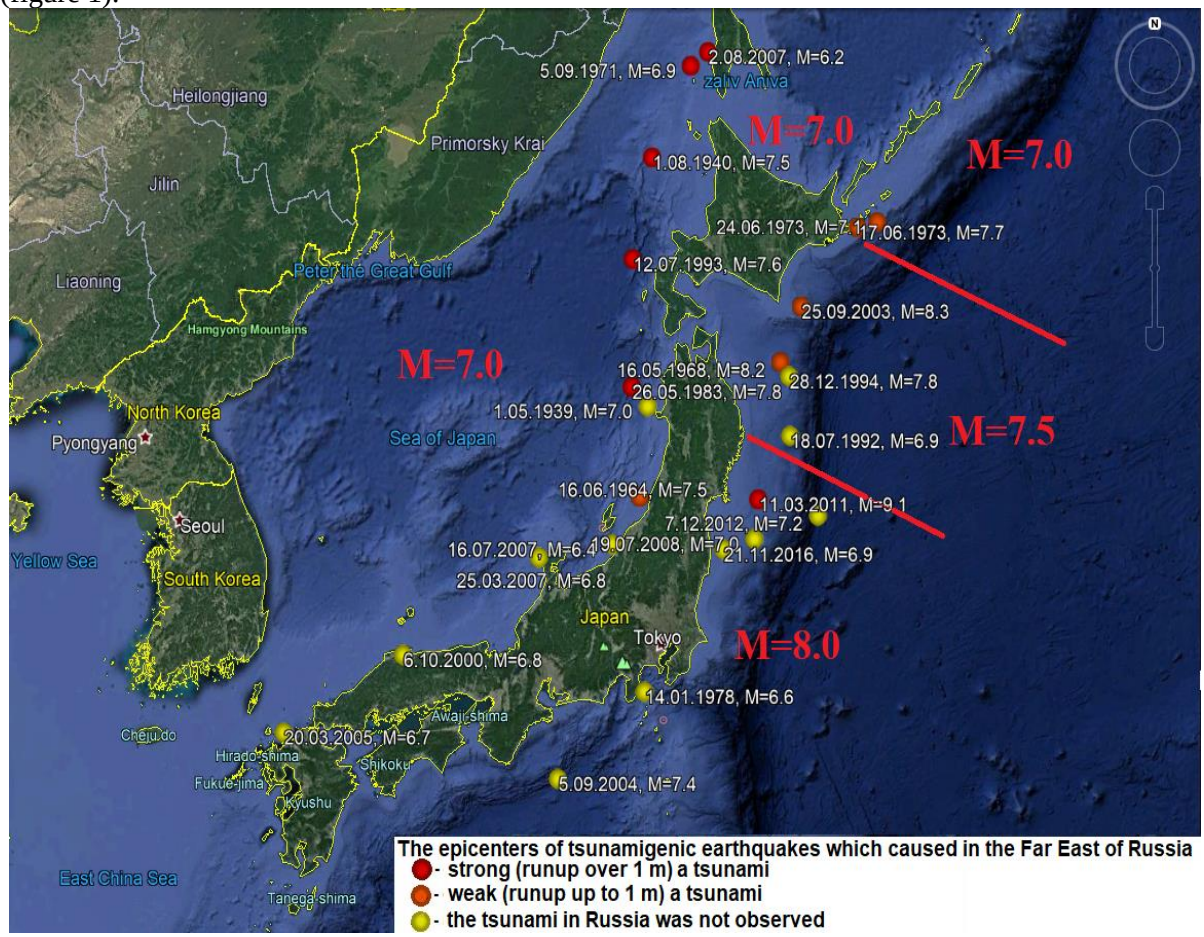

Figure 1. Magnitude and geographical criterion of tsunami risk against the background of historical tsunami.

Basic data on manifestation of the strongest tsunami in the Sea of Japan (since 1939) and in the water area of the Pacific Ocean to the east from the Japanese islands (since 1968) in the 20-21st centuries are presented in table 1. Data on a tsunami are taken from [3, 4, 5, 6, 7, 8].

Epicenter of a tsunamigenic earthquake 16.06.1964, measuring M=7.5, not caused dangerous (with runup, the exceeding 1 m) a tsunami on the coast of the Far East of Russia, was to the west of the island of Honshu. The epicenters of dangerous tsunami 05.09.1971 and 02.08.2007 measuring M <7 were in the southern part of Tatar Strait.

