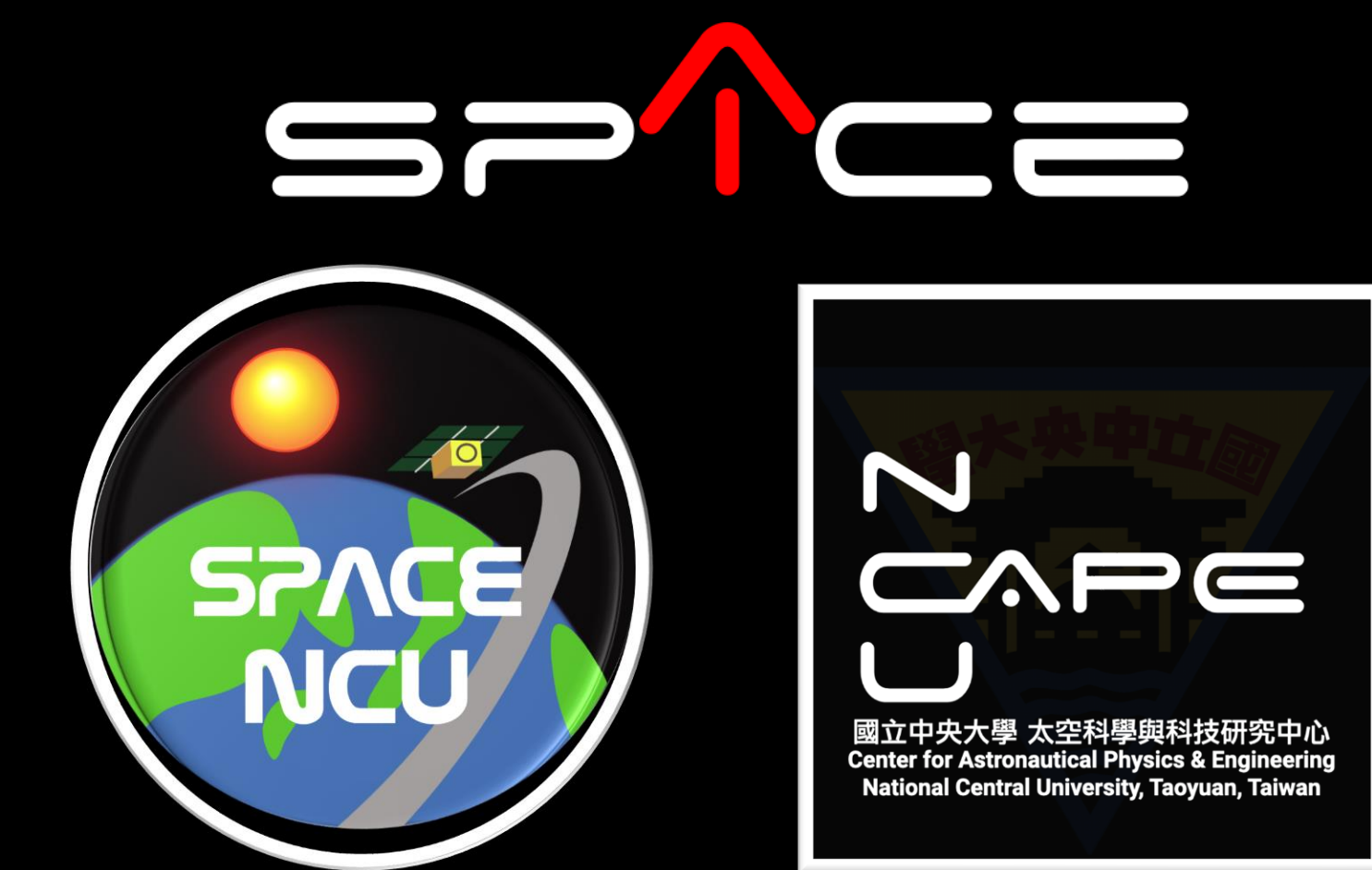




Traveling Ionospheric Disturbances of the 15 January 2022 Tonga Volcano Eruption Observed in Taiwan and Japan

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Introduction

At 04:15 UT, severe eruptions of the Tonga volcano (20.536°S, 175.382°W) generated atmospheric shocks and pressure fluctuations, which induced traveling atmospheric disturbances (TADs) near the Earth's surface, further went into the upper atmosphere, and activated traveling ionospheric disturbances (TIDs) on 15 January 2022. In this study, we use Himawari-8 satellite images to calculate the TADs horizontal velocity, while ground-based barometers, Doppler sounding systems, and ionosondes are used to observe TADs and TIDs in Taiwan and Japan.

