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# Initial Results from the HummingLobo Multi-Modal Ground Truth Experimental Campaigns

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Cleared for release

Funding for this research effort was provided by the Defense Threat Reduction Agency, USA.

# Outline

1. Experimental Motivation + Research Goals
2. Experiment Design + Execution
3. Multi-Modality Data + Results
    1. Ariel Acoustic
    2. RF Doppler Radar
    3. Optical Observations
    4. Seismoacoustic Ground Data
4. Conclusions + Future Directions

# Experiment Motivation I: Explosive Events for Regional Infrasound Analysis

- 2016 – Forensic Surface Experiment[1] (FSE)
  - Nevada National Security Site; November and December
  - Single infrasound array deployed towards east (St. George) to capture stratospheric arrivals
- 2018 – Humming RoadRunner[2] (HRR)
  - White Sands Missile Range, NM; August
  - Series of arrays deployed from 240-460 km west of the source
- 2020 – Large Surface Explosive Characterization Experiment[3] (LSECE)
  - Nevada National Security Site; October
  - Sparse regional network of preexisting assets

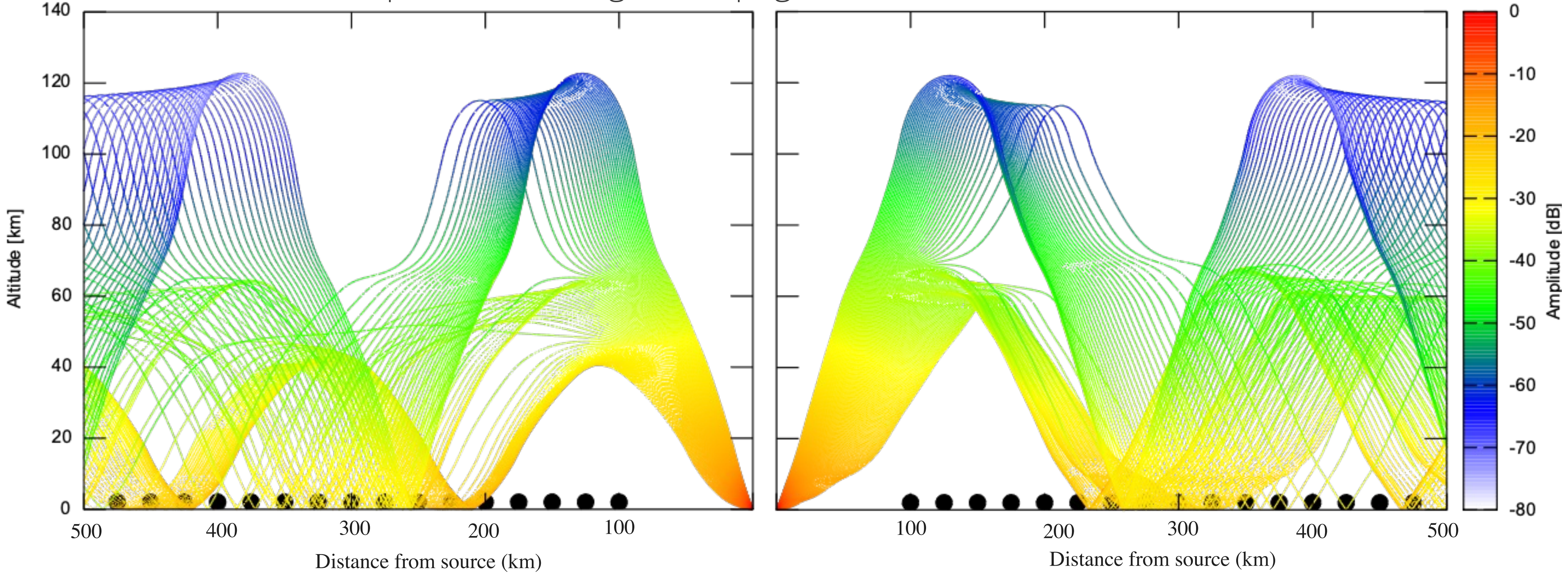
*Recent experimental series have focused on validating the propagation of primarily stratospheric arrivals through favorable atmospheres. This results in specific campaign deployments and timing aimed at optimizing signal arrivals.*

[1]Blom, P. (2019). Modeling infrasonic propagation through a spherical atmospheric layer—Analysis of the stratospheric pair. *The Journal of the Acoustical Society of America*, *145*(4), 2198-2208.
[2]Green, D. N., Waxler, R., Lalande, J. M., Velea, D., & Talmadge, C. (2018). Regional infrasound generated by the Humming Roadrunner ground truth experiment. *Geophysical Journal International*, *214*(3), 1847-1864.
3Pyle, M. L., & Walter, W. R. (2022). Exploring the Effects of Emplacement Conditions on Explosion P/S Ratios across Local to Regional Distances. *Seismological Society of America*, *93*(2A), 866-879.

# Experimental Motivation II: Spatio-temporal Variability in the Acoustic Shadow Zone

Recent evaluation of arrivals from ordnance disposals at the Utah Test and Training Range indicate that stratospheric signals consistently arrive at stations located between 100-260 km from the source[3]. These arrivals are not predicted throughout propagation modeling and illustrate limitations in our understanding of acoustic shadow zones.

Example Acoustic Signal Propagation in the American Southwest




[3]Dannemann Dugick, F. K., Stump, B. W., Blom, P. S., Marcillo, O. E., Hayward, C. T., Carmichael, J. D., & Arrowsmith, S. (2020). Evaluating factors influencing infrasonic signal detection and automatic processing performance utilizing a regional network. *The Journal of the Acoustical Society of America*, *148*(6), 3509-3526.

# Experiment Motivation II: Exploring Opportunities for Multi-Modality Data Fusion

**Inter-sensor fusion** measures the same observable on many sensors, such as source location

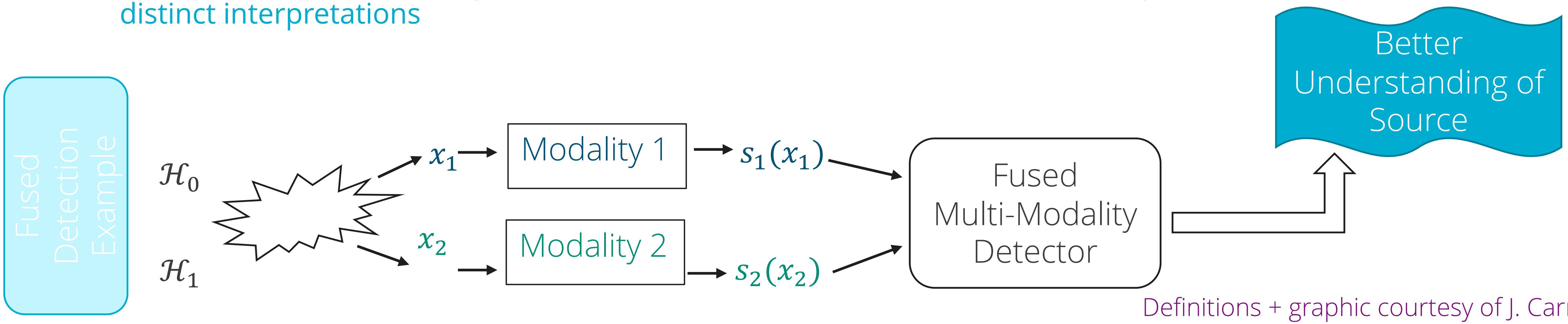
i. Example: seismic, acoustic, and hydroacoustic localization of the Tonga event

**Inter-attribute fusion** measures distinct signal or source parameters with multiple sensors

i. Example: electromagnetic emissions inform origin time, and seismic array beamforming estimates the back-azimuth of a source localization parameter

**Inter-domain fusion** measures the same source parameter across modalities.

i. Example: the yield of an explosion includes estimates from seismic, RN, and optical emissions, with distinct interpretations




Definitions + graphic courtesy of J. Carmichael
Los Alamos National Laboratory

# Overall Experimental Execution Goals

1. Record multi-modality signals from similar detonations at the same location throughout the year to evaluate acoustic propagation patterns at local and regional distances in different **(summer vs. winter)** seasonal regimes.