Thus, the tsunami risk of an underwater earthquake in the Sea of Japan significantly changes with change geographical coordinates of epicenter. It means that TWS must consider data on depth and geographical coordinates of hypocenter of a tsunamigenic earthquake at making decision on the announcement of alarm of a tsunami in the Sea of Japan. In other words, the magnitude and geographical criterion of tsunami risk for the Sea of Japan demands specification.

Also, it is necessary to pay attention that tsunamigenic earthquakes in the Pacific Ocean to the east the Hokkaido Islands and Honshu Island (in particular, tsunamigenic earthquakes 16.05.1968, 28.12.1994 and 25.09.2003 with a magnitude M > 7.5) did not cause dangerous tsunami on coast of the

Far East of Russia. An exception is the catastrophic earthquake 11.03.2011 of the measuring M=9.1, caused tsunami up to 3 meters on the Southern Kuril Islands. It raises a question of validity of a magnitude criterion of M=7.5 for this water area.

Table 1. The strongest tsunami in the Sea of Japan and in the water area of the Pacific Ocean to the east from the Japanese islands.

Date	Region[a]	Latitude	Longitude	Depth of the hypocentre, km	Magnitude	Max Event Runup (m)	
						Everywhere[b]	In Russia[c]
01.05.1939	J.S.	40.10°N	139.50°E	22	7.0	0.3	
01.08.1940	J.S.	44.47°N	139.52°E	35	7.5	5.0	5.0
16.06.1964	J.S.	38.43°N	139.23°E	11	7.5	5.8	0.6
16.05.1968	P.O.	40.70˚N	143.60˚E	29.9	8.2	5.0	0.5
05.09.1971	J.S.	46.57°N	141.18°E	17	6.9	2.05	2.05
17.06.1973	P.O.	43.23˚N	145.79˚E	48	7.7	5.96	0.5
24.06.1973	P.O.	43.32˚N	146.44˚E	50	7.1	0.64	0.56
26.05.1983	J.S.	40.47°N	139.08°E	23	7.8	14.5	5.0
12.07.1993	J.S.	42.85°N	139.20°E	16	7.6	30.6	4.43
28.12.1994	P.O.	40.53˚N	143.42˚E	26.5	7.8	1.10	
25.09.2003	P.O.	41.82˚N	143.91˚E	27	8.3	2.13	0.78
05.09.2004	P.O.	33.18˚N	137.07˚E	10	7.4	0.93	–
02.08.2007	J.S.	46.83°N	141.75°E	10.6	6.2	3.2	3.2
11.03.2011	P.O.	38.30˚N	142.37˚E	29	9.1	38.9	3.0
07.12.2012	P.O.	37.89˚N	143.95˚E	31	7.3	1.0	
21.11.2016	P.O.	37.39˚N	141.39˚E	9	6.9	1.4	–

[a] J.S. – the epicentre of a tsunami in the Sea of Japan, P.O. – the epicentre of a tsunami in the Pacific Ocean to the east of the Japanese islands.

[b] Maximum runup of a tsunami.

[c] Maximum runup of a tsunami on the coast of the Far East of Russia.

3. Numerical modelling of a tsunami with the Okada model use

For the purpose of specification of magnitude and geographical criterion of tsunami risk in the Sea of Japan and to water areas of the Pacific Ocean to the east from Japan, the author conducted two series of computing experiments. Model sources of a tsunami were placed in a tsunamigenic zone of the Sea of Japan and in Japan Trench.

At the request of the author, Kolesov S V (department of physics of the sea and waters of land, M. V. Lomonosov Moscow State University) on the basis of the Okada model [9, 10] were calculated the model sources of a tsunami on the basis of data on fifteen real tsunamigenic earthquakes (eight - in the Sea of Japan, and seven – in the water area of the Pacific Ocean to the east of the Japanese islands). Data about the Nevelsk earthquake 2.08.2007 are taken from the book [4], about other earthquakes - from the database [6]. At the same time, for the purpose of identification of threshold magnitude, for each real earthquake several model sources with various magnitudes were constructed.

In total the author executed two series of computing experiments. In the first series 42 computing experiments for 8 model sources located to the west from the Japanese islands were executed. Heights of runup paid off for 28 points on the Russian coast of Sea of Japan, the majority of which coincided with coastal settlements.

In the second series 35 computing experiments for 7 model sources located to the east from the Japanese islands were executed. Heights of runup paid off for 41 points of the coast of the Far East of Russia from which 28 was on the coast of the Sea of Japan, and 13 on the coast of the Sea of Okhotsk and the Pacific Ocean.

