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Advances in Seismoacoustic Science and Technology Based on Long-Term Network Operations

Junghyun Park[1*], Brian Stump[1], Chris Hayward[1], Il-Young Che[2], Stephen Arrowsmith[1]

1: Southern Methodist University (SMU)
2: Korea Institute of Geoscience and Mineral Resources (KIGAM)

11 September 2025

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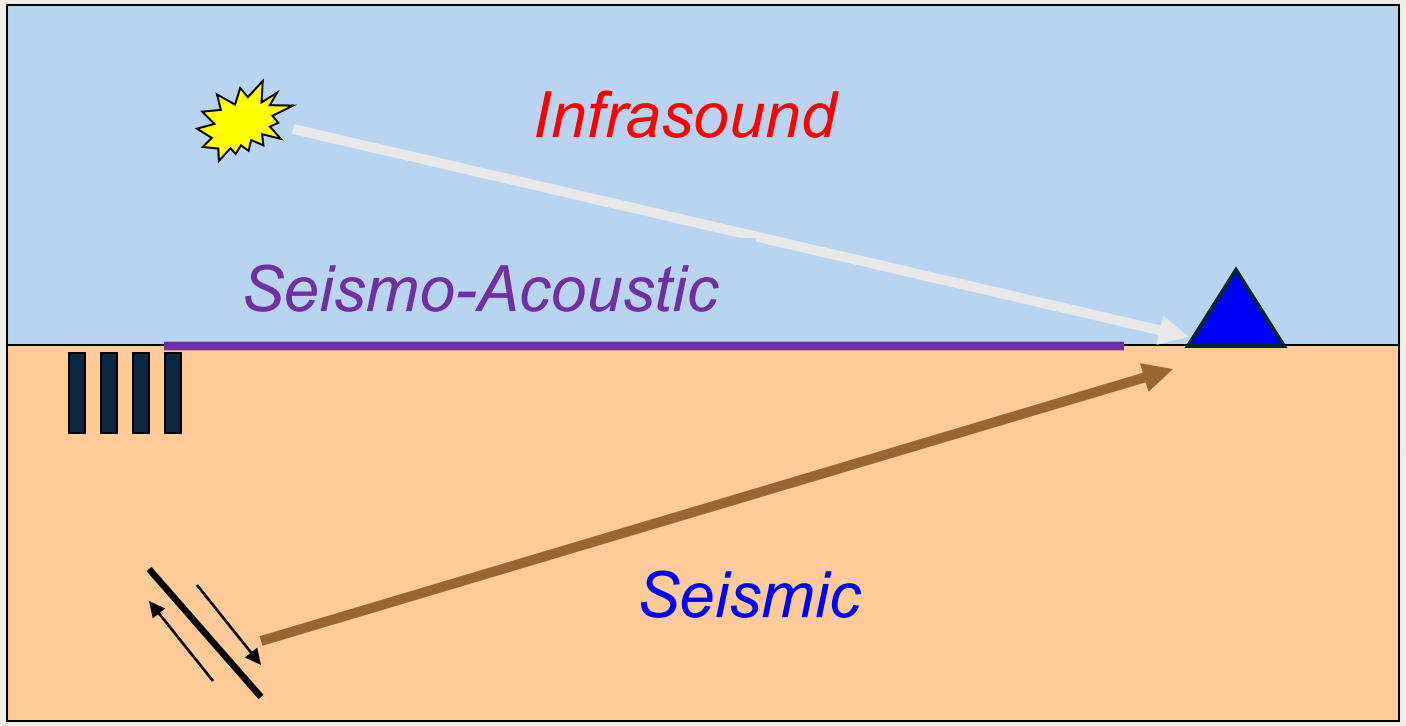
Motivation



- *Quantify Sources at Local and Regional Distances*
- *Improve Understanding of Seismo-Acoustic Propagation*

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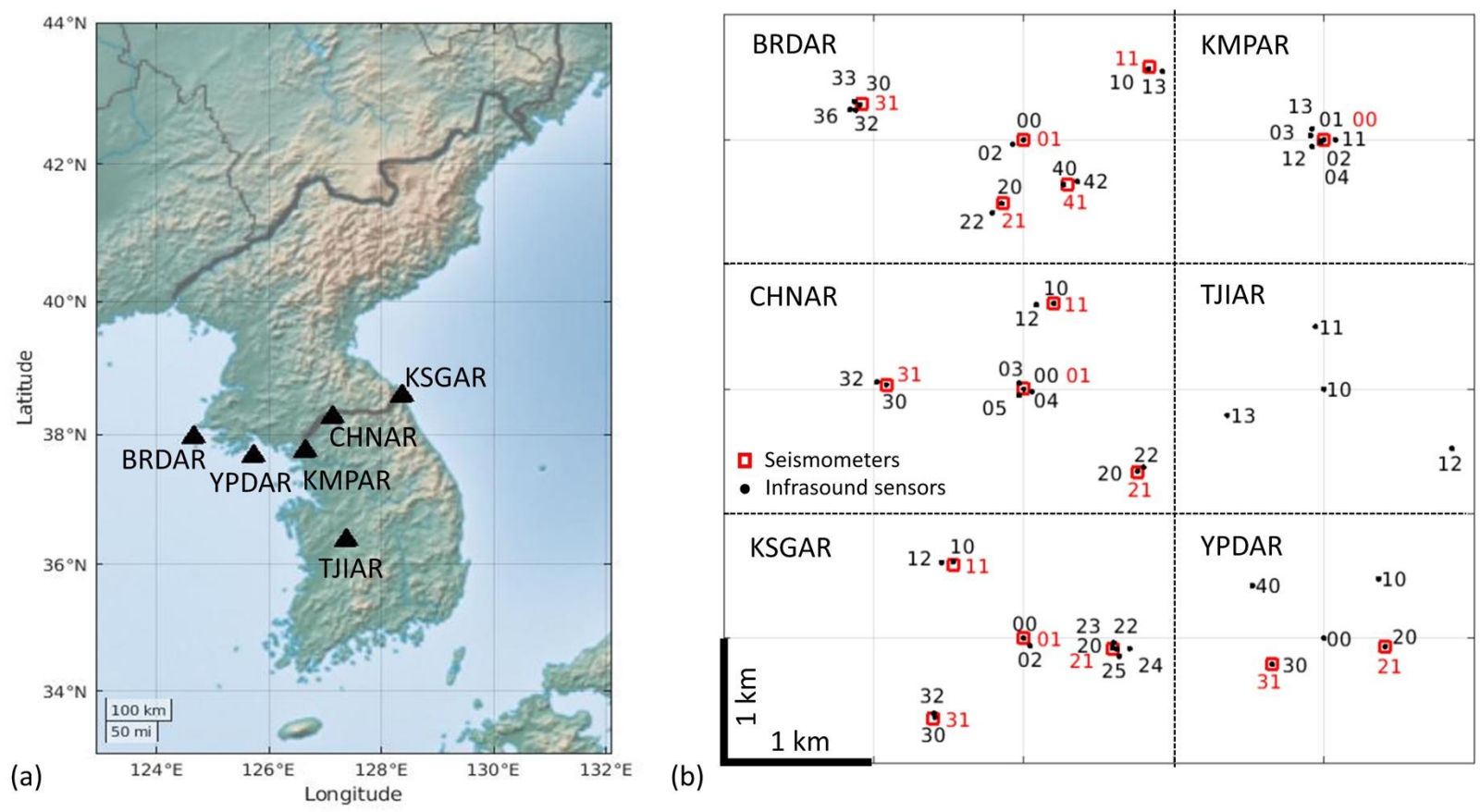
Seismo-Acoustic Research Arrays (SARAs)



- History and Design
- System Monitoring
- Science and Technology
- Lessons Learned

Park et al. (Journal of Seismology, 2023)

Overview

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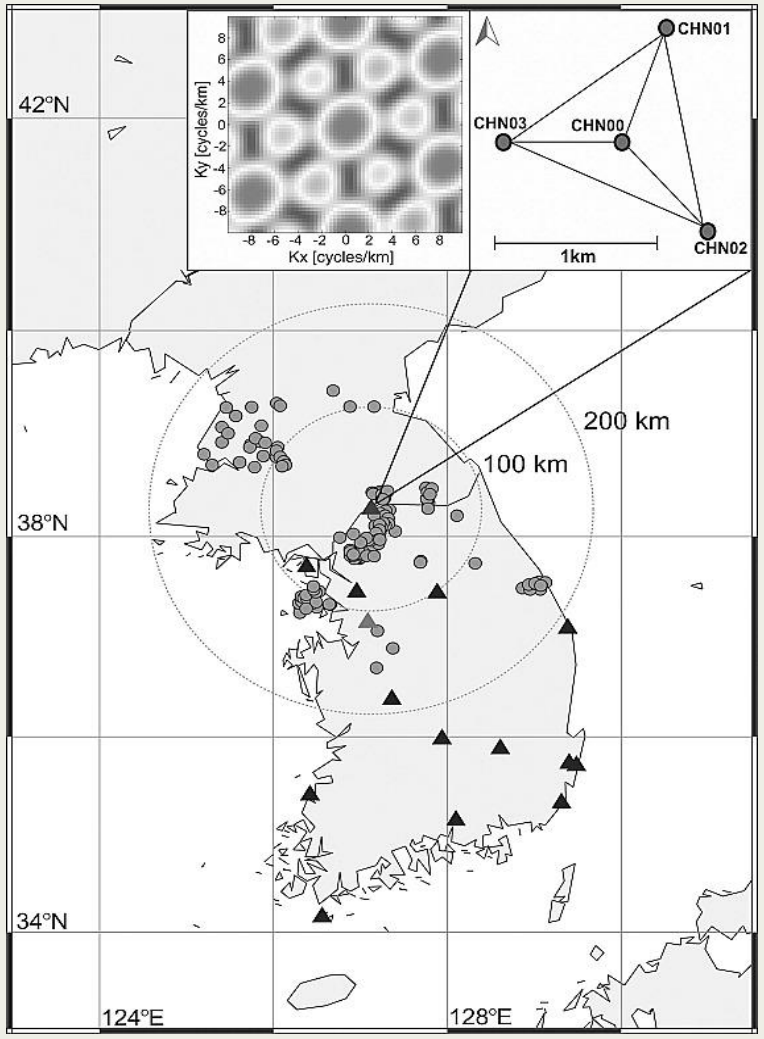
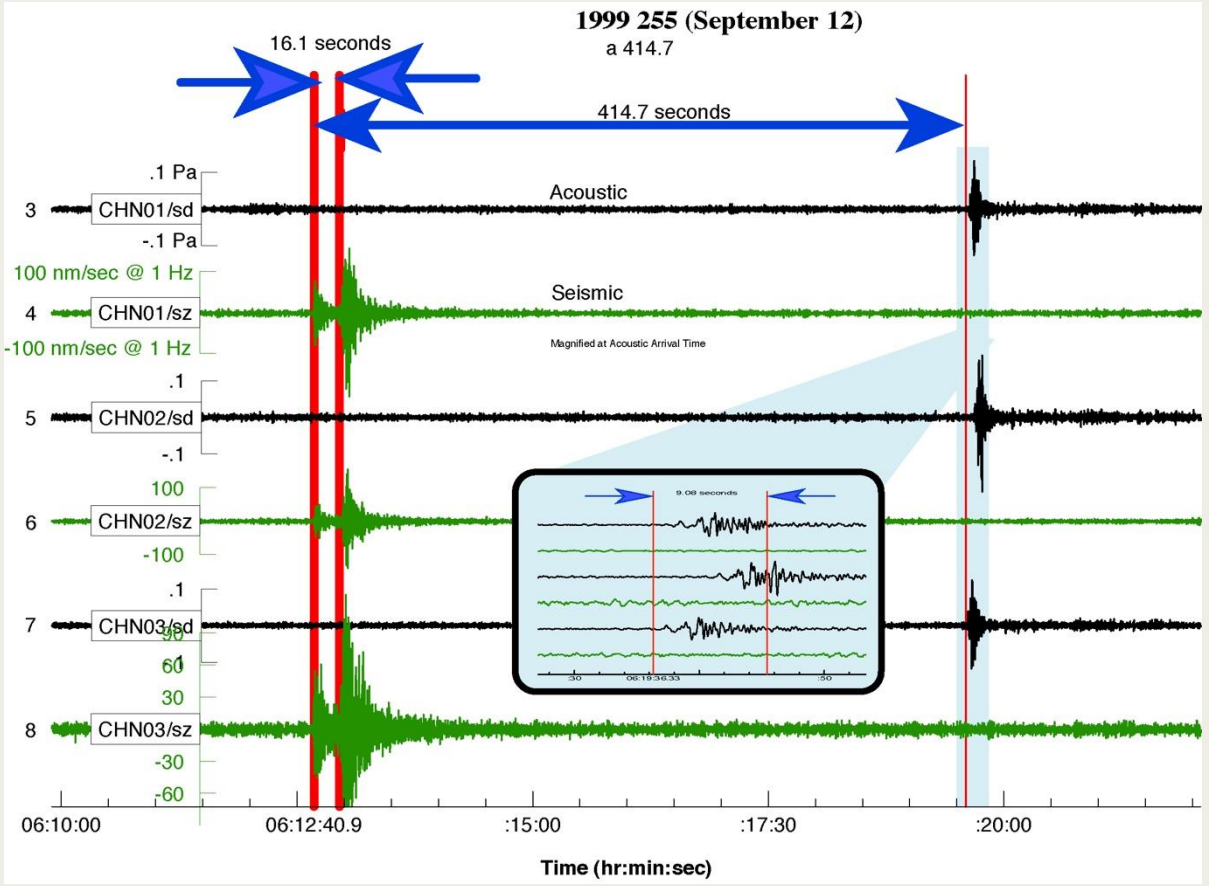