Methods

- Himawari-8: With the wavelength of 6.2 μm infrared band (#8) (spatial resolution of 2 km; time resolution of 10 minutes), we observe clearly the TADs of upper-level tropospheric water vapor at about 8.2 km altitude.
- Ionosondes: Observation data from 4 ionosonde stations (Wakkanai, Tokyo, Yamagawa and Okinawa) in Japan and the Xinwu station in Taiwan.
- Doppler: The Doppler sounding system in Taiwan consists of 10 receivers as the transmitter is located at Liyutan Dam.
- Barometer: Air pressure data from Japan Meteorological Agency and the 10m-tower of National Central University.

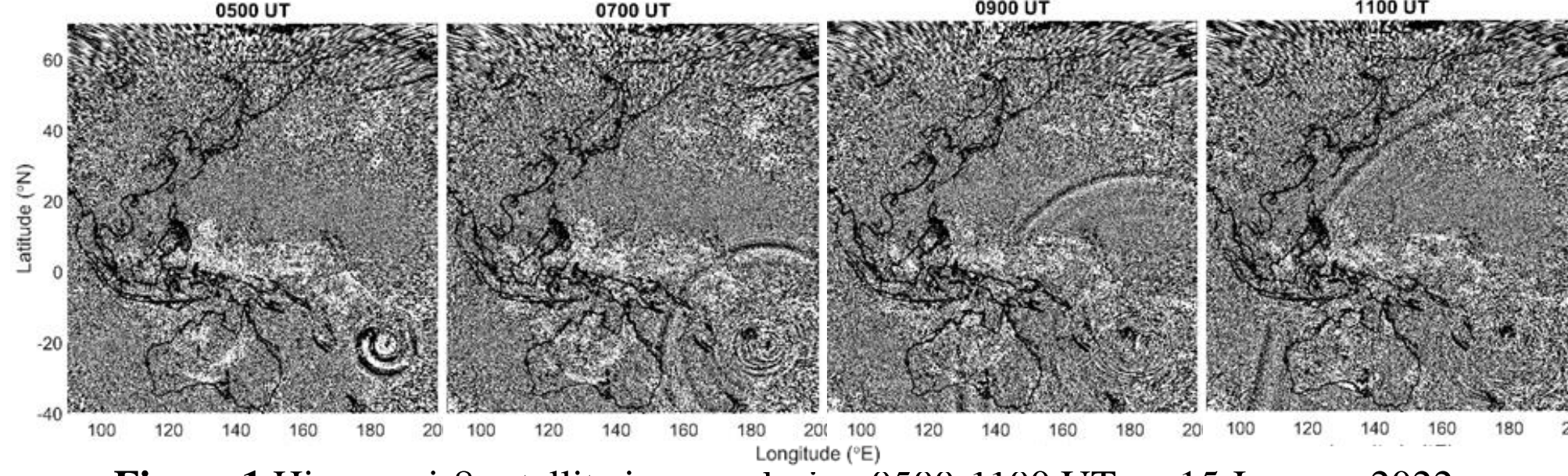


Figure 1 Himawari-8 satellite images during 0500-1100 UT on 15 January 2022.

