Traveling Ionospheric Disturbances Induced by the 2022 Hunga Tonga–Hunga Ha'apai Volcano Eruption: Observation and Simulation

COUP-11

Tien-Chi Liu[1,2], Cissi Y. Lin[1,2], Tiger J.Y. Liu[1,2], Po-Han Lee[1], and Chi-Yen Lin[1,2]

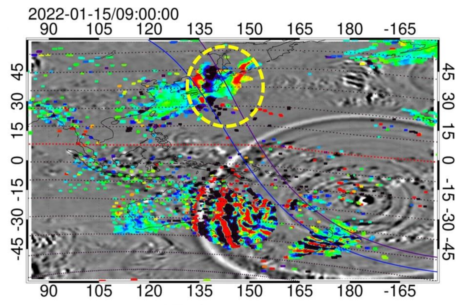
1 Department of Space Science and Engineering, National Central University, Taiwan; 2 Center for Astronautical Physics and Engineering, National Central University, Taiwan

Introduction & Motivation

Introduction

- On 15 January 2022, the Hunga Tonga–Hunga Ha'apai (HTHH) submarine volcano (20.54° S, 175.38° W) erupted violently.
- The eruption generated atmospheric pressure disturbances that propagated in the form of Lamb waves, which have been detected globally along with the associated oscillations (Wright et al., 2022).
- The volcanic eruption induces traveling atmospheric disturbances (TADs) near the Earth's surface and traveling ionospheric disturbances (TIDs) in the upper atmosphere.

Motivation


(Shinbori et al., 2022)

- TADs and TIDs
  - Instruments observing different altitudes.
- TIDs are observed before TADs
  - The early arrival could be contributed by electromagnetic conjugacy (Lin et al., 2022; Shinbori et al., 2022).
  - Conduct numerical simulations to study the direct impact of the global propagation TAD front.

Data & Model

Data

Himawari-8
λ = 6.2 µm infrared band (res: 2 km; 10 min)

Ionosonde
Japan (Wakkanai, Tokyo, Yamagawa and Okinawa)
Taiwan (Xinwu)

Doppler Sounding Radar
Liyutan Dam, Taiwan

Barometer
Air pressure data from JMA and NCU

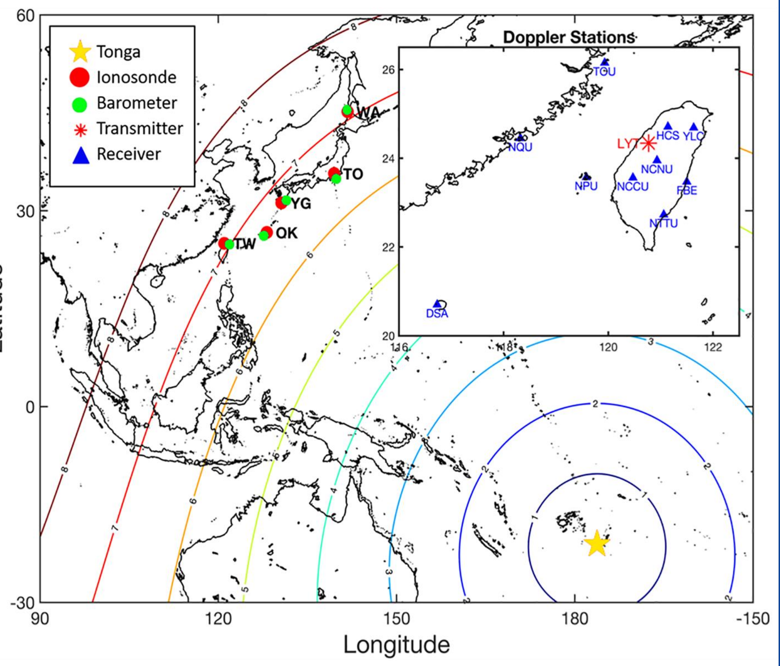
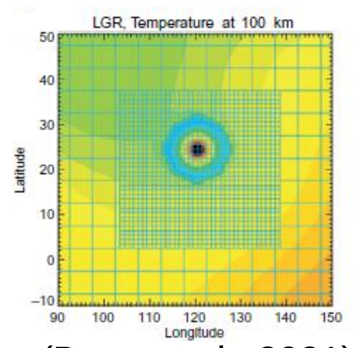


Fig 1. Locations of the Tonga volcano and observing instruments. Colored curves stand for the travel time of TADs in Himawari-8 images.

