SAND2016-2016PE

Infrasound data processing at Sandia

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Prepared for Pierrick Mialle, Jan 25/26/27, 2016

Background

Time

Arrowsmith et al., 2015 publication in GJI
(Referred to as 'Paper 1')
Adaptive F + Graph-based associator

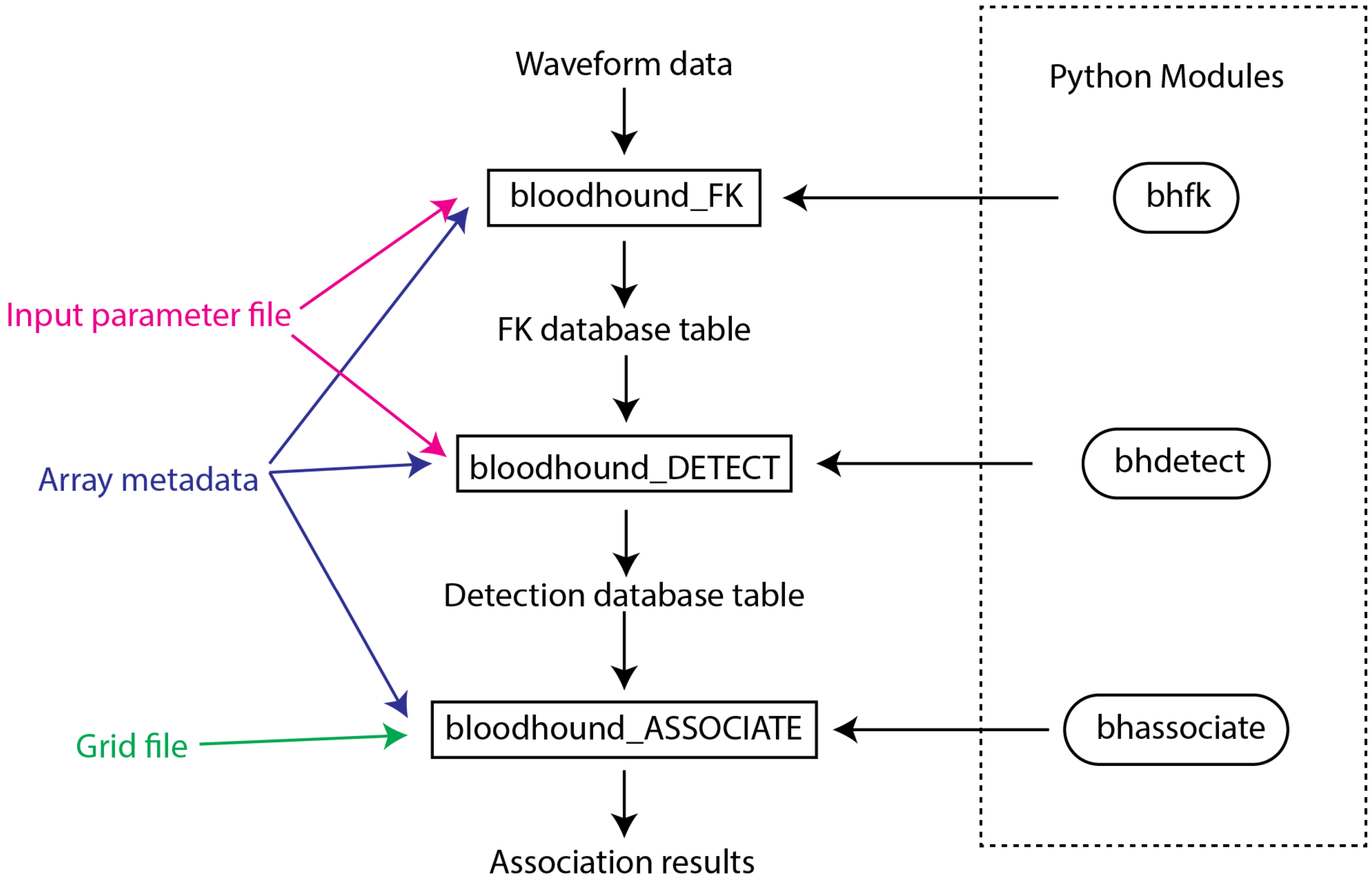
InfraPy (0.1)
Note: InfraPy dev. continues at LANL

ITW 2015: Presentation by Jones and Arrowsmith on limitations of Paper 1 algorithms for low-coherence signals

BloodHound (in dev.)
- Completely independent code base (planned to be open-source)
- New multivariate detector (enabling detection of low-coherence signals)
- New associator (works better for larger # detections)

Preliminary event catalog for 2014 with BloodHound

BloodHound



Waveform data
Python Modules
bloodhound_FK
bhfk
Input parameter file
FK database table
Array metadata
bloodhound_DETECT
bhdetect
Detection database table
Grid file
bloodhound_ASSOCIATE
bhassociate
Association results

Combining detectors to detect low-coherence signals without clutter

- Different detectors might exploit different signal properties (e.g., coherence, duration, bandwidth)
- How can we combine detections from different detectors?
- Logical
  - Doesn't fully exploit the combined effects of two detectors

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

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

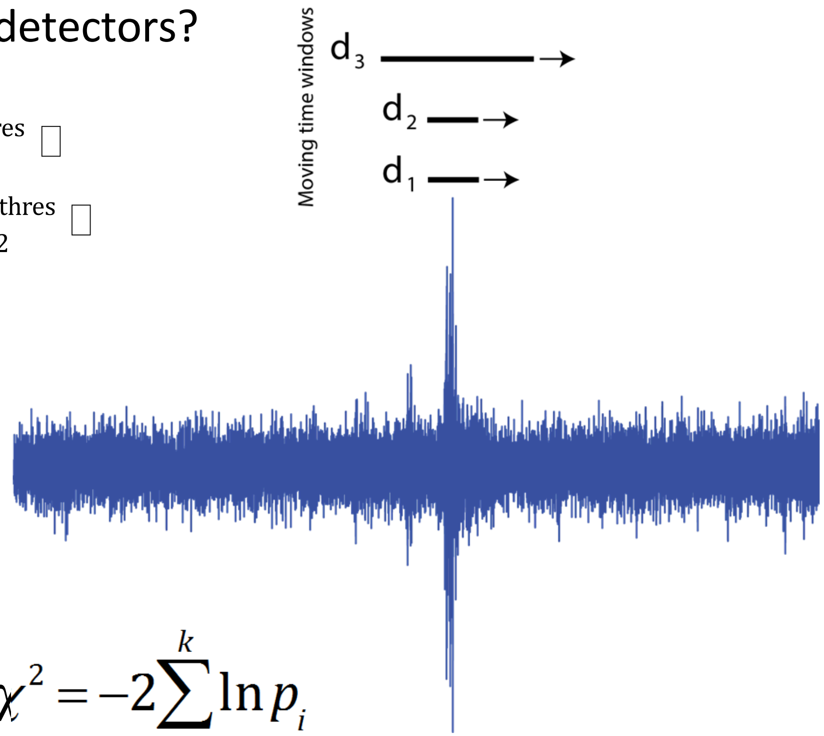
- Arithmetic
  - Doesn't use noise distribution information

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

- <u>Fishers Combined Probability Test</u>
  - Uses distributional properties of H0
  - Each detector is thus normalized by it's distribution

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

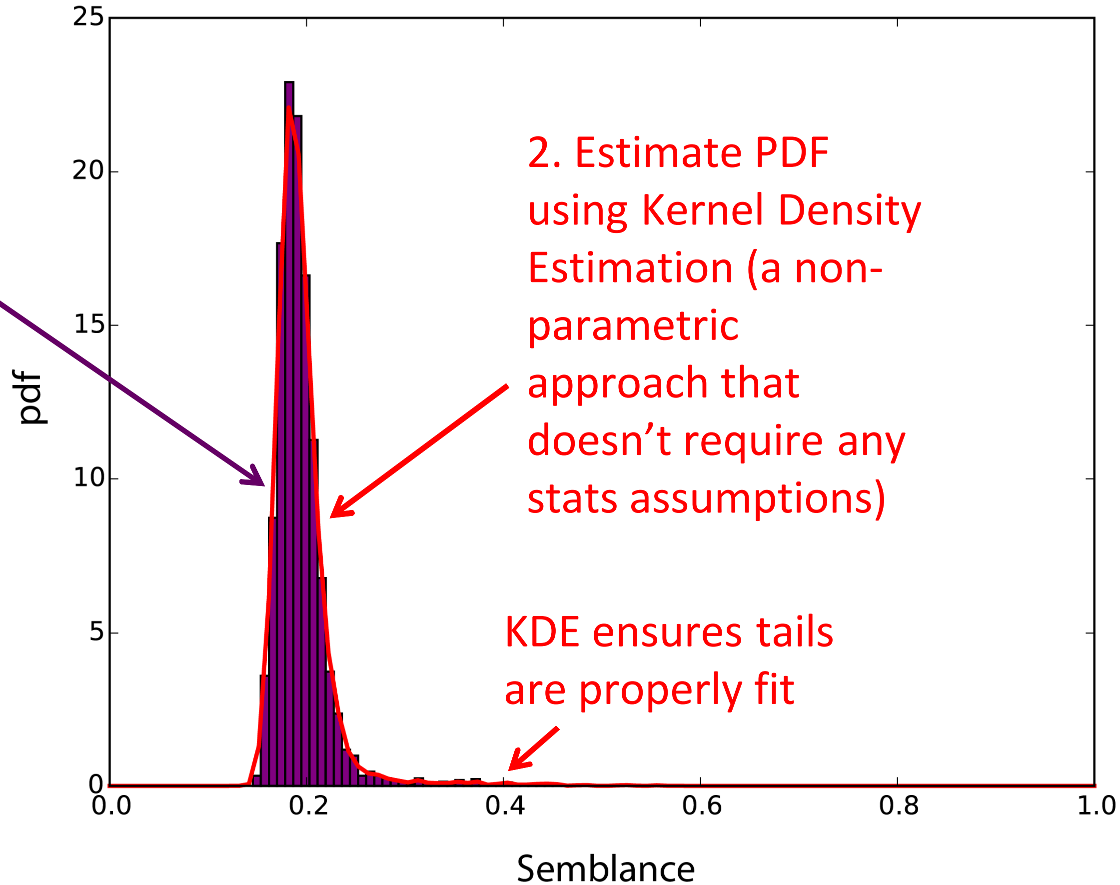
- …



Detectors should ideally exploit different signal characteristics

How do we calculate p-values?

