Traveling Ionospheric Disturbances in the GNSS TEC Triggered by the Tonga Volcano Eruption on 15 January 2022

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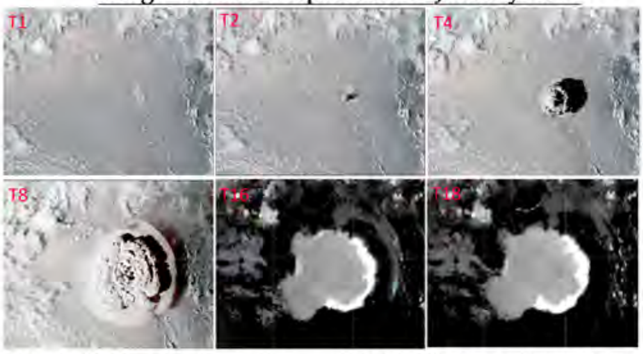
Abstract

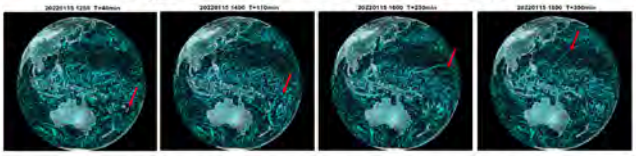
GOES-17 and Himawari-8 images show that at 04:15UT, intense eruptions of the Tonga volcano generated atmospheric shock waves, sonic booms (or atmospheric pressure disturbances), and tsunami waves, which further traveled into the upper atmosphere and activated traveling ionospheric disturbances (TIDs) worldwide on 15 January. The ionospheric total electron contents (TECs) derived from measurements of 1000+ GNSS (global navigation satellite system) ground-based receivers of the world are employed to detect TIDs. We apply the Beamforming technique on the TIDs, and compare time rate of TEC changes with records of buoys and tide gages in Hawaii, Taiwan, and Japan to have a better understanding on TIDs triggered by the Tonga volcano eruption.

Tonga Volcano Eruption on 15 January 2022



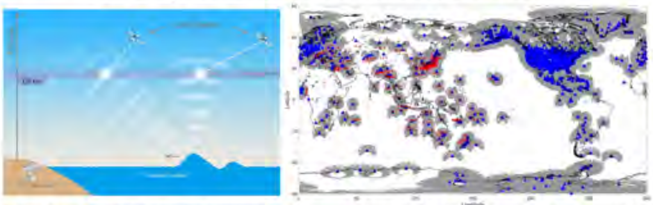
➢ **Figure 1.** NOAA's Geostationary Operational Environmental Satellite 17 (GOES-17) captured images of the Tonga Volcano (20.5°S 175.4°W) Eruption at T1-T18 after 04:15 UT on 15 January 2022. The generated atmospheric shock waves, sonic booms, and tsunami waves traveled the world.
https://earthobservatory.nasa.gov/images/149347/hunga-tonga-hunga-haapai-erupts

Images of ひまわり8号 (Himawari-8)



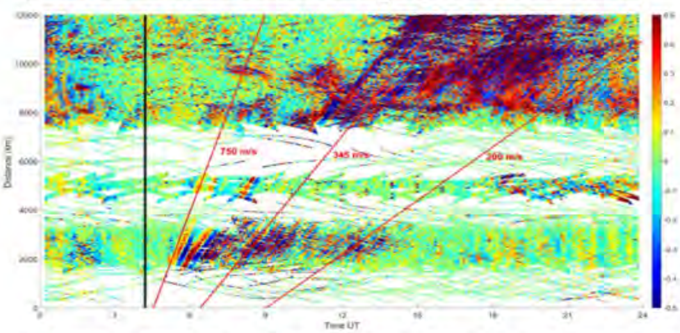
➢ **Figure 1.** Himawari-8 images show that the atmospheric shock waves triggered by the Tonga Volcano eruption traveled with about 350 m/s allover the world. The red arrow marks the atmospheric pressure disturbances.

