Measuring D-region ionospheric variations near the Hunga Tonga volcanic explosion using VLF/LF lightning waveforms

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Abstract

In this study, we use VLF/LF lightning waveforms observed by Earth Networks Total Lightning Network (ENTLN) to examine the ionosphere near the Hunga Tonga volcanic explosion on 15 January 2022. The lightning waveforms used in this study (negative cloud-to-ground events) consist of a ground wave (which travels to the station along the ground) and an ionospheric reflection wave (which travels to the station by reflecting off the ionosphere). These events can be used to probe the D-region (60-95 km) ionosphere halfway between the lightning event and the detecting station, as both the time difference and peak ratio between these two waves depend on the electron density at the probing location. So far, we have focused on stations in northeastern Australia, particularly AUK06, AUK89, and AUK98. We calculated the time differences and peak ratios for lightning events 400-900 km away from each station. These parameters can also depend on the distance of the lightning event from the station and normal daily ionosphere variations, so these factors were accounted for by fitting best fit lines to distance and local time and subtracting out the trend. We show the ionospheric variation, in terms of the time differences and peak ratios against both local time and the probing locations' distances from Hunga Tonga.

Method

Example ENTLN waveforms

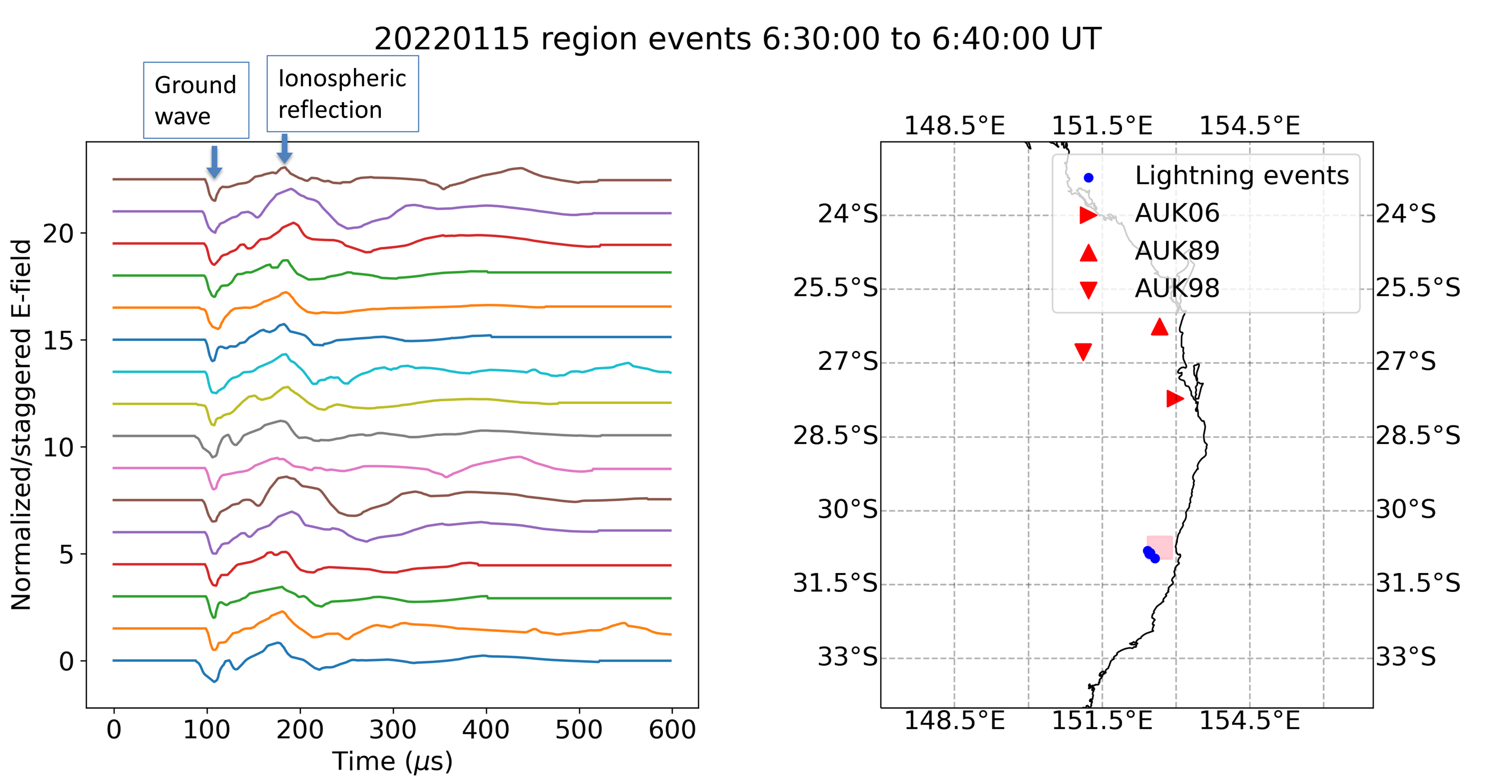

Fig. 1. Left: Lightning waveforms detected at AUK06, AUK89, and AUK 98 from a selected region to the south. Right: A map showing the locations of AUK06, AUK89, and AUK98 and the location of the lightning events and highlighted region.

