Sandia National Laboratories

Arrival Time Based Seismoacoustic Source Location using a Bayesian Framework

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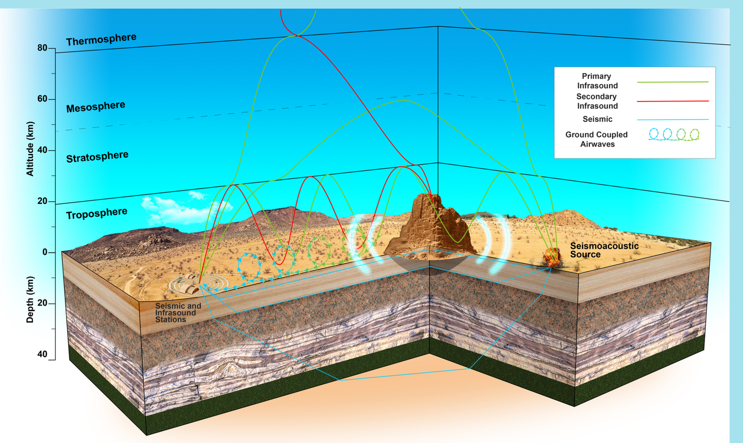
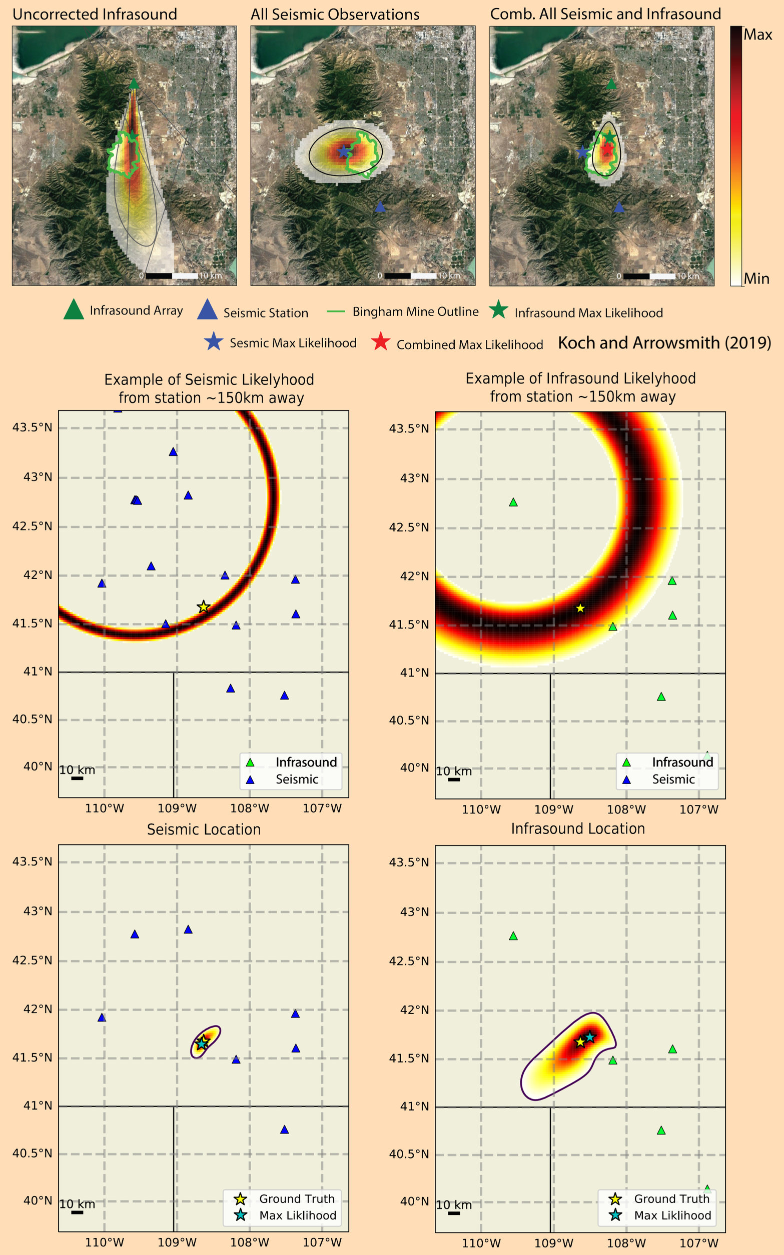
Abstract

