Traveling Ionospheric Disturbances Tracked through Doppler-Shifted AM Radio Transmissions

Presented by: Claire Trop

Project Members: Jim LaBelle, Phil Erickson, Shunrong Zhang, David McGaw, Terry Kovacs

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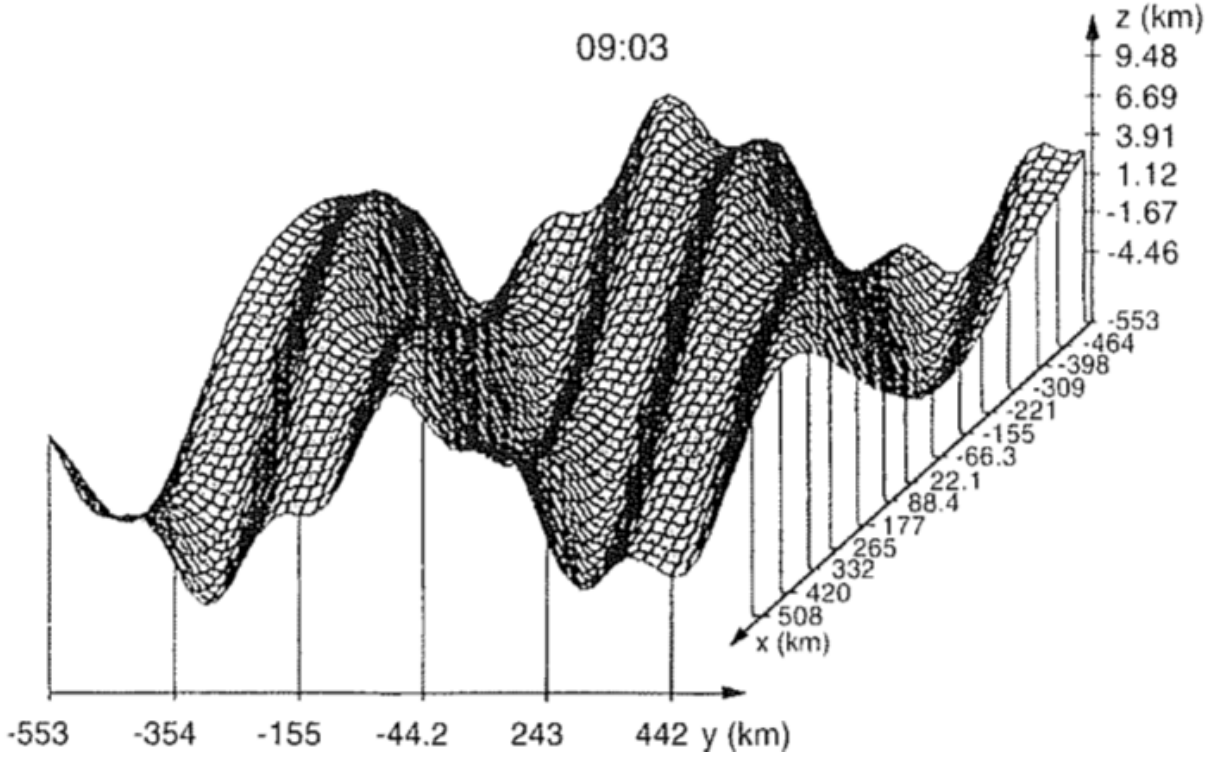
DARTMOUTH

MIT HAYSTACK OBSERVATORY

Traveling Ionospheric Disturbances (TIDs)

TID Modeled in the Ionosphere



Beley et al. 1995

What are they?

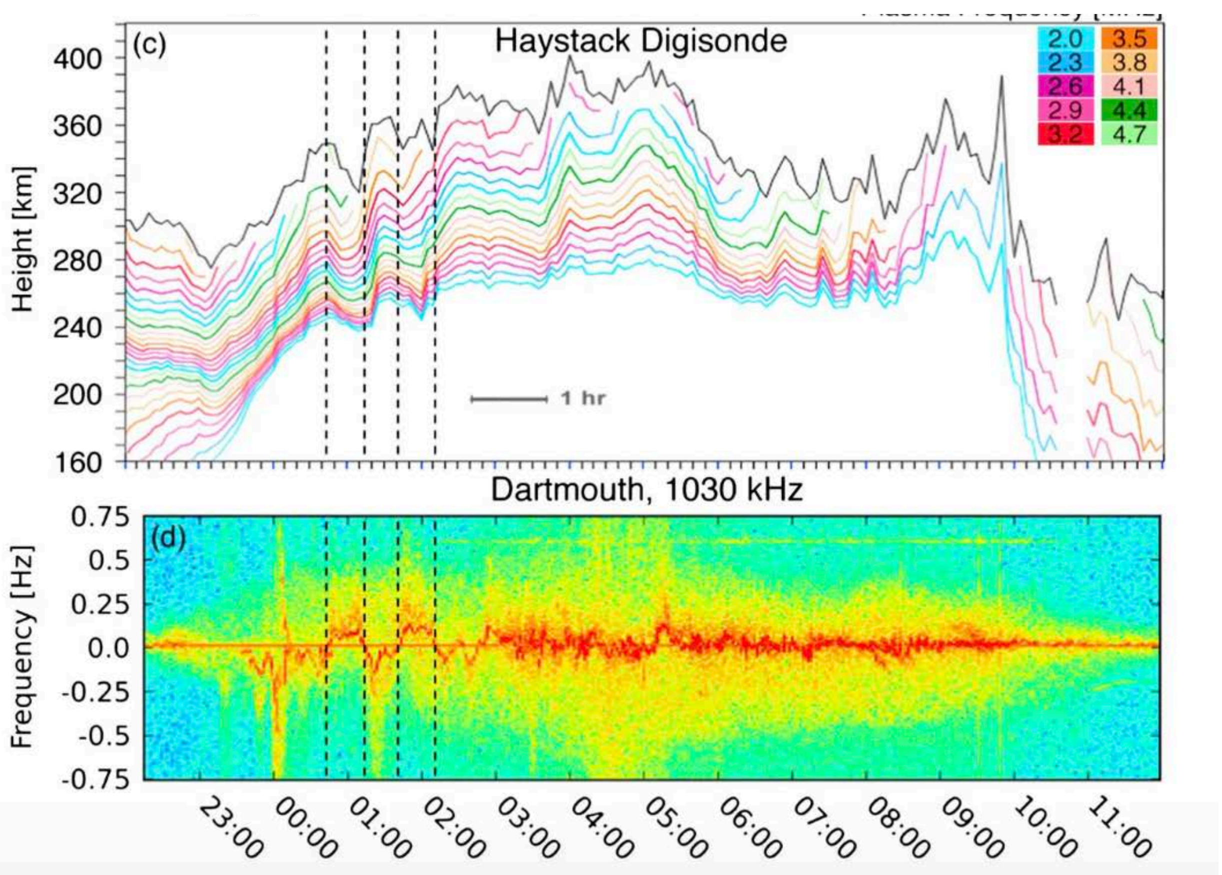
- Buoyancy waves driven by geomagnetic activity
- Convey and redistribute energy through the atmosphere

Why do they matter?