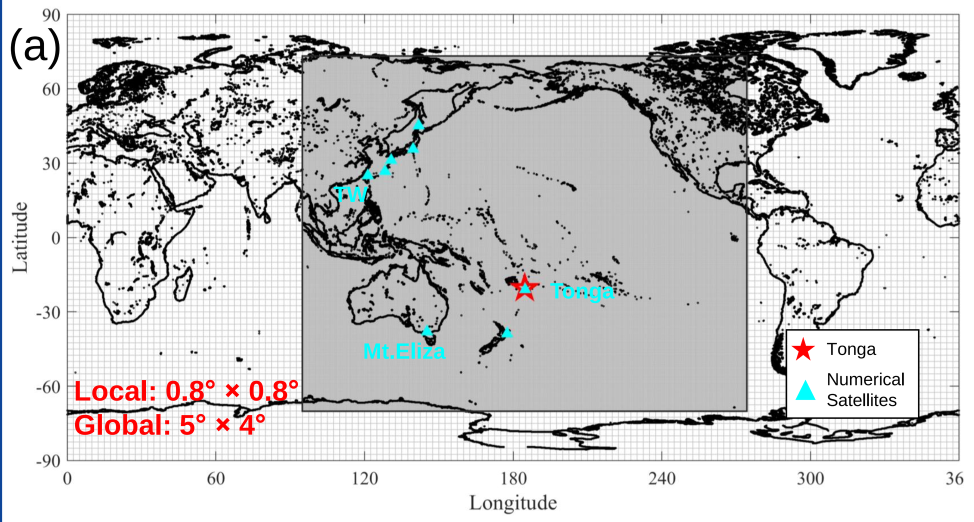
Model

GITM-R

- GITM: Global Ionosphere Thermosphere Model
  3D parallel, spherical code that models the I-T system (Ridley et al., 2006)
  Flexible resolution in both Lon and Lat; Allows non-hydrostatic solutions.
- Local-Mesh Refinement Technique
  Practical for simulating mesoscale phenomena (Deng et al., 2021)



(Deng et al., 2021)

(a)


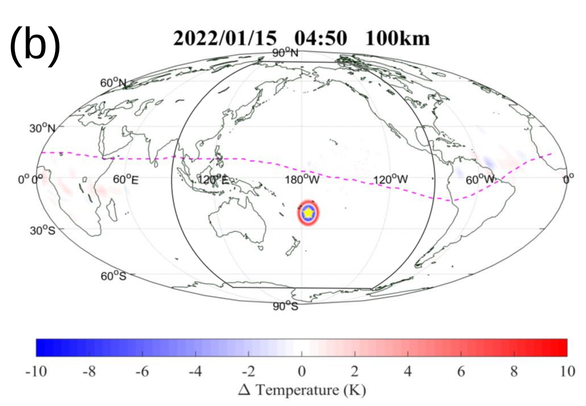
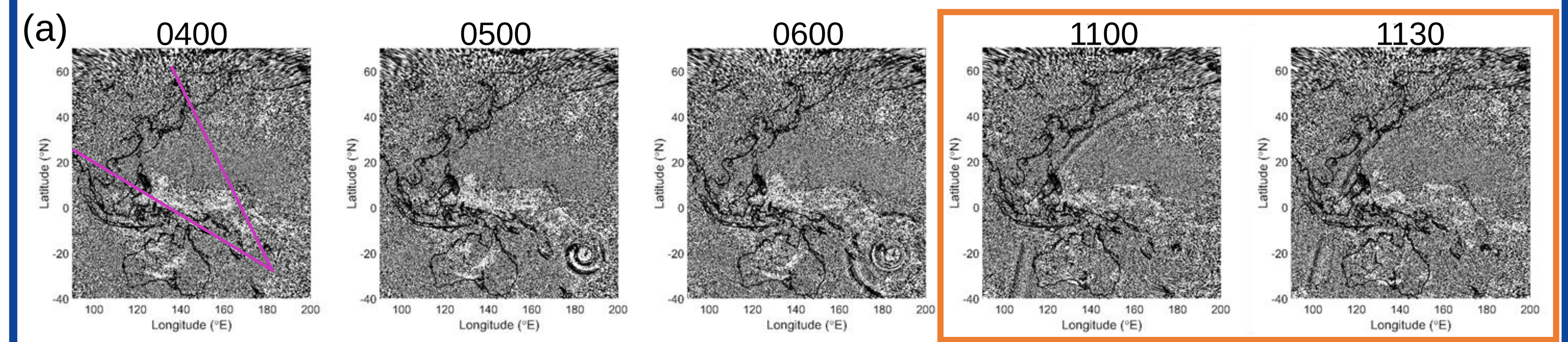
(b)


Fig 2. GITM-R (a) simulation domain and (b) perturbation at the lower boundary.