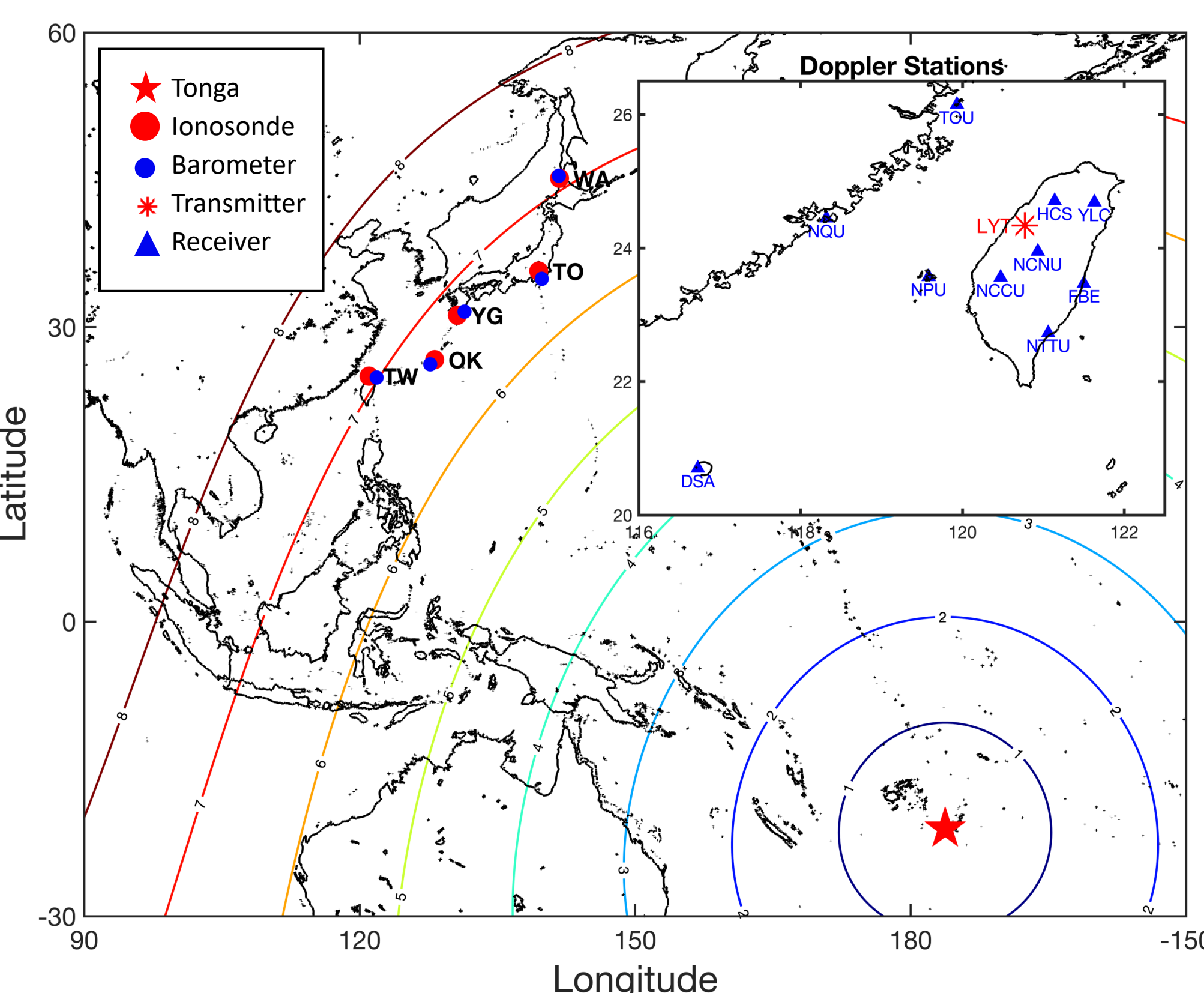


Figure 2 Locations of the Tonga volcano, barometers, ionosondes, as well as the Doppler sounding systems in Taiwan and Japan. Colored curves stand for the travel time of TADs in Himawari-8 images.

Barometers and Ionosondes

Red curves stand for the ground pressures data recorded by the barometers near the ionosondes. The blue and magenta arrows denote the ticking time and peak time of the bottom of F-layer trace in ionograms, respectively. The air pressure jumps occur about 2 hours after the peaks of ionosondes.