1. Calculate distribution of detection statistic from a long time interval



2. Estimate PDF using Kernel Density Estimation (a non-parametric approach that doesn't require any stats assumptions)

KDE ensures tails are properly fit

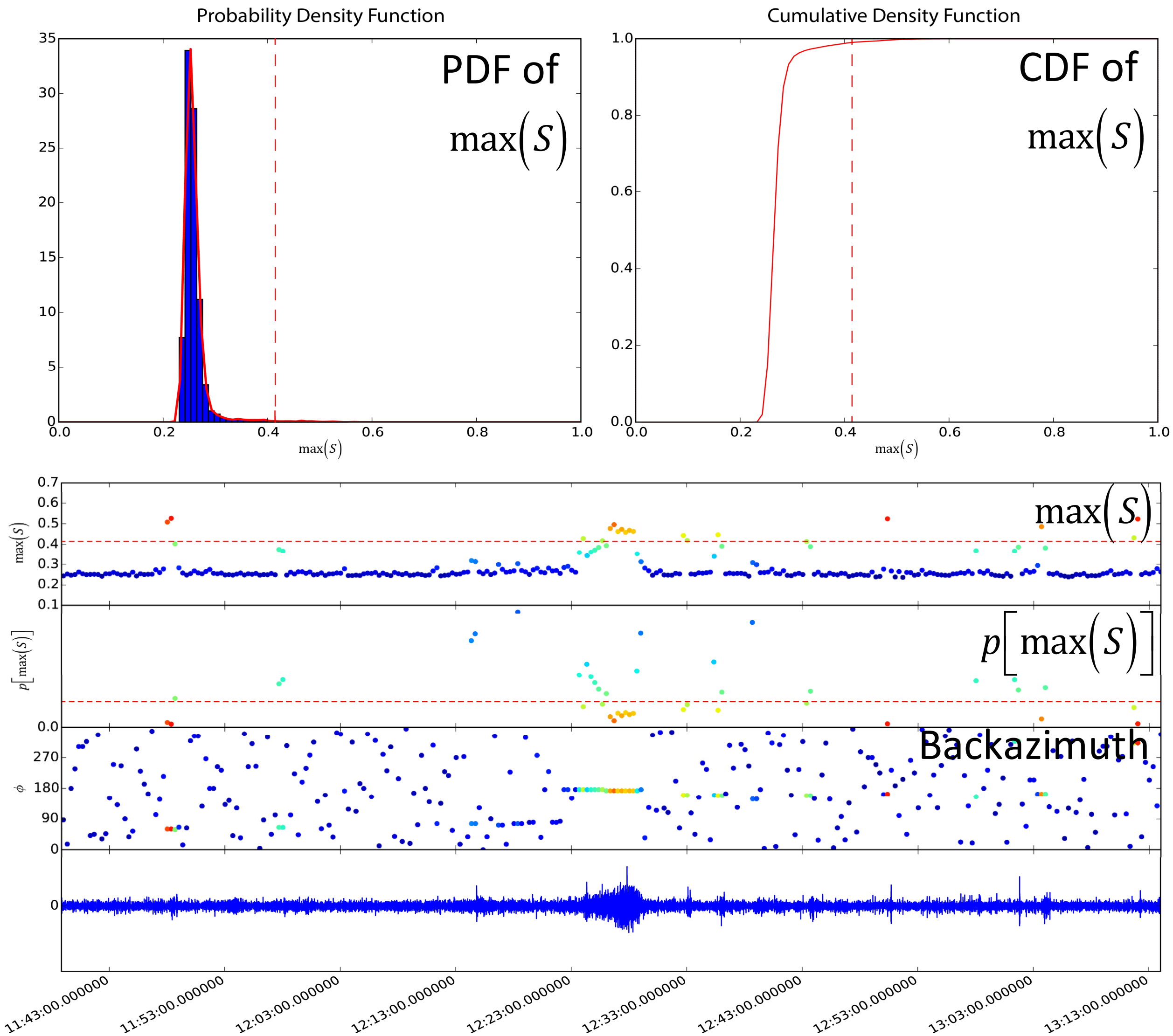
A p-value is the probability of obtaining a result equal to or more extreme than actually observed given the PDF of the test statistic (empirical PDF of signal+noise).

A Semblance-based Detector

- Semblance is a normalized measure of coherent power across an array

$$S=\frac{\sum_{j=-W/2}^{W/2}\left(\sum_{i=1}^{M}a\left(\mathbf{x}_i,t_j\right)\right)^2}{M\sum_{j=-W/2}^{W/2}\sum_{i=1}^{M}a\left(\mathbf{x}_i,t_j\right)^2}$$

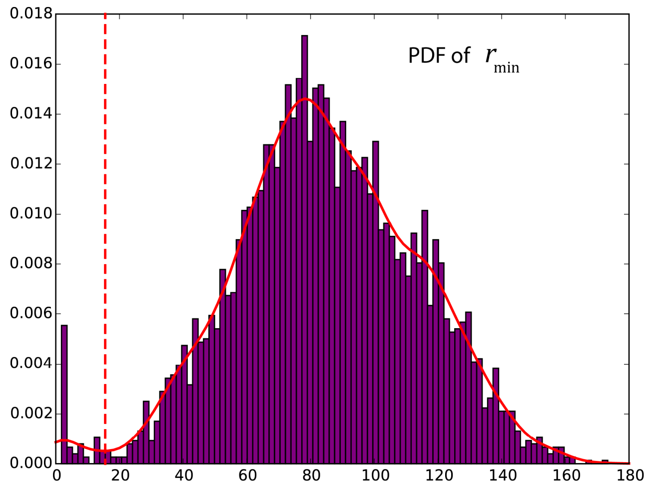
- $\max(S)$ is estimated over a fixed slowness grid and converted to p-values using KDE over a long time interval.

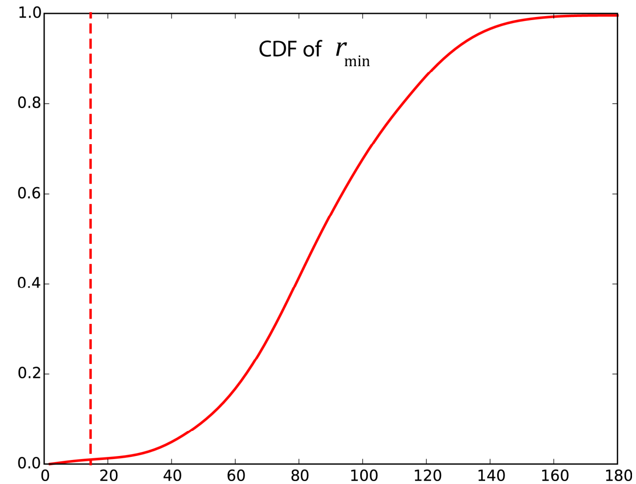


A Stationary Source Detector

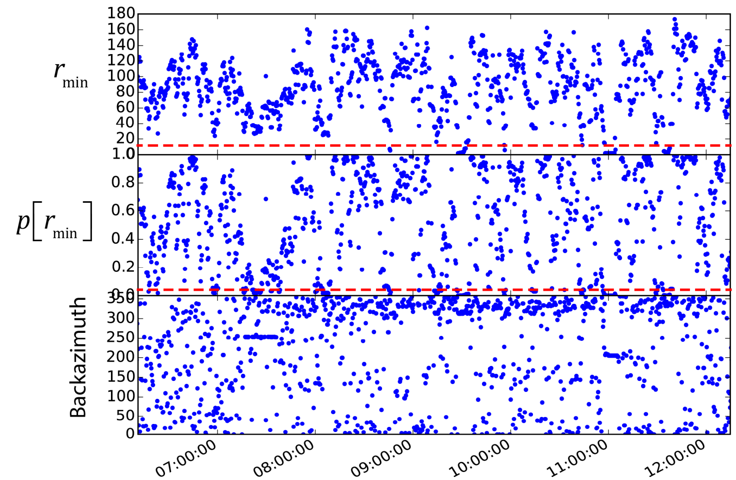
- Stationary sources are fit by straight lines in backazimuth/time space:

$$r_{\min} = \min_j \left(\sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(\phi_{ji} - \phi_i \right)^2} \right)$$



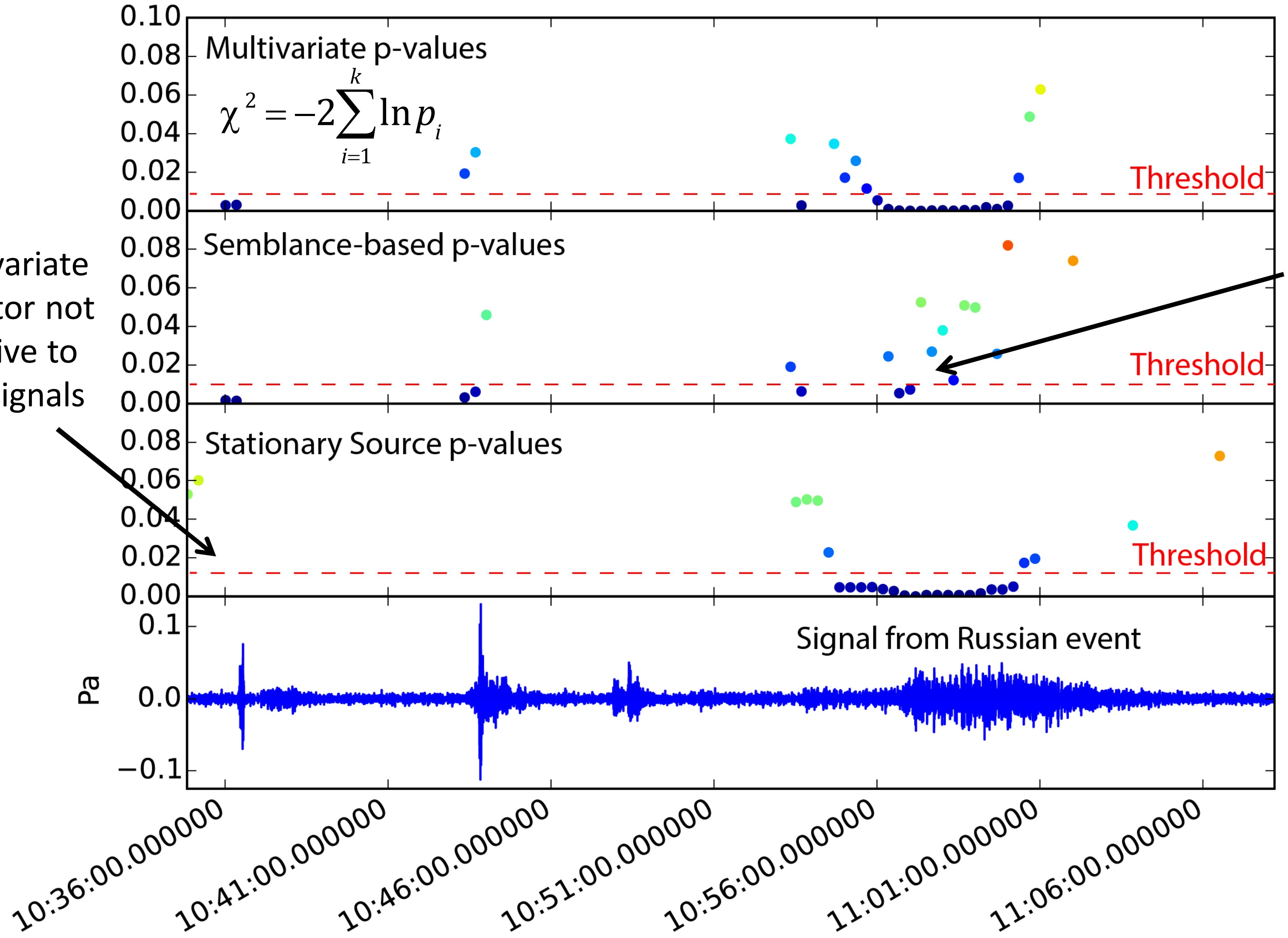


- $r_{\min}$ is estimated over all backazimuths over a fixed time window.



