U.S. DEPARTMENT OF ENERGY

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National Nuclear Security Administration

Defense Nuclear Nonproliferation Research & Development

Nuclear Explosion Monitoring Program Review
NEM2020

Signal Analysis for Waveform Technologies

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Sandia National Laboratories

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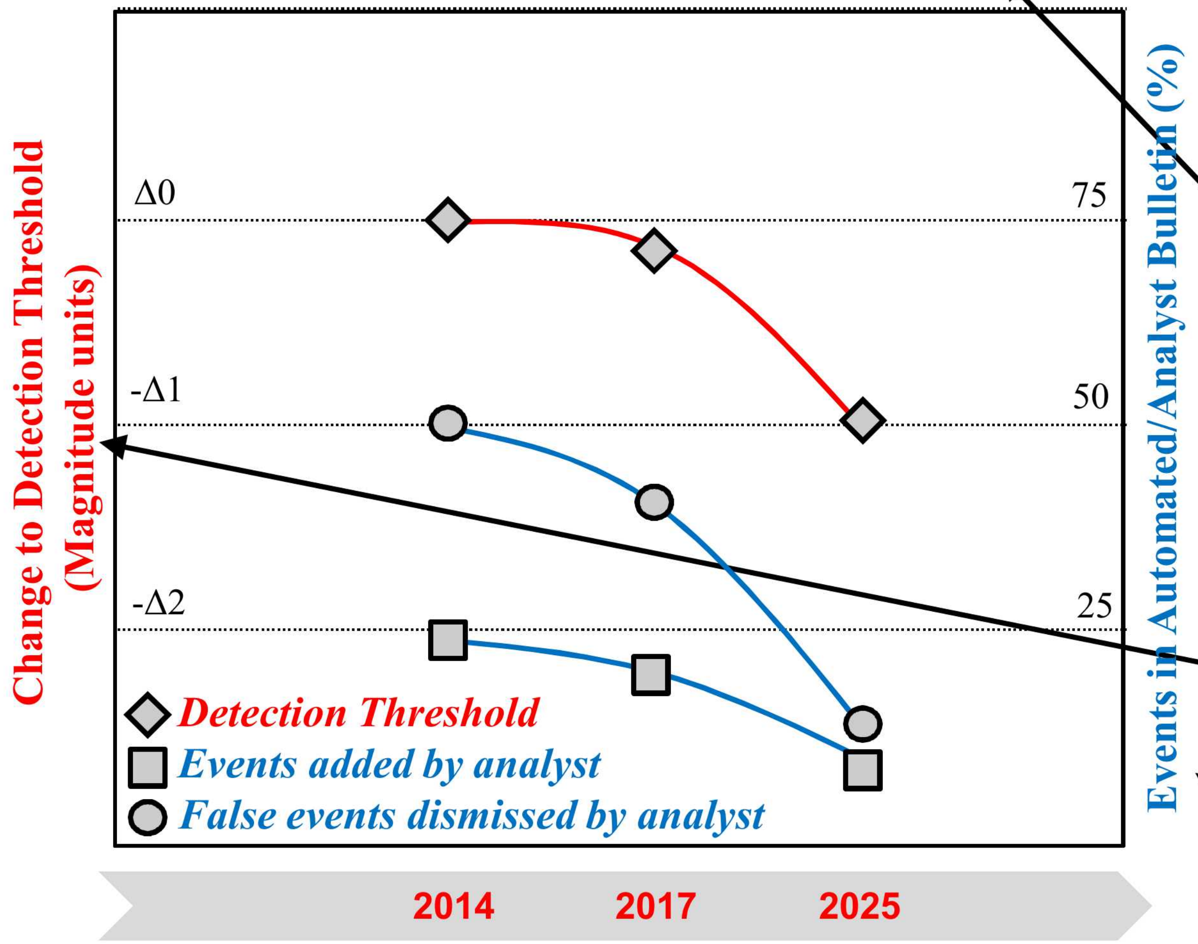
Geophysical Waveform: Signal Analysis

Waveform Signal Analysis Metric: **Lower event detection thresholds while decreasing analyst workload**



The major R&D for Signal Analysis has evolved as monitoring practices changed from relying primarily on teleseismic distances (>2000km) to include regional distances (<1500km).

The overarching metric for Signal Analysis is to improve the ability to detect events of interest while decreasing workload for the human analyst.

Lower the minimum detectable threshold

Increase true events and decrease false events built by automated systems.

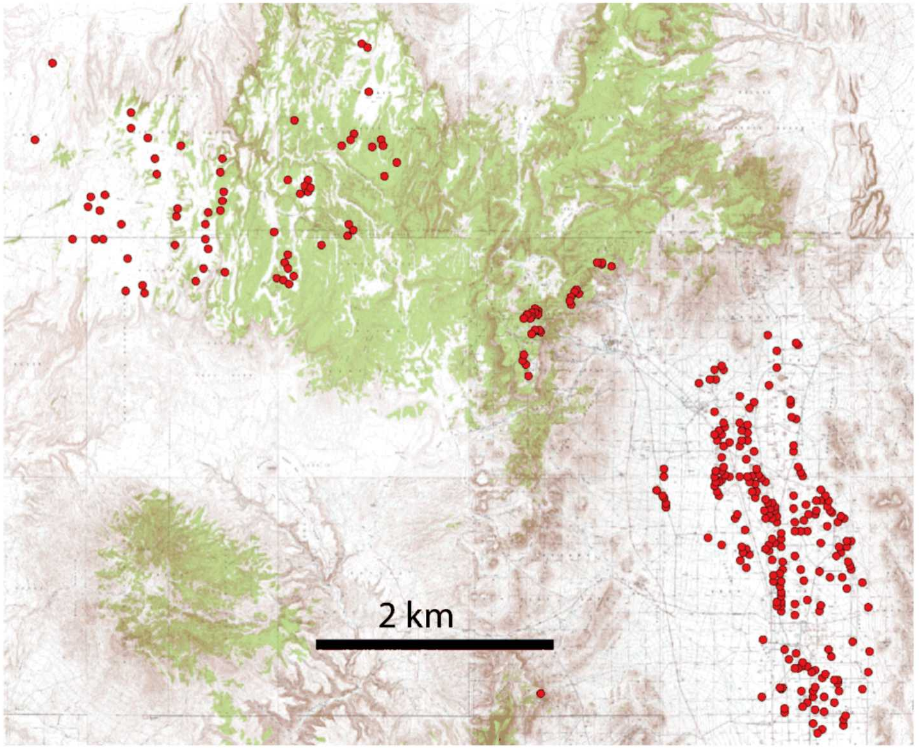
FY19 Highlights

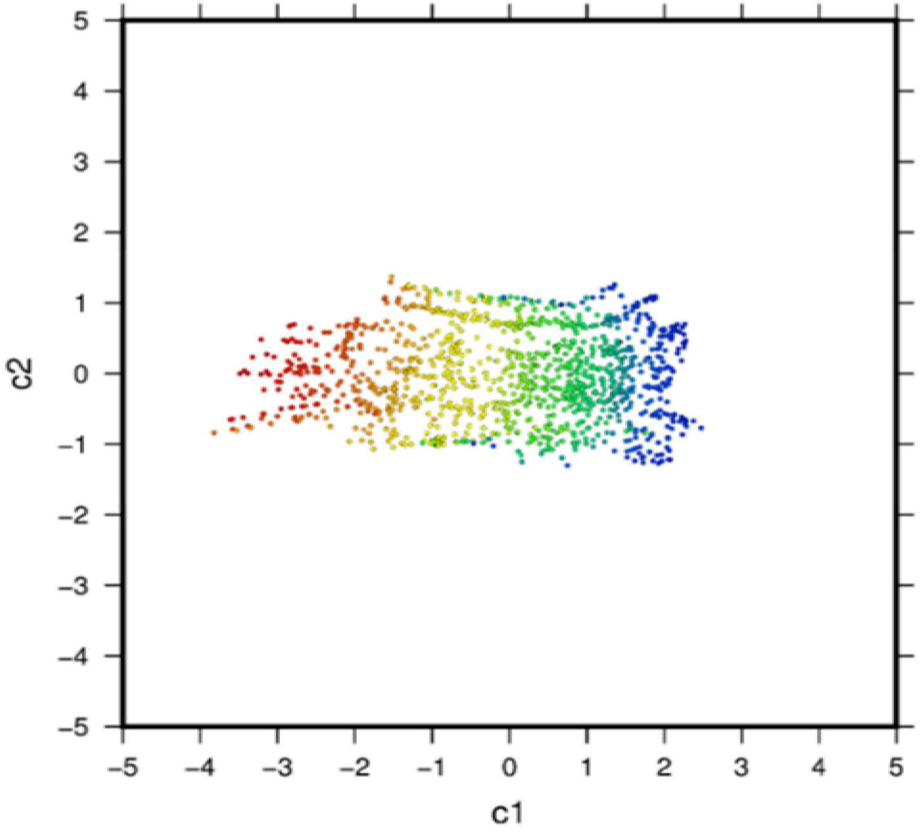
Geophysical Waveform: LLNL Signal Analysis

Lawrence Livermore National Laboratory (LLNL) expanded on the theoretical basis for waveform similarity as a function of frequency and the distance between events.

- These advances are leading to the use of parameter-space manifolds for estimating the probability that two signals recorded at the same station are similar in source type and close to each other.

Event Locations ⟷ ***Signal Subspace***



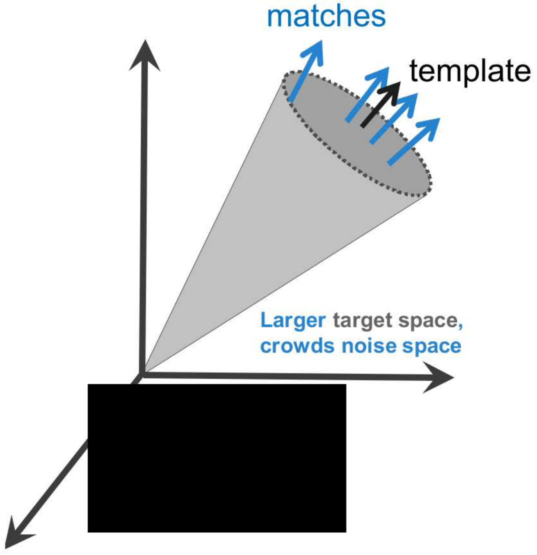


Geophysical Waveform: LANL Signal Analysis

<u>Los Alamos National Laboratory (LANL) researchers delivered the full “Cone Detector” algorithm and demonstration examples</u>.