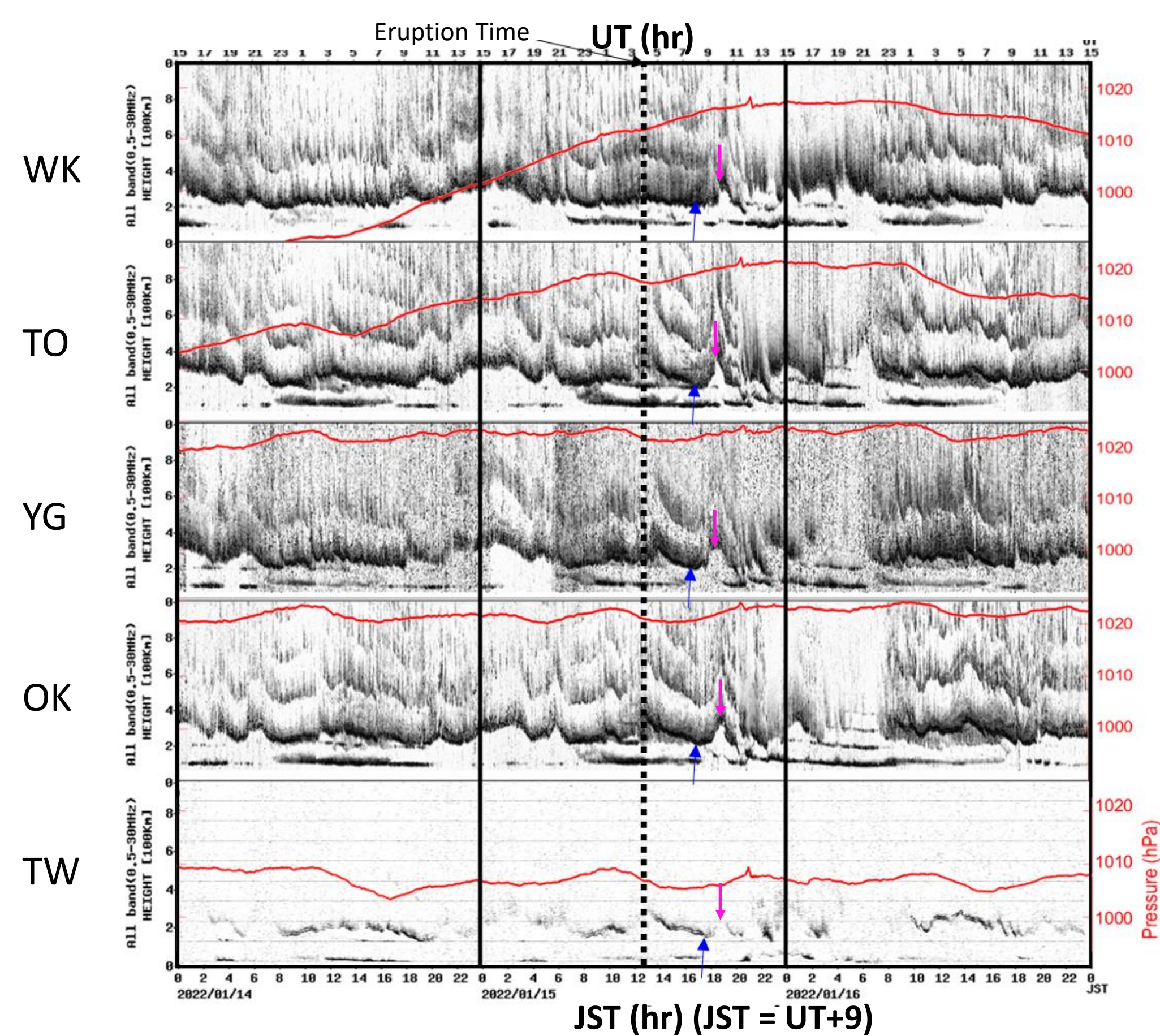


Figure 3 Compressed ionograms and co-located ground pressures in Taiwan and Japan.

Doppler Sounding Systems

The dashed line indicates the onset time of the volcano eruption. Denoting by the gray line, TIDs arrived in Taiwan from 09:15-09:20 UT.