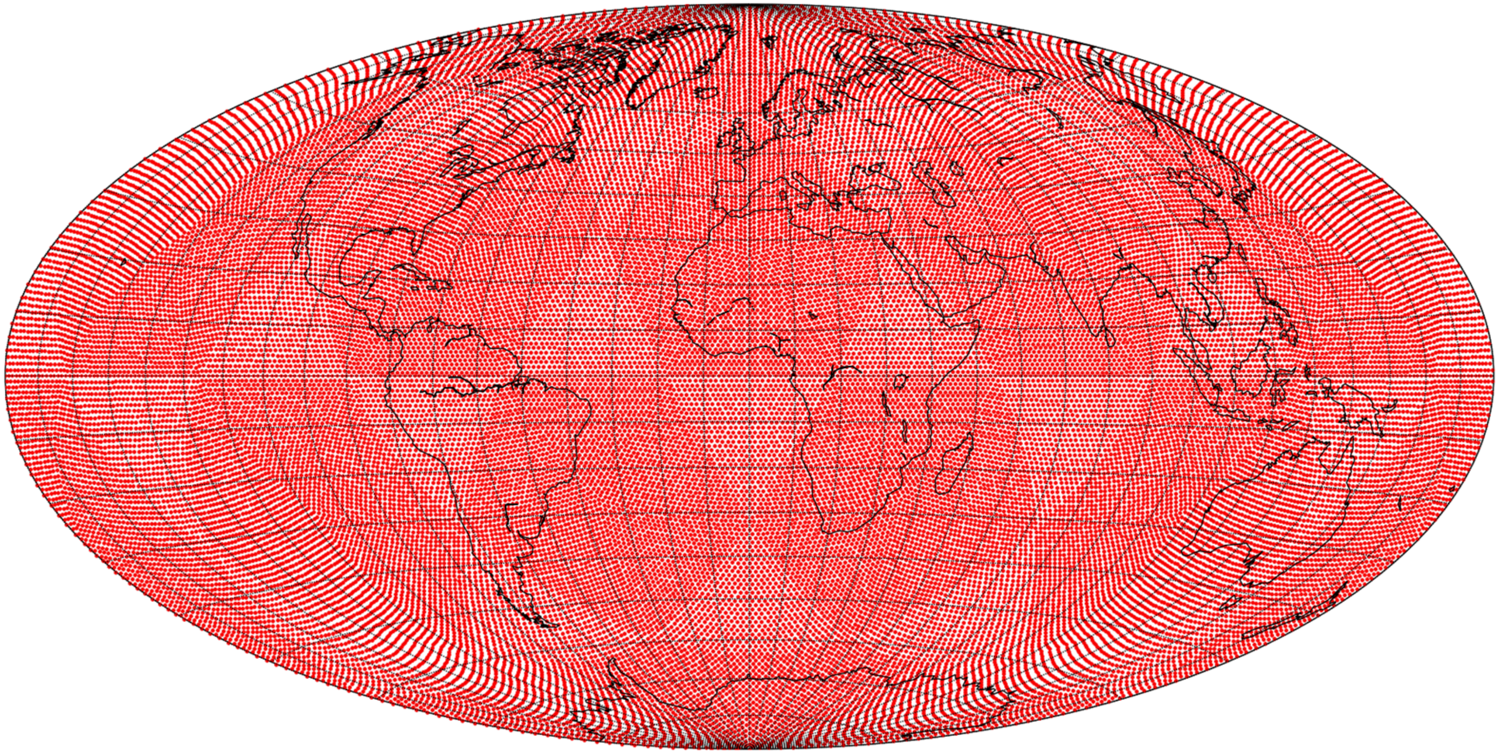
A multivariate signal detector

Multivariate detector not sensitive to local signals



Coherence-based detector barely detects the event

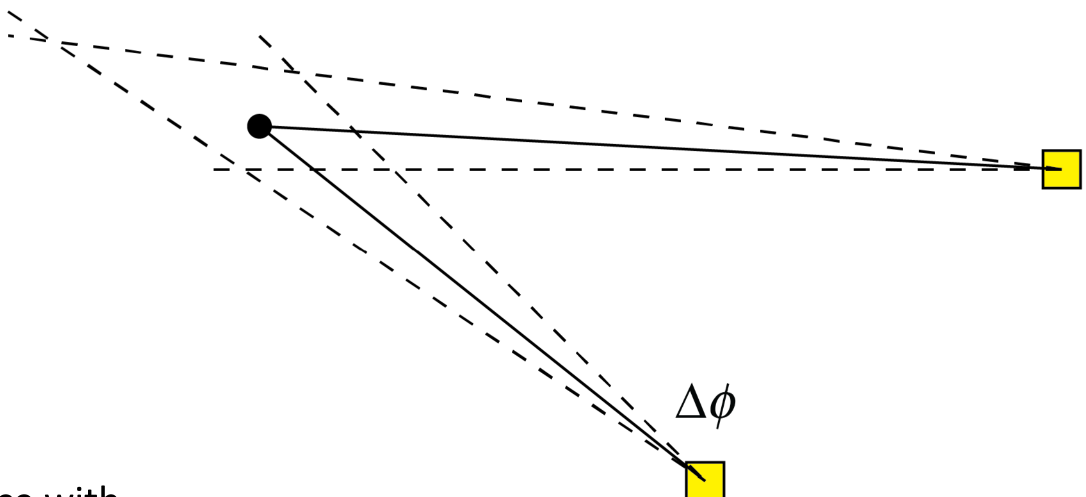
Grid-based associator



40962 nodes, generated using triangular tessellations with GeoTess.

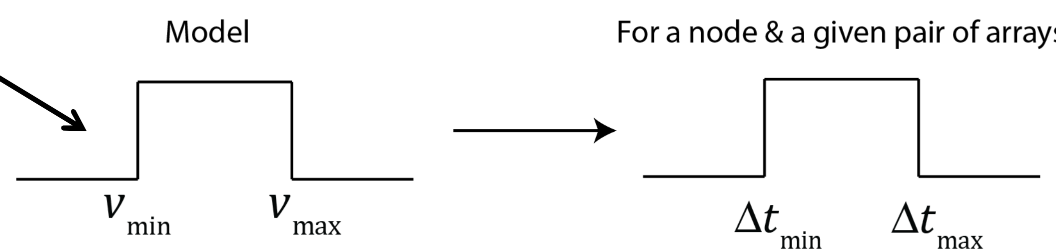
Physical constraints stored in look-up table

1. Backazimuth Constraints for a node & given pair of arrays:

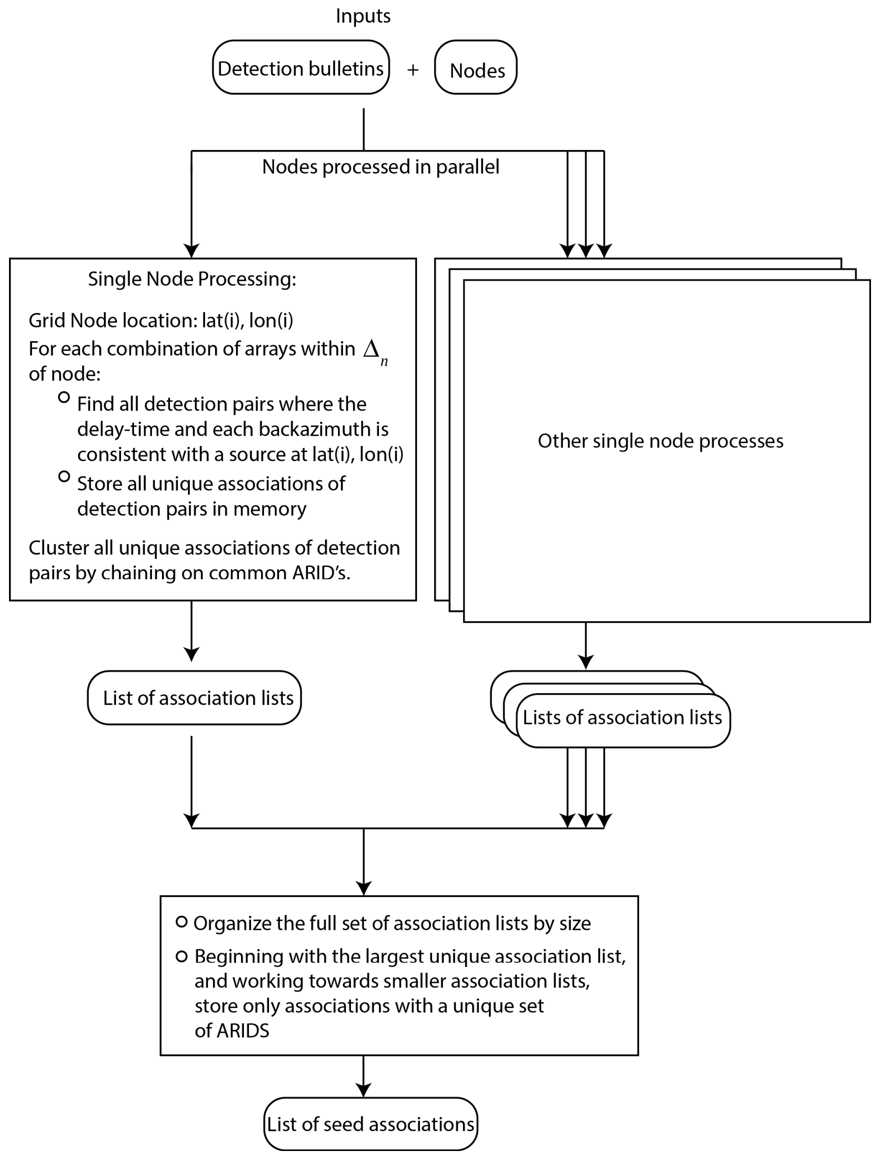


Plan to replace with range-dependent Gaussian Mixture Model

2. Travel-time Constraints for a node & given pair of arrays:

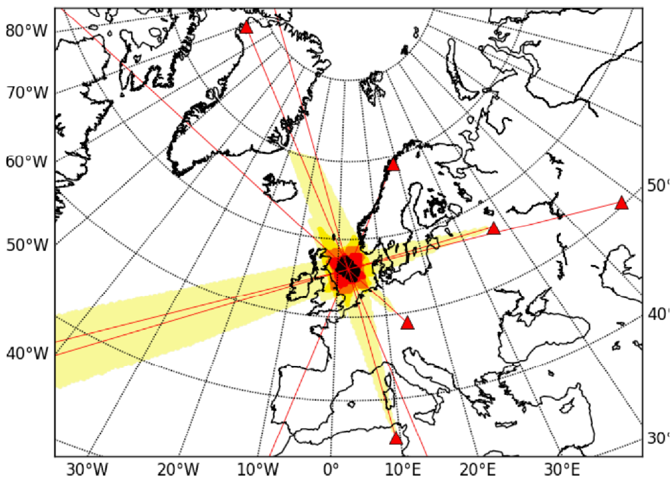


Implementation of associator

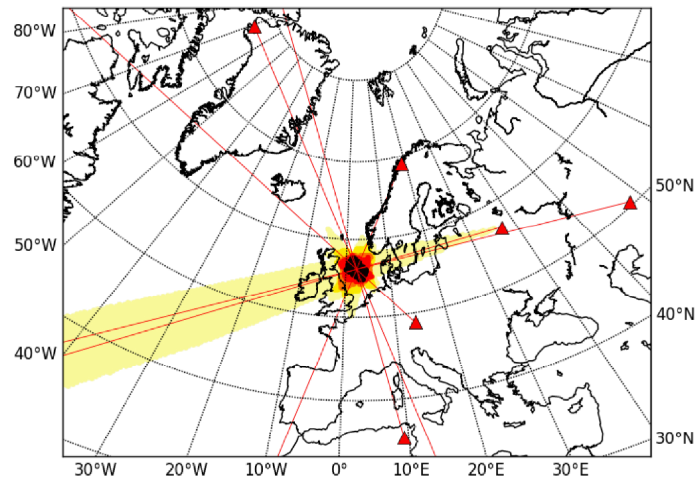


Synthetic Tests

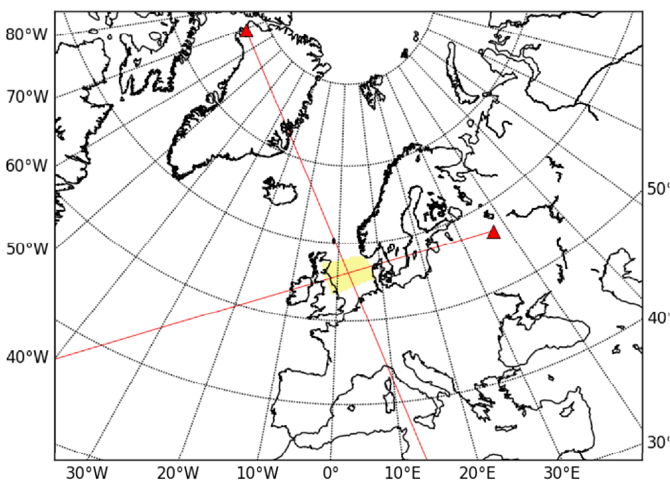
Six array association: Azimuth constraints only