- ENTLN records lightning waveforms at each station (Fig. 1, left).
- We find time difference between ground wave and ionospheric reflection. We also find the peak amplitude ratio between ionospheric peak and ground peak, but don't focus on peak ratio here.
- Account for trends in waveforms due to distance and daily ionospheric variations.
- Plot time differences and peak ratios against time and distance.
- Fit a 2-D Gaussian plane curve to the data, then subtracted it out.
- After this, looked at overall ionospheric trends in the residuals.

Acknowledgments

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Remove trends due to time of day and distance

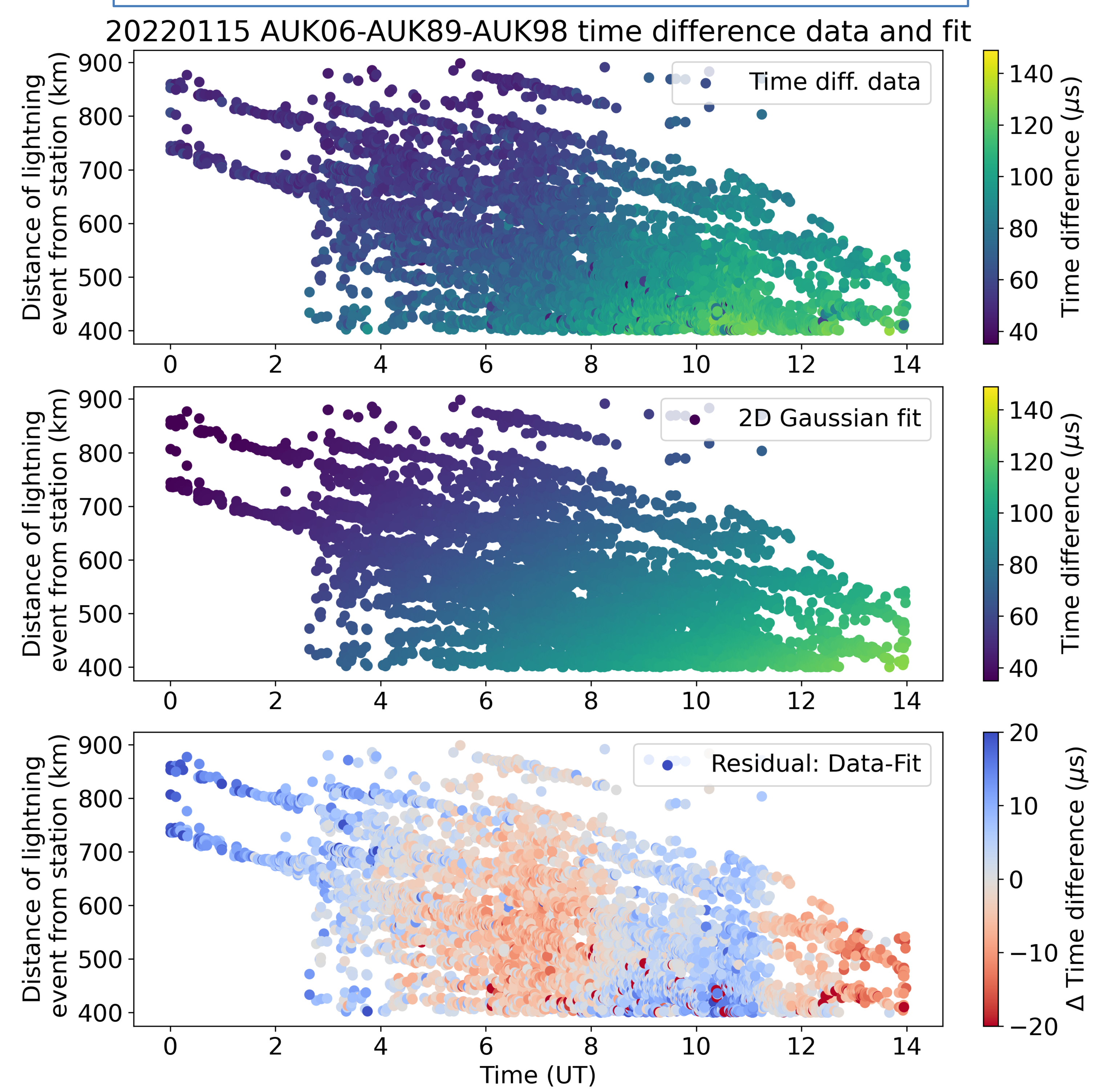

Fig. 2. Top: time difference data. Middle: Gaussian plane curve fit. Bottom: Difference (residual) between the time difference data and the fit.

