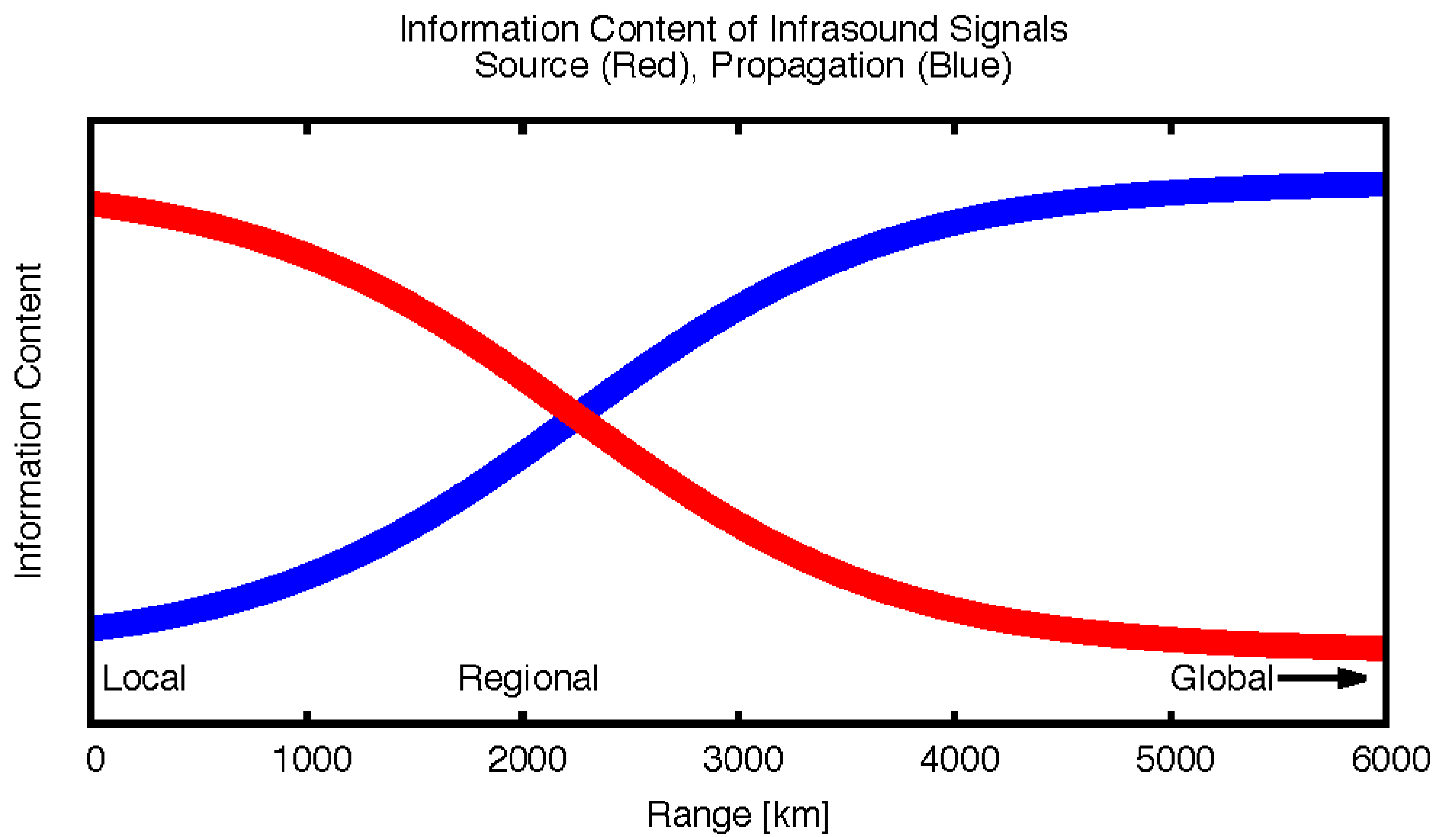
SAND2015-7236PE

Infrasound Event Detection

Infrasound Event Detection



- An inherent assumption of global infrasound data processing is that there is little source information that is extractable at global distances.
- Thus, event detectors are based almost exclusively on coherence at arrays, and on agreement of arrival times and azimuths at spatially-separated arrays