2. Utilize a dense network of stations at regional distances to document the extent and variability of the acoustic shadow zone.

3. Building upon prior experiments (TurboWave I and TurboWave II), detonate explosives at closely spaced spatiotemporal intervals to examine short-term atmospheric variability at local and regional distances.

# Campaign Conducted at the New Mexico Tech Energetic Materials Research and Testing Center [EMRTC]

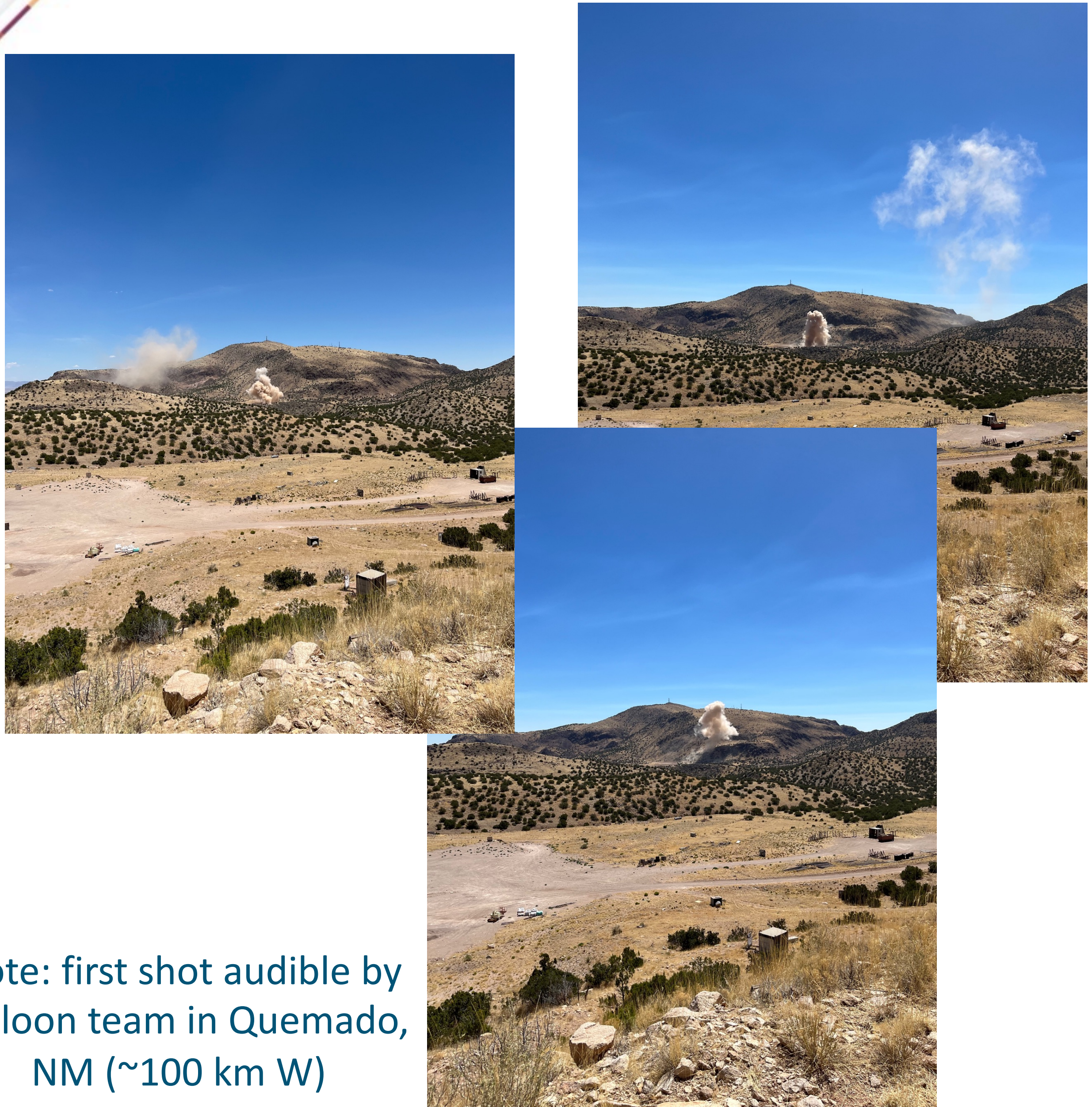
# Campaign I Execution: March 28, 2022

| | Shot Time (UTC) | Yield |
|---|---|---|
| AM | 16:33:00.263645100 | 1 ton TNT equiv. |
| | 16:36:00.264492000 | 1 ton TNT equiv. |
| PM | 19:18:00.002477200 | 1 ton TNT equiv. |
| | 19:21:00.002547700 | 1 ton TNT equiv. |