Che et al. (GRL, 2002)

Phase I. Concept Development

Investigating Mining Activities



Stump et al. (BSSA, 2004)

Successfully Identified Mining Explosions

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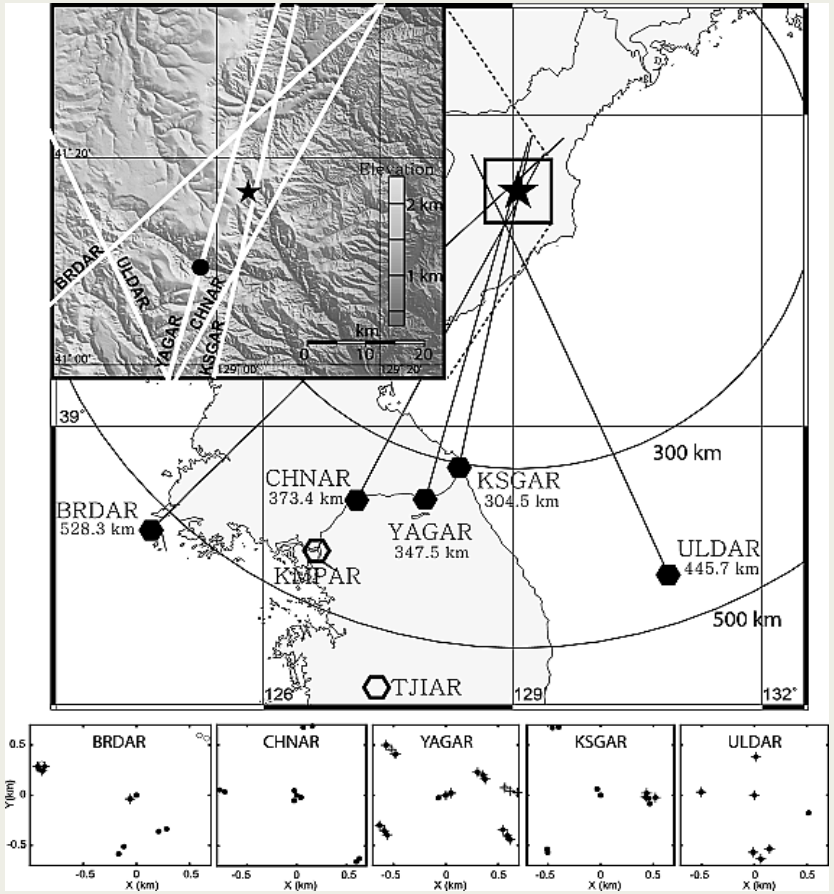
2009 DPRK UNE Infrasound Location
(Che et al., 2009)



Phase II. Building a Network

Signal Characterization of Various Sources

- Earthquakes
- Small-magnitude surface explosions
- DPRK underground nuclear explosions (UNEs)

Network Locates Seismic, Infrasound, and Seismo-Acoustic Events

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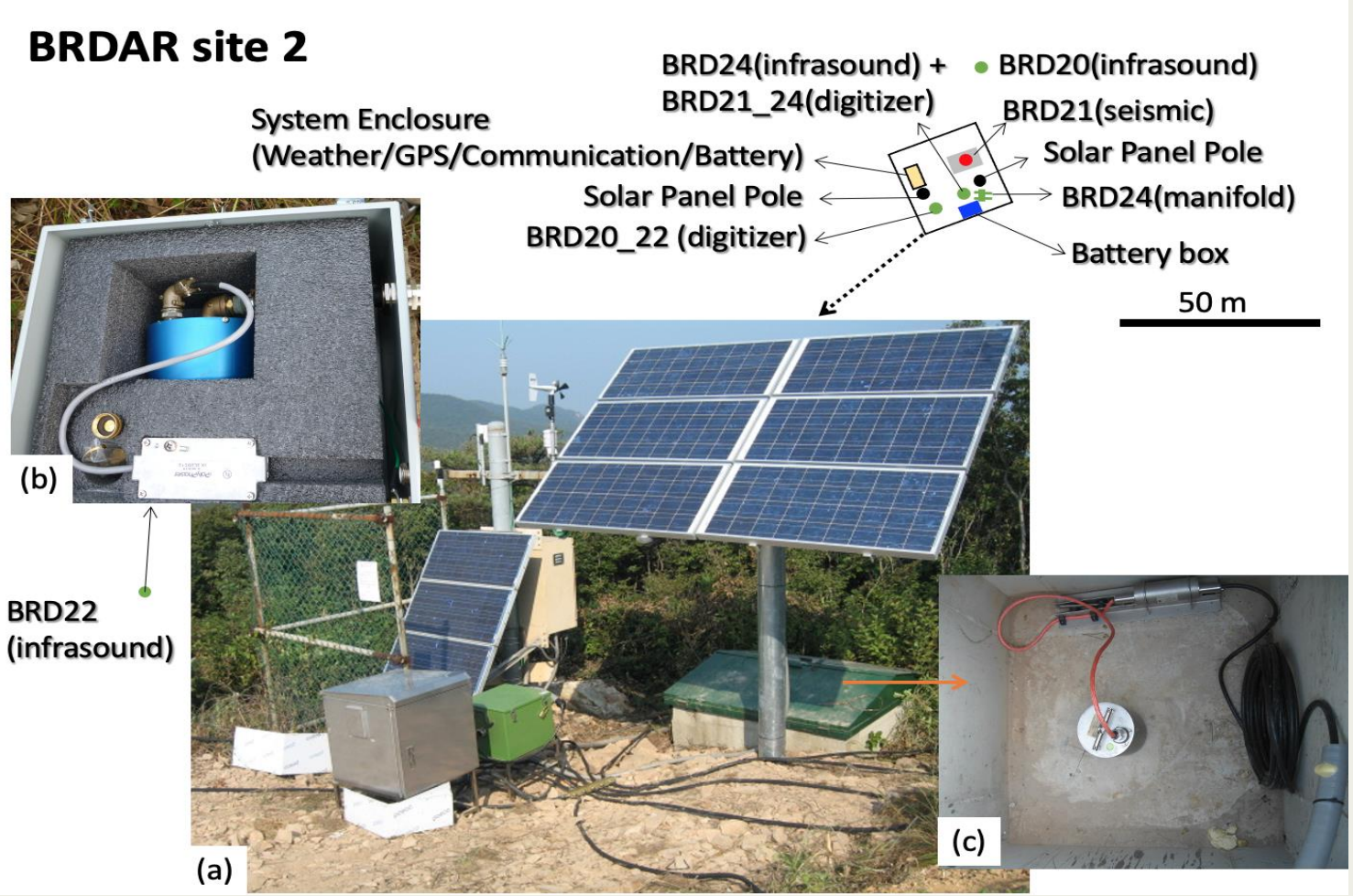

Phase III. Upgrade

Integrated SARAs

Geophysical Observation Platforms Provide Multi-Disciplinary Measurements

Stump et al. (SRL Data Mine, 2022)

Integrated Array Design is Essential for Seismo-Acoustic Processing and Data Quality

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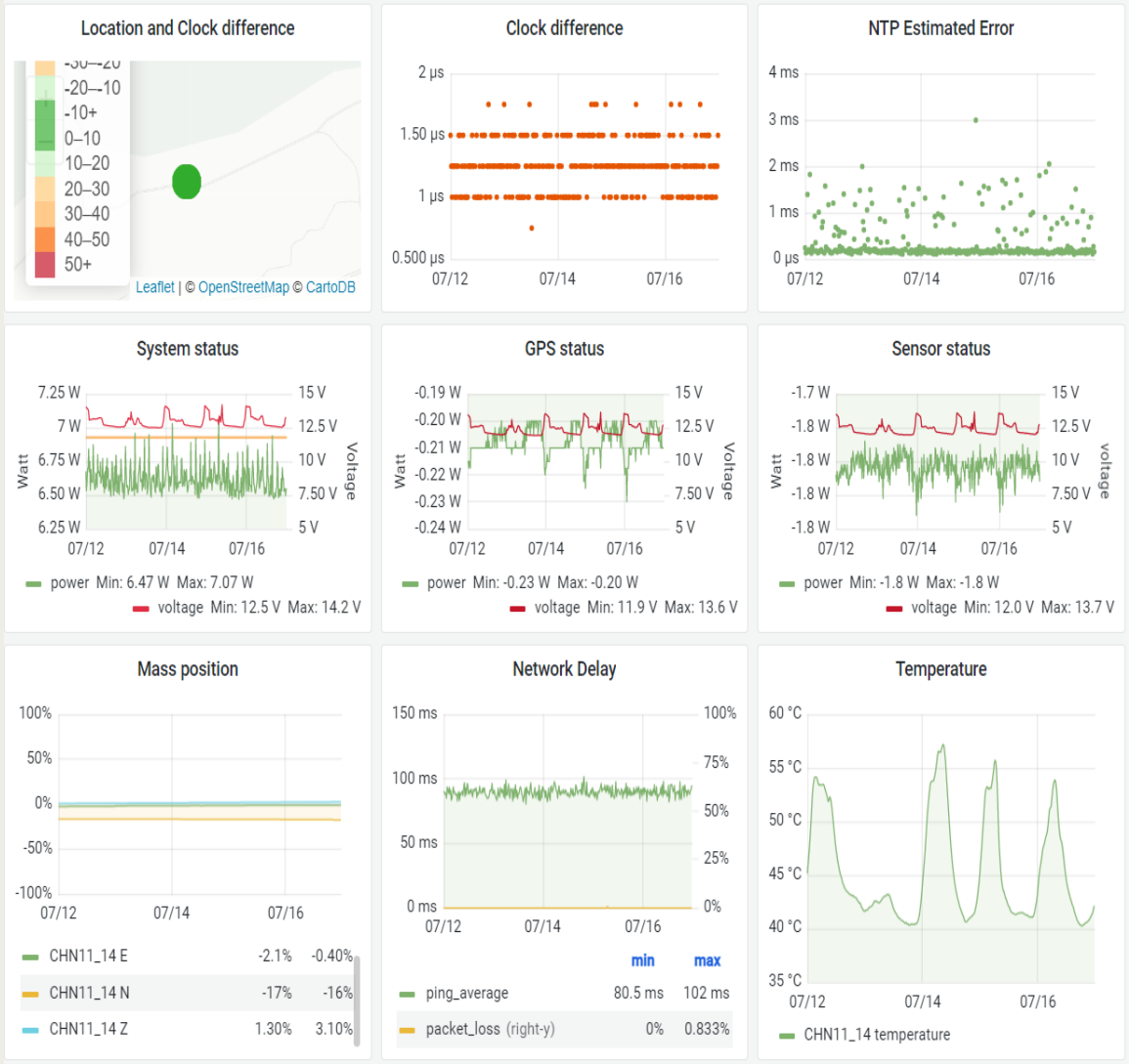
System Monitoring Tools

