MAPÚA UNIVERSITY

DEPARTMENT OF PHYSICS

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Observation of Electron Density Variations in the Ionosphere associated by the Tonga Volcano Eruption in 2022 over the Philippines using Global Navigation Satellite System

GELLA MAE J. FLORES, Dr. ERNEST P. MACALALAD

gmjflores@mymail.mapua.edu.ph epmacalalad@mapua.edu.ph

Space and Atmospheric Research Group

Department of Physics - Mapua University

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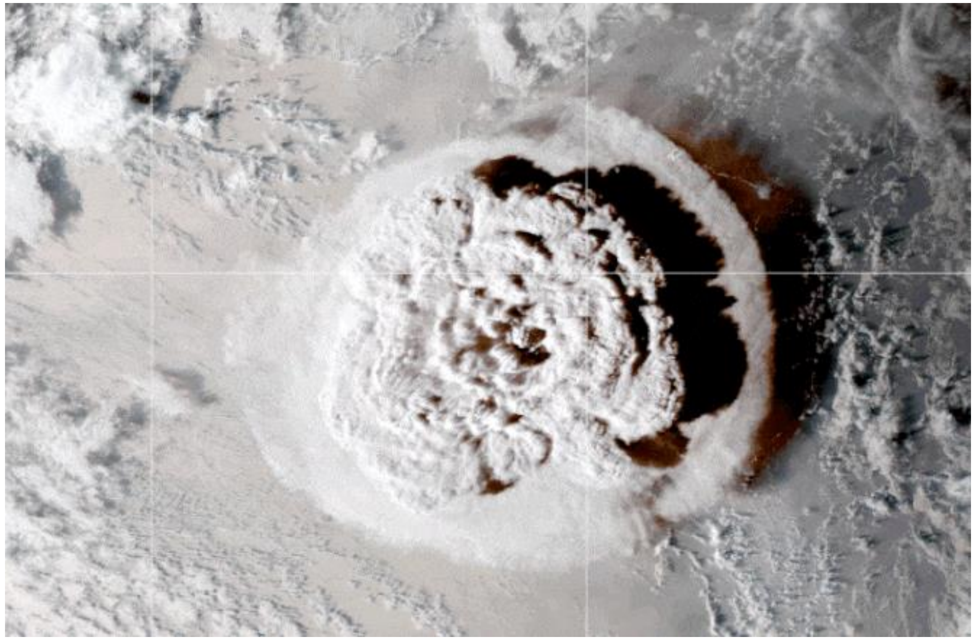
Hunga Tonga-Hunga Ha’apai Volcano eruption

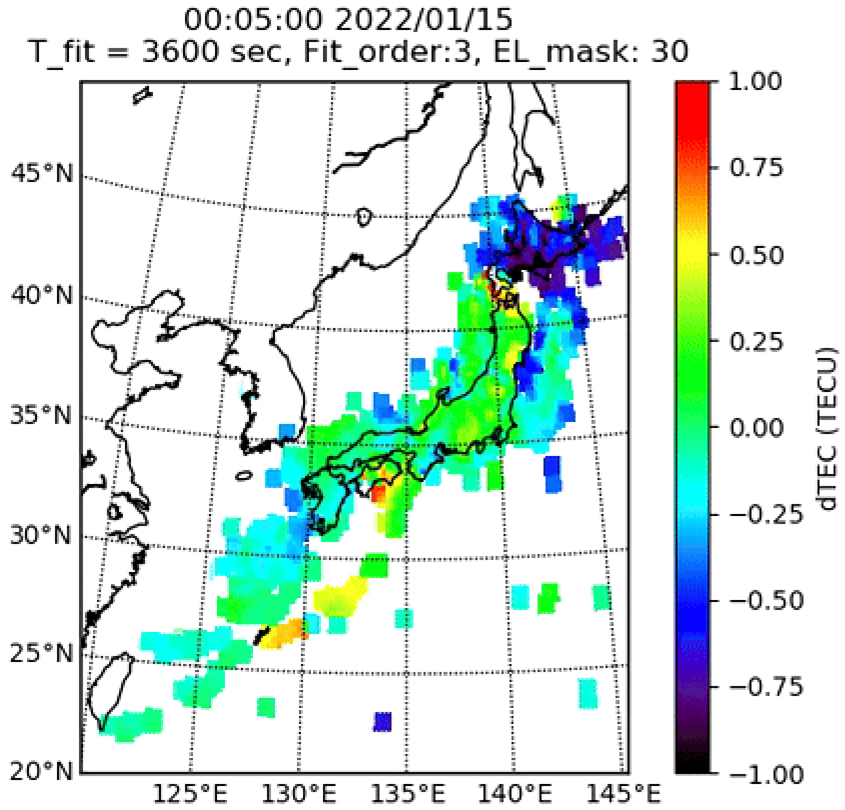
- January 15, 2022, at 04:15 UT
- a submarine volcano located in the Southwest Pacific (20.545° S 175.393° W)
- lies about 100 km (62 mi) above a very active seismic zone and rises around 2,000 m from the seafloor– roughly 150 m below sea level and 4 km at its widest extent
- Volcanic explosivity index (VEI) 5



https://eos.org/research-spotlights/tonga-eruption-made-waves-in-earths-ionosphere?fbclid=IwAR1Vdo0GXamp1nzrL7yFR7w9IJREKj4xTNzlm762pS0fKtu4L1_Dj70iDpU

Traveling Ionospheric Disturbances (TIDs)