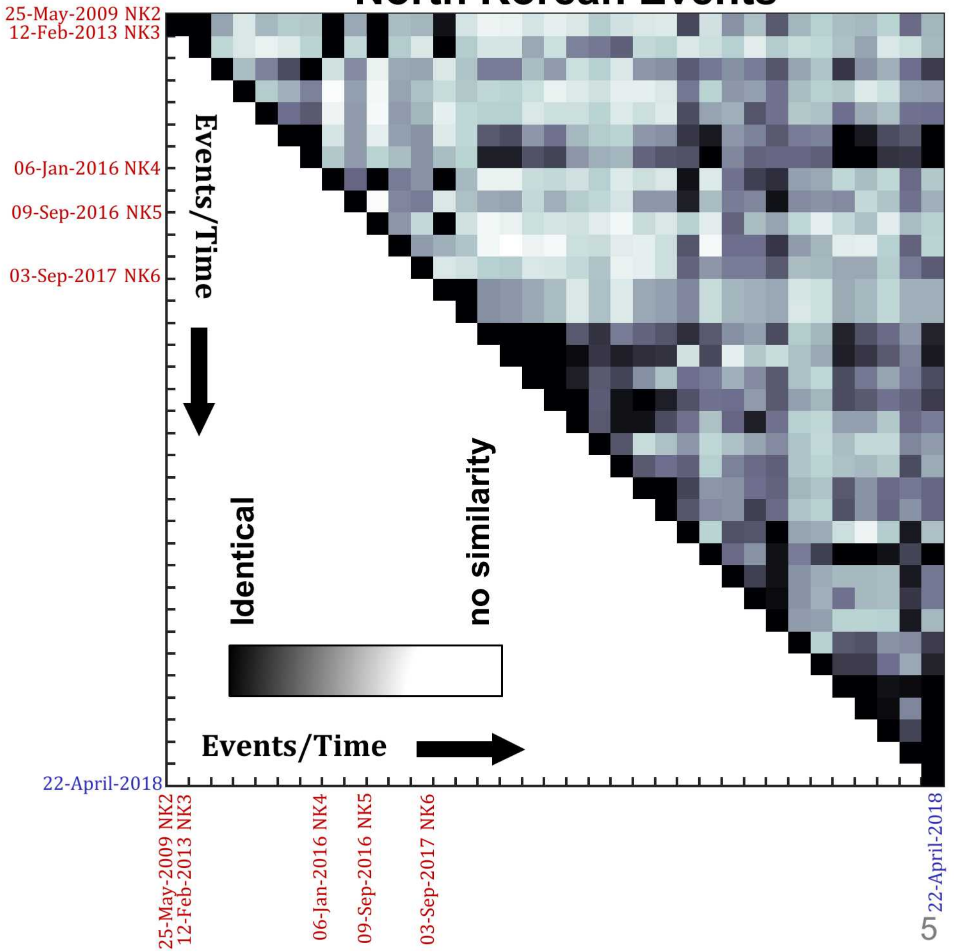
The Cone Detector is a noise-adaptive waveform matching method. It advances beyond waveform correlation and accommodates uncertainty into the shape of target or template waveforms. The algorithm shows improved predictive capability over that of the correlation detector.

Cone Detector Convex Data Model



- LANL Cone Detector matches events with non-identical waveform shapes like a correlation detector, and correctly grouped the North Korea explosions
- Requires one template waveform and is suited to monitor new test sites with sparse historical data
- Shows fewer false detections when compared to a correlation detector, with a potential to reduce analyst workload!

North Korean Events



Geophysical Waveform: SNL Signal Analysis

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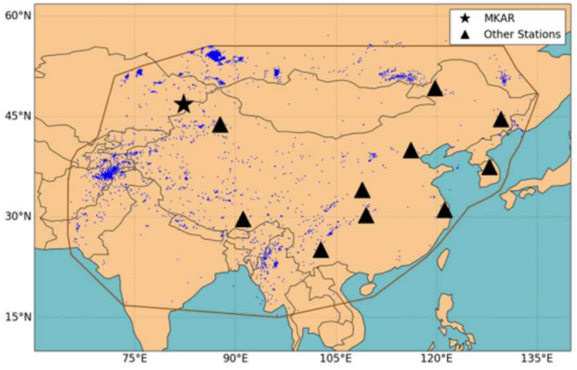
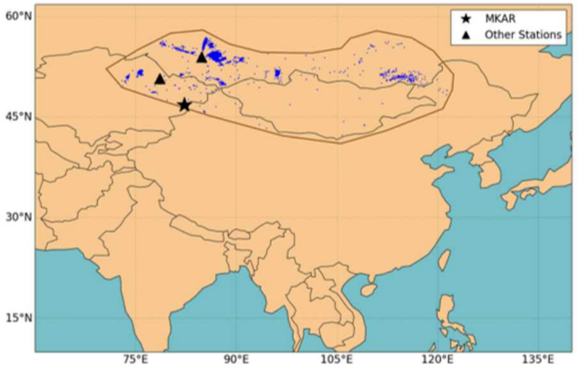
<u>Sandia National Laboratory (SNL) researchers performed a study applying waveform correlation to seismic events in Mongolia</u>

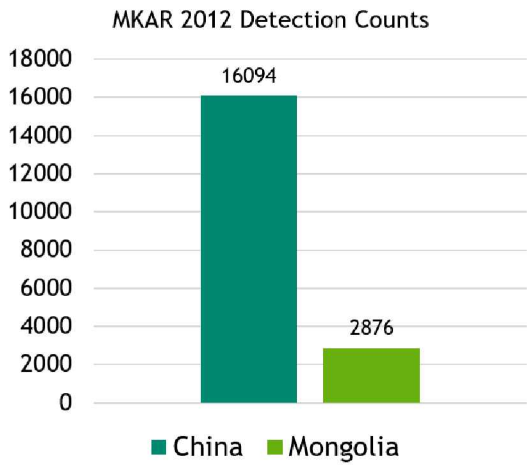
- Results were compared against an earlier Eastern Asia study to determine consistency in applying waveform correlation to different regions
- The comparison revealed that the rates of detection and the number and quality of events that could be built are very different between the two regions

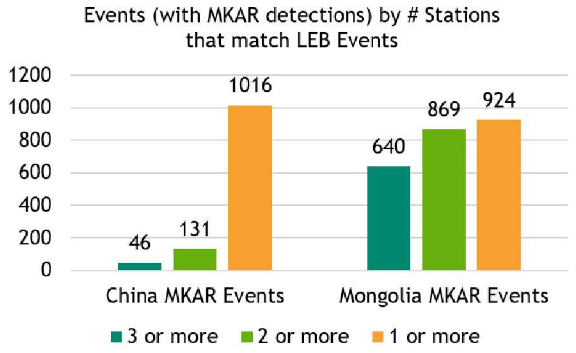


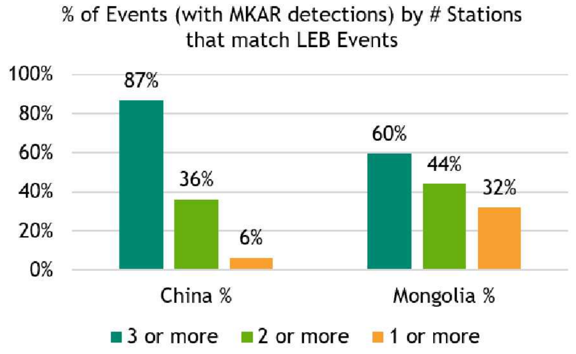
Eastern Asia / China



Mongolia







FY20 Highlights and Works in Progress

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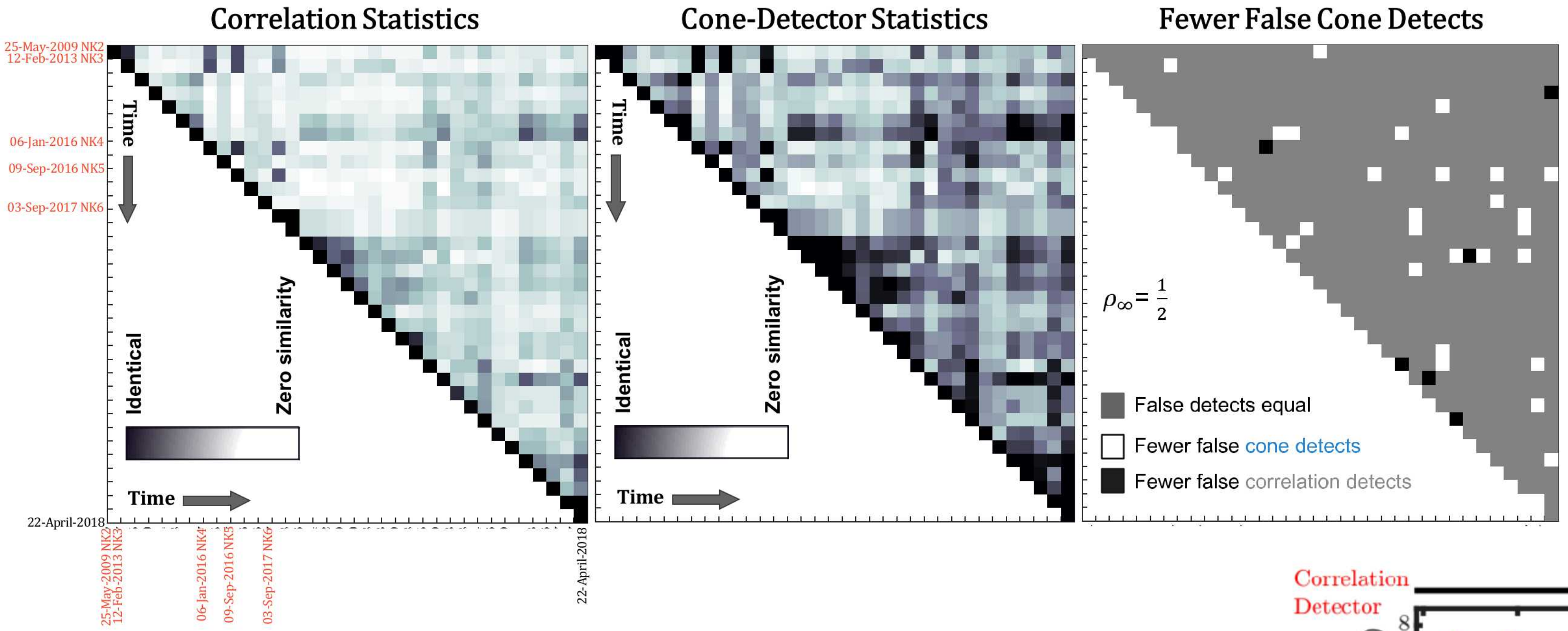
Cone Detector: Errors and Predictive Capability

