Ionospheric Responses to Acoustic and Gravity Waves Generated from Derechos

Björn Bergsson[1], Pavel Inchin[1], Shantanab Debchoudhury[1], Christopher Heale[1], Shibaji Chakraborty[2]
Embry-Riddle Aeronautical University[1], Virginia Tech[2]

EMBRY-RIDDLE Aeronautical University
DAYTONA BEACH, FLORIDA

AMS 2024
Baltimore
Abstract #430824

Motivation and Objective of the Study

A new automated method for tracking convective systems as seen in precipitation data is presented here, and precipitation intensity metrics are derived for these systems that are used to correlate with the amplitude of Traveling Ionospheric Disturbances (TIDs) generated over them. **In this poster, we investigate 3 derecho events and their resulting space weather impact over the midwestern US.** A derecho is a special type of damaging and long-lived thunderstorm that can form when specific wind conditions are present within a complex of thunderstorms termed mesoscale convective systems (MCS). They are different from tornados or hurricanes because their associated strong winds move forward in straight lines, causing damage that is often termed straight-line wind damage. Discussing the similarities and differences of the correlation between characteristics of tropospheric sources and resulting ionospheric disturbances is of scientific significance as it can highlight missing considerations of the physics of how different convective sources couple the lower atmosphere to the ionosphere.

Dataset

- Precipitation rate measurements over the continental US from the Next Generation Weather Radar (**NEXRAD**), available every 2 minutes.
- Ionospheric total electron content (**TEC**) perturbations from GNSS measurements over the continental US, available every 30 seconds.