- plasma density fluctuations that move as waves through the ionosphere
- Associated with auroral and geomagnetic activity.
- TIDs affect the performance of high-accuracy navigation systems and can cause problems in high precision differential Global Position System (GPS) applications



https://earth-planets-space.springeropen.com/articles/10.1186/s40623-022-01619-0

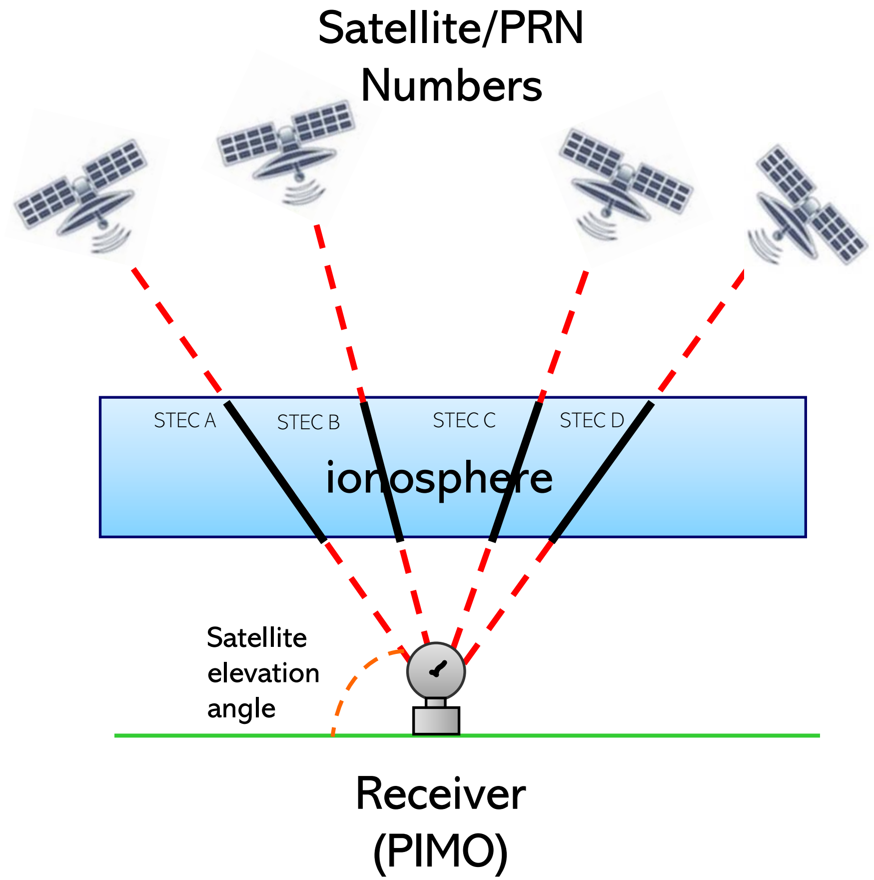
Total Electron Content (TEC)

- GNSS receivers use total electron content (TEC) to calculate the number of electrons along the line-of-sight (LOS).

$$1 \text{ TEC Unit (TECU)} = 10^{16} \text{ electrons/m}^2$$

$$Vertical\ TEC = Slant\ TEC\ (\cos\theta)$$

- Are strongly affected by solar activity.