[improving predictive capability and reducing nuisance alarms]



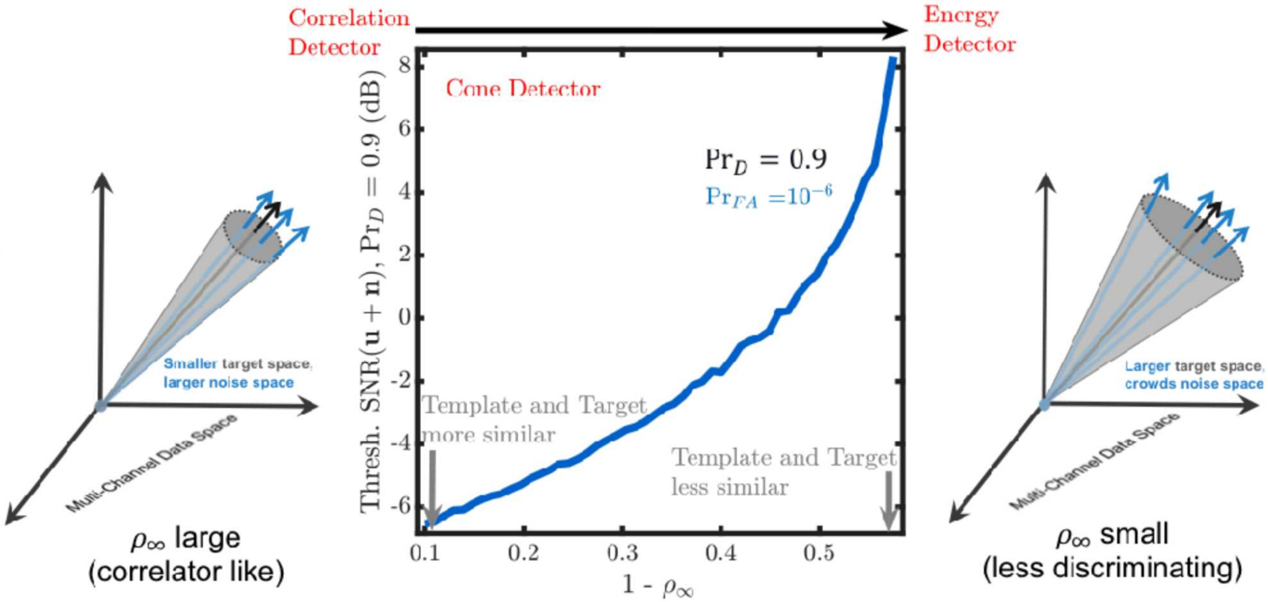
FY19 Accomplishments

- **Demonstrated** cone detectors achieve their predictive capability better than correlation detectors with NK explosion templates, and return fewer nuisance events (*figure left*)
- **Published** BSSA Erratum, include new predictive density functions
- **Delivered bulletin events** output by cone detector, verified independently

New Science, FY20 Planned Work

- **Under Development:** tune geophysical target space of the cone detector to make waveforms "appear" more similar, while *simultaneously decreasing* nuisance alarms (*figure right)*
- **Planned Publication**: Part II of a BSSA paper that leverages new theory of cone detector to further reduce false detections on background seismicity

Carmichael, J. D. (2019). Erratum to A Waveform Detector that Targets Template-Decorrelated Signals and Achieves Its Predicted Performance, Part I: Demonstration with IMS Data. *Bulletin of the Seismological Society of America*, *109*(5), 2142-2144.

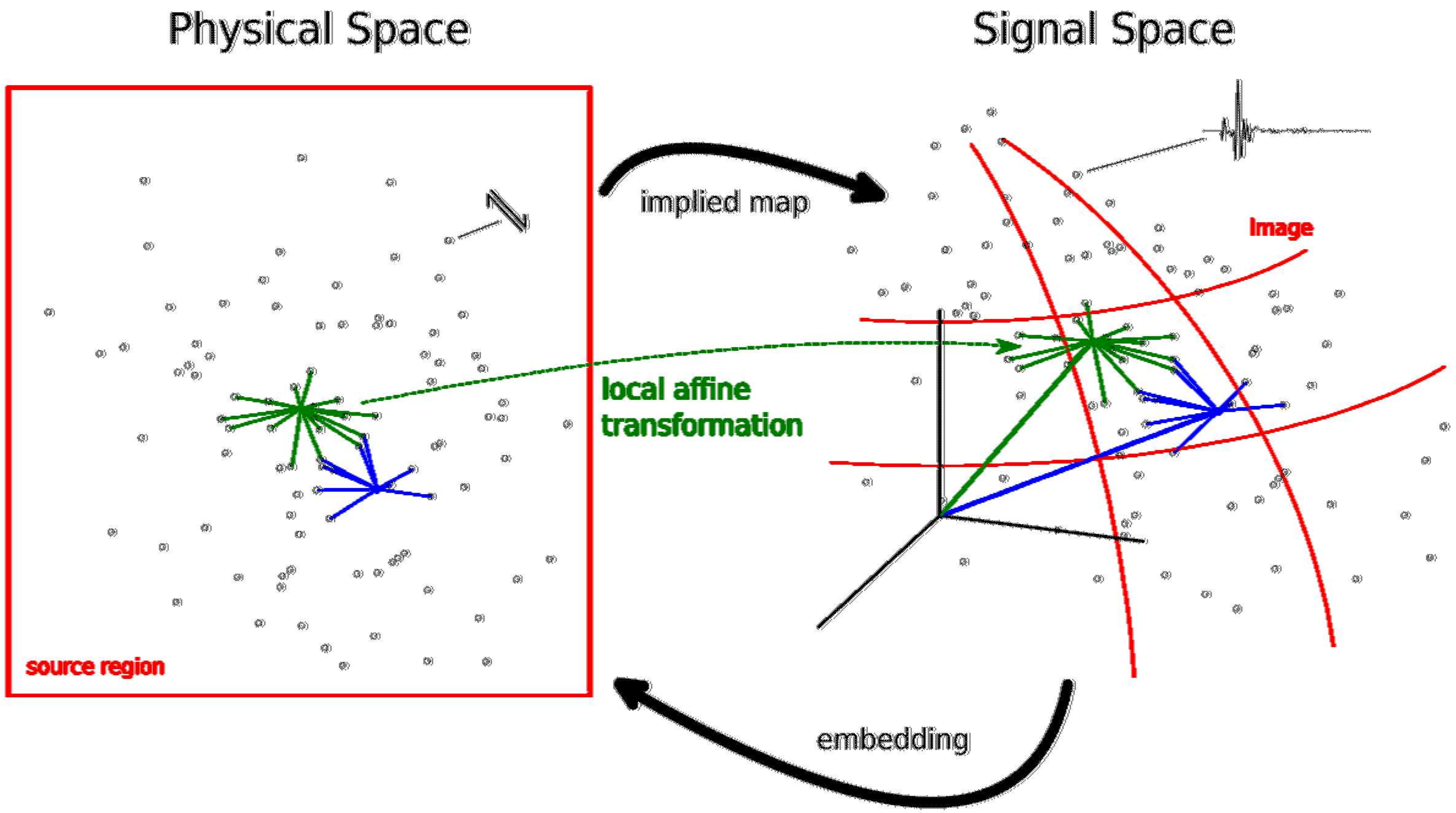


The Structure of Signal Space

[toward direct mapping of signals to a low-dimensional geometry]

Vectors in signal space can be mapped to vectors in a lower-dimensional (possibly geographic) space if the sources have similar mechanisms and positions.

Overlapping neighborhoods of points in one space map to overlapping neighborhoods of points in the other, which is the basis for reconstructing the global distribution of sources from observed waveforms.