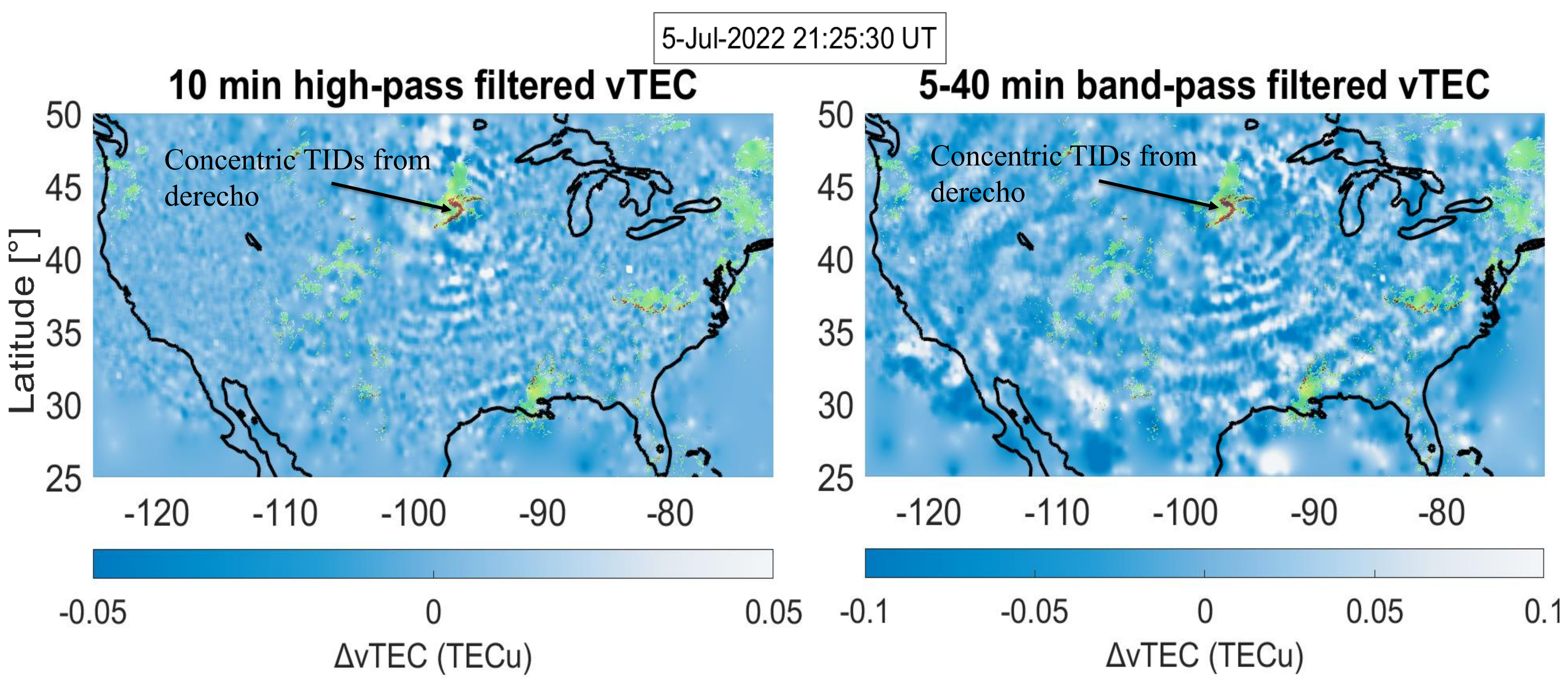

Figure 1 – vTEC perturbations showing TIDs in the ionosphere from acoustic-gravity waves (left) and gravity waves (right). Overlaid is precipitation data from NEXRAD at the time of a derecho storm, ***showing the impact of severe terrestrial weather on space weather*** *by demonstrating that the* ***derecho is a source of the concentric TIDs****.*