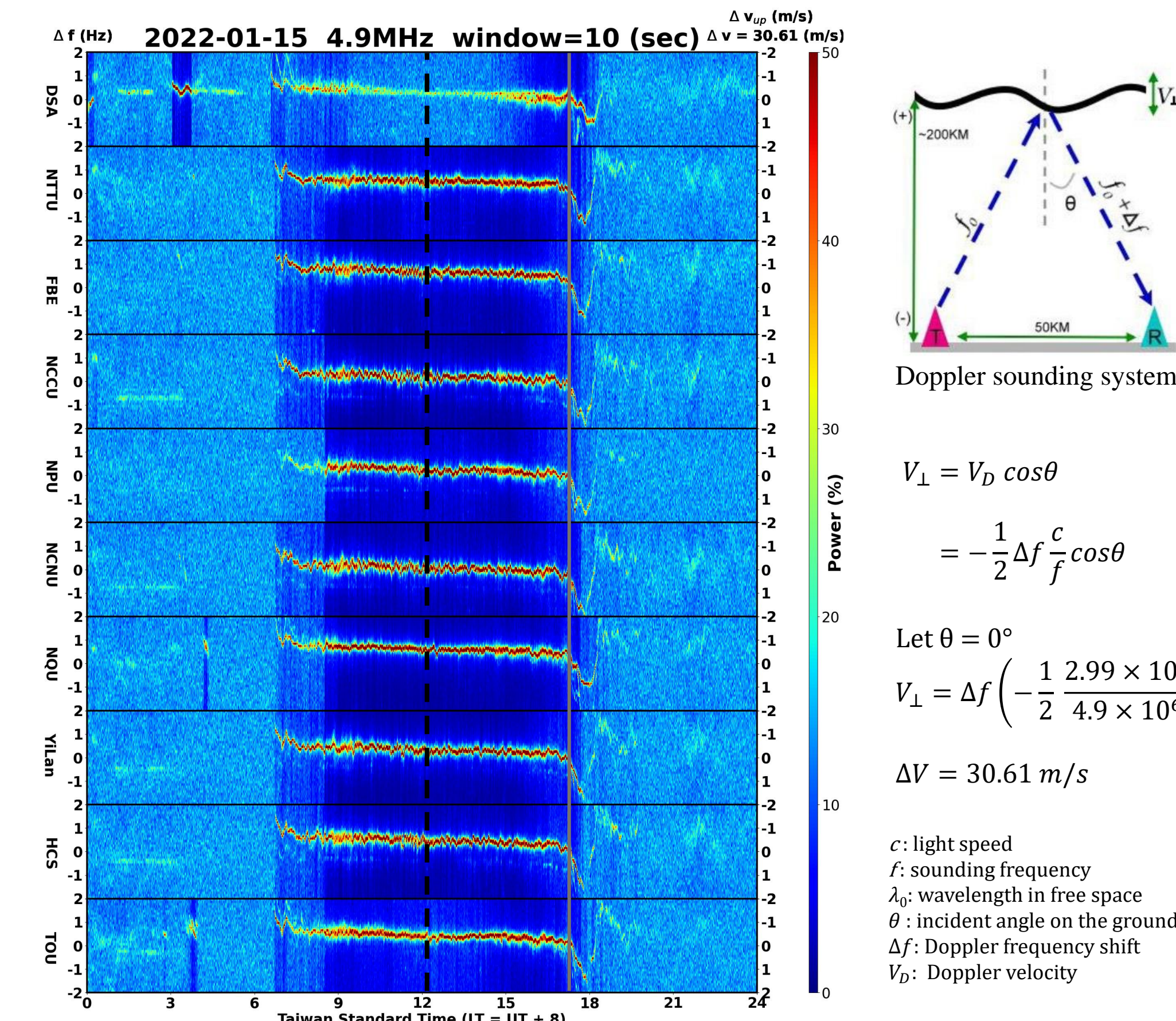


Figure 4 Doppler shift spectrogram recorded in Taiwan on 15 January 2022 (LT=UT+8)

Uplifting of the Ionosphere

Dashed, thin purple, and blue lines denote the prominent volcano eruption time, the ticking/peak time of the bottom of F-layer trace in ionograms, and the arrival time of the air pressure front, respectively. The ionosphere is uplifted by the TIDs triggered by the Tonga volcano eruption. The compressed ionograms shows an uplift of 105.6 km while the uplift height calculated from the integrated Doppler velocities is 137.2 km in Taiwan.