Accurately locating seismoacoustic events is a continuing topic of interest within the monitoring community. The high variability in atmospheric temperatures and winds makes modeling infrasound source-to-receiver travel-times highly uncertain in comparison to infrasound array direction of arrival estimates and seismic arrival times. As such, previous seismoacoustic location methods combine infrasound backazimuth estimates from arrays of infrasound stations with seismic arrival times to determine spatiotemporal location estimates, along with a confidence region representing the uncertainty in that location. Although array-based location methods represent the standard for infrasound source location, global infrasound arrays are limited due to design requirements and high deployment and maintenance costs. Conversely, single infrasound stations require minimal effort to deploy, but lack the ability to provide direction of arrival estimates. In this study, we expand on an existing seismoacoustic location method to include arrival times from single sensor infrasound stations. We utilize the celerity-range priors from the improved Bayesian Infrasound Source Localization (BISL) method to account for variability in the atmosphere. This study demonstrates the feasibility of spatiotemporal location using a variety of observation and instrument types which increases location capabilities in areas of sparse instrumentation.



Applying Previous Methodology

Previous work by Koch and Arrowsmith (2019) showed that combining seismic arrival times with infrasound backazimuths is capable of reducing event location uncertainty. The authors utilize a grid search approach, forward modeling the seismic travel times through a velocity model and the infrasound backazimuths along a great circle path to obtain a residual at each point in the grid. Here, we expand this method to include infrasound arrival times from single station infrasound sensors. First, we test paralleling the seismic approach for infrasound using a highly simplistic forward model of 300 m/s. To account for the variability of celerities in infrasound signals, we include a model uncertainty term, σ_m, which scales with distance to account for the range of infrasound celerities. σ_m is combined with pick uncertainty, σ_p, to give the total travel time uncertainty. This approach yields reasonably accurate solutions, but results in very large uncertainty regions due to the high model uncertainties, and ultimately contribute little to a seismoacoustic location.



Celerity-Range Approach

To improve on the infrasound location we incorporate the celerity-range approach developed by Blom at al. (2015) for locating arrivals at infrasound arrays. In this approach, a prior estimate is used to provide the likelihood of an observation arriving at a station with a given celerity and distance. We expand the Koch and Arrowsmith (2019) approach to include celerity-range priors. For every position in the grid, we calculate the distance and celerity for a given observation (station) and use the prior to determine the likelihood of the observation. The product of each station's individual likelihood is taken and integrated over space and time to determine the probability of an arrival coming from each point. This is further integrated over time to determine the marginal distribution and plot probability as a function of latitude and longitude.

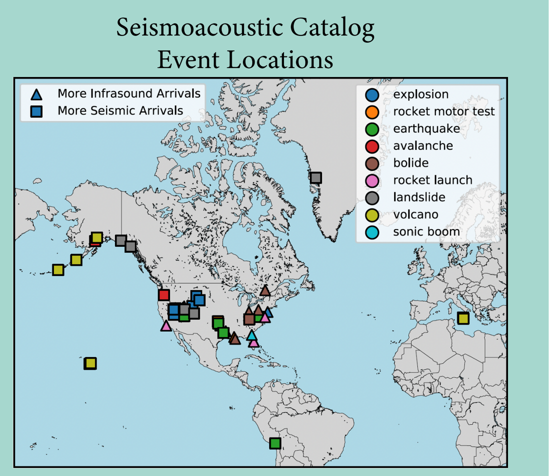
The prior is critical in determining the accuracy of the location. Here, we test two methods for determining the priors;

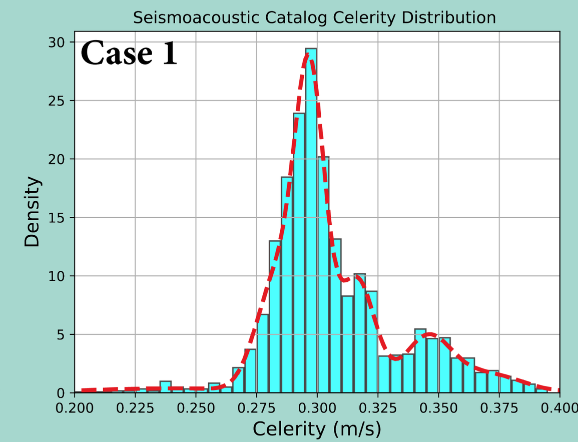
1) Catalog Celerity Distribution: Using a range independent distribution of celerities obtained from a seismoacoustic catalog of 67 events from a wide range of sources (natural and man-made) and geographic distribution.