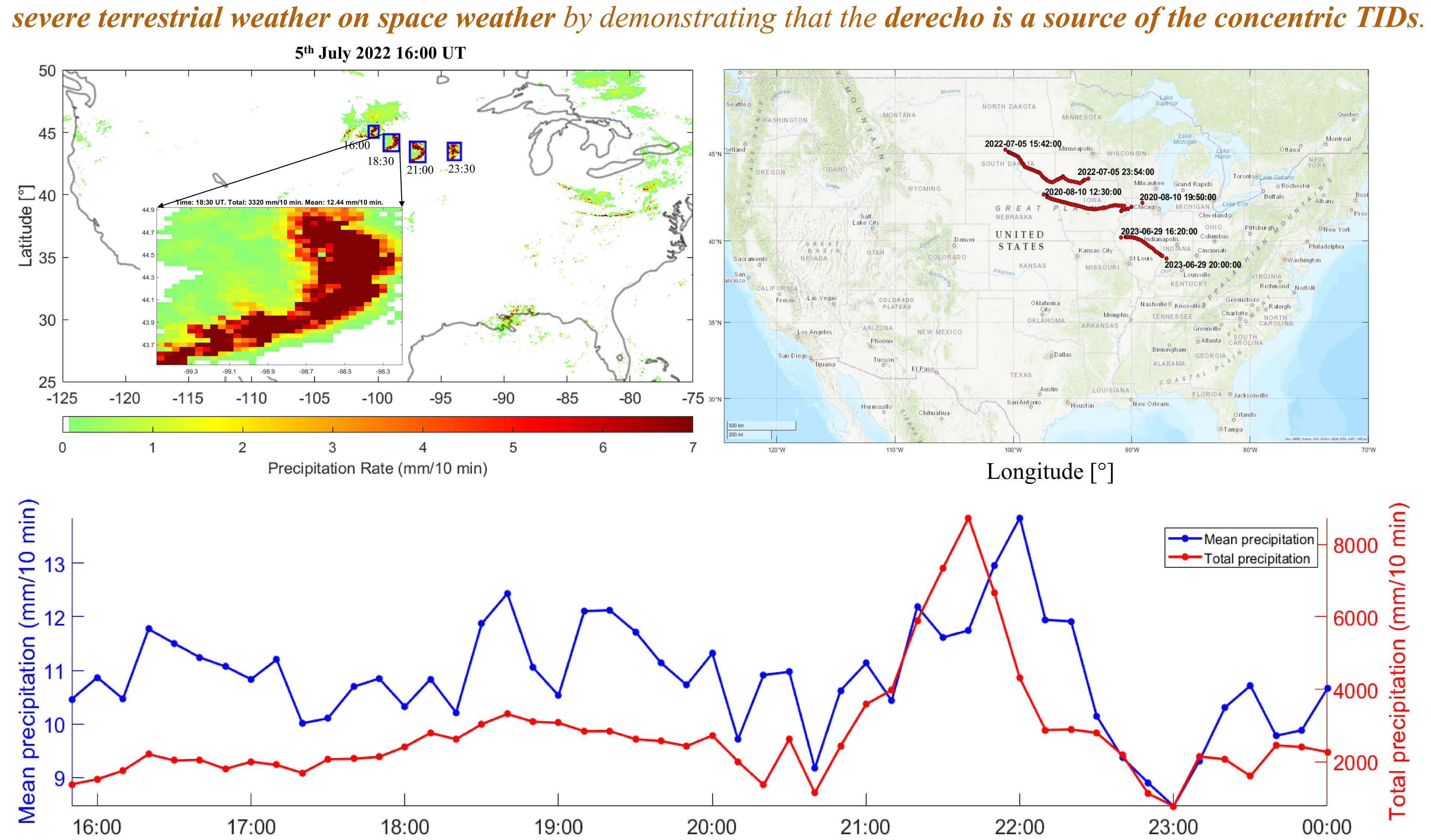

Figure 2 – Demonstration on how ***precipitation intensity metrics are derived from NEXRAD data****. The upper-left frame shows how* ***a derecho evolves with time****. An* ***automated tracking algorithm*** *was developed, which quantifies the extent (blue boxes) of a derecho at each time and* ***tracks its movement.*** *For each time,* ***the mean and total precipitation rate is calculated*** *from all pixels with precipitation values above a certain threshold,* ***resulting in precipitation intensity metrics*** *in the form of time series, as shown in the below frame. The upper-right frame shows the* ***derived tracks*** *of three different derechos, which are* ***used to construct time-distance diagrams*** *from vTEC.*