- Data assessment monitoring
  - Data gaps, noise characteristics, infrasound polarity, seismometer orientation, and calibration
- Real-time station status of health monitoring
- Data telemetry and archive monitoring



J Seismol
https://doi.org/10.1007/s10950-023-10164-6

RESEARCH

Data quality control tools used to monitor seismoacoustic research arrays in South Korea

Junghyun Park · Chris Hayward · Byung-Il Kim · Brian Stump · Il-Young Che · Stephen Arrowsmith · Kwangsu Kim

Integrated Monitoring Tools Support High Data Recovery

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J. Park, B. Stump, C. Hayward, I.-Y. Che, S. Arrowsmith

Regional Seismic Monitoring of 6 DPRK UNEs

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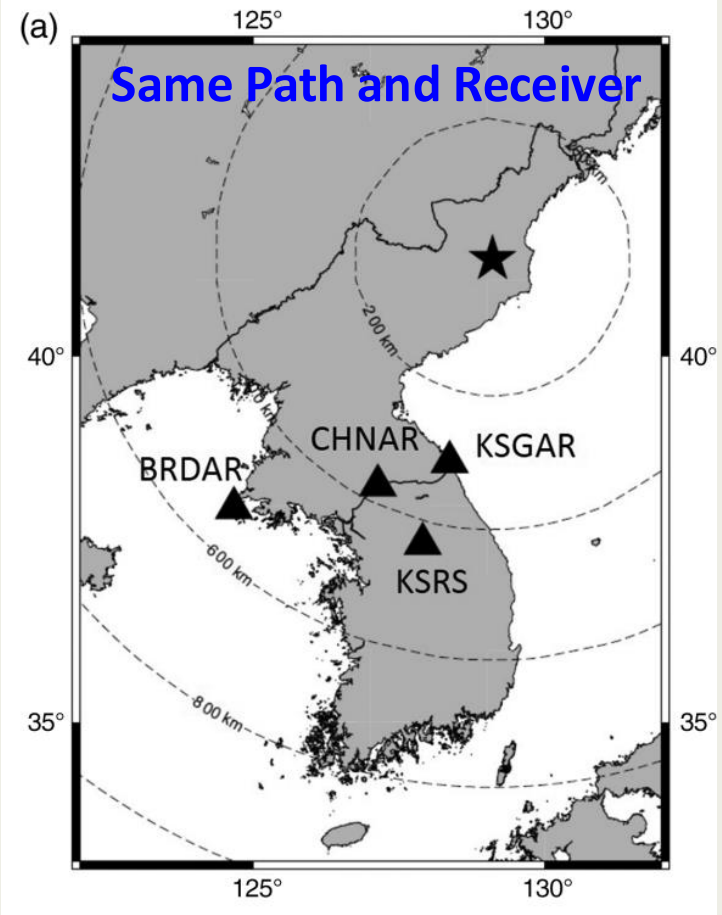
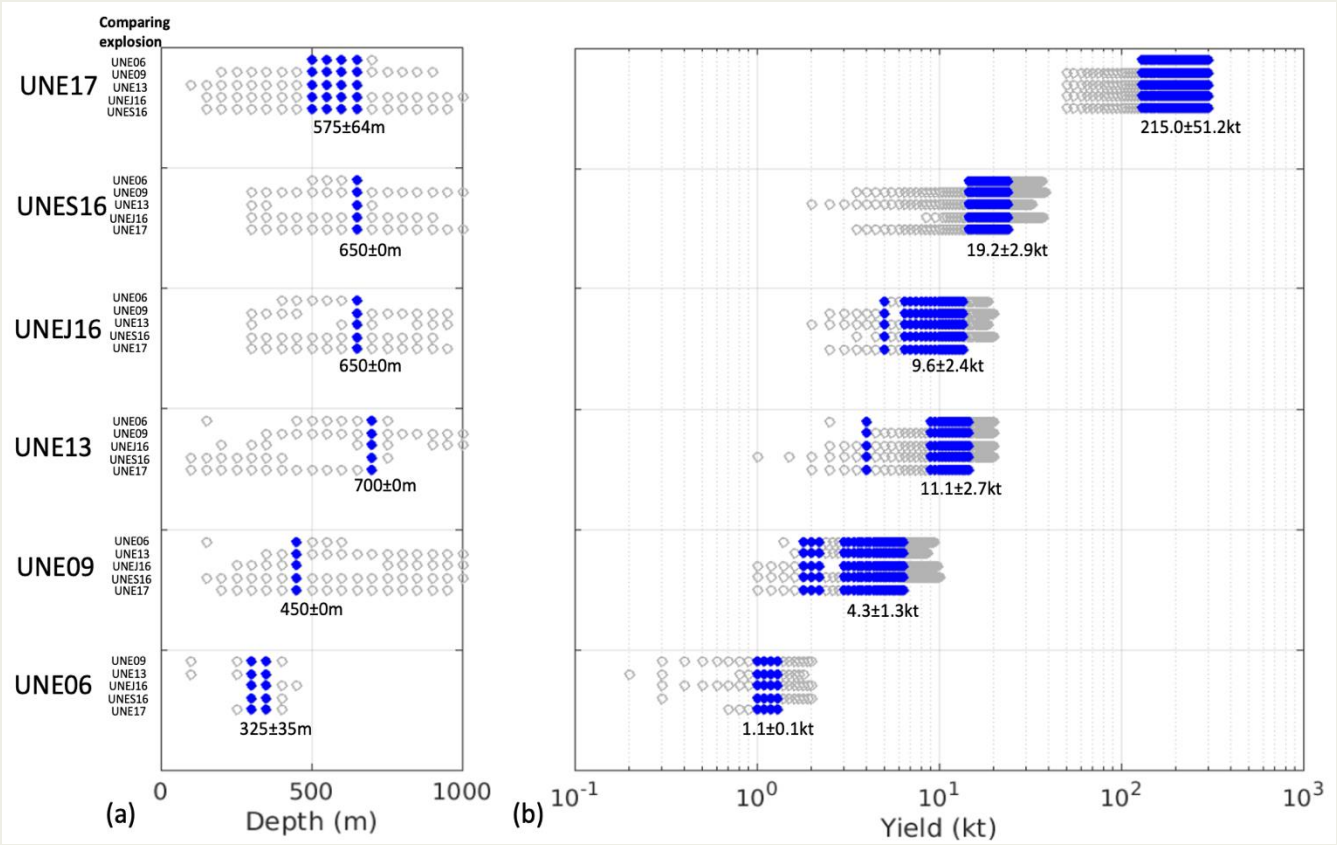


Depth & Yield Estimates (Park et al., BSSA 2022)



Relative Source Estimates Estimate Yield and Depth of DPRK UNE's

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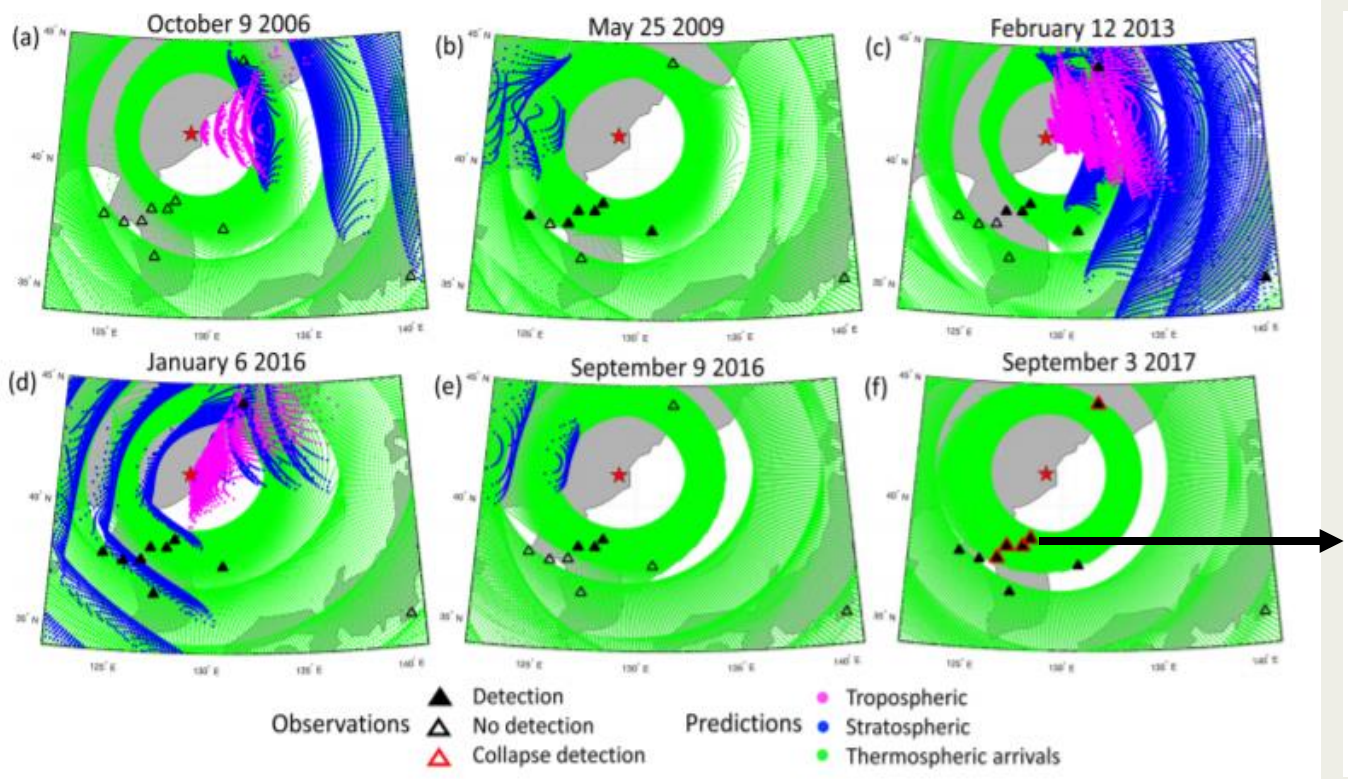
Regional Infrasound Monitoring of 6 DPRK UNEs