For each model source threshold magnitude - magnitude in the epicenter of a tsunamigenic earthquake at which at least in one of the mareograph points the tsunami was observed intensive (with runup 1 m or more) was defined. A large number the mareograph points on the southwest coast of the island of Sakhalin it is necessary for exact determination of threshold magnitudes of the sources of tsunami 1.1 and 2.1 in Tartar Strait.
Parameters of model sources of a tsunami, dates of real earthquakes - "prototypes", and the threshold magnitudes received as a result of numerical modeling are presented in table 2 and in figure 2. Also, in figure 2 mareograph points of the coast are shown.

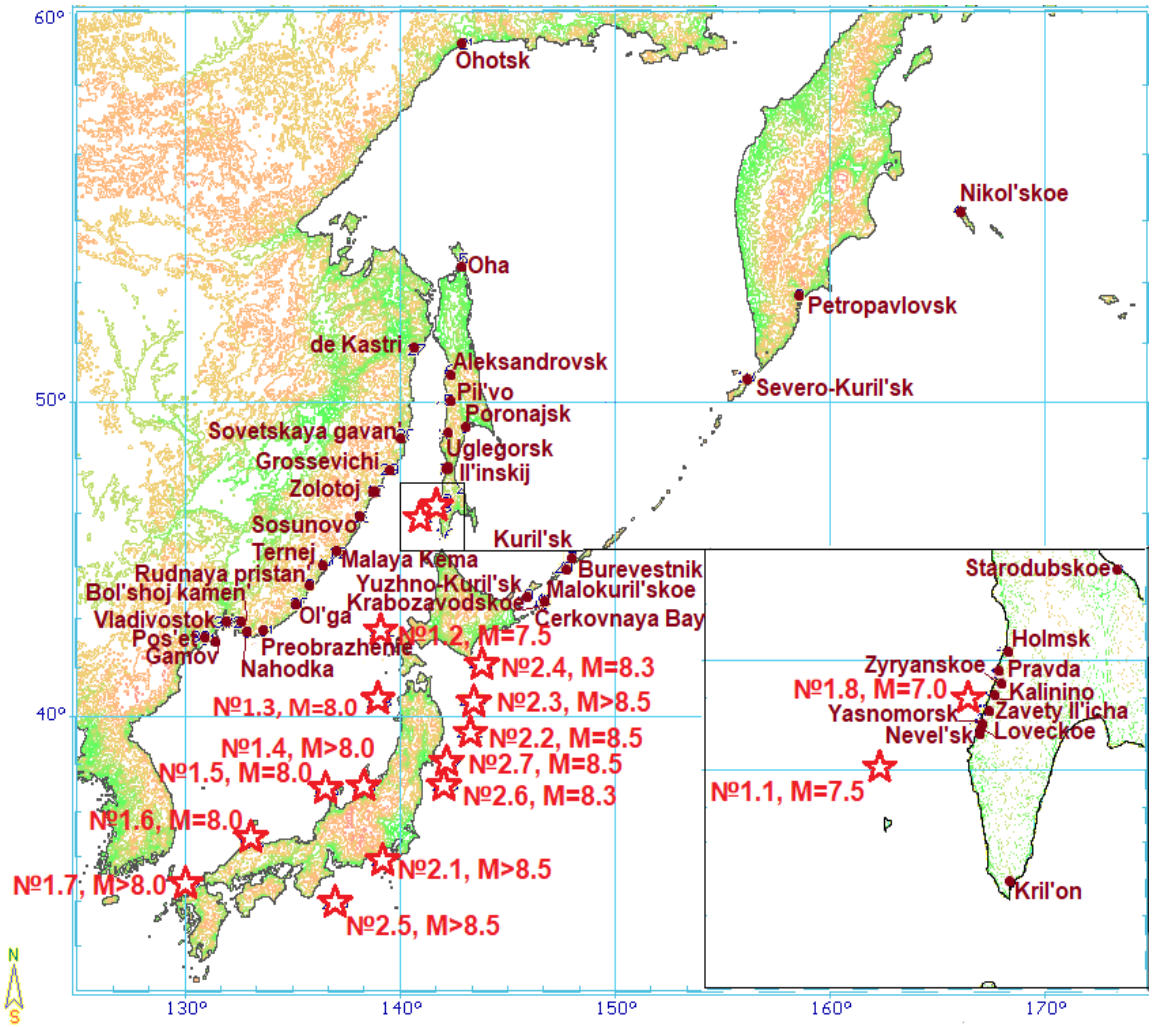

Figure 2. Model sources and results of computing experiments.