Results

Keogram of ionospheric variation after Hunga Tonga explosion

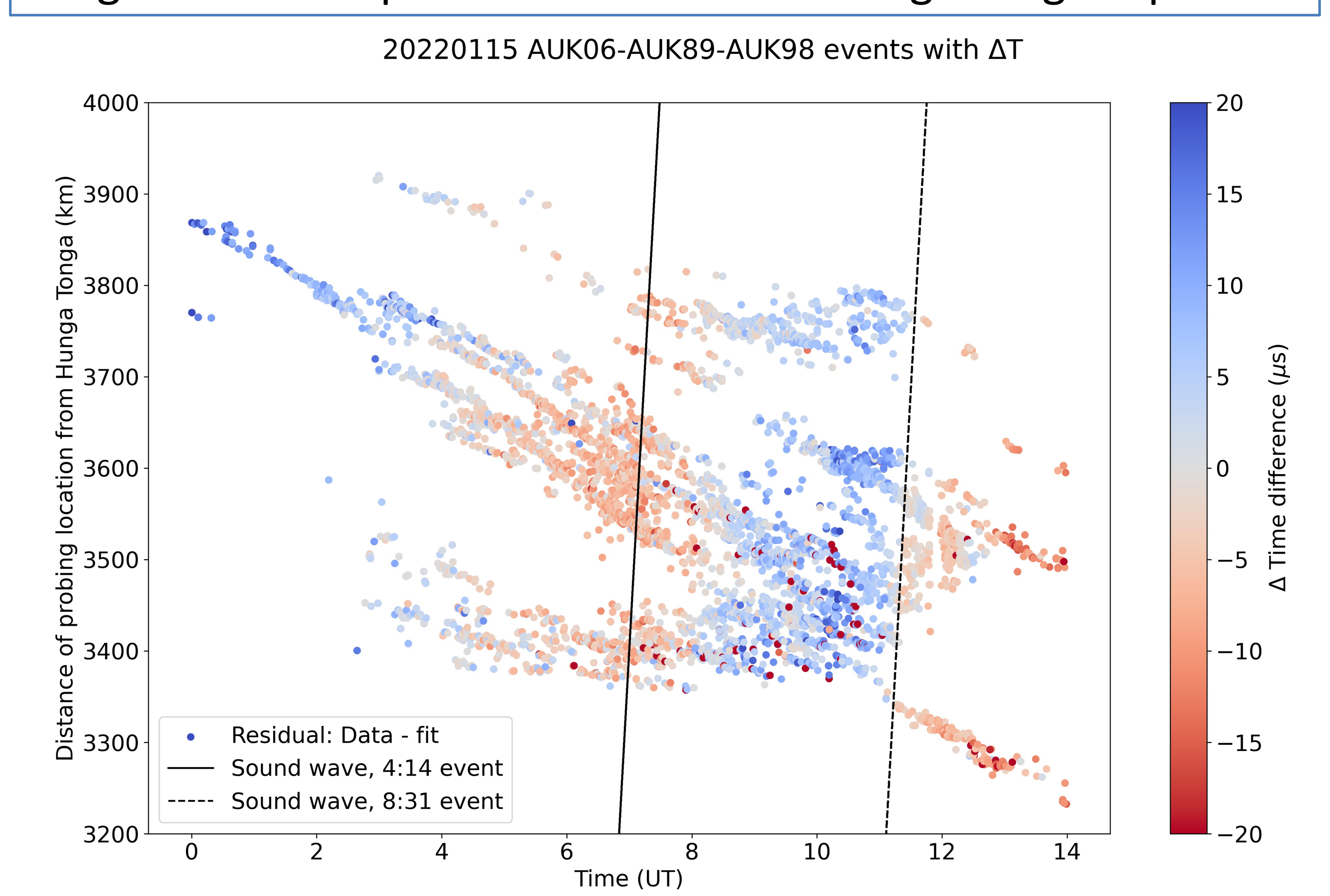

Fig. 3. Delta time differences vs. the probing locations' distances from Hunga Tonga. Solid line: travel of 4:14 UT event wave. Dashed line: travel of 8:31 event wave.

