Tsunami Characteristics Along the Peru–Chile Trench: Analysis of the 2015 Mw8.3 Illapel, the 2014 Mw8.2 Iquique and the 2010 Mw8.8 Maule Tsunamis in the Near-field

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Abstract—Tsunamis occur quite frequently following large magnitude earthquakes along the Chilean coast. Most of these earthquakes occur along the Peru–Chile Trench, one of the most seismically active subduction zones of the world. This study aims to understand better the characteristics of the tsunamis triggered along the Peru–Chile Trench. We investigate the tsunamis induced by the Mw8.3 Illapel, the Mw8.2 Iquique and the Mw8.8 Maule Chilean earthquakes that happened on September 16th, 2015, April 1st, 2014 and February 27th, 2010, respectively. The study involves the relation between the co-seismic deformation and the tsunami generation, the near-field tsunami propagation, and the spectral analysis of the recorded tsunami signals in the near-field. We compare the tsunami characteristics to highlight the possible similarities between the three events and, therefore, attempt to distinguish the specific characteristics of the tsunamis occurring along the Peru–Chile Trench. We find that these three earthquakes present faults with important extensions beneath the continent which result in the generation of tsunamis with short wavelengths, relative to the fault widths involved, and with reduced initial potential energy. In addition, the presence of the Chilean continental margin, that includes the shelf of shallow bathymetry and the continental slope, constrains the tsunami propagation and the coastal impact. All these factors contribute to a concentrated local impact but can, on the other hand, reduce the far-field tsunami effects from earthquakes along Peru–Chile Trench.

Key words: Peru–Chile Trench, tsunami, local impact, numerical modeling, spectral analysis.

1. Introduction

Chile has a long history of large earthquake-induced tsunamis. Along the Peru–Chile Trench, that marks the convergence of the oceanic Nazca plate and the continental South America plate (Fig. 1), the occurrence of large magnitude earthquakes is frequent. The Nazca plate is subducting beneath the South America plate with a convergence speed that varies from north to south. It moves approximately at 80 mm/year in the south and at about 65 mm/year in the north, relative to a fixed South America plate (DeMetz et al. 2010).

The Peru–Chile subduction zone was responsible for numerous large earthquake magnitudes (Mw8 or greater) since 1500 (Lomnitz 2004). Among them, the Mw9.5 May 22th, 1960 Chilean event is known as the largest earthquake of the twentieth century (Kanamori 1977). It generated a trans-Pacific tsunami that was recorded at many tide gauges around the coasts of the Pacific Ocean (Berkman and Symons 1964).

In the last 5 years, three massive earthquakes took place along the Peru–Chile Trench. They occurred off the coast of Chile on September 16th, 2015, April 1st, 2014 and February 27th, 2010 with magnitudes Mw8.3, Mw8.2 and Mw8.8, respectively (Fig. 1 for location). The earthquakes were followed by tsunamis that impacted the coast of Chile causing heavy damage on harbors and producing substantial local impacts. These three tsunamis were recorded at many coastal tide gauges and deep-ocean-bottom pressure stations. The Coquimbo tide gauge (Fig. 1 for location) recorded maximum wave amplitude of 4.75 m for the Illapel 2015 tsunami (NOAA 2015). Aránguiz et al. (2016) measured a maximum run-up height of 10.75 m in Totoral during the 2015 post-tsunami survey (Fig. 1 for location). The 2014 event triggered tsunami waves that reached about 2 m in amplitude at Iquique tide gauge (An et al. 2014) (Fig. 1 for location). The 2014 post-tsunami survey conducted by
Catalán et al. (2015) reported run-up heights of the range 2–3 m with a maximum value of 4.63 m measured in Caleta Camarones (Fig. 1 for location). The tsunami impact posed by the Maule 2010 event was larger. The Talcahuano tide gauge shows only maximum wave amplitude of 2.34 m before its failure to record the rest of the tsunami signal, while a localized maximum run-up height of 29 m near Constitución was measured by Fritz et al. (2011) (Fig. 1 for location).

The seismic and tsunami data available for these three events present a unique opportunity to examine the specificities of the tsunami events occurring along the Peru–Chile Trench. In this study, we attempt to distinguish the specific characteristics of the tsunamis generated at the Peru–Chile Trench through a detailed analysis of the three tsunami events occurred in the last 5 years. We restrict our analysis to the near-field to avoid the bathymetric effects that the tsunami can undergo during its far-field propagation. The analysis of the events includes co-seismic deformation inducing coastal morphological changes, tsunami initial potential energy, numerical modeling of generation and propagation, and spectral analysis of the recorded signals. Finally, we compare the results and discuss the similarities that can characterize the tsunamis caused by large earthquakes in the Peru–Chile Trench.

2. The Three Recent Chilean Tsunamis

The September 16th, 2015 earthquake of Mw8.3 occurred at 22:54:33 UTC at 25 km depth, 46 km west of Illapel (USGS 2015), (Fig. 1 for location). It ruptured a fault of more than 200 km in length (Ye et al. 2016). The seismic source has been recently studied by Heidarzadeh et al. (2015) and Ye et al. (2016) that proposed finite-fault models for the 2015 event. The companion tsunami affected an area of more than 700 km (Aránguiz et al. 2016). The field surveys showed a concentrated local coastal impact with a maximum run-up height of 10.75 m at Totoral and a maximum inland penetration of 800 m at Coquimbo (Fig. 1 for location) (Aránguiz et al. 2016; Contreras-López et al. 2016).

On April 1st, 2014 at 23:46:46 UTC, an earthquake of magnitude Mw8.2 occurred 95 km northwest of Iquique, Chile (Fig. 1 for location). The event resulted from a shallow thrust-faulting rupture at 20.1 km depth (USGS 2014). The seismic rupture area was 200 km length and 160 km width (An et al. 2014). The earthquake finite-fault model was