1 ton AN/FO

# Campaign I Execution: March 28, 2022

# Campaign II Execution: June 07, 2022



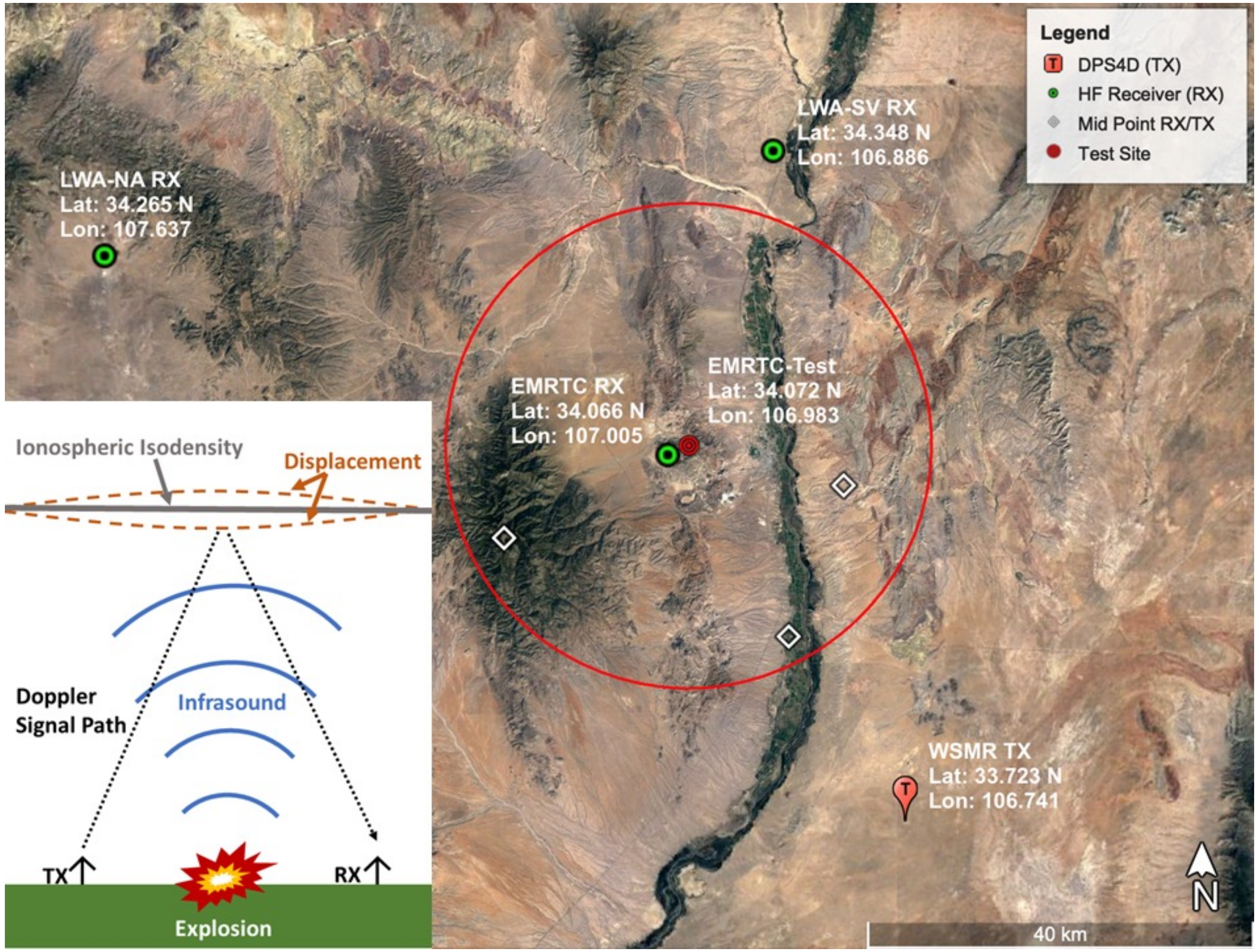
| | Shot Time (UTC) | Yield |
|---|---|---|
| AM | 17:02:00.002723300 | 1 ton TNT equiv. |
| | 17:06:00.001974700 | 1 ton TNT equiv. |
| PM | 19:18:00.003822100 | 1 ton TNT equiv. |
| | 19:21:00.002305800 | 1 ton TNT equiv. |

1 ton AN/FO Source

Note: first shot audible by balloon team in Quemado, NM (~100 km W)

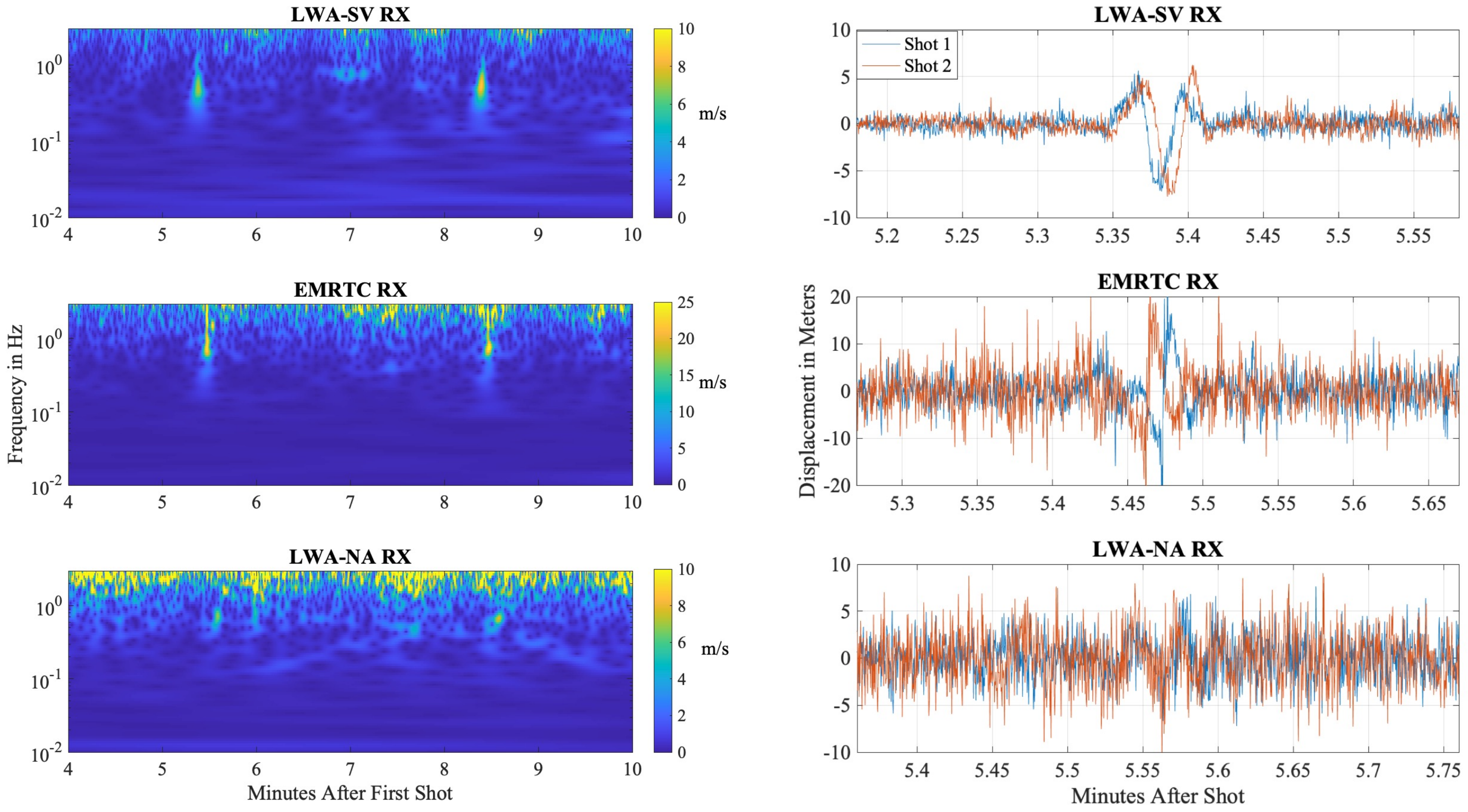
# Remote Sensing Surface Explosions with Ionospheric Doppler Radar

## Led by Kenneth S. Obenberger, Air Force Research Laboratories




- One Digisonde Portable Sounder 4D (DPS4D) located at White Sands Missile Range (WSMR) transmitting pulsed Doppler at 2.4 and 2.6 MHz (red T)
- Three MF/HF receivers located at EMRTC, LWA-SV and LWA-NA (green circles)
- All mid-points near 100 km altitude and within 25 km horizontal from explosion site