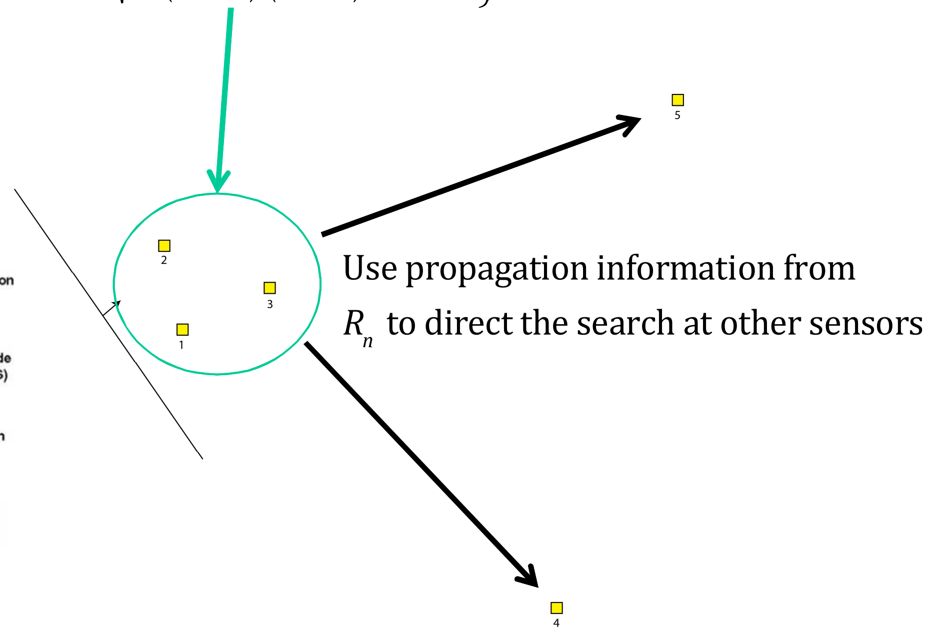
Infrasound Event Detection: PMCC

Ground-based Nuclear Explosion Monitoring R&D

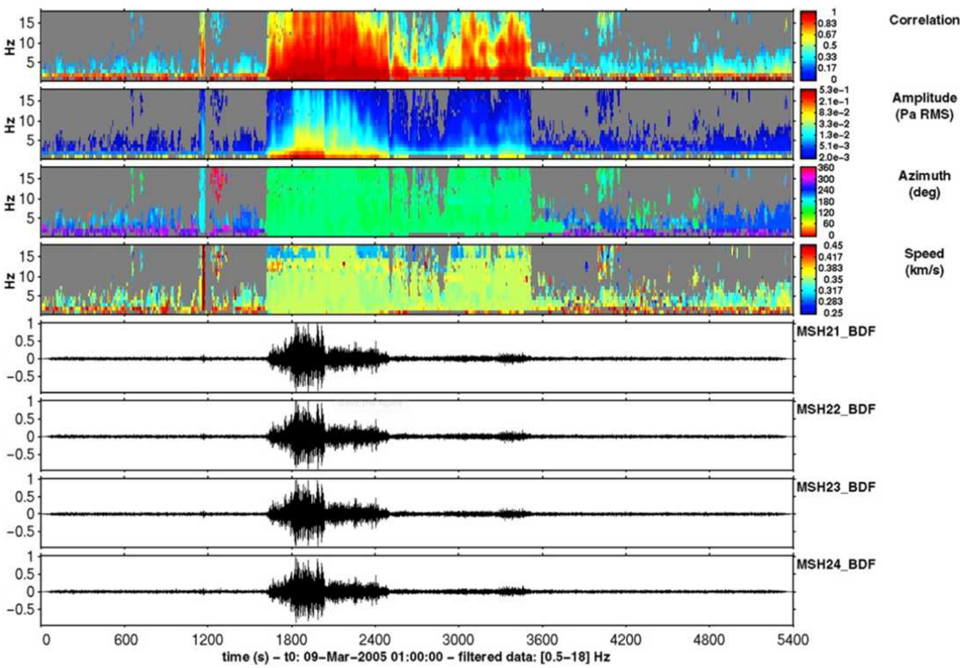
Basic hypothesis: $x_i(t) = s(t - \mathbf{r} \cdot \mathbf{u}) + w_i(t)$

- ‘Clutter’ or ‘correlated noise’ under this definition is a signal
- Use of multiple narrowband filters to separate simultaneous signals in the f-domain
- Progressive -> Handles noisy channels
- Requires extensive post-processing

$$\left. \begin{aligned} r_{ijk} &= \Delta t_{ij} + \Delta t_{jk} + \Delta t_{ki} \\ c_n &= \sqrt{\frac{6}{n(n-1)(n-2)} \sum_{i>j>k} r_{ijk}^2} \end{aligned} \right\} i,j,k \in R_n$$



PMCC detections from the eruption of Mt. St. Helens. Different colored pixels represent detections in time/frequency space.



Pixels are coalesced into families (‘detections’) using distance metrics

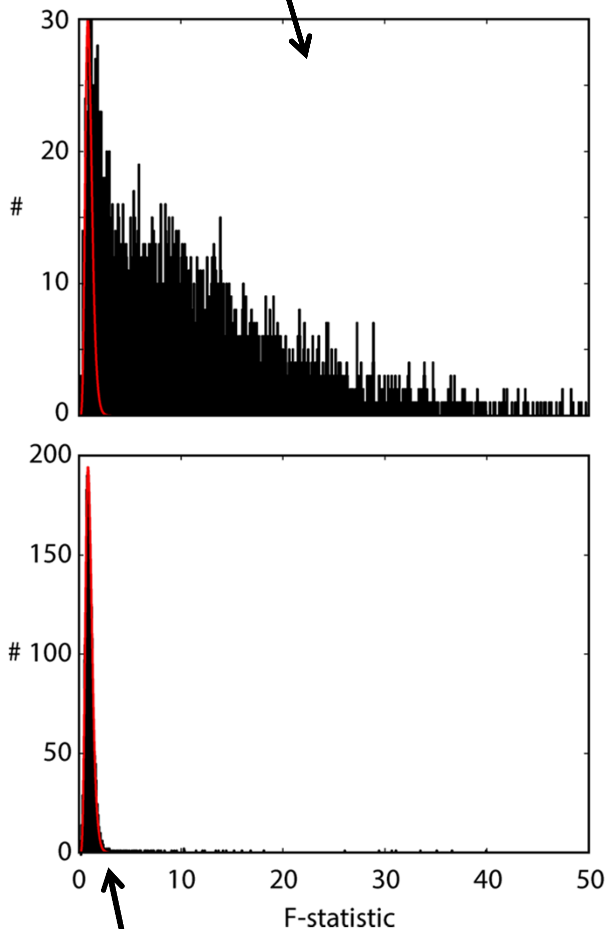
$$d(P_1, P_2) = \sqrt{\frac{\Delta t^2}{\sigma_t^2} + \frac{\Delta f^2}{\sigma_f^2} + \frac{\Delta v^2}{\sigma_v^2 v_2 v_1} + \frac{\Delta \theta^2}{\sigma_t^2}} < d_{\text{thres}}$$