Residual time differences in latitude/longitude for daytime (top) and nighttime (bottom)

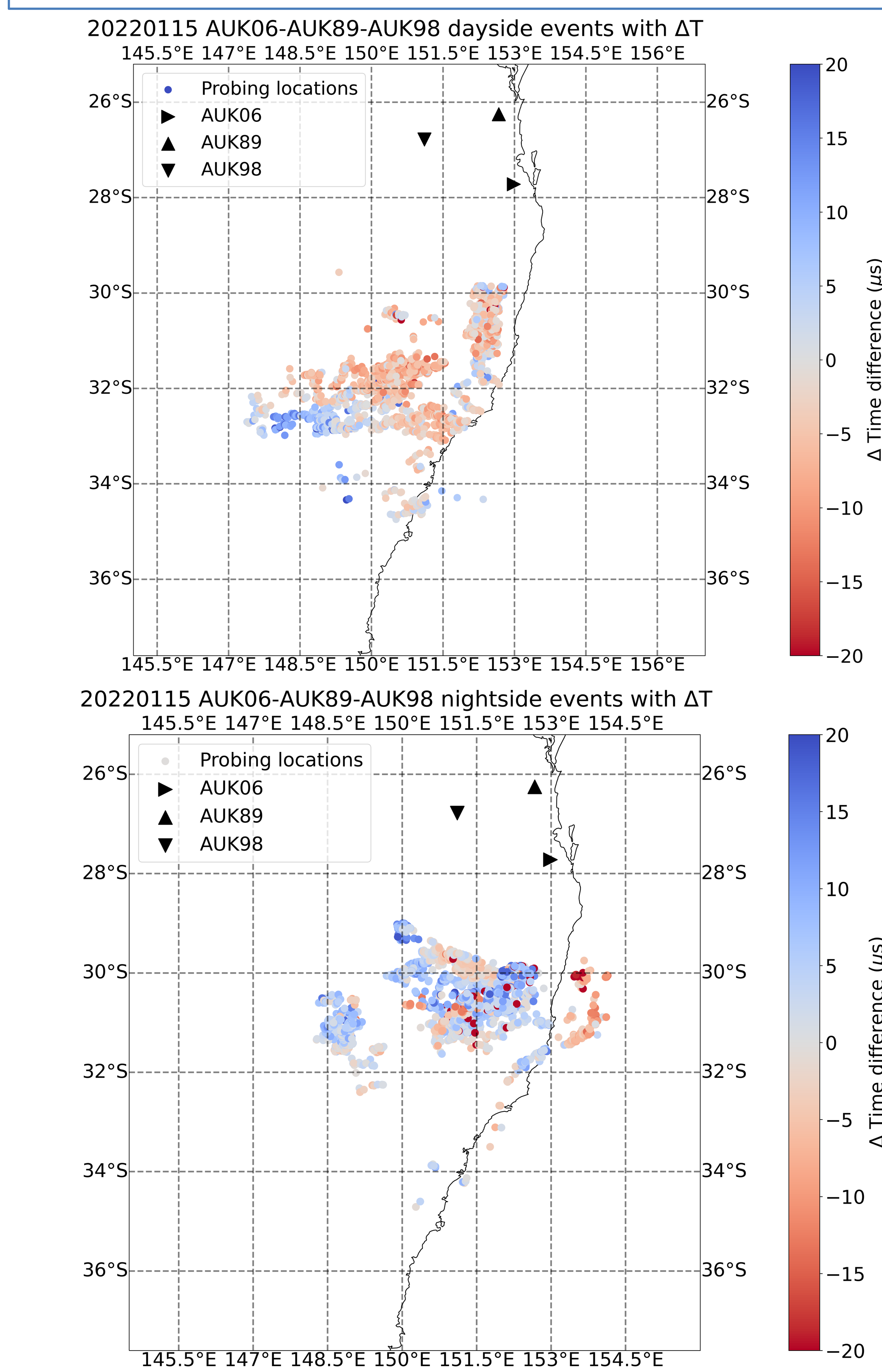

Fig. 4. Maps of the probing locations' corrected time differences for Jan. 15, 2022, separated by dayside and nightside.

- Time differences are proportional to ionospheric height.
- Fig. 3: The residual ionospheric height increases after the 4:14 event wave and decreases after the 8:31 event wave.

Conclusion/Future Work

- After correcting for both distance and diurnal trends, initial results show effects on ionospheric height from the Hunga Tonga explosion.
- The ionospheric height increased after the arrival of the 4:14 UT wave and decreased after the arrival of the 8:31 UT wave.
- However, because the ionosphere could have been severely modified from a typical daily fluctuation, we need to compare waveforms to modeled waveforms to fully understand variability.
- Ongoing and future work includes averaging the waveforms to account for noise and comparison to modeled waveforms to determine the D-region ionospheric profile.
- Peak amplitude ratios are too noisy for individual data analysis but may be useful after averaging to account for noise.

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