Toward A Global Real-Time Tsunami Monitoring Network Using GNSS-Derived Ionospheric Disturbances: 2022 Tonga Eruption Case Study

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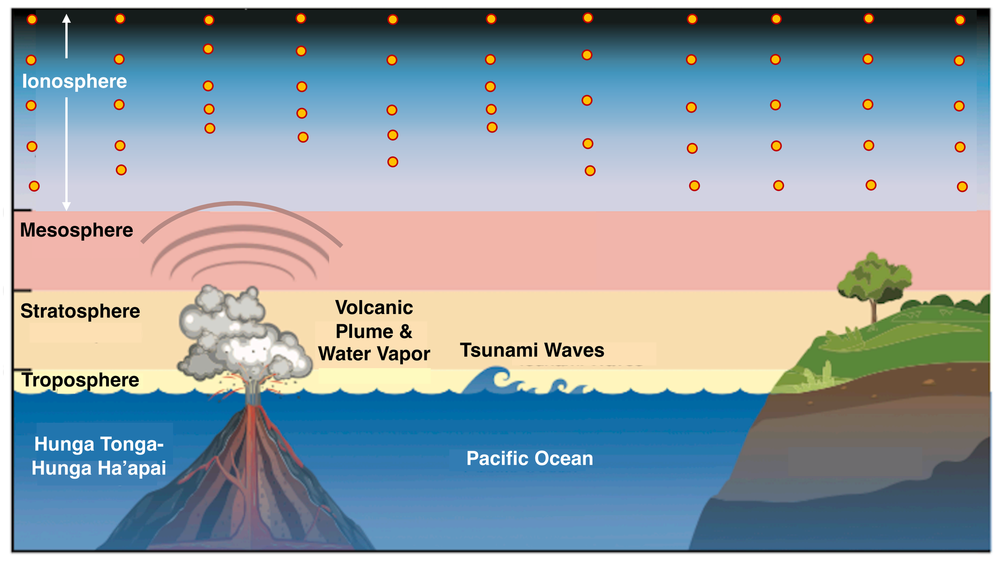
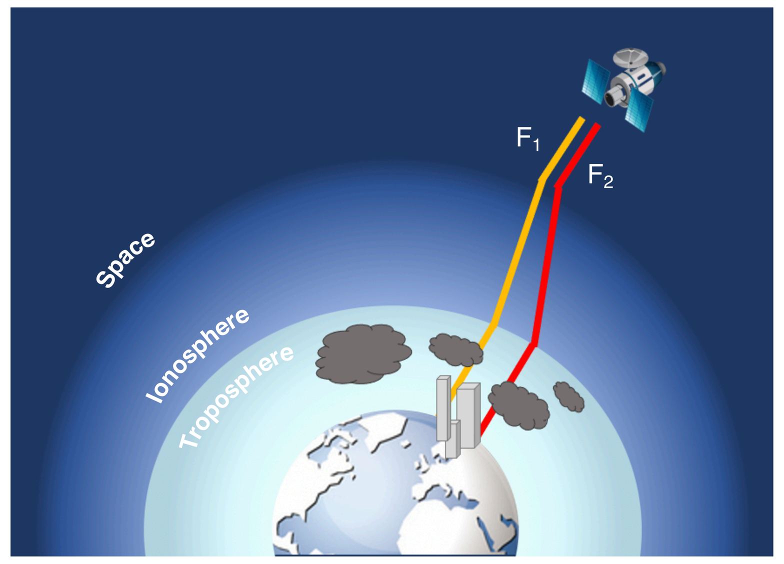
NATURAL HAZARDS, GNSS, & THE IONOSPHERE



Ionosphere is disturbed by large natural events...