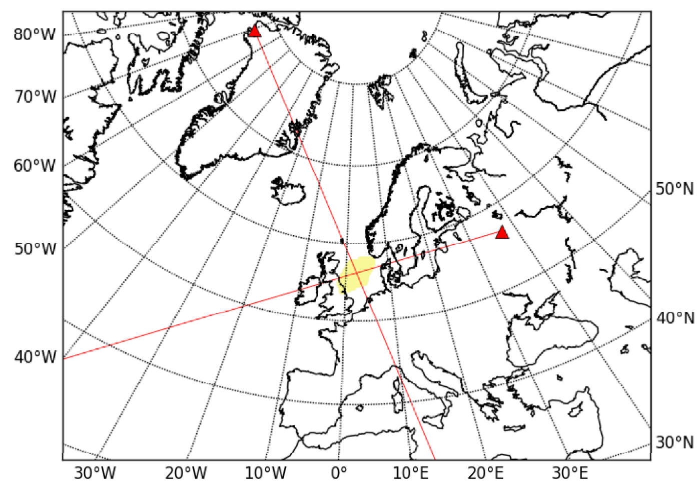
Six array association: Azimuth + Time constraints



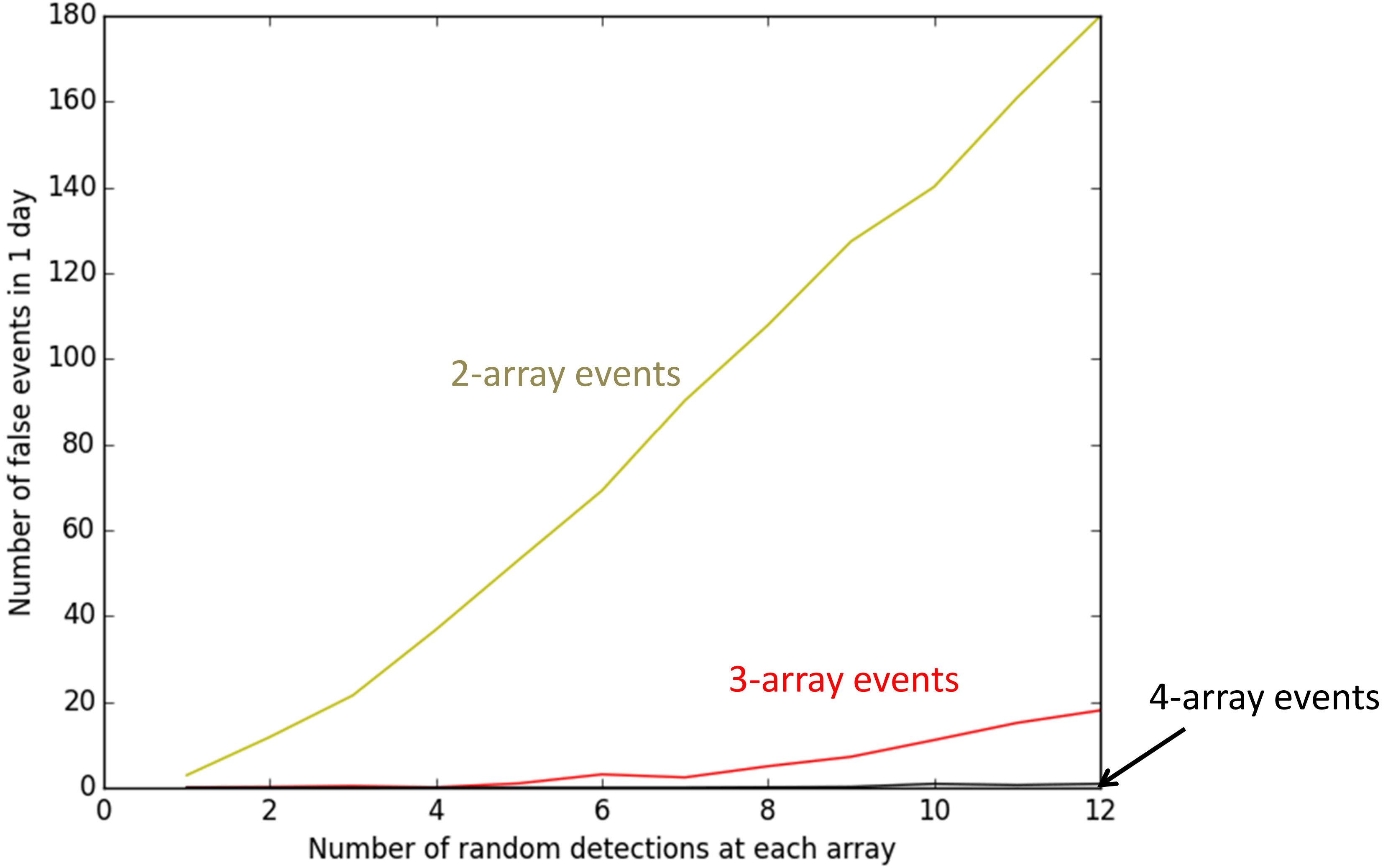
Two array association: Azimuth constraints only