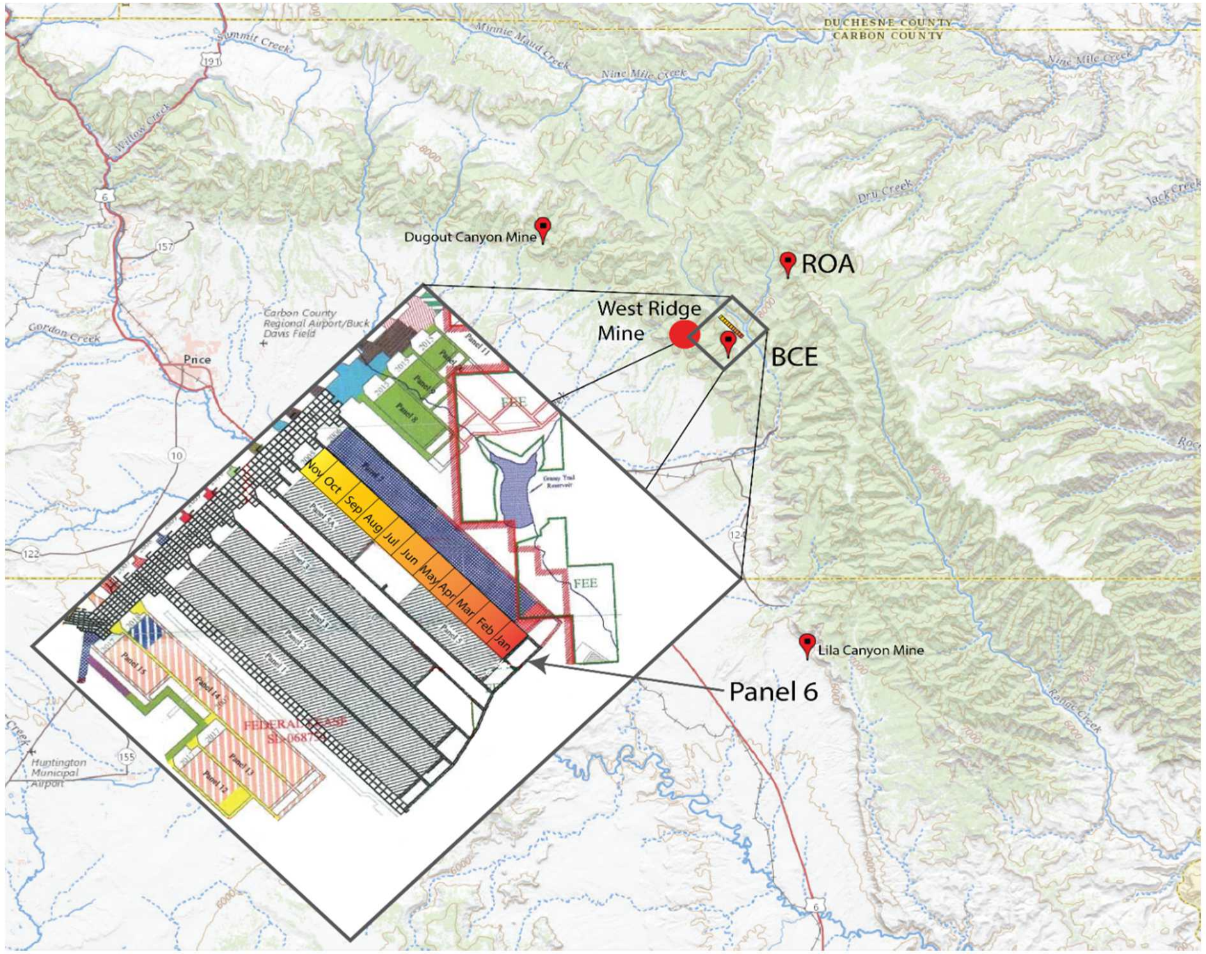


The Structure of Signal Space

[toward direct mapping of signals to a low-dimensional geometry]

Experiment Geometry

Orientation map with topography showing the southeastern half of the underground workings of the West Ridge mine.



The map indicates the panel 6 location (colored rectangular region), the locations of the stations BCE and ROA, and the mine entrance (red dot).

We invert correlations from the single-component instrument at ROA to image the progression of collapse events as panel 6 is mined out.

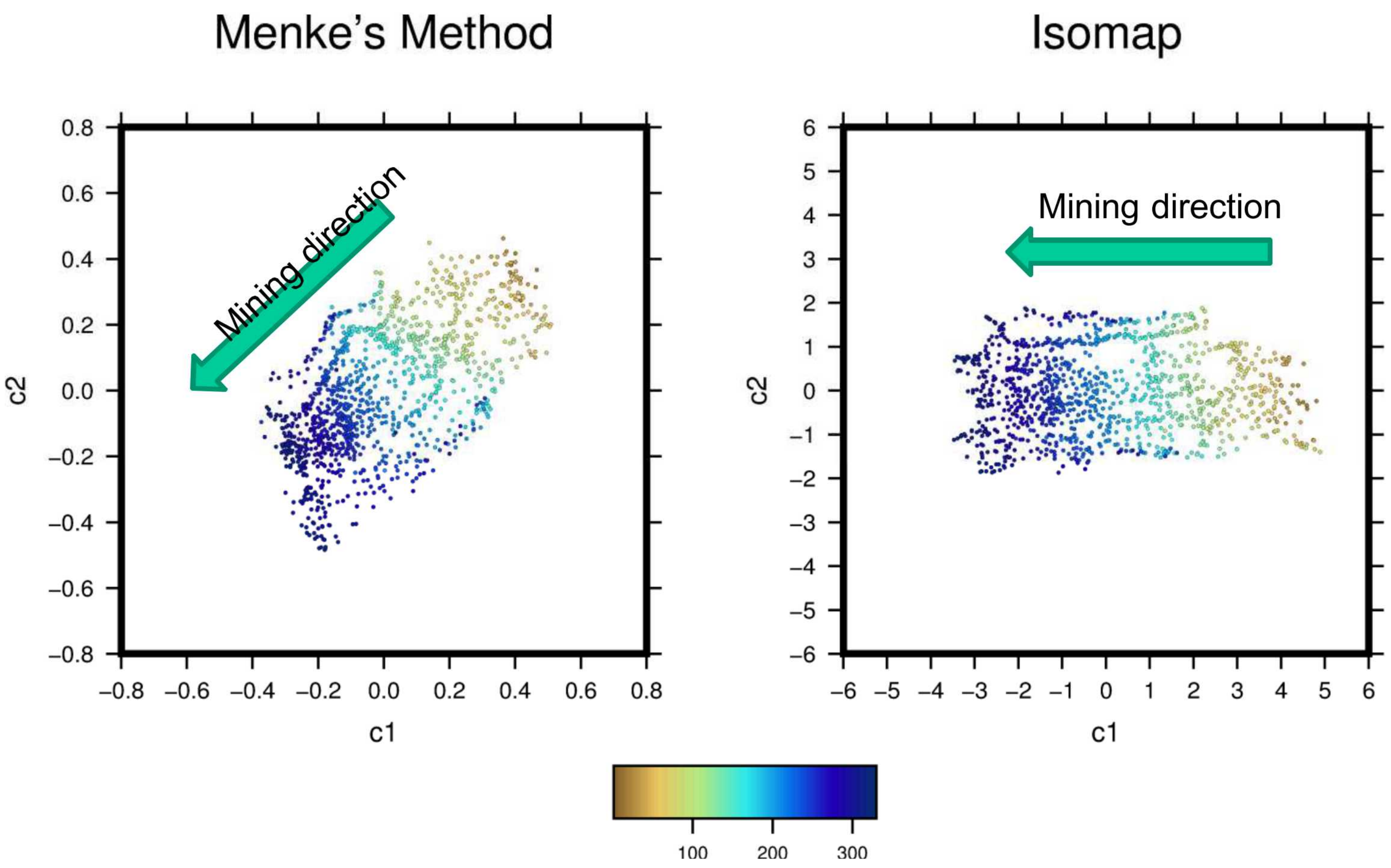
The Structure of Signal Space

[toward direct mapping of signals to a low-dimensional geometry]

Reconstruction of panel 6

Reconstructions of the panel 6 source distribution from the ROA stacked templates using Menke's algorithm (left) and Isomap (right).

The reconstructions differ slightly in distortions and detailed placement of points. They have a striking common feature in the linear structures along the top left of the Menke embedding and the top of the Isomap embedding.



(days since mining started in panel 6)

LLNL
IRP 1.46

The Structure of Signal Space

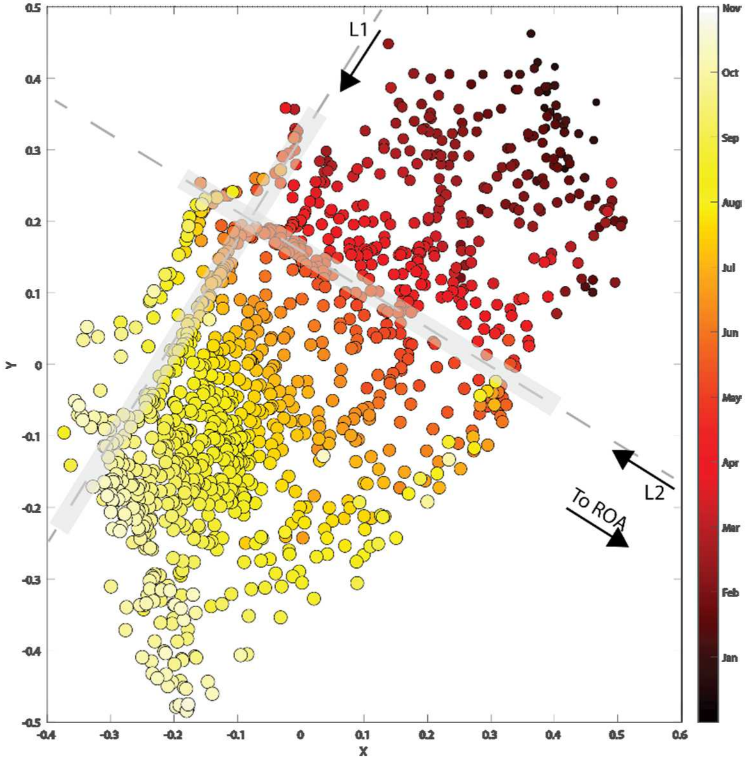
[toward direct mapping of signals to a low-dimensional geometry]

Recovered geometry is consistent with S-wave moveout across the panel.

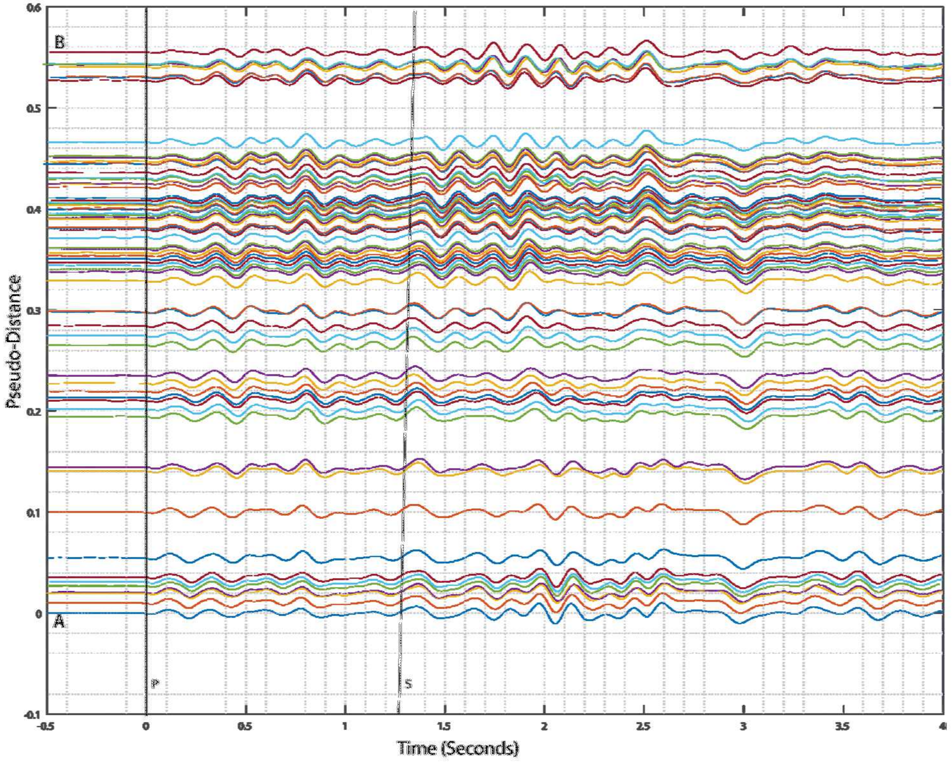
Phase arrival times were not used in the inversion, but S-wave moveout along the L2 line is consistent with the recovered geometry.