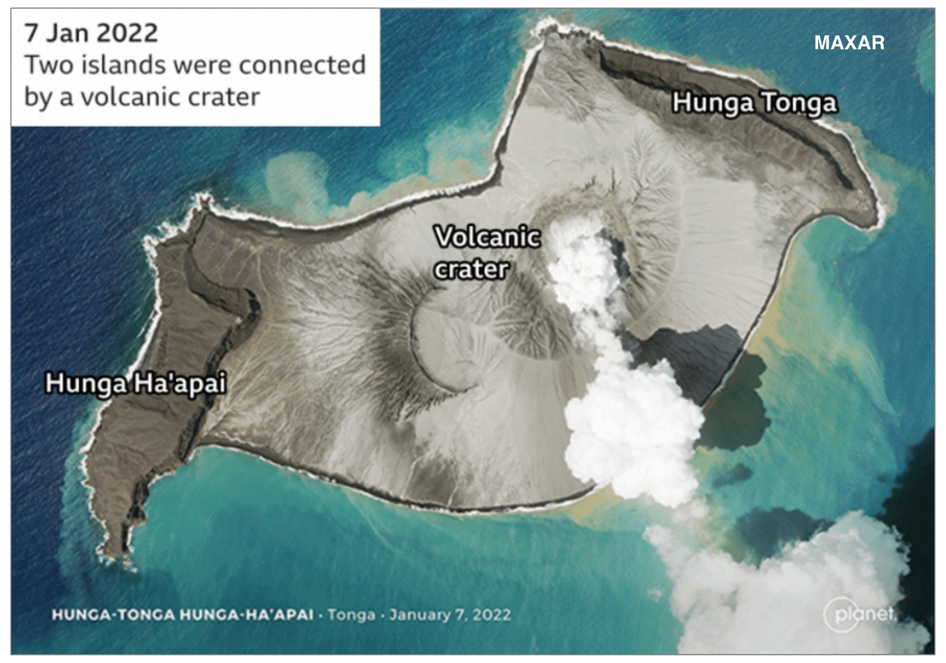
... and observed by dual-frequency GNSS

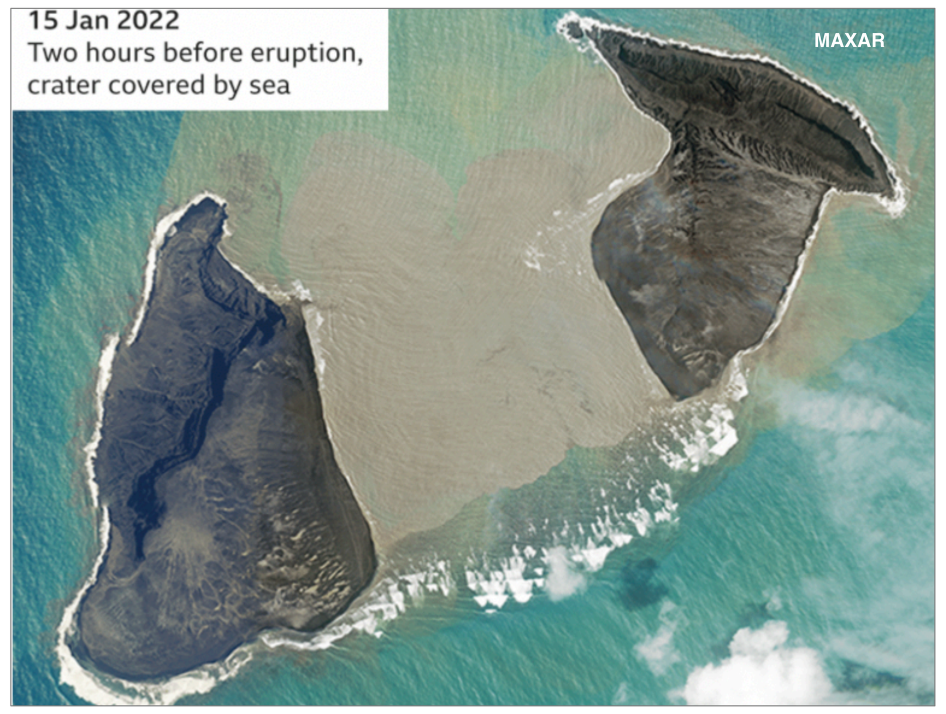


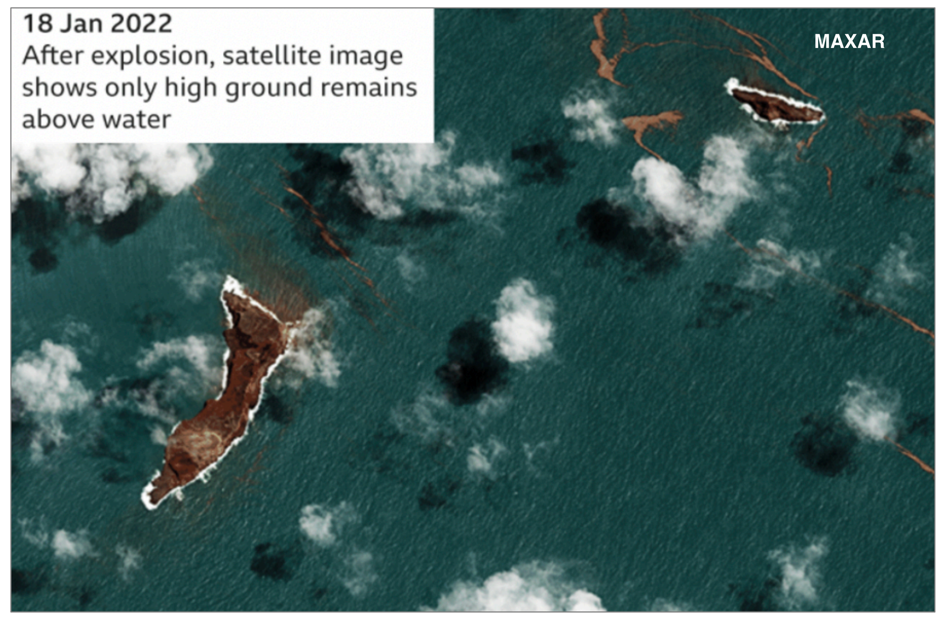
- Ionosphere: Layer of Earth's atmosphere with ions & free electrons
- Electron layers are compressed by passing acoustic-gravity (AG) waves from volcanic eruptions, tsunamis, and more[1]
- Change in Total Electron Content (TEC) found using Global Navigation Satellite Systems (GNSS)
- TEC waveforms used as proxy for atmospheric AG waves

Goal: Separate acoustic and tsunami phases within GNSS signals to isolate tsunami activity