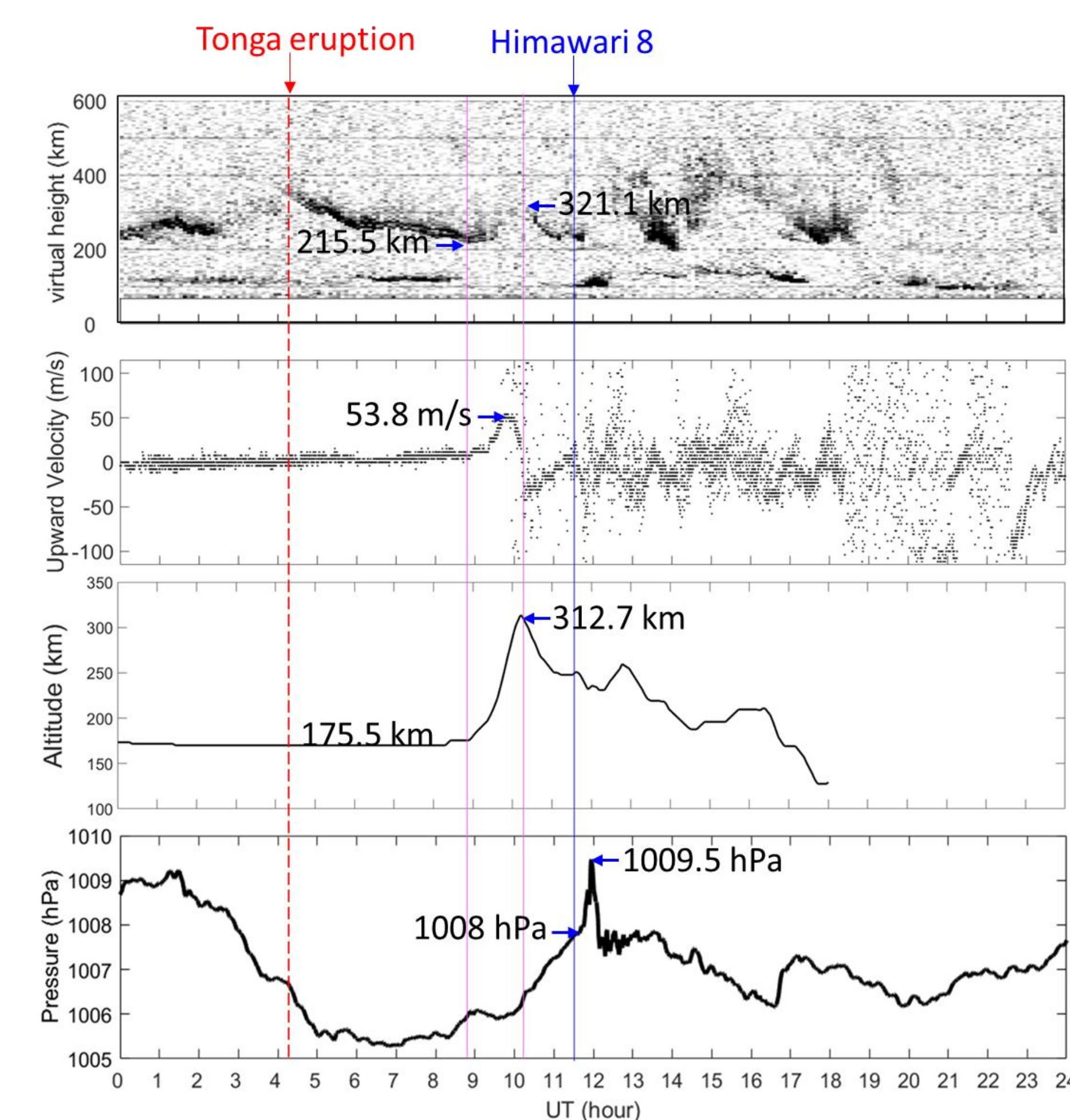


Figure 5 Compressed ionograms, Doppler velocities/reflection height of sounding frequency 4.9 MHz, and ground pressure in Taiwan on 15 January 2022.

Horizontal Speed of TADs and TIDs

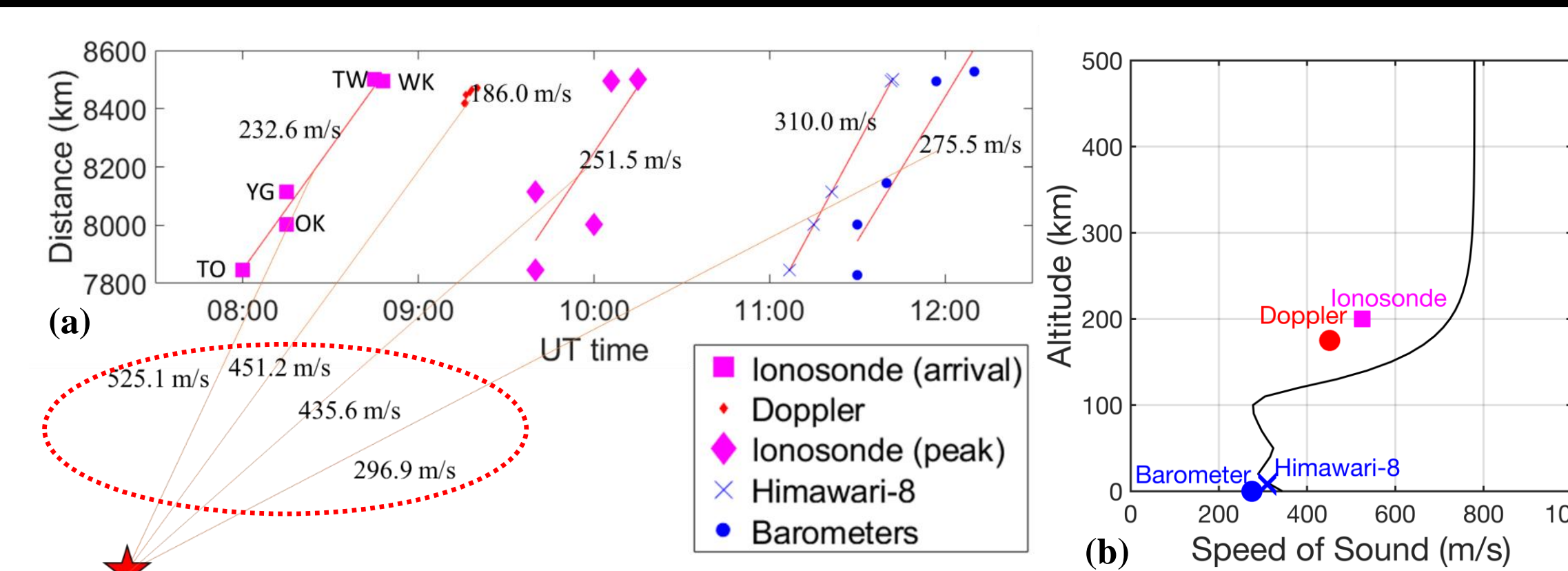


Figure 6 The horizontal speed of the ionosondes, Doppler sounding systems, and the air pressure. (a) Network speeds and the averaged horizontal speed calculated with the distance between the stations and the volcano. (b) Comparison of the observation and the computed atmosphere sound speed profile.