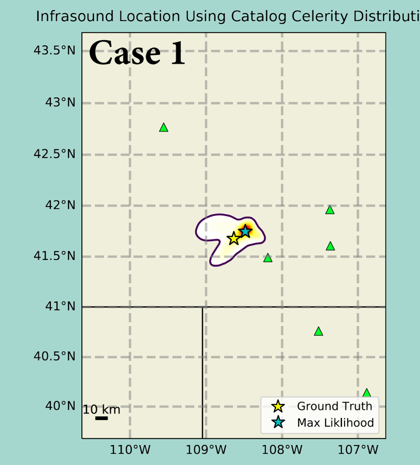
2) Ray Tracing Celerity-Range: incorporating arrivals constructed using a Ground 2 Space (G2S) atmosphere specification for the ground truth time and location of each event.

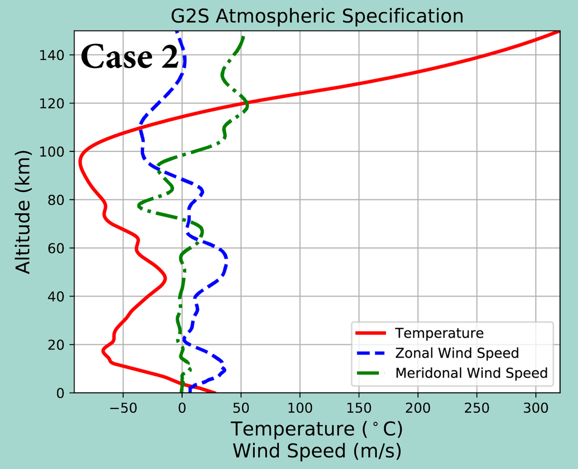
In each case we use a Gaussian mixture model (GMM) to fit a series of Gaussian distributions to the data.

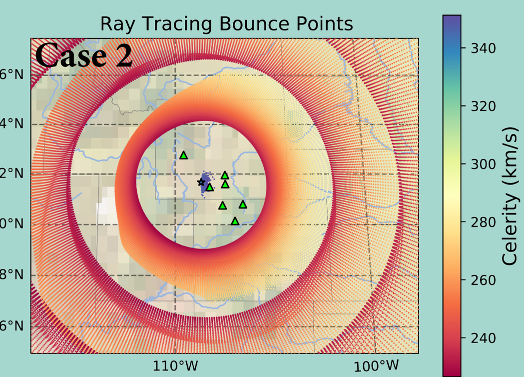
In case 1, we keep this range-independent to simplify the process and act as a proof of concept for the method. The results show a much tighter distribution than is observed when using the forward model approach. This approach is able to decrease the size of the uncertainty interval by ~43%. In case 2, the inclusion of ray tracing through an atmospheric model further reduces the uncertainty interval by an additional ~50%. Both results indicate that the celerity-range approach provides significant improvements over the simplistic foward model approach.

