Ionospheric Responses to Acoustic and Gravity Waves Generated from Derechos

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Introduction

We investigate acoustic and gravity wave (AGW) signals during a derecho event over the continental US in a multi-layer manner. A recent derecho occurring in July 2022 is selected for the study which shows clear signs of AGWs and Traveling Ionospheric Disturbances (TIDs). The event caused widespread wind damage across the region of travel. Data from different satellite and ground-based measurements is analyzed to observe AGW evolution over a range of atmospheric layers and the resulting ionospheric responses, where spatial and temporal characteristics of the TIDs generated over the derecho are estimated. **The objective of the study is to ultimately determine if the TID characteristics differ between derecho events, and if the TID characteristics from derechos differ from those resulting from differing convective systems.** Our study highlights the complexity of analyzing coupled lower atmosphere-ionosphere processes [1, 2], and illustrates the type of ionospheric responses that can be expected from a derecho event.

Dataset

- Precipitation rate measurements over the continental US from the Next Generation Weather Radar (**NEXRAD**), available every 2 minutes.
- Stratospheric brightness temperatures from the Atmospheric Infrared Sounder (**AIRS**) instrument on the Aqua satellite, available twice a day.
- Ionospheric total electron content (**TEC**) perturbations from GNSS measurements over the continental US, available every 30 seconds.

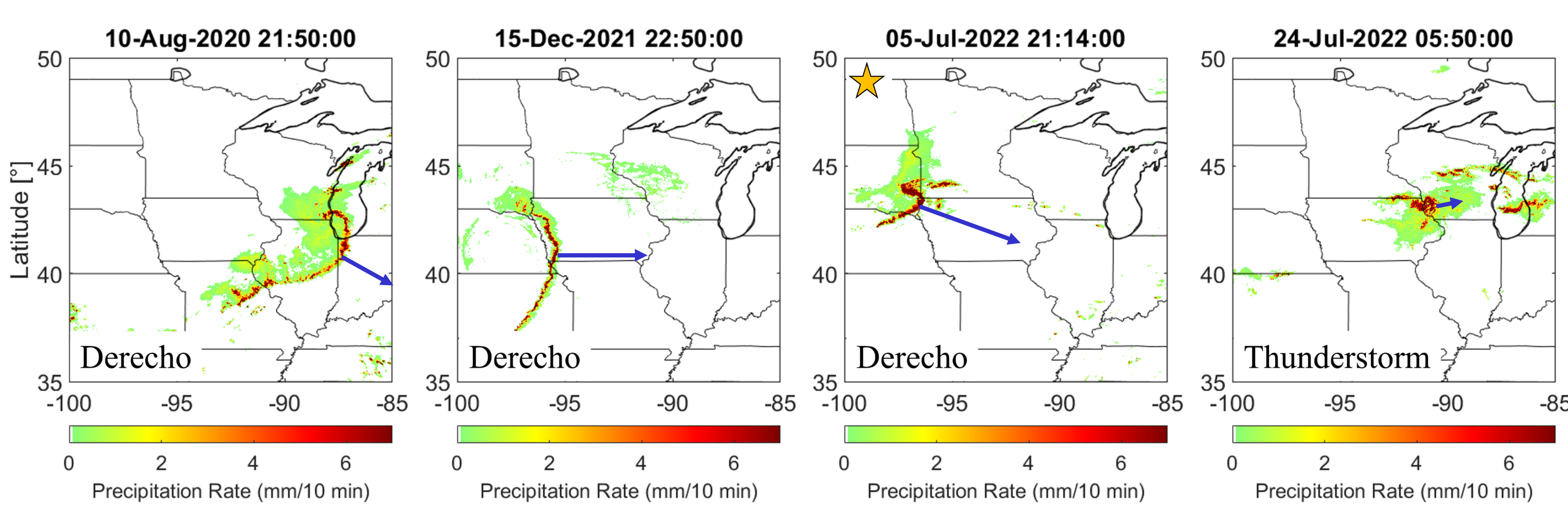

Figure 1 – Examples of how derecho fronts appear in NEXRAD data. The rightmost figure is an example of a regular thunderstorm, where no clear front is visible. The blue arrows show the approximate direction of travel of each convective system.