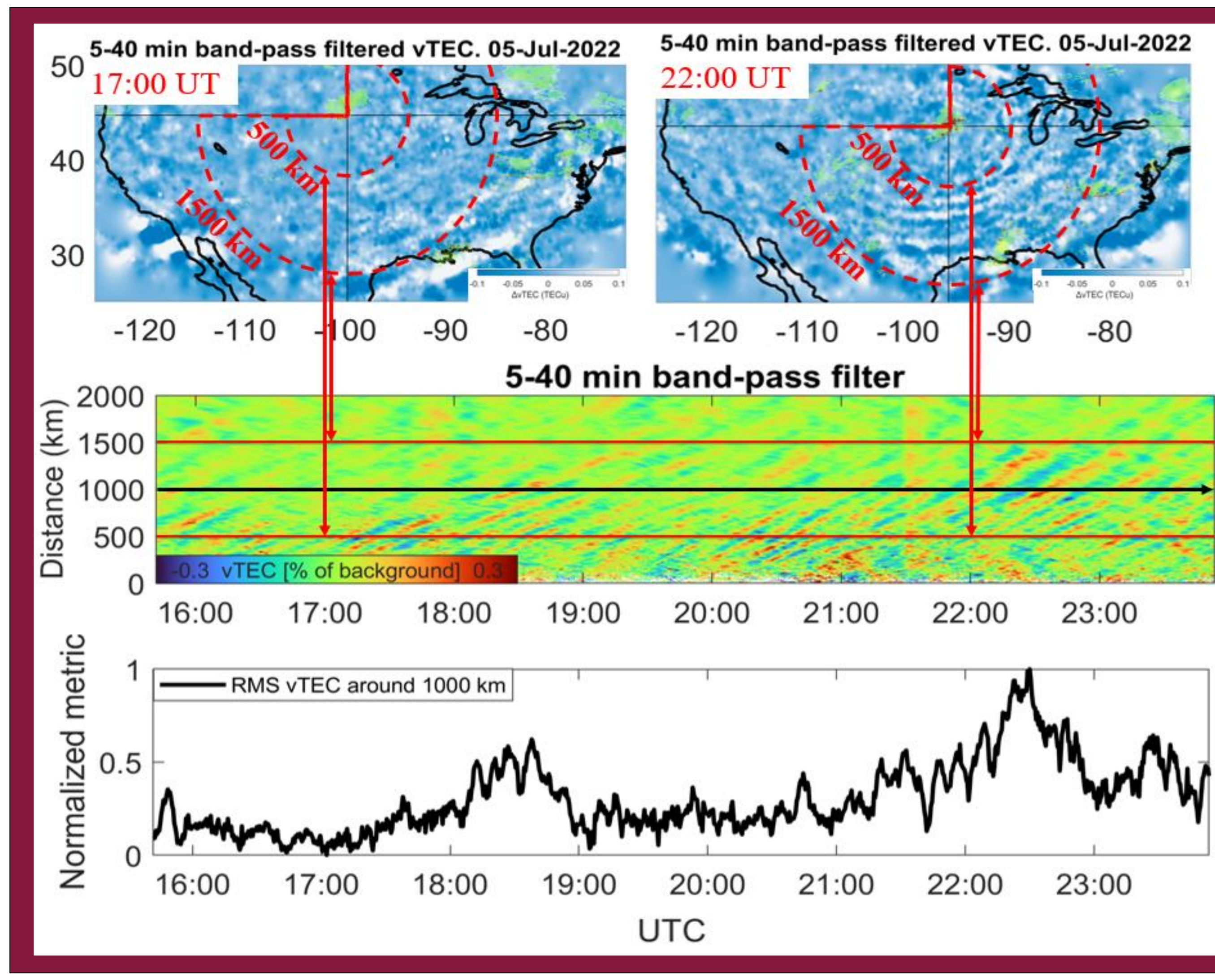

Figure 3 – Method:
Deriving the Amplitude of TIDs

Shown in the top panel are vTEC perturbations at two different times, exhibiting TIDs driven by gravity waves (using a 5-40 min band-pass filter) from thunderstorms.

The middle panel shows a time-distance diagram. They are constructed from vTEC perturbations by finding the mean value of a concentric region around the convective source location (as derived with the tracking algorithm) for all distances at all times.

The amplitudes of TIDs are estimated from time-distance diagrams as root mean square values around a given distance (denoted by a black arrow). This results in a time series of TID amplitudes (bottom panel) which can be correlated with the precipitation metrics.