Coverage of Ground-based GNSS Stations



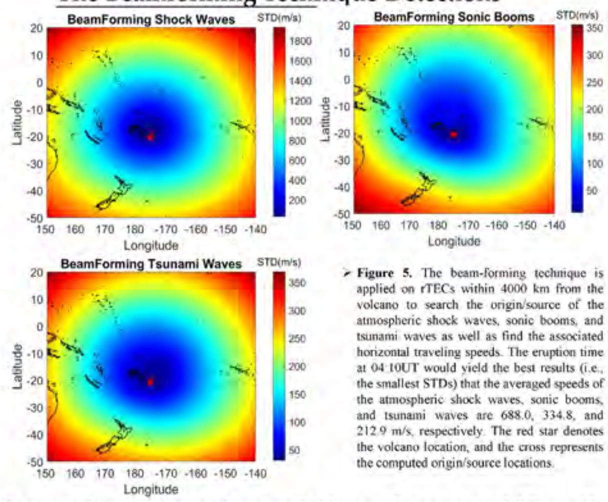
➢ **Figure 3.** Sea surface disturbances induced by tsunami propagate into ionosphere (left panel), while a ground-based GNSS receiving station monitors traveling ionospheric disturbances (TIDs) (right panel). The thin-shell ionospheric (i.e. ionospheric pierce or ionospheric) height is at 325 km altitude (left panel). The coverage of ground-based GNSS receiving stations of the world. Blue triangles are the GNSS stations. Gray curves denote the path of ionospheric pierce points. Red dots denote the ionospheric pierce points of BeiDou geosynchronous satellites. About 1000+ stations of them provide data in real time. The Tonga Volcano at (20.5°S 175.4°W) (Liu et al., 2019)

TIDs in TEC Time Rate of Changes (rTEC) of the Globe



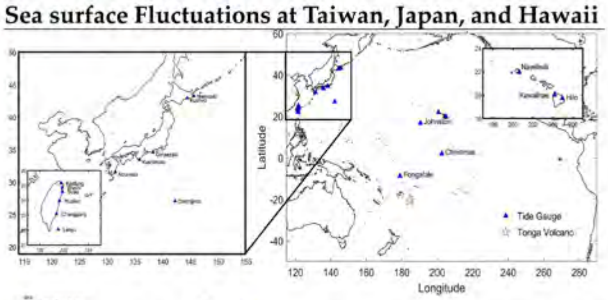
➢ **Figure 4.** rTEC-time-distance of the world on 15 January 2022. rTEC stands for the TEC time rate of changes. The time is in UT (hr). The distance is the ionospheric pierce point to the Volcano. The black line denotes the intense eruptions of the Tonga Volcano at 04:15 UT. Red lines stand for the atmospheric shock waves, sonic booms, and tsunami waves traveling with 750, 345, and 200 m/s, respectively.

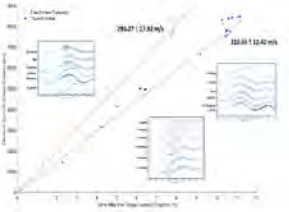
The Beamforming Technique Detections



➢ **Figure 5.** The beam-forming technique is applied on rTECs within 4000 km from the volcano to search the origin/source of the atmospheric shock waves, sonic booms, and tsunami waves as well as find the associated horizontal traveling speeds. The eruption time at 04:10UT would yield the best results (i.e., the smallest STDs) that the averaged speeds of the atmospheric shock waves, sonic booms, and tsunami waves are 688.0, 334.8, and 212.9 m/s, respectively. The red star denotes the volcano location, and the cross represents the computed origin/source locations.

Sea surface Fluctuations at Taiwan, Japan, and Hawaii





➢ **Figure 6.** Locations of buoys and tide gages at Taiwan, Japan, and Hawaii (top panels). The arrival times of the free surface fluctuations and tsunami waves versus the distance to the volcano after the eruption at 04:15 UT. The horizontal speeds of the free surface fluctuations and tsunami waves are 300 and 210 m/s, respectively (lower panel).

Discussion

- **The TIDs induced by the Tonga volcano eruption are rather various and very complex. The shock/blast waves, sonic booms, and tsunami in the STIDs travel with averaged horizontal speeds of about 750, 345, and 200 m/s, respectively.**
- **The shock/blast waves make the other waves being difficultly identified. Therefore, for the onset times of the Beamforming technique have to be offset at 06:10 and 08:15 UT for the sonic booms/pressure disturbances and tsunami waves, respectively.**
- **The computed and observed location of the Tonga volcano are nearly identical, which confirm that the shock waves, atmospheric disturbances, and tsunami waves can be triggered by the volcano eruptions.**
- **Himawari-8 images observed that the atmospheric pressure disturbances triggered by the Tonga Volcano eruption travel with about 350 m/s allover the world.**
- **Records of the buoys and tide gages show that the free sea surface fluctuations lead the tsunami waves, which suggests the atmospheric pressure disturbances might also disturb the sea surface. It seems that the shock waves do not induce sea surface fluctuation. The speed of the free sea surface fluctuation is smaller than that of the atmospheric disturbances.**
- **This preliminary result shows that the ionospheric tsunami warning system is useful.**

Reference

Liu, J. Y., Lin, C. Y., Tsai, Y. L., Liu, T. C., Hattori, K., Sun, Y. Y., and Wu, T. R. (2019). Ionospheric GNSS Total Electron Content for Tsunami Warning. Journal of Earthquake and Tsunami, doi 10.1142/S1793431119410070.
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