TONGA ERUPTIONS







Separation of Acoustic & Tsunami Phases

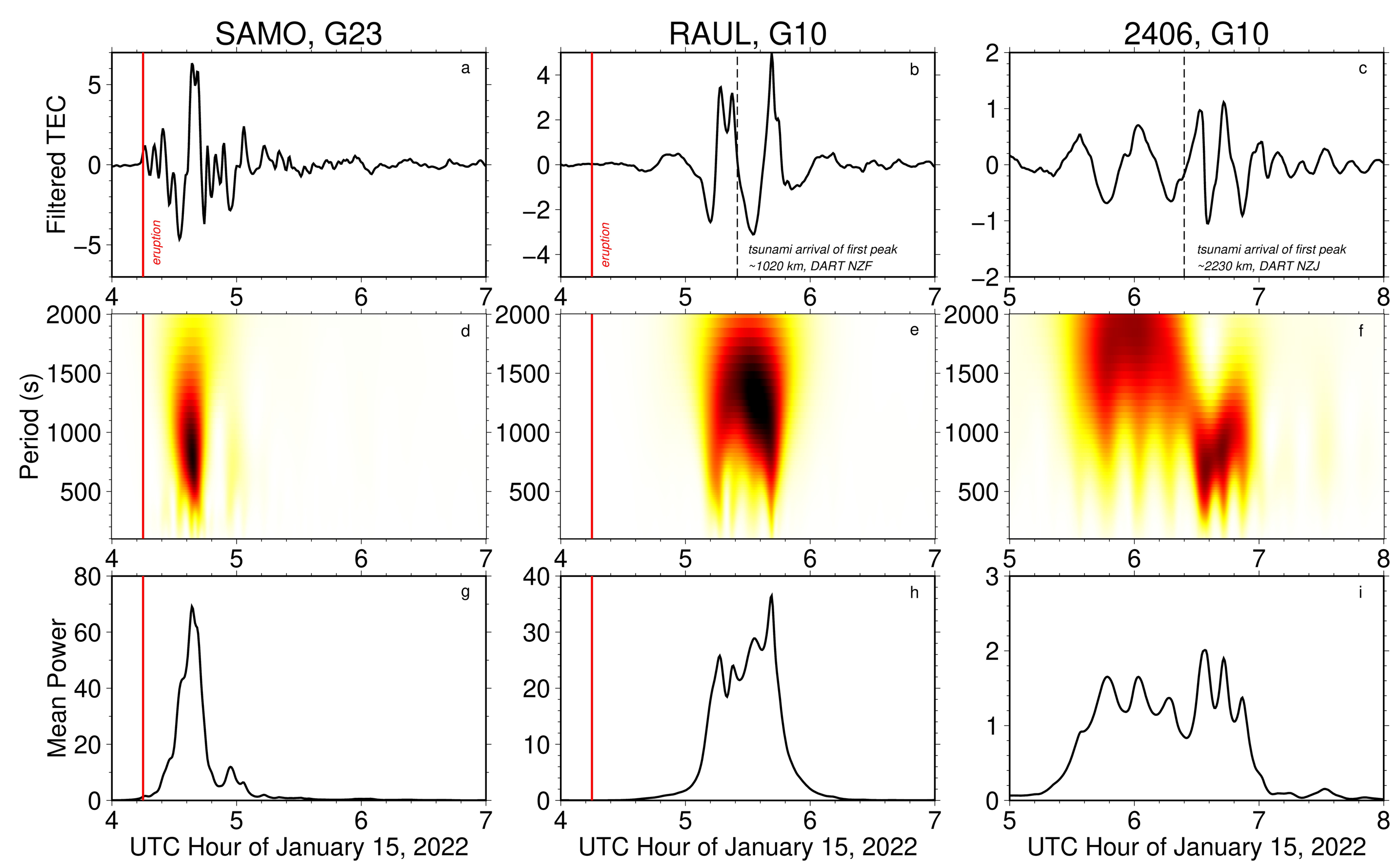


Fig. 2 Phases are superimposed within 837 km (a, d, g). Early separation appears 1000 km from HTHH (b, e, h). ***Arrivals of acoustic and tsunami phases are distinct 2,175 km from volcano (c, f, i).*** *Phase separation is supported by arrival of tsunami's first peak[2] and shift in period domain.*