- Critical for understanding energy transfers in Earth's atmosphere
- Large disturbances can interfere with technology that relies on propagation through the atmosphere such as GPS

Motivation: Chilcote et al. 2015

Data Summary from Chilcote et al. 2015



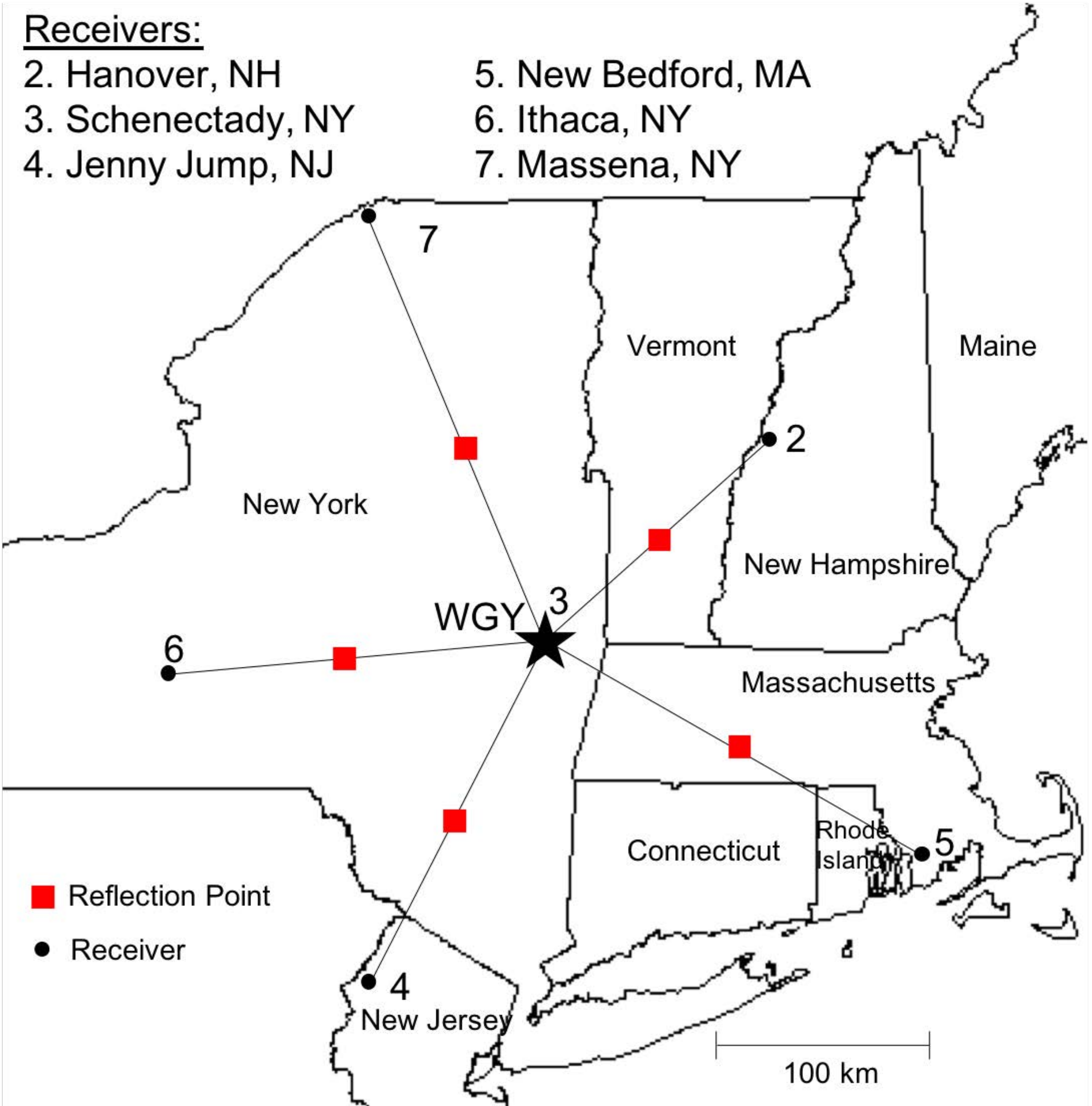
Chilcote et al. 2015:

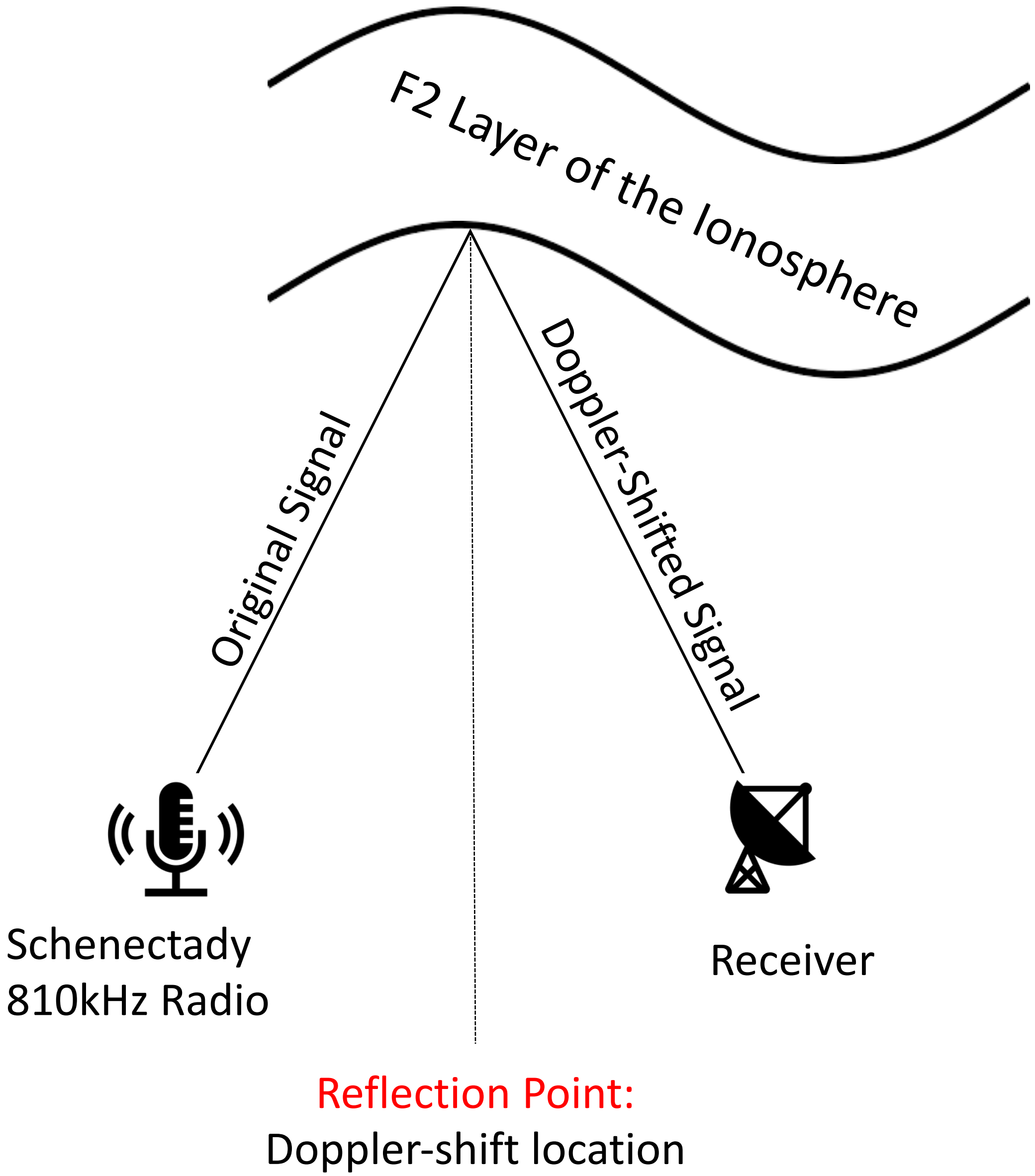
- **Successfully identified a TID** using Doppler–shifted signals
- Found a **discrepancy** between their **phase velocity** and GPS VTEC maps