Himawari-8



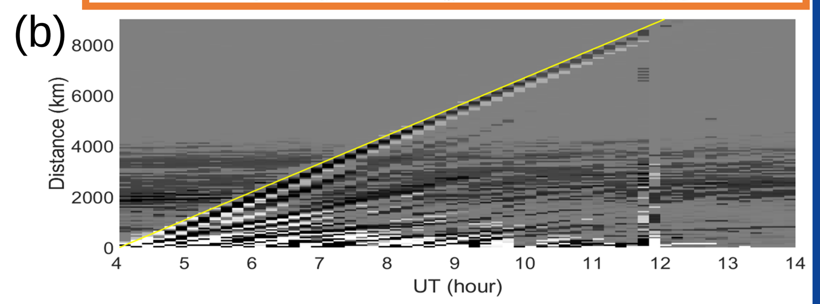


Fig 3. Himawari-8 satellite (a) images on 15 January 2022 and (b) TAD front speed. Images within magenta lines are used to compute the speed of the TAD front.

TADs arrival: JP (11:10) TW (11:40)

310 m/s, λ= 580 km

Horizontal Speed of TADs and TIDs

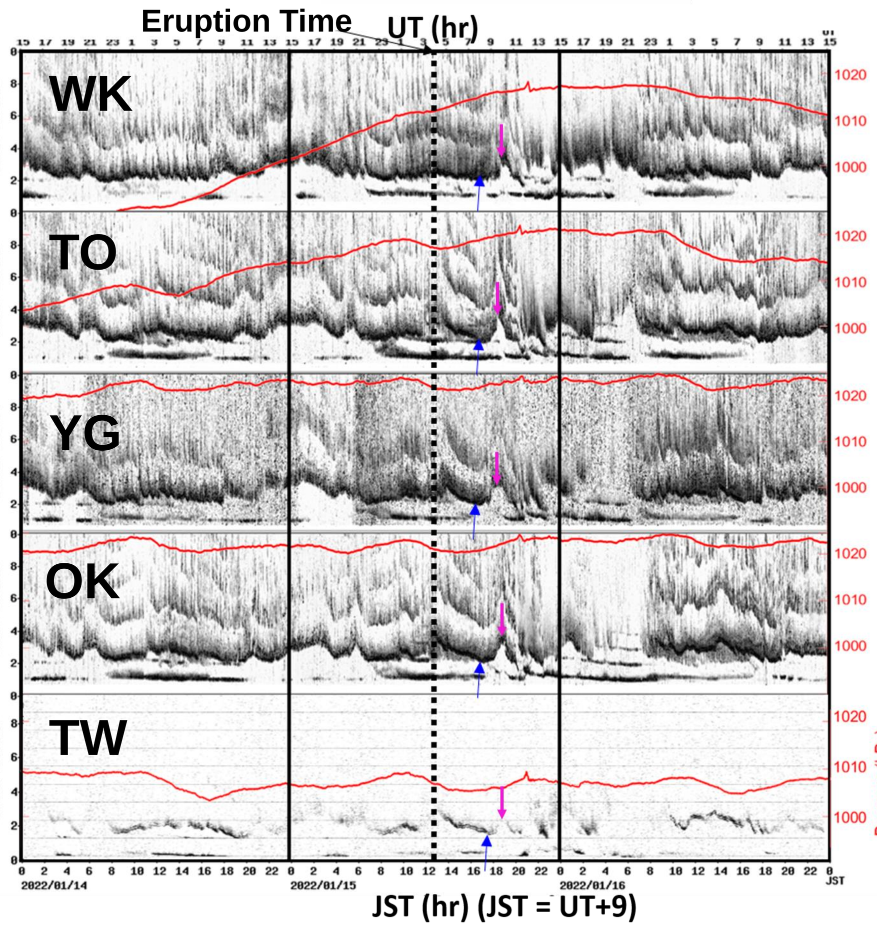


Fig 4. Compressed ionograms and co-located ground pressures in JP and TW.