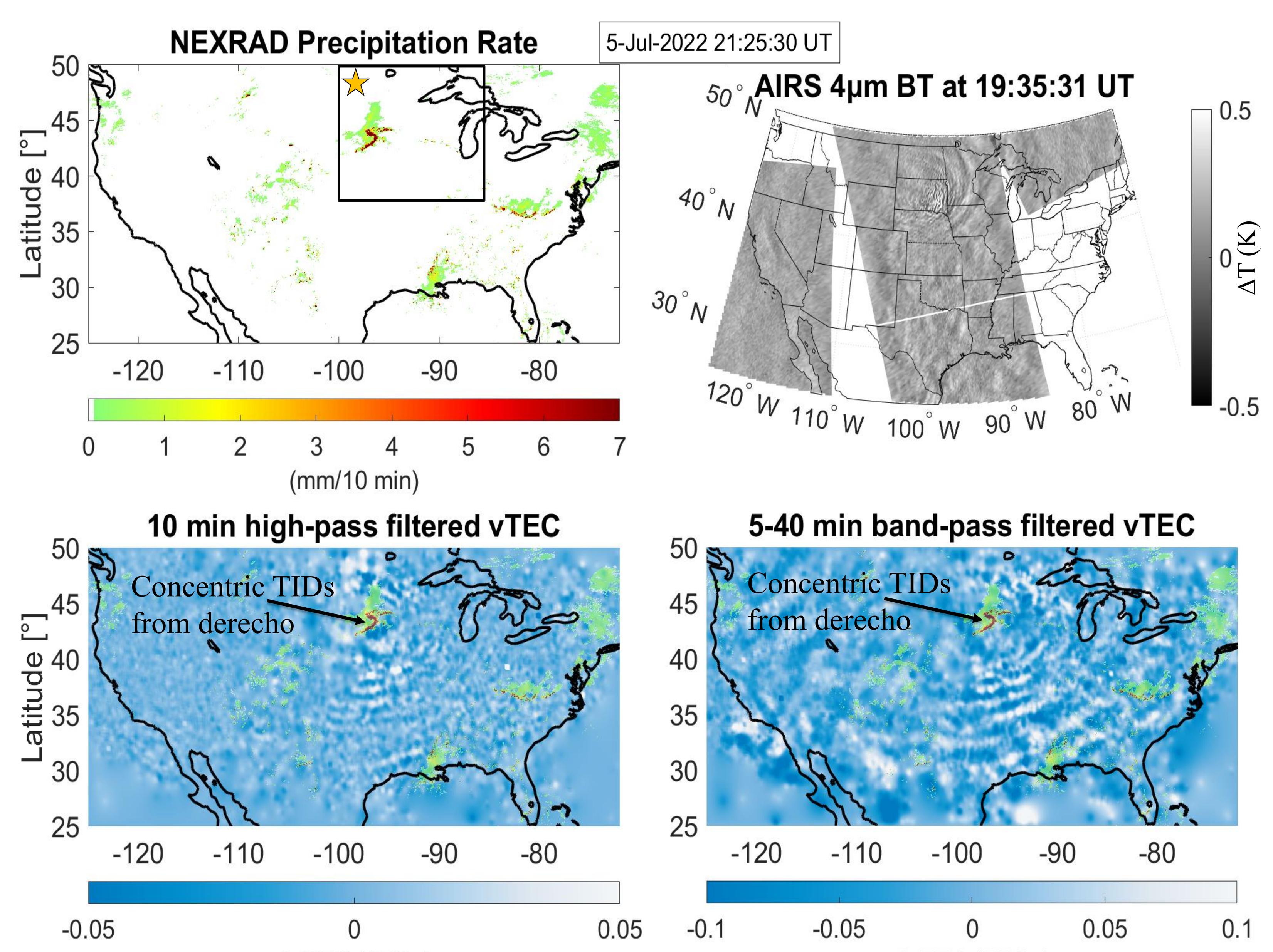

Figure 2 – Multi-layer observation of the July 5th 2022 derecho. Upper-left: NEXRAD precipitation rate. Upper-right: AIRS brightness temperature. Bottom: vTEC perturbations.