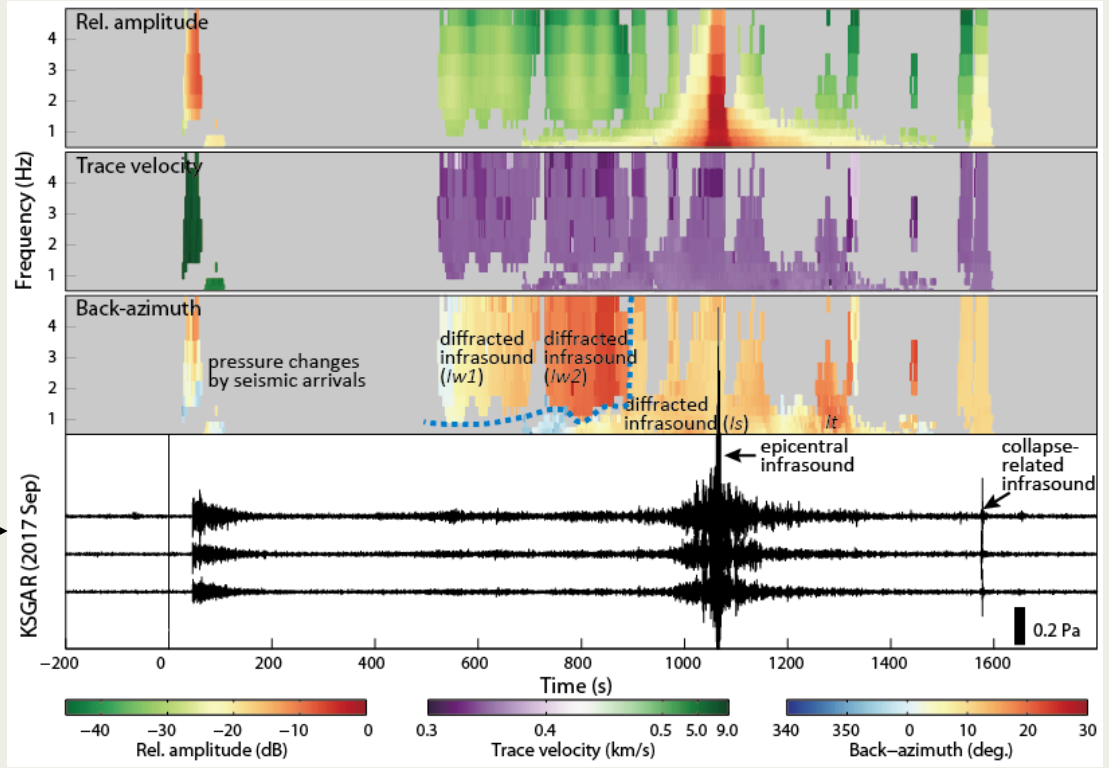
Infrasound Observations vs. Ray Tracing Simulations

Park et al. (GJI 2023)



Infrasound Signals from the 2017 DPRK UNE

Che et al. (GJI 2022)



Infrasound Observations & Atmospheric Models Quantified Detection Capabilities

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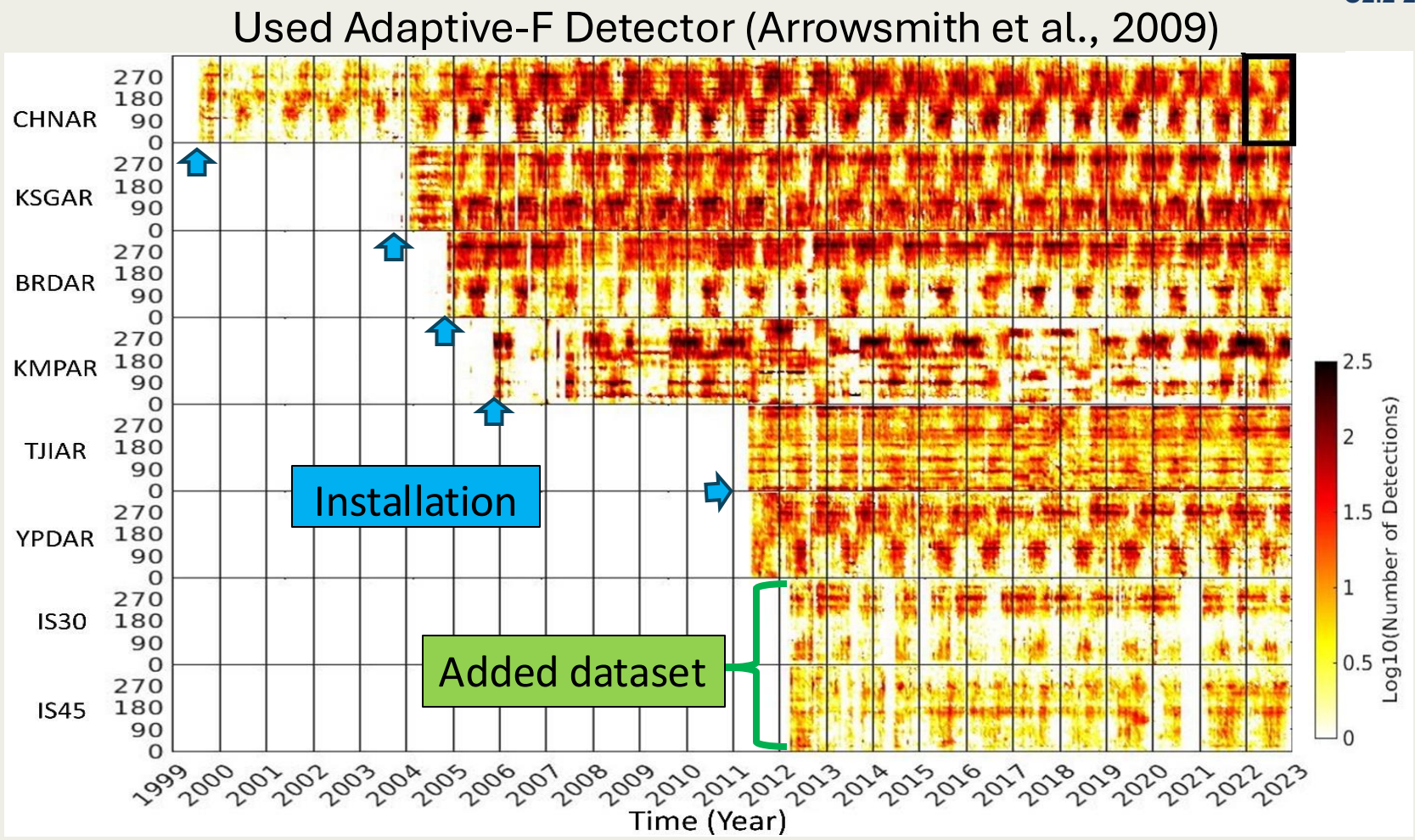
Automatic Infrasound Detections for 24 Years

Park et al. (GJI 2024)

Temporal Variations are Related to Seasonal Variations in the Atmosphere.



Decadal Data Documents Atmospheric Change at a Number of Time Scales

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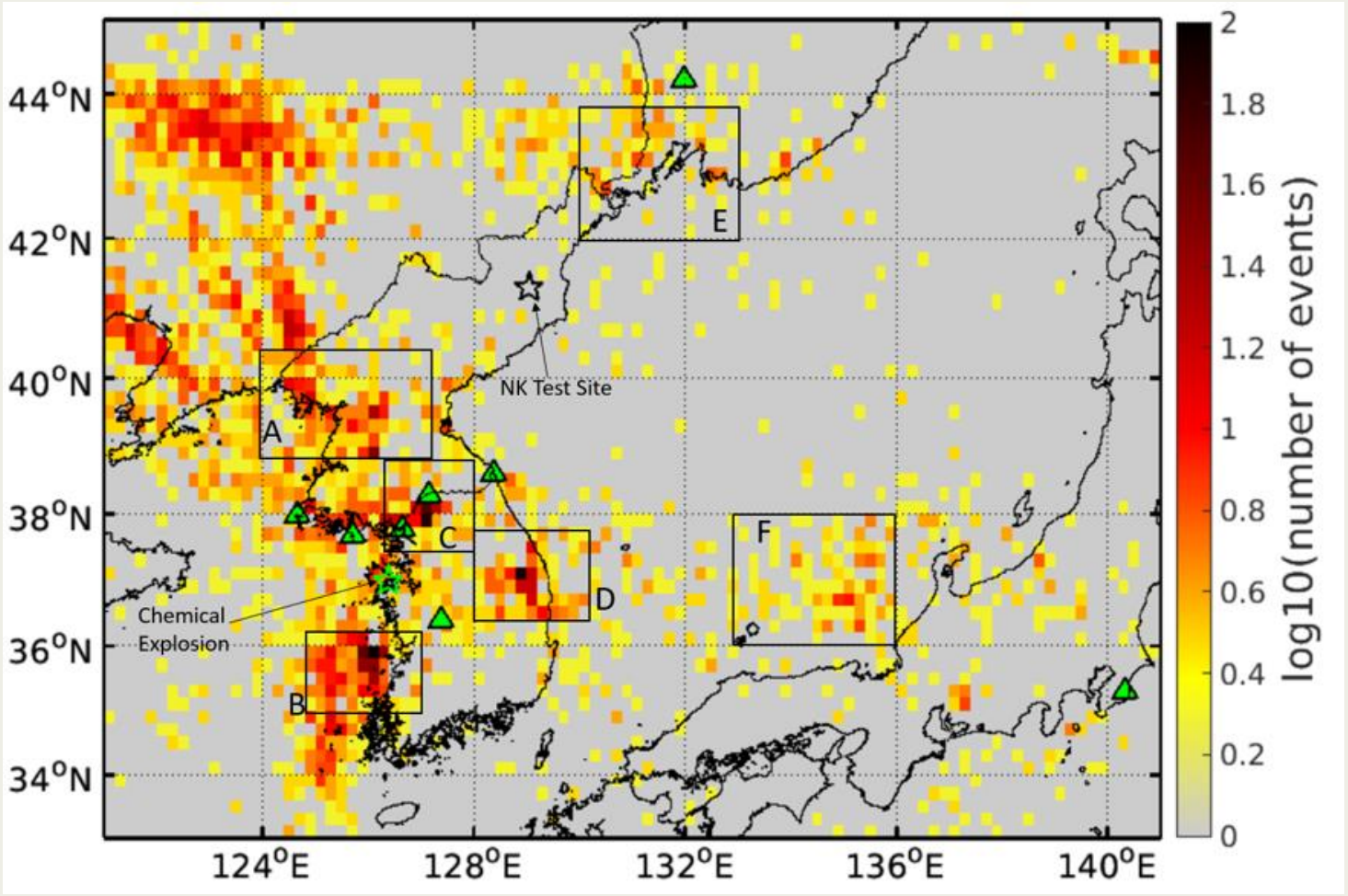
The Korean Infrasound Catalogue for 1999-2022
(Park et al., GJI 2024)

38,455 Infrasound Locations in 24 Years Using Eight Infrasound Array Data.

Repeated Sources are from Human Activities.