Traveling Ionospheric Disturbance (TID) Moveout, Satellite G10

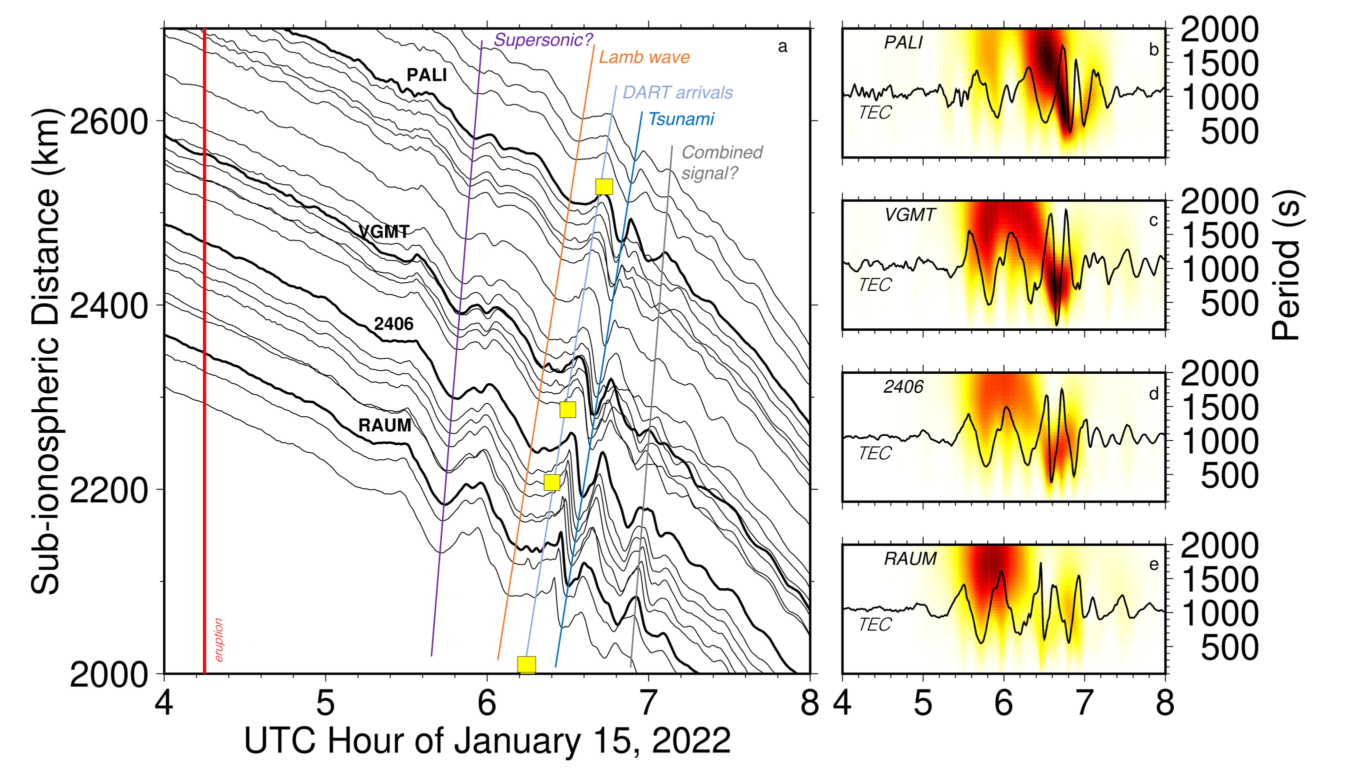


Fig. 3 (a) TEC waveforms from multiple receivers displayed along satellite path. Yellow boxes are DART positions and timings of first tsunami peaks.[2] ***Supersonic and combined TIDs have same velocity. Lamb and tsunami TIDs have same velocity as through DARTs.*** *Period shift for four receivers is laid atop flattened TEC waveform in (b-e) to emphasize phase change.*

