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AFRL

Clear E Layer Impacts from Conventional Surface Explosions

Kenneth S. Obenberger (1), Danny Bowman (2), and Fransiska Dannemann Dugick(2)

(1) AFRL - Space Vehicles Directorate; (2)Sandia National Laboratories

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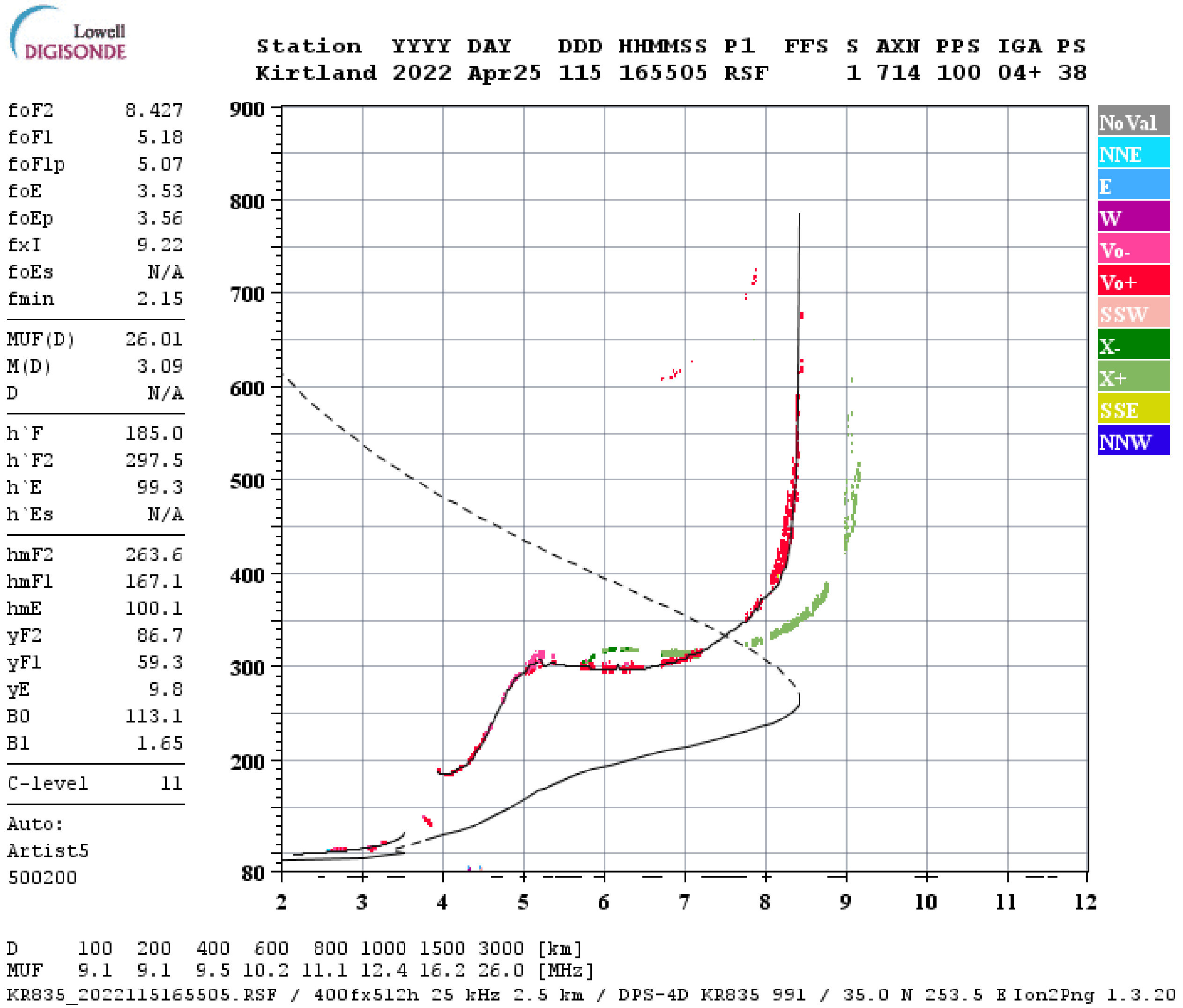
Abstract

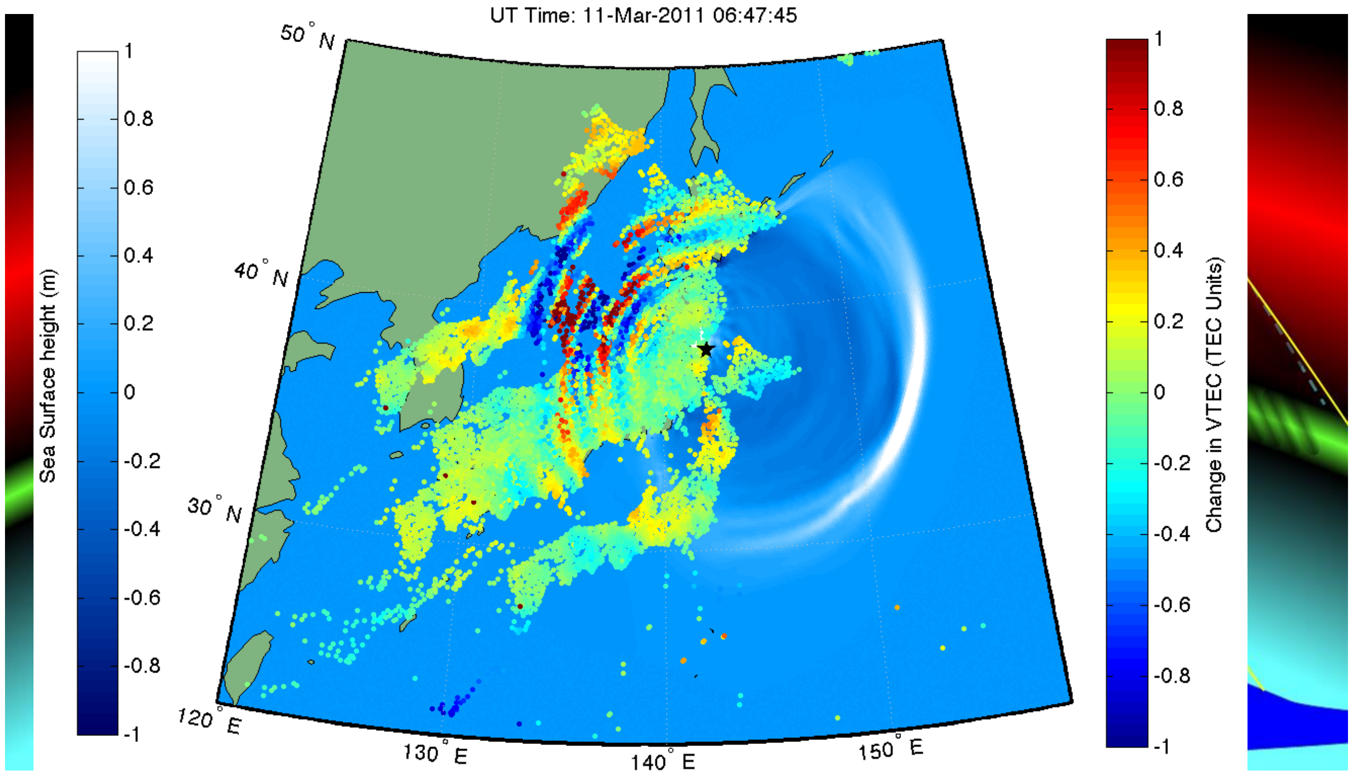
We present Doppler radar measurements of the lower ionosphere (~100 km) which show strong impacts from infrasound generated by 1 ton TNT equivalent explosives. The explosives were detonated at the Energetic Materials Research and Testing Center (EMRTC) test range just west of Socorro. We present three different experiments spanning 2019 to 2022. For each experiment we used multiple receivers spread over a few hundred km and an ionospheric sounder, which operated a pulsed Doppler radar between 2 and 4 MHz. Each receiver provided a unique measurement of the displacement of an ionospheric isodensity layer. As infrasound from the explosives reaches the ionosphere they displace the electrons, producing a detectable signature. We find that the detectability of each shot depended strongly on the geometry of the sounder/receiver and is likely influenced by wind filtering and/or terrain features.

