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Seismoacoustic Reverse Time Migration

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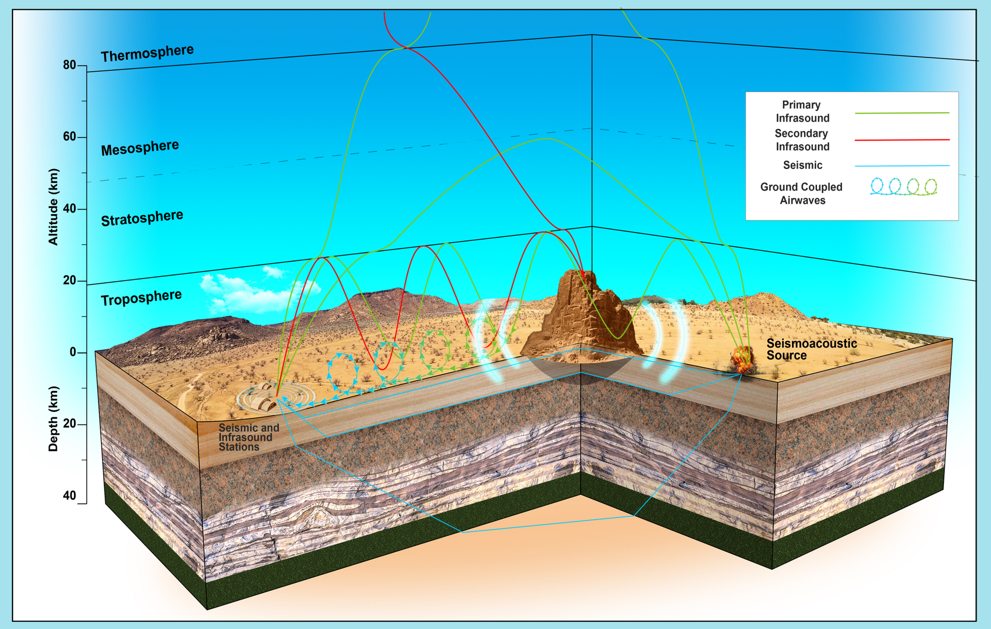
Overview

Problem Description

- Accurate location of seismoacoustic energy is crucial for monitoring both natural and man-made events globally.
- Traditional methods often rely on derived products (arrival times and backazimuths), which can introduce additional uncertainty in source location.
- Recent studies indicate that waveform-based methods, such as *reverse time migration* (RTM), can effectively locate seismic and acoustic sources, but integration of both data types remains a challenge.

Approach

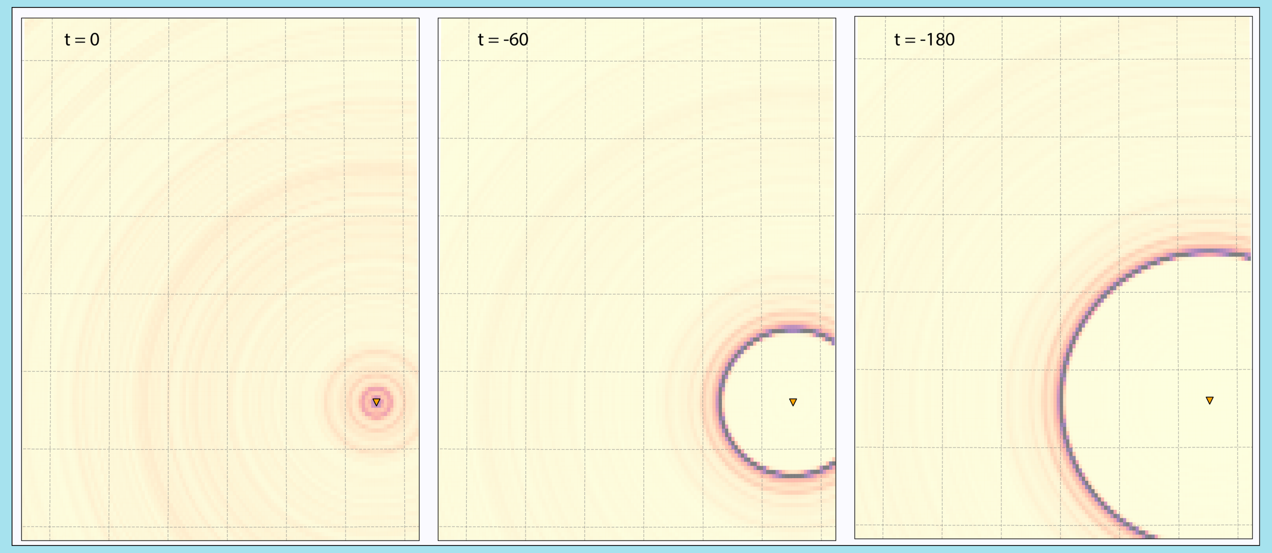
- Modify open-source RTM packages for acoustic data to include seismic travel time models.
- Utilize enveloped waveforms to minimize discrepancies in waveform characteristics between phenomena.
- Apply the joint RTM technique to various seismoacoustic signals to assess its effectiveness in improving source location accuracy.