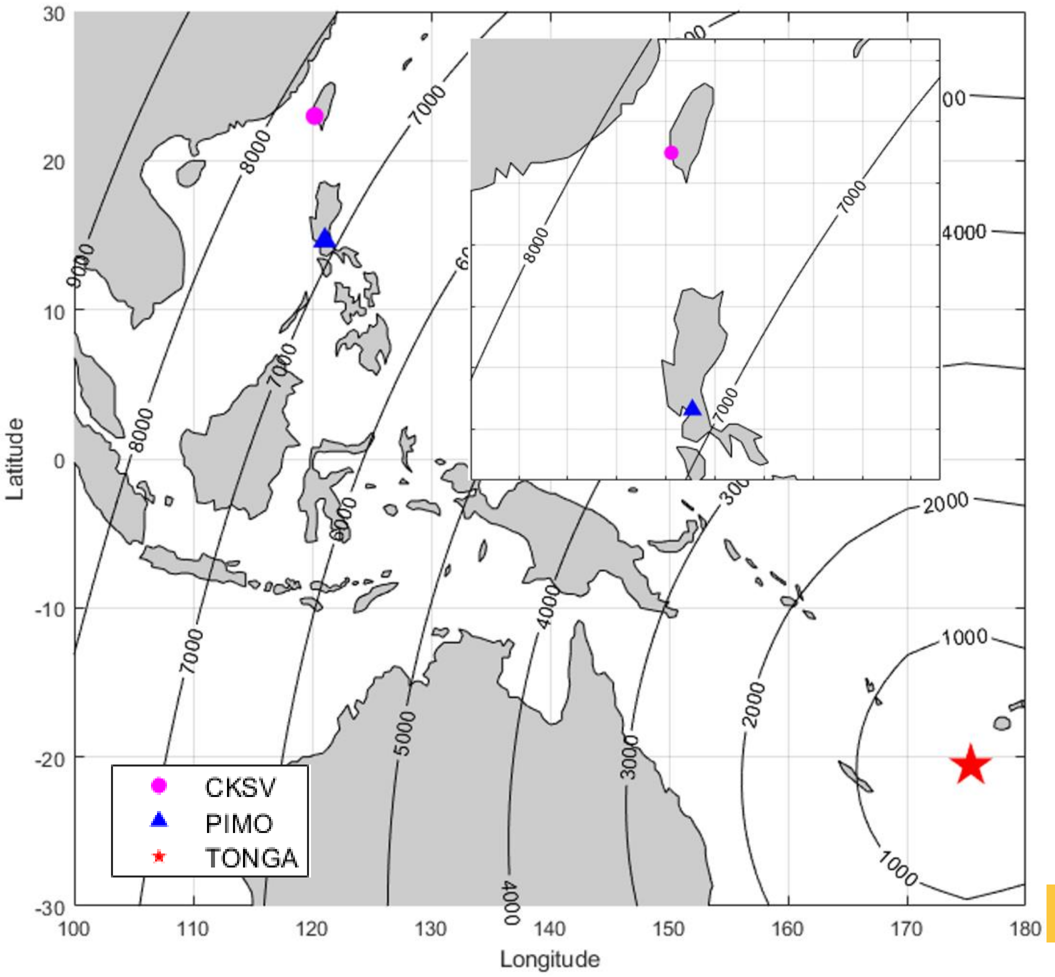


GNSS-TEC Technique

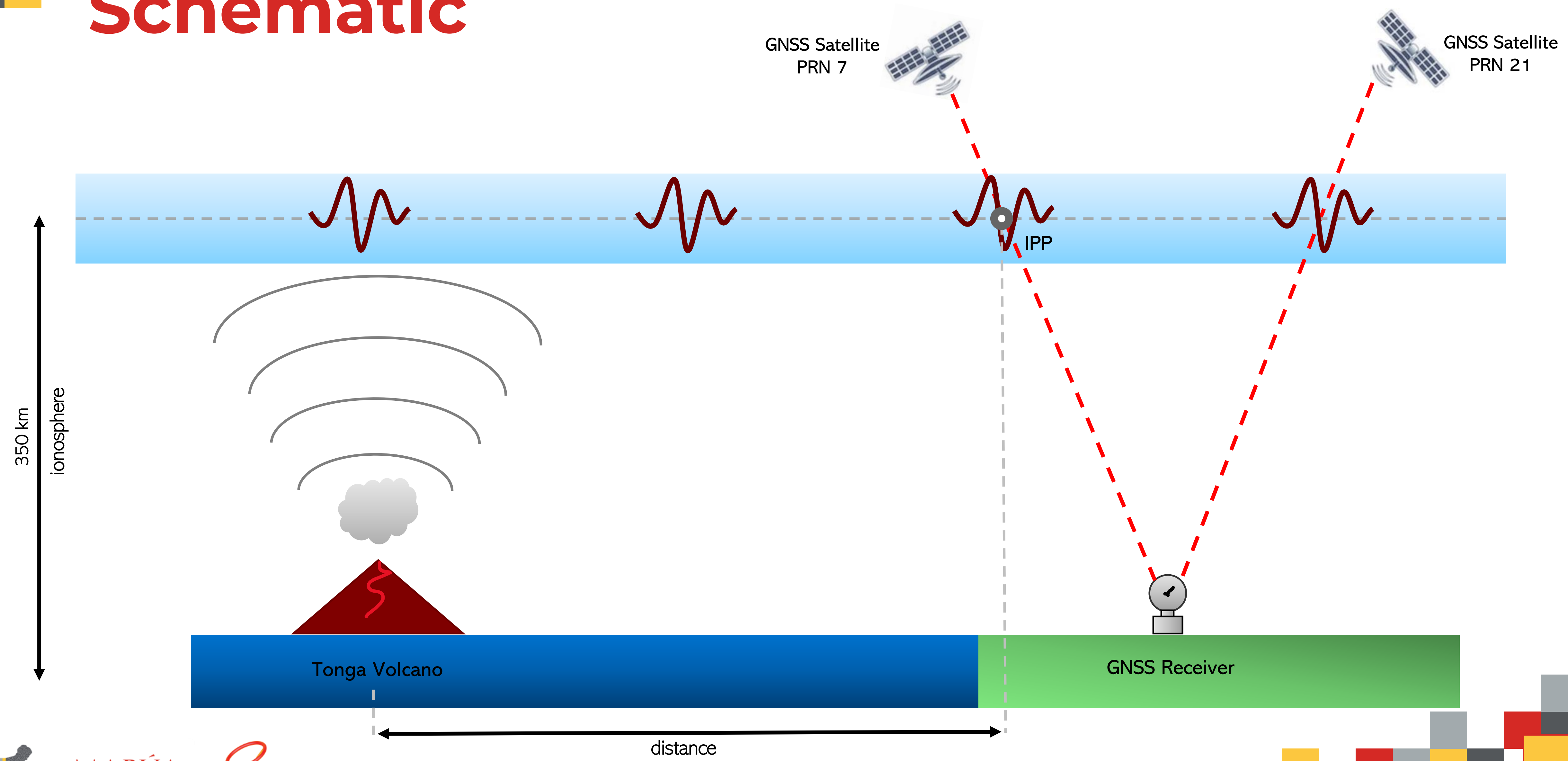
- Easier to detect ionospheric responses.
- Receiver-independent exchange (RINEX) raw data with 30-seconds