The Bottom Side Ionosphere

- Bottom side ionosphere is somewhat predictable
- The electron density profile is monitored for both scientific and space weather situational awareness
- Can display highly dynamic behavior on a range of size/time scales
- For vertical propagation a radio wave is reflected when it reaches a plasma with plasma frequency equal to the radio frequency
- Enables monitoring of isodensity movement through Doppler measurement



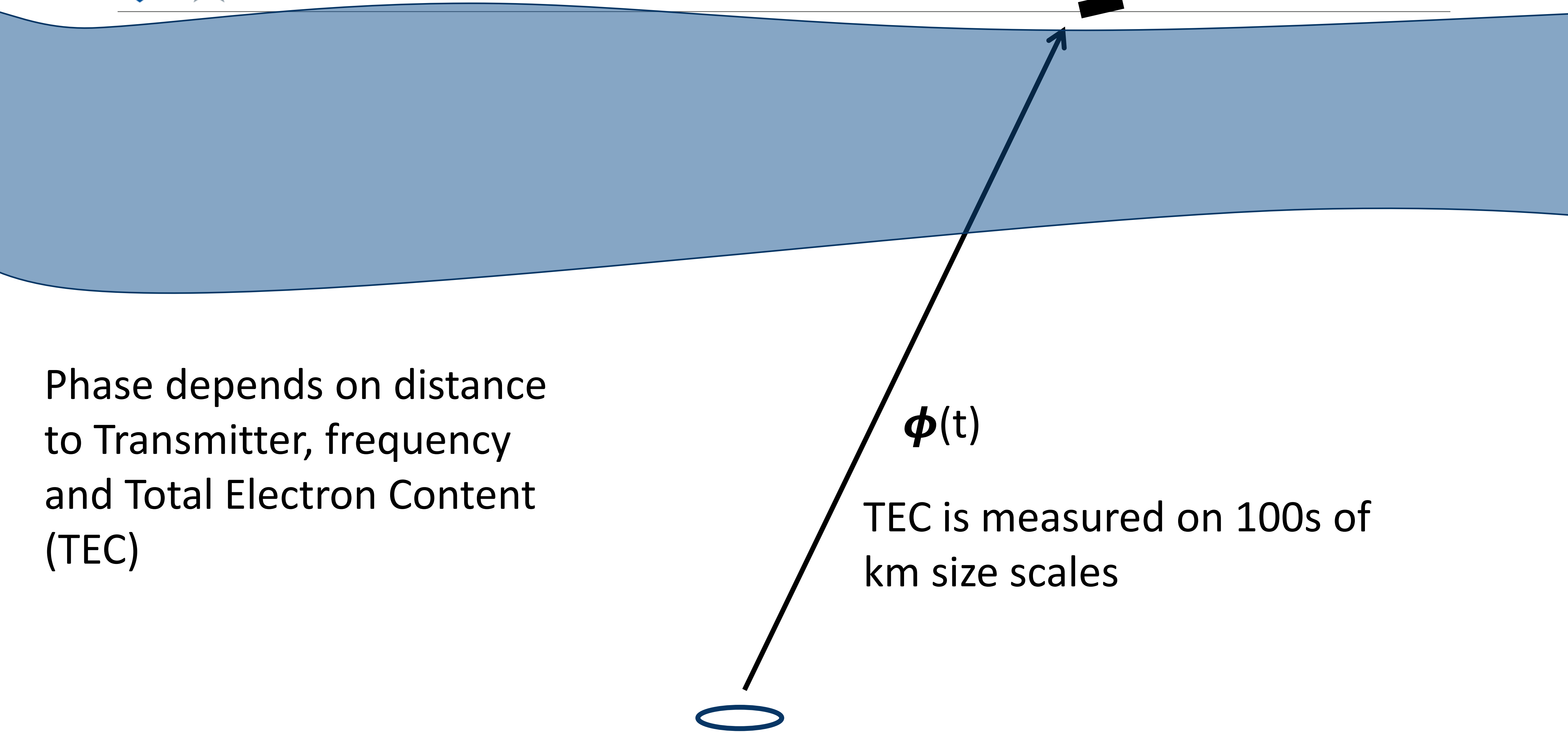
Ionospheric Effects from Atmospheric Waves



NASA / JPL-Caltech

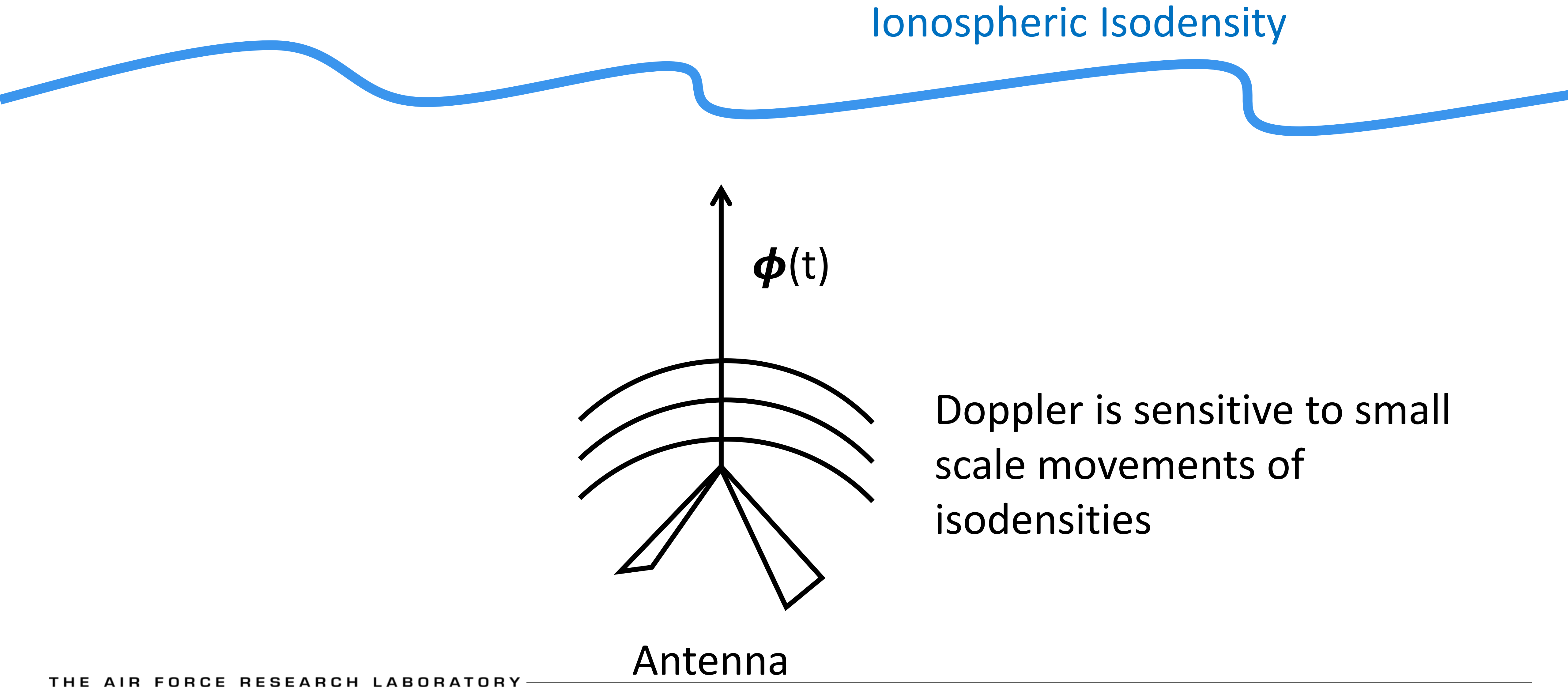
- Atmospheric gravity and acoustic waves propagate to the ionosphere and couple to the ionospheric plasma
- Electrons are ”sloshed” around as the waves pass through
- Electrons interact strongly with RF
- GNSS receivers can monitor total electron content (TEC)
- An HF Doppler radar can monitor an isodensity as it moves around due to propagating wave

How GNSS TEC works



Phase depends on distance to Transmitter, frequency and Total Electron Content (TEC)