Seismoacoustic Reverse Time Migration

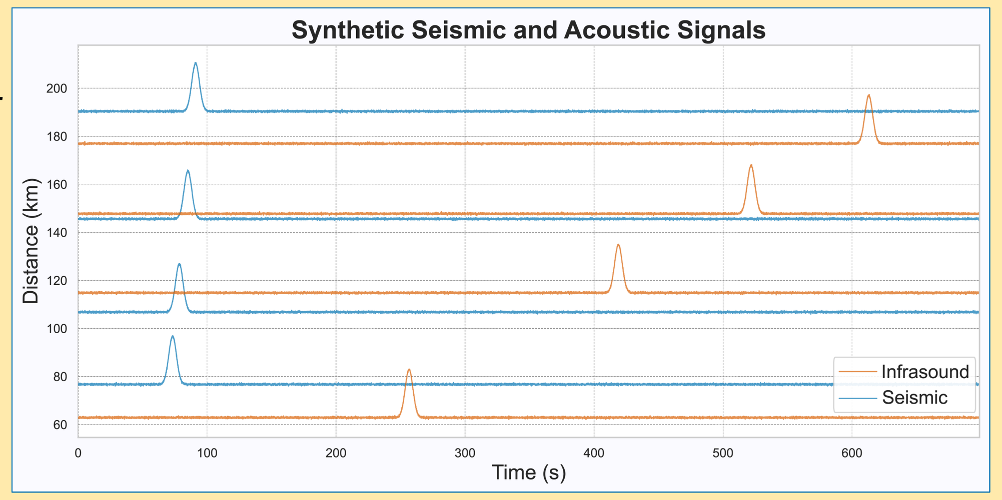
Reverse Time Migration involves of back-projecting recorded waveforms at different time steps over a grid of potential source locations assuming a velocity model. Preprocessed waveforms (e.g., filtered, enveloped) are back-projected to each potential source location and then stacked, with waveform energy adding constructively at likely source locations. Previous work has demonstrated the value of RTM on both seismic and acoustic phenomena individually. Here we explore a **seismoacoustic RTM** by simultaneously back-propagating and stacking seismic and acoustic waveforms through different velocity models. We modified the RTM python package developed by Fee et al. (2021; available at https://github.com/uafgeotools/rtm) to include P-wave traveltimes using the 1-D velocity model AK135 (Kennet et al, 1995).

Three time steps showing the back-propagation of an acoustic waveform using a constant 320 m/s velocity.

