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Reply to: Comment by Rodrigo Cienfuegos on "Rapidly Estimated Seismic Source Parameters for the 16 September 2015 Illapel, Chile, Mw 8.3 Earthquake" by Lingling Ye, Thorne Lay, Hiroo Kanamori, and Keith D. Koper

Lingling Ye,[1] Thorne Lay,[2] Hiroo Kanamori,[3] and Keith D. Koper[4]

In his comment, Dr. Cienfuegos clarifies the specific protocol for tsunami hazard assessment followed by the Chilean National Emergency Office (ONEMI) and the National Hydrographic and Oceanographic Service of the Chilean Navy (SHOA) for the 16 September 2015 Tsunami Alarm bulletin issued 8 min after the earthquake nucleated. While he acknowledges that a regional W-phase inversion performed by the Chilean National Seismological Center of the University of Chile appears to have been provided within 5 min of the origin, and the result was presumably transmitted to the authorities as we report, this information was apparently not used in the decision-making process regarding the issuing of the Tsunami Alarm bulletin. While our statement appears to be factually correct, to the best of our knowledge, any inference of cause and effect between the W-phase solution and the bulletin issued by ONEMI and SHOA appears to not be valid. It is often the case that protocols for emergency response decision-making lag behind the technological capabilities of the scientific community. Hopefully, the valuable W-phase information will be included in future protocols for decisions regarding Chilean tsunami.

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Comment on Lingling Ye, Thorne Lay, Hiroo Kanamori, and Keith D. Koper, "Rapidly Estimated Seismic Source Parameters for the 16 September 2015 Illapel, Chile M_w 8.3 Earthquake", 173(2), 2016, p. 321–332

Rodrigo Cienfuegos[1]

The Illapel earthquake that struck north-central Chile on September 16th 2015 generated a tsunami that reached the coast in front of the rupture area in a matter of minutes (Aránguiz et al. 2016; Contreras-López et al. 2016; Fuentes et al. 2016). Maximum observed runups ($\sim$ 10 m) occurred in a sparsely populated area and only a few casualties were attributed to the tsunami (Tang et al. 2016; ONEMI 2015a).

The rapidity of the tsunami inundation challenged the early warning system operated by the National Hydrographic and Oceanographic Service of the Chilean Navy (SHOA). At the time this event occurred, the tsunami hazard assessment protocol in operation utilized rapid seismic magnitude estimations provided by national and international agencies, whose reports were automatically sent to SHOA. Soon after the earthquake, SHOA received earthquake magnitude estimations from the US National Tsunami Warning Center (NTWC), the Pacific Tsunami Warning Center (PTWC), the National Seismological Center of the University of Chile (CSN), the GEOFON Global Seismic Network from the GFZ German Research Centre for Geosciences, and the National Earthquake Information Center from the US Geological Service (NEIC/USGS). In Table 1, the rapid seismic estimations received by SHOA are listed as reported in ONEMI (2015b) and SHOA (2015).

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From Table 1, large variability is observed among rapid seismic magnitude estimations provided by different agencies. The lowest magnitude estimation (6.8) was sent by CSN at 20:14 h, while the largest and more accurate estimate (8.3) was issued by NEIC/USGS at 20:14.

At 20:02, SHOA issued the first tsunami alarm bulletin based on the seismic magnitude estimation provided by the PTWC, thus using the largest magnitude estimation received within the first 6 min following the earthquake (SHOA 2015). Nevertheless, many witnesses declared that they evacuated coastal areas immediately after the earthquake, even before the official tsunami alarm was issued (Contreras-López et al. 2016).

The official reports referenced above describe the different actions taken by the Chilean National Emergency Office (ONEMI) and SHOA according to the protocols that were established at that time and the sources of information that supported their decision-making process. These facts do not support the following paragraph taken from the article "Rapidly Estimated Seismic Source Parameters for the 16 September 2015 Illapel, Chile M_w 8.3 Earthquake" published in Pure and Applied Geophysics, 173(2), 2016, p. 321–332 (Ye et al. 2016):

> "An operational application of regional W-phase inversion was performed by the Chilean National Seismological Center of the University of Chile, and provided a solution within 5 min using data from 22 stations within 12° of the epicenter, with MW 8.1. This information was automatically transmitted to the Navy Hydrographic Service in charge of the tsunami alerts, and the Emergency Office of the Interior deployed an evacuation plan

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Table 1

Rapid seismic estimations received by SHOA on September 16, 2015, as part of its protocol for tsunami hazard assessment Source: ONEMI (2015b) and SHOA (2015)

Local time	Magnitude estimation	Agency
19:58	7.2	NTWC
19:59	7.9	PTWC
20:00	7.2	CSN
20:01	7.7	GEOFON
20:14	8.3	NEIC/USGS
20:14	6.8	CSN

The earthquake occurred at 19:54 local time

> for the coastal population. It is estimated that about 1 million people were evacuated from various exposed regions in central Chile."

It appears that CSN did have at the time an automated W-phase inversion method that provided this solution within 5 min (personal communication with the Director of CSN), but this was not part of the official protocols at that time, and was not used in the decision-making process performed by ONEMI and SHOA for the Illapel 2015 event as recounted in official reports. The W-phase inversion has proven to be a powerful method for providing rapid magnitude estimations for large subduction earthquakes, and great progress has been made in that direction in recent years; nevertheless, it is important to clarify that the bulletins issued by ONEMI and SHOA were not based on the W-phase assessment performed by CSN, and the successful evacuation of about one million people cannot be attributed to this.

We acknowledge that technological advancements have shortened the required time for rapid seismic magnitude estimations, but we cannot underestimate the fundamental importance of past experiences, education, and awareness programs, which are critical to ensuring prompt tsunami evacuation immediately after a strong shaking, especially in areas where the distance between the trench and the coast is short and the first tsunami waves can reach coastal settlements at time scales which are comparable to the required time for gathering and post-processing of seismic signals.

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