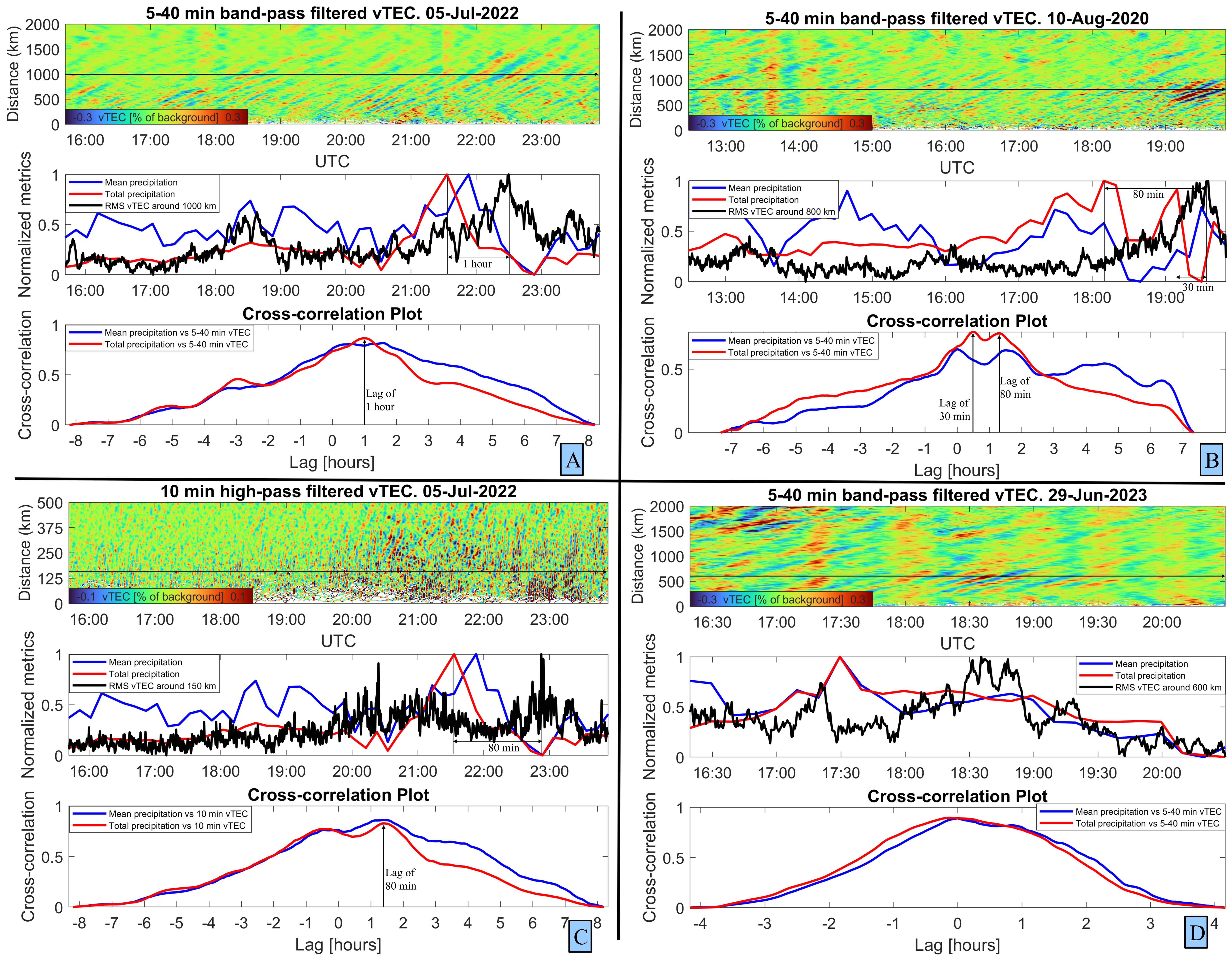

Figure 4 – Correlation analysis between the NEXRAD precipitation metrics and TID amplitudes. The left side shows analysis for a derecho on the 5th of July 2022, where it is carried out for both gravity waves (frame A) and acoustic-gravity waves (frame C). The right side shows the analysis for gravity waves for two more derechos. The metrics for precipitation and TID amplitude are shown in the middle panels, and the bottom panels show the correlation of each precipitation metric with the TID amplitude. The precipitation metrics are shifted over the TID amplitude time series. In this plot positive lags correspond to shifting to the right, which helps to see how the precipitation might affect the ionosphere.

Conclusions and Discussions

- This study introduces a **new automated algorithm** for tracking the movement of convective sources and quantifying their precipitation intensity and extent.
- Correlation analysis shows that **peak TID amplitudes occur following peak precipitation**, indicating a relationship between the two. This is, however, not clearly observed for all cases.
- Both mean and total precipitation can be used to compare with TID amplitude, although **total precipitation tends to show clearer correlation**.
- Figure 4 (C) shows a larger lag between peak precipitation and TID amplitudes than would be expected for acoustic waves. This should be investigated further.
- Figure 4 (D) in the middle panel a **delay between peak precipitation and TID amplitude can be observed, but correlation plots do not always indicate that clearly.** Alternative approaches for correlation analysis will be investigated.
- TID amplitudes are derived based on a selected distance from the source. Autonomous ways could be developed to detect which distance gives the best correlation.
- The methods in this study can potentially be used to **compare ionospheric responses between differing convective systems**.

Future Work

- Investigate alternative approaches to estimate concentric TID amplitudes.
- Consider other ways for analyzing the correlation between precipitation and TID amplitudes.
- Analyze other thunderstorm events and compare TID characteristics to determine the extent of the differences in resulting ionospheric responses.
- Consider background conditions, such as temperature and winds, to investigate if or how much effect these conditions have on TID parameters.

Acknowledgement

This work was supported by NASA LWS grant 80NSSC22K1022.