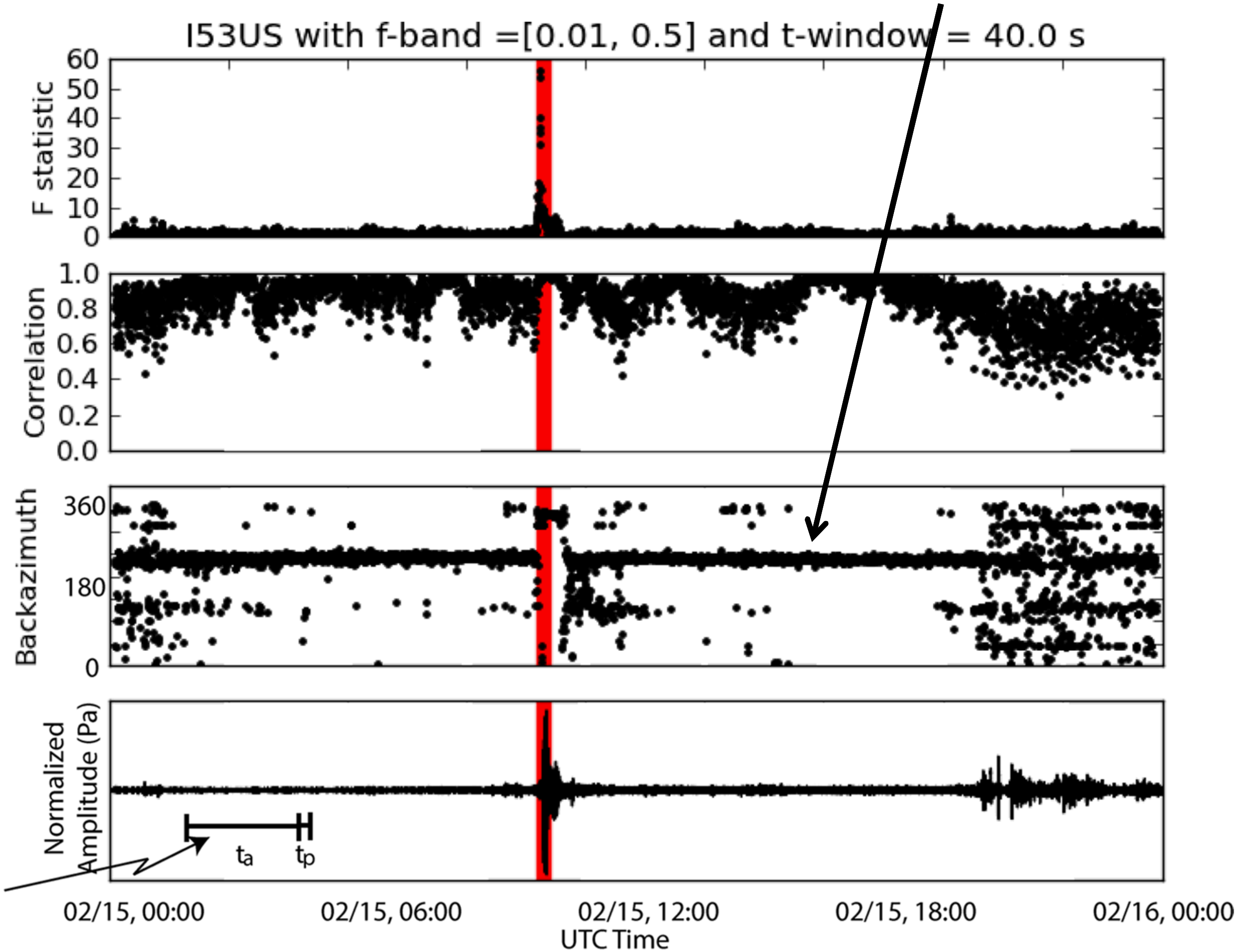
Infrasound Event Detection: AFD

Basic hypothesis: $x_i(t) = s(t - \mathbf{r}_s \cdot \mathbf{u}_s) + n(t - \mathbf{r}_n \cdot \mathbf{u}_n) + w_i(t)$

F does not follow H0

Background coherence from oceans





F/C follows H0

As shown by Shumway: $F|_{H_0} \sim F_{2BT,2BT(N-1)\lambda} \approx CF_{2BT,2BT(N-1)}$

Sandia National Laboratories

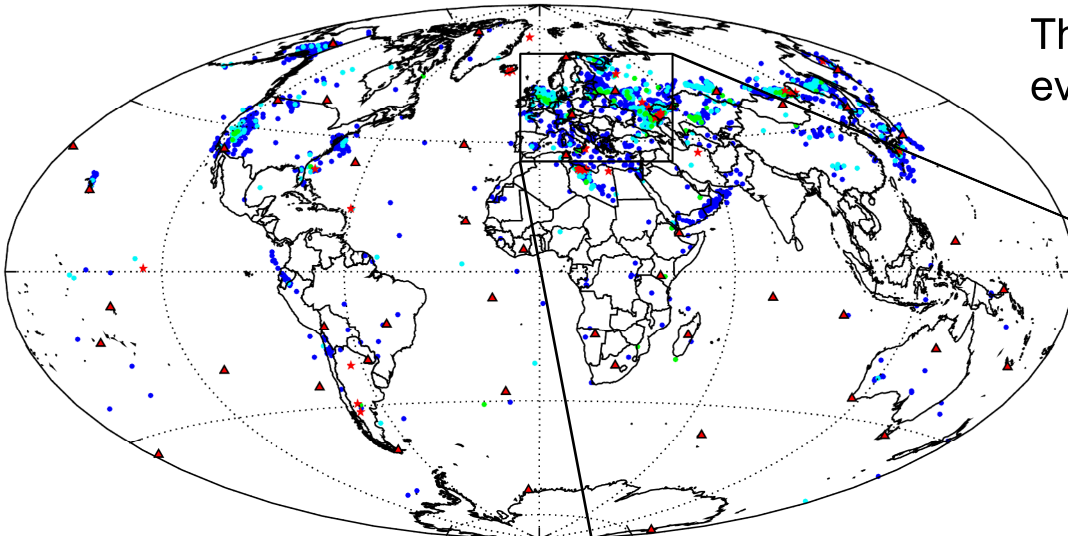
NNSA National Nuclear Security Administration

Infrasound Event Detection: Limitations

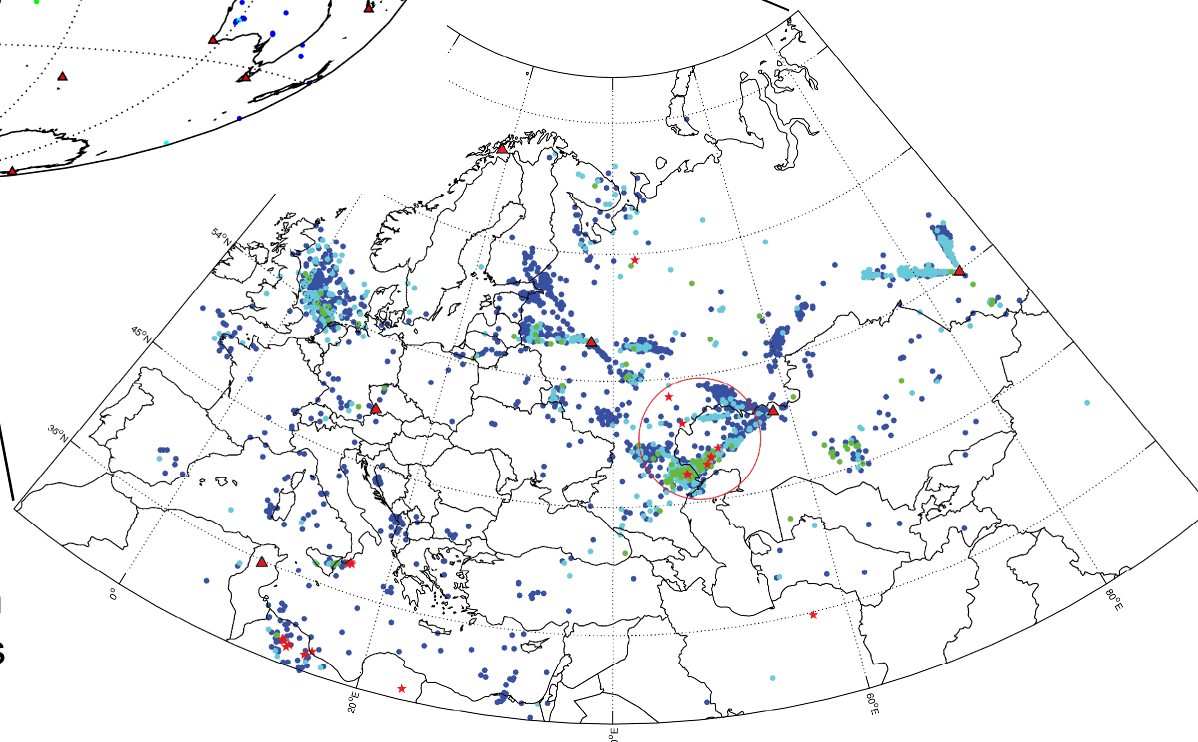
- Existing infrasound hypothesis tests are based on coherence only
- Post-processing is employed to sift through detections to identify possible explosion signals
  - Interesting signals could be associated at multiple arrays
  - Interesting signals may have certain characteristics at an individual array
- How might we identify explosion signals?
  - Explosions are broadband
  - Explosions have finite duration that typically increases with range
  - …
- What about formulating detectors that exploit these properties from the outset?