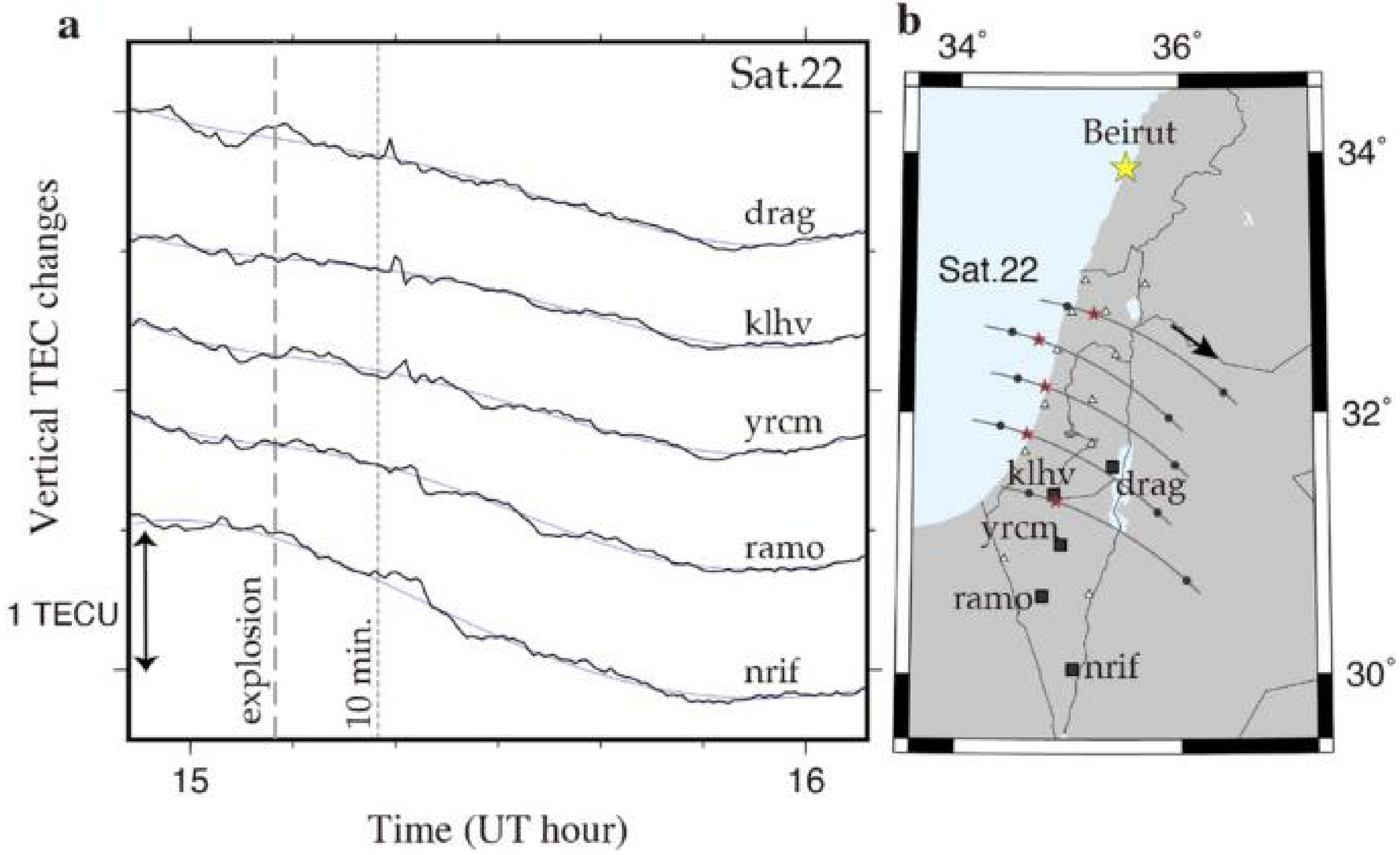
How Ionospheric Doppler Radar Works



Doppler is sensitive to small scale movements of isodensities

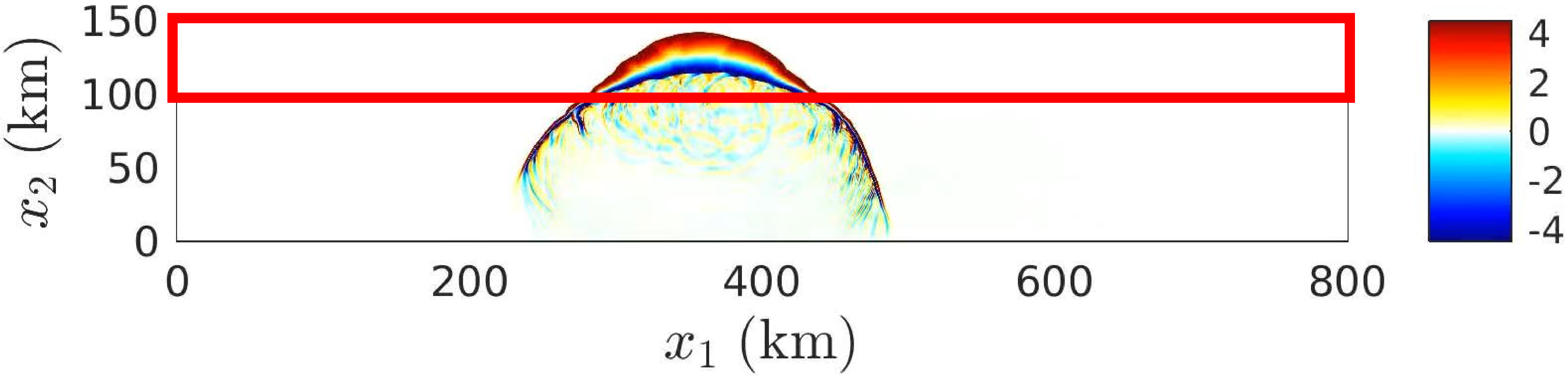
Can we use RF measurements of the ionosphere to ”listen” to impulsive tropospheric events – An RF Microphone

- Advantages
  - Can be done from very long ranges
  - Only need to wait for signal to reach the ionosphere
  - Can probe region directly
- Known
  - Tsunamis
  - Earthquakes
  - Volcanoes
  - Nuclear Explosions
  - kTon chemical explosions
  - Storms
- Unknown
  - Pretty much everything else



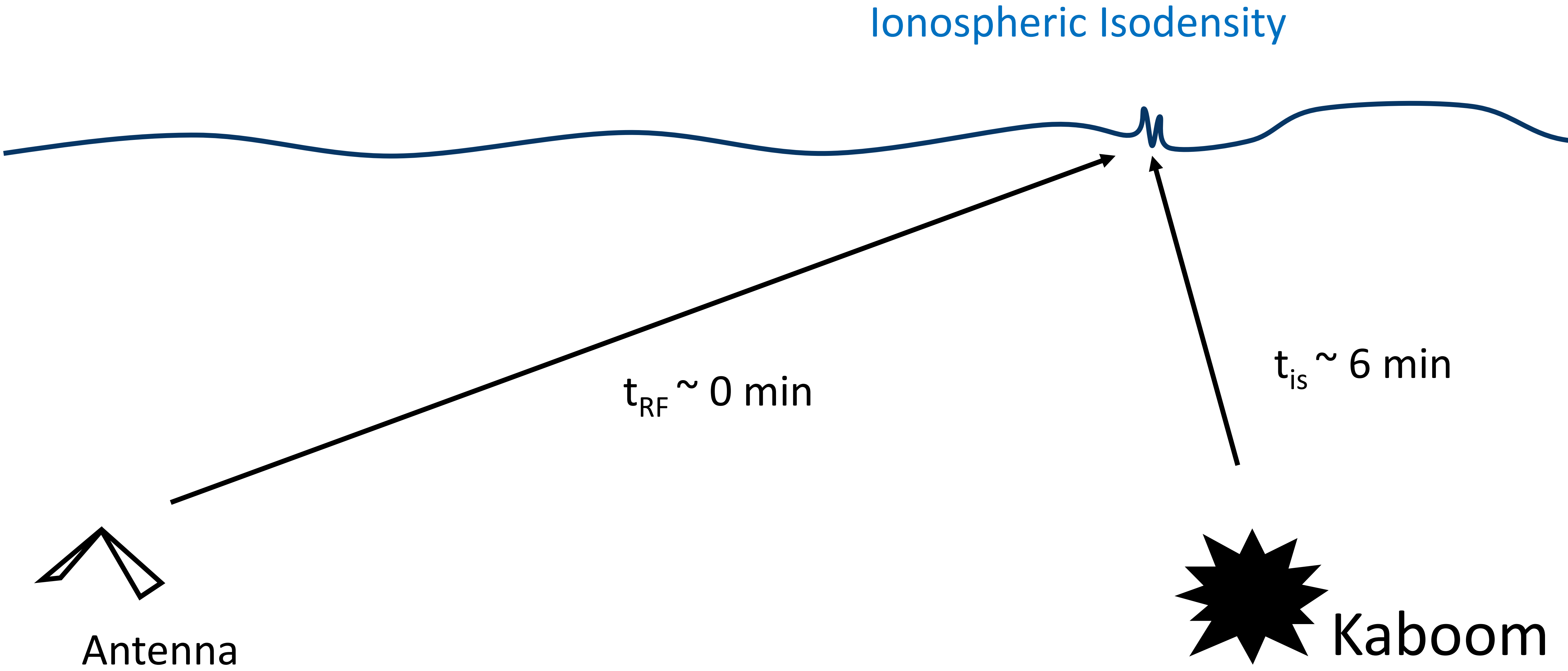
Kundu et al. 2021

Can we use RF measurements of the ionosphere to ”listen” to tropospheric events – An RF Microphone

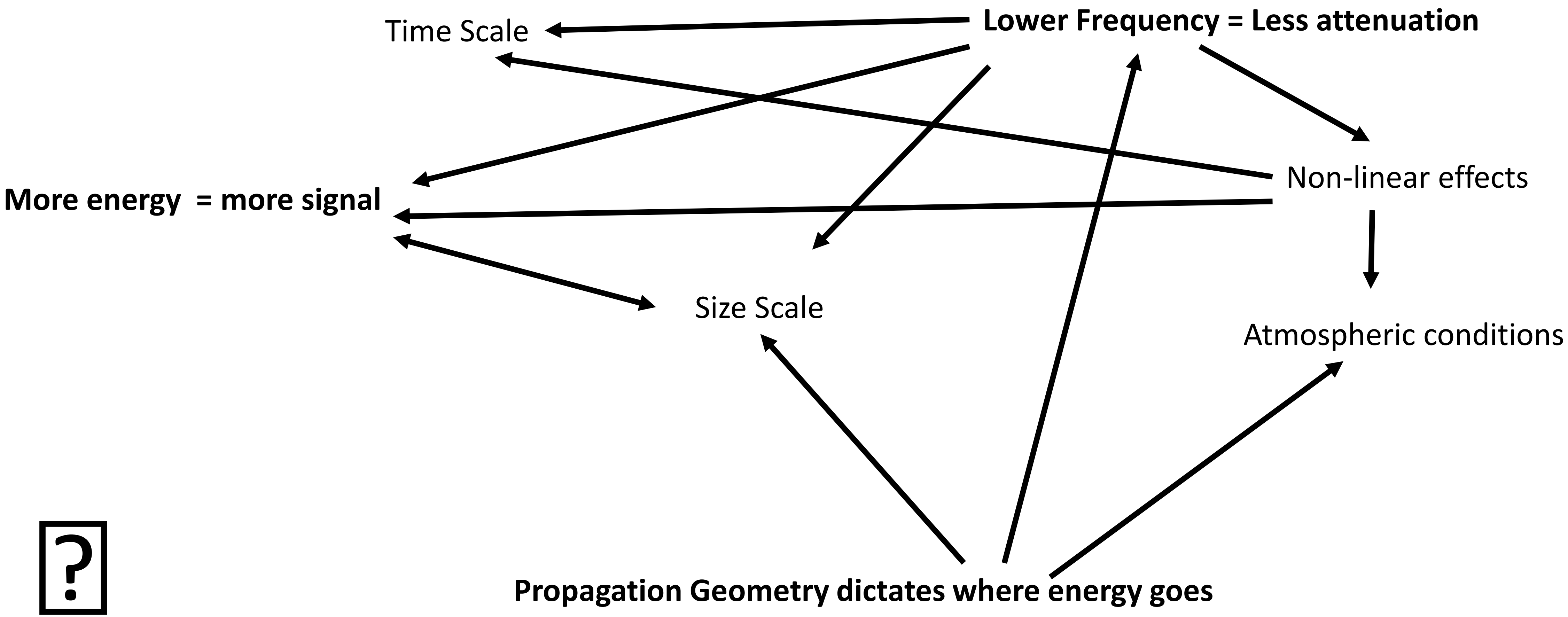


Sabatini et al. 2019

Remote sensing kabooms



Detectability is Complicated (SNR at location and frequency)



