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Evaluation of tsunami potential based on conditional probability for specific zones of the Pacific tsunamigenic rim

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ABSTRACT

The Pacific tsunamigenic rim is one of the most tsunamigenic regions of the world which has experienced large catastrophic tsunamis in the past, resulting in huge loss of lives and properties. In this study, probabilities of occurrences of large tsunamis with tsunami intensity (Soloviev–Imamura intensity scale) $I \geq 1.5$, $I \geq 2.0$, $I \geq 2.5$, $I \geq 3.0$, $I \geq 3.5$ and $I \geq 4.0$ have been calculated over the next 100 years in ten main tsunamigenic zones of the Pacific rim area using a homogeneous and complete tsunami catalogue covering the time periods from 684 to 2011. In order to evaluate tsunami potential, we applied the conditional probability method in each zone by considering the inter-occurrence times between the successive tsunamis generated in the past that follow the lognormal distribution. Thus, we assessed the probability of the next generation of large tsunamis in each zone by considering the time of the last tsunami occurrence. The a-posteriori occurrence of the last large tsunami has been also assessed, assuming that the time of the last occurrence coincides with the time of the event prior to the last one. The estimated a-posteriori probabilities exhibit satisfactory results in most of the zones, revealing a promising technique and confirming the reliability of the tsunami data used. Furthermore, the tsunami potential in different tsunamigenic zones is also expressed in terms of spatial maps of conditional probabilities for two levels of tsunami intensities $I \geq 1.5$ and $I \geq 2.5$ during next 10, 20, 50 and 100 years. Estimated results reveal that the conditional probabilities in the South America and Alaska–Aleutian zones for larger tsunami intensity $I \geq 2.5$ are in the range of 92–93%, much larger than the Japan (69%), for a time period of 100 years, suggesting that those are the most vulnerable tsunamigenic zones. The spatial maps provide brief atlas of tsunami potential in the Pacific rim area.

1. Introduction

The term 'tsunami potential' can be expressed as a probability of occurrence of a tsunami of particular intensity (I) or run-up height (H) during specific time intervals in an area of interest (Orfanogiannaki and Papadopoulos, 2007; Tinti, 1991). The foreshadow determination of tsunami occurrence is among the scientific interest of natural hazards, because it usually results in severe damages, which sometimes are much larger than those caused by an earthquake occurrence (e.g. December 26, 2004 Sumatra tsunami and March 11, 2011 Japan tsunami etc.). Presently, there is no standard methodology for the forecasting of tsunami occurrences in any region of the world. However, some statistical and probabilistic techniques have been proposed for the estimation of recurrence of maximum tsunami intensity (I) and tsunami wave height (H) in a particular tsunamigenic region (Kulikov et al., 2005a,b; Orfanogiannaki and Papadopoulos, 2007; Papadopoulos, 2003; Tinti, 1991) or to evaluate the probability of exceedance of tsunami run-up heights during different return periods using probabilistic tsunami hazard assessment (PTHA) methodology (Tinti et al., 2005; Dimri and Srivastava, 2007; McCloskey et al., 2008; Geist and Parsons, 2009; González et al., 2009; Tselentis et al., 2010; Grezio et al., 2010; Heidarzadeh and Kijko, 2011; Kumar et al., 2012a,b; Mitsoudis et al., 2012; Singh et al., 2012; Sørensen et al., 2012; Lorito et al., 2015; among others). Different statistical models (e.g. Poisson, Gumbel, Exponential, Gamma, Weibull, Lognormal, Bayesian etc.) have been proposed by a number of researchers to estimate tsunami recurrence intervals in different tsunamigenic regions of the world (Soloviev, 1970; Rikitake and Aida, 1988; Tinti, 1993; Choi et al., 2002; Kulikov et al., 2005a,b; Papadopoulos et al., 2010; Kijko et al., 2013; Yadav et al., 2013a,b; Chamoli and Telesca, 2014). The circum-Pacific tsunamigenic region (Fig. 1) is of special interest for such kind of study, since it has experienced several destructive tsunamis in the past as a result of large to great earthquakes or volcanic eruptions.

Soloviev (1970) made a first effort for the estimation of tsunami recurrence in the circum-Pacific belt which was based on the probabilities

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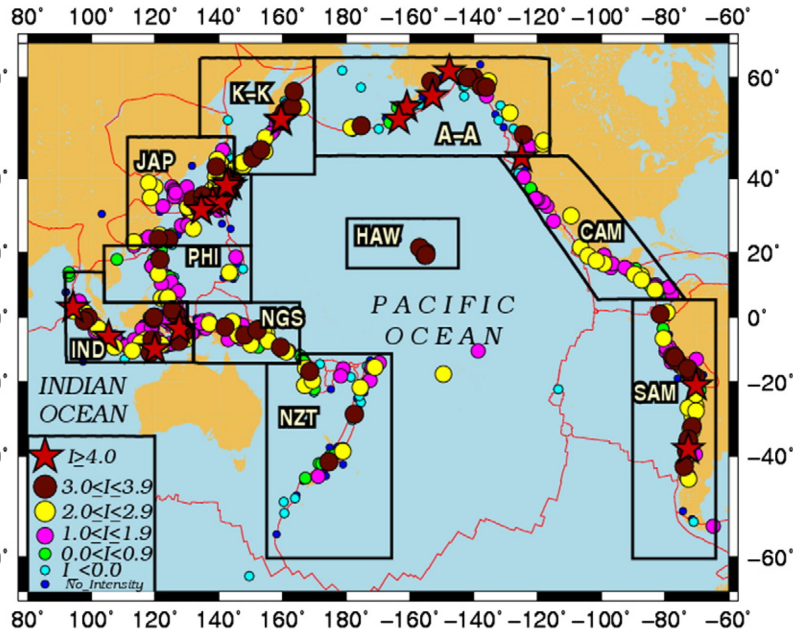