Two array association: Azimuth + Time constraints

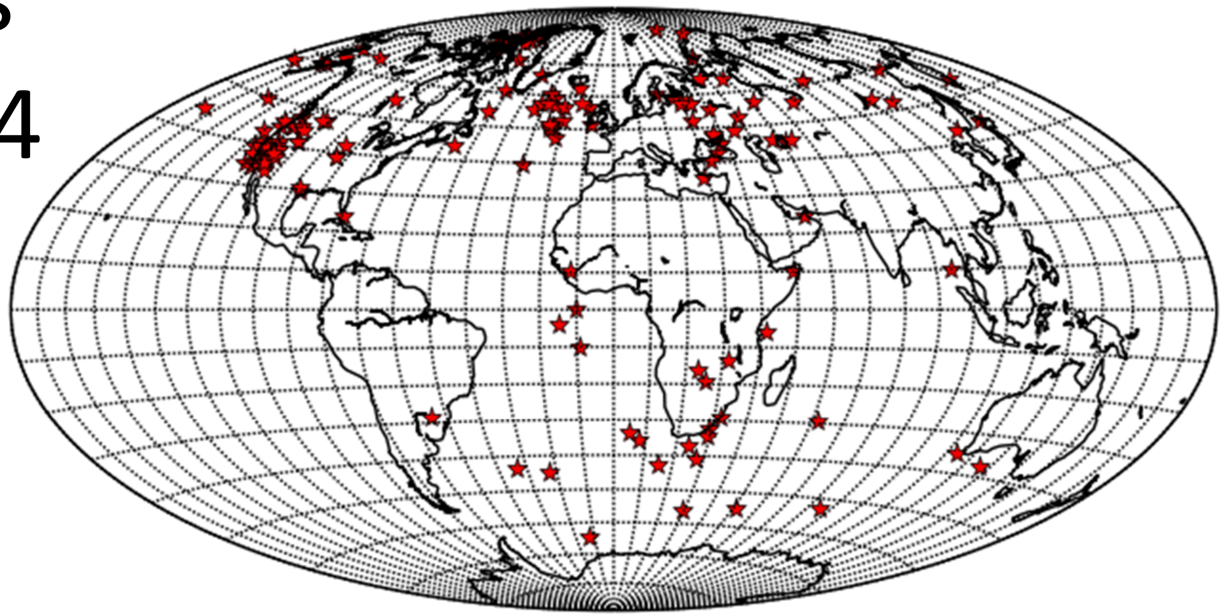


FAR from Monte Carlo Simulations



Results for 2014

BloodHound



SEL3

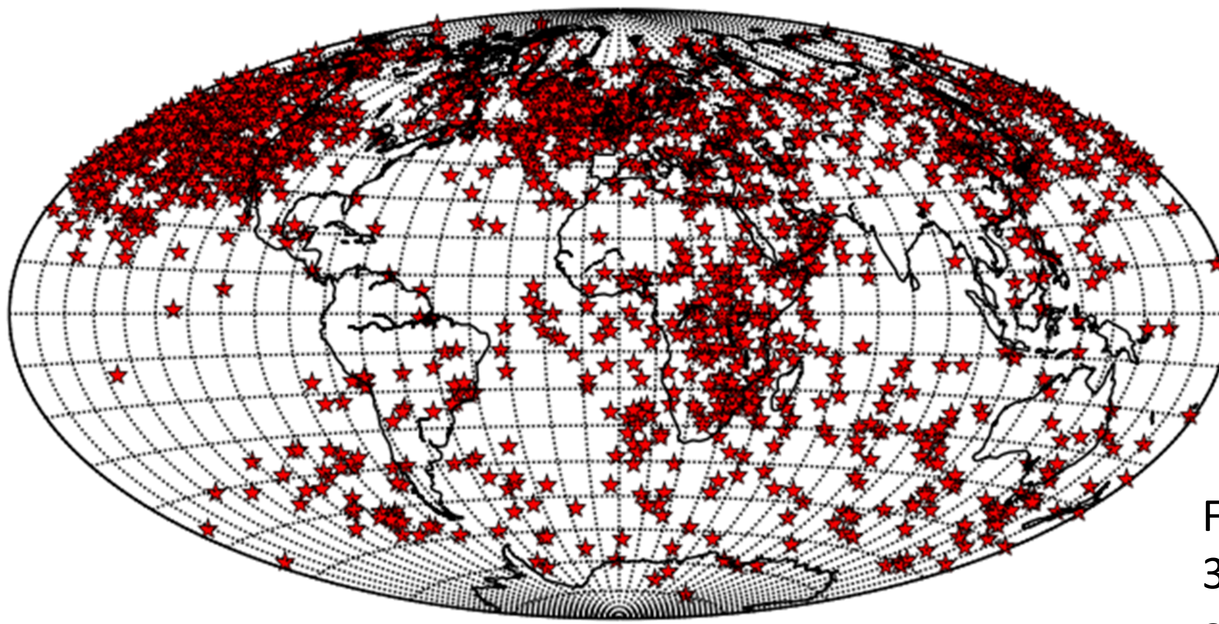
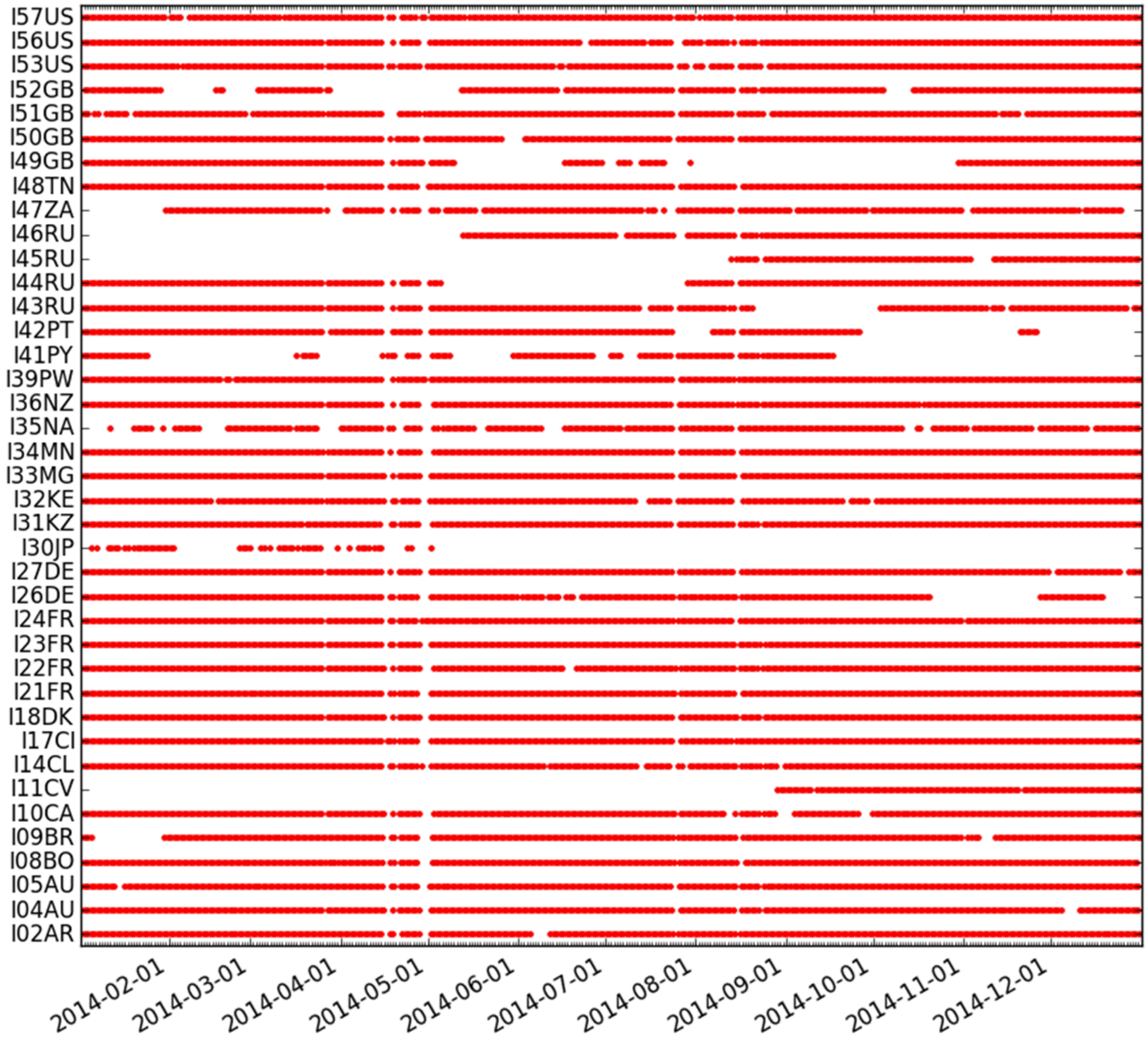


Figure shows 3-array events and above…

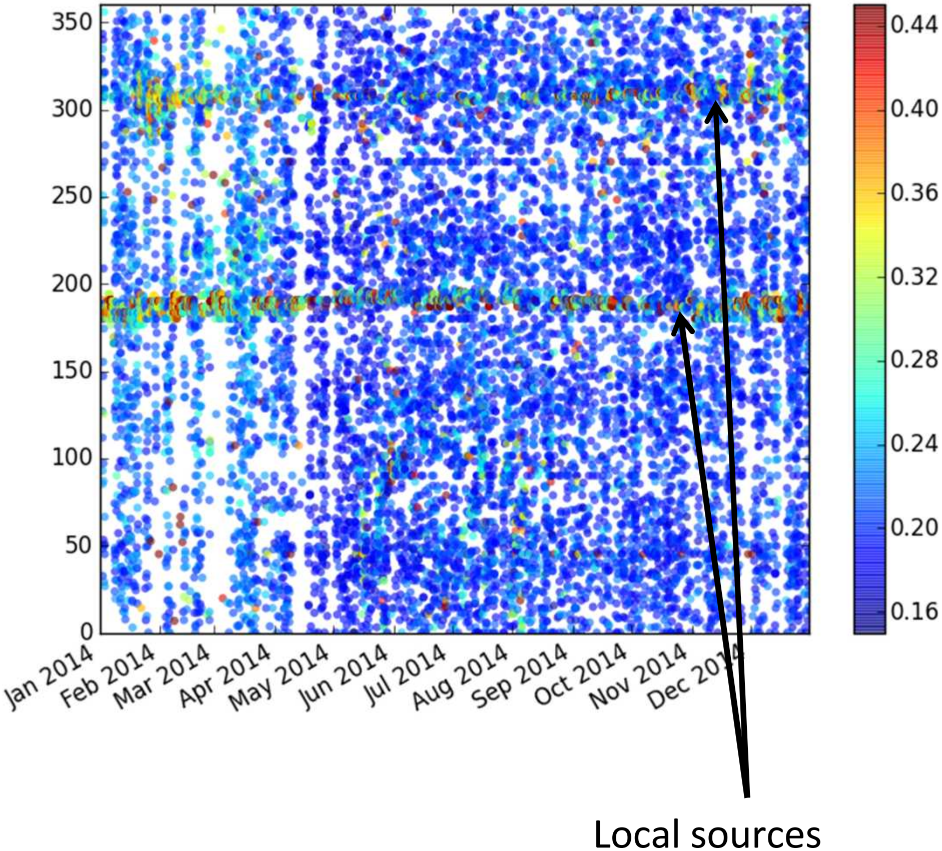
Data Availability at SNL for 2014



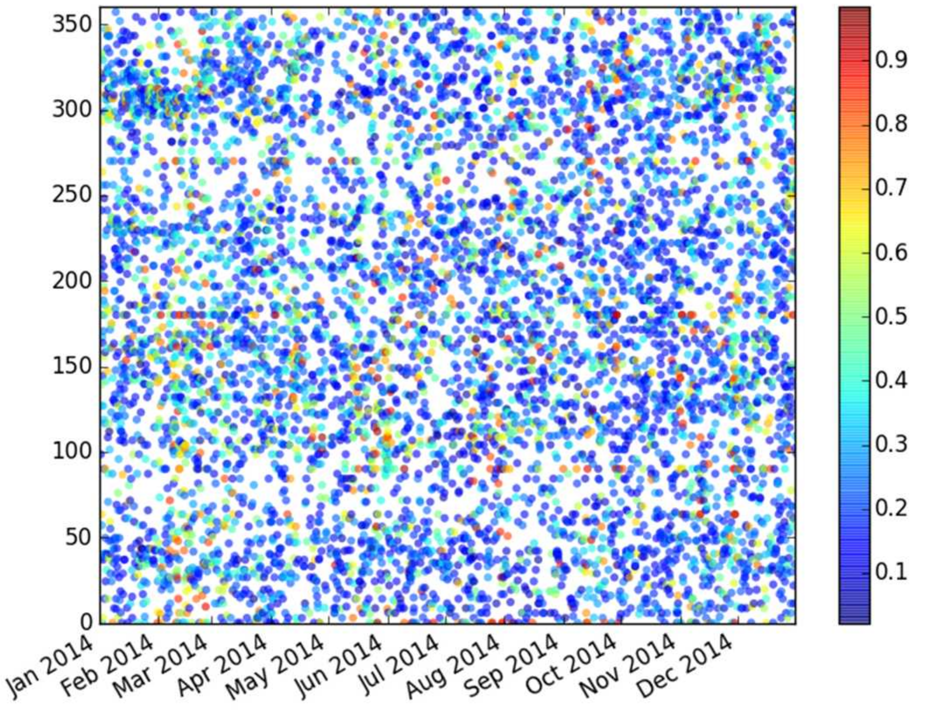
In many cases we have waveform data but no metadata