Ionograms Arrival: 4 hrs
Ionograms Peak: 5.5 hrs
Air Pressure: 7.5 hrs
(after the volcanic eruption)

TIDs are observed before TADs

Averaged Horizontal Speeds

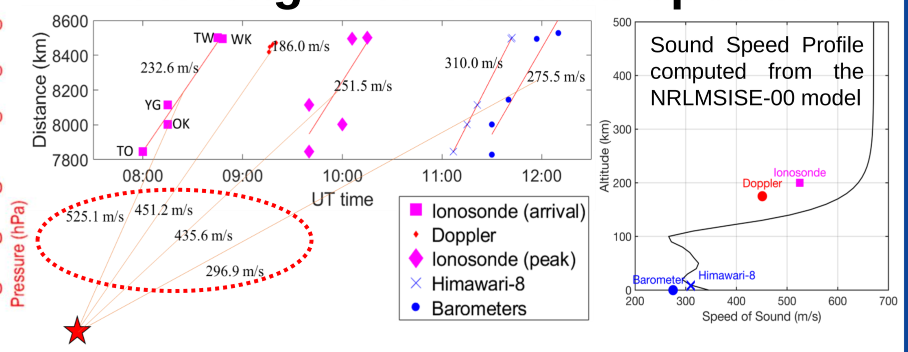


Fig 5. The horizontal speeds of the ionosondes, Doppler sounding systems, Himawari-8, and air pressure data.

