# Global ocean-bottom pressure observation of tsunami generated by atmospheric pressure waves on the 2022 Tonga eruption

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On January 15, 2022, a massive volcanic eruption occurred at an uninhabited island in Tonga, the Hunga Tonga-Hunga Ha’apai. Globally-distributed ocean-bottom pressure gauge network recorded tsunamis related to this eruption; however, they arrived much earlier by > ~2–3 hr than the theoretical tsunami travel time. The worldwide barographs also observed the atmospheric pressure rises propagating with amplitudes of ~2 hPa at a velocity of ~300 m/s. These waves are Lamb waves, which propagate in the air at the acoustic speed (Lamb 1932). We here investigated the generation mechanism of these enigmatic global tsunamis recorded by the global ocean-bottom pressure gauges, as well as the global tide gauges, caused by the atmospheric pressure waves due to this eruption.
We first synthesized the global propagation of the Lamb wave, supposing a propagation velocity of $V_0$ = 300 m/s. We then simulated tsunamis driven by atmospheric pressure. We finally obtain the ocean-bottom pressure changes by calculating the sum of the pressure change contributions of the atmospheric pressure and sea-surface height changes (Kubota et al. 2021).
The simulation explained the observed leading ocean-bottom pressure changes arriving earlier than the theoretical tsunami arrival. The leading uplift tsunamis, propagating at a velocity of $V_0$, are interpreted as waves forcedly displaced by the Lamb wave. We note that these leading waves were not generated by a “resonant mechanism” of tsunamis (Proudman 1929) because the sea-surface height did not increase with travel distance. After the leading uplift tsunami, the small ocean fluctuations were excited at the regions of steep bathymetry changes such as small islands, indicating the bathymetric scattering contributes to the subsequent disturbances. After passing the leading uplift and scattering-originated tsunamis, the subsidence waves propagated around at a tsunami velocity $c_0 = (g_0 h_0)^{0.5}$ ($g_0$: gravity acceleration, $h_0$: seawater depth), which are interpreted as a result of the water-volume conservation. When the sea surface was forcedly displaced by the Lamb wave and propagated around at a velocity of $V_0$, the sea surface at the source subsided to conserve the total water volume, which then collapses and propagates due to gravity as tsunamis.
The information from the global ocean-bottom pressure gauges is very important for the real-time tsunami forecast. In the case of ordinary earthquake-induced tsunamis, the bottom pressure $p$ is directly converted to the tsunami height $\eta$ via the relationship $p = \rho_0 g_0 \eta$ ($\rho_0$ is the seawater density). However, the atmospheric pressure due to the Lamb wave also contributes to the ocean-bottom pressure change in the present case; $p = \rho_0 g_0 \eta + p_{atmos}$. This mishandling may result in the overestimation of $\eta$. Another critical issue for the global tsunami forecast will be atmospheric gravity waves, waves propagating at a velocity close to the tsunami for most parts of the Pacific Ocean ($V_0$ ~$c_0$ ~200–220 m/s, $h_0$ ~4–5 km). The resonance between the atmospheric gravity wave and ocean wave (e.g. Press & Harkrider 1966) may continuously amplify the tsunami, resulting in larger tsunami amplitudes than tsunamis generated by a seafloor crustal deformation at the source, after propagating a certain distance. The continuous amplification by the gravity wave may also lead to long-lasting waves. To forecast tsunamis due to the volcanic eruption based on the global ocean-bottom pressure gauges, it will be essential to accurately model the atmospheric pressure changes due to atmospheric gravity waves and Lamb waves.

 

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