Big events

- Pros
  - More kinetic energy
  - Peak at lower frequencies
    - Propagate farther
    - Propagate higher where they interact with more plasma
    - Require lower cadence data
- Cons
  - Lots of sources of noise in frequency band
  - Practically impossible to produce in controlled setting

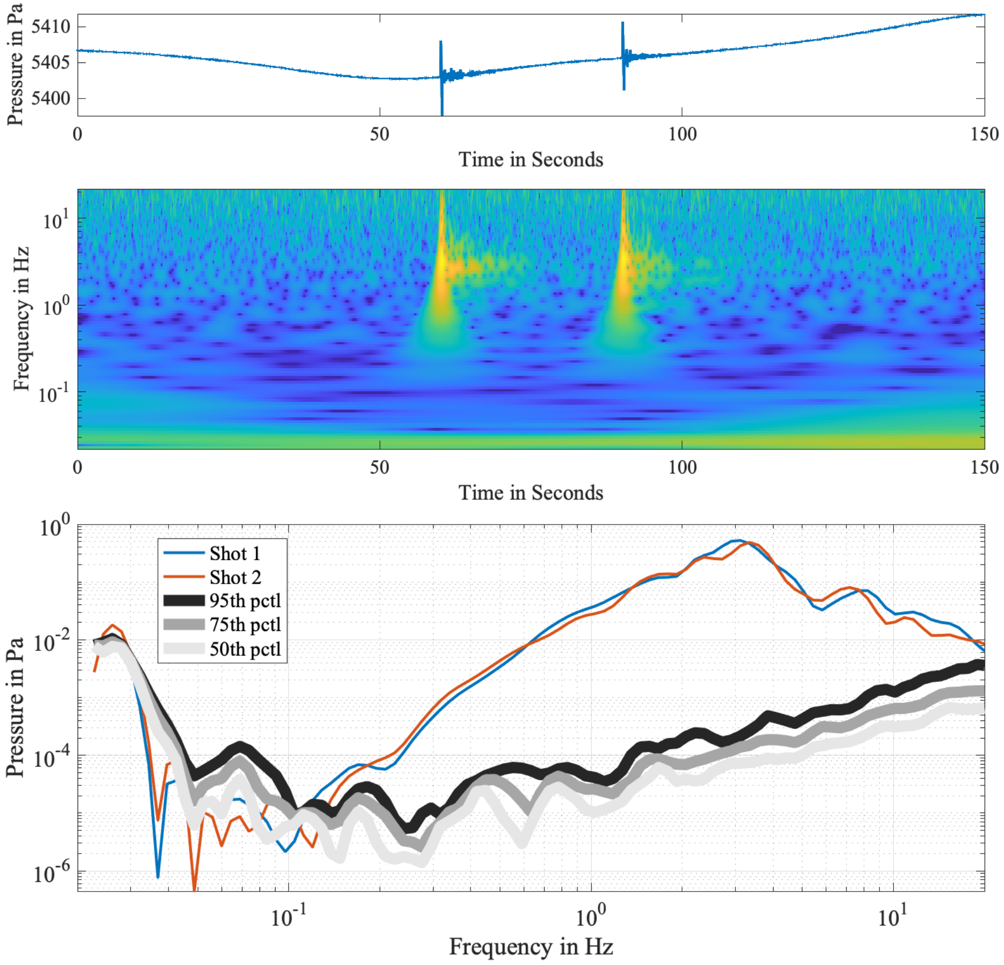
Small events

- Pros
  - Non-linear period lengthening may help signal reach ionosphere
  - Cheap and easy to produce in controlled setting
- Cons
  - Low energy
  - High frequency
  - Lots of sources of noise
  - Requires higher cadence data

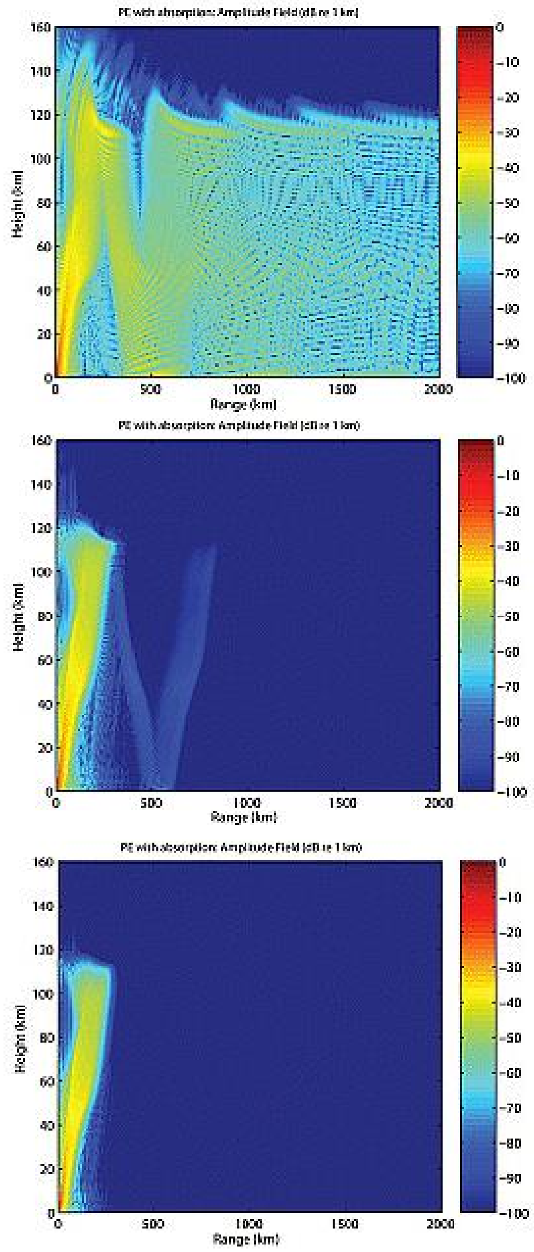
Higher frequency requires Lower Altitude

Time series and spectra of two 1 ton TNT equivalent shots.

Measured from a balloon roughly 10 km horizontal and 20 km vertical from site.