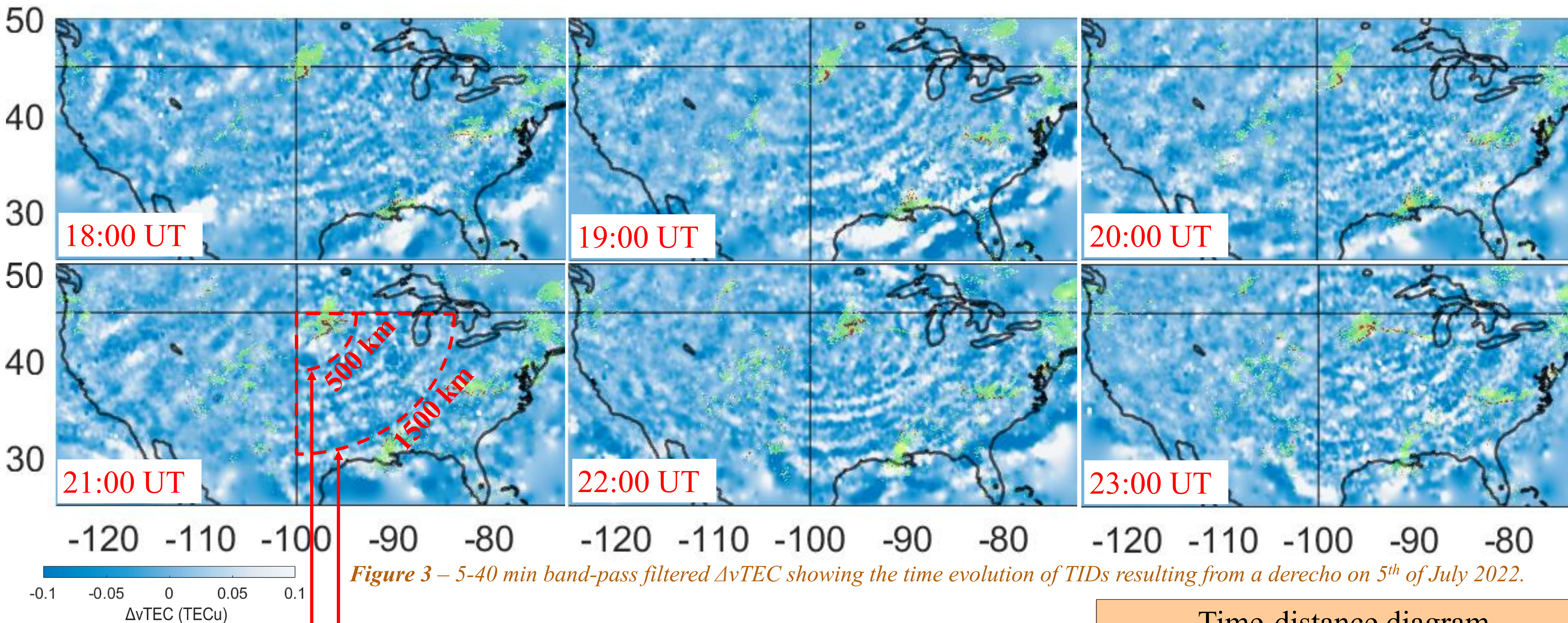

Figure 3 – 5-40 min band-pass filtered ΔvTEC showing the time evolution of TIDs resulting from a derecho on 5th of July 2022.