It is necessary to pay attention that for the different model sources of a tsunami different ranges of magnitudes were set. For the sources of tsunami 1.1 and 1.8 in the southern part of Tatar Strait are set ranges of magnitudes 6.3-7.7 and 6.0-7.7, respectively, as earthquakes even with a small magnitude in this area can cause dangerous tsunami on the southwest coast of the island of Sakhalin. For other sources of a tsunami in the Sea of Japan (1.2-1.7) remote from coast of the Far East of Russia is set the range of magnitudes 7.0-8.0 as an earthquake measuring less than 7.0 (that corresponds to the existing magnitude threshold of tsunami risk) as showed experience, tsunami do not generate dangerous to the Far East of Russia, and the tsunami risk of earthquakes measuring over 8.0 in the water area of the Sea of Japan is obvious.

Table 2. Earthquakes - "prototypes", parameters and results of computing experiments.

Number of model source	Date	Latitude	Longitude	Depth of the hypocentre, km	Model magnitudes	Threshold magnitude
1.1	05.09.1971	46.51°N	141.20°E	18.1	6.3. 7.0. 7.2. 7.5. 7.7	7.5
1.2	12.07.1993	42.85°N	139.20°E	16.7	7.0. 7.2. 7.5. 7.7. 8.0	7.5
1.3	26.05.1983	40.46°N	139.10°E	23.7	7.0. 7.2. 7.5. 7.7. 8.0	8.0
1.4	16.07.2007	37.54°N	138.45°E	12.0	7.0. 7.2. 7.5. 7.7. 8.0	>8.0
1.5	25.03.2007	37.34°N	136.59°E	8.0	7.0. 7.2. 7.5. 7.7. 8.0	8.0
1.6	6.10.2000	35.46°N	133.13°E	10.0	7.0. 7.2. 7.5. 7.7. 8.0	8.0
1.7	20.03.2005	33.81°N	130.13°E	10.0	7.0. 7.2. 7.5. 7.7. 8.0	>8.0
1.8	2.08.2007	46.81°N	141.83°E	10.0	6.0. 6.3. 6.5. 7.0. 7.2. 7.5. 7.7	7.0
2.1	14.01.1978	34.81°N	139.26°E	14.0	7.5. 7.7. 8.0. 8.3. 8.5	>8.5
2.2	18.07.1992	39.42°N	143.33°E	28.6	7.5. 7.7. 8.0. 8.3. 8.5	8.5
2.3	28.12.1994	40.53°N	143.42°E	26.5	7.5. 7.7. 8.0. 8.3. 8.5	>8.5
2.4	25.09.2003	41.82°N	143.91°E	27.0	7.5. 7.7. 8.0. 8.3. 8.5	8.3
2.5	5.09.2004	33.18°N	137.07°E	10.0	7.5. 7.7. 8.0. 8.3. 8.5	>8.5
2.6.	19.07.2008	37.55°N	142.21°E	22.0	7.5. 7.7. 8.0. 8.3. 8.5	8.3
2.7	11.03.2011	38.30°N	142.37°E	29.0	7.5. 7.7. 8.0. 8.3. 8.5	8.5

For the tsunami sources in the Pacific Ocean to the east from the Japanese islands (2.1-2.8) is set the range of magnitudes 7.5-8.5 as it was important to author of a research to find out whether it is capable strong (but not catastrophic, as an earthquake 11.03.2011 measuring 9.1) an earthquake in this water area to cause the tsunami dangerous to the Far East of Russia.

4. The analysis of the received results

Results of the first series of computing experiments executed by authors showed that earthquakes measuring less than 8.0 in a southeast part of the Sea of Japan do not generate the tsunami dangerous to the coast of the Far East of Russia.

Results of the second series of computing experiments showed that earthquakes measuring less than 8.0 in the water area of the Pacific Ocean to the east of Hokkaido and northern Honshu, and measuring less than 8.5 to the south of the Southern Honshu do not generate the tsunami dangerous to the coast of the Far East of Russia.

5. Conclusion

Results of these numerical experiments I show redundancy of TWS now in use of a magnitude threshold of tsunami risk and can be used in work of Service of warning of a tsunami in the Far East of Russia, for the purpose of specification of magnitude and geographical criterion of tsunami risk.

Results of these numerical experiments show redundancy of TWS now in use of a magnitude threshold of tsunami risk and can be used in work of Tsunami Warning Service in the Far East of Russia, for the purpose of specification of magnitude and geographical criterion of tsunami risk.

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