The sound speed profile (Fig 6b) is computed from the NRLMSISE-00 model on 15 January 2022 at 9:00 UT (17:00 Local Time) above Taiwan. The horizontal TAD speed from the Himawari-8 images is about 310 m/s while the barometers recorded an average horizontal speed of 296.6 m/s. On the other hand, the horizontal speeds observed by the ionosondes is 525.1 m/s as the one obtained from the Doppler sounding system is 451.2 m/s.

Ocean Waves

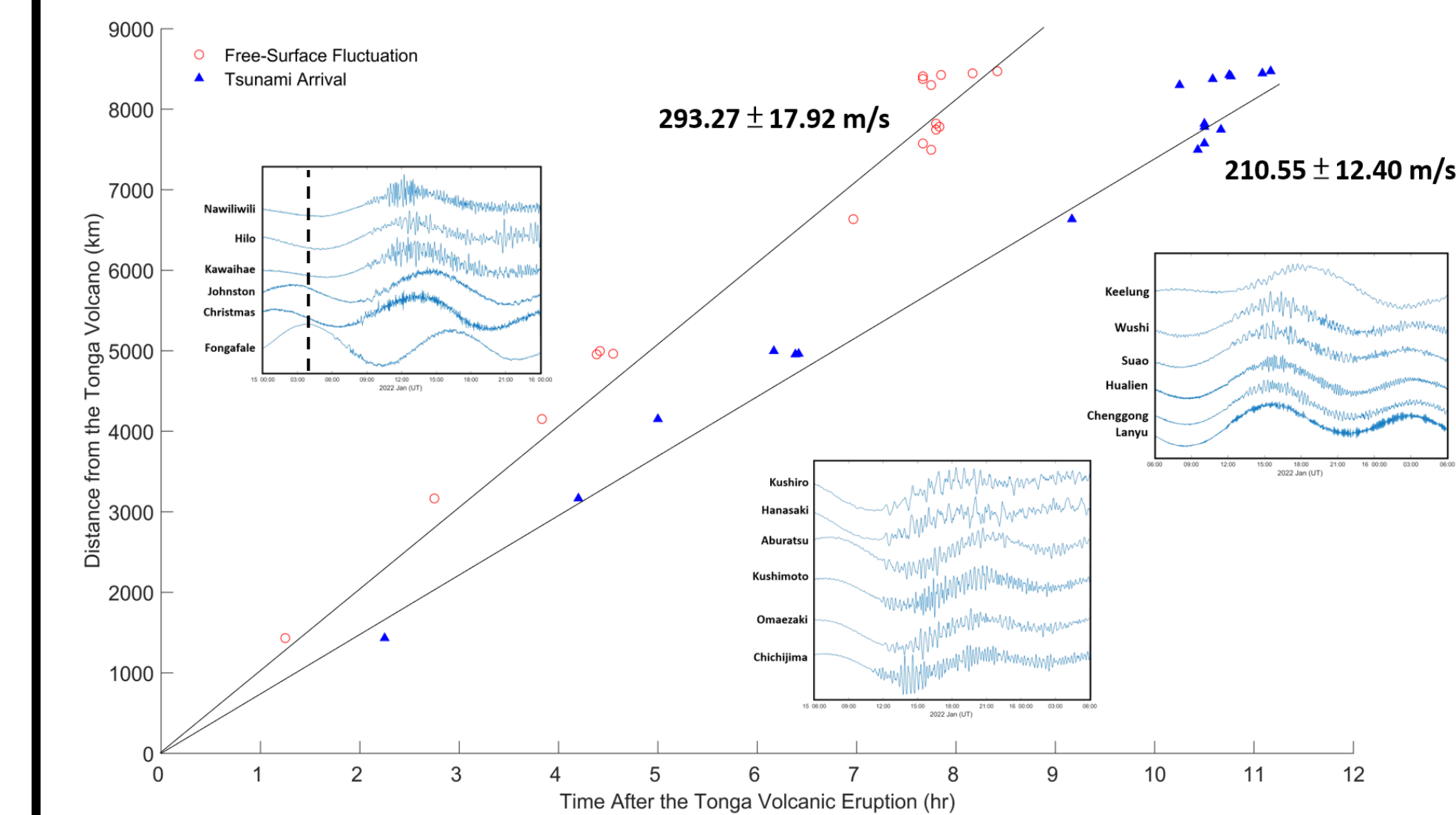


Figure 7 The arrival times of the free surface fluctuations and tsunami waves versus the distance to the volcano after the eruption at 04:15 UT. The horizontal speeds of the free surface fluctuations and tsunami waves are 300 m/s and 210 m/s, respectively.