GITM-R Simulation

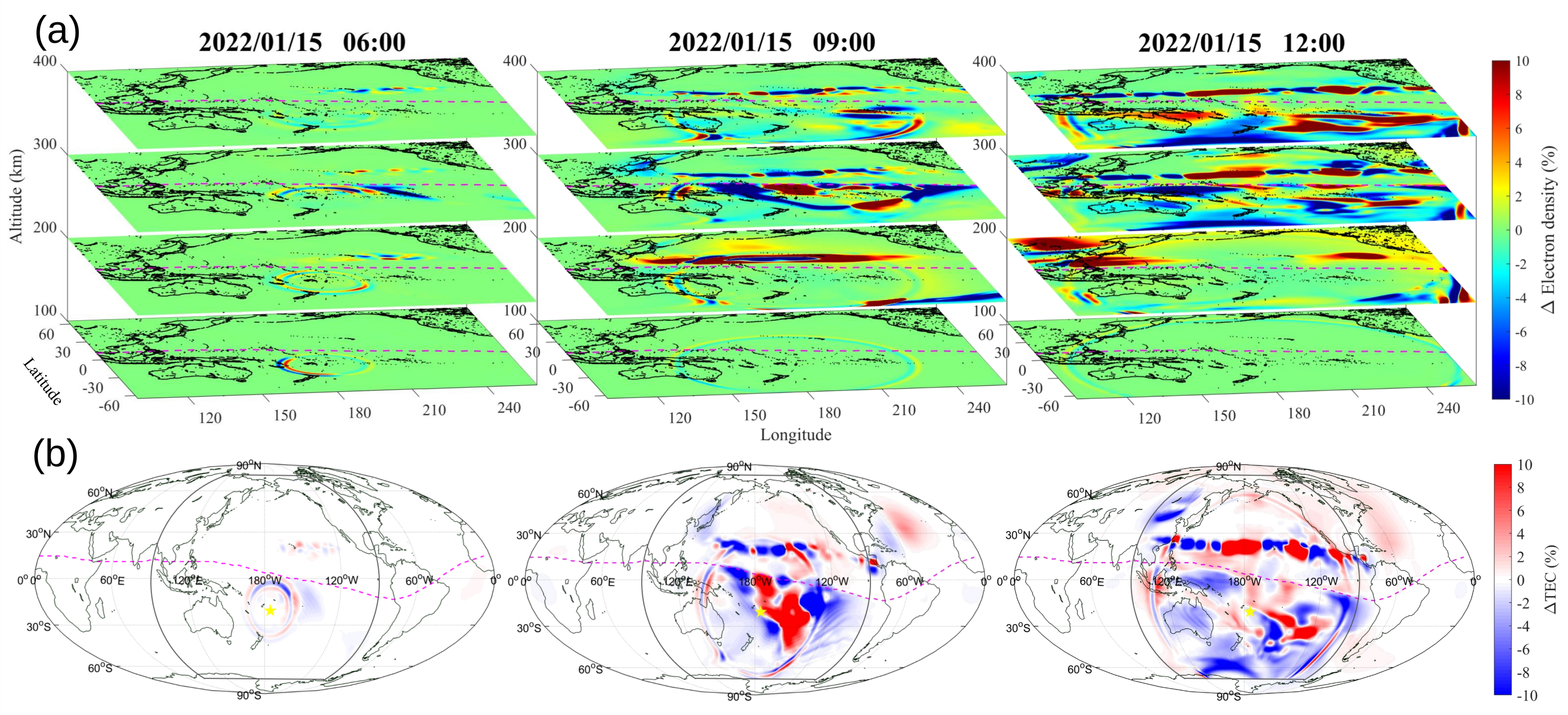
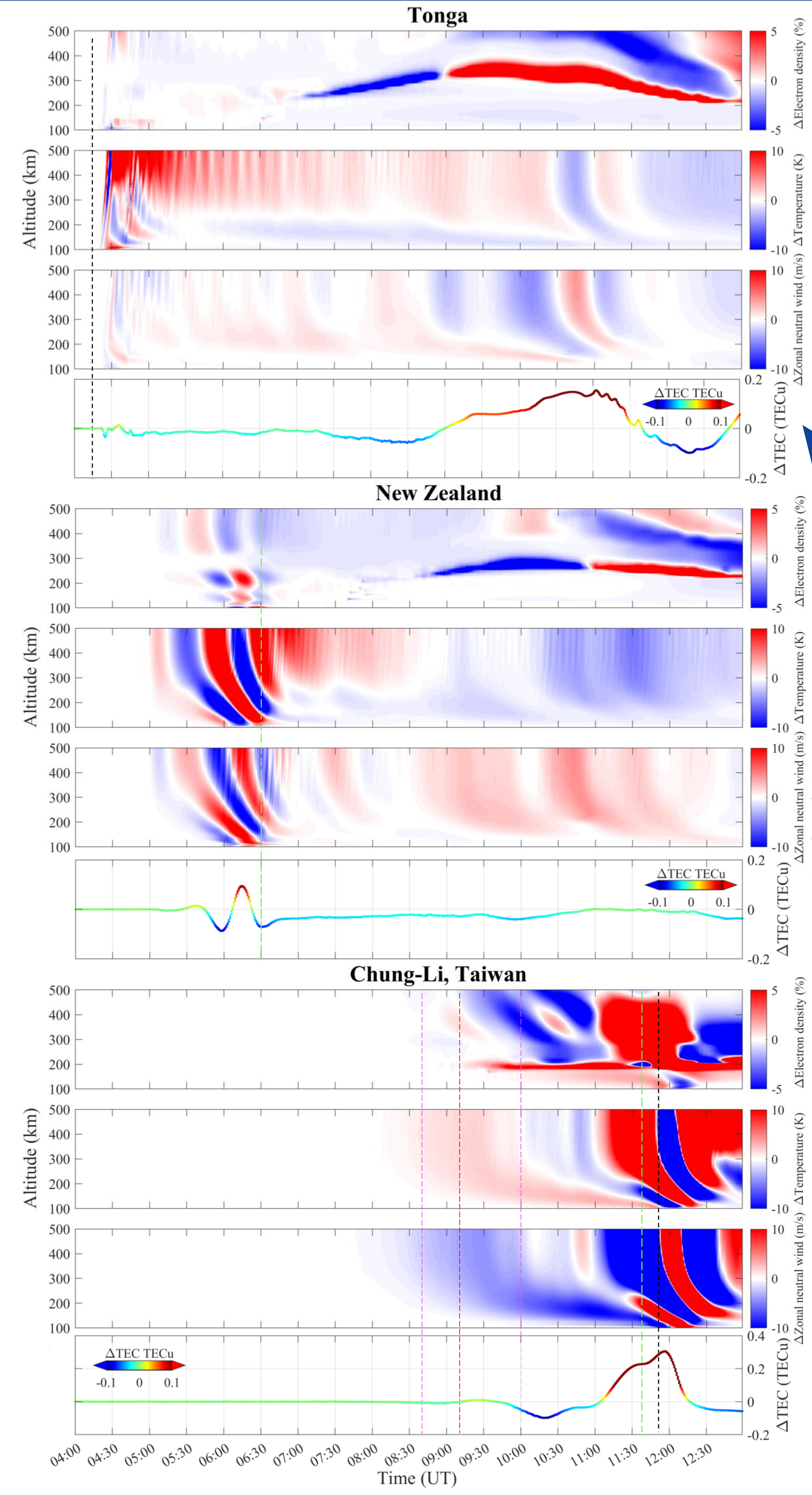