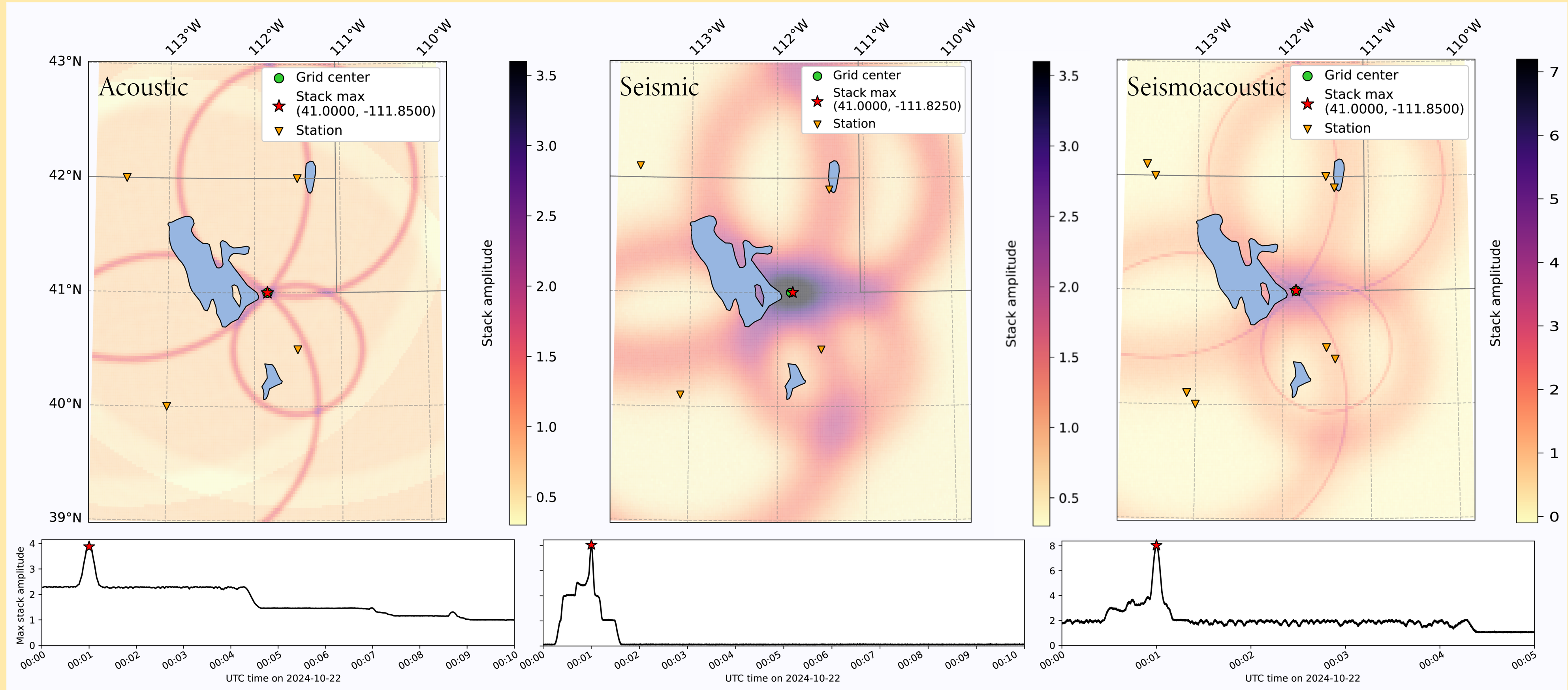


Synthetic Tests

Simple synthetic waveforms were constructed using a Gaussian pulse at arrival times predicted for infrasound, employing a velocity of 320 m/s, and seismic, using AK135. Four stations were utilized for both seismic and infrasound data. The RTM algorithm uses the same velocity models to propagate the energy backward in time, ensuring that the correct solution is found.