Fig. 1. Map shows boundaries of ten main tsunamigenic zones in the Pacific rim area (modified after Gusiakov, 2005). Circles with different colors show the source position of tsunamis occurred during 47 BC to 2011, with different tsunami intensity intervals, that are used in the present study for conditional probability estimation.

resulting from magnitude–frequency relationship for earthquakes and tsunamis data. Tinti (1993) assessed the tsunami hazard in Italy using combination of the magnitude–frequency relationship of earthquakes with the translation of earthquake occurrence estimates into tsunami probabilities. A method based on the frequency of occurrence of large tsunamis and coefficient of wave amplifications near the shore was introduced by Rikitake and Aida (1988) and Go et al. (1985) in the Japan region. Papadopoulos (2003) used intensity–frequency statistics for tsunamis to calculate mean recurrence and probabilities of occurrence of tsunamis of different intensity levels in the Corinth gulf of central Greece. Orfanogiannaki and Papadopoulos (2007) examined the tsunami potential in three tsunamigenic zones (South America, Kuril-Kamchatka and Japan) through conditional probabilities approach which indicated that the likelihood of a tsunami generation in Japan is higher as compared to the South America and Kuril-Kamchatka. The probabilistic tsunami hazard assessment (PTHA) approach has been developed during the last decade. This approach is based on the integration of computational methods with empirical analysis of past tsunami run-ups and probabilistic seismic hazard assessment (PSHA) using near and far-field tsunami sources (Burbidge et al., 2008; Geist and Parsons, 2006; Liu et al., 2007).

Conditional probability technique has been applied in the past to evaluate the seismic potential in certain seismic zones around the Pacific belt (McCann et al., 1979; Nishenko, and McCann, 1981; Nishenko, 1985, 1991; Ruff, 1996 and others). The conditional probability technique, applied in this study for tsunami potential assessment, is borrowed from a similar approach used in seismic hazard assessment (Nishenko, 1985). We evaluated the tsunami potential as a function of probability for occurrences of a tsunami event during a specified time period in a particular tsunamigenic zone.

This paper confines itself to assess the tsunami potential in the ten main tsunamigenic zones in the Pacific rim area in terms of conditional probabilities during time periods of 10, 20, 50 and 100 years for tsunami intensities (Soloviev–Imamura intensity scale) $I \geq 1.5$, $I \geq 2.0$, $I \geq 2.5$, $I \geq 3.0$, $I \geq 3.5$ and $I \geq 4.0$. In addition to this, we have also computed a-posteriori generation of the last tsunami in each zone, taking into account that the time of the last occurrence of a particular tsunami coincides with the time of the tsunami prior to the last one. Thus, we have introduced a foreshadow tool which allows us to estimate the probability of the time of the next tsunami occurrence in the study area.

2. Data used and delineation of tsunamigenic zones

The probabilistic tsunami potential assessment of any region totally depends upon the reliable, homogeneous and complete tsunami catalogue covering historical as well as instrumental records. For the tsunami potential assessment in the Pacific rim area, two international tsunami data sources, namely, the Novosibirsk Tsunami Laboratory of the Institute of Computational Mathematics and Mathematical Geophysics (NTL/ICMMG) SDRAS, Novosibirsk, Russia (HTDB/WLD, 2013) and the National Geophysical Data Center (NGDC) NOAA, Boulder, USA (NGDC/NOAA, 2013) are consulted for both historical and instrumental data. In addition to these sources, several other published literatures are also consulted to prepare tsunami catalogue during historical epoch. The prepared raw tsunami catalogue consists of 2260 tsunami events during 47 BC to 2011 with tsunami intensity $I \geq -5.0$. The 'tsunami intensity (I)' is the most important parameter of this catalogue, which is used to measure the 'size' of the tsunami. It is based on the Soloviev–Imamura intensity scale (Soloviev, 1972), that is adopted by both NGDC/NOAA and NTL/ICMMG databases as the main measure of tsunami size. The Soloviev–Imamura tsunami intensity scale is a base-2 logarithmic scale which is based on the *average of tsunami run-up height* (H_{avg}) and expressed as $I = 1/2 + \log_2 H_{avg}$ (Gusiakov, 2011; Soloviev, 1972). The GITEC catalogue criteria (Tinti and Maramai, 1996; Tinti et al., 2001) are considered to assess the reliability of the tsunami events with some alteration and having only five values i.e. 0: very improbable (probability near 0%), *1*: improbable (probability approximately 25%), *2*: questionable (probability approximately 50%), *3*: probable (probability approximately 75%) and *4*: definite tsunami (probability near 100%). The final catalogue for the Pacific rim area consists of only those tsunami events whose reliability stands *2* (probability approximately 50%) or more. Papadopoulos (2003) also considered this criterion for the selection of tsunami events in the eastern Mediterranean region for the estimation of tsunami potential. Now, considering the reliability criteria, the prepared catalogue consists of 1508 tsunami events during the period 47 BC to 2011 with tsunami intensity $I \geq -5.0$ and reliability 2 or more.

The completeness of the prepared tsunami catalogue has been analyzed with respect to tsunami intensity (I) and time. The tsunami intensity of completeness (I_C), also called *threshold* or *cut-off tsunami intensity* is defined as the lowest tsunami intensity at which 100% of tsunami