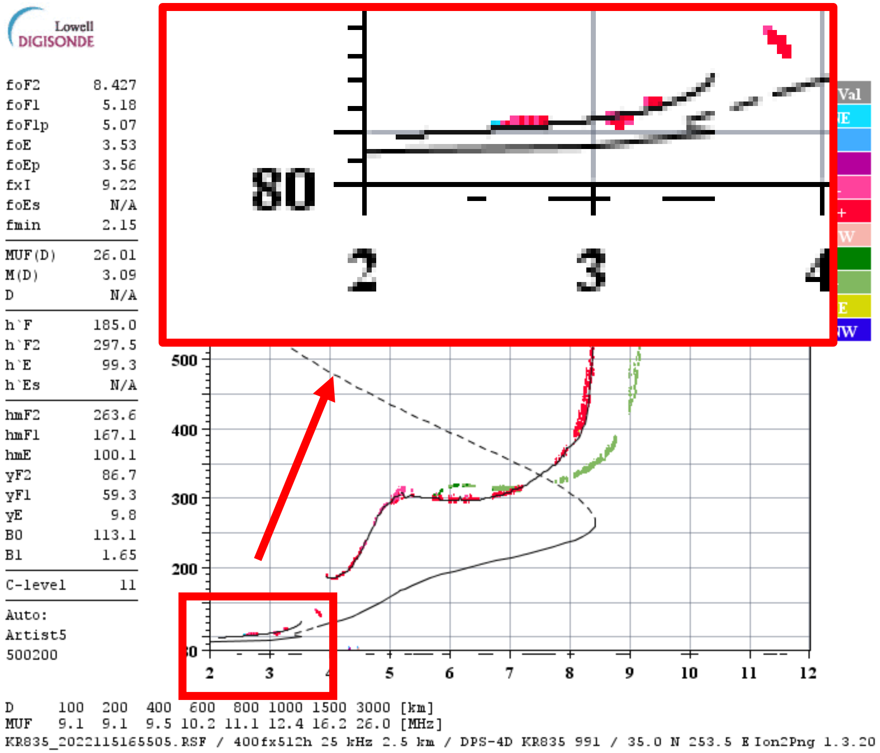


Obenberger et al. 2022

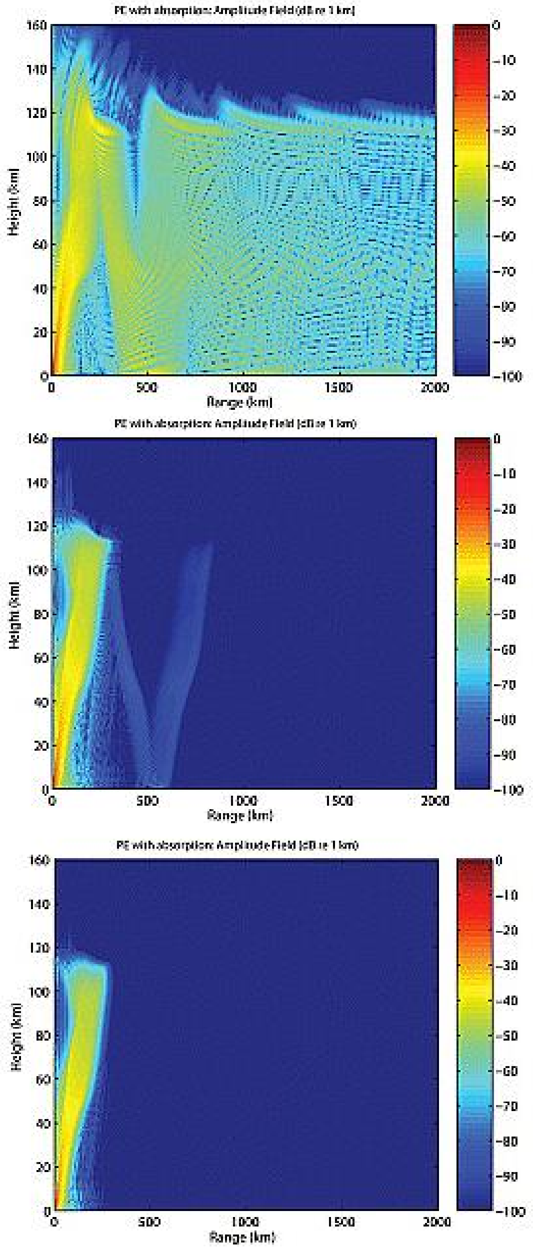


Bass et al. 2007

Higher frequency requires Lower Altitude



- For frequencies > 0.1 Hz we should target the E region
- Unlikely to see much signal if we integrate through entire ionosphere (GNSS/GPS)
- A good approach may be to use Doppler radar of E layer ~100 km
- Directly probe region of interest
- Should stay below 3 MHz



0.1 Hz

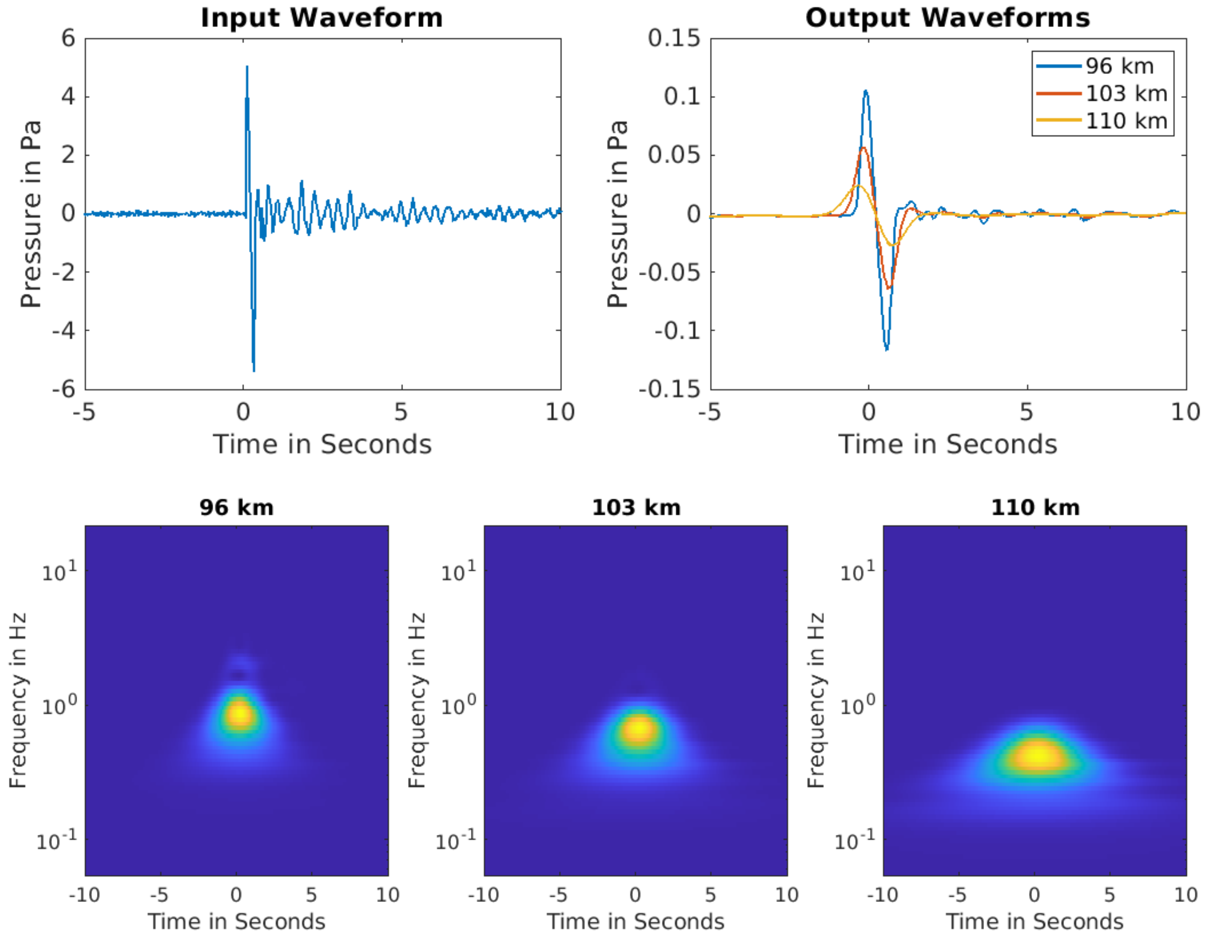
0.5 Hz

0.9 Hz

Bass et al. 2007

Modeling waveform evolution using infraGA

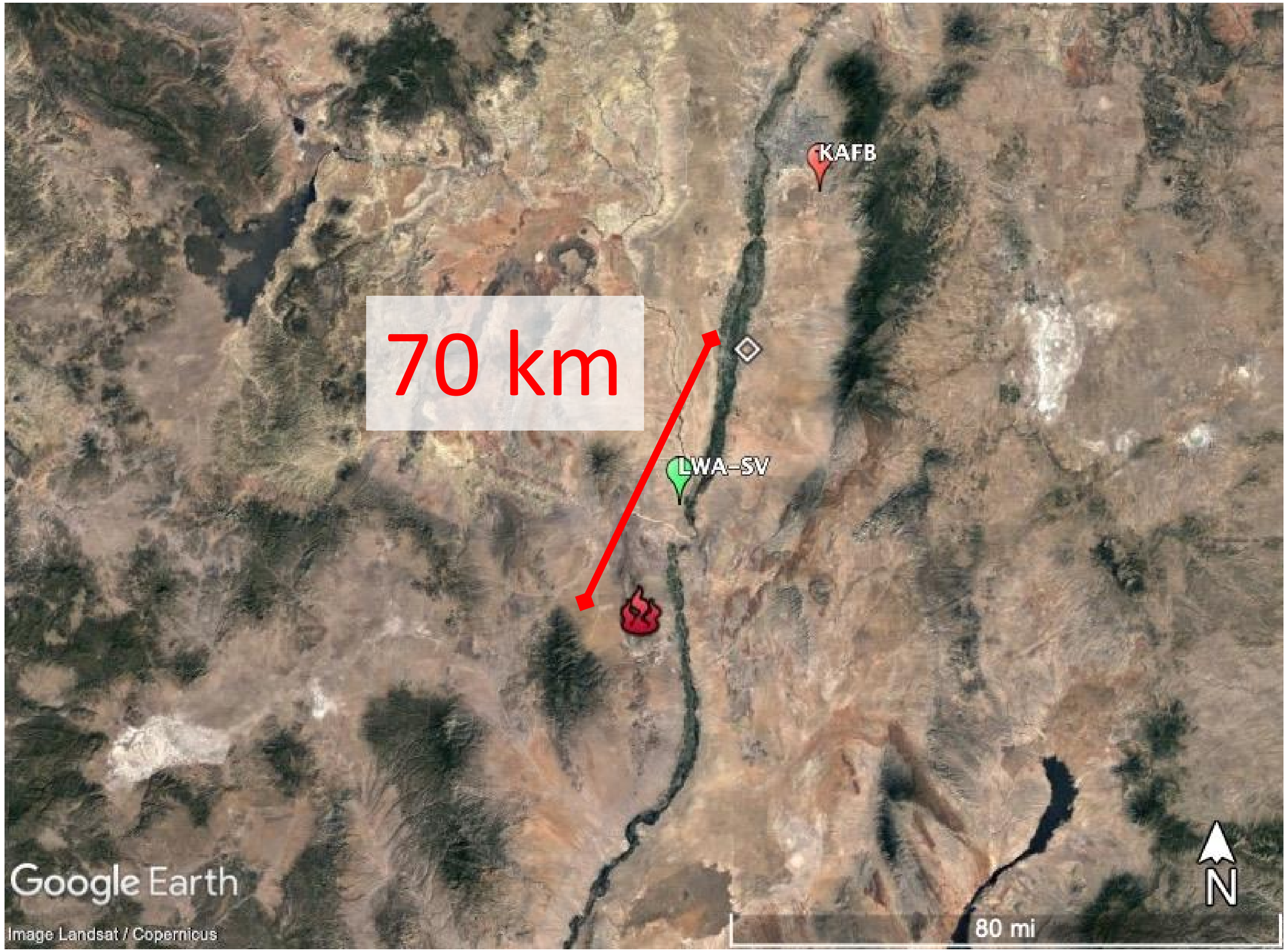
- We can model the waveform as it propagates to the E layer using the infraGA/GeoAC package
- Starting with the waveform measured at a balloon
- Waveform output shown for at 96, 103 and 110 km
- Peak frequencies at 0.9, 0.7 and 0.4 Hz respectively



