Simulation of the 2022 Tonga Eruption Tsunami Using Pressure Wave Approximated by Triangular Shape

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The Hunga Tonga-Hunga Ha'apai volcano in Tonga started a massive eruption at approximately 4 am UTC on January 15, 2022, accompanied by a tsunami. Tide gauges recorded the tsunami near the volcano and widely in the Pacific Ocean. In Japan, tidal fluctuations began approximately four hours earlier than theoretical tsunami arrival time. The height of the tsunami exceeded one meter, causing some fishing boats to capsize. The tsunami struck at night in Japan, but the damage would have been much worse if it had struck during the daytime in the summer season. Widespread atmospheric pressure fluctuations were observed around the tsunami arrivals, suggesting that it was a meteorological tsunami. In this study, the equation of motion in the linear long-wave equations included atmospheric pressure fluctuation for finite difference tsunami calculations. The tsunami calculations were performed over the entire Pacific Ocean. Topographic nesting improved computational spatial resolution from 3 arcminutes over the entire Pacific Ocean to 20/9 arcseconds near tide stations. We compared the simulation results and tidal records at Hanasaki, Miyako, Ayukawa, Onahama, Omaezaki, Muroto, Amami, and Chichijima. We assumed that a pressure wave spreads from the volcano in a circular pattern and that the total amount of sonic energy above the circle is conserved. Pressure fluctuations decay from the eruption point by 1/sqrt(sin(R/A)), where R is the distance along the earth's surface from the eruption point to an observation point, and A is the earth radius. We approximated the pressure wave by a triangle shape and calculated the total sonic energy, $E=1.1\text{-}2.2 \times 10^{16}$ J, using barometer data observed in Japan. This tsunami analysis adopted $E=2.16 \times 10^{16}$ J, a triangle wave’s width of 1620 seconds, and a propagation velocity of 315 m/s, explaining pressure fluctuations at Ofunato. The peak value of pressure fluctuation at Ofunato was approximately 2 hPa. The simulation results reproduced the tsunami's arrival, amplitude, and period recorded at Hanasaki and Miyako. At Onahama, Omaezaki, Muroto, Amami, and Chichijima, the waveforms for the first few cycles (about 1 hour of record) after the arrival of the tsunami were well simulated, but large amplitude signals that appeared later (10 to 12 hours after the eruption) were not. Tsunamis excited by the eruption-induced collapse were weak near the volcano, such as in Nauru, so their impact on Japan is likely small. Even if tsunamis were excited by the eruption-induced collapse, their arrivals should be after these large amplitude signals. Therefore, we should consider the effects of atmospheric gravity waves, which propagate slower than the speed of sound, for accurate simulations of the meteorological tsunami.

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