# Clear detections indicate that the ionosphere can be used for remote sensing for small explosive events



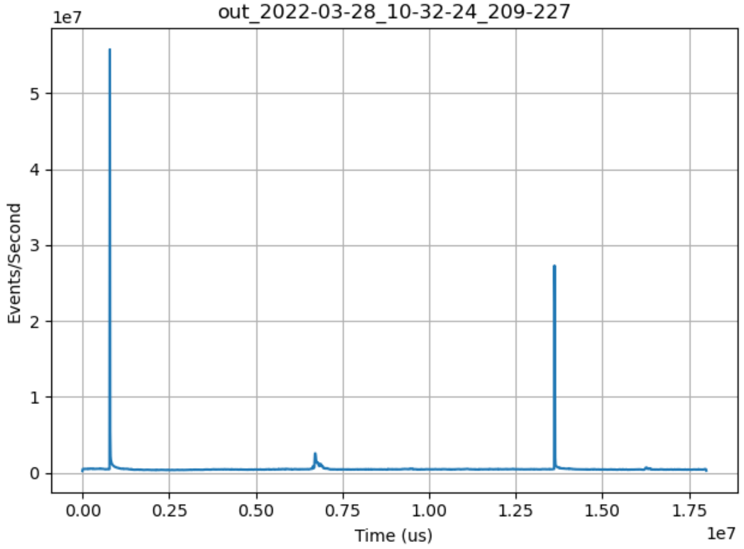

- Variation in waveform seen between each station and timing between shots
- 2.4 MHz arrived 3 seconds ahead of 2.6 MHz, indicating about 1 km difference in altitude

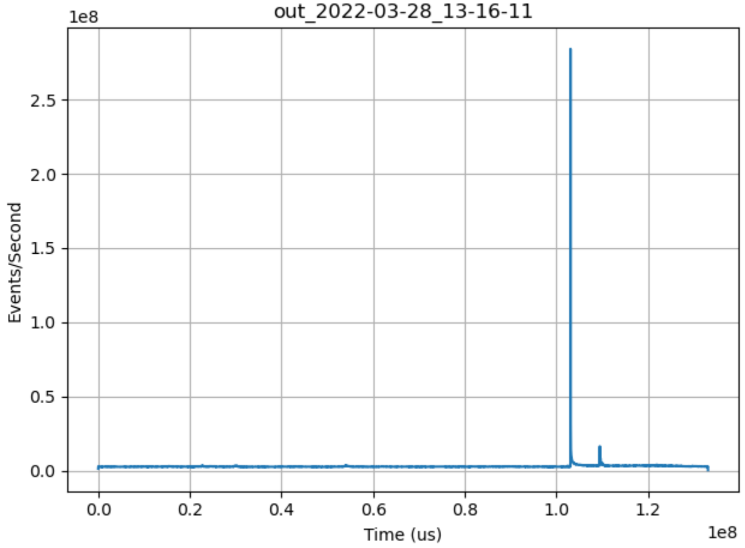
For more see:
Obenberger, K., Dannemann Dugick, F., and Bowman, D.C. Clear Ionospheric Detections of Infrasound produced by Conventional Surface Explosives. *Earth and Space Science* (under review)

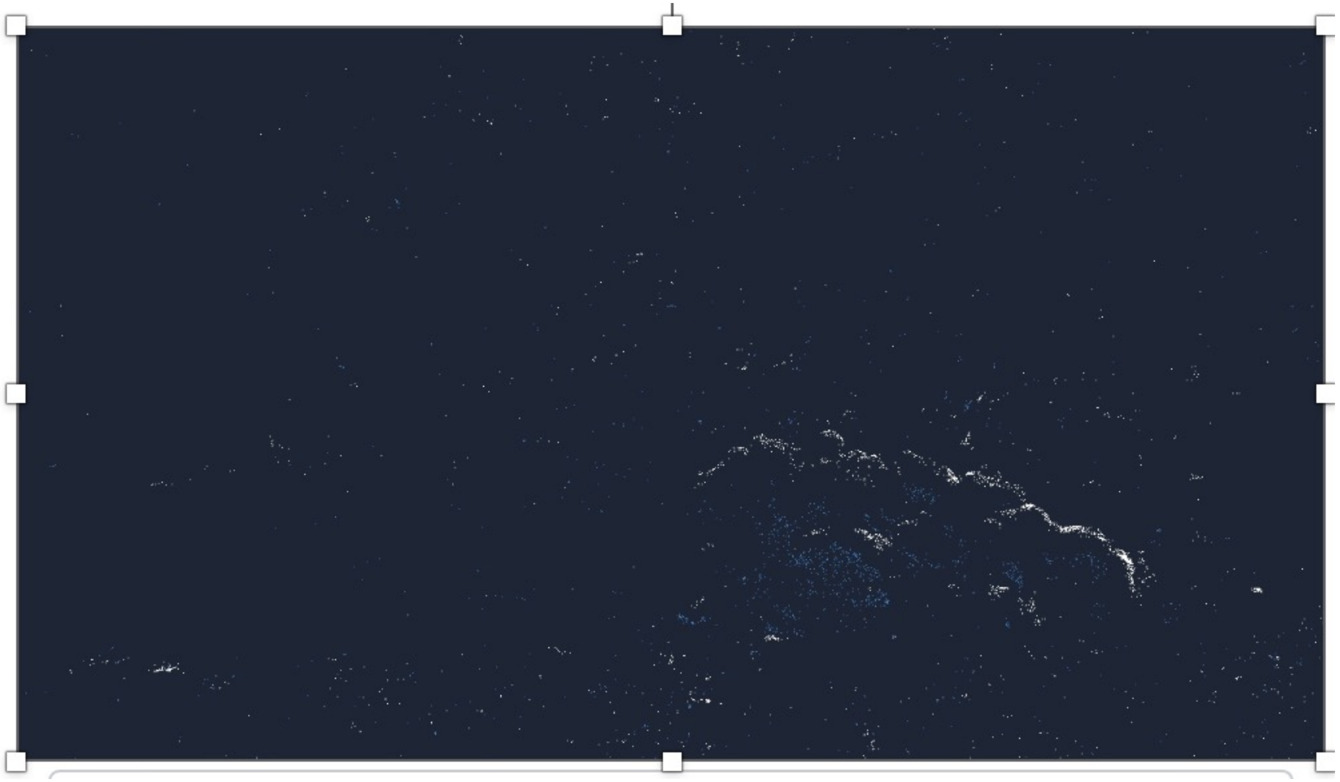
# Local Range (<2km) Optical Identification of Explosive Sources

