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Tsunamis on the Russian Pacific coast: history and current situation

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Abstract

The Pacific coast, including the Kamchatka Peninsula, the Kuriles, the Sea of Japan, the Sea of Okhotsk, and the Bering Sea, is the main tsunami-prone area in Russia. The Far East tsunamis are much more frequent, extensive, and devastating than those in the Black, Caspian, Baltic, and White Sea coasts, as well as in major inland lakes of Baikal, Ladoga, etc. The tsunami catalog of the Russian Far East from 1737 to present lists 110 events with mainly near-field and few far-field sources (105 and 5 events, respectively). Most of the catalogued tsunamis (95 cases) were induced by earthquakes, and few events had volcanic (3), landsliding (2), meteorological (3), and unknown (2) triggers. Altogether there were eleven devastating tsunamis for the period of observations, with >10 m heights, two of which were great events in 1737 and 1952, when the waves exceeded 20 m. The wave heights were in the range 2.5–10 m in fifteen hazardous tsunami events and within the tidal range (~1–2 m) in thirteen cases; the other events were small and detectable only instrumentally. Thus, the average recurrence times for tsunamis of different magnitudes in the Russian Pacific coast are 25 years for devastating events and 10–15 years for hazardous tsunamis; small tsunamis occur almost every year, according to statistics for the last sixty years collected at the regional network of tide stations. The topics discussed in the paper concern the completeness and reliability of the Far East catalog; distribution of tsunami events in space and time; correlation between the intensity of tsunami and the magnitude of the causative undersea earthquake; tsunami recurrence; tsunami warning; and long-term hazard assessment and mapping.

Keywords: natural disaster; earthquake; seismotectonics; tsunami; tsunami hazard; tsunami risk mapping

Introduction

Assessment of tsunami hazard is a key seismological problem in the Russian Far East where submarine earthquakes generated within the island-arc slope of the Kuriles–Kamchatka seismic belt can reach $M = 9.0$ and often trigger tsunami waves. Tsunami is the fourth major hazard by life and infrastructure losses after earthquakes, floods, and typhoons. Tsunamis were responsible for about 1% of fatalities from natural disasters in the 20th century having killed more than four million people (Topics..., 2001), but became the deadliest hazard in the 21st century after the Indian ocean Sumatra event of 2004, with a death toll of 227,000 (NGDC/WDS GHTDB, 2016).

Sudden, brief, and sweeping tsunamis can inflict great damage and pose fatal risks to people within the attack zone. Efficient protection from this hazard is problematic because of large recurrence times at each specific part of the coast: deadly tsunamis occur every 30–50 years even in most active areas of the Pacific coast (Japan, Chili, or Peru), and the recurrence of great devastating events is as large as 100–150 years. This is far greater than the recurrence of floods or typhoons and commensurate with that of earthquakes or volcanic eruptions. Tsunamis become hazardous above some natural threshold of wave height while the waves below this value can pass unnoticed or confused with wind, storm, or tide surge. This is, among others, a reason why people may be fatally unprepared to meet the tsunami emergency.

The Pacific coast, including the Kamchatka Peninsula, the Kuriles, the Sea of Japan, the Sea of Okhotsk, and the Bering Sea, is the main tsunami-prone area in Russia. The Far East tsunamis are far more frequent, extensive, and powerful than those known in the Black, Caspian, Baltic, and White Sea coasts, as well as in major inland lakes of Baikal, Ladoga, etc. The first exhaustive synthesis of tsunami data, mainly in the Kuriles and Kamchatka coasts, belongs to Soloviev (1968) who discussed the physical causes of tsunami events and the

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significance of the problem to Russia. Soloviev (1968) tabulated the basic parameters of thirty nine historic tsunamis in the area between 1737 and 1965, explained their possible mechanisms, and suggested models for estimating their seaward and inland spread. The final section of the paper (Soloviev, 1968) is devoted to brief forecast and risk mapping, two principal objectives of theoretical and applied tsunami research.

According to Soloviev (1968), reliable prediction is possible with the use of tide gauges placed on the ocean bottom along the shelf margin at key protected sites; such cable or buoy stations are currently used in Japan, India, Chili, and other countries (Rabinovich and Eble, 2015). As for short-term prediction, the probabilistic seismotectonic approach outlined by Soloviev (1968) has never been implemented in Russia. Similar ideas made basis for the method of probabilistic tsunami hazard assessment (PTHA) developed about forty years later and used broadly for tsunami risk mapping of different scales in the US, Canada, Australia, and New Zealand (Gonzales et al., 2009; Knighton and Bastidas, 2015; Leonard et al., 2014; Power and Downes, 2009; Power et al., 2011).