Sandia National Laboratories

A Dataset for Testing some improvements



The largest density of infrasound events in the LEB is in Eurasia

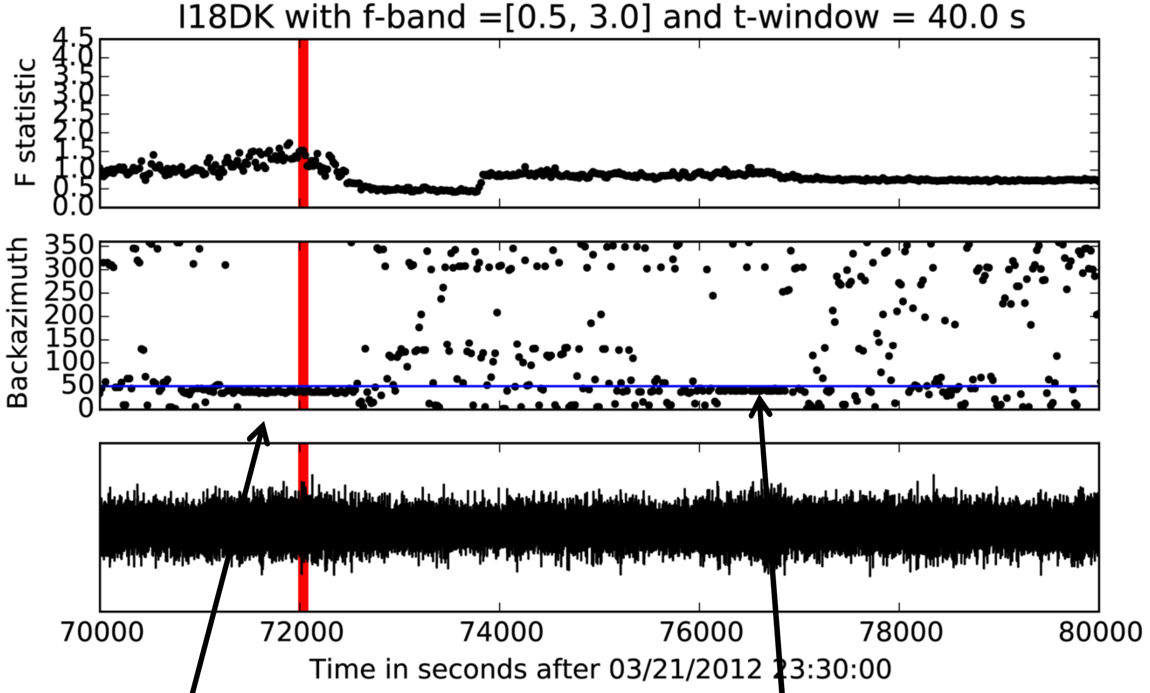


8 events located near I31 are each recorded at 5 arrays -> Test events

The need for detector improvements

- Adaptive F detector (AFD) insensitive to coherent noise but can miss low SNR signals.
- Can we combine the AFD with additional constraints to lower the detection threshold, while preserving the advantages of the AFD?
- Initial testing of a simple 'Hough-like' (line) detector
- Initial testing of Fishers Combined Probability test

Arrival in LEB from 5-array association



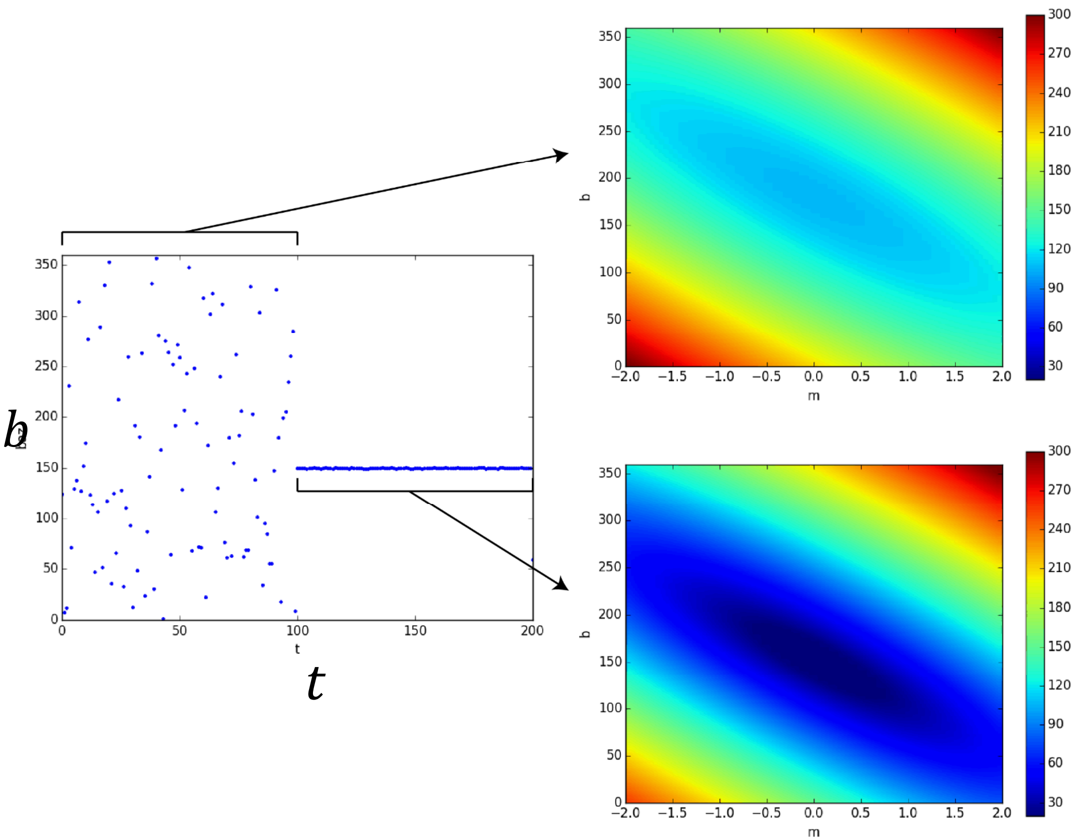
Second arrival is not detected

Consistent backazimuth over some time interval
but weak F-statistic barely above ambient

A ‘Hough-like’ detector

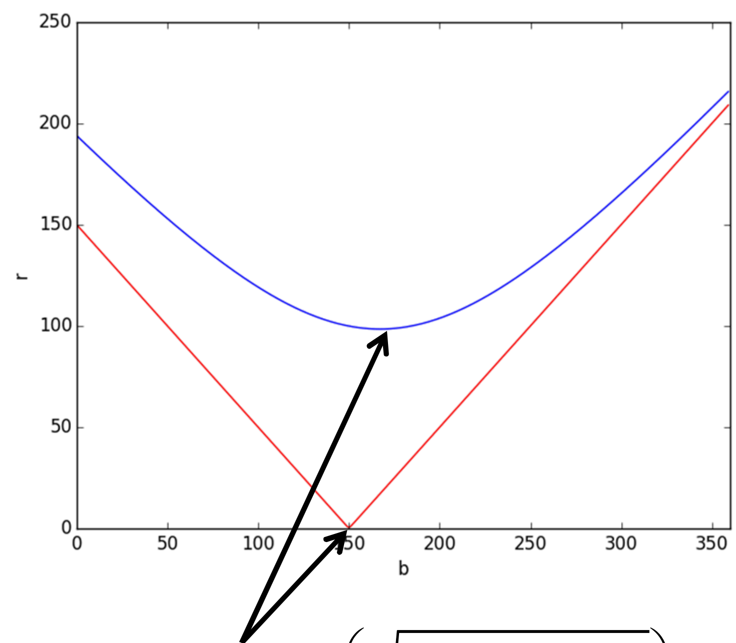
Detecting lines in backazimuth, time space:

Model: $y_{pi} = mt_i + b$ Residual: $r = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(y_{pi} - y_i\right)^2}$



At long distances, we only want to search for horizontal lines:

Model: $y_{pi} = b$



$$r_{\min} = \min\left(\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(b - b_i\right)^2}\right)$$

$$b \in \left[0,360\right]$$

Combining detectors

How to combine detections from different detectors?