Led by Jeremy B. Wright, Sandia National Laboratories


# Deployed optical equipment successfully detected all explosive events

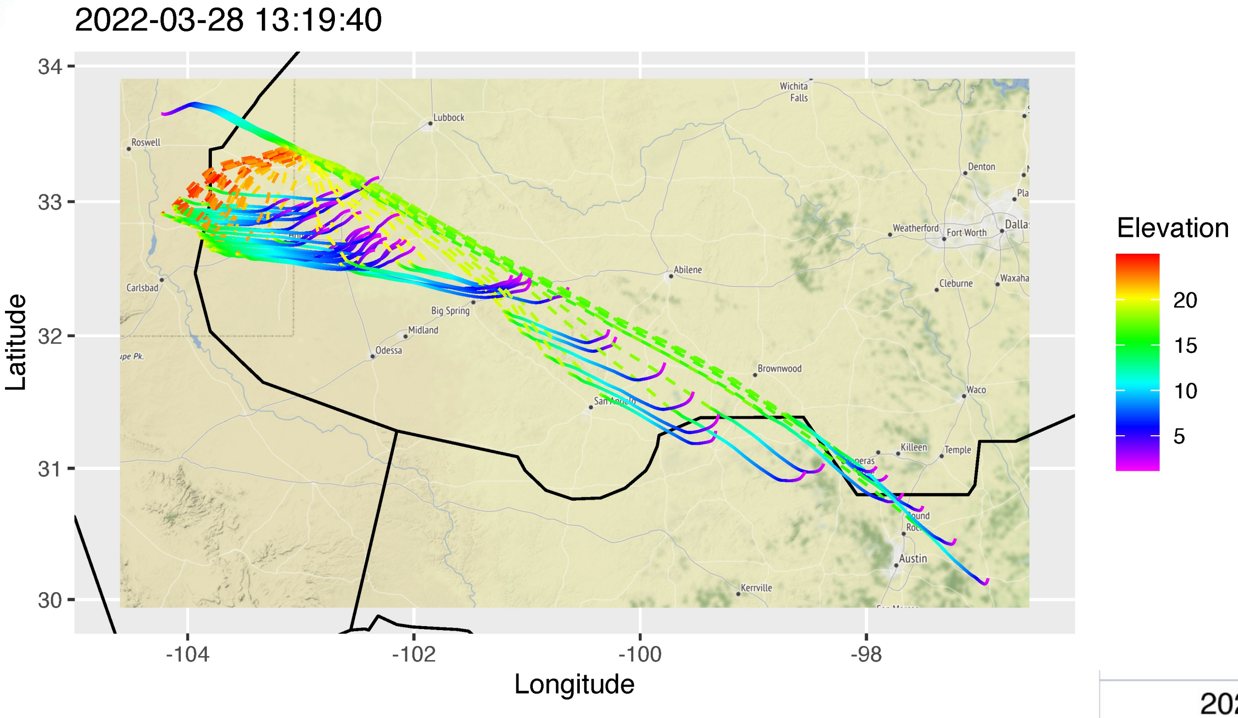


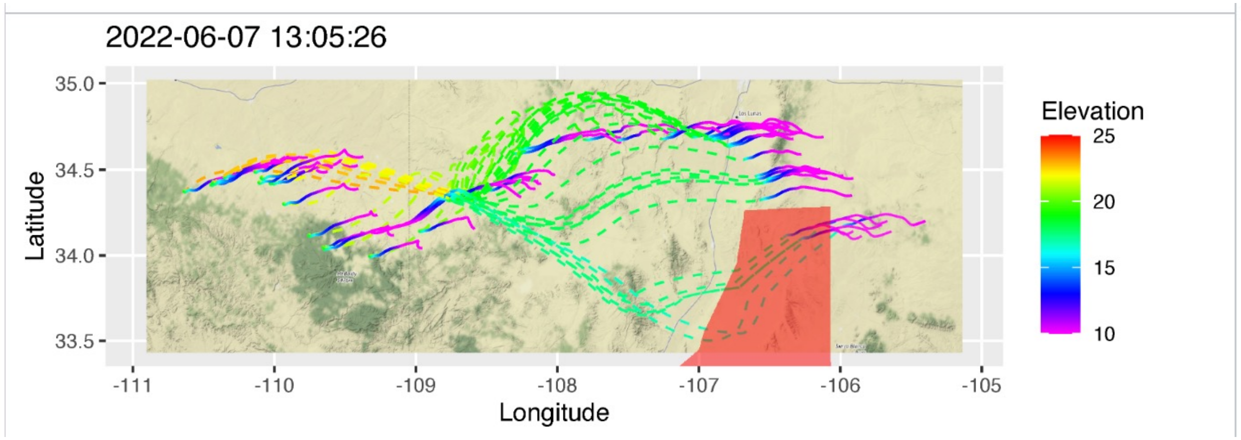
# High speed video imagery demonstrates combustion of explosive package

# Winter and Summer Explosive Events Supported by Ariel Acoustic Campaigns

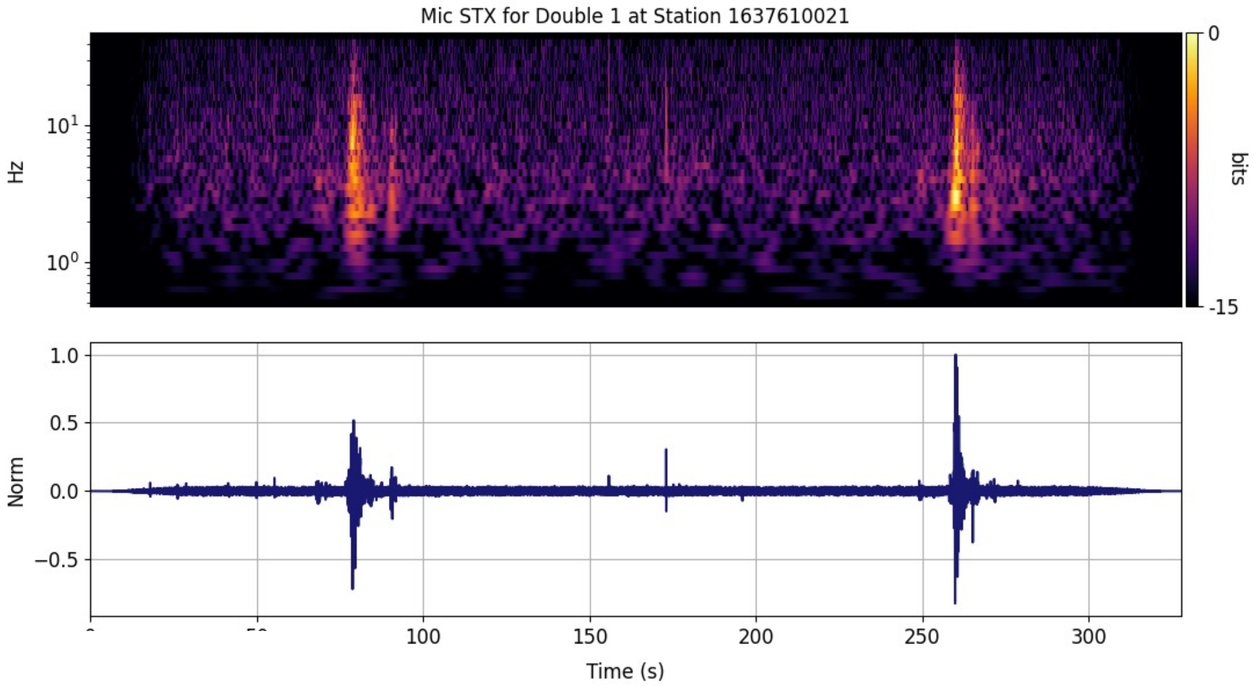


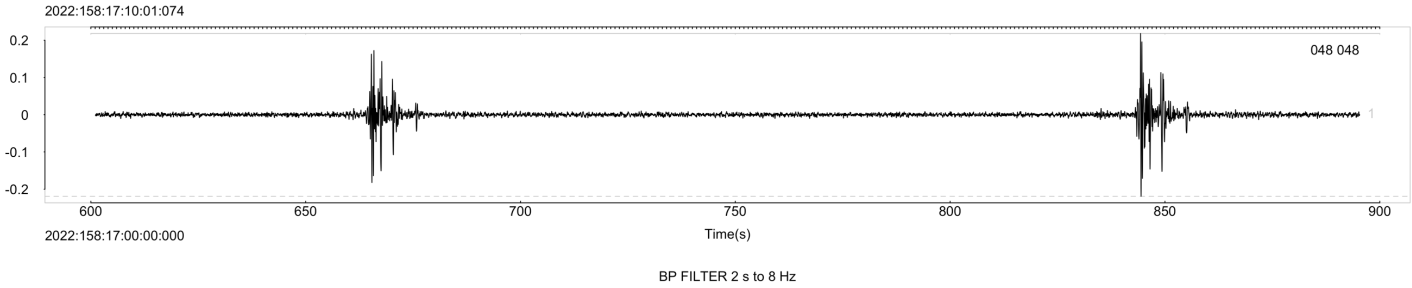

- Challenging launch conditions
- 4/6 balloons successfully launched
- 2/6 remained in flight throughout test series
  - 1 landed in Lubbock TX
  - 1 landed in Houston TX