See Blom & Waxler, 2012, 2017; Blom, 2019; P. Blom & Waxler, 2021 for details about the package

Turbowave I and II and Humming Lobo

- Sandia NL led experiments (Bowman and Danneman)
- Multiple 1 ton TNT equivalent shots at EMRTC in Socorro NM
- microbarometers located at ground sites and on balloons
- AFRL tagged along with ionospheric sounders and receivers



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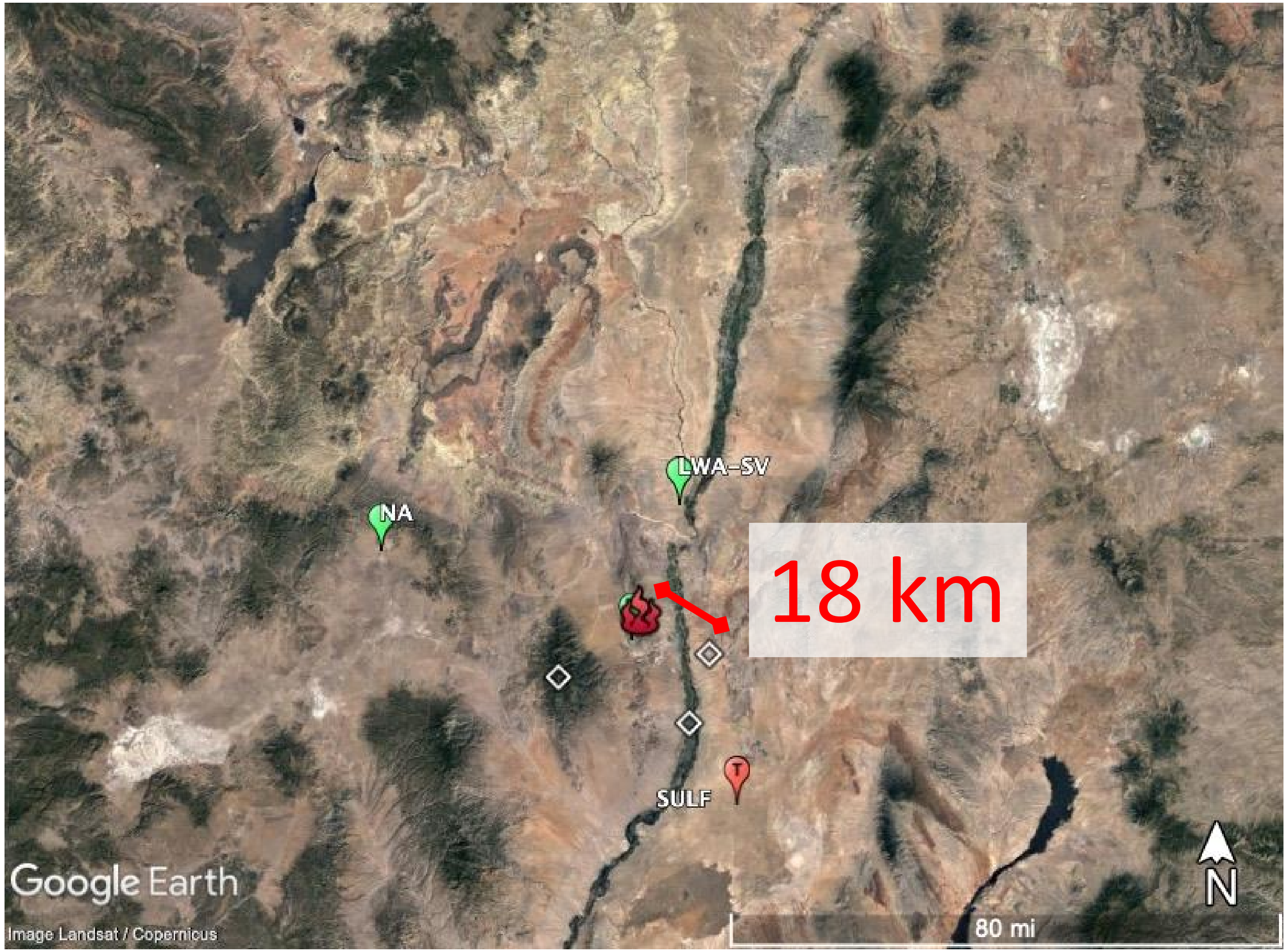
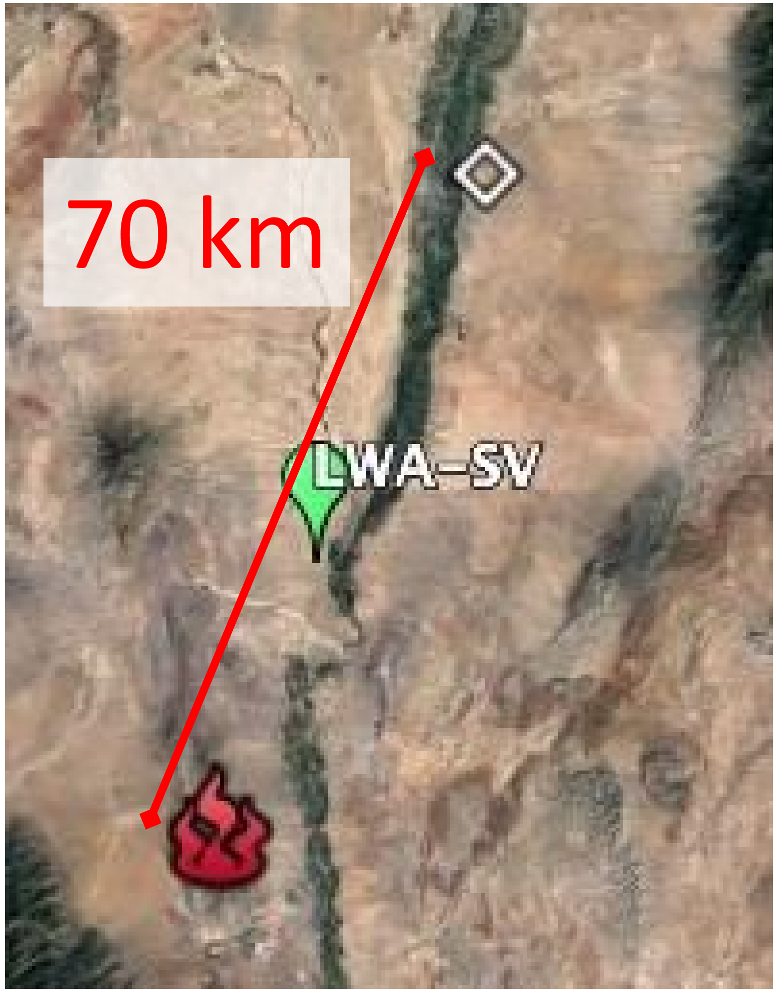
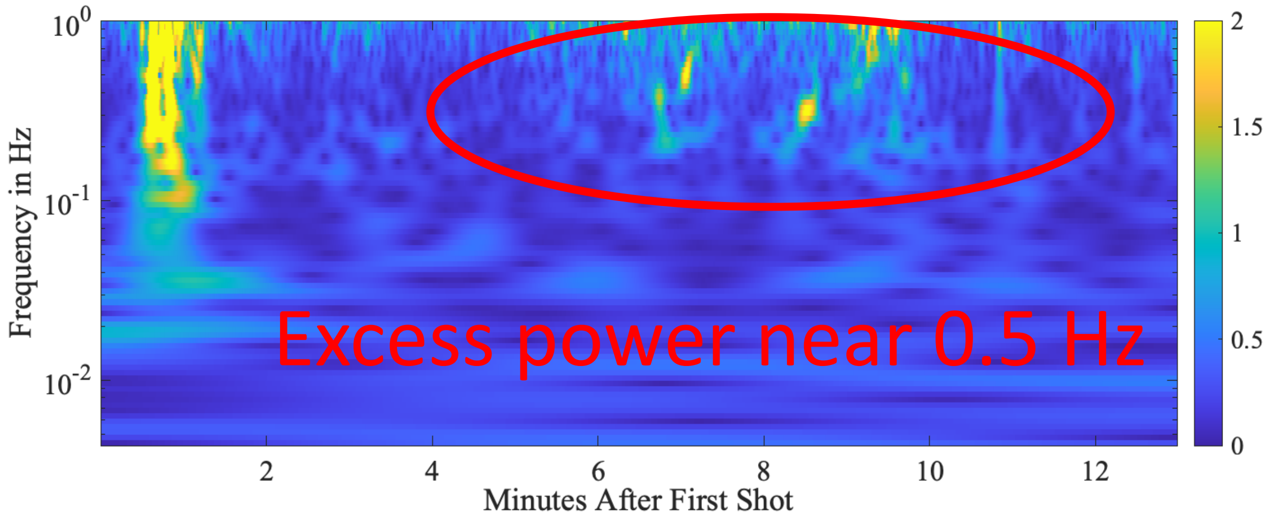