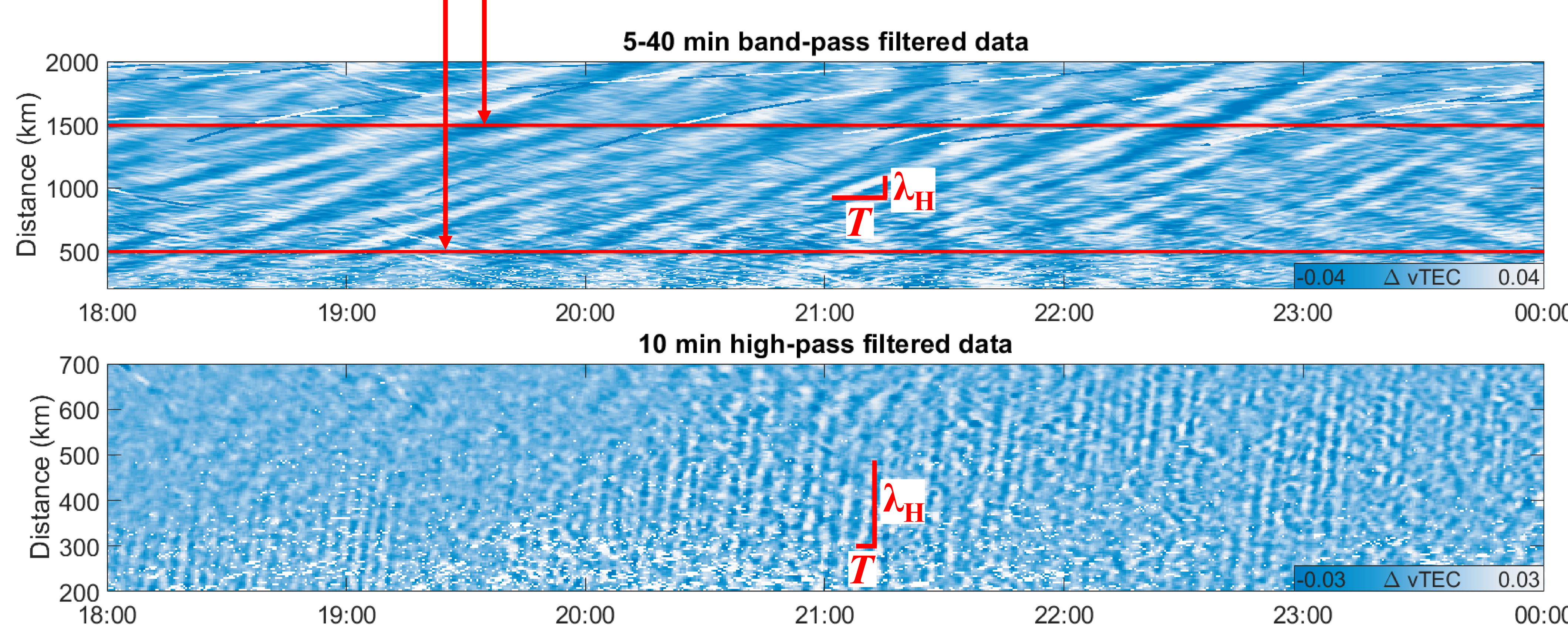

Figure 4 – Time-distance diagrams, showing the mean ΔvTEC value at a given time and distance away from an estimated convective source. The resolution is 4km x 30 seconds.

Time-distance diagram

Figure 4 consists of two time-distance diagrams used to estimate TID characteristics driven by acoustic-gravity waves (using a 10 min high-pass filter) and gravity waves (using a 5-40 min band-pass filter) from thunderstorms. For each filter, they are constructed from vTEC perturbations (as shown in Figure 3) by finding the mean ΔvTEC value of a concentric south-east region around the convective source for all distances at all times.

Filter	λ_H [km]	T [min]	v_φ [m/s]
5-40 min band-pass	181 ± 45	13.1 ± 2.5	232 ± 47
10 min high-pass	291 ± 28	4.3 ± 0.3	1136 ± 160

Table 1– Estimated TID parameters from Figure 4.

Extracted TID parameters

The time-distance diagrams in Figure 4 are used to estimate the TID parameters, shown in Table 1. This is done to analyze the effects of both acoustic-gravity waves (lower panel) and gravity waves (upper panel). The parameters obtained are:

1) **Horizontal wavelength λ_H**, calculated by looking at a fixed time in Figure 4.
2) **Period T**, calculated by looking at a fixed distance in Figure 4.
3) **Phase velocity v_φ**, calculated from the horizontal wavelength and the period.

All numbers in Table 1 are the mean and standard deviation of five estimates, extracted using a datapoint selection tool.

Conclusions and discussions

- Results shown in Figure 3 and 4 reveal that TID parameters resulting from a derecho can be retrieved from ground-based GNSS observations and the construction of time-distance diagrams.
- The study illustrates the capabilities of multi-layer observations and shows that such methods can potentially be used to compare ionospheric responses between differing convective systems. **Such comparison is of scientific significance as it can highlight missing considerations of the physics of how different sources couple the lower atmosphere to the ionosphere.**
- **This is the first step of an extensive study to characterize differences in ionospheric responses from derechos and differing convective systems.**

Future Work

- Investigate alternative approaches to construct the time-distance diagrams and reliably estimate TID parameters from concentric propagating fronts.
- Analyze other derecho and thunderstorm events, and compare TID characteristics in order to determine the extent of the differences in resulting ionospheric responses.
- Investigate additional metrics for comparing the ionospheric effects from derechos versus thunderstorms.
- Consider background conditions, such as temperature and wind conditions, in order to investigate if or how much effect these conditions have on TID parameters.
- Compare observations with MAGIC-GEMINI model simulations to validate or question the results of our data-guided investigations.

References

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[2] Nishioka, M., Tsugawa, T., Kubota, M., and Ishii, M. (2013), Concentric waves and short-period oscillations observed in the ionosphere after the 2013 Moore EF5 tornado, *Geophys. Res. Lett.*, 40, 5581– 5586.

Acknowledgement

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