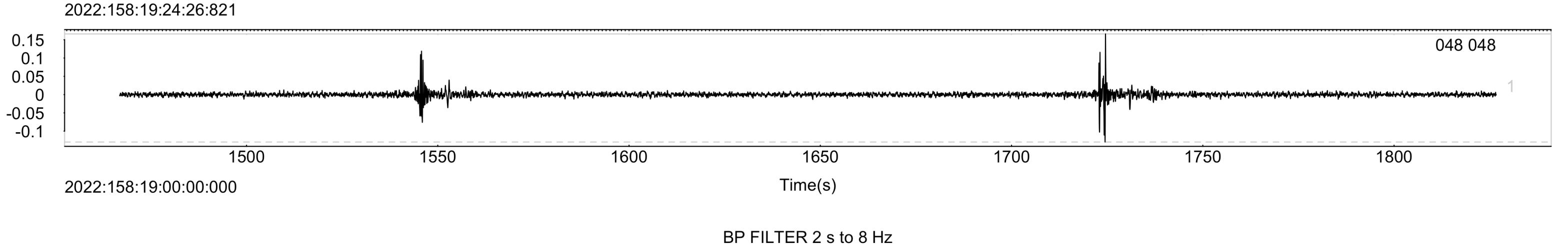
- Launched from Springerville, AZ
- 6/8 balloons successfully launched
- 6 remained in flight throughout test series



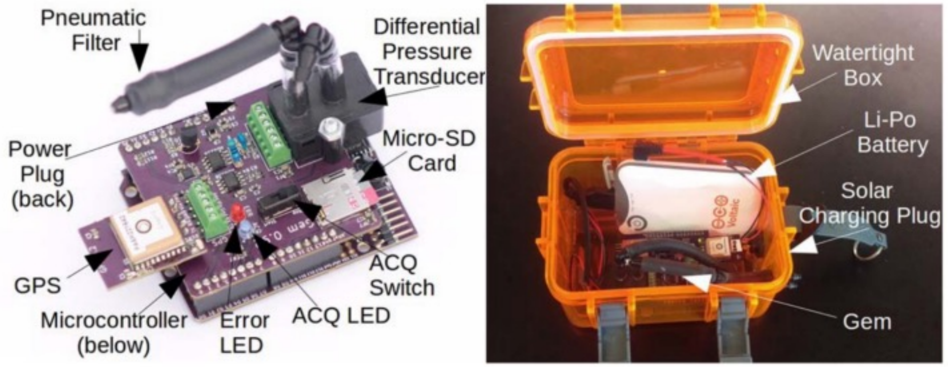
# Balloons located 100km from the source location successfully recorder high SNR signals associated with the explosive event

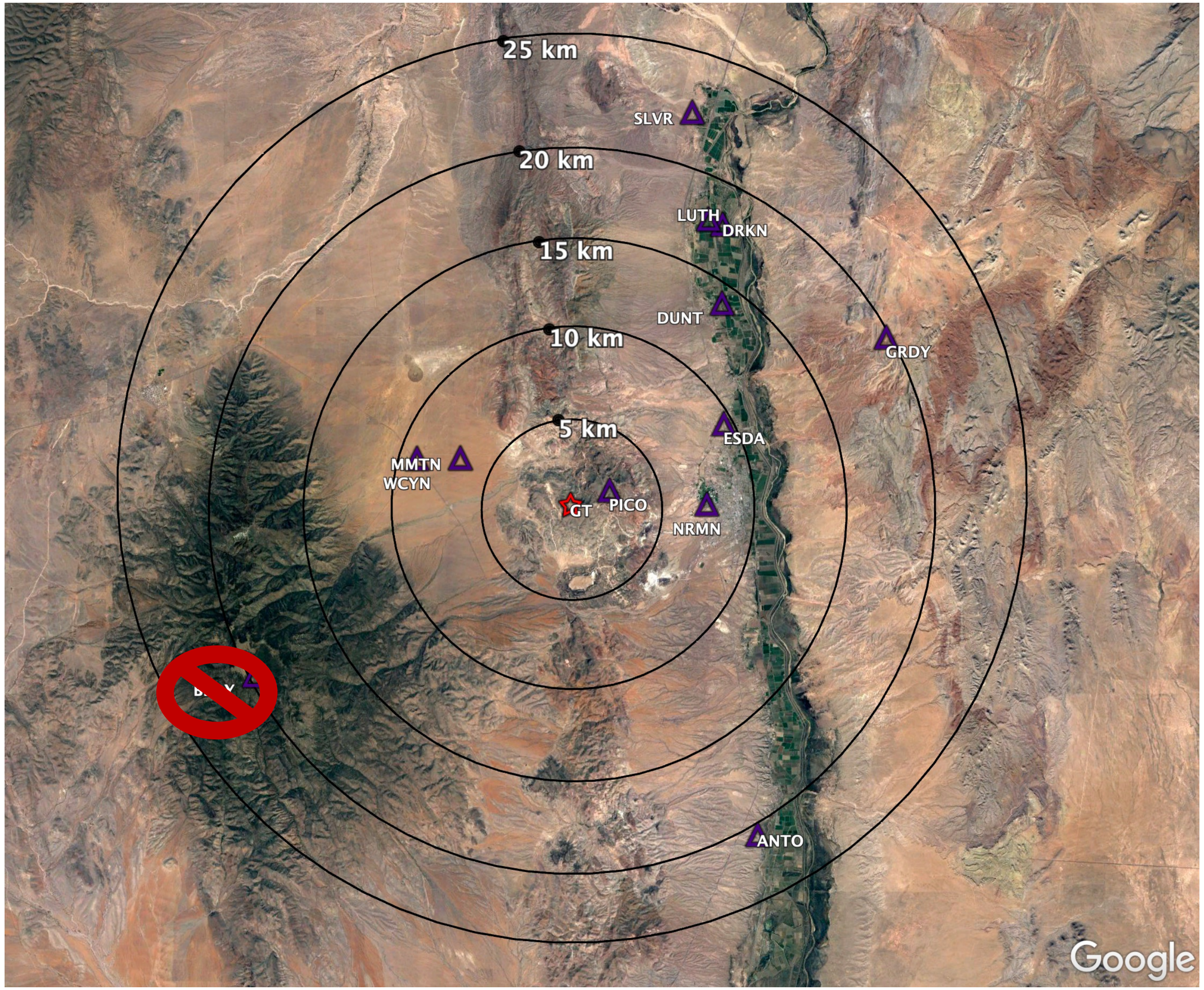


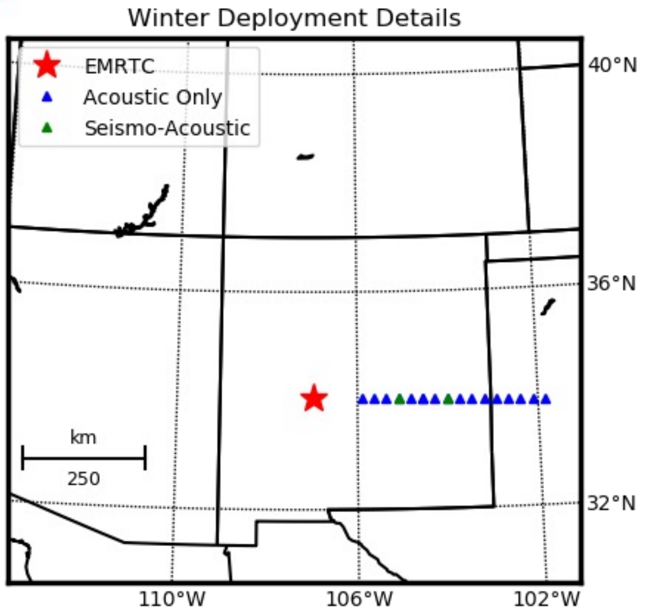
# Local acoustic network consisted of 10 sites located between 2-25 km from the source