FK Results

I31KZ: 0.5 – 3 Hz



I31KZ: 0.01 – 0.5 Hz



Detection Results

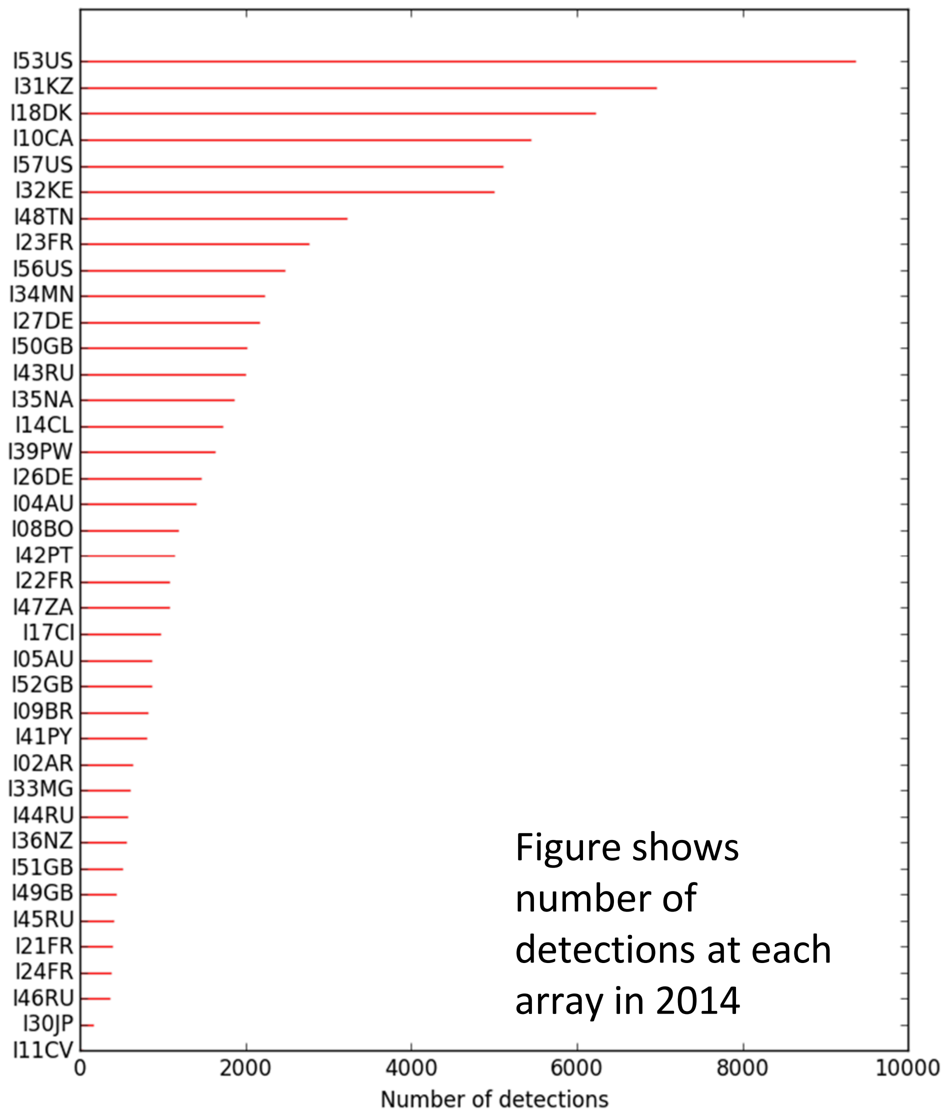
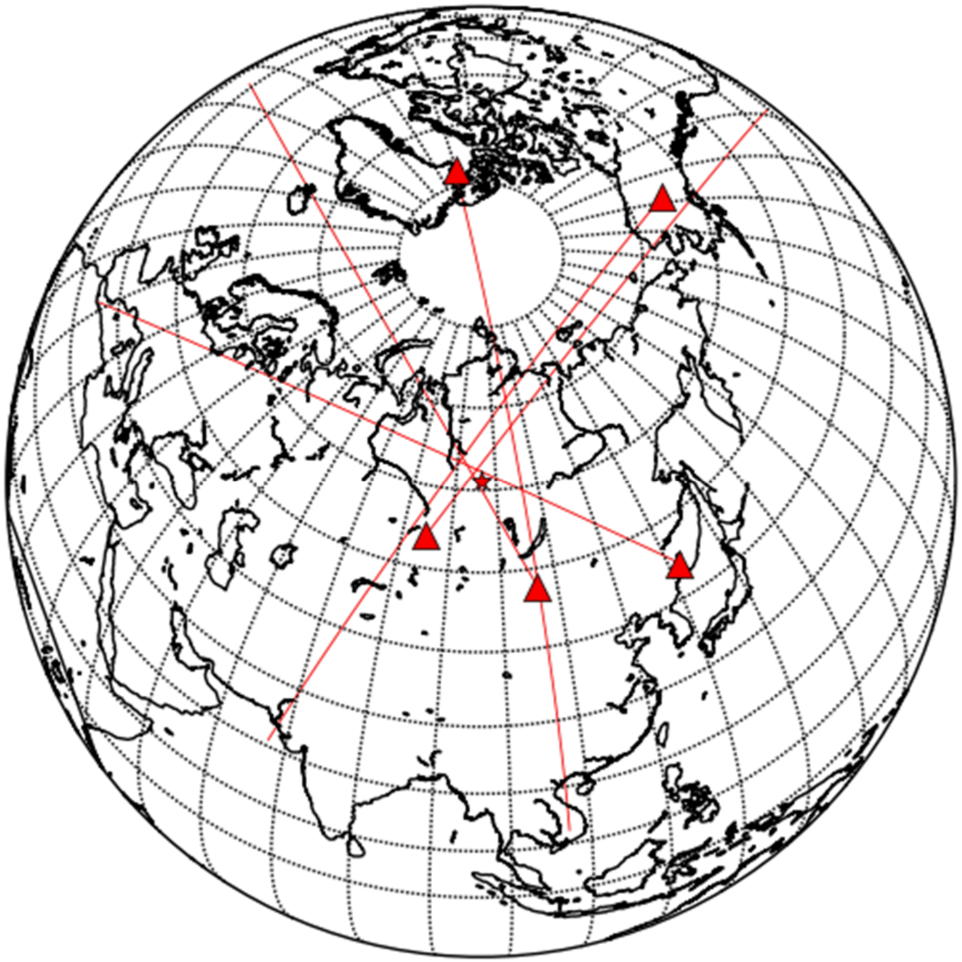
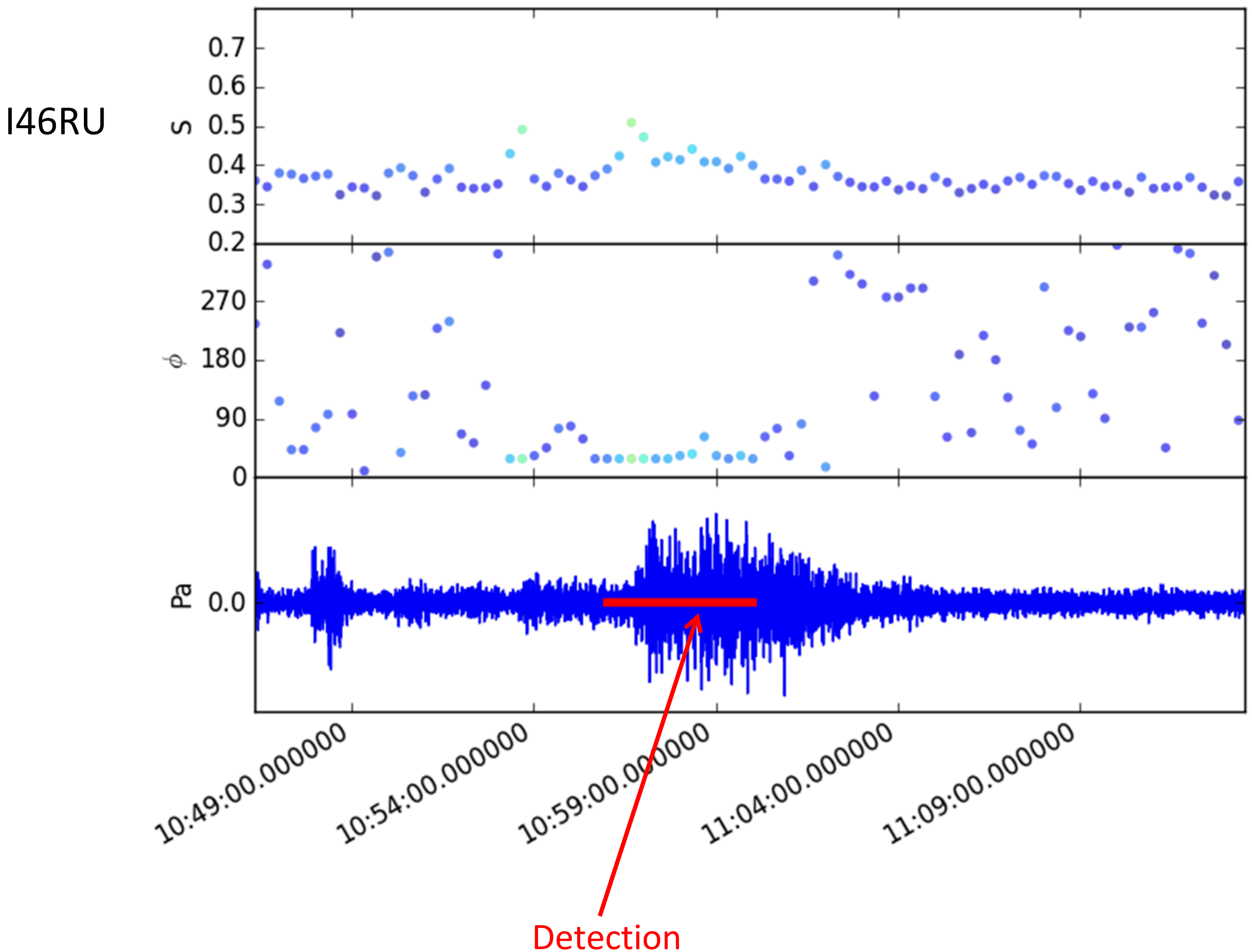


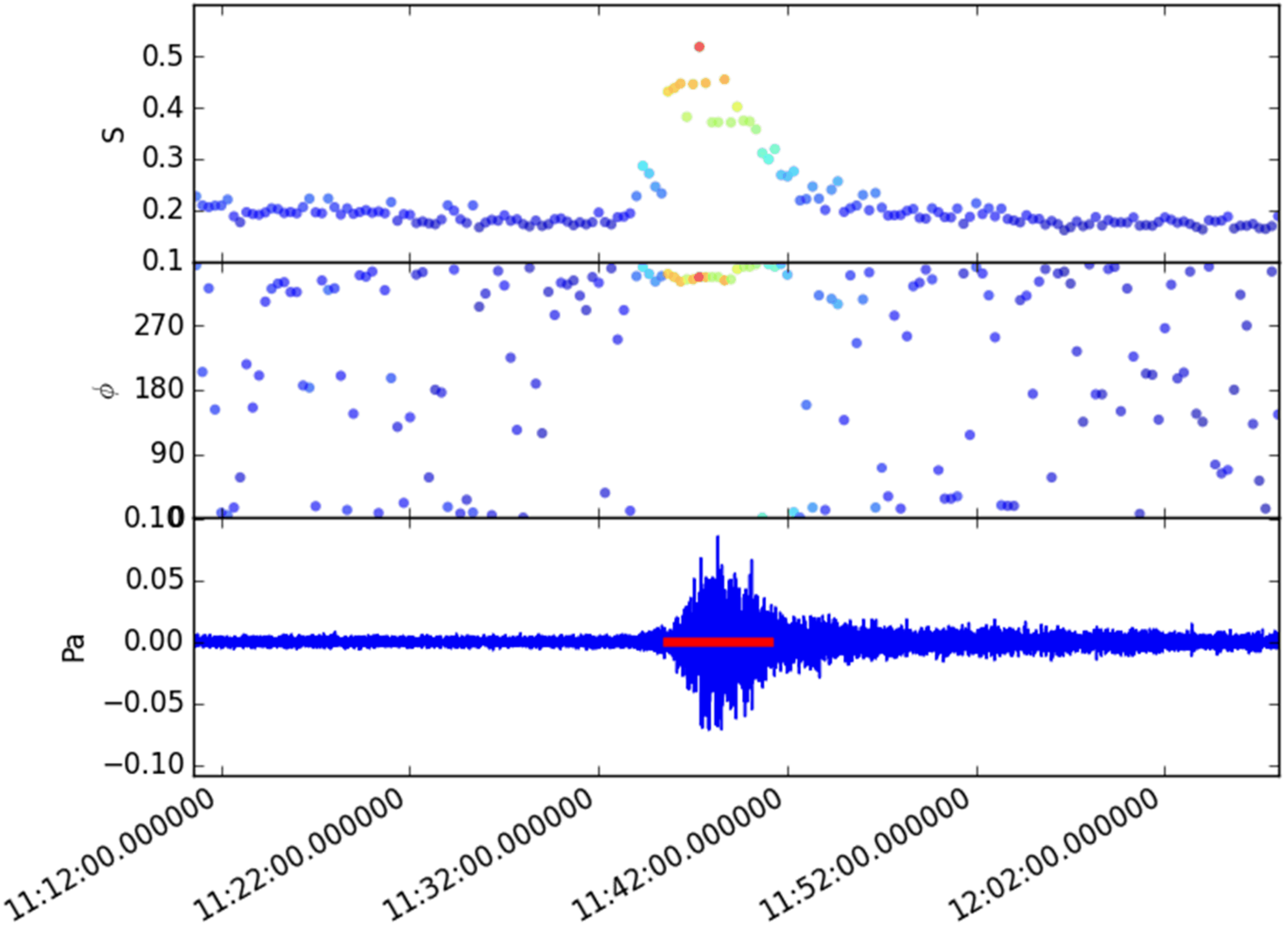
Figure shows number of detections at each array in 2014