Bayesian Infrasonic Source Location (Modrak et al., 2010)

Identified Recurring Infrasound Locations

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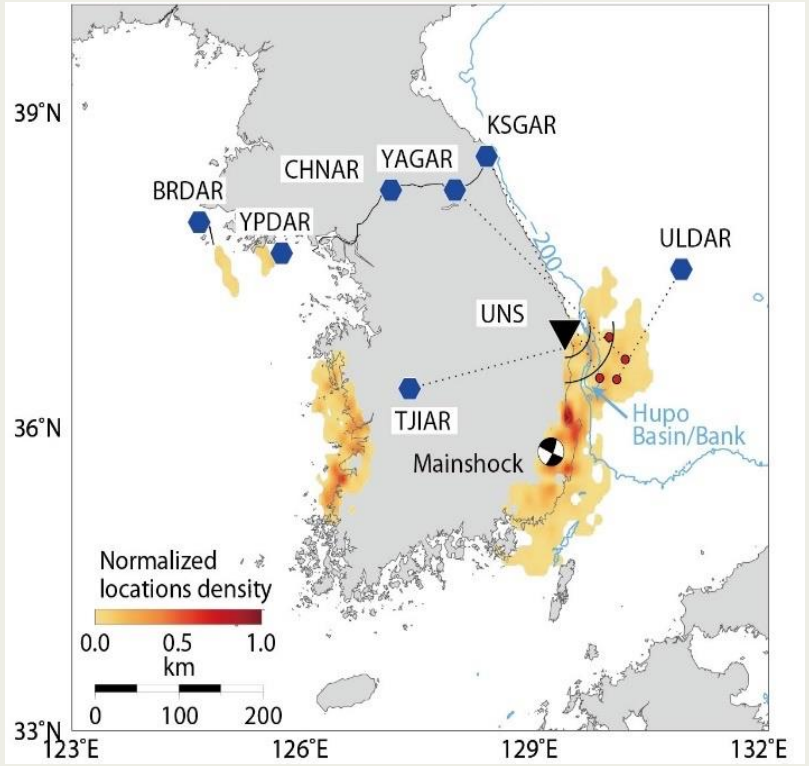
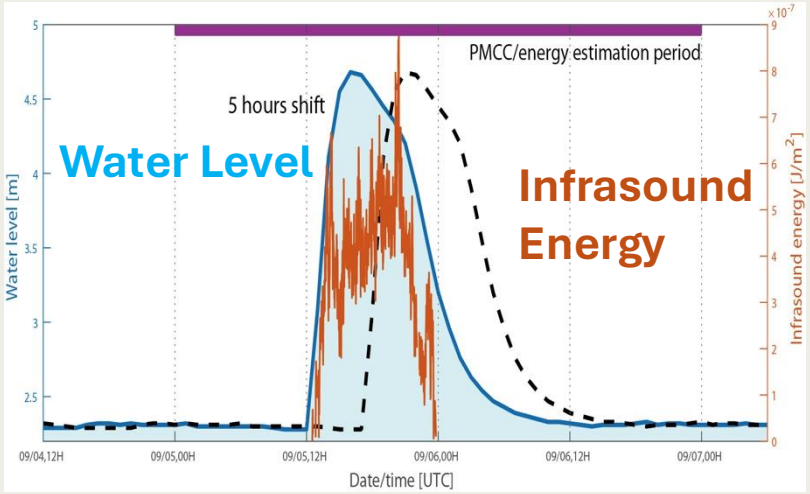
Research Highlights



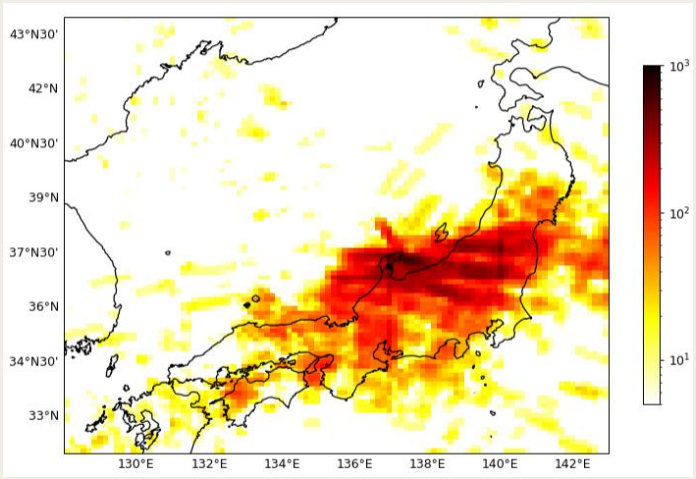
Earthquake-Generated Infrasound Waves

(Che et al., GJI 2025)



Infrasound can be used for Flash Flood Early Alert

(Che et al., GRL 2023)



Infrasound Sources Associated with the Noto Earthquake

(Park et al., 2024 SSA Annual Meeting)

New and Unique Uses for Infrasound Data Analysis

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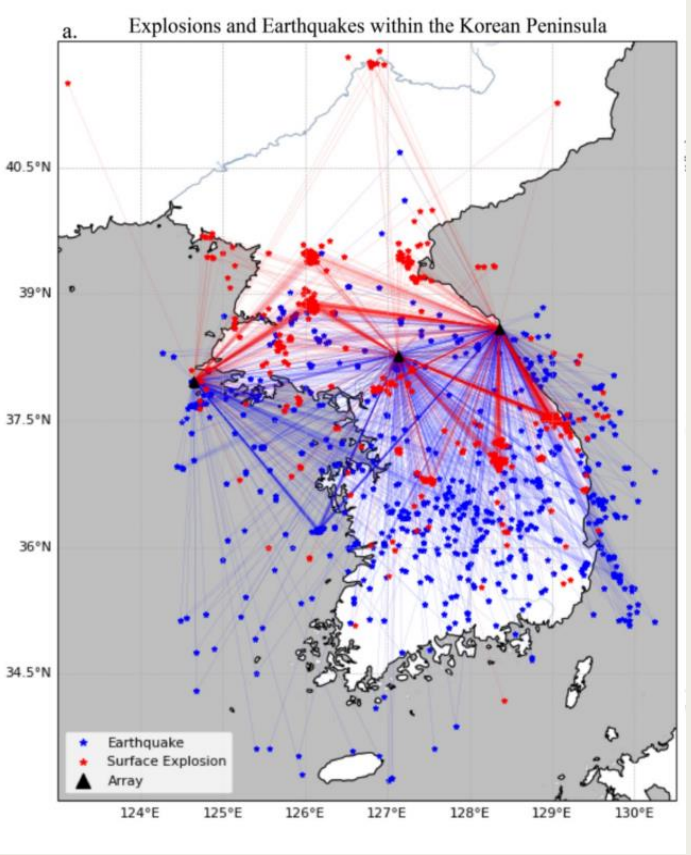
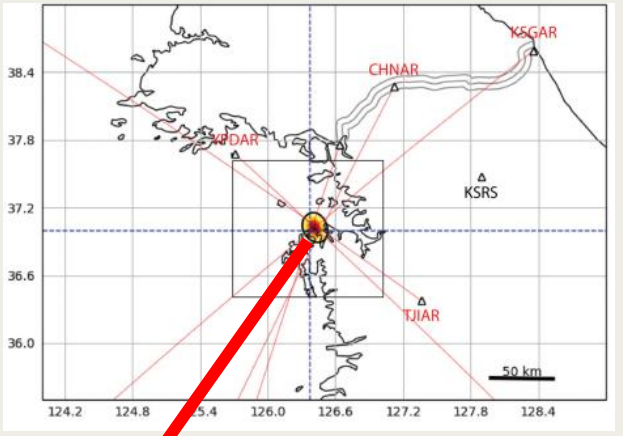
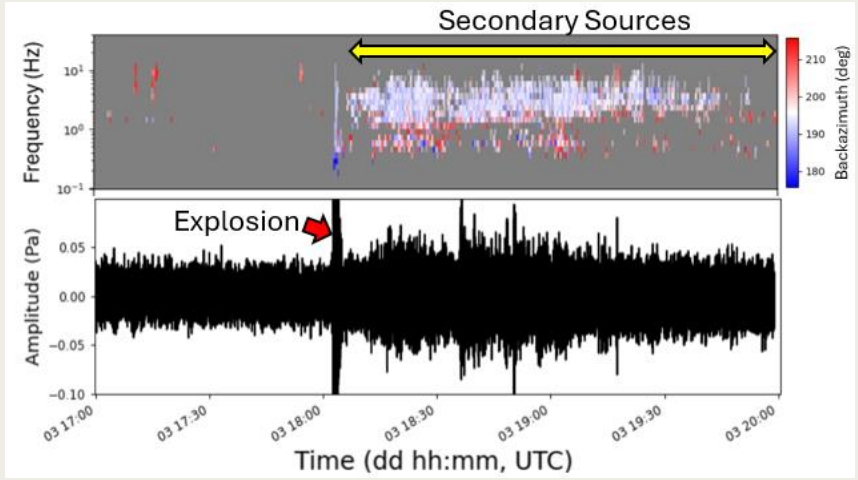
Tool Developments (1)



Deep Multimodal Learning for Seismoacoustic Discrimination
(Ronac Giannone et al., GRL 2024)



Probabilistic Global Search (PGS) method using Seismic Arrival + Infrasound Backazimuth
(Arrowsmith et al., SRL 2020)



Infrasound from Fire (Park et al., TSR 2025) Based on Cardinal (Frequency-Time Based Array Processing Tool; Ronac Giannone et al., SRL 2025)

New Processing Tools Motivated by Dataset

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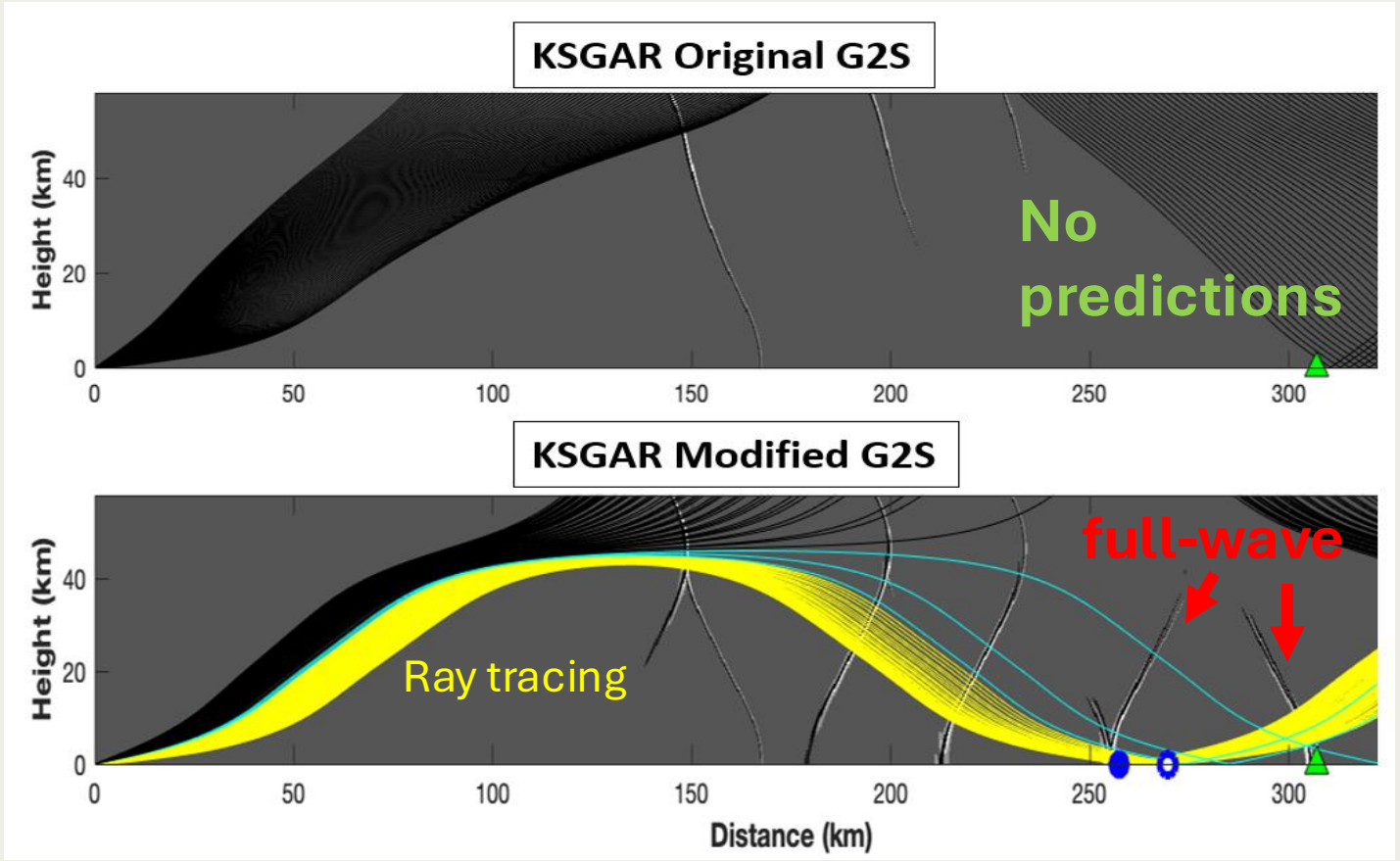
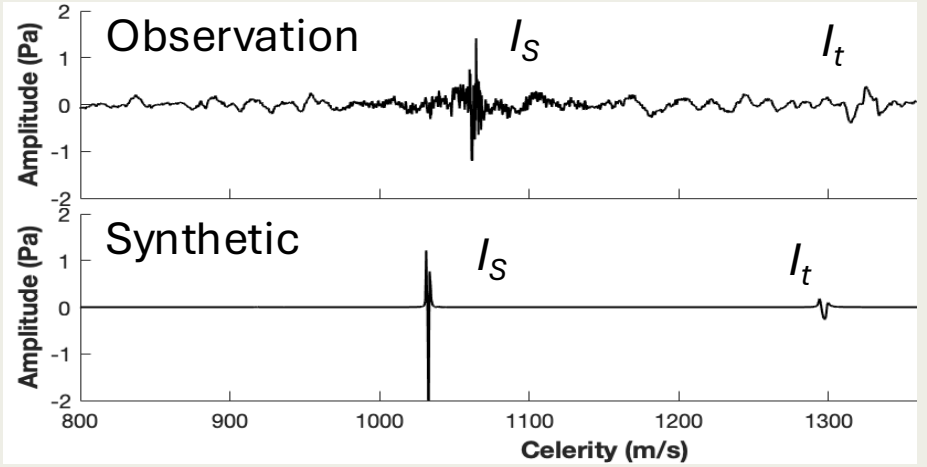
Tool Developments (2)