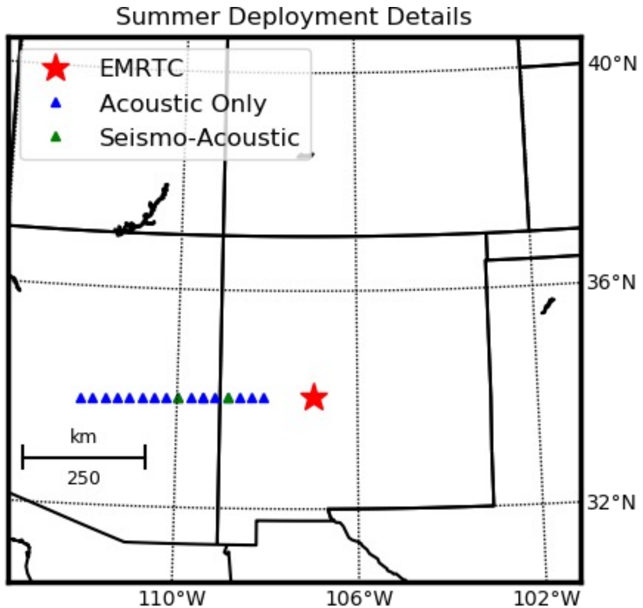


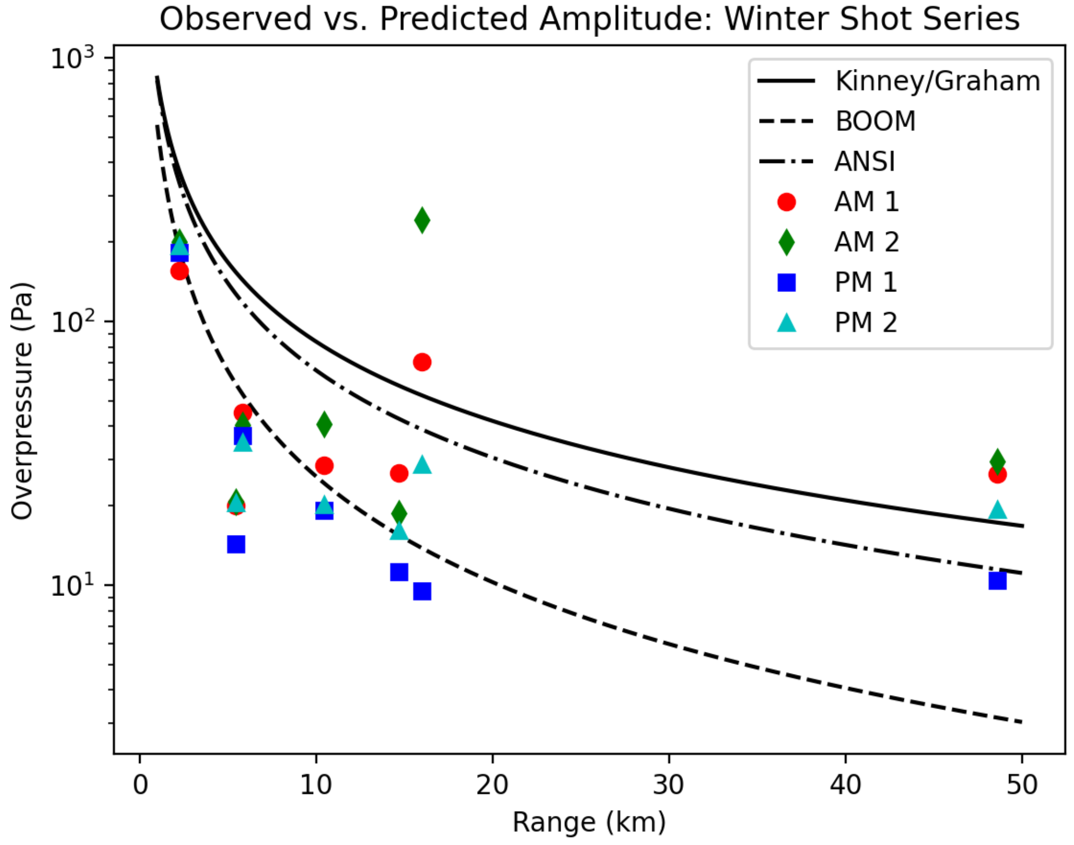

Anderson, J. F., Johnson, J. B., Bowman, D.C., and Ronan, T. (2018). The Gem Infrasound Logger: a Lightweight, Low-Power, Low-Cost, Open-Source Infrasound Logger.

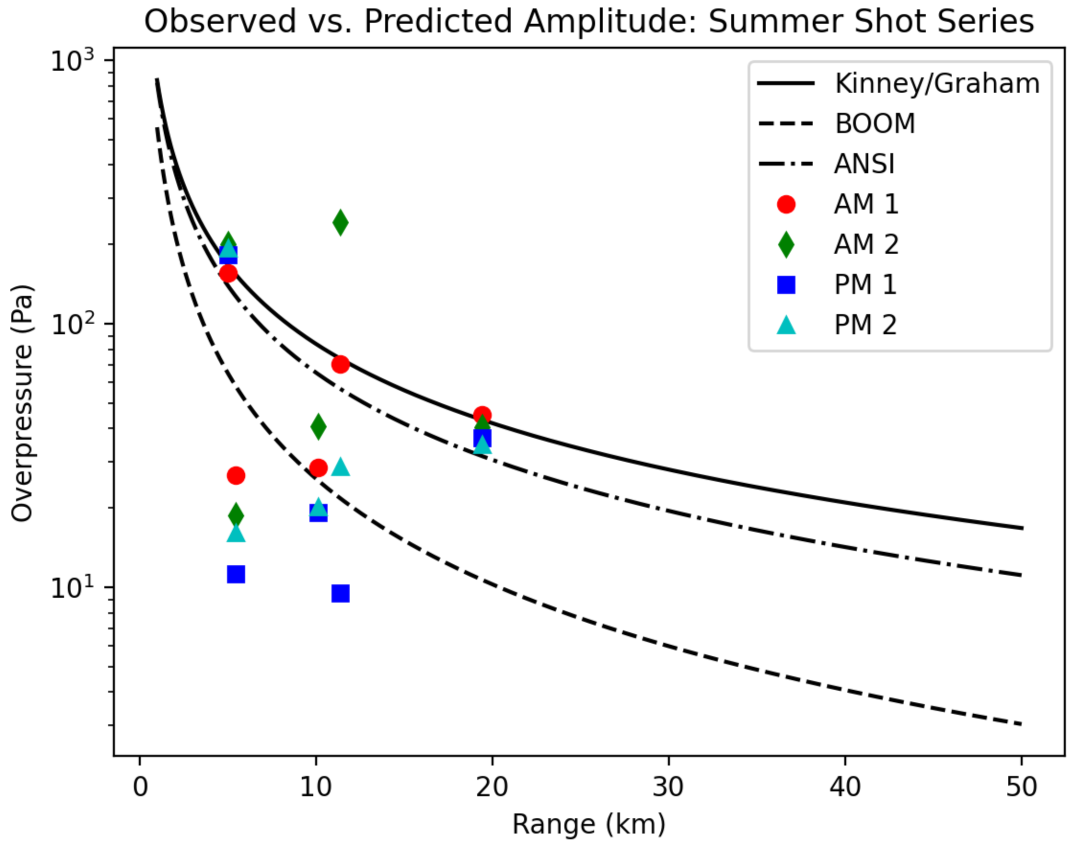
# Rotating regional network captures arrivals from the transitioning stratospheric jet