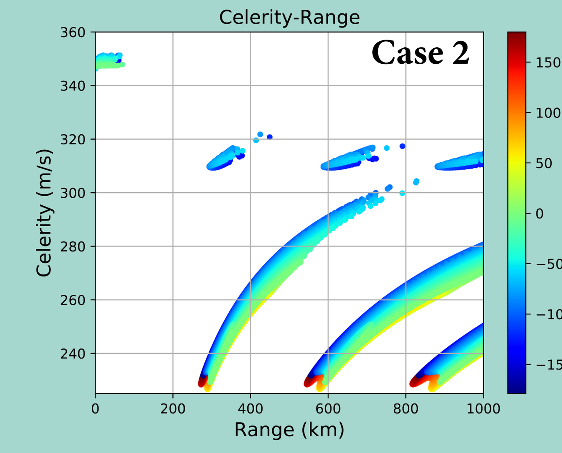


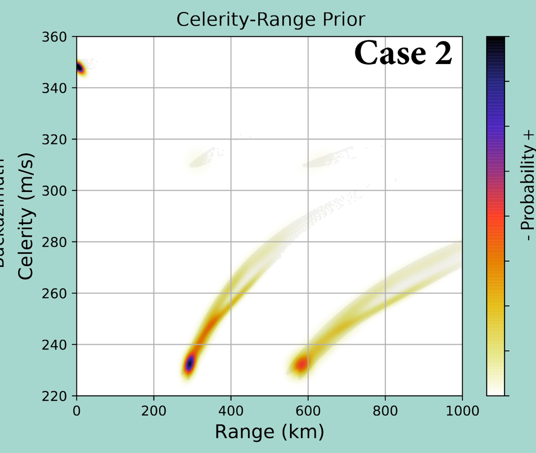


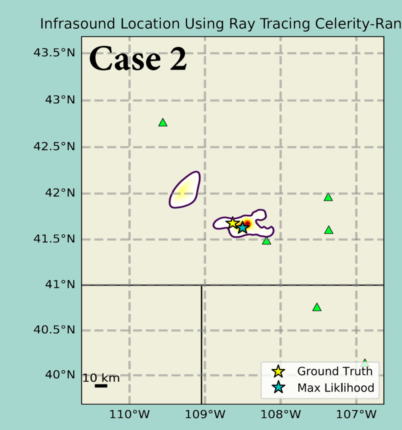








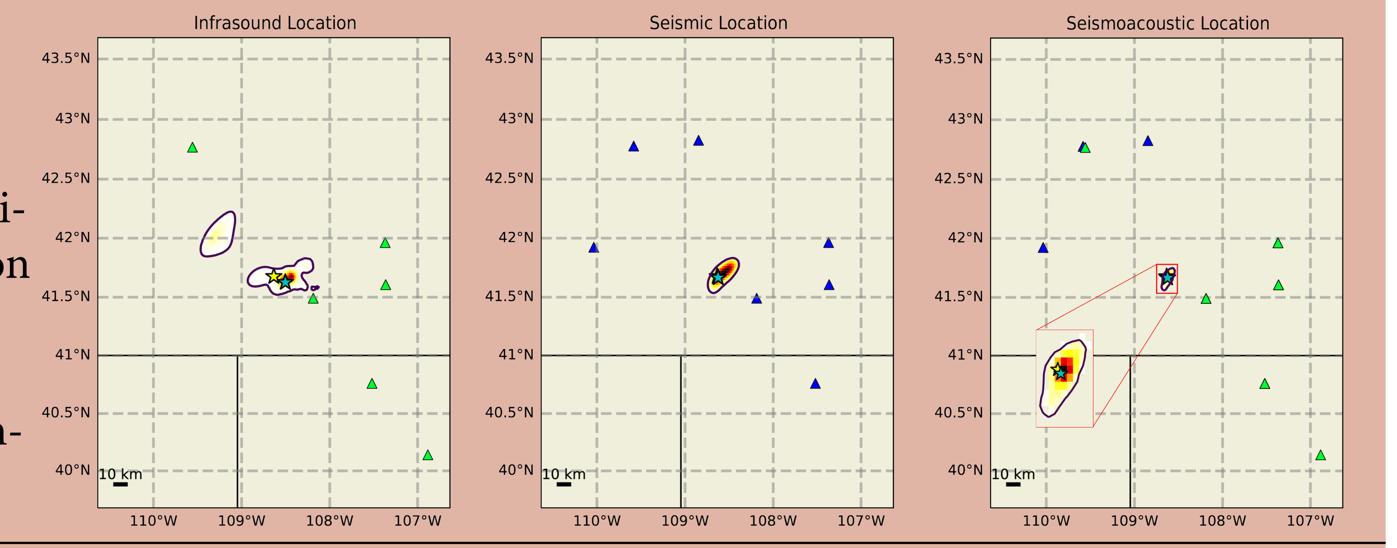




Location Results

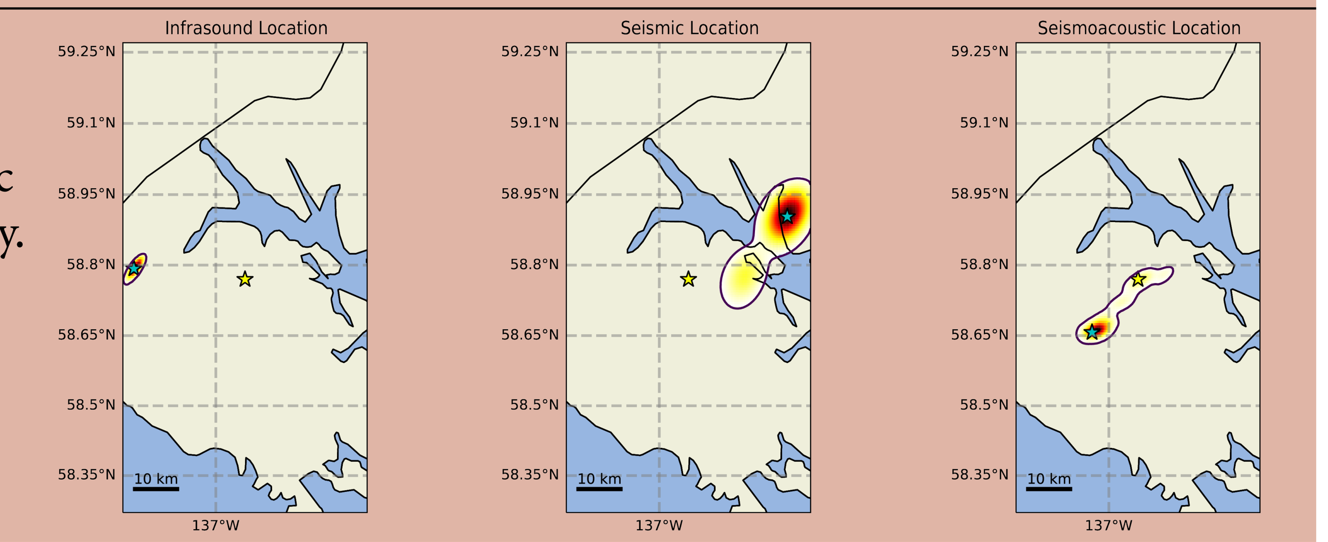
Explosion

The infrasound location is accurate, but low precision. The seismic location is accurate and precise. The joint location improves on precision without sacrificing accuracy.



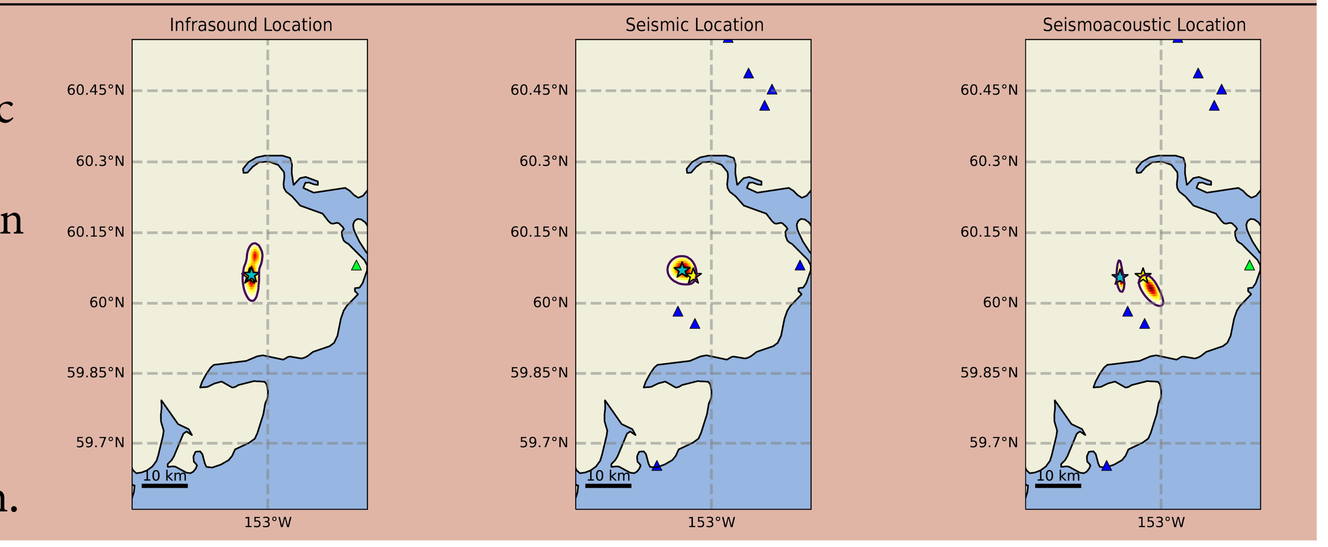
Rock Avalanche

Both infrasound and seismic locations have poor accuracy. The joint location improves its accuracy of the location by moving closer to the ground truth event.



Ice Avalanche

Both infrasound and seismic locations are accurate and precise, but the joint location decreases accuracy by moving away from the true location. However, the bi-model distribution still encompases the GT location.



Conclusions

- Incorporating atmosphere based celerity-range priors can greatly increase the accuracy of locations using single station infrasound sensors.
- Fusing seismic anzd infrasound locations can further increase precision, in some cases, at the cost of accuracy.

Future Work

- Complete locations for full seismoacoustic catalog
- Explore how variability in atmospheric models affects model uncertainty
- Better understand effect of merging seismic and acoustic observations.

References

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