- PIMO station located in central Manila (14.5982° N 120.9727° E) and station CKSV from the Taiwan region

 (22.999° N 120.220° E)

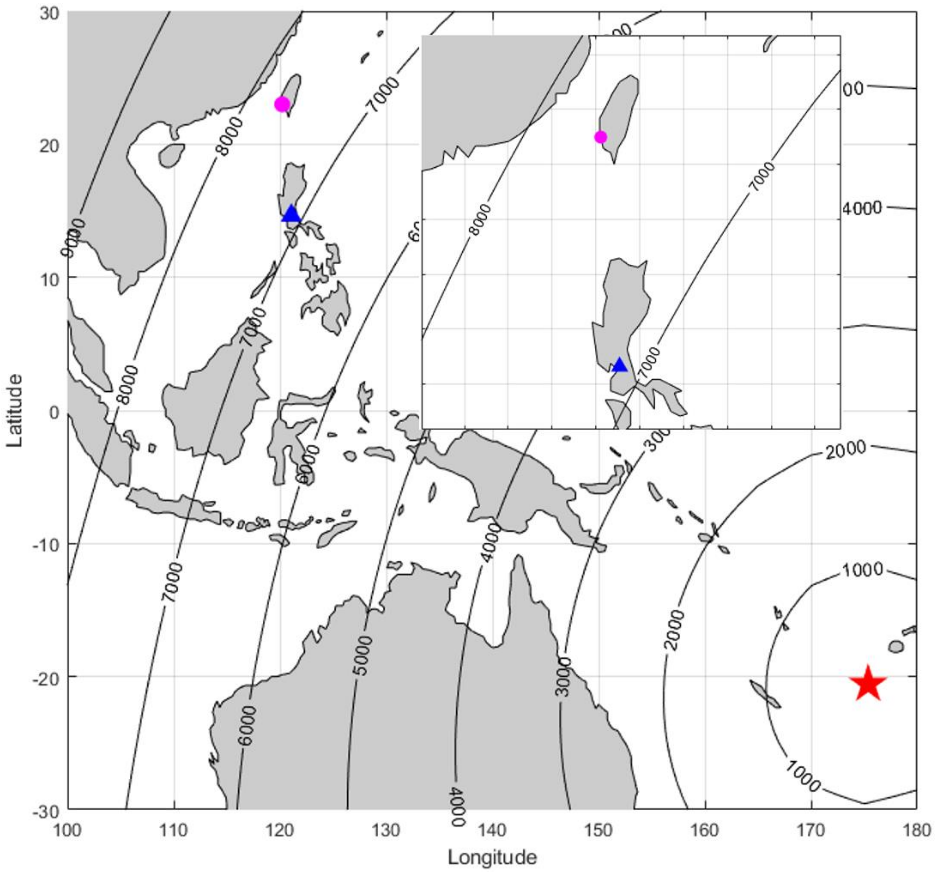
- Individual receiver-satellite TEC data