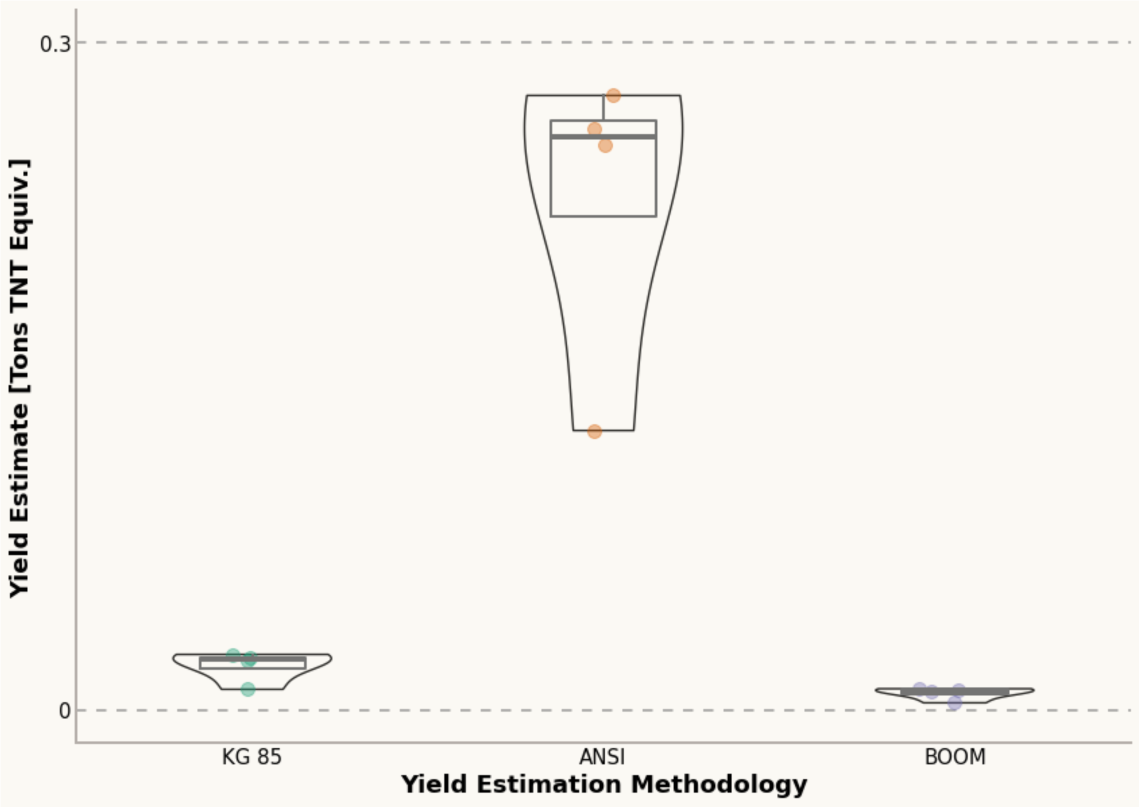

# Repeating explosive series allow for the evaluation of local-distance yield estimations with multiple data points



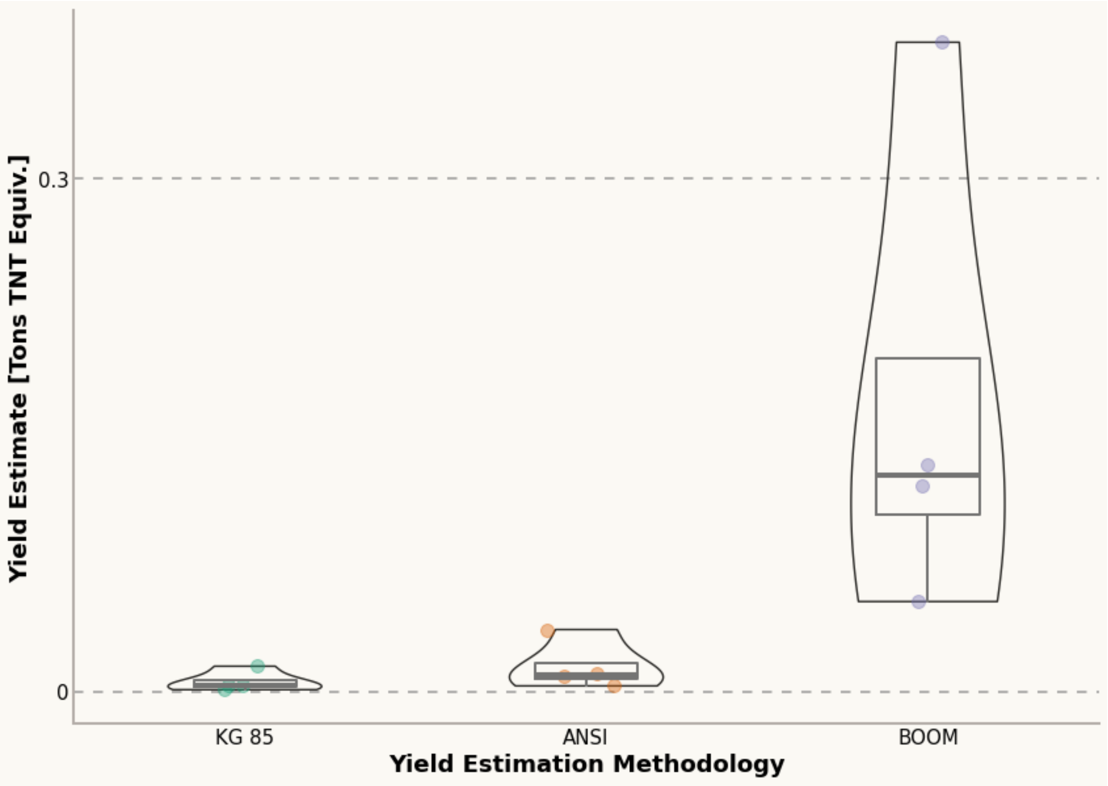



# Amplitude Based Estimates Significantly Under-Estimate Yield for all series

Winter Test Series




Summer Test Series



# Looking Forward

- Continue comparisons of ANSI, BOOM and Kinney Graham models for low yield explosions
- Utilize local seismic data to produce seismoacoustic yield estimates
- Extension of stratospheric amplitude scaling relationships to 1) lower yields and 2) tropospheric ranges
- Extension of stratospheric frequency-based methods to 1) lower yields, 2) tropospheric ranges, 3) acoustic arrivals on seismic stations

# Acknowledgements


- M. Fleigle and E. Berg → field assistance
- D. Bowman and launch crew → balloon flights
- S. Egan → EMRTC operations and explosives
- Multiple property owners → permission to place sensors on land

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