- Logical
  - Doesn't fully exploit the combined effects of two detectors

$$d_1 > d_1^{\text{thres}} \text{ OR } d_2 > d_2^{\text{thres}}$$

$$d_1 > d_1^{\text{thres}} \text{ AND } d_2 > d_2^{\text{thres}}$$

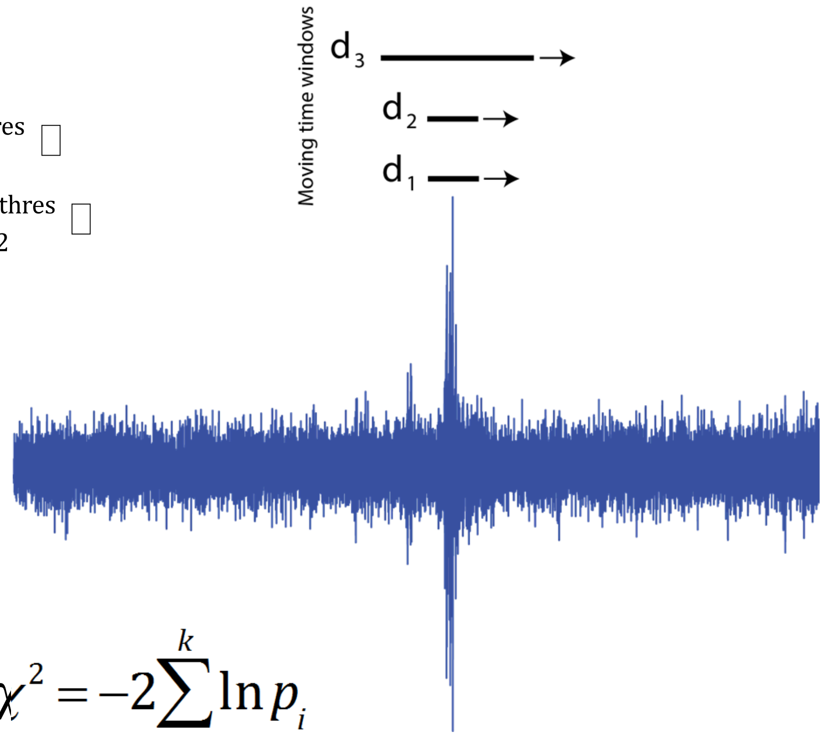
- Arithmetic
  - Doesn't use noise distribution information

$$\sum_{i=1}^{k} w_i d_i > \text{thres}$$

- <u>Fishers Combined Probability Test</u>
  - Uses distributional properties of H0
  - requires a probability model

$$p_i = \int_{d_i}^{\infty} p(\text{x}; H_0) \qquad \chi^2 = -2\sum_{i=1}^{k} \ln p_i$$

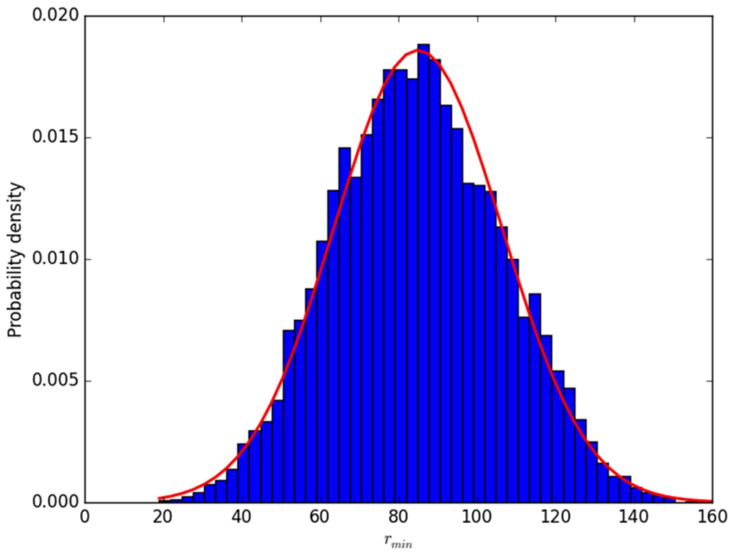
- …



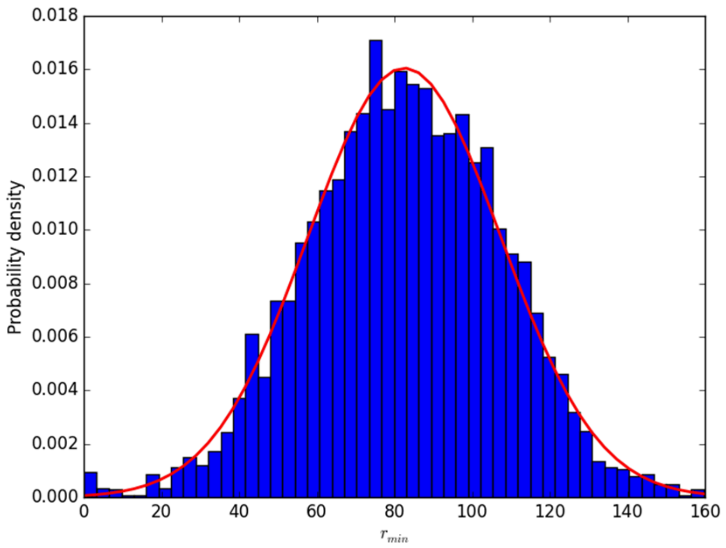
Detectors should ideally exploit different signal characteristics

Fishers Combined Probability Test

Distributional properties of $r_{\min} = \min\left(\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(b - b_i\right)^2} \right)$



Uniformly distributed noise
U[0,360]