The long axis of the panel is foreshortened presumably because of directional dependence in the correlation statistic.

Geometry recovered by Menke's method



Record section along the (Radial) L2-line



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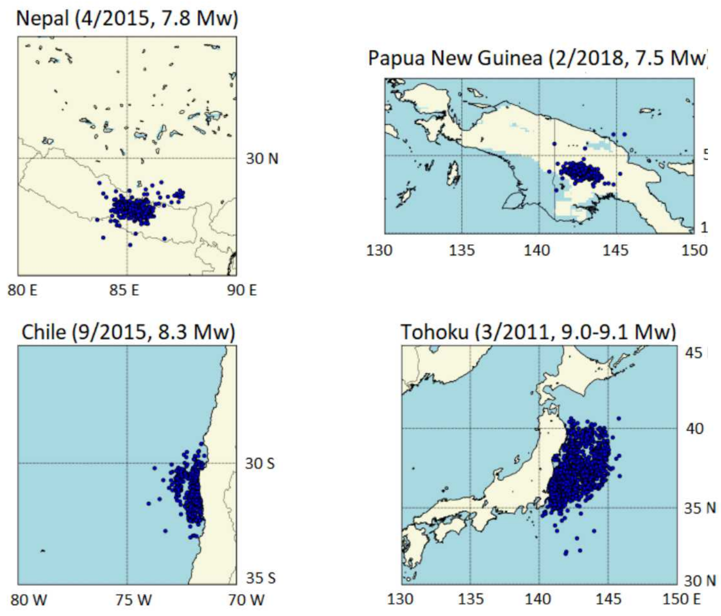
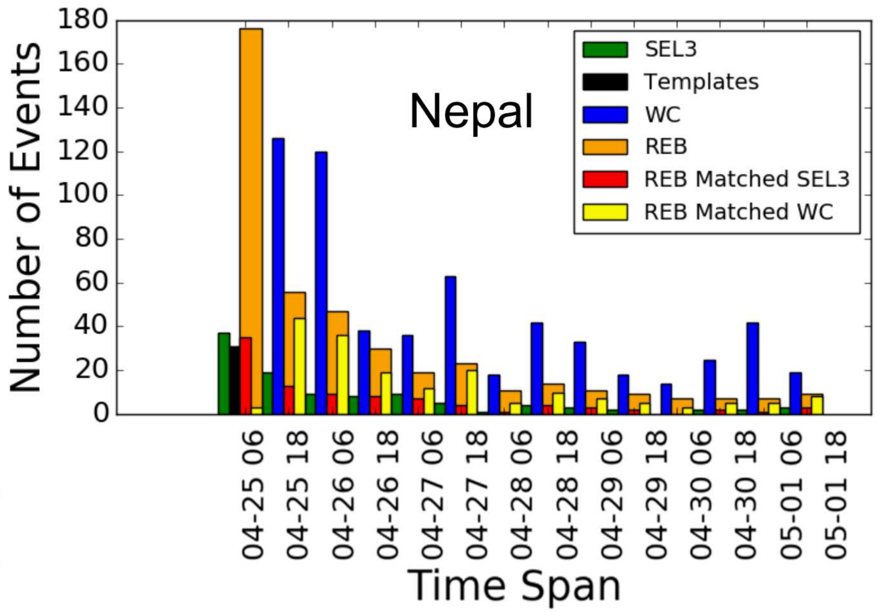
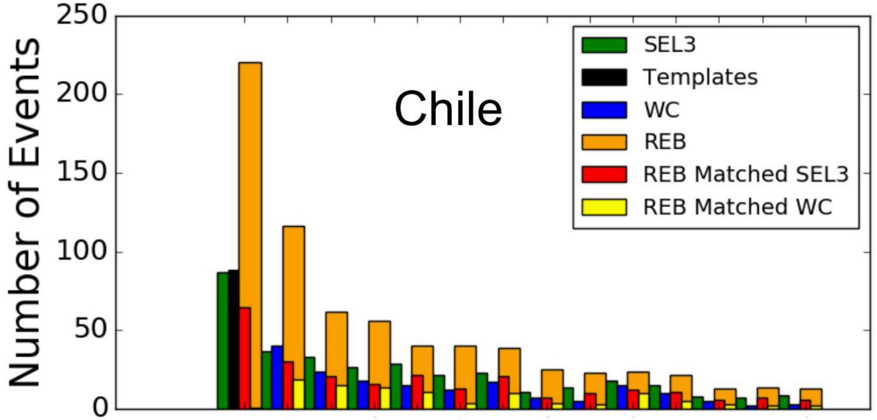
Waveform Correlation: Aftershock Sequences

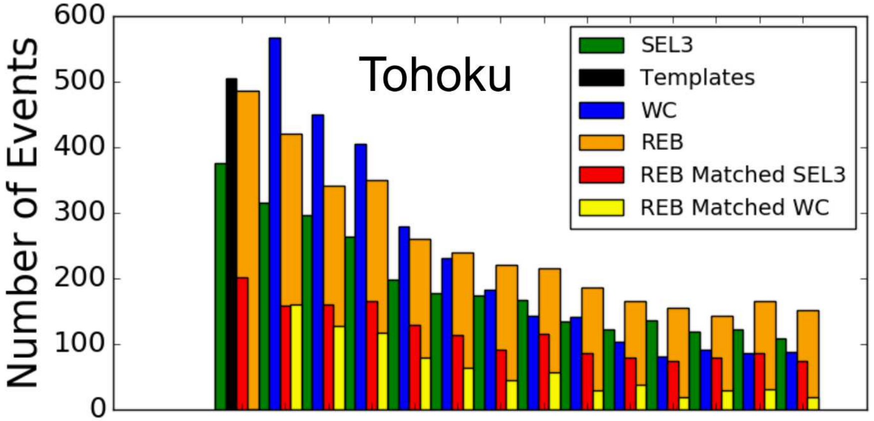
[decreasing automated detection thresholds]

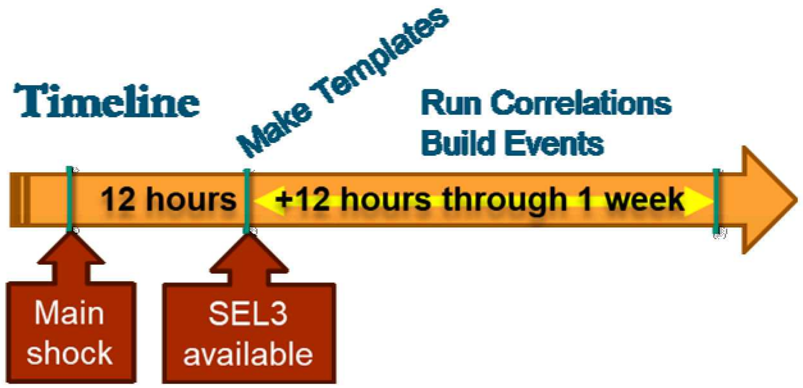
Waveform Correlation improves detection of aftershock sequences







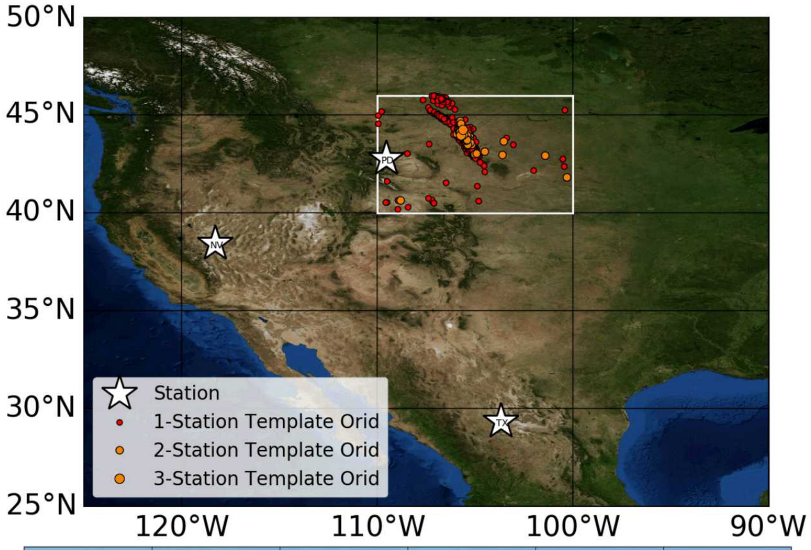


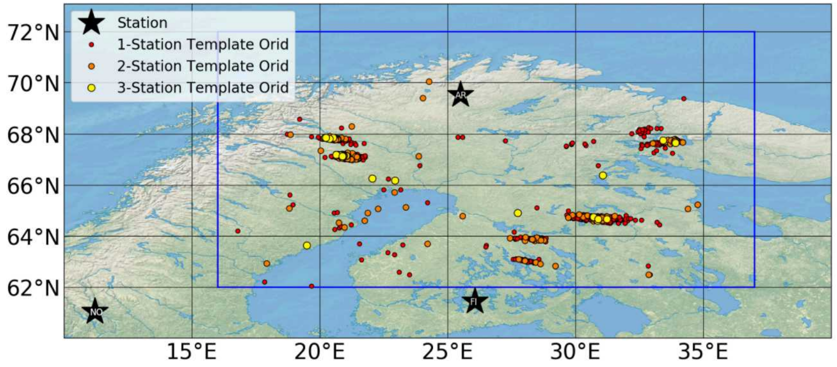


Waveform Correlation: Mining Blasts

[decreasing automated detection thresholds]