Current Study:

- We have a **larger network, advanced analysis**, and **more events**
- Seek to **confirm the capabilities** of this technique and **identify further applications**
- Seek to **understand discrepancies** between GPS VTEC and this method

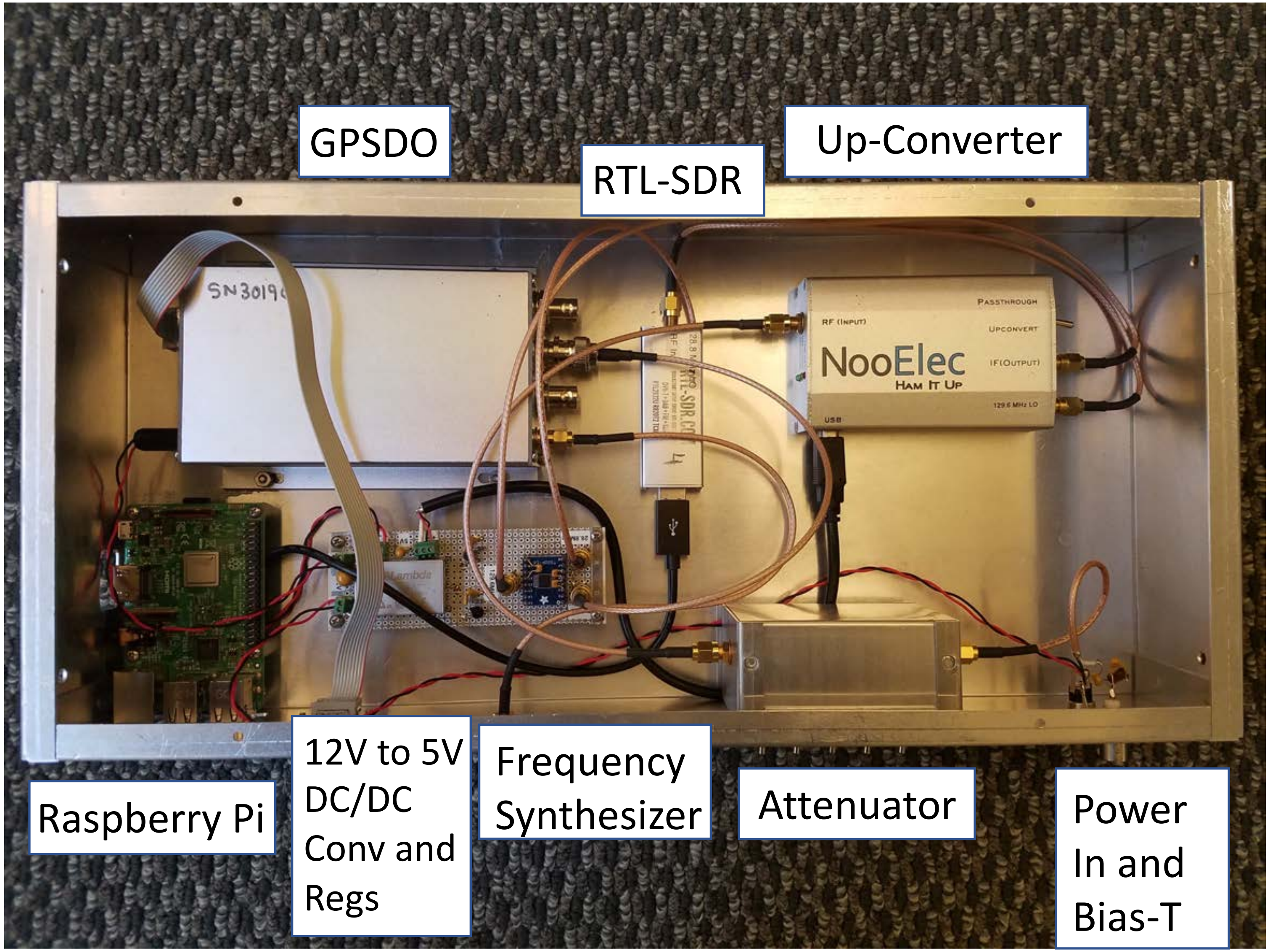
Map of Receiver Network:





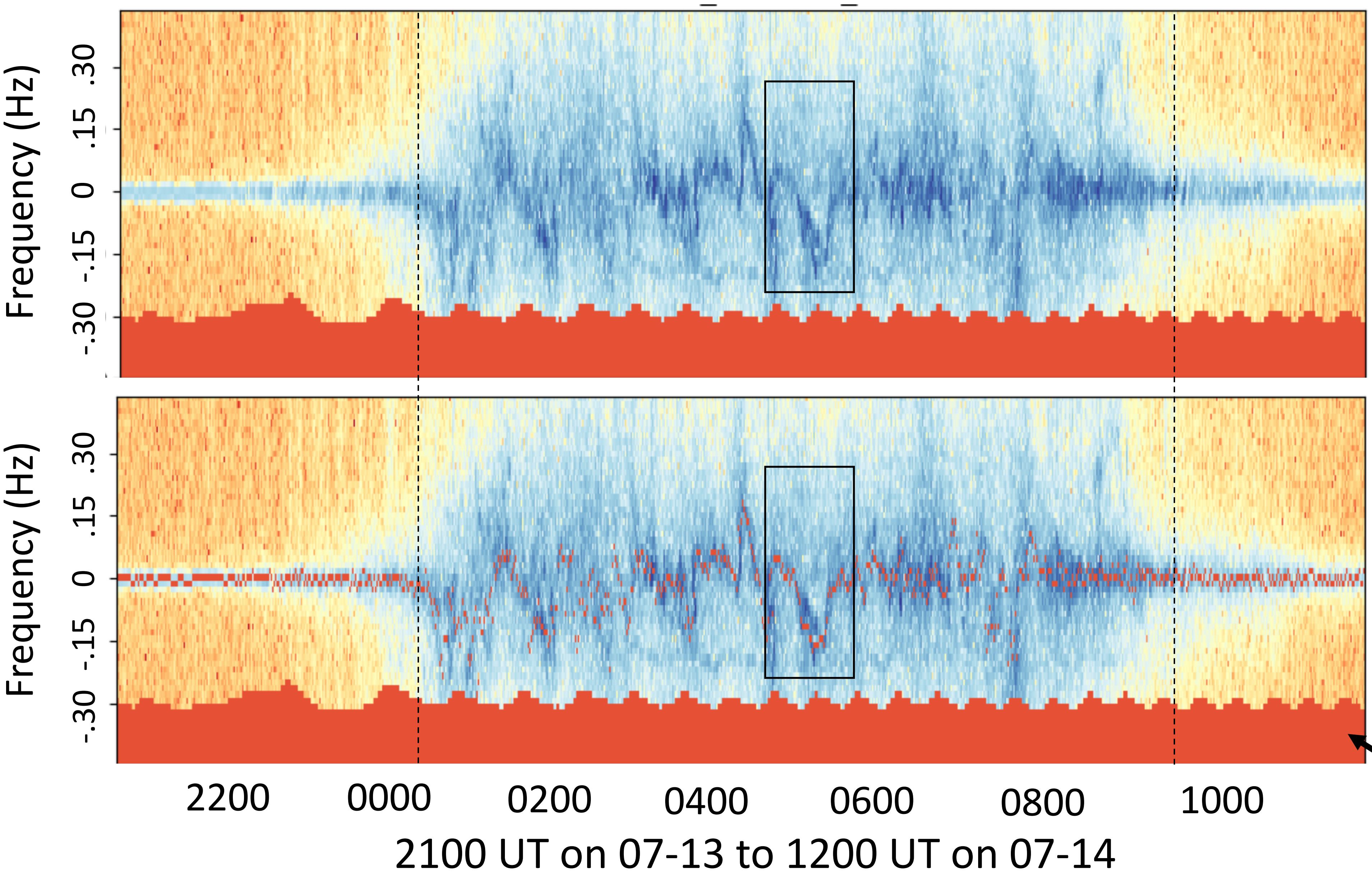
Instrumentation:

Receiver Antenna



Inside of AM Receiver

Methodology: 2020-07-13 to 2020-07-14



Raw data from the Hanover (2) station

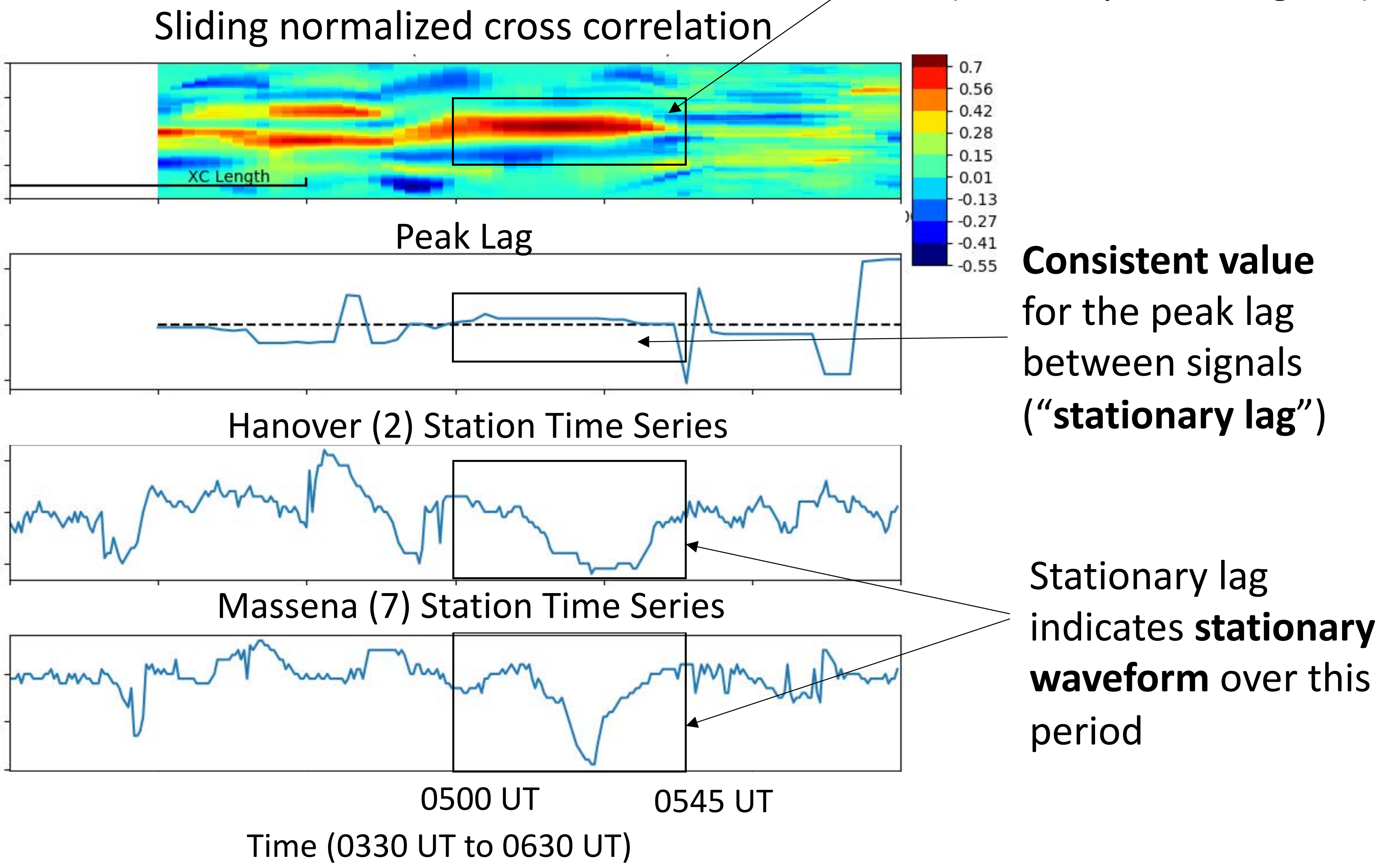
Raw data overlaid with the semi-automated tracked signal path