Example Event 1



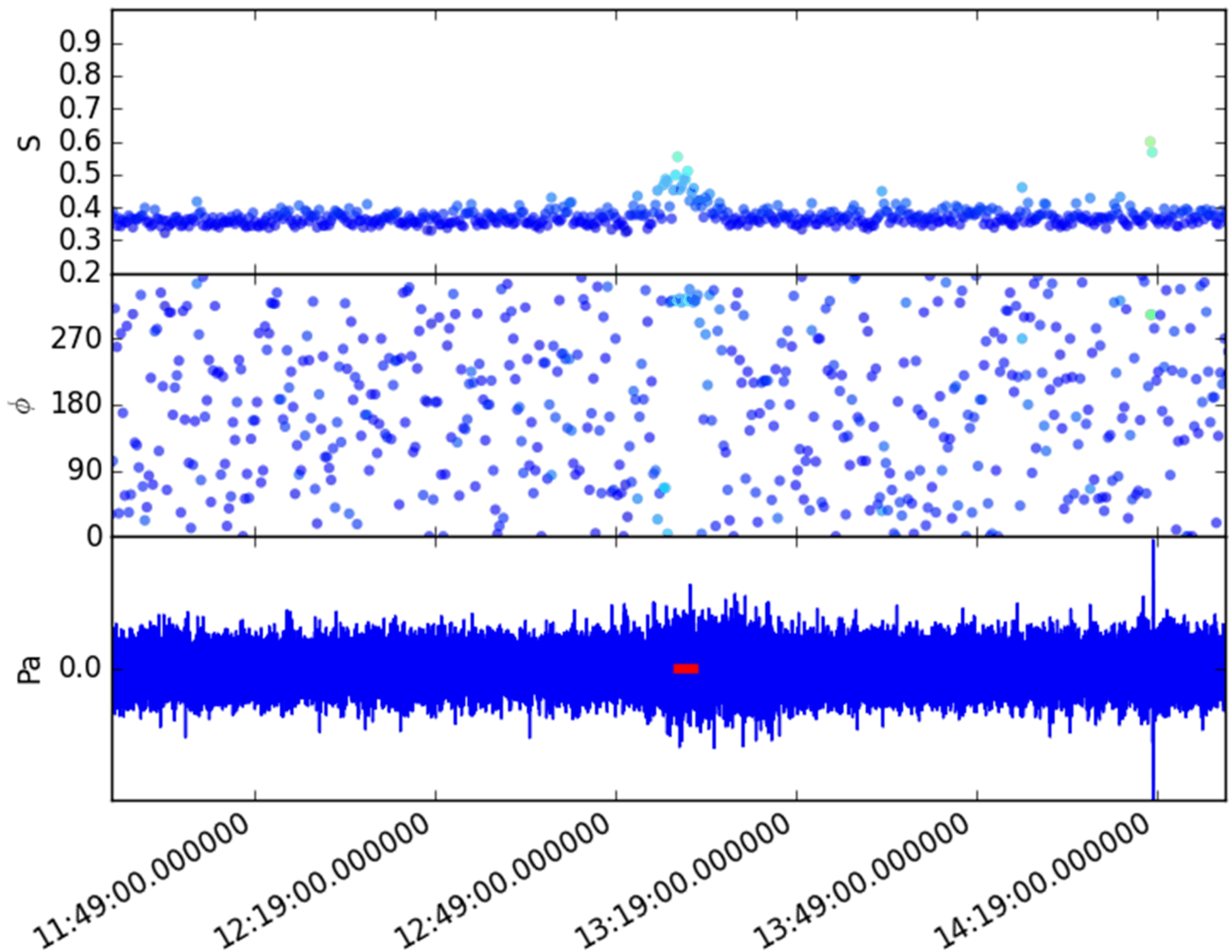

I46RU
S
0.7
0.6
0.5
0.4
0.3
0.2
ϕ
270
180
90
0
Pa
0.0
10:49:00.000000
10:54:00.000000
10:59:00.000000
11:04:00.000000
11:09:00.000000
Detection

I34MN

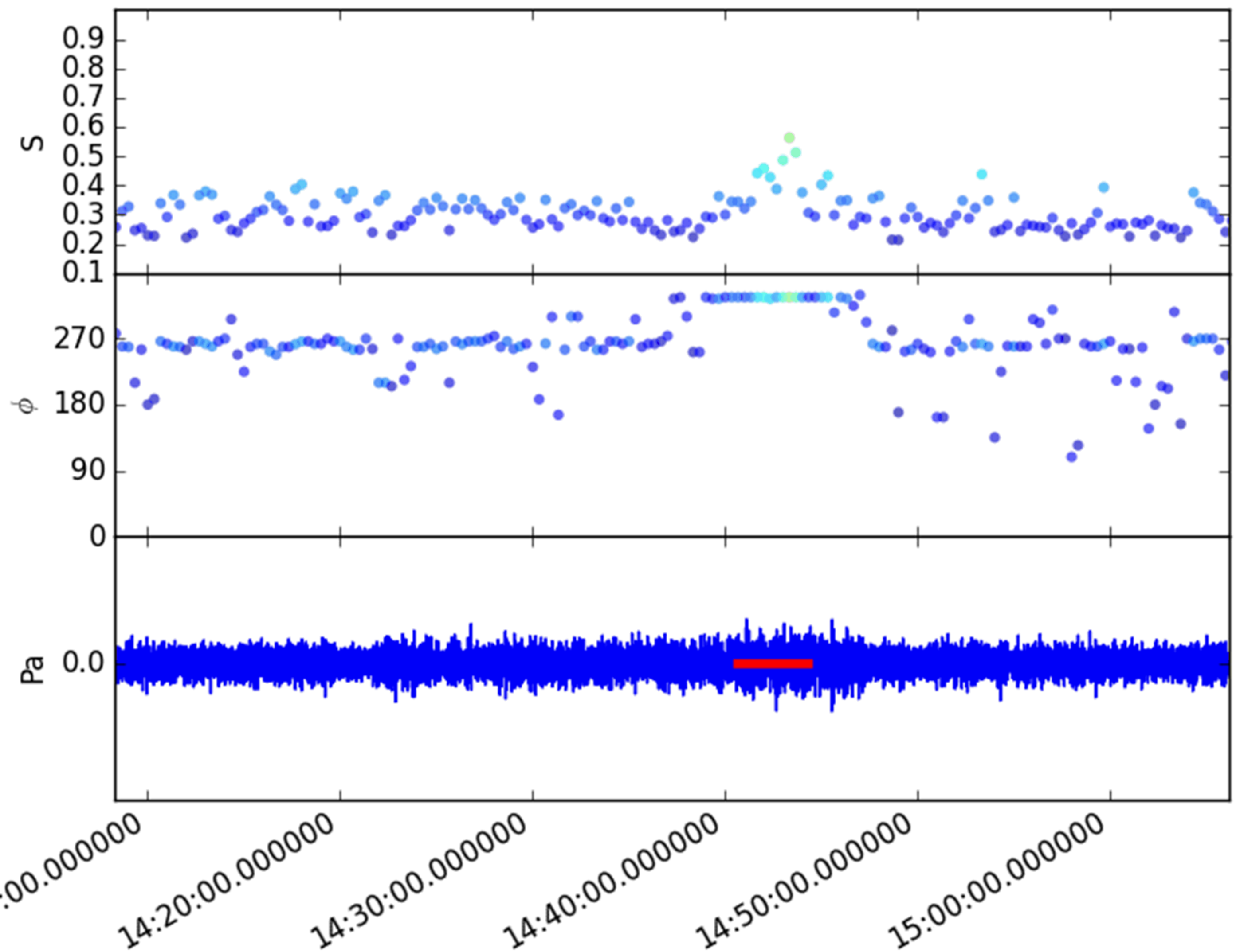


S
0.5
0.4
0.3
0.2
0.1
ϕ
270
180
90
0.10
0
Pa
0.05
0.00
−0.05
−0.10
11:12:00.000000
11:22:00.000000
11:32:00.000000
11:42:00.000000
11:52:00.000000
12:02:00.000000

I45RU

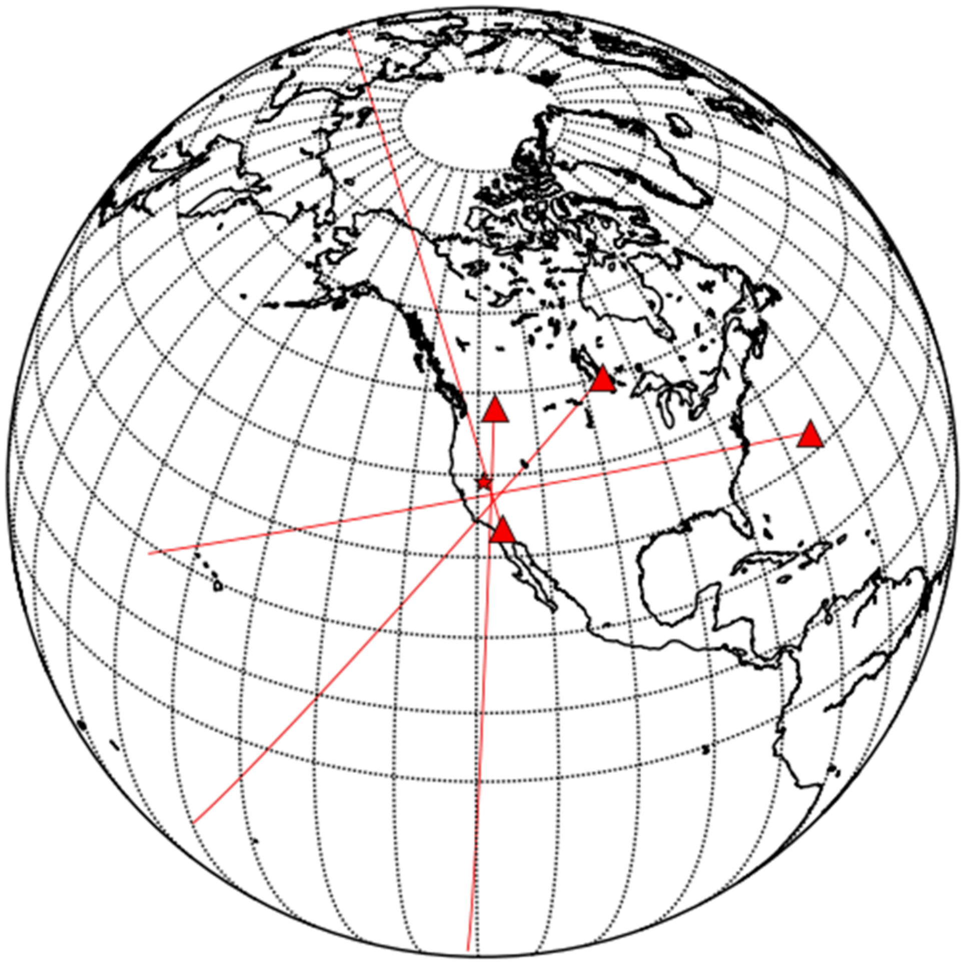

S
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
ϕ
270
180
90
0
Pa
0.0
11:49:00.000000
12:19:00.000000
12:49:00.000000
13:19:00.000000
13:49:00.000000
14:19:00.000000