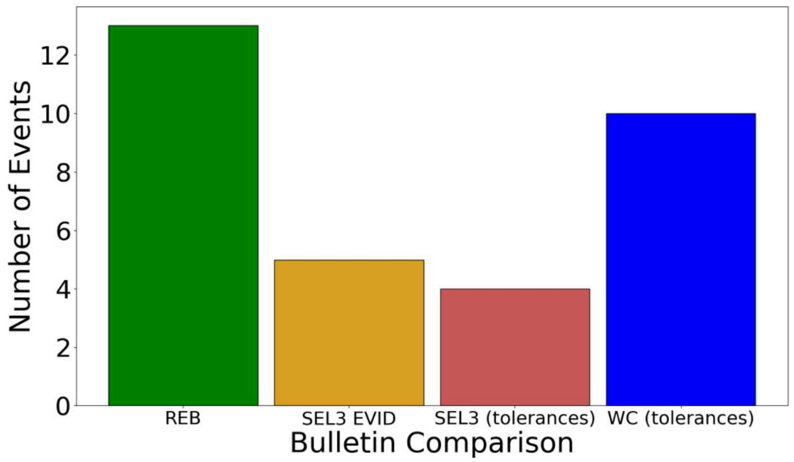
Waveform Correlation improves detection of mining blasts.



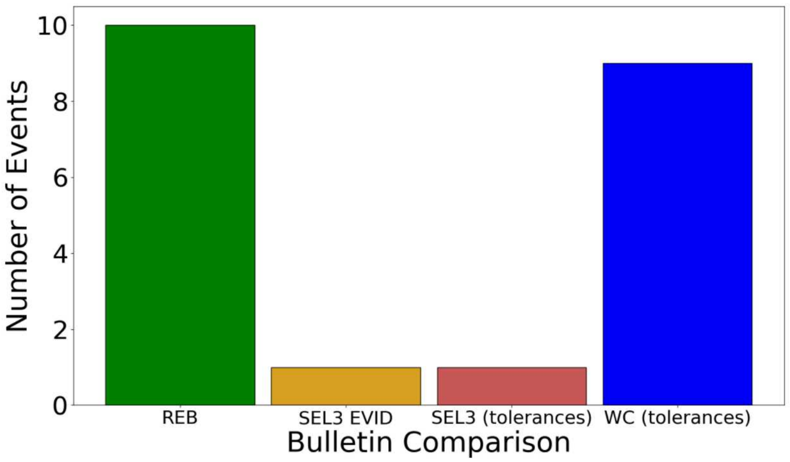


Event comparison tolerances (1.0°, ±15s)

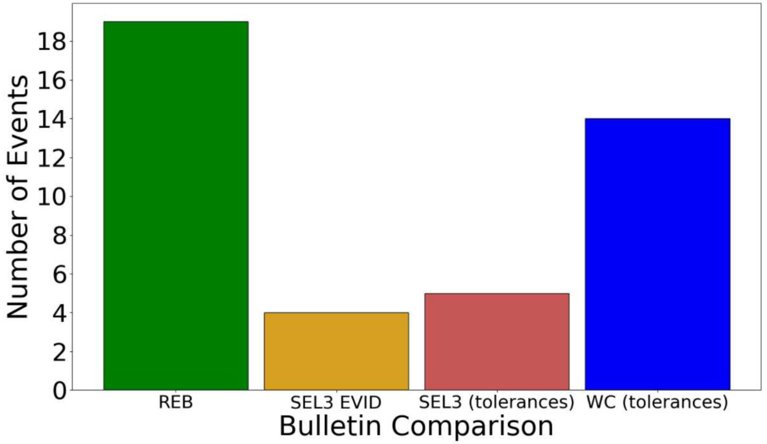
Wyoming Week 1 (4/4/2018 – 4/11/2018)



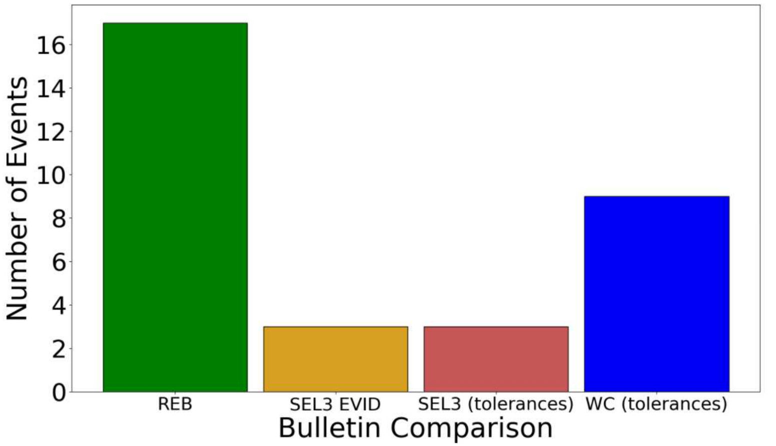
Wyoming Week 2 (8/8/2018 - 8/14/2018)



Scandinavia Week 1 (2/12/2018 - 2/18/2018)



Scandinavia Week 2 (7/06/2018 - 7/12/2018)

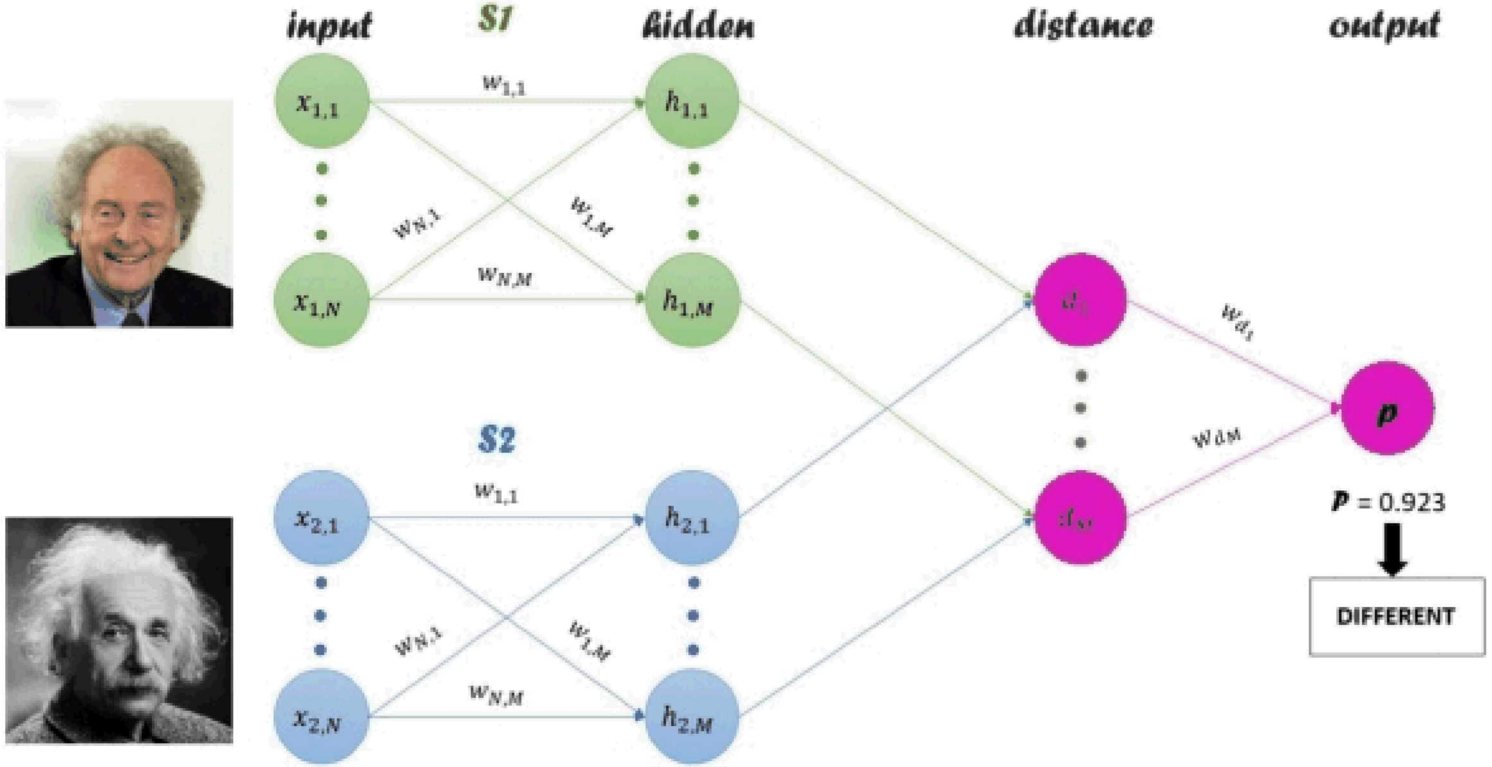


Machine Learning: Aftershock Sequences

[decreasing automated detection thresholds]

Application of Supervised One-Shot Machine Learning to Aftershock Identification:

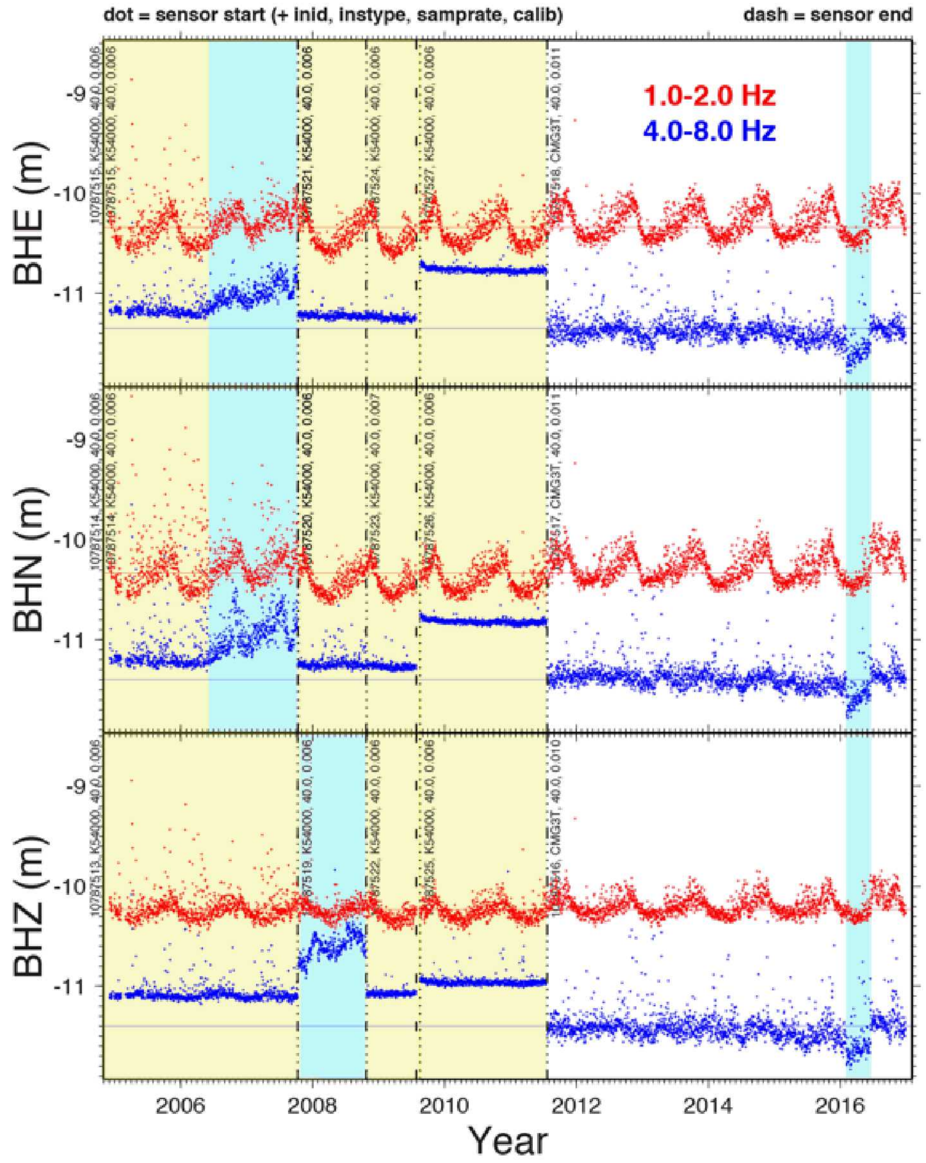
- **Train a Siamese Neural Network (SNN)**
- **Perform testing using 3 aftershock sequences:**
  - **Nepal (2015)**
  - **Chile (2015)**
  - **Papua New Guinea (2018)**



Instrument QC

[reduce misclassification rate and yield estimation thresholds]

- **Delivery: Midnight Noise results for AFTAC and IRIS holdings 9/9/19:**
  - Noise table (noise: 252×10^6 rows)
  - Suspect interval table (noiserev: 26,225 rows)
  - Review status table (noiserevstatus: 40,103 rows)
- **Global coverage, AFTAC and IRIS stations**
- **High frequencies targeted at discrimination**
- **For Asia we use in-house continuous data**
- **Outside Asia we use in-house event segment data**
- **We consult IRIS MUSTANG (noise mode)**
- **Results applied to UAMP1.0 delivery (IRP 2.62, 3.25)**
- **Performed in collaboration with LYNM-Dynamic Nets**
- **Example (right):**
  - Sensor start/ends marked
  - Suspect intervals chosen manually:
    - *Level changes (yellow, likely response error)*
    - *Drift (cyan, likely station health issue)*
- **Next delivery: report/publication, 8/28/20 planned**



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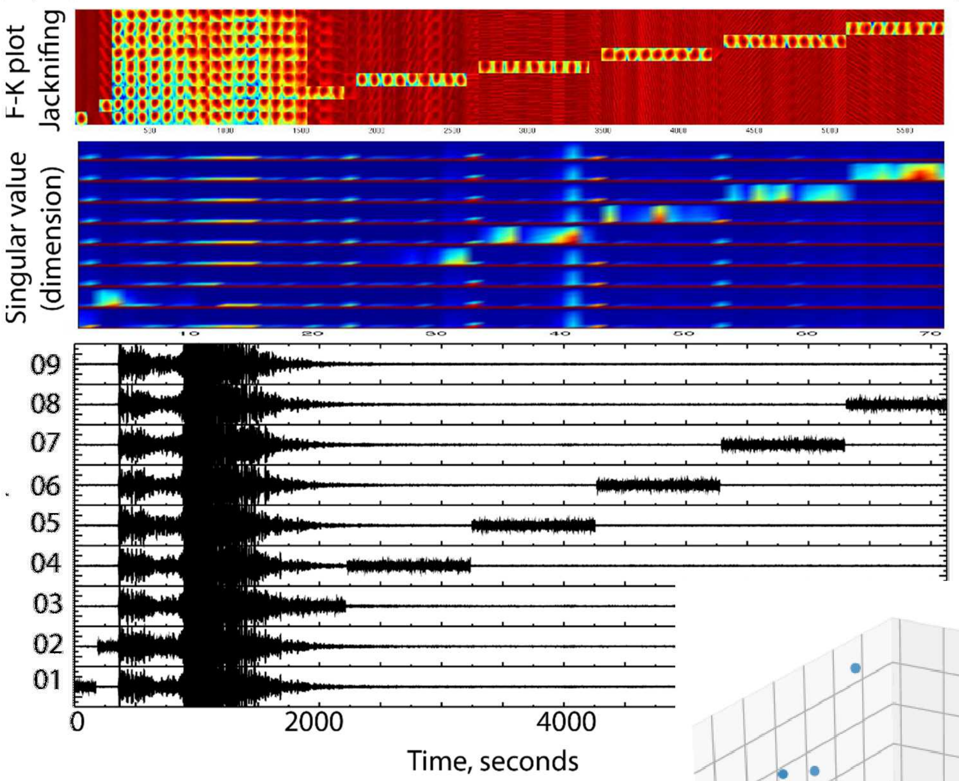
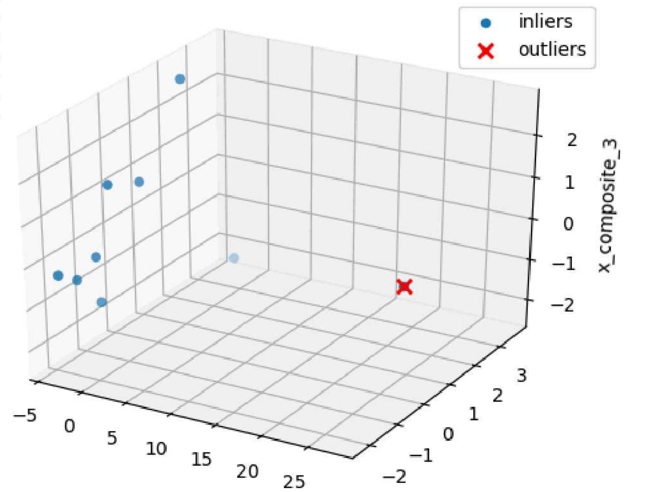
Automated Array QC

[reduce analyst workload]

- **The power of arrays has been well established, but as with any long time series, issues with signal quality can affect their performance.**
  - Often a failure or contamination of one or a few components can compromise the results of array analysis methods.
- **Building an automated algorithm that can perform quality checking on array components to flag those channels that may hinder the usefulness of the array.**
- **Technique leverages anomaly detection approach for nodes on large systems (e.g., IP traffic)**
  - Dimensionality of system

Example: Automated Scanning Dimension test and F-K analysis with Jacknife Approach to Identify Noisy Component





In a new collaboration with machine-learning specialists, we are exploring the explicit use of the eigenvectors to identify the offending channel via K-means clustering.

NetCAP: Software for Network Modelling

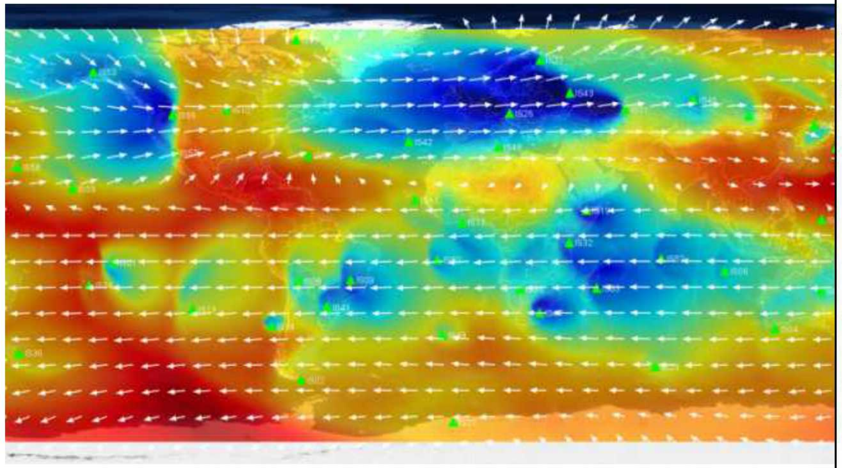
[decreasing analyst workload]