The paper of Soloviev (1968) concerns currently live issues and has been largely cited in all Russian publications on the subject. However, 430 new tsunami events have occurred since it was written, and a large progress has been made in ways of their characterization and interpretation. The Far East catalog has been extended with forty five tsunamis postdating 1968, as well as with some historic events of the 18th and 19th centuries reported in historic accounts and in recently discovered old publications. Along with a wealth of new evidence on tsunami occurrence in the Pacific coast of Russia, more insights have been gained on the generation and propagation of tsunami waves. The new data call for synthesis and analysis, with implications for prediction and assessment of tsunami hazard.

There is no exact scientific definition of tsunami yet. In the 1960s, tsunami was interpreted as long-period (2 to 200 min) waves induced by sudden processes, mainly of tectonic origin, on the sea bottom or surface: submarine earthquakes, volcanic eruptions, as well as onshore or offshore landslides (Soloviev, 1968). Geographically, the Pacific coast was considered to be the most vulnerable while only minor waves coming occasionally from far-field sources (e.g., the Lisbon earthquake of 1755 or the Krakatau eruption of 1883) were expected in other coasts. The most faithful model defined tsunami as long waves in shallow water. However, the waves like those in the 1958 Lituya Bay megatsunami hardly have long wavelengths, though being obviously anomalous and disastrous. The Lituya Bay tsunami followed an earthquake with a moment magnitude of 7.9 (Miller, 1960) which triggered an enormous rockslide. The wave that traveled across the bay during the event had a crest reaching 30 m in height, and the sudden displacement of water destroyed vegetation up to 525 m above the bay level.

As far as these phenomena were further studied and ever more data were collected, it became clear that huge water displacement hazardous to population and engineering structures was possible in marine as well as in continental settings: natural or manmade lakes or even large rivers (Didenkulova and Pelinovsky, 2009; Nikonov, 2004, 2007; etc.). The periods of such waves may vary from 1–2 min to one hour, which corresponds to the frequency range between wind and tidal waves. Some tsunamis have atmospheric (air pressure) triggers: meteotsunamis arise more often than others in the eastern US and Adriatic coast, the Bengal Bay, the Bolear islands, etc. (Vilibić et al., 2014).

Therefore, the modern tsunami catalogs include classical earthquake-induced marine tsunamis, as well as tsunami-like events that result from external impacts in any water body and consist in sudden water displacement near the shore hazardous for people and structures.

Whichever be its trigger, the tsunami wave involves the whole water column and displaces enormous water masses. They are thus disastrous events basically different from wind waves which likewise can reach heights of 8–10 m but cause far lesser losses.

Available tsunami data from the Russian Pacific coast

The knowledge of historic tsunami events observed in the Russian Far East has been summarized in earthquake catalogs (Kondorskaya and Shebalin, 1977; Mushketov and Orlov, 1893), special tsunami catalogs (Soloviev, 1978; Soloviev and Ferchev, 1961; Soloviev and Go, 1974, 1975; Soloviev et al., 1986; Zayakin, 1996), scientific publications and reports of specific events, as well as in global parametric databases supported by the National Geophysical Data Center in Boulder, USA (NGDC/WDS GHTDB, 2016) and the Tsunami laboratory at the Institute of Computational Mathematics and Mathematical Geophysics (ICMMG) in Novosibirsk (HTDB/WLD, 2016). The databases are generally consistent in amount and content of data, with some difference in estimates of tsunami size, confidence level, classification of triggers, etc. The tsunami data (tables and plots) from the Russian Far East region reported in this paper are mainly selected from the global database supported by ICMMG with the *WinITDB* graphical shell (WinITDB, 2007).

To be included into the regional Far East tsunami catalog, a near-field event has to fall within the responsibility zone of the Far East tsunami warning service (TWS) and a far-field one has to be felt at least once within the Russian Pacific coast. The first regional catalogs of Soloviev (1978), Zayakin (1996), and others *de facto* used this formal criterion and included far-field tsunamis that caused damage or hazardous flood at the coasts of Russia. However, the approach needs update nowadays.

As the instrumental facilities have progressed, the tide stations of the Far East regional network detect ever more events of minor sea level change detectable only in station readings. Advanced digital stations deployed at some sites of the Russian Pacific coast record almost all significant events within and outside the region. For instance, the Sumatra event of 26 December 2004 was recorded as a 29 cm wave height at the Severo-Kurilsk tide station (Rabinovich et al., 2006).