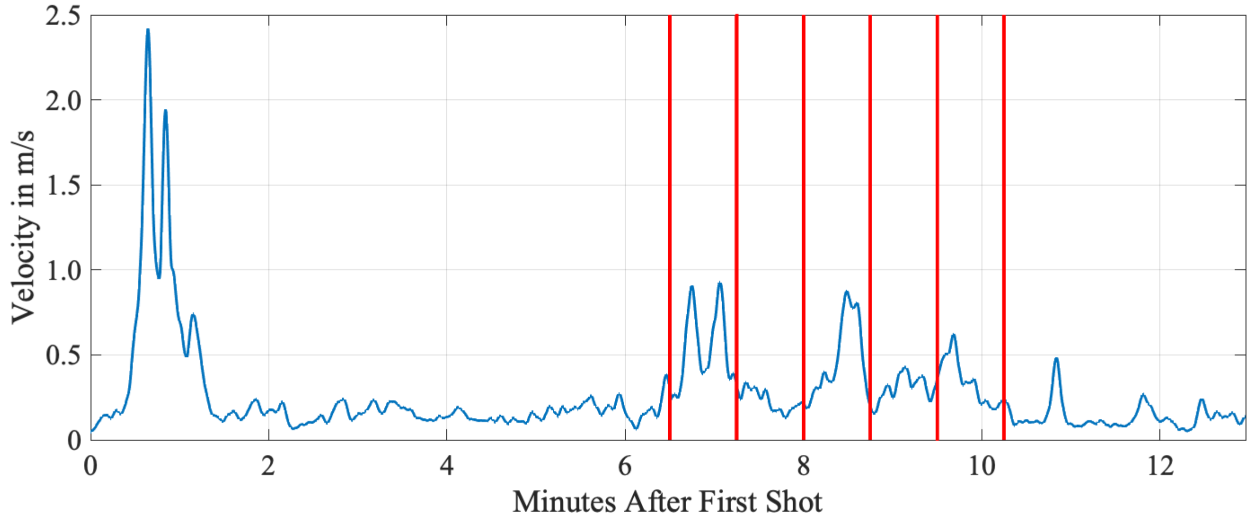
Turbowave I and II and Humming Lobo

Credit: EMRTC

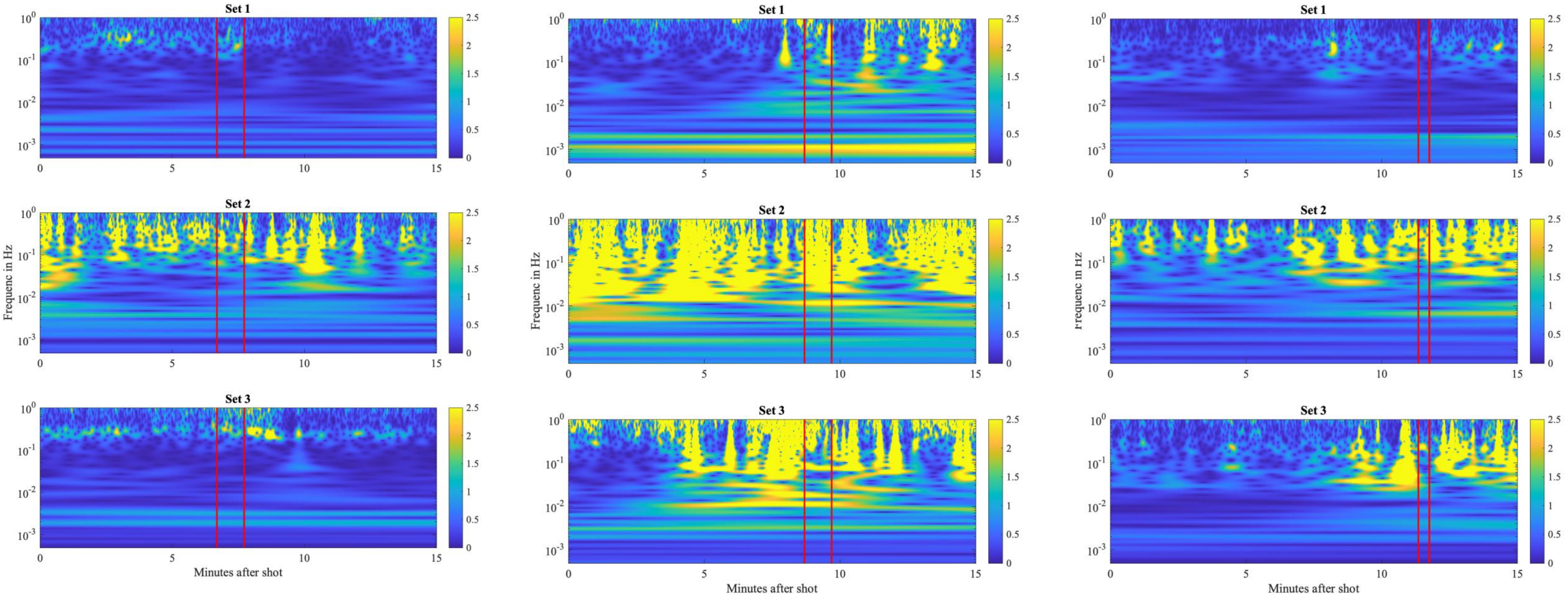
Turbowave I – 3 Shots Separated by 1.5 Minutes



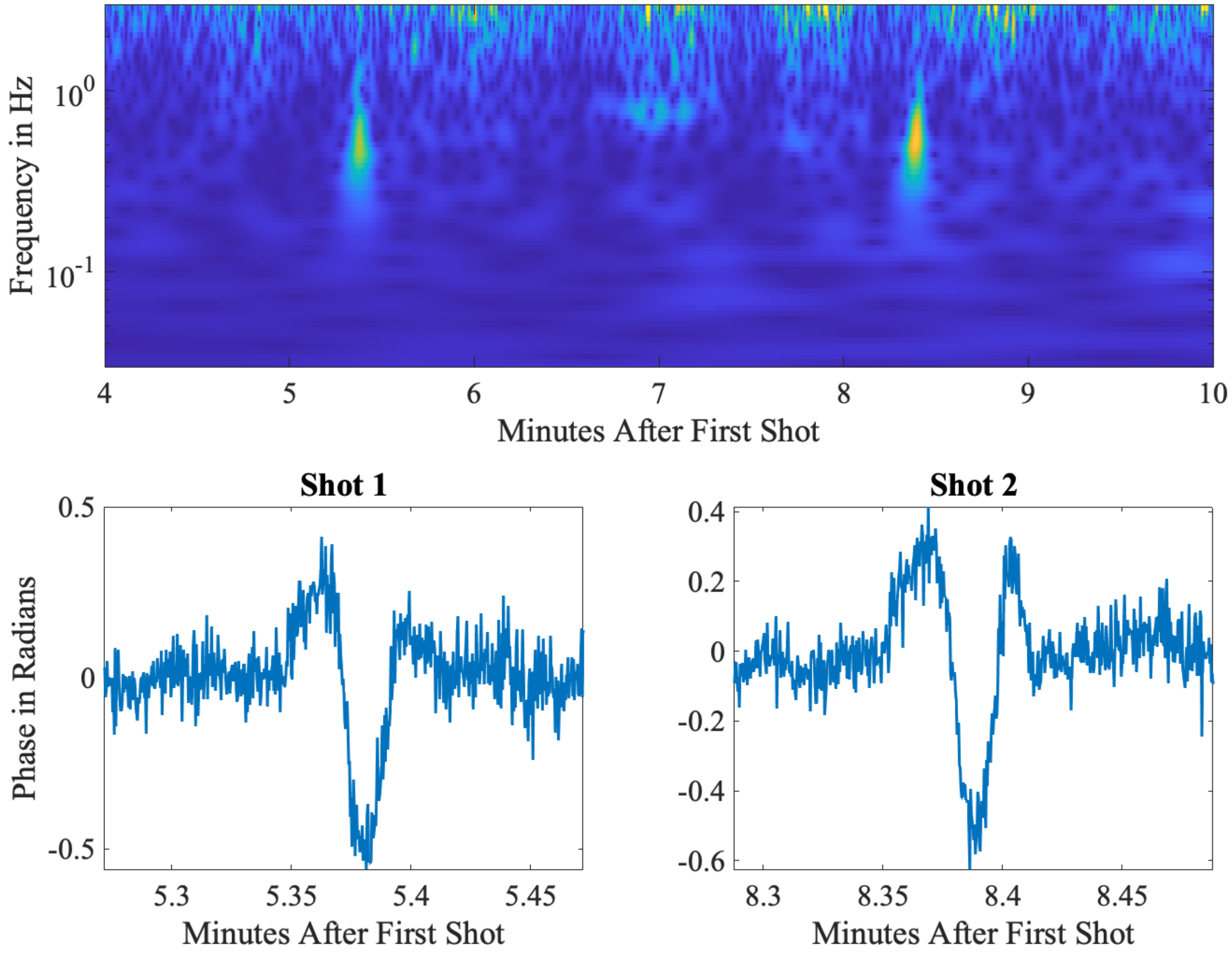




Turbowave II – Way too much scintillation and microbarom noise?