I53US



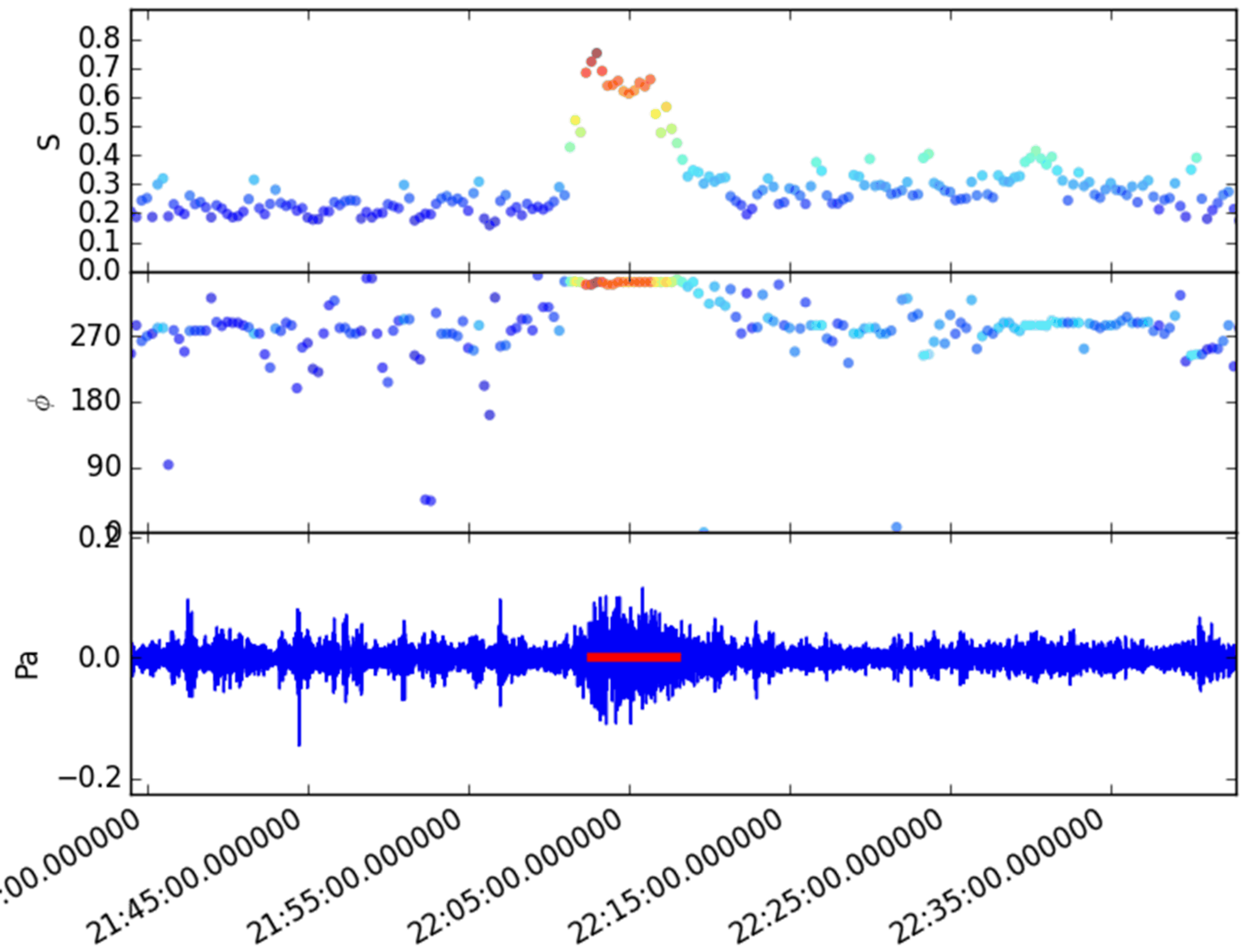
S
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
ϕ
270
180
90
0
Pa
0.0
14:10:00.000000
14:20:00.000000
14:30:00.000000
14:40:00.000000
14:50:00.000000
15:00:00.000000

Example event 2



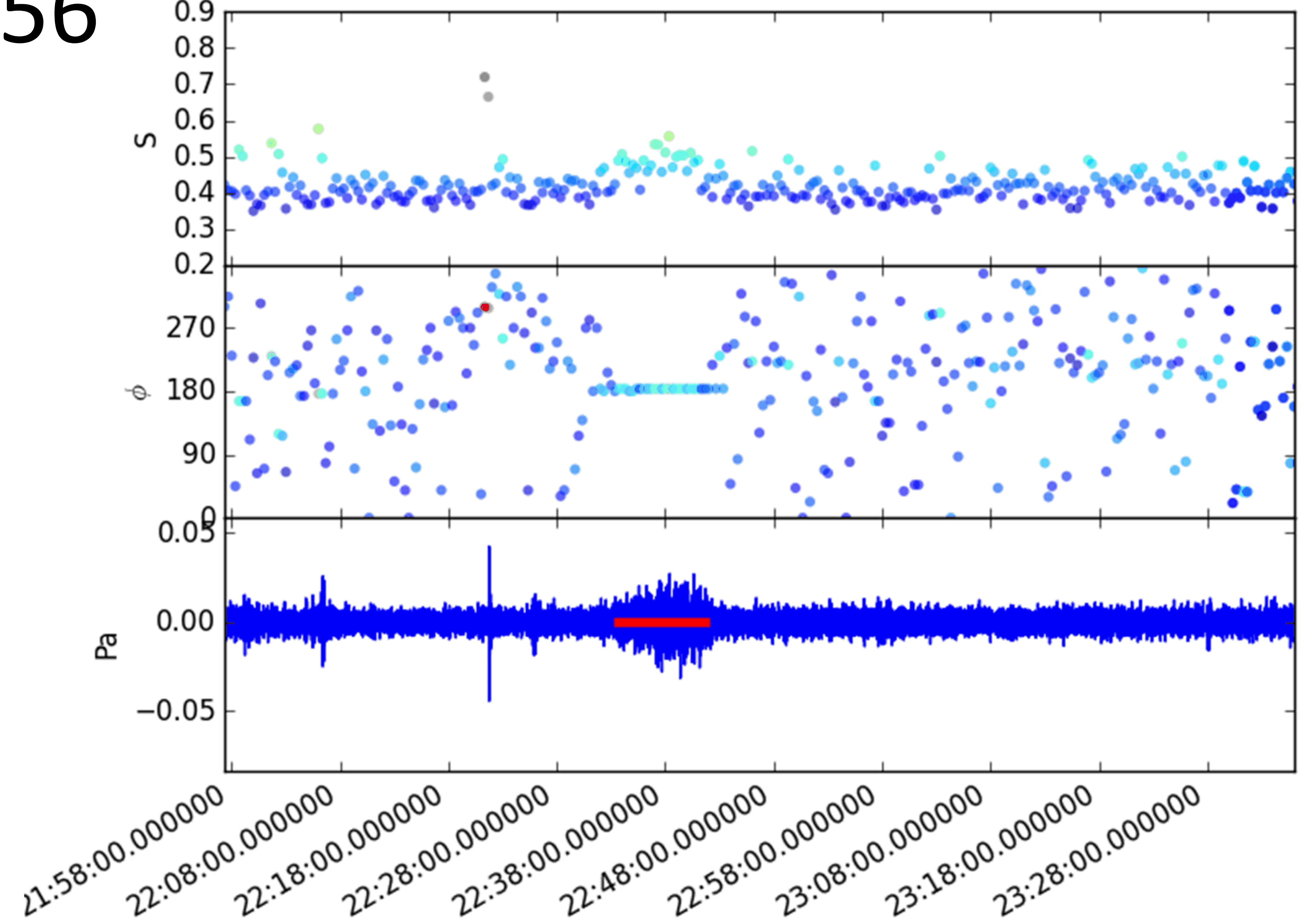
Only 2-array association in LEB

I57



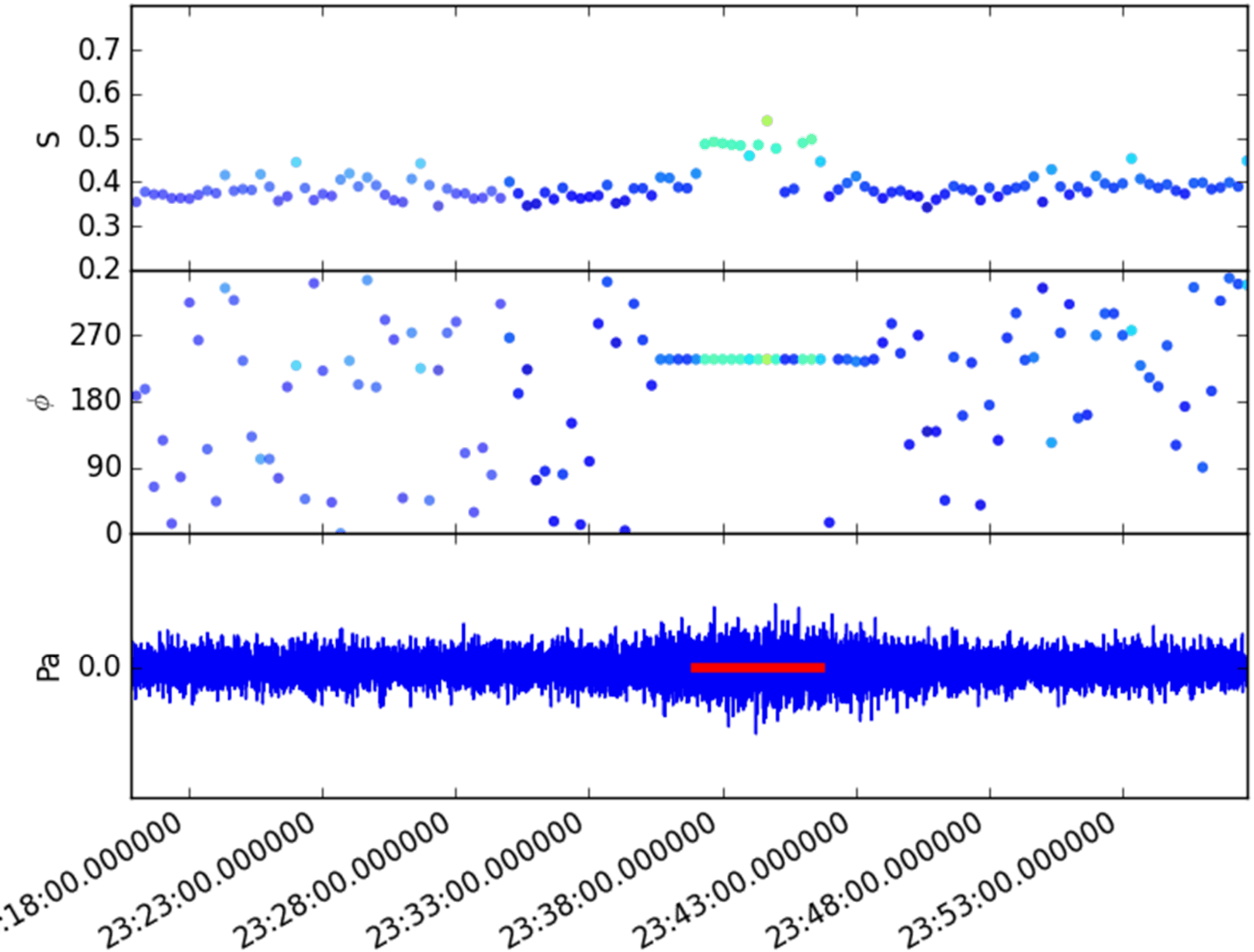
S
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
ϕ
270
180
90
0
Pa
0.2
0.0
−0.2
21:35:00.000000
21:45:00.000000
21:55:00.000000
22:05:00.000000
22:15:00.000000
22:25:00.000000
22:35:00.000000

I56



S
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
ϕ
270
180
90
0
Pa
0.05
0.00
−0.05
21:58:00.000000
22:08:00.000000
22:18:00.000000
22:28:00.000000
22:38:00.000000
22:48:00.000000
22:58:00.000000
23:08:00.000000
23:18:00.000000
23:28:00.000000

I10



S
0.7
0.6
0.5
0.4
0.3
0.2
ϕ
270
180
90
0
Pa
0.0
23:18:00.000000
23:23:00.000000
23:28:00.000000
23:33:00.000000
23:38:00.000000
23:43:00.000000
23:48:00.000000
23:53:00.000000