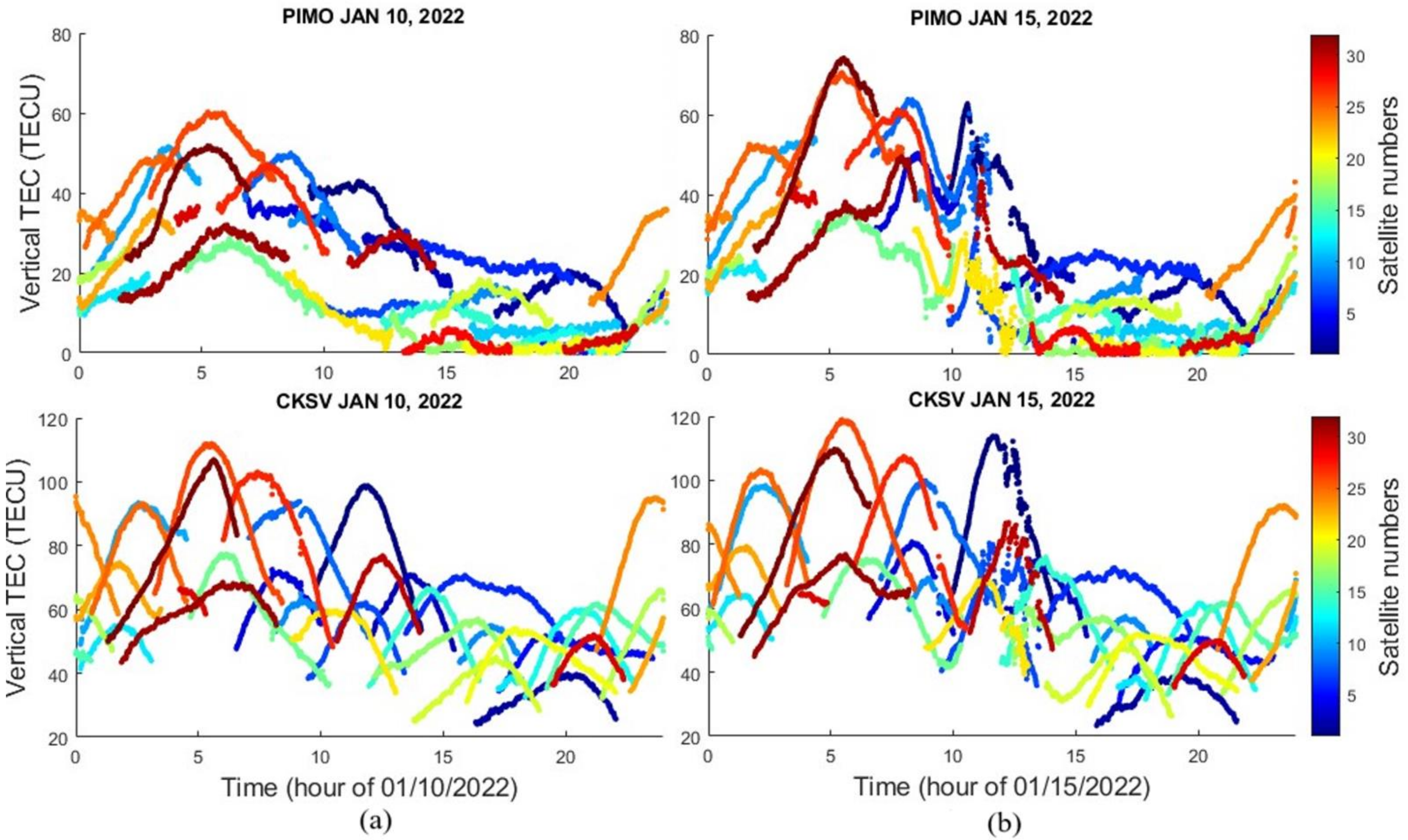


Schematic

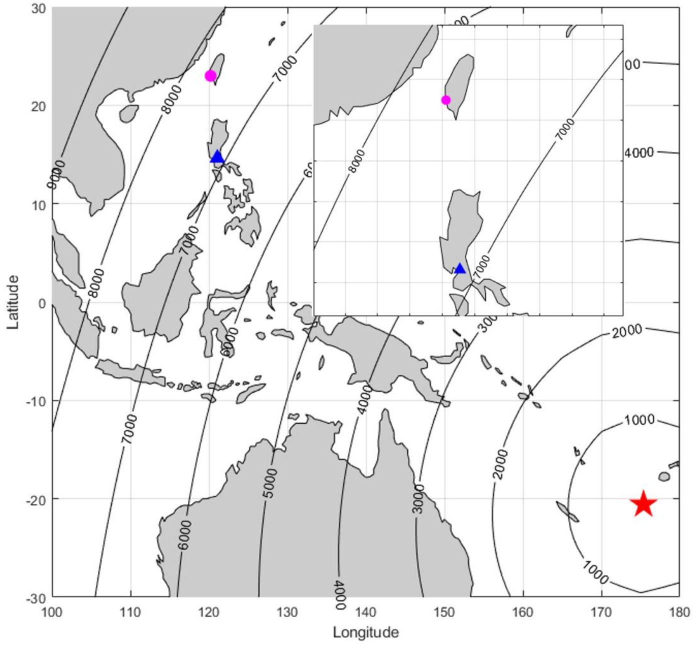


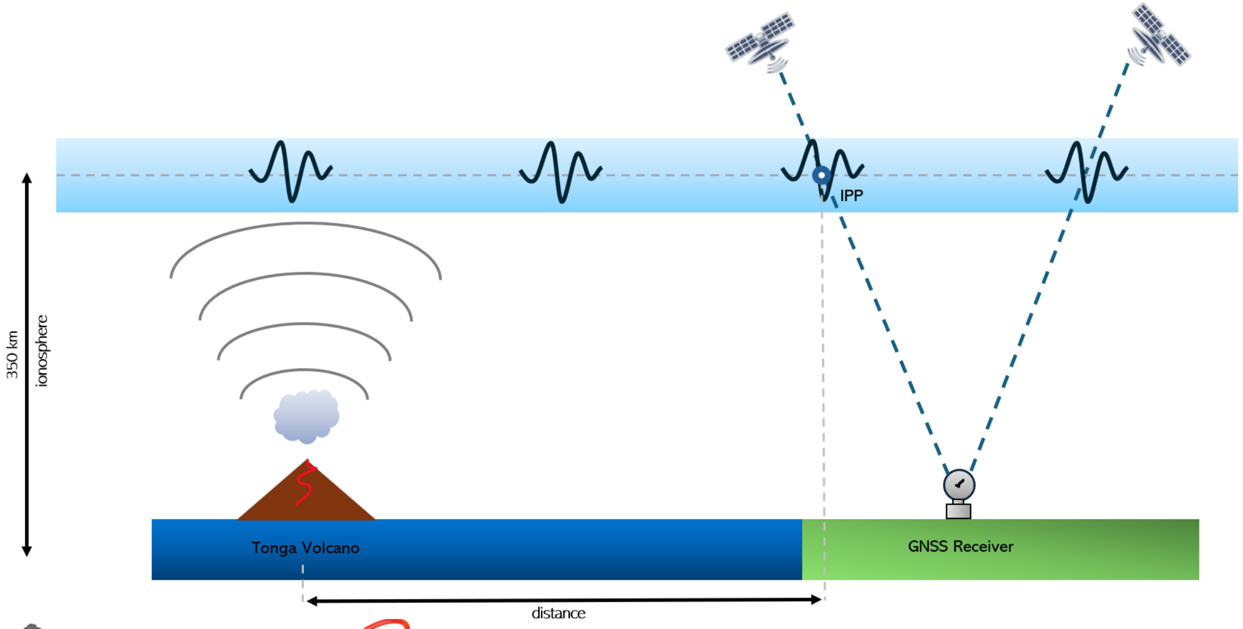
GNSS Satellite
PRN 7
GNSS Satellite
PRN 21
IPP
350 km
ionosphere
Tonga Volcano
GNSS Receiver
distance