Infrasound Finite-Difference Time-Domain Propagation Modeling of Infrasound Signals from 2017 DPRK UNE

(Howard et al., ES-SSA 2023 Annual Meeting)



Developed Broadband Full Wave Modeling Tools

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Ongoing and Future Efforts

- We are continuing to build the infrasound catalog using additional array data and are developing seismo-acoustic and AI/ML-based catalogs.
- High-frequency array research at local to regional distances.
- We introduce the Sapphire Mini sensors developed by SMU, a small, low-power infrasound recorder designed for the campaigns.

Sapphire sensor on a drone during an experiment

Thank You!

Contact:
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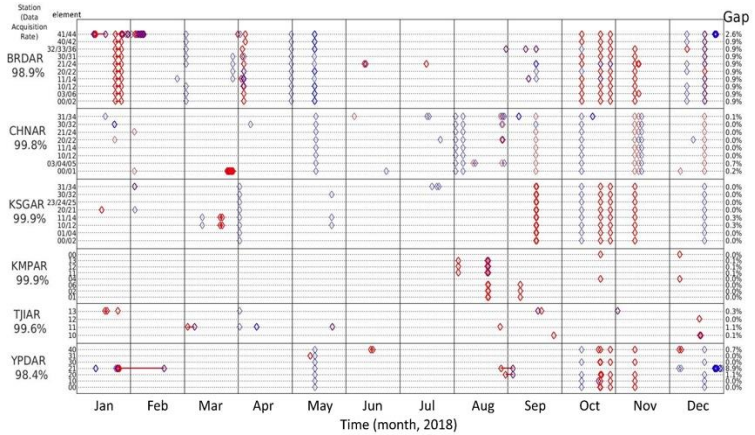
Seismo-Acoustic Completed Tasks and Lessons

- Seismo-acoustic array data characterizes diverse sources.
- Automated data QC tools improve regional multi-array monitoring.
- A network of seismo-acoustic arrays provides seismic, infrasound, and seismo-acoustic bulletins.
- Time-varying atmospheric effects are critical to source detection, location, and interpretation at regional scales.
- Detection, location, discrimination, and propagation modeling tools are being developed.
- Infrasound contributes to event discrimination and hazard mitigation.

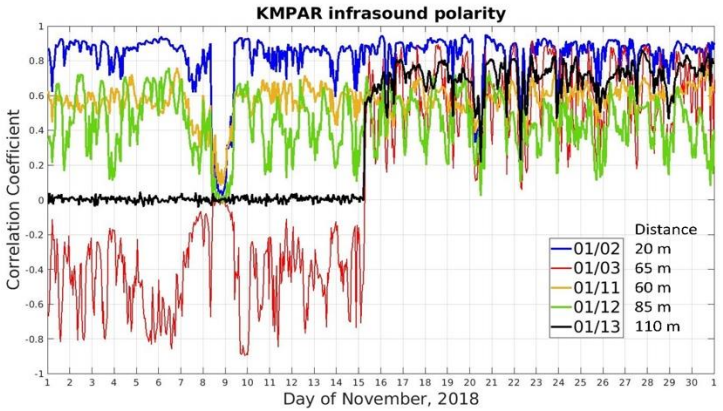
Utilizing System Monitoring Tools

- Data assessment monitoring
- Real-time station status of health (SOH) monitoring
- Data telemetry and archive monitoring