Simulation tool to assess network detection performance

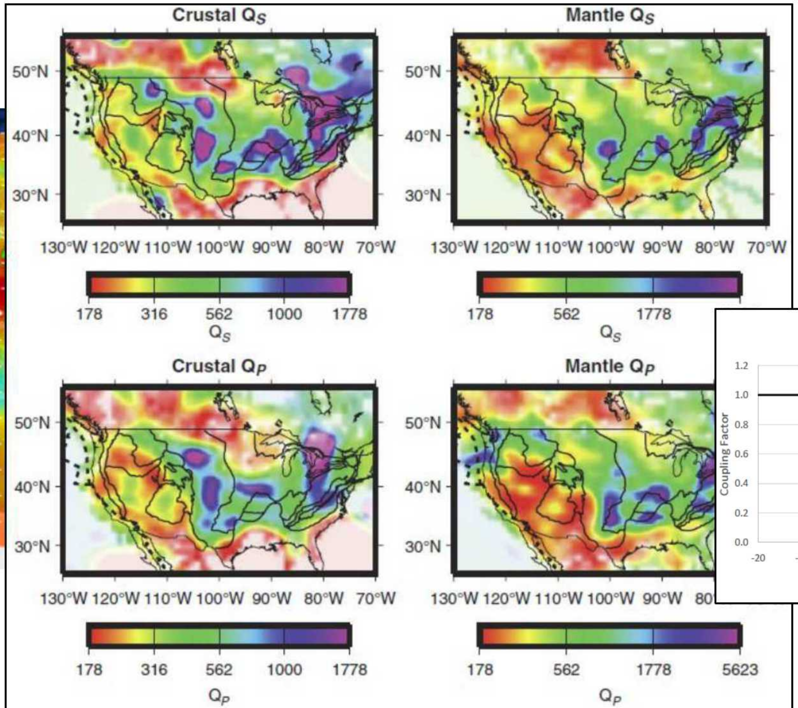
- Performed seismic, infrasound, and hydroacoustic detection simulations

What's New:

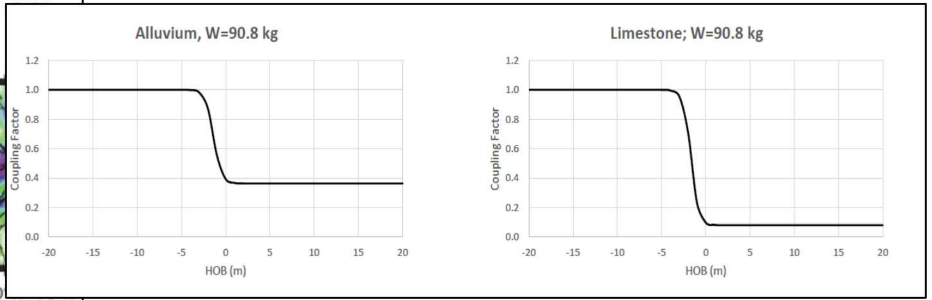
- Continued improvements to the usability of the software.
- Increased the performance of performing 2D Q path attenuation calculations
  - Simulation time went from days to < 1 hr.



Example Infrasound IMS Simulation with wind



US Q Attenuation
Pasyanos (2013)



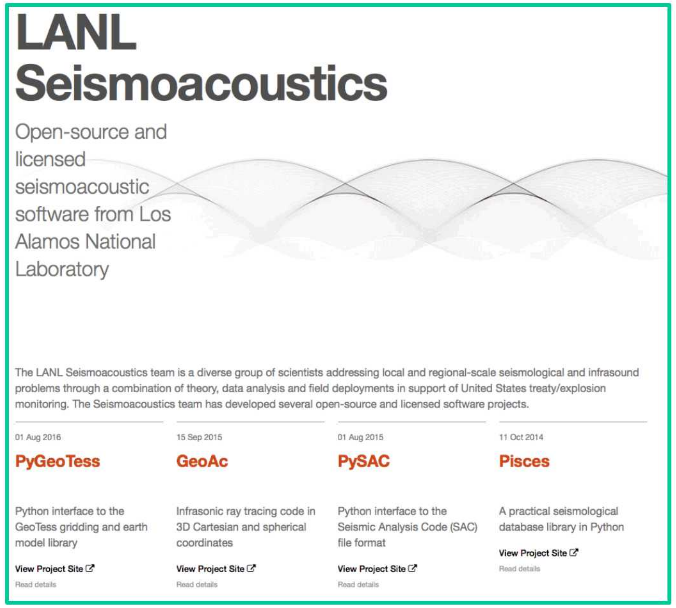
Depth of Burial / Height of Burst Correction
Pasyanos & Ford (2015)

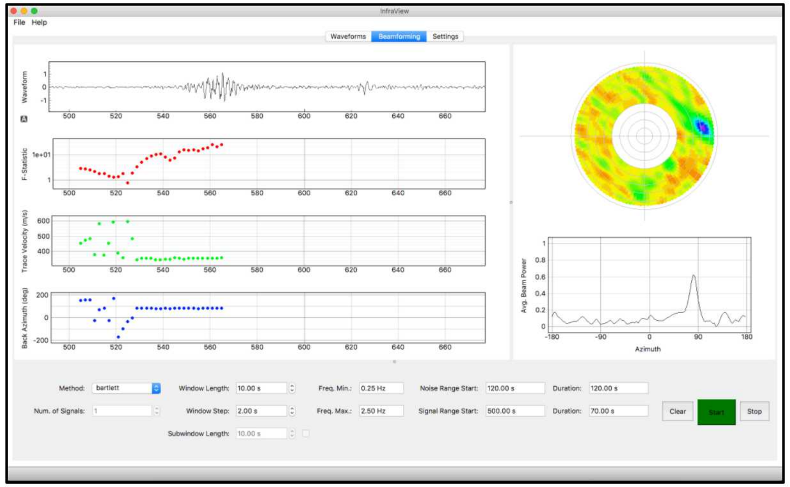
Infrasonic Association Methods; InfraPy

[lower detection thresholds; reduce analyst workload; improve travel-time prediction]

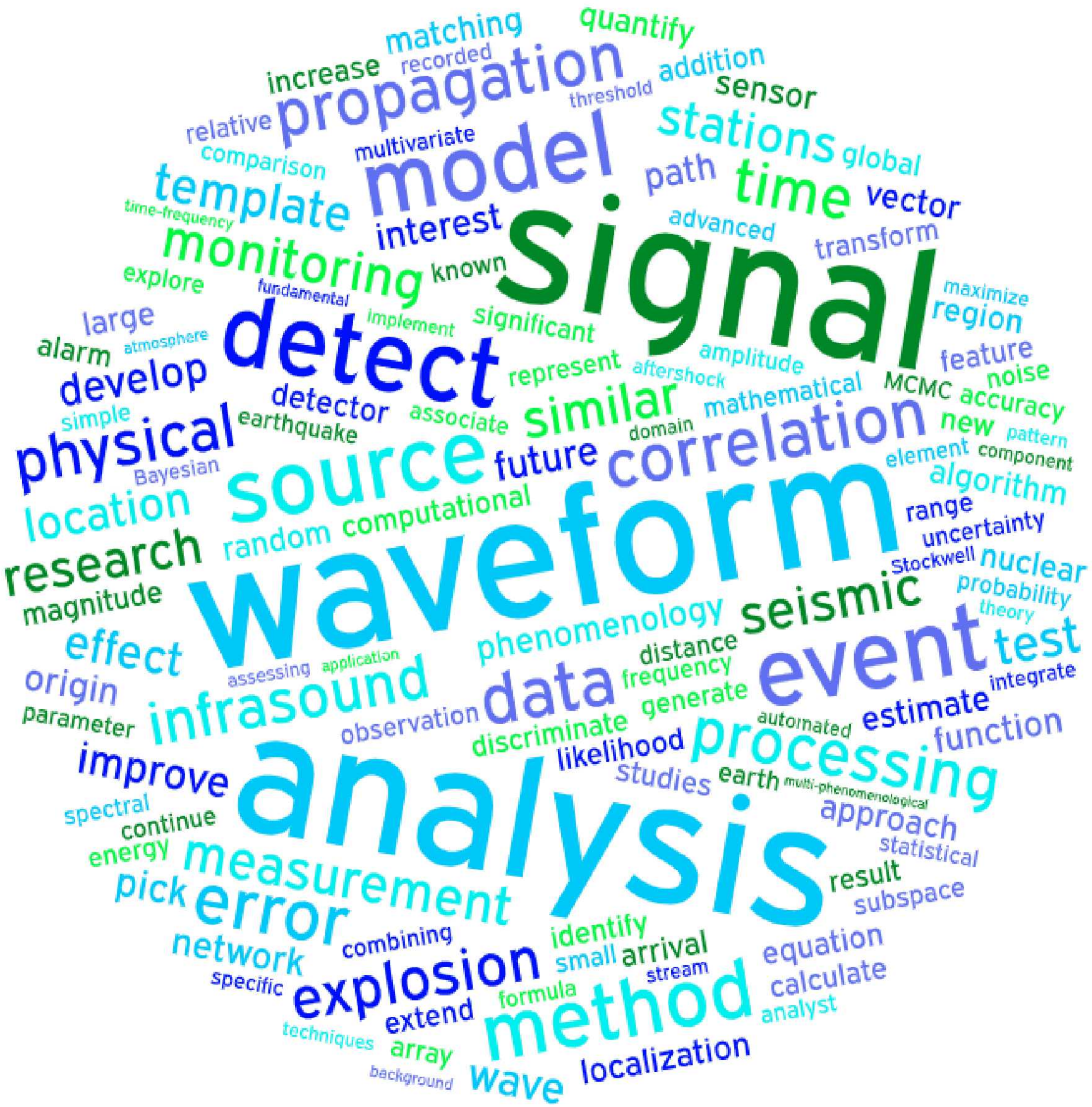
InfraPy has been approved for open-source release

- Includes array and network analysis algorithms
  - *Adaptive F-Detection*
  - *Pair-based, joint-likelihood association algorithm*
  - *Bayesian Infrasonic Source Localization (BISL)*
- New Innovations:
  - *GUI for analyst waveform review*
  - *Command Line Interface for rapid processing and management of large datasets*
  - *Jupyter Notebook tutorials*





Thank You!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propagation
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relative
multivariate
stations
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model
global
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vector
interest
advanced
signal
monitoring
transform
known
explore
fundamental
maximize
implement
significant
region
large
atmosphere
detect
amplitude
feature
alarm
aftershock
represent
noise
develop
MCMC
mathematical
accuracy
detector
similar
simple
associate
new
earthquake
domain
pattern
physical
correlation
element
component
future
Bayesian
source
algorithm
location
range
computational
uncertainty
random
waveform
research
Stockwell
nuclear
probability
magnitude
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observation
discriminate
function
likelihood
processing
improve
studies
analysis
earth
multi-phenomenological
spectral
approach
continue
statistical
energy
measurement
result
pick
subspace
error
identify
equation
combining
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