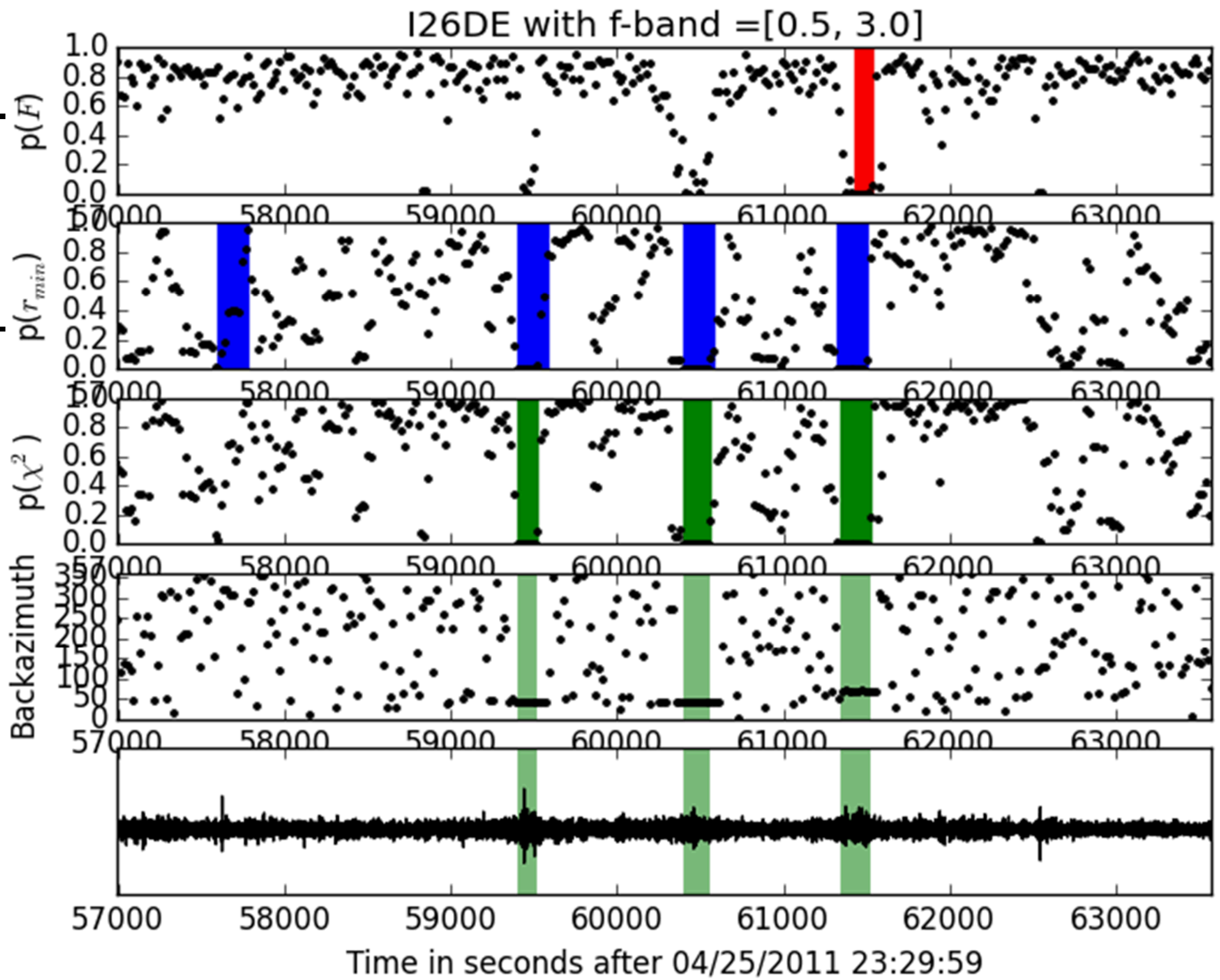


1-day interval at I26DE

An initial multivariate detector result

Separate
p-values

Combined
p-value



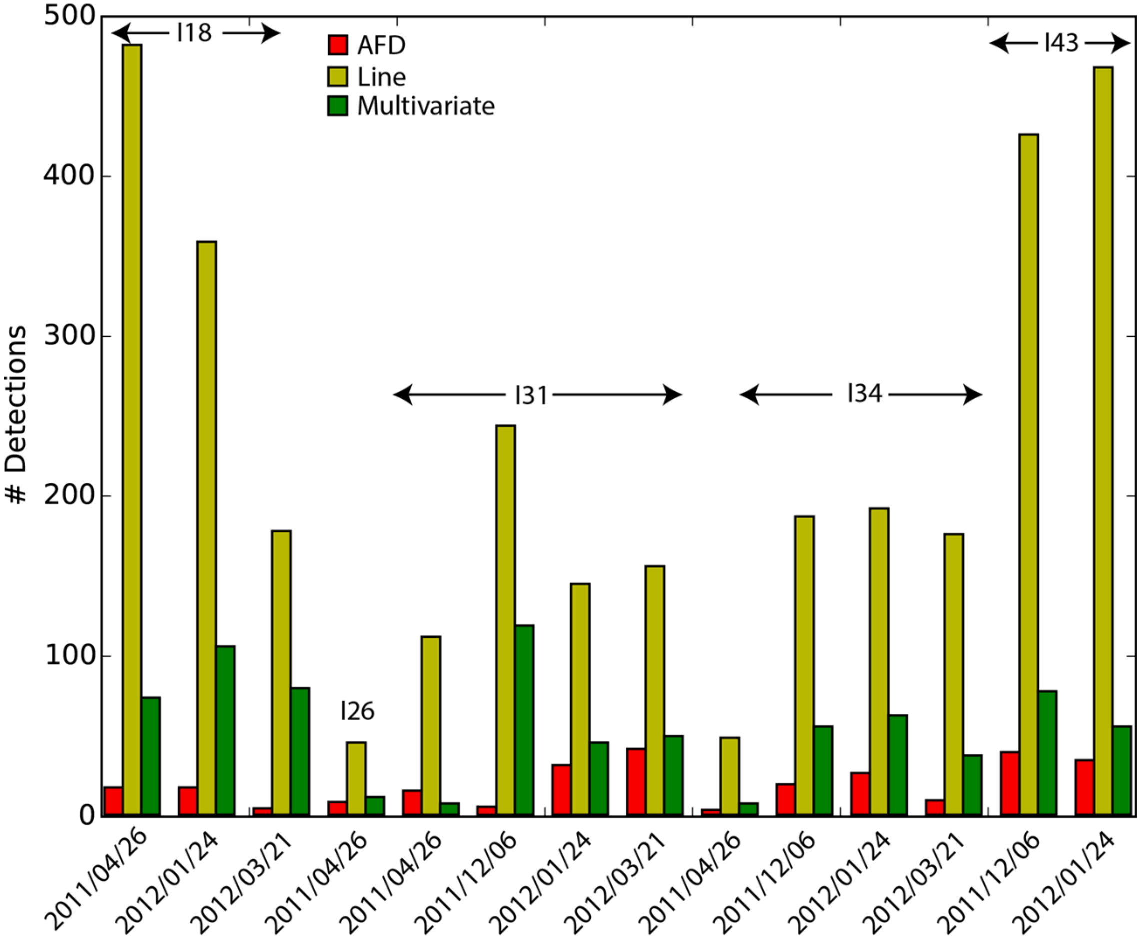
Combining AFD and line detector results in a much stronger detection of the first arrival, and weak detection of the second arrival.

Some initial detection statistics

Detections of LEB arrivals from test events

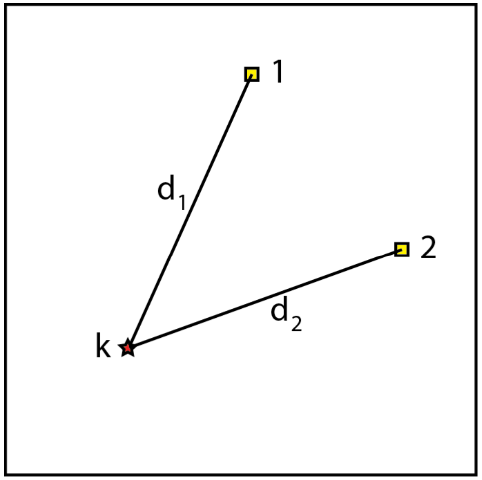
# detections	Catalog
17	LEB
13	AFD
15	Multivariate

- Multivariate detector find two LEB arrivals from AFD
- Missing two arrivals are not observed in broadband FK processing



14 days of data in different noise environments

Association



Forward model observations for each grid node...