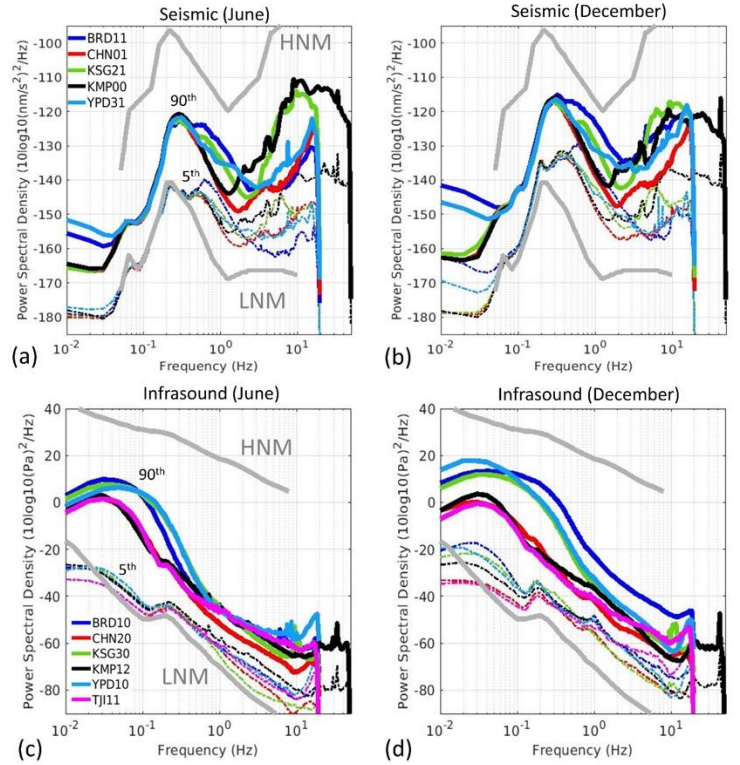
Data gaps



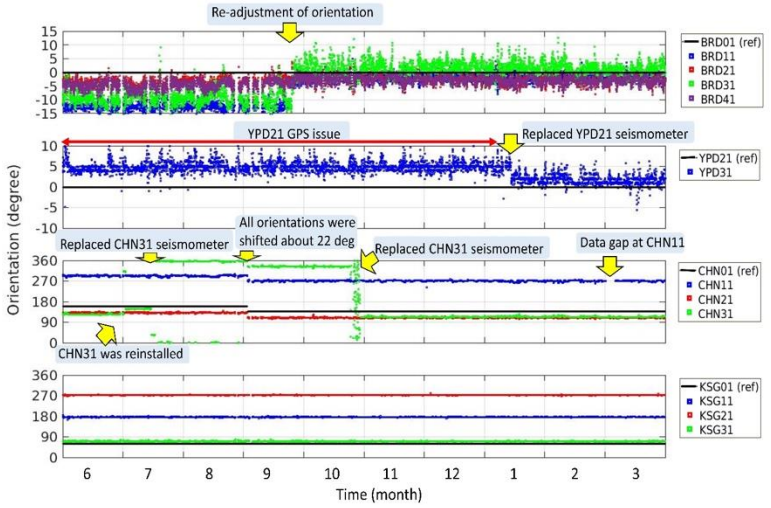
Infrasound polarity



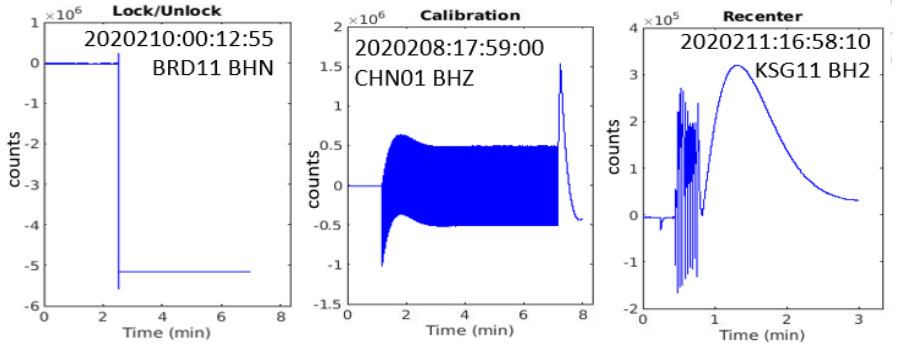
Noise evaluation



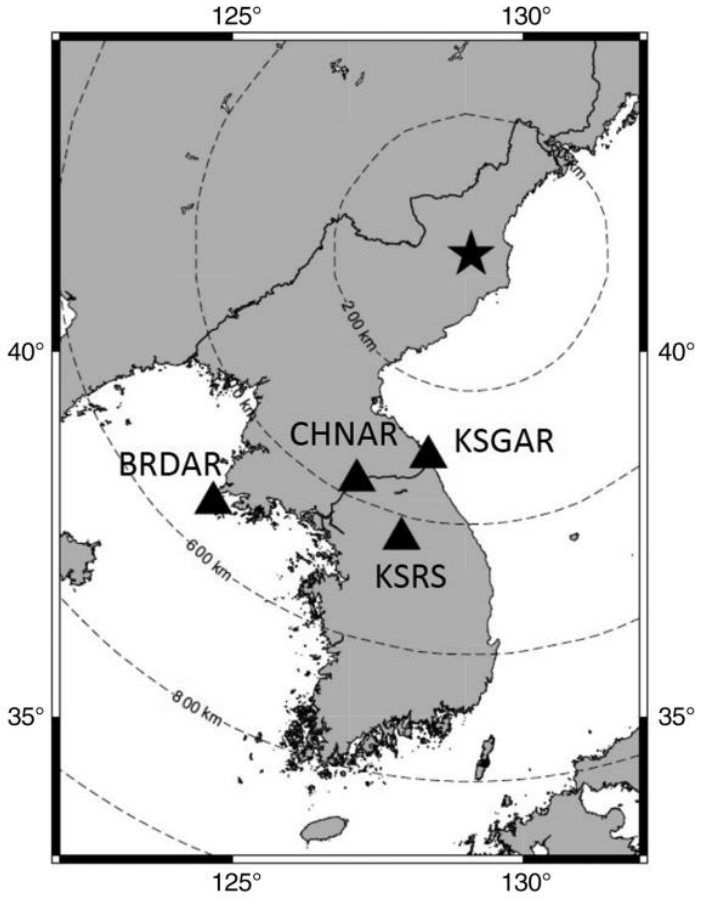
Seismometer orientation



Instrument-generated signal detection

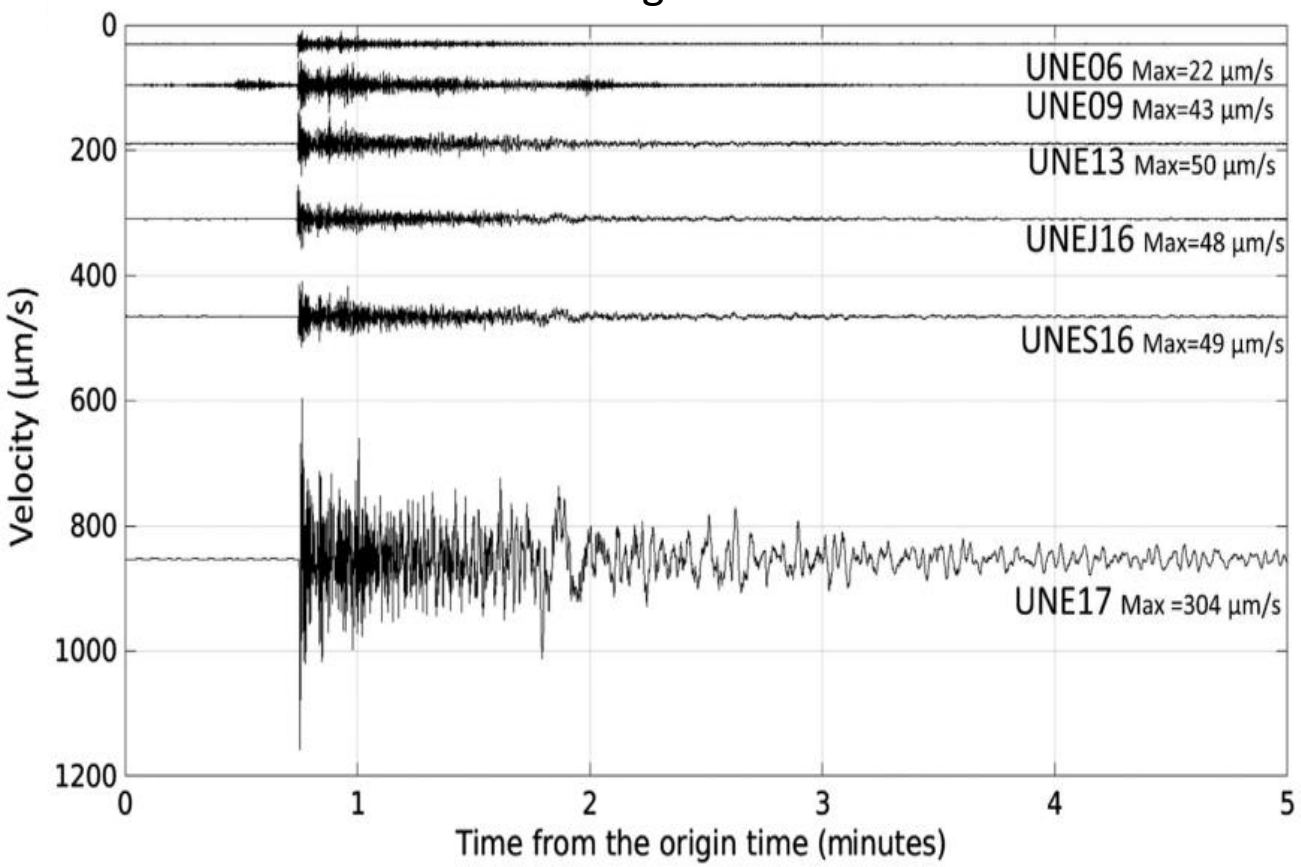


Regional Seismic Monitoring of 6 NK Underground Nuclear Explosions (UNEs)



Park et al. (BSSA, 2022)

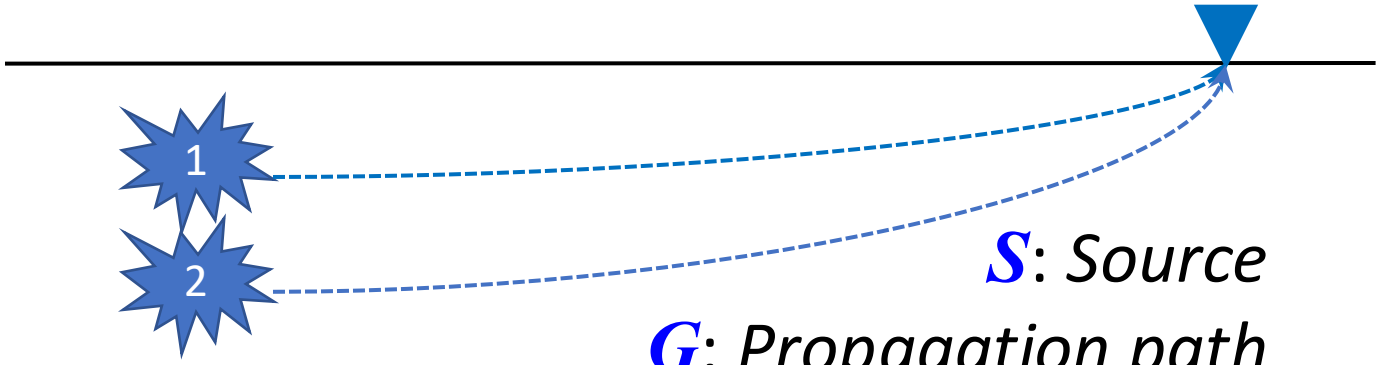
Vertical seismograms at KSGAR



Same Path and Receiver

Data is open to the public
Stump et al. (SRL Data Mine, 2022)

Seismic Source Model



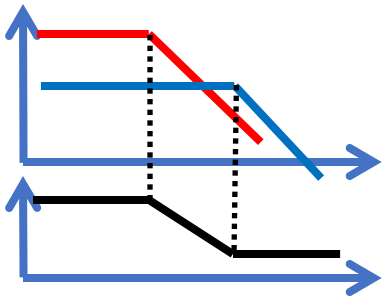
S: *Source*

G: *Propagation path*

W: *Local Site*

R: *Instrumental Response*

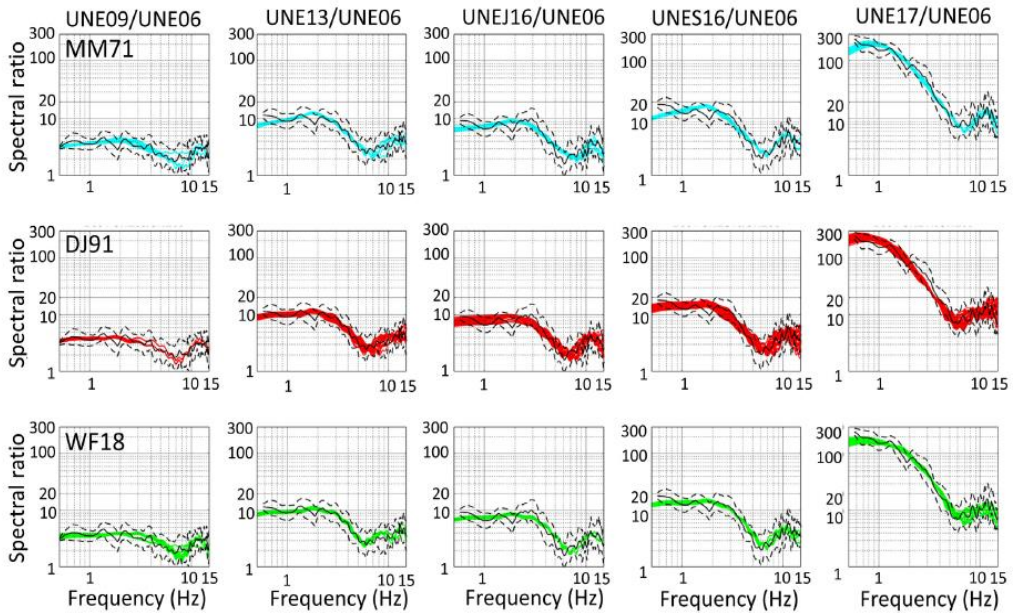
$$\frac{U_{ki1}(f)}{U_{ki2}(f)} = \frac{S_1(f) \times G_{ki1}(f) \times W_i(f) \times R_{ki}(f)}{S_2(f) \times G_{ki2}(f) \times W_i(f) \times R_{ki}(f)} = \frac{S_1(f)}{S_2(f)}$$



Calculated spectral ratio

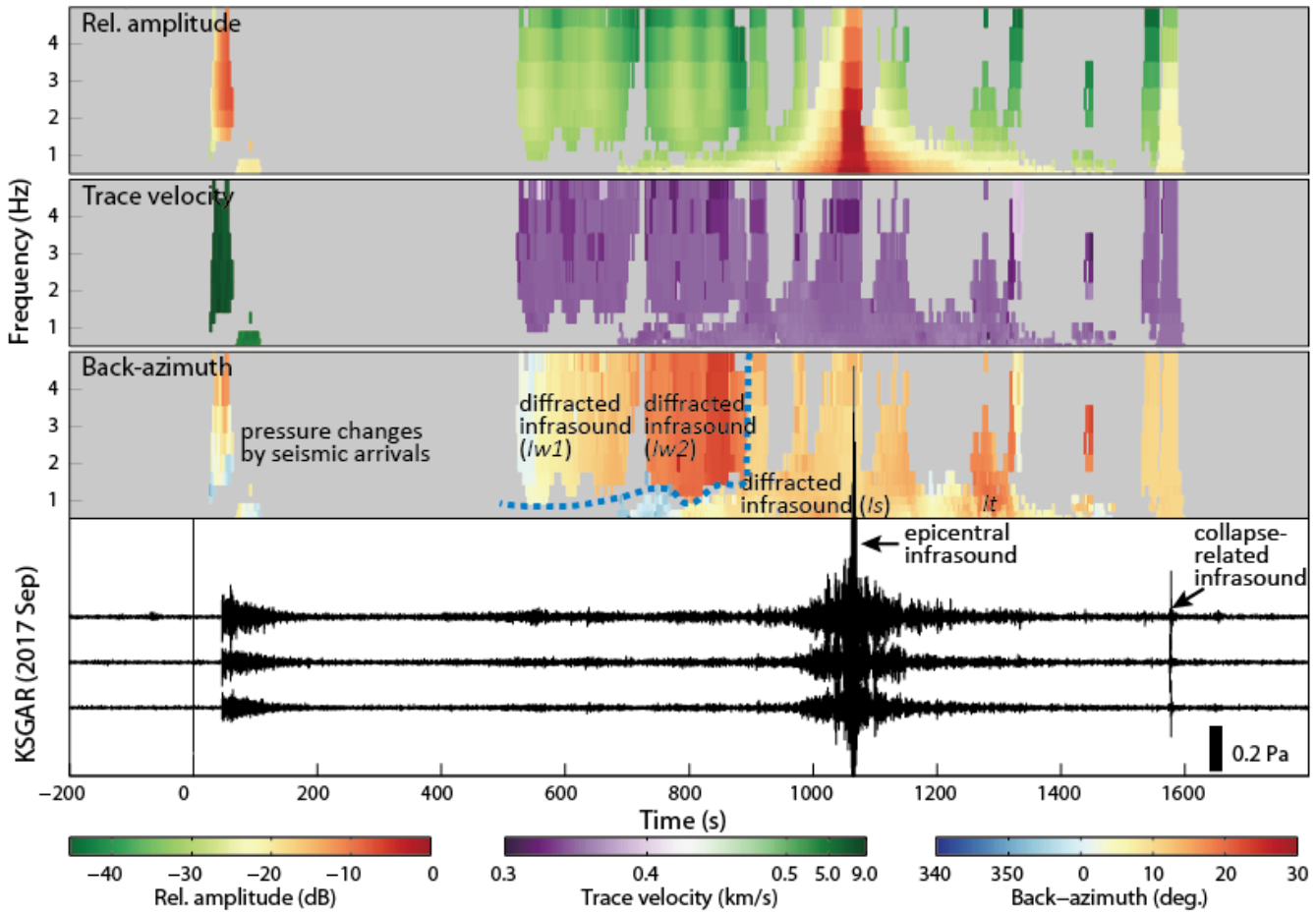
Fitting with theoretical spectral ratios