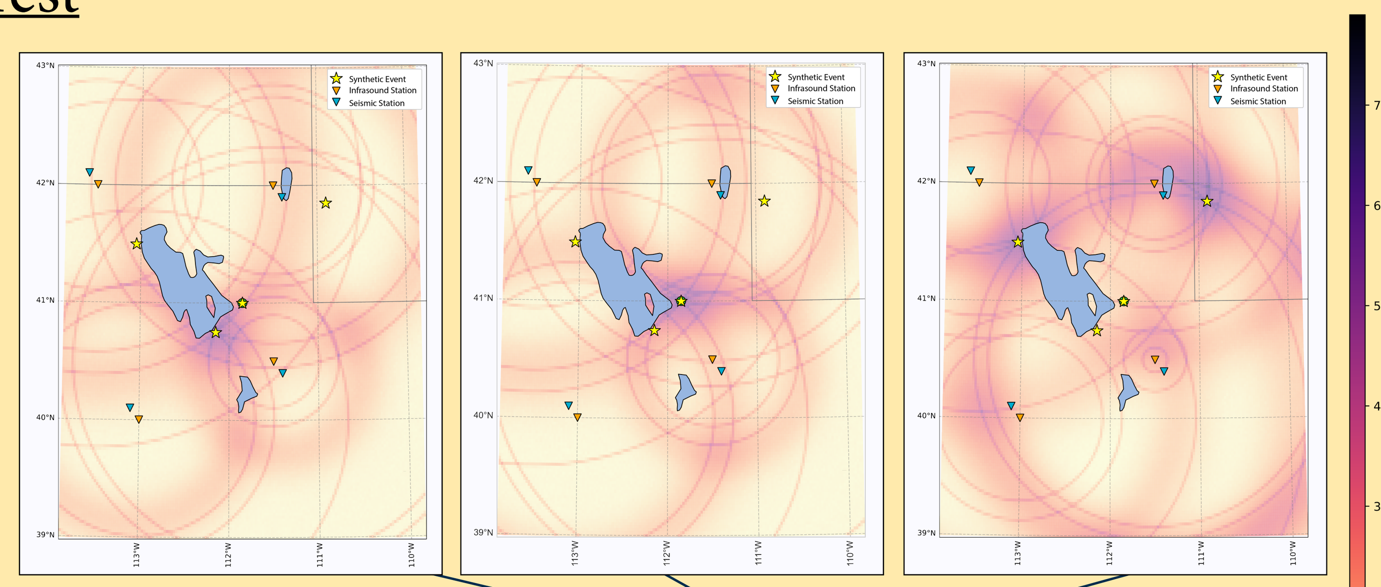


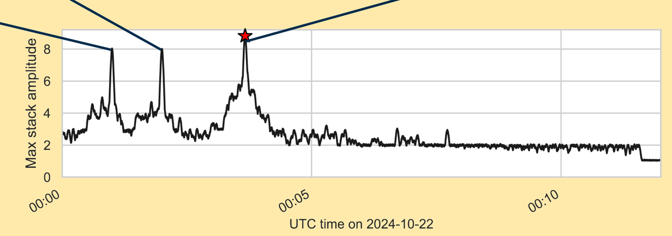
Maps and time views of acoustic (left), seismic (center), and seismoacoustic (right) RTM. Each instance identifies the maximum amplitude at the synthetic event location. The slower velocity of infrasound results in narrower peaks in the spatial view, while the time stack is more spread out. In contrast, seismic data exhibit the opposite trends, with a broader spatial and narrower time distribution.



Multi-Event Synthetic Test

Using the same models as above, synthetic waveforms were constructed containing four events at different locations, with two of the events occurring at the same time. By employing reverse time migration (RTM), we are able to isolate all events. The two events with the same origin times can only be resolved by examining a map view.

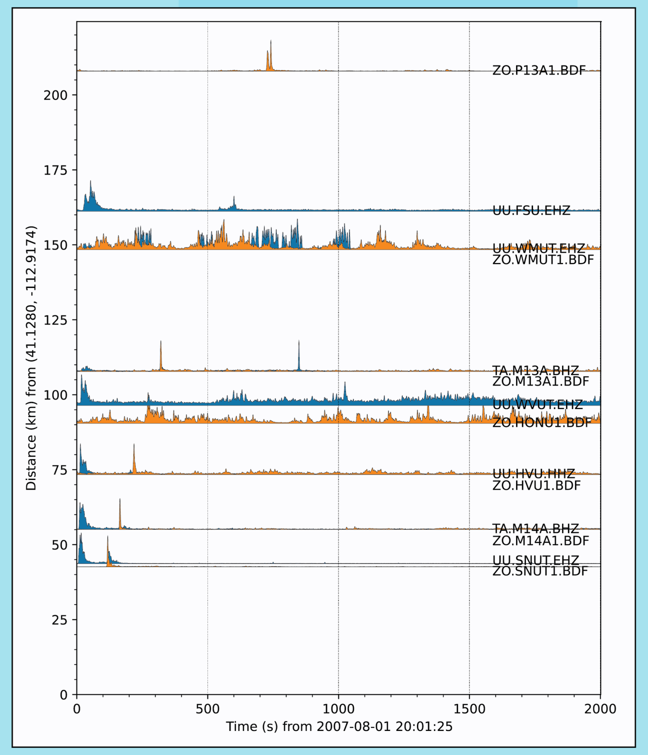




Map views of RTM amplitude at each event time (top). Time series showing stacked amplitude at each time (right).