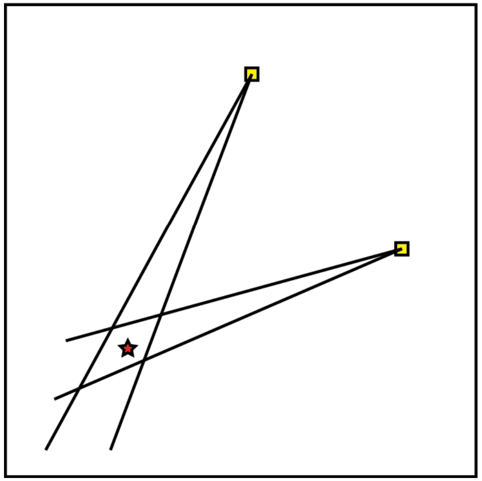
$$\Phi_k = \left(\phi_1^k, \phi_2^k, \ldots\right) \qquad dT^k_{\max} = \left[\frac{(d_1 - d_2)}{v_{\min}}, \frac{(d_1 - d_3)}{v_{\min}}, \ldots\right] \qquad dT^k_{\min} = \left[\frac{(d_1 - d_2)}{v_{\max}}, \frac{(d_1 - d_3)}{v_{\max}}, \ldots\right]$$

Loop over GRID NODES...

- Find detection pairs that are compatible
- Cluster detection pairs based on ARID linkages

e.g., GA, InfraMonitor

Slower/greater memory load



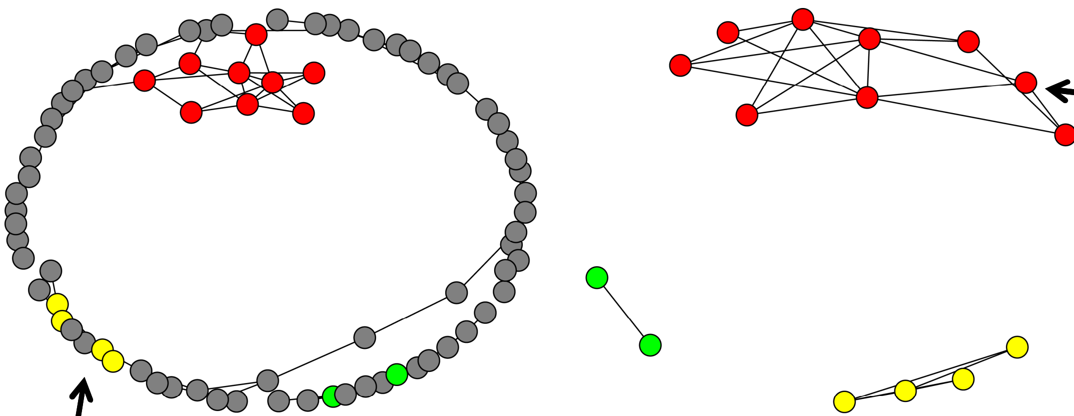
Loop over DETECTION PAIRS...

- Find detection pairs that are compatible
- Cluster detection pairs based on ARID linkages
- Process cluster (or 'graph') using physical criteria
- Search for associated signals at remaining arrays

e.g., CEA algorithm, InfraPy

Existing methods fall under two basic categories. Criteria are basically azimuth/time but GA may include additional empirical constraints

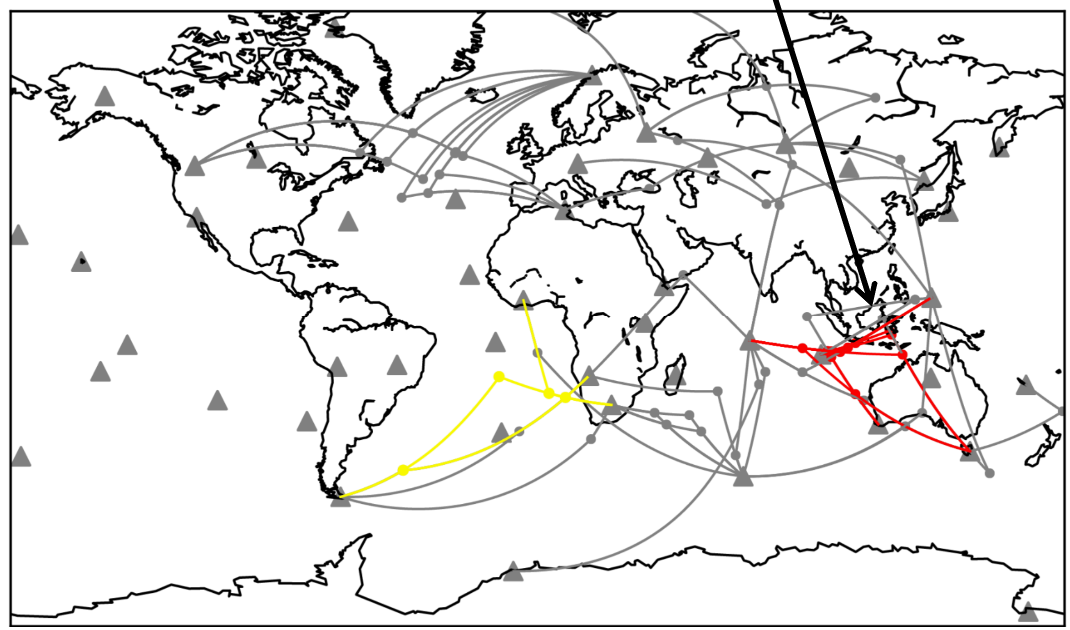
Association – Looping over detection pairs



a

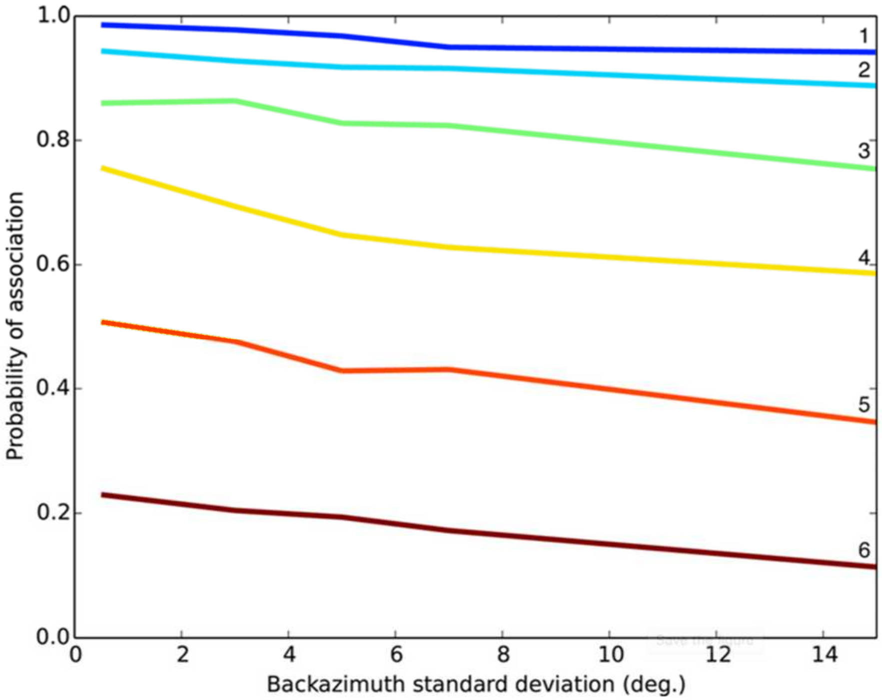
Eruption of Kelud volcano

Compatible detection pairs plotted as 16 separate graphs. Three graphs are highlighted separately.