Fig 6. Snapshots of simulated (a) electron density variation and (b) dTEC (%).

Electron density depletion appears after ionospheric perturbation (15-40°S, 160-200°E and along Mag equator, 150-180°E)

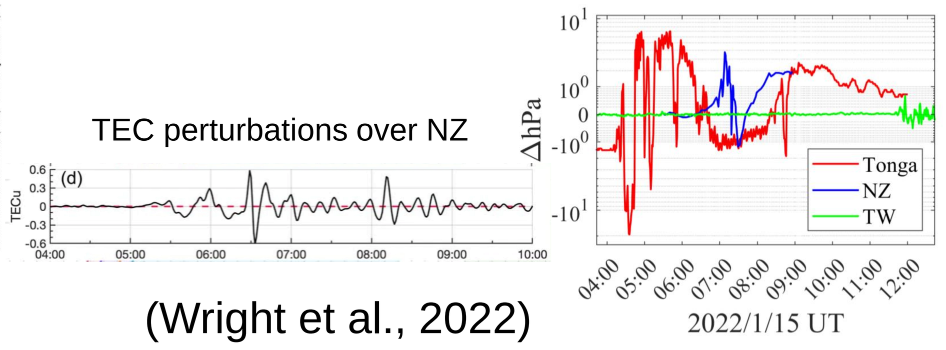
Numerical Satellite Records



- Acoustic - Gravity Waves Near Tonga

Pre-reversal enhancement
Electron Density Depletion

TIDs at higher altitudes are ahead of the lower ones



(Wright et al., 2022)

TEC variation's arrival is in advance of air pressure.

TW: about 3 hr

Fig 7. Variations of electron density, temperature, zonal neutral wind, and TEC recorded near Tonga, Mt. Eliza in Australia, and Taiwan.

Conclusion

Data

- Horizontal TAD speeds: Himawari-8 images: 310 m/s; Air pressure: 297 m/s
- Horizontal TID speeds: Doppler sounding systems: 451 m/s; Ionosondes: 525 m/s
- TID arrival times show differences from the conjugated wave direction.

Simulation

- Electron density depletion
- TIDs at higher altitudes arrive earlier than the lower ones.
- Simulated TIDs lead the observed TAD for about 2-3 hrs.

References

Deng, Yue, et al. "Electric field variability and impact on the ionosphere-thermosphere." Cross-scale Coupling and Energy Transfer in The Magnetosphere-Ionosphere-Thermosphere System, edited by Yukitoshi Nishimura, et al., Elsevier, 2022, pp. 17-33.

Lin, Jia-Ting, et al. "Rapid conjugate appearance of the giant ionospheric Lamb Wave signatures in the Northern Hemisphere after Hunga-Tonga Volcano eruptions." Geophysical Research Letters 49.8 (2022): e2022GL098222.

Ridley, A. J., Yue Deng, and G. Toth. "The global ionosphere–thermosphere model." Journal of Atmospheric and Solar-Terrestrial Physics 68.8 (2006): 839-864.

Shinbori, Atsuki, et al. "Electromagnetic conjugacy of ionospheric disturbances after the 2022 Hunga Tonga-Hunga Ha'apai volcanic eruption as seen in GNSS-TEC and SuperDARN Hokkaido pair of radars observations." Earth, Planets and Space 74.1 (2022): 1-17.

Wright, Corwin J., et al. "Surface-to-space atmospheric waves from Hunga Tonga–Hunga Ha'apai eruption." Nature 609.7928 (2022): 741-746.

Acknowledgment

This project is supported by the National Science and Technology Council (MOST110-2111-M-008-034-MY2; MOST111-2111-M008-018).