Correction from oscillation of 810kHz station

TID Characteristics Analysis: Step 1

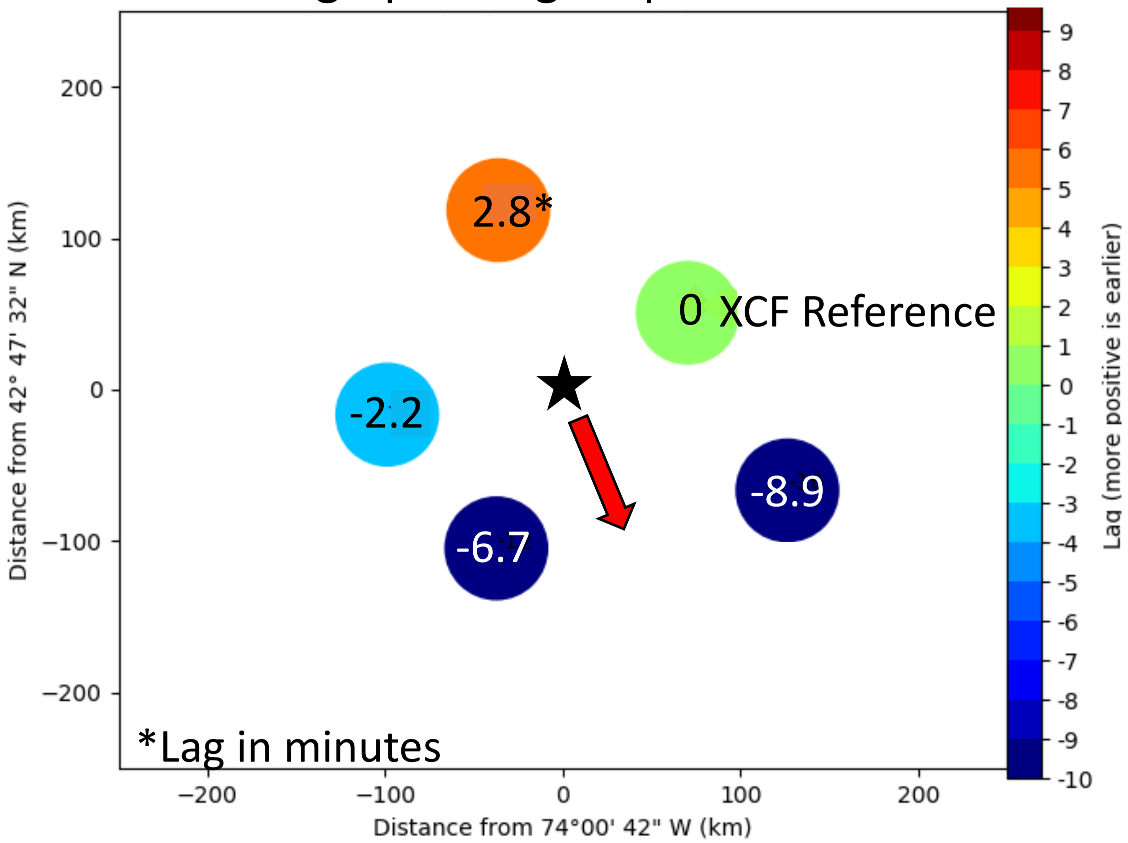
Procedure:

- **Sliding normalized cross correlation** with respect to the Hanover, NH (2) baseline signal
- Shared region of **stationary lag** identified



TID Characteristic Analysis: Steps 2 & 3

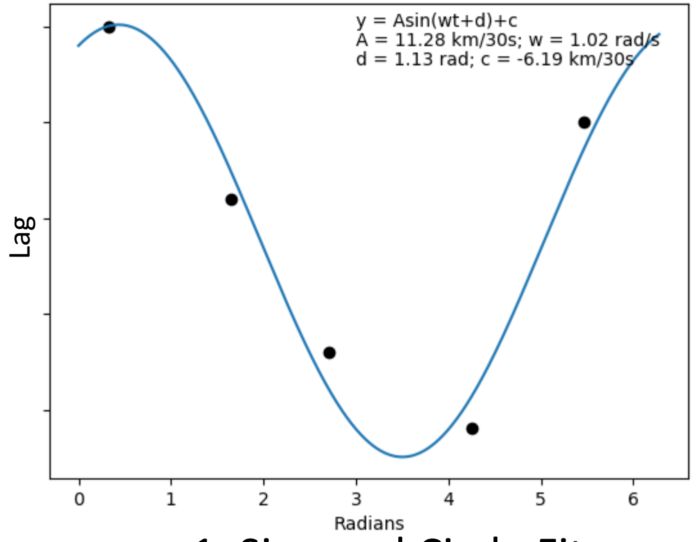
Geographic Lag Map 2020-07-14



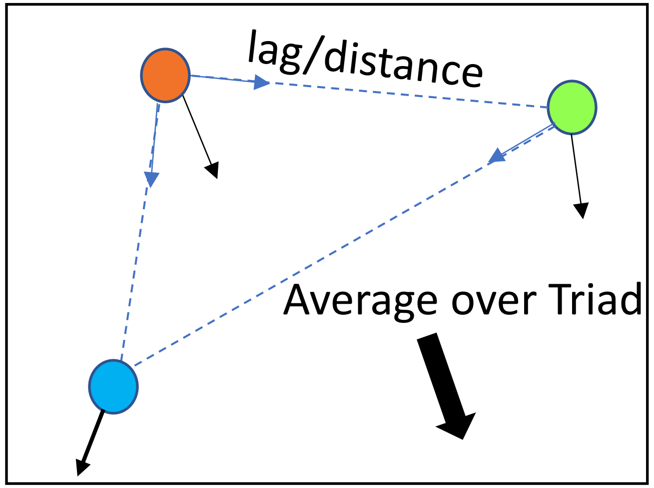
- Geographic Distribution of lag over stationary region
- AMD2 as reference for all cross-correlations (XCF)
- Positive (red/orange) values precede negative (blue) values

Phase Velocity:
300 m/s
Wavelength:
770 km
Direction:
SE

Phase Velocity and Direction Methods:



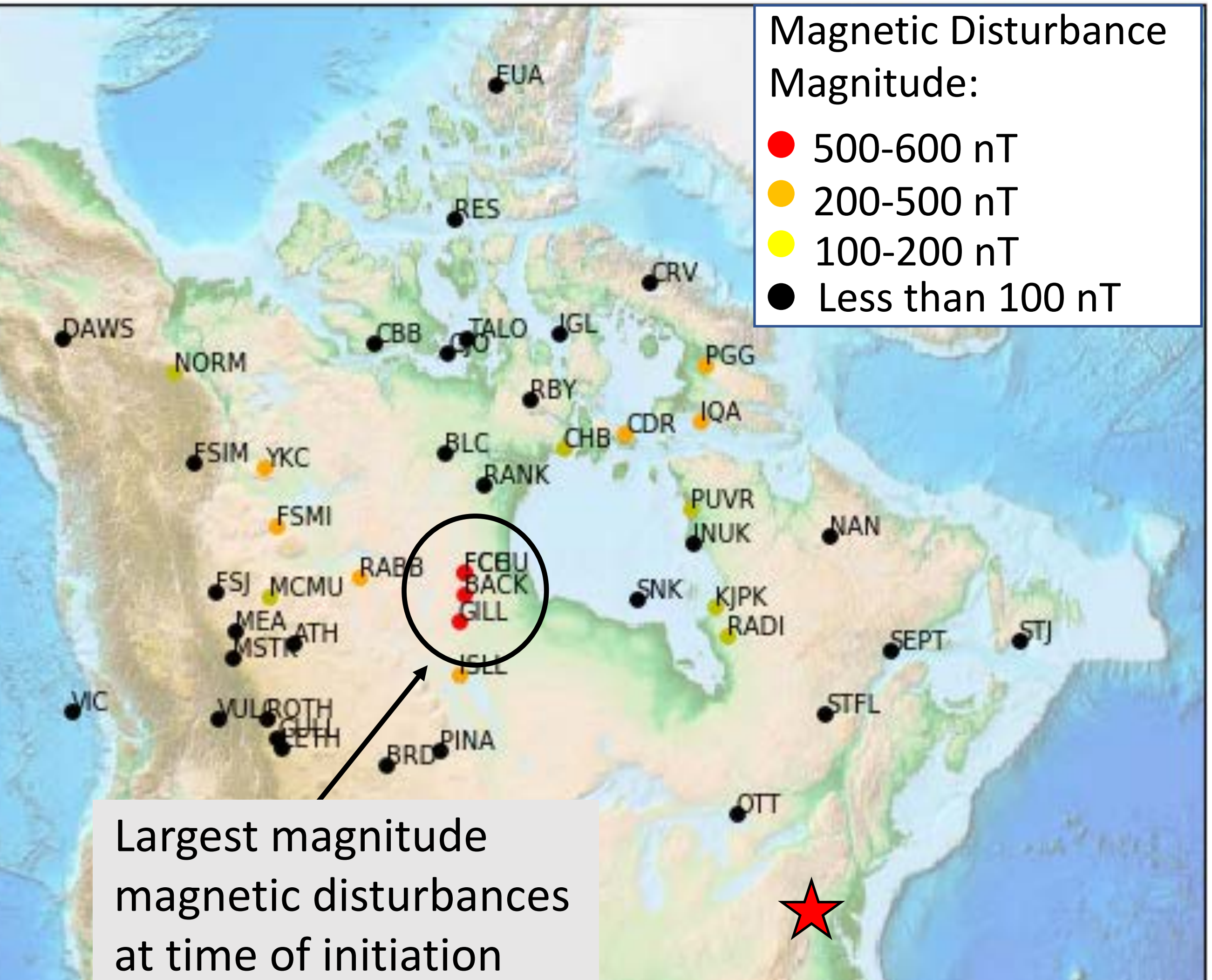
1. Sine and Circle Fit

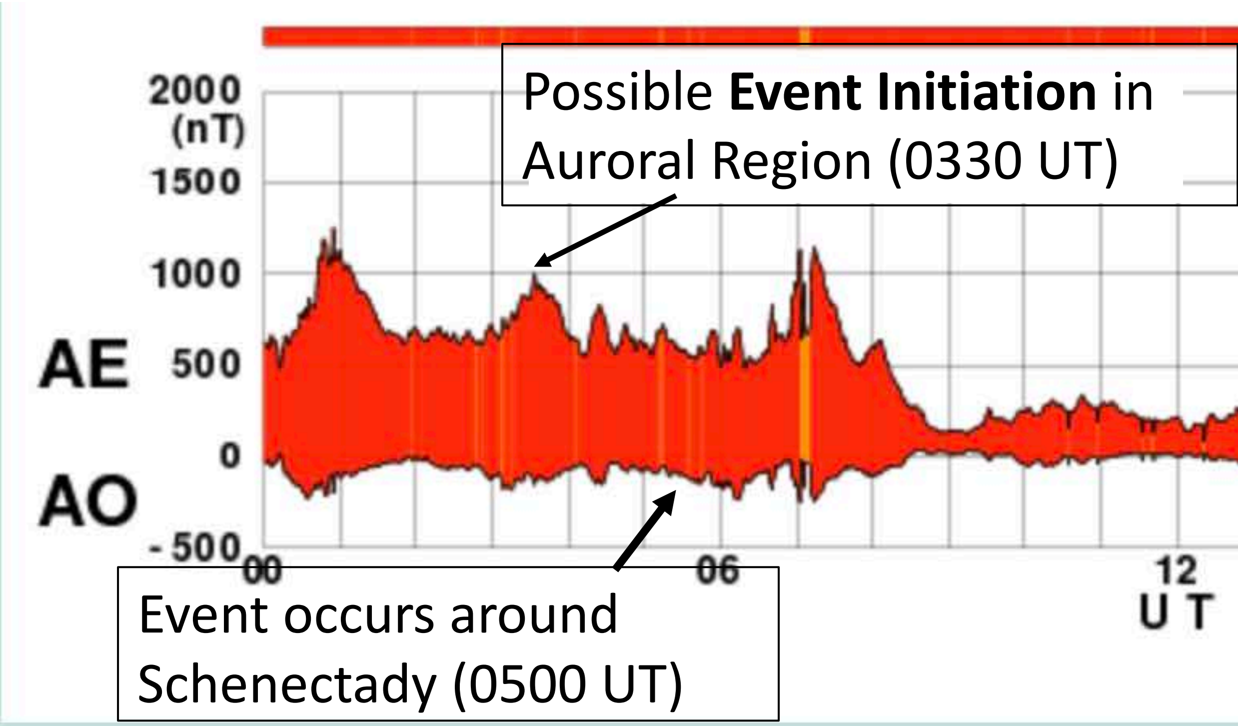


2. Triad Vector Averaging

Auroral Source Locating

Magnetometer Activity Location and Strength Map





Auroral Electrojet (AE) Index for 2020-07-14

- Distance from source to receivers is 2000km
- Phase velocity of wave 300 m/s
- Phase velocity and distance agree with initiation timing

Summary of Event Data: Collection Ongoing

Event Date	810 Hz Triad Phase Velocity	Potential Cause	GPS Phase Velocity
03/23/2020	559 SW	**Auroral**	485 S and W
05/06/2020	340 SE	**Auroral**	320 S and 190 E
07/14/2020	305 SE	**Auroral**	645 S and 165 E
09/09/2020	230 N	Unknown	170 N
09/22/2020	384 SE	Unknown	----
09/26/2020	406 S	**Auroral**	Two wavefronts: (1) 430 S and large zonal (2) 80W
09/27/2020	300 SE	**Auroral**	-----
09/29/2020	859 SW	**Auroral**	580 S
11/15/2020	463 WNW	Unknown	130 N
12/10/2020	529 S	Unknown	80 S and 60 W
12/29/2020	171 W	Unknown	215 S and 60 W
12/30/2020	235 NW	Unknown	145 N and 80 W
1/26/2021	289 SE	**Auroral**	130 W