Study Region: Southwest Pacific

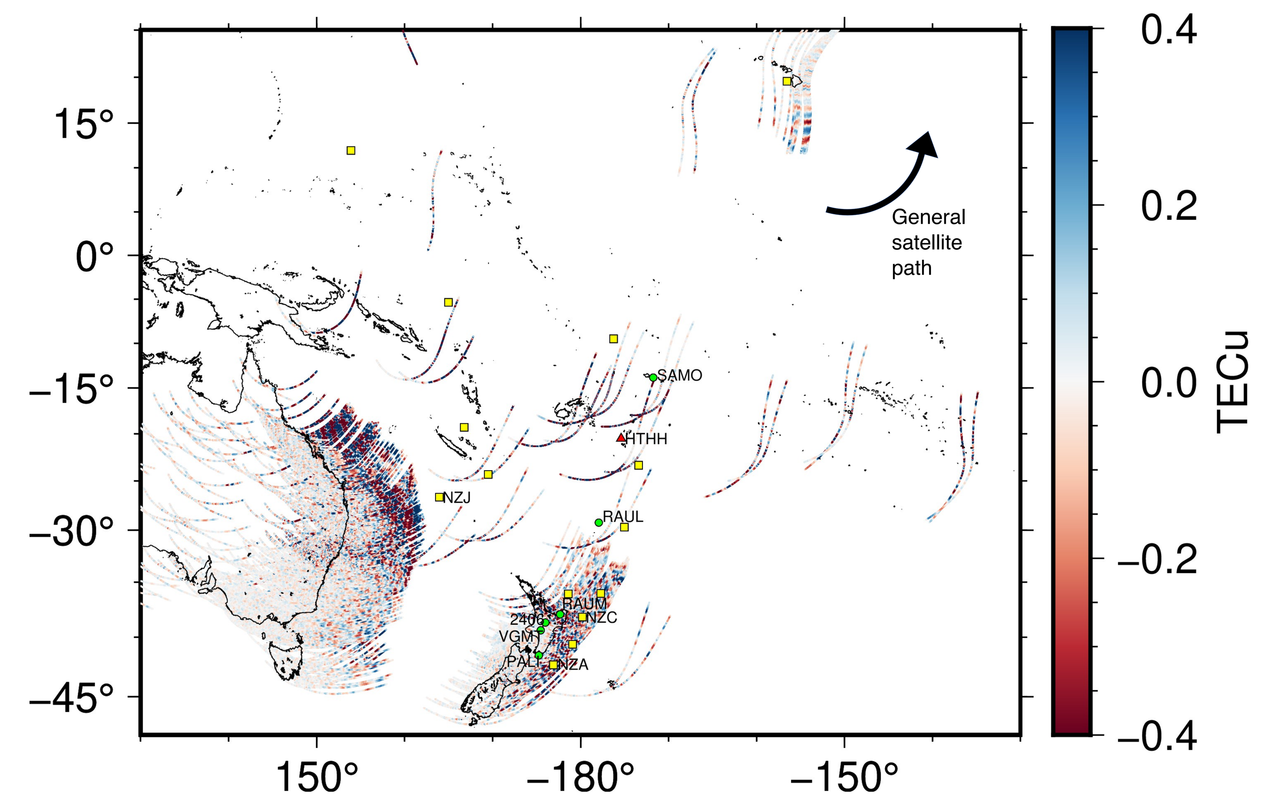


Fig. 1 Mapview of ionospheric disturbances over region from satellites G10 and G23. Red triangle is volcano, green circles are GNSS stations, yellow boxes are Deep-ocean And Reporting of Tsunami (DART) buoys. TEC units (TECu) saturated beyond +/- 0.4 to emphasize strongest signals.