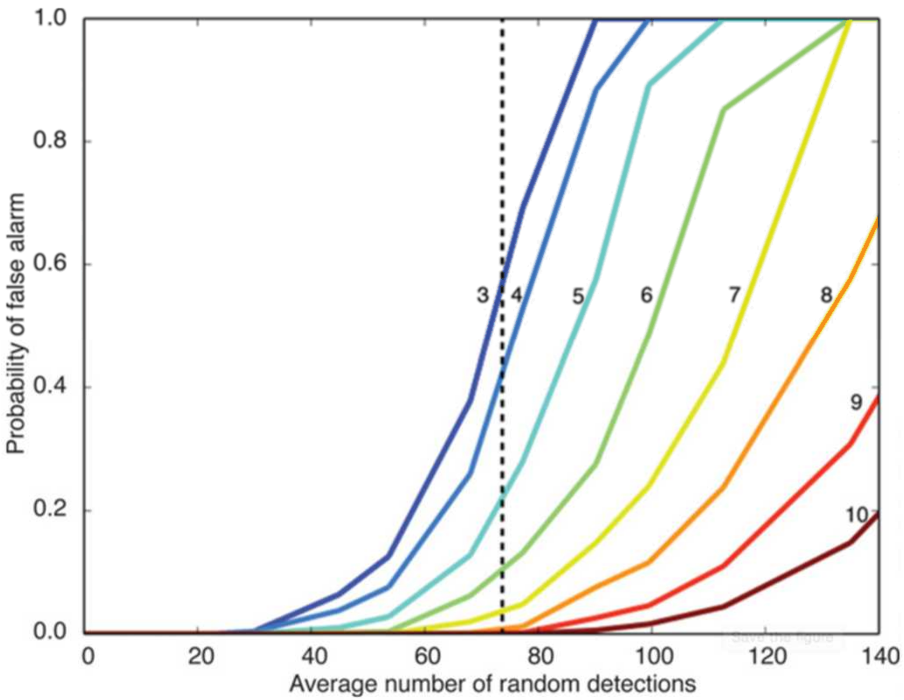


The geographic consistency of each graph is used to develop a robust event hypothesis

Association synthetic tests

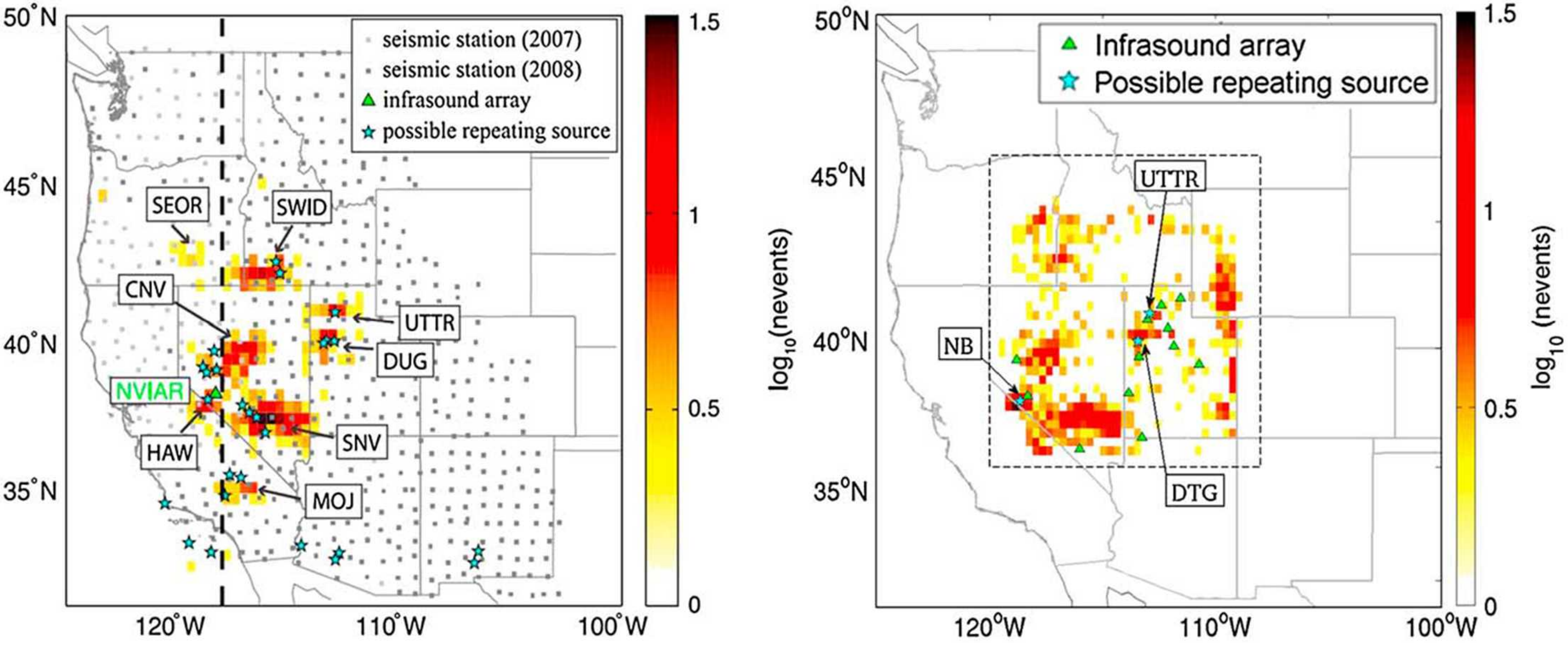


Probability of association (1 = all synthetic events associated, 0 = no synthetic events associated) as a function of event size (# of detecting stations) and noise added to backazimuths



Probability of false association as a function of event size (# of detecting stations) and # of detections

Association – Looping over grid nodes



Comparison between reverse-time migration on 100's of seismic sensors (left) and node-based association results using 12 infrasound arrays (right)

Summary

- Infrasound event detection is a challenging endeavor that has historically been hampered by the use of very simple models
- The main consequence of these simple models is a big false positive problem.
  - Moving towards more realistic signal and noise models should reduce the false positive problem
  - Adding physics-based constraints via propagation modeling should reduce the false positive problem at the network level.