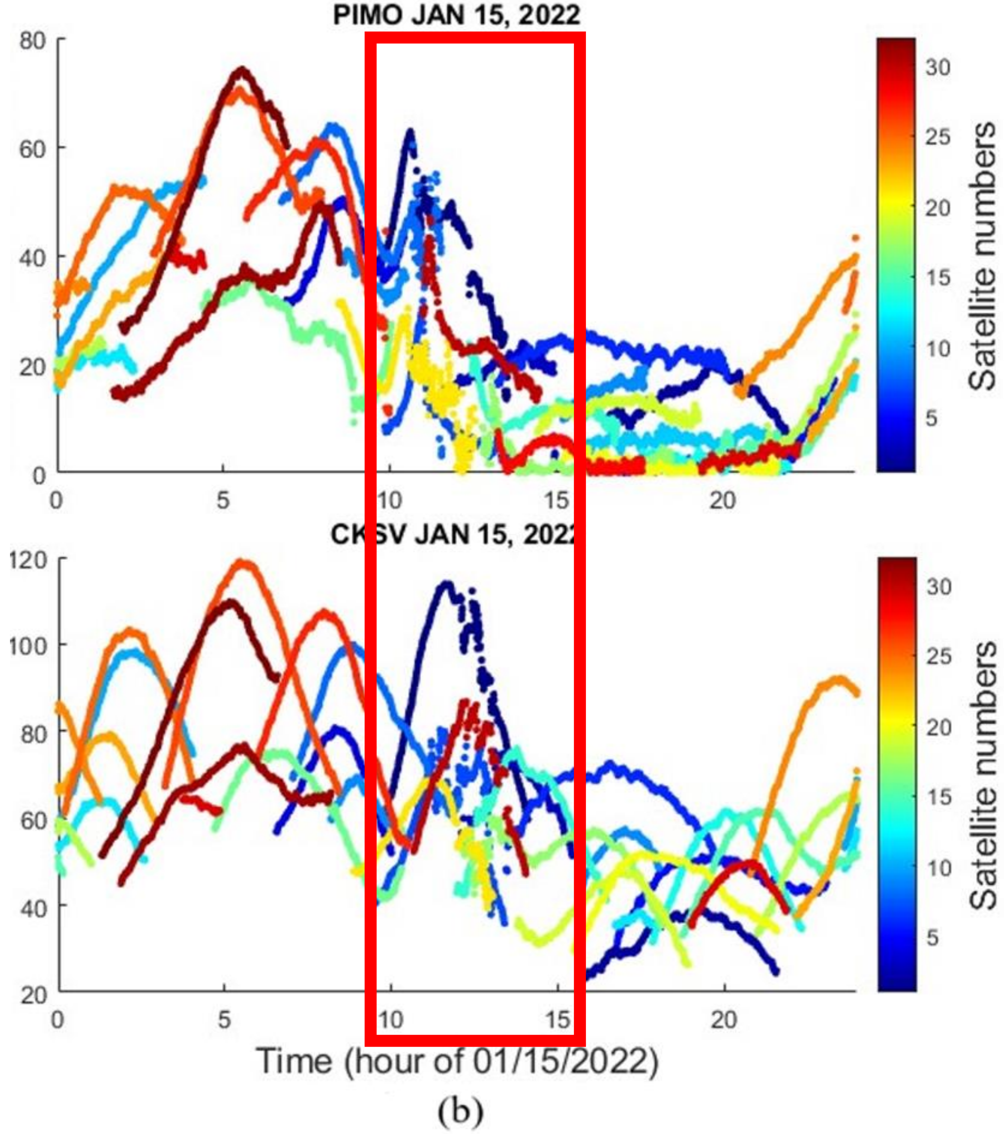


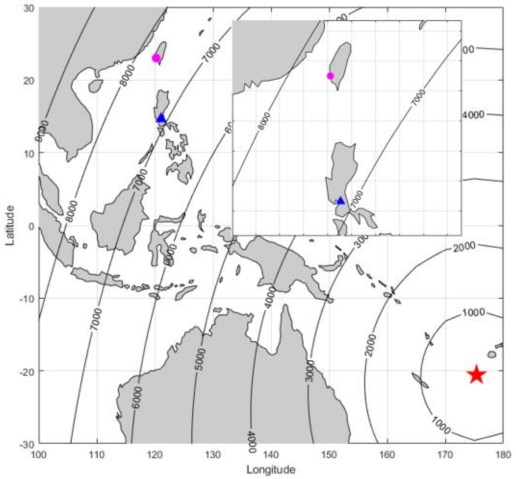


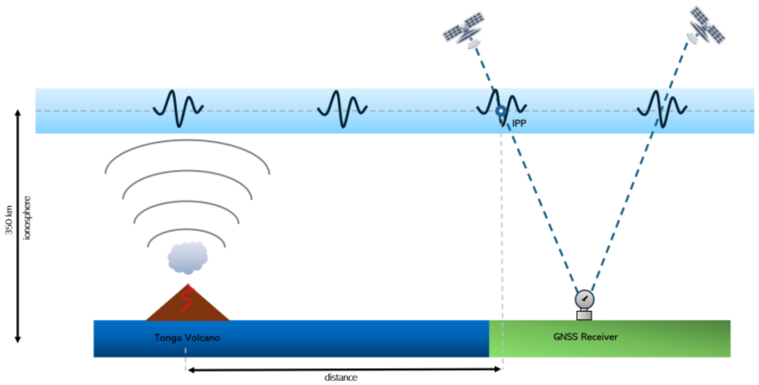
Time series of the relative Vertical TEC for all GPS satellites observed at PIMO (Philippines) and CKSV (Taiwan) on (a) 10 January 2022, a nominal day, and (b) 15 January 2022, a disturbed day.

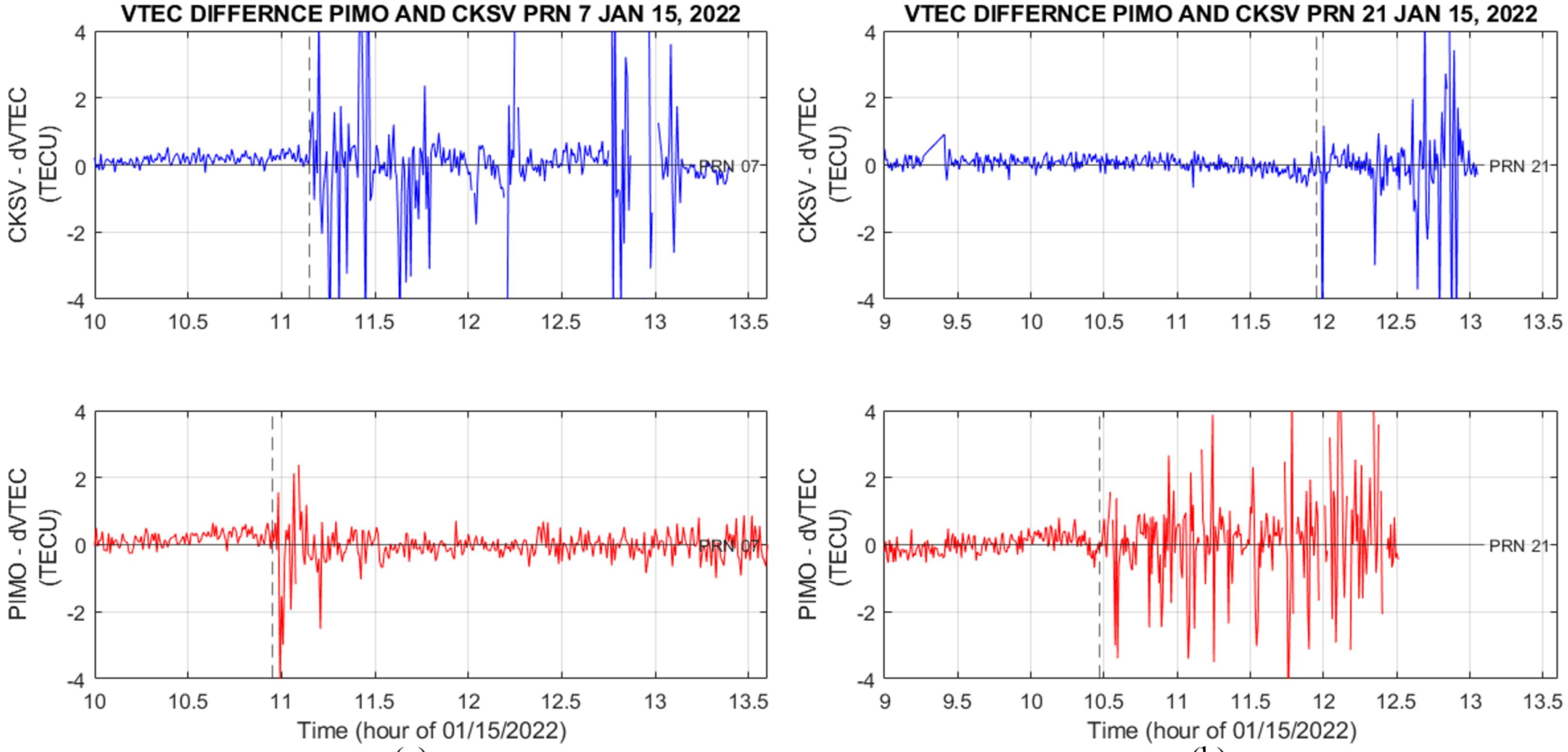

Latitude
Longitude


IPP
350 km
ionosphere
Tonga Volcano
GNSS Receiver
distance


PIMO JAN 15, 2022
CKSV JAN 15, 202
Satellite numbers
Time (hour of 01/15/2022)
(b)