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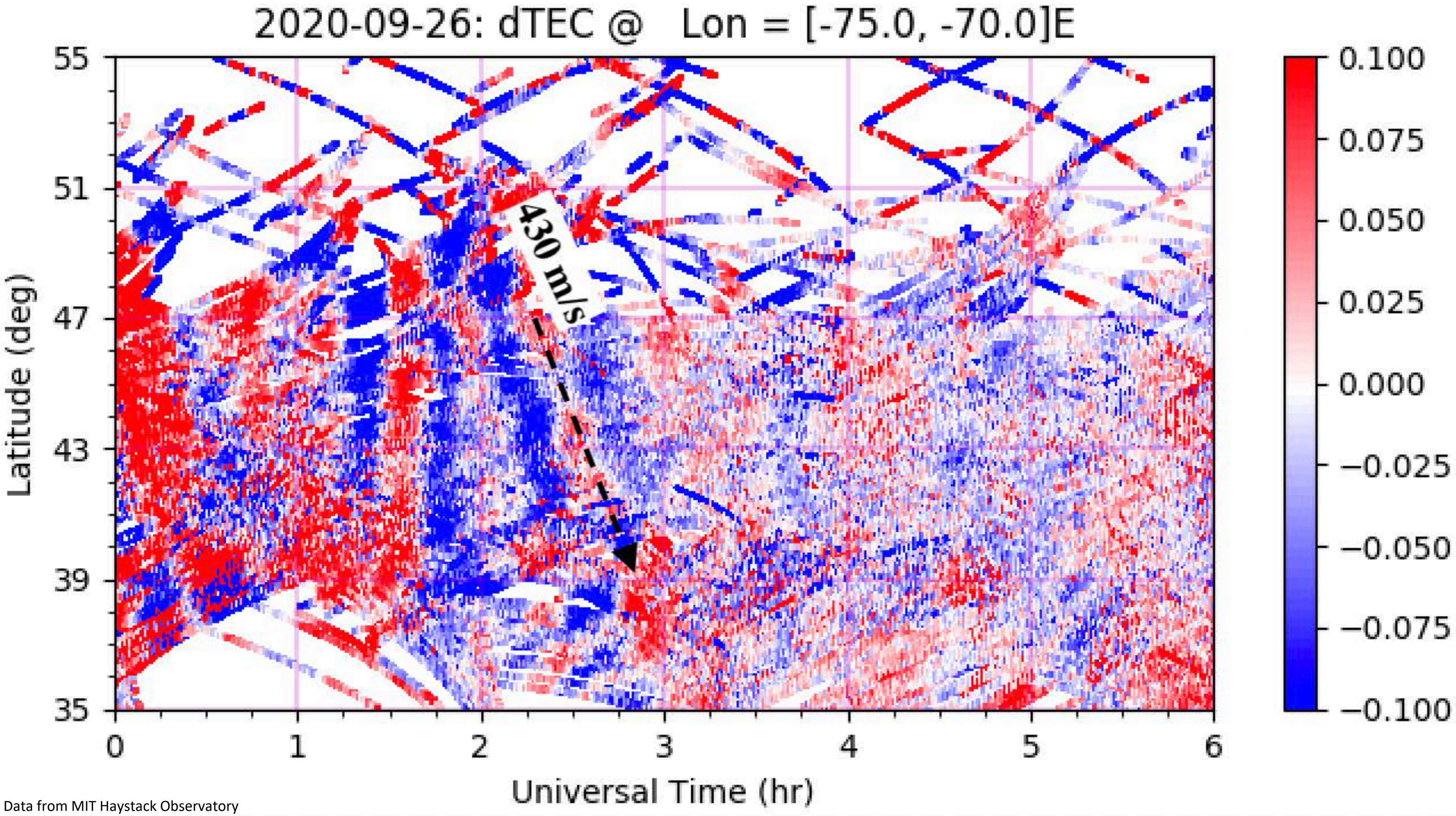
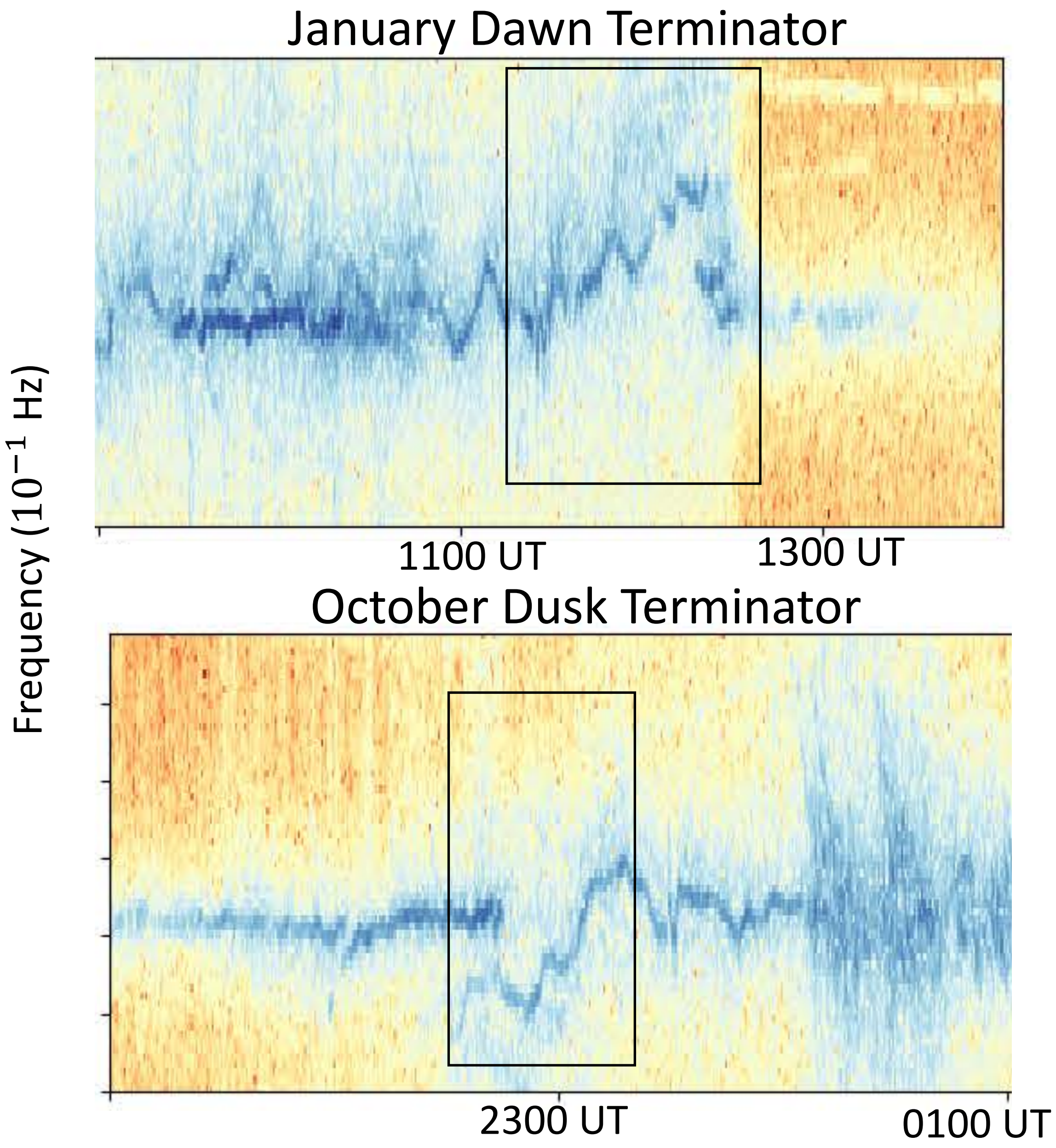
Technique Highlights: GNSS TEC



