Wave Separation of Tsunami Near Japan Induced by Air Pressure Pulse After the 2022 Tonga Volcanic Eruption

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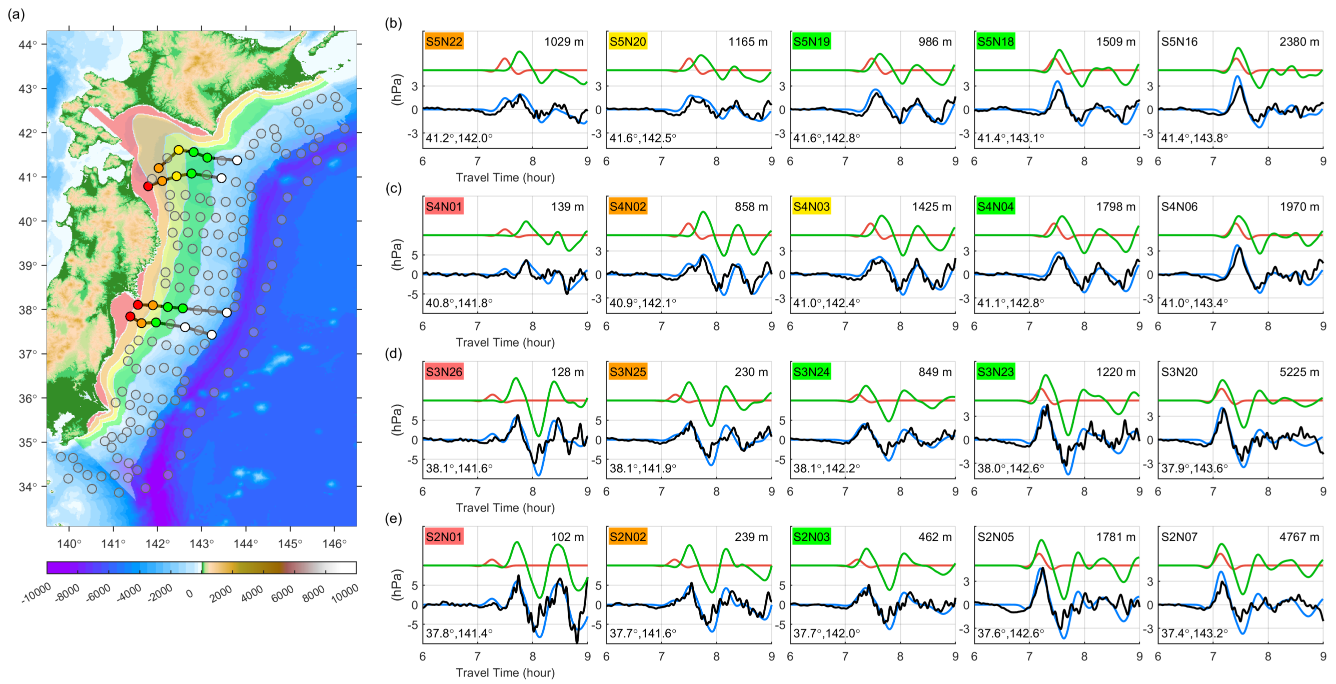
Hunga Tonga-Hunga Ha'apai volcano erupted at UTC 04:14, 15 Jan. 2022. After the eruption, global tsunami monitoring systems and tide gauges observed tsunami signals earlier than expected tsunami waves (Carvajal et al., 2022). The recorded data revealed that the fast-traveling traveled at a velocity of about 300-315 m/s (Kubota et al., 2022; Yamada et al., 2022), which was much faster than the conventional tsunami average velocity of around 200 m/s. The eruption excited an air pressure pulse known as the Lamb wave (Matoza et al., 2022). The sea surface disturbances induced by Lamb wave (hereafter, pressure-forced wave) traveling with the Lamb wave at the same velocity. The pressure-forced waves were observed much earlier and are considered the fast-traveling tsunamis (Kubota et al., 2022). However, studies indicated that the pressure-forced waves could generate ocean gravity waves after a major water depth change, such as continental slopes. The generated ocean gravity waves were first instrumentally recorded after the eruption of the Krakatau volcano in 1883, where the ocean gravity waves were generated when air pressure pulse at major changes in depth (Garrett, 1970). After the eruption of Hunga Tonga, it was the first time that pressure-forced waves were widely observed by ocean bottom pressure gauges (OBPGs). Tanioka et al. (2022) reported the separated waves observed by the OBPGs near Japan Trench. Their synthetic test indicated that the separation effect is sensitive to the wavelength of the Lamb wave. Yamada et al. (2022) pointed out that compared to OBPGs, the sea surface disturbances were much delayed at tide gauges because the tsunami separated and traveled in ocean gravity wave after passing the continental slope. To understand the mechanism of the wave separation, we performed two-dimensional simulations of synthetic tests and the real bathymetry with the case of Hunga Tonga. Our simulations show that the separated waves were the pressure-forced wave, which traveled at the same velocity of Lamb wave, and the ocean gravity wave generated at changes in depth. Variation of water depth rescales the amplitude of the pressure-forced wave, and the amplitude change generates an ocean gravity wave due to conservation of mass. The generated ocean gravity wave travels at long wave velocity, which is slower than the Lamb wave. The velocity difference between the pressure-forced wave and the generated ocean gravity wave led to the wave separation. We reproduced different stages of separated waveforms recorded by S-net stations between Japanese east coast and Japan Trench. Our result suggests that any volcano may induce the fast-traveling tsunami, i.e., the pressure-forced waves and ocean gravity waves, as the volcanic eruption excites a significant air pressure pulse, such as 2022 Hunga Tonga or 1883 Krakatau. Our synthetic tests showed that the pressure-forced wave would be amplified as it travels to deeper water. The pressure-forced waves are small in shallow-water coastal areas, where the ocean gravity waves are usually larger. The wave heights of ocean gravity waves are associated with the change of depth. In other words, a larger depth change results in a larger amplitude change of pressure-forced wave, and the generated ocean gravity wave is larger. It implies that the induced tsunami wave height is limited when the air pressure pulse travels only in shallow water. Future works on the tsunamis in the Atlantic Ocean, such as the Caribbean Sea and the Mediterranean Sea, can help us understand the tsunami induced by the air pressure traveling from land.


(a)
(b)
(c)
(d)
(e)
S5N22 1029 m
S5N20 1165 m
S5N19 986 m
S5N18 1509 m
S5N16 2380 m
S4N01 139 m
S4N02 858 m
S4N03 1425 m
S4N04 1798 m
S4N06 1970 m
S3N26 128 m
S3N25 230 m
S3N24 849 m
S3N23 1220 m
S3N20 5225 m
S2N01 102 m
S2N02 239 m
S2N03 462 m
S2N05 1781 m
S2N07 4767 m
(hPa)
Travel Time (hour)