Mueller-Murphy (1971), Denny and Johnson (1991), and Walter and Ford (2018) models for interpretation

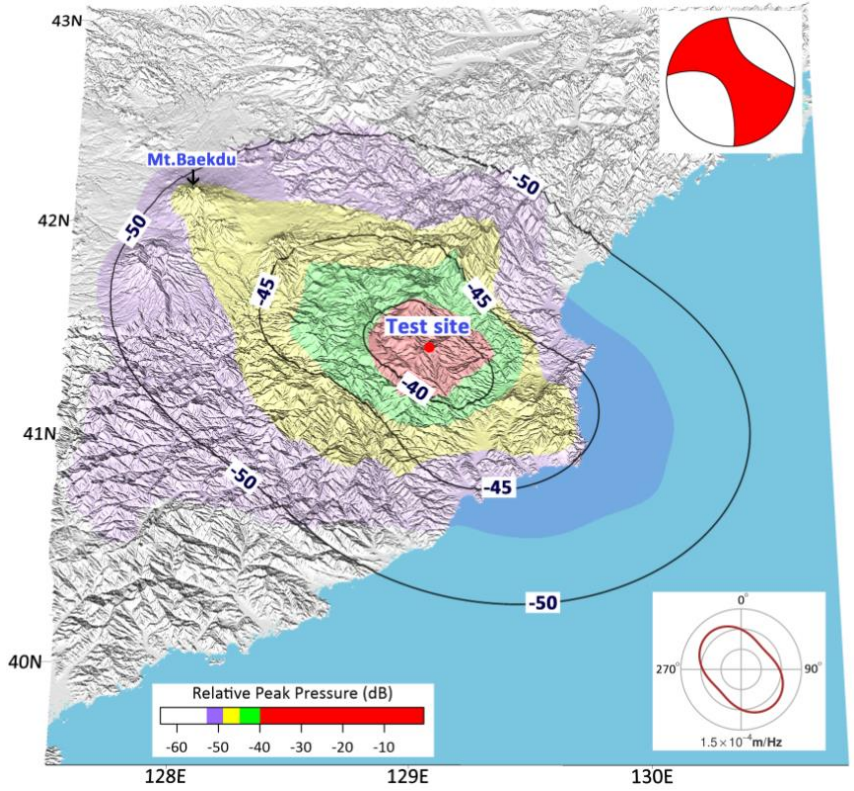


Park et al. (BSSA, 2022)

Regional Infrasound Monitoring of September 2017 NK UNE



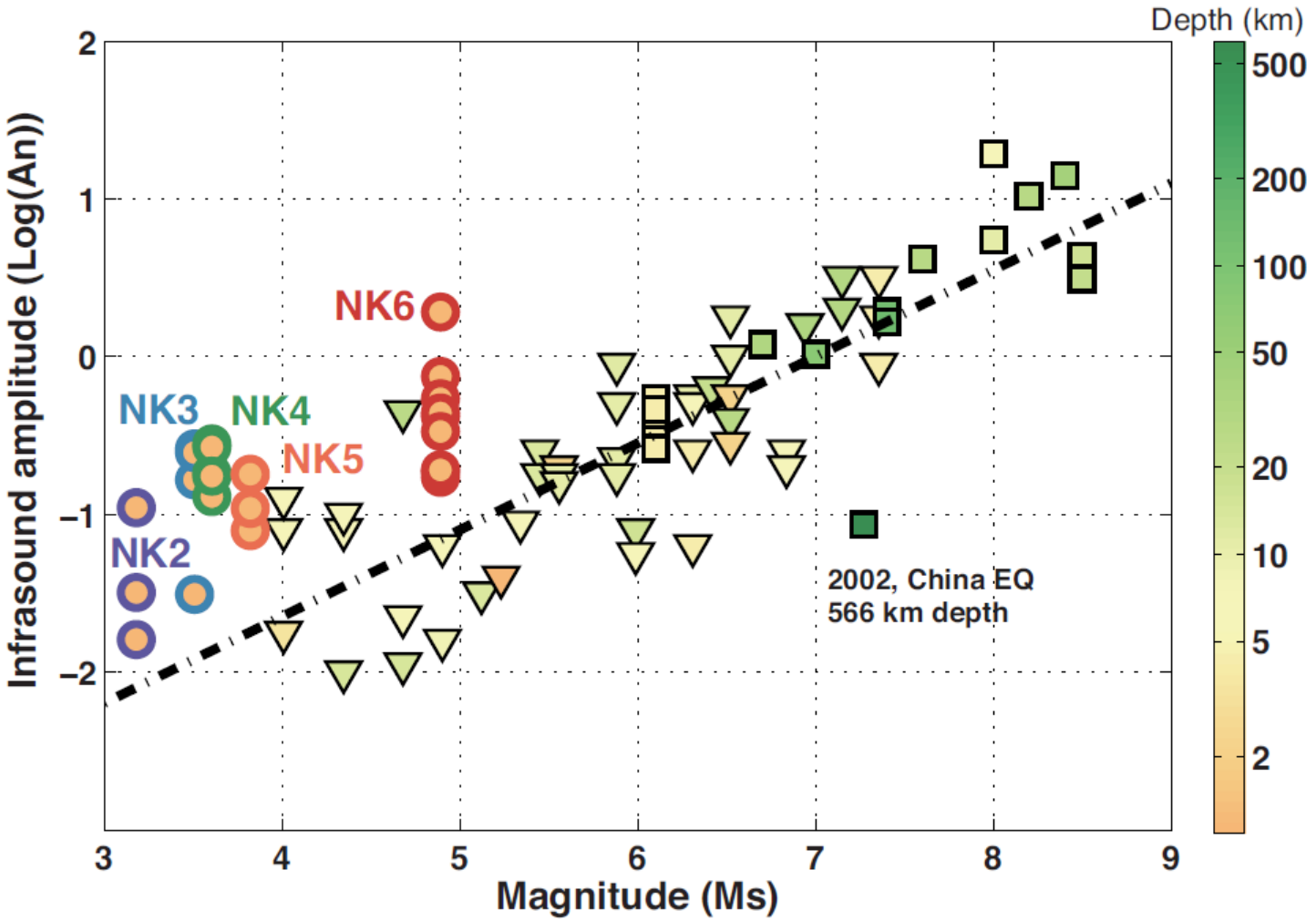
We simulated seismic to acoustic energy conversion for the 2017 explosion.



Che et al. (GJI, 2022)

Enhanced Source Identification

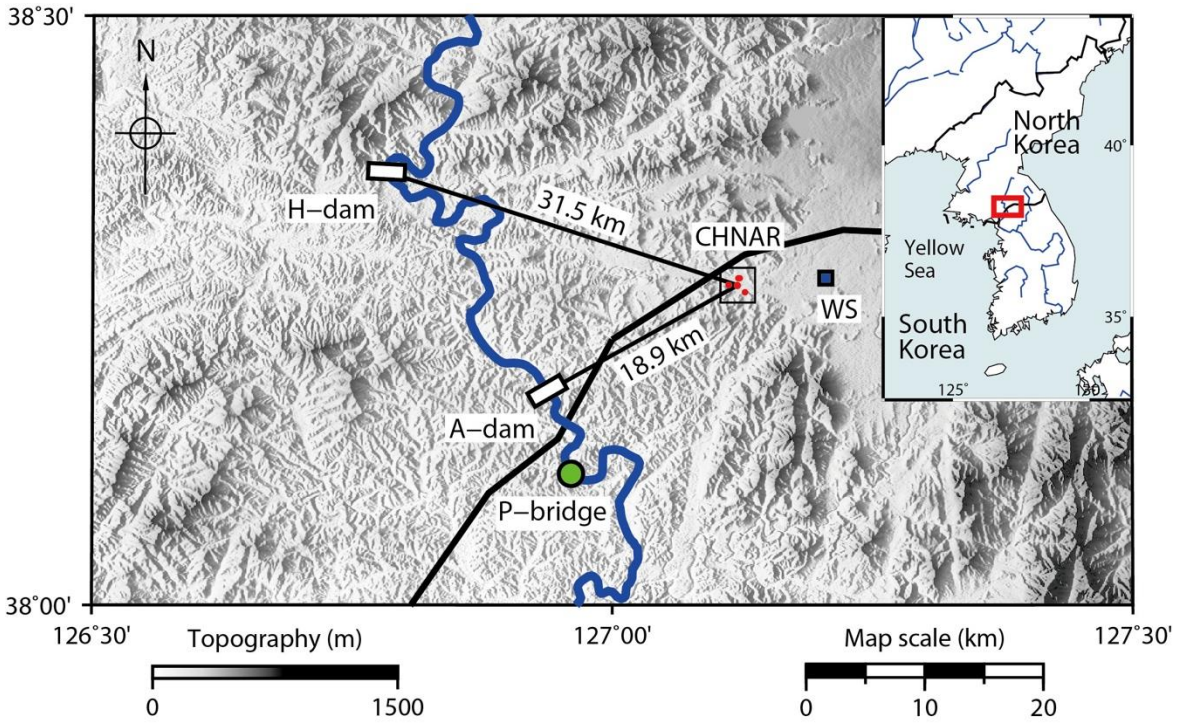
Infrasound can be used to improve event discrimination

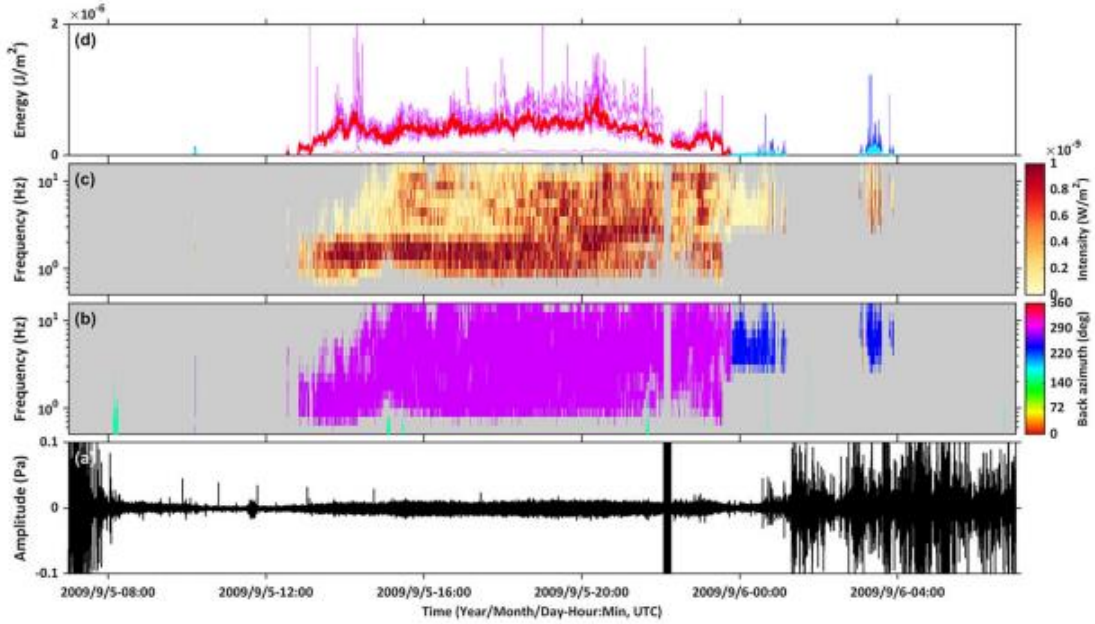


Che et al. (GJI, 2022)

Natural Hazard Study

Infrasound can be used for flash flood early alert





Water level at P-bridge vs. Infrasound energy at CHNAR from water discharges at a hydroelectric dam in N Korea
Che et al. (GRL 2023)