Raw & Interpolated TEC, Propagation Velocities

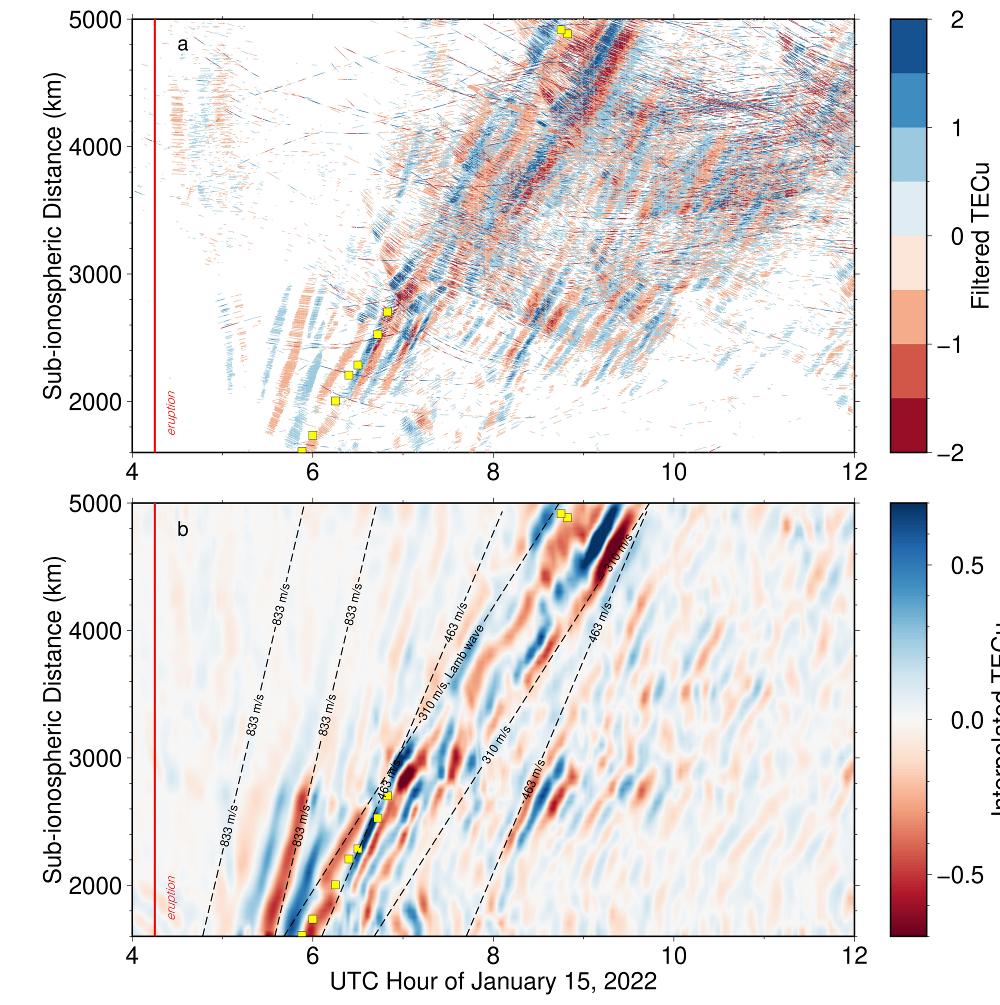


Fig. 4 Great circle distance-time plots of (a) raw and (b) interpolated TEC. Yellow boxes same as Fig. 2. TEC is saturated in both panes. ***Potential combined signal (463 m/s) is seen at multiple times and locations.*** *Velocities align with recent publications.[3, 4]*

