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A hybrid deterministic and stochastic approach for tsunami hazard assessment in Iquique, Chile

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Abstract

The southern Peru and northern Chile coastal region is an active subduction zone that contains one of the most significant seismic gaps in the eastern Pacific basin (~ 17°S–~ 24°S). Although the gap was partially filled by the 2014 M_w 8.1 Iquique earthquake, there is still a high seismogenic potential to release a M_w ~ 9 earthquake in the near future; therefore, all the near-field coastal cities in the region face a latent tsunami threat. In this article, we propose a hybrid deterministic–stochastic multi-scenario approach to assess the current tsunami hazard level in the city of Iquique, an important commercial and industrial center of northern Chile that is home to 184,000 inhabitants. In our approach, we defined 400 stochastic, 10 deterministic and 10 homogeneous tsunamigenic earthquake scenarios, covering the entire area of the seismic gap. Based on the regional distribution of gravity anomalies and published interseismic coupling distributions, we interpreted the occurrence of four major asperities in the subduction interface of the seismic gap. The asperity pattern was used to construct a group of deterministic slip-deficit earthquake sources with seismic magnitudes ranging between M_w 8.4 and M_w 8.9. Additionally, we constructed 10 homogeneous slip scenarios to generate an inundation baseline for the tsunami hazard. Subsequently, following a stochastic scheme, we implemented a Karhunen–Loève expansion to generate 400 stochastic earthquake scenarios within the same magnitude range as the deterministic slip-deficit sources. All sources were used as earthquake scenarios to simulate the tsunami propagation and inundation by means of a non-hydrostatic model (Neowave 2D) with a classical nesting scheme for the city of Iquique. We obtained high-resolution data for flow depth, coastal surface currents and sea level elevation. The results suggest that the peak slip location and shelf resonance play an important role in the calculated coastal flow depths. The analysis of the entire set of simulated stochastic earthquake scenarios indicates that the worst-case scenario for Iquique is a M_w 8.9 earthquake. This scenario presented a tsunami arrival time of ~ 12 min, which is critical for the evacuation process. In addition, the maximum wave height and tsunami flow depth were found to be ~ 10 m and ~ 24 m, respectively. The observed coastal resonance processes exhibit at least three destructive tsunami wave trains. Based on historical and instrumental catalog statistics, the recurrence time of the credible worst-case earthquake scenario for Iquique (M_w 8.9) is 395 years, with a probability of occurrence of ~ 11.86% in the next 50 years.

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Keywords Earthquake scenarios · Tsunami hazard assessment · Southern Peru · Northern Chile

1 Introduction

The coastal region of southern Peru and northern Chile, extending between 17°S and 24°S, is located in the active subduction zone formed by the convergence of the Nazca and South American plates (Fig. 1). The segment has been recognized as one of the most significant seismic gaps in the eastern Pacific basin (Comte and Pardo 1991; Kelleher 1972; McCann et al. 1979; Nishenko 1985). It has undergone a prolonged seismic quiescence since the two last large historical earthquakes occurred in southern Peru (M_w 8.8, 1868) and northern Chile (M_w 8.7, 1877). Detailed descriptions of the 1868 event reported an extended tsunami impact along more than 4000 km of the coast between Trujillo, Peru, and Chiloe Island, Chile (Soloviev and Go 1975). In northern Chile, the tsunami severely impacted the city of Arica, where tsunami wave heights of ~18 m were reported (Soloviev and Go 1975). The tsunami caused by the 1877 earthquake destroyed many cities in northern Chile, including Arica, Iquique, Cobija and Mejillones. Historical reports mention tsunami waves heights of ~20 m in Mejillones harbor (Milne 1880; Soloviev and Go 1975; Vidal Gormaz 1878). More recently, the southern Peru and northern Chile seismic gap has been affected by moderate earthquakes, including the M_w 8.1 Antofagasta earthquake in 1995, the M_w 8.4 Arequipa earthquake in 2001, the M_w 7.7 Tocopilla earthquake in 2007 and the M_w 8.2 Iquique earthquake in 2014 (Delouis et al. 1997; Hayes et al. 2014; Peyrat et al.

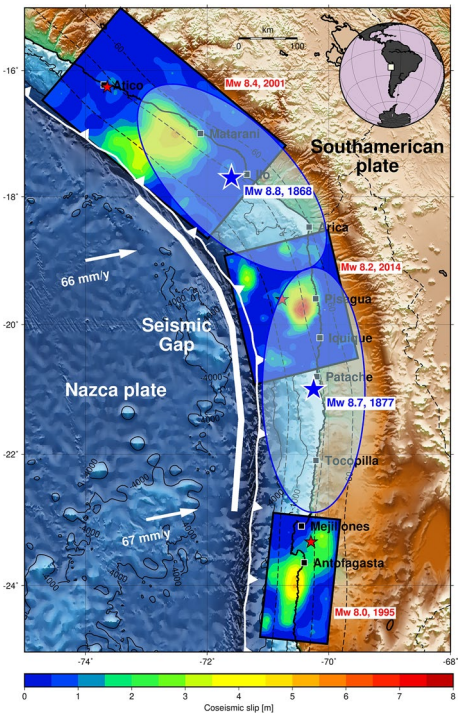

Fig. 1 Tectonic framework of the southern Peru and northern Chile seismic gap. Blue ellipses indicate the historical tsunamigenic earthquakes of 1868, M_w 8.8 and 1877, M_w 8.7. The coseismic slip distributions of moderate earthquakes ($M_w > 8$) are taken from Hayes (2017)