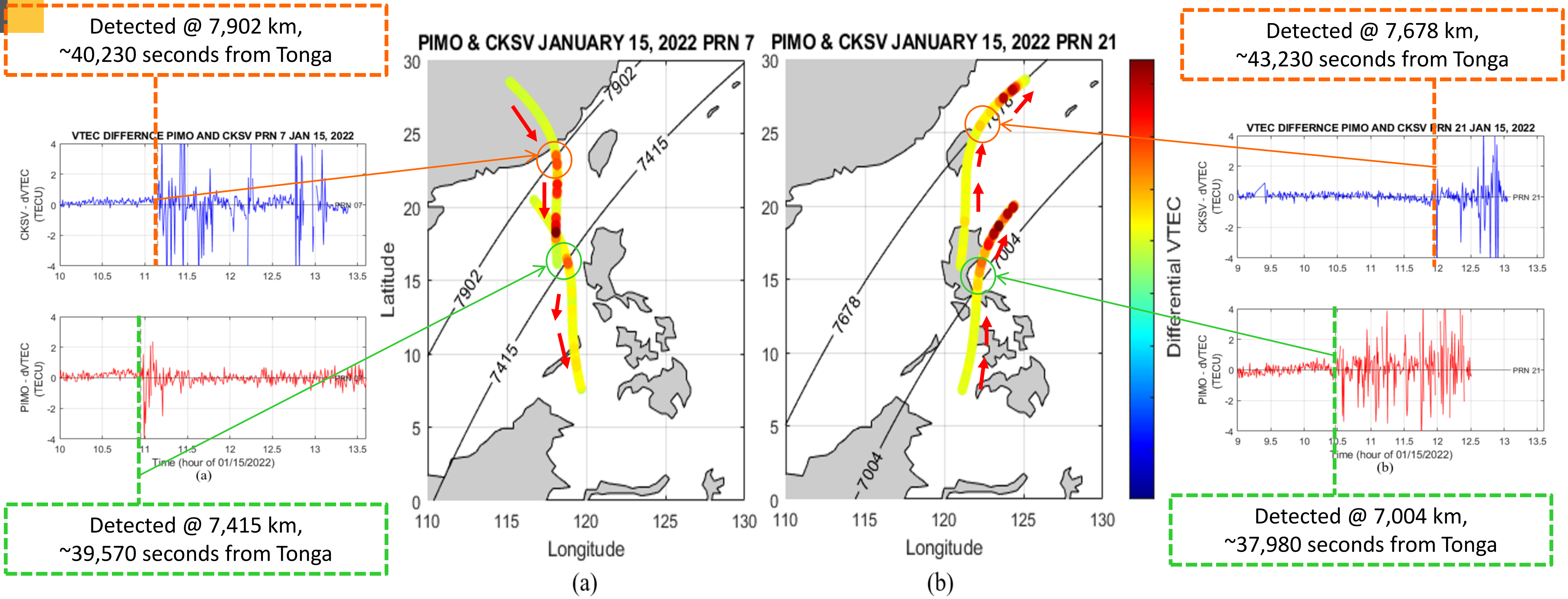






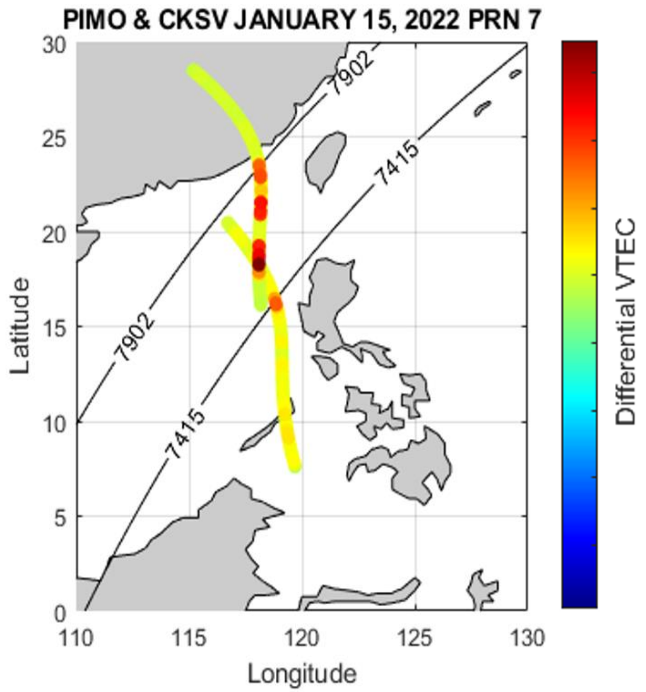
(a) (b)

Time series of Vertical TEC difference at PIMO (Philippines) and CKSV observed in PRN 07 and PRN 21, respectively.



Differential TEC at IPPs between receivers, PIMO and CKSV, and (a) PRN 7 and (b) PRN 21 on January 15, 2022.

Average Speed



	Time (s)	Latitude	Longitude	Distance (km) (from Tonga)	Average (km/s)
PIMO	39570	16.44416	118.7839	7415	0.305
CKSV	40230	23.5533	118.0914	7902	0.317

the computation of the average speed of PRN 07. Using the general speed formula s = distance/time (km/s). The average speed calculated is ~0.3km/s