Rotated interpolation, DART & TEC Arrivals

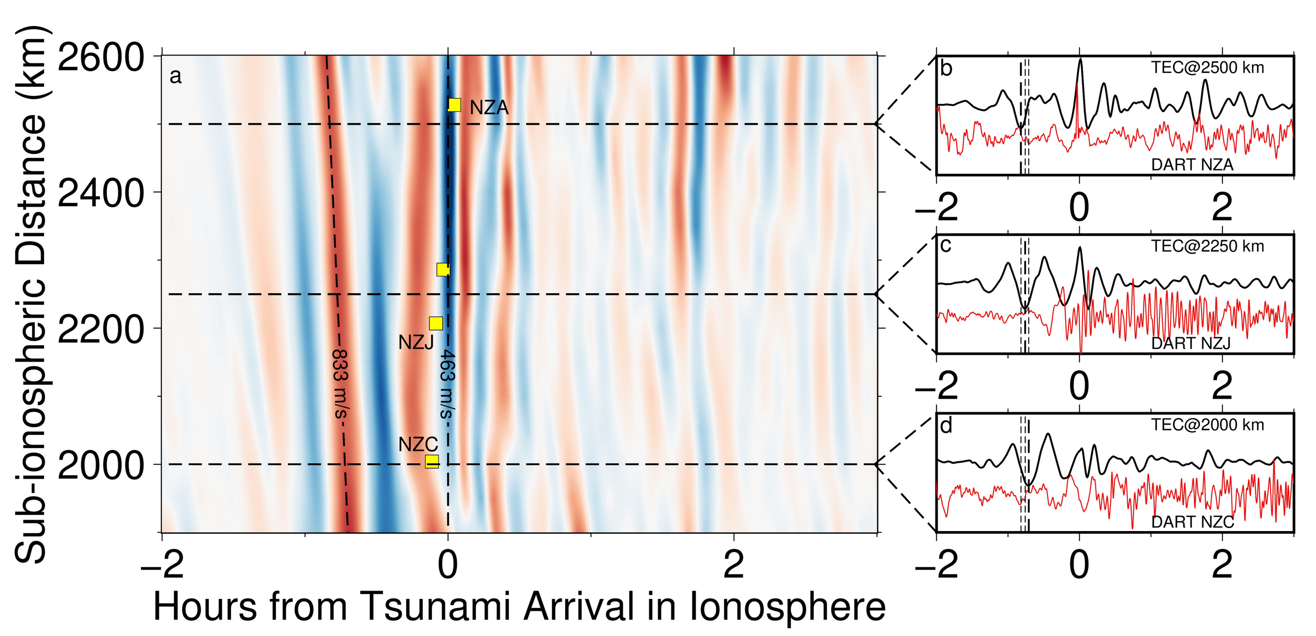


Fig. 5 (a) Interpolated TEC rotated to vertical first tsunami peak in ionosphere, with distance slices (b–d). Yellow boxes same as Fig. 2. Vertical dashed lines in (b-d) are timings of TECu minimum preceding tsunami arrival, with bolded dashed line representing timing at that distance. ***Time between TECu minimum and tsunami arrival increases with distance.***

DISCUSSION

Phase arrivals from Jan 15 begin to separate at ~1,000 km from HTHH and are fully separated by ~2,200 km

- Drop in period aligns with arrival of actual tsunami
- Period domain shift is witnessed across our full dataset

463 m/s disturbance in Fig. 4 propagates 1 hr post-eruption and meets tsunami perturbation ~3,000 km from the volcano

- Source could be combined signals? Resonance effects?
- Enhanced signal shortly after 08:00 UTC ~2400-3000 km from volcano also travels at 463 m/s

Future work:

- Explore phase separation between other volcanic tsunami events
- Compare to earthquake-generated tsunamis
- **GUARDIAN – Collaboration with NASA Jet Propulsion Laboratory to move toward real-time TEC monitoring network[5]**

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ACKNOWLEDGMENTS

This work is funded through the NASA Disasters program, Grant 80NSSC19K1104 to Brendan Crowell at the University of Washington. Additionally, Jessica Ghent is funded through the National Science Foundation's Graduate Research Fellow-ship Program under Grant DGE-2140004.

The authors would like to thank two anonymous GRL reviewers who contributed helpful feedback in the interpretation of this data.

REFERENCES

[1]Hines, C. O. (1972). Gravity waves in the atmosphere. Nature, 239(5367), 73–78.

[2]Gusman, A. R., & Roger, J. (2022). Hunga Tonga-Hunga Ha'apai volcano-induced, sea level oscillations and tsunami simulations. *GNS Science Webpage*.

[3]Astafyeva, E., Maletckii, B., Mikesell, T. D., Munaibari, E., Ravanelli, M., Coisson, P., et al. (2022). The 15 January 2022 Hunga Tonga eruption history as inferred from ionospheric observations. *Geophysical Research Letters*, 49(10), e2022GL098827.

[4]Themens, D. R., Watson, C., Zagar, N., Vasylkevych, S., Elvidge, S., McCaffrey, A., et al. (2022). Global propagation of ionospheric disturbances associated with the 2022 Tonga volcanic eruption. *Geophysical Research Letters*, 49(7), e2022GL098158.

[5]Martire, L., Krishnamoorthy, S., Vergados, P., Romans, L. J., Szilágyi, B., Meng, X., et al. (2022). The GUARDIAN system – A GNSS upper atmospheric real-time disaster information and alert network. *GPS Solutions*.