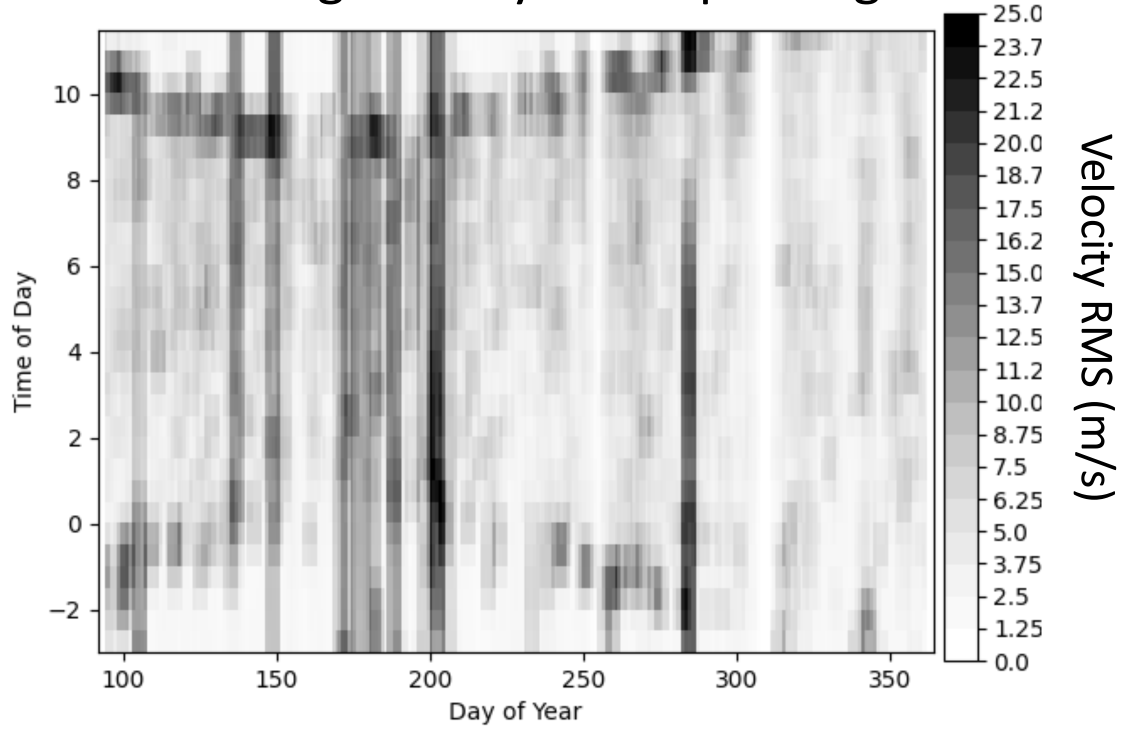
Velocity (S) and **phase velocity (430 m/s)** corroborate our 406 m/s (S).

Data from MIT Haystack Observatory

Terminator Features (1560 kHz)



Year-Long Activity RMS Spectrogram



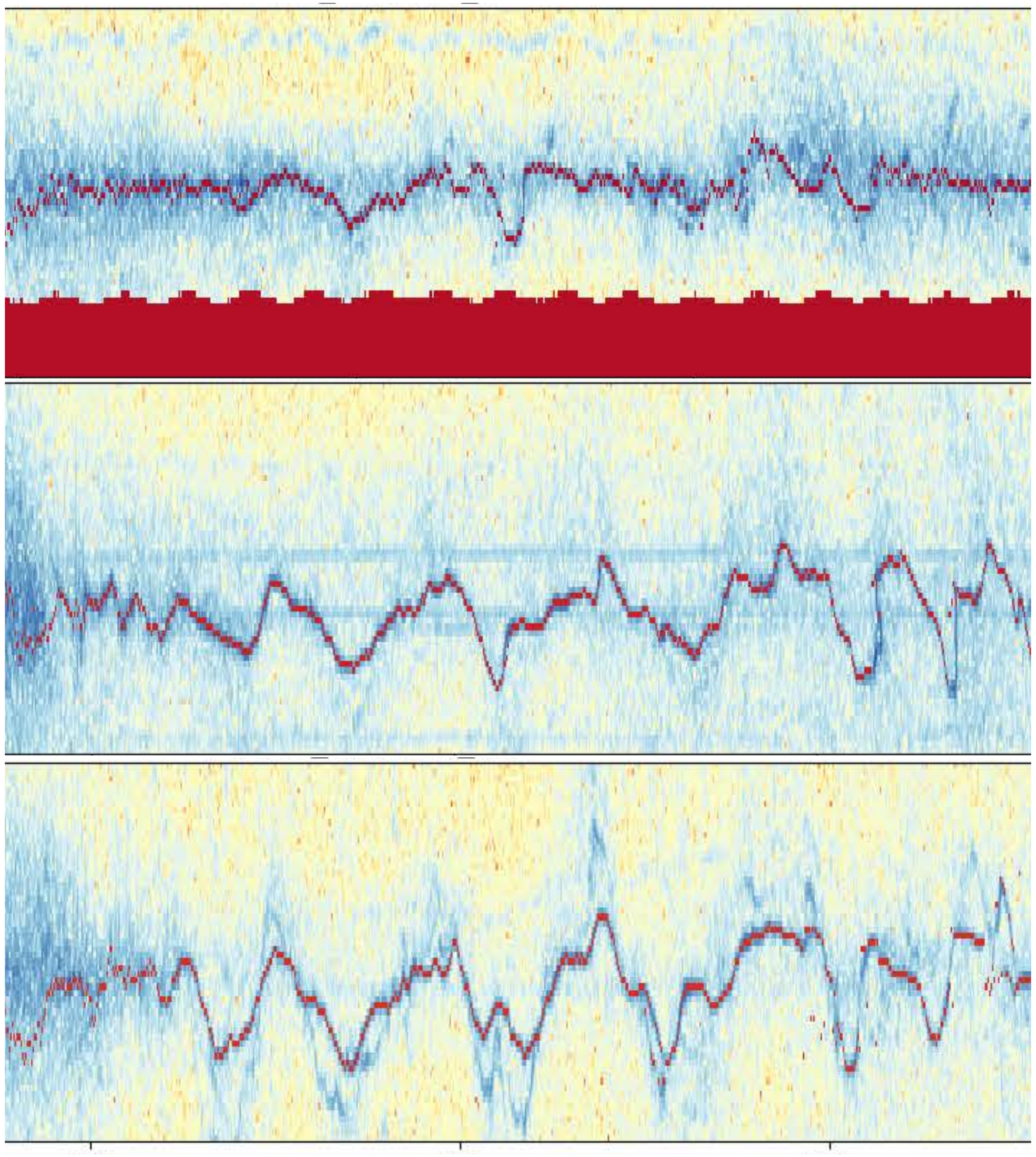
Terminator **seasonal dependence** indicative of **photochemical** source (Mathew et al. 2017; Kouba and Knizova 2017)

AM Sounding Frequency Comparison

810 kHz

1080 kHz

1560 kHz



Higher Frequency Transmission:

- Higher **Amplitude** Doppler Shifts
- Larger Number of **Periods**
- More **Frequent Events** Identified

Conclusions:

1. We have succeeded in identifying TIDs using Doppler-shifted AM radio transmissions

2. In most of these cases, we find that the direction of propagation agrees with other established TID tracking methods

3. We can identify auroral sources for TIDs in some cases

4. Seasonal dependence of terminator features at dawn and dusk characterizes them as products of photochemistry effects

5. Higher sounding frequencies (top half of the AM band) create clearer Doppler shifts for analysis

Thank you to to Michael Chilcote for sharing resources from his original study.