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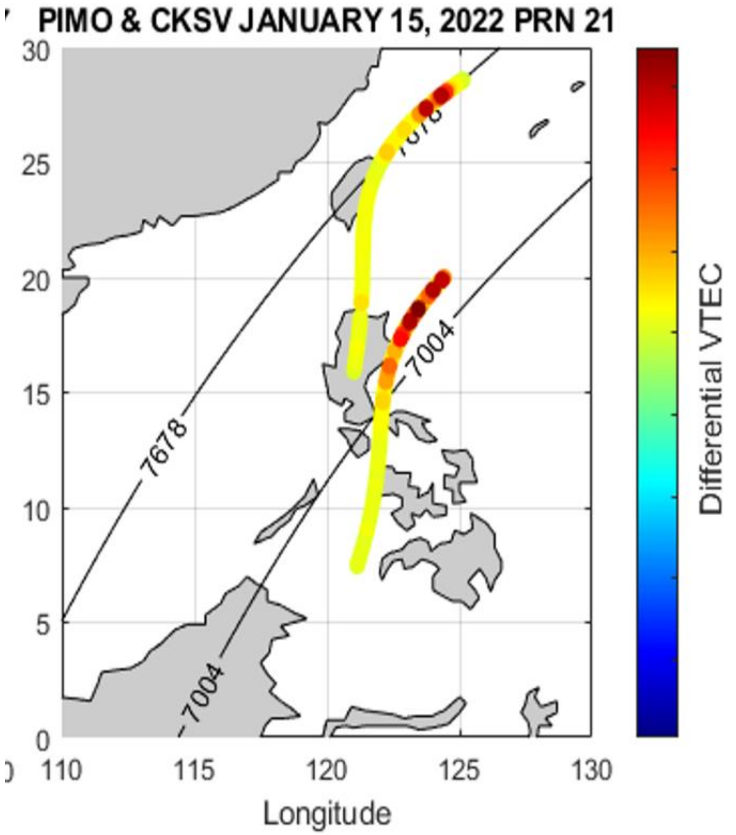
Average Speed



	Time (s)	Latitude	Longitude	Distance (km) (from Tonga)	Average (km/s)
PIMO	37980	14.59846	122.1065	7004	0.309
CKSV	43230	25.4476	122.2616	7678	0.273

Conclusion

- It was observed that the event triggered TIDs and has a consistent average speed of ~0.3km/s.
- TIDs with wavefronts traveling northwest that confirm that the atmospheric waves produced by the eruption are the same as previous studies.

Recommendation

- Additional work is needed to quantify the magnitude of the threat's likelihood of occurrence.
- Combining modelling with additional measurements like radio occultation could also improve the performance of the existing ionospheric anomaly monitoring.
- Maximizing the use of all GPS observation data from dense and widely distributed stations would help to better understand the regional behavior of the disturbance.

References

- Hocke, K.; Schlegel, S. A review of atmospheric gravity waves and travelling ionospheric disturbances.
- Earthquake Research Institute (2022) Volcanic activity of Hunga Tonga Hunga Ha'apai underwater volcano. www. eri.u- tokyo. ac. jp/ en/ news/ 4824/
- JJet Propulsion Laboratory (2022) Tonga eruption sent ripples through earth's ionosphere. www.jpl. nasa. gov/ news/ tonga-erupt ion- sent-ripples- throu ghearths-ionosphere
- Heki K (2021) Chapter 21: Ionospheric Disturbances Related to Earthquakes in Ionospheric Dynamics and Applications. Geophysical Monograph 260
- Shults K, Astafyeva E, Adourian S (2016) Ionospheric detection and localization of volcano eruptions on the example of the April 2015 Calbuco events. J Geophys Res Space Phys 121:10303–10315
- Orús, R.; Hernández-Pajares, M.; Juan, J.M.; Sanz, J. Improvement of Global Ionospheric VTEC Maps by Using Kriging Interpolation Technique. J. Atmos. Sol. Terr. Phys. 2005, 67, 1598–1609.
- Gurtner,W.; Estey, L. RINEX: The Receiver Independent Exchange Format, version 2.11; UNAVCO: Boulder, CO, USA, 2007.
- Muafiry, I.N.; Heki, K.; Maeda, J. 3D tomography of midlatitude sporadic-E in Japan from GNSS-TEC data. Earth Planets Space 2018, 70, 45.
- Saito, A., Fukao, S., and Miyazaki, S. (1998). High Resolution Mapping of TEC Perturba-tions with the GSI GPS Network over Japan. Geophys. Res. Lett. 25, 3079–3082. doi:10.1029/98GL52361
- Misra, P., and P. Enge (2006), Global Positioning Systems: Signals, Measurement, and Performance, 2nd ed., Gang0Jamuna, Lincoln, MA.

- Mendoza, M.M.; Juadines, K.E.S.; Macalalad, E.P.; Tung-Yuan, H. A Method in Determining Ionospheric Total Electron Content Using GNSS Data for Non-IGS Receiver Stations. In Proceedings of the 2019 6th International Conference on Space Science and Communication (IconSpace), Johor Bahru, Malaysia, 28–30 July 2019; pp. 186–191.
- Kasuke Heki (2022), Ionospheric signatures of repeated passages of atmospheric waves by the 2022 Jan 15 Tonga eruption detected by QZSS-TEC observations in Japan.
- Sahai, Y., et al. (2009), Effects observed in the ionospheric F region in the east Asian sector during the intense geomagnetic disturbances in the early part of November 2004,
- Saito, A.,M. Nishimura,M. Yamamoto,S. Fukao,T. Tsugawa,Y. Otsuka,S. Miyazaki, and M. C. Kelley (2002),Observations of traveling ionospheric disturbances and 3-m scale irregularities in the nighttime F-region ionosphere with the MU radar and a GPS network, Earth Planets Space
- Lanese, N. (2022, June 30). Record-breaking Tonga volcano generated the fastest atmospheric waves ever seen.
- Heki, K. (2022, July 20). Ionospheric signatures of repeated passages of atmospheric waves by the 2022 Jan. 15 Hunga Tonga-Hunga Ha'apai eruption detected by QZSS-TEC observations in Japan earth, planets and space.
- Inchin, P. A., Snively, J. B., Zettergren, M. D., Komjathy, A., Verkhoglyadova, O. P., & Tulasi Ram, S. (2020). Modeling of ionospheric responses to atmospheric acoustic and gravity
- Tsugawa, T., Otsuka, Y., Coster, A. J., and Saito, A. (2007). Medium-scale Traveling Ionospheric Disturbances Detected with Dense and Wide TEC Maps over North America. Geophys. Res. Lett. 34, L22101. doi:10.1029/2007GL031663
- Symons, G. J. (1888). The Eruption of Krakatoa, and Subsequent Phenomena: Report of the Krakatoa Committee of the Royal Society. Wiley Online Library.