Testing the Seismoacoustic Framework: Surface Explosion at UTTR

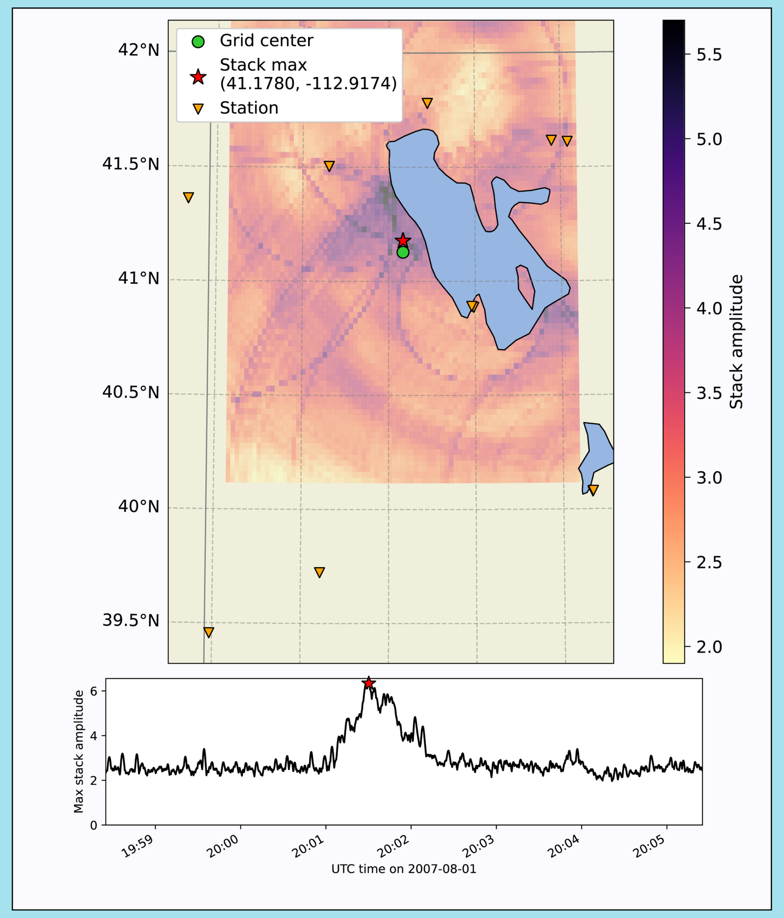
Event Overview: On August 1, 2007, a surface explosion resulting from the disposal of old rocket motors at the Utah Test and Training Range (UTTR) produced detectable infrasound arrivals over 200 km away. For this example, six seismic and six acoustic arrivals were used.



Preprocessing Steps:

- **Bandpass Filtering:** Apply a 0.5 - 5 Hz bandpass filter to isolate relevant frequency components.
- **Downsampling:** Reduce the sampling rate to 20 Hz for efficient processing.
- **Hilbert Transform:** Compute the envelope waveform to enhance signal characteristics.
- **Normalization:** Normalize the waveforms to ensure consistent amplitude levels.
- **Smoothing:** Apply a 5-second Hann smoothing window to reduce noise and improve signal clarity.

As infrasound signal coherency can diminish with increasing range and frequency, preprocessing helps ensure that waveforms remain coherent during stacking. Here, the same preprocessing is applied to both seismic and infrasound. It may be beneficial to consider separate processing strategies tailored to the unique characteristics of each phenomenon.



Conclusions

- By simultaneously back-propagating and stacking seismic and acoustic waveforms, we enhance the resolution of event localization, leveraging the strengths of both data types.
- This initial work demonstrates promise; however, further research is needed to fully understand the strengths and weaknesses of this approach.

Future Work

- Explore different event types to evaluate the capability of RTM as a discriminant for event classification.
- Investigate various preprocessing parameters for seismic and infrasound data to optimize signal quality and event detection.
- Conduct seismoacoustic RTM over extended time periods to assess the method's event detection capabilities in diverse scenarios.
- Incorporate atmospheric models to develop more accurate travel time models for infrasound, enhancing the precision of event localization.

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References:

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