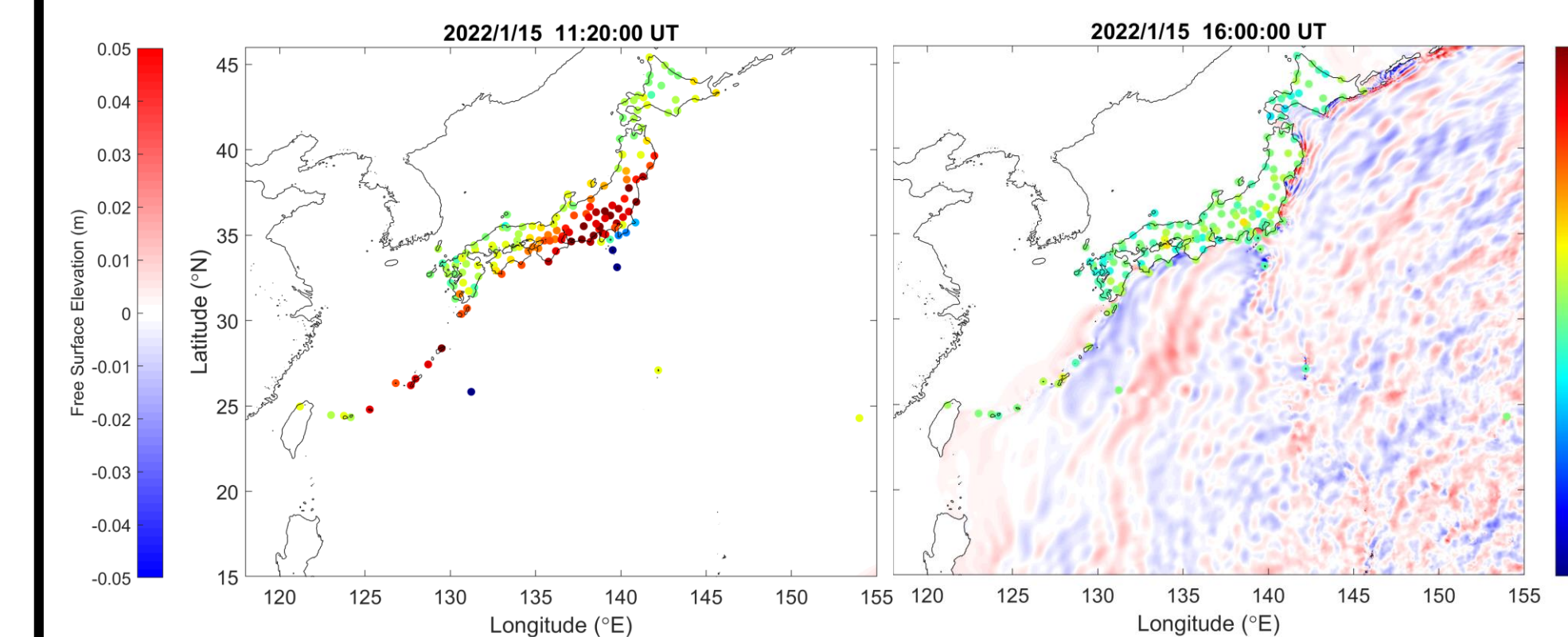


Figure 8 Air pressure variation in Taiwan and Japan and the submarine mass failure tsunami scenario. The tsunami simulation is performed with COMCOT. The tsunami waves arrive at Japan at about 14:20 UT and then arrive at the coast of Taiwan at about 15:50 UT.

The free surface fluctuations took place at about the same time when the pressure waves arrive.

Remarks

- Tonga volcano eruptions induced TADs, TIDs and fluctuations on sea-surface.
- The TIDs observed by the ionosondes lead the air pressure jumps recorded near the surface by about 2 hours.
- Ionograms and integrated Doppler velocities show that the TIDs uplift the ionosphere about 78-146 and 137 km, respectively.
- The horizontal TAD speed in Himawari-8 images is about 310 m/s, while that in ground pressures is about 296.9 m/s over Japan and Taiwan during 11:10-12:10 UT.
- The averaged horizontal TID speeds observed by the Doppler sounding systems and ionosondes are respectively about 451.2 and 525.1 m/s, which fall in the range of sound speed in the ionosphere.
- The possibility of an early warning system for tsunamis.