Humming Lobo– 2 Shots Separated by 1.5 Minutes



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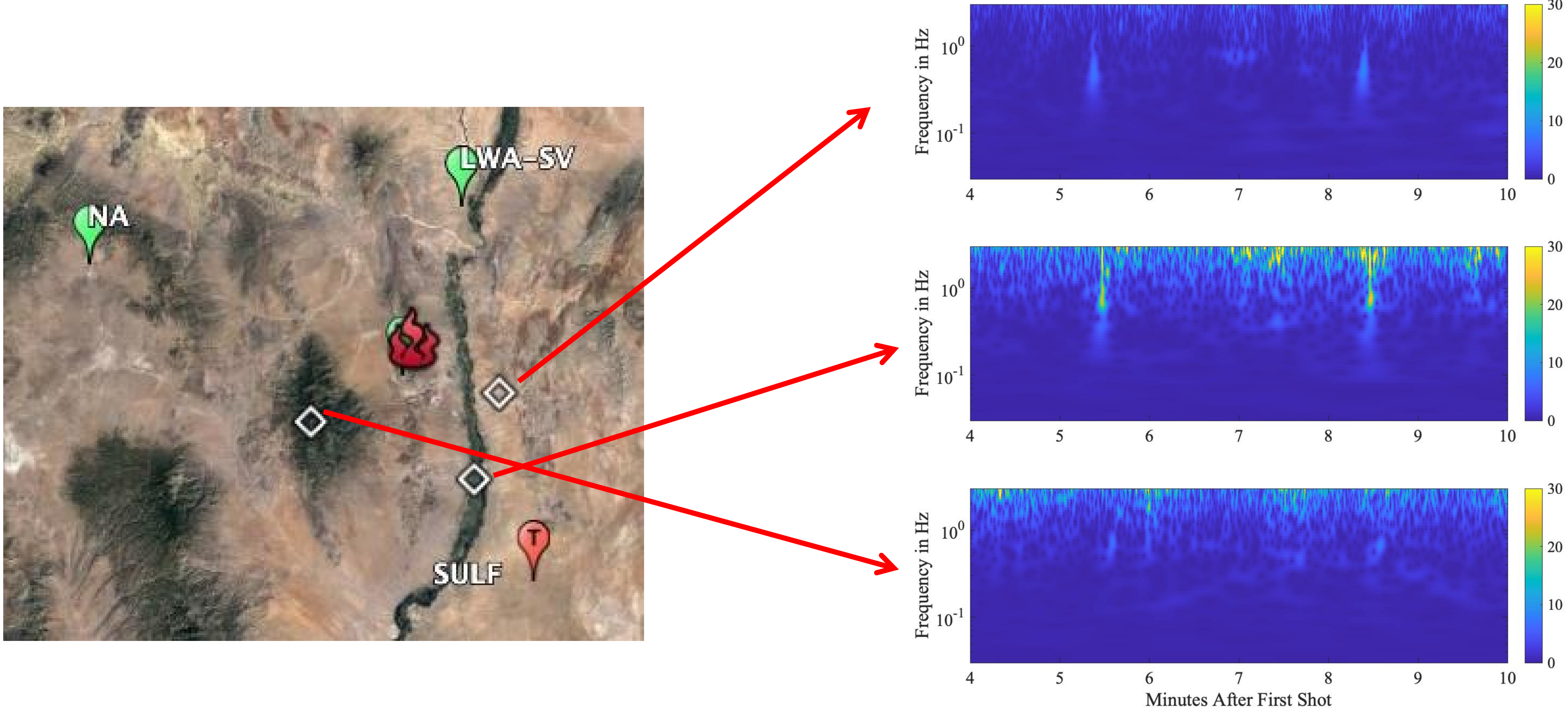
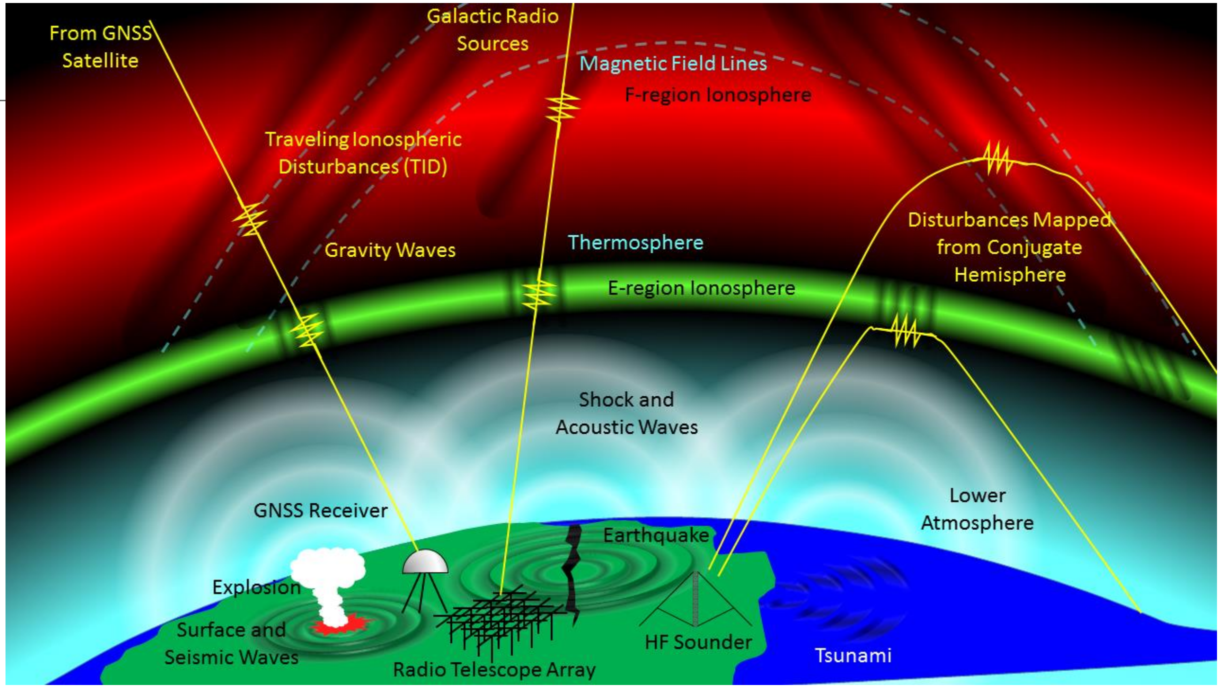
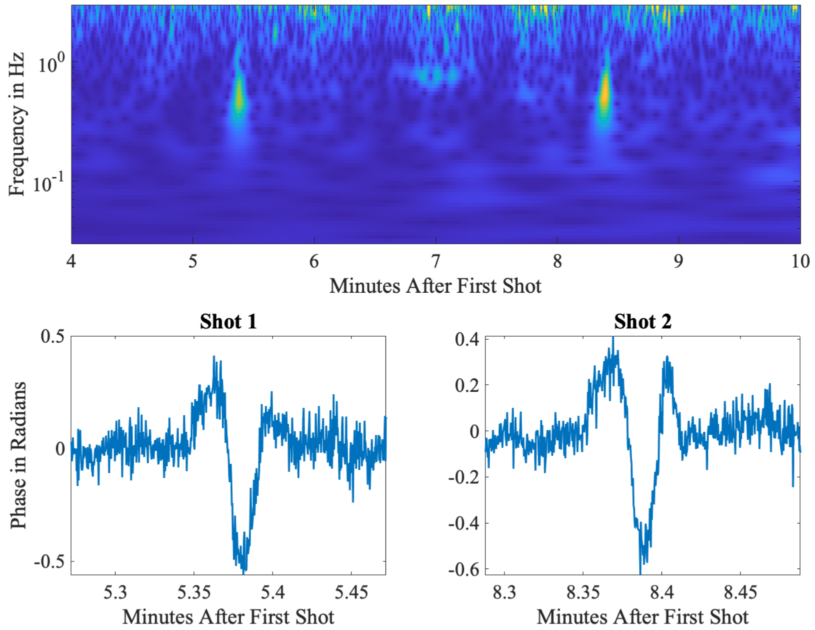


Summary

- Small, 1 ton TNT equivalent explosions can be detected in the ionosphere
- HF/MF Doppler radar provides a tool for measuring the amplitude of the infrasound wave packet
- Waveform matches well with the expectation provided by infraGA
- Amplitude of detection varies strongly with geometry, could be some sort of effect from wind filtering.





Acknowledgements

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