Satellite altimetry reveals genesis of volcanic tsunami

Y. Tony Song, Philip Callahan, Jean-Damien Desjonqueres, Severine Fournier & Josh Willis

Jet Propulsion Laboratory

Introduction:

The 2022 Tonga volcanic eruption generated a surprisingly large air-pressure wave (lamb wave) and a locally damaging tsunami. The tsunami generation is still puzzling because both the air wave and submarine explosion drove changes in sea level.

Science Questions:

- How could the volcano generate the tsunami with very little water above?
- Why volcanic tsunami was so destructive near-field, but not far-field?
- How to predict/forecast volcanic tsunamis for early warning?

Methodology:

1. Satellite altimetry and a coupled atmosphere-ocean model were used to analyze the air-pressure waves and the volcanic tsunami.
2. We proposed a mass-conserving tsunamigenic mechanism, which couples the volcanic ejecta to ocean waters filling in the erupted crater, to explain the tsunami and observations.

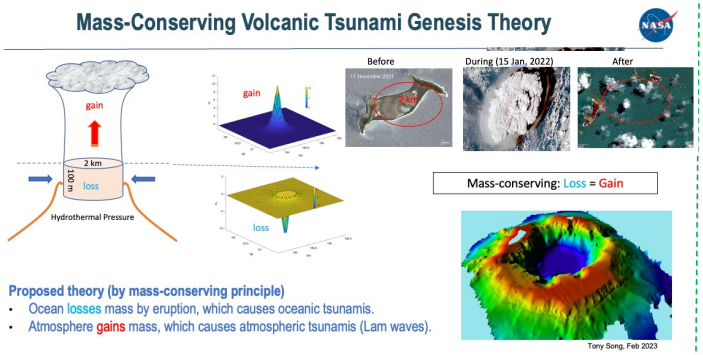


Figure 1. Schematics of volcanic ejecta of waters, gases and magma to the atmosphere.

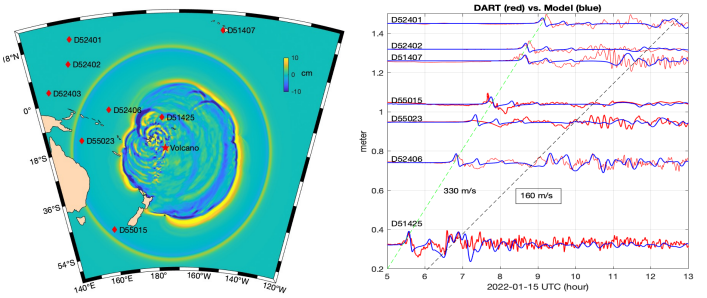
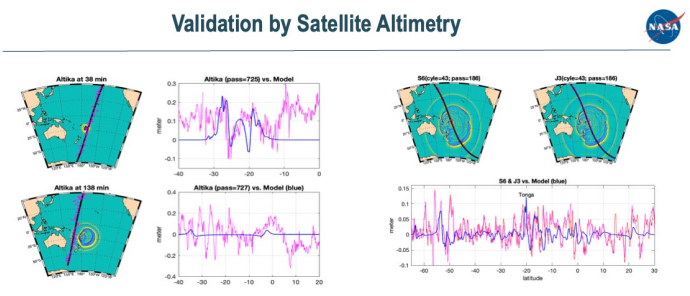
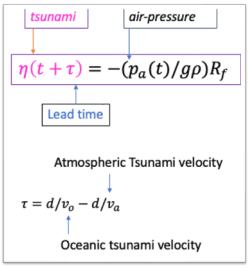


Figure 2. (left) A snapshot of the modeled atmospheric tsunami (outer circle) and oceanic tsunami (inner circle); (right) comparison with DART measurements of ocean bottom pressure, which was converted to the thickness of water. Their locations are marked on the map. The dashed-green line represents the lamb wave speed of 330 m/s.



Model vs. AltiKa & Jason-3 & SA6 data: Magenta is the altimetry data and blue is the model.

Figure 3. Selected altimetry measurements of the 2022 Tonga volcanic tsunami.



Application for Tsunami Early Warning:

- How to predict/forecast volcanic tsunamis for early warning?

A mathematical formulation between air-pressure sensors and tide-gauges is established to predict volcanic tsunamis for early warning.

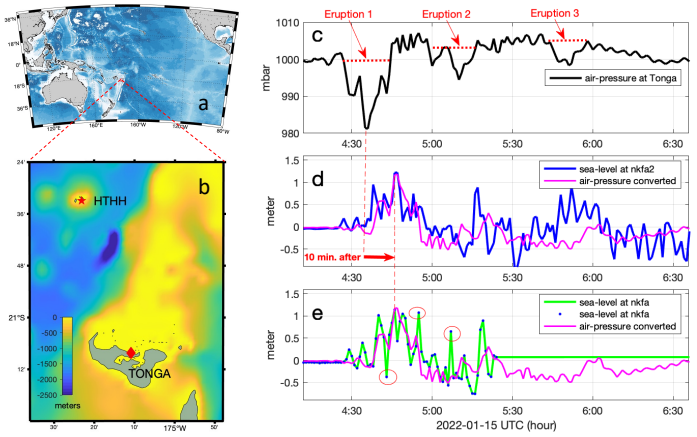


Figure 4. Air-pressure and tide-gauge in Tonga showing the predictive skills.

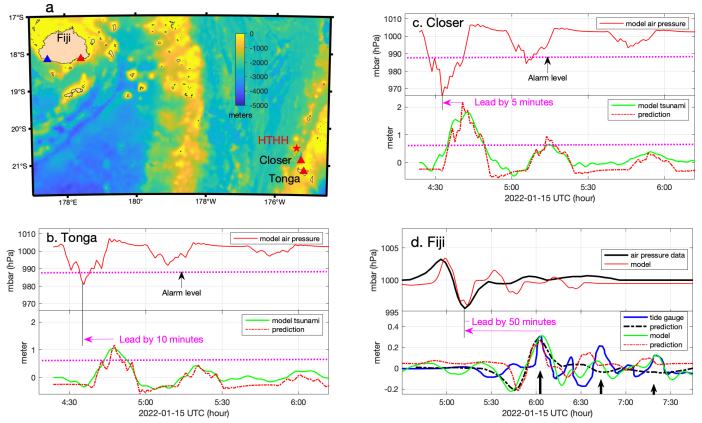


Figure 5. Air-pressure waves predict following tsunamis. Within the near-field perimeter of 60 km, a lead-time of approximately 5 to 10 minutes exists, providing a crucial window for evacuations.

Summary:

- We used satellite altimetry and a coupled ocean-atmosphere model to explain the air-pressure waves and volcanic tsunami, revealing their coupling mechanism.
- The coupling mechanism provides a way to predict/forecast volcanic tsunamis by air-pressure waves, which leads the tsunamis by 5~10 minutes within near-field of 60 km perimeter.

Publication

Song, Y. T., P. S. Callahan, J. D. Desjonqueres, S. Fournier, and J. K. Willis (2024) A coupled atmosphere-ocean source mechanism was a predictor of the 2022 Tonga volcanic tsunami, *Communications Earth & Environment*, https://doi.org/10.1038/s43247-024-01694-z.