

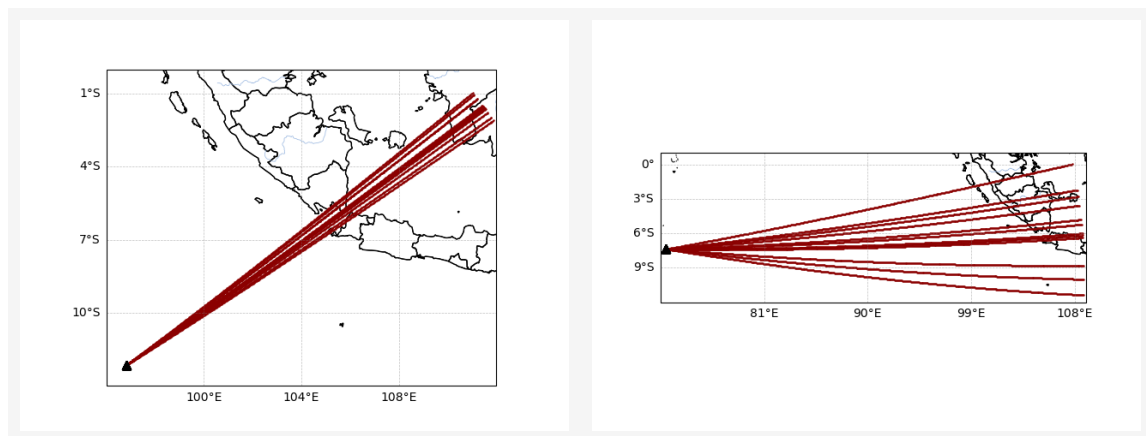
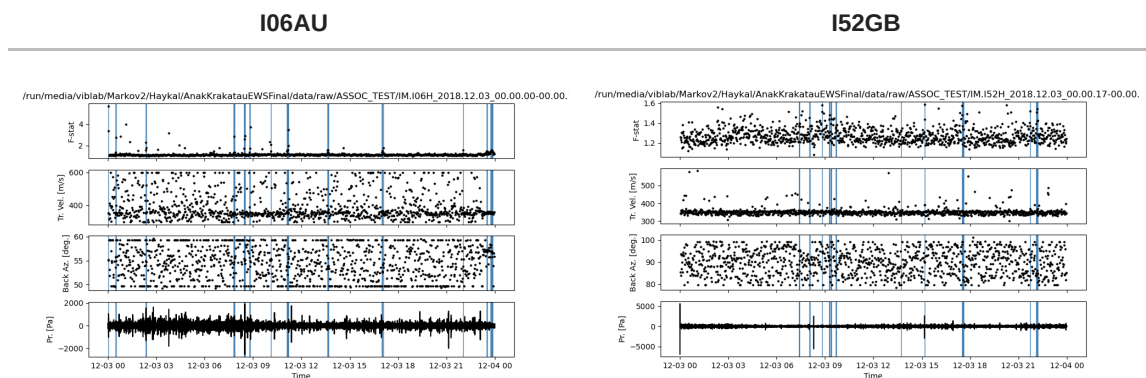
Beamforming & AFD

Beamforming, a form of array processing, is the first step in the analysis of data from infrasonic arrays. Conventional beamforming methods (Bartlett, Capon) separate coherent and incoherent parts of a signal through the assumption of planar waves arriving at the array. A signal backazimuth and slowness can be estimated as signals are shifted to account for travel time differentials across array elements, bringing the signal into phase across as the noise destructively cancels out. In the classical, or Bartlett methodology, data records on each array element are time-shifted versions of the other with local noise,

InfraPy uses an Adaptive Fisher-Detector (AFD) for identifying detections in the beamforming results. The standard F-detector is based on decision rules for the F-statistic, which provides an estimate of the signal's beam power and is calculated as the power in the beam divided by the average over all channels of the power difference between the beam and the individual channels cite{Blandford:1982}. The AFD accounts for both correlated and uncorrelated noise through an increase in the value of the F-statistic required to declare a detection based upon background F-values being elevated from coherent or persistent noise sources. The figure below illustrates how the AFD remaps the F-statistic through the application of a C-value, which effectively reduces the detection threshold (p-value) and decreases the number of noise-related detections.

```
In [ ]: # I06AU
!infrapy run_fk --local-wvfrms '/run/media/viblab/Markov2/Haykal/AnakKrakatauEWSFinal/data/raw/ASSOC_TEST/IM.I06H_2018.12.03.00.00.00.00.00'
```

```
In [ ]: # I52GB
!infrapy run_fk --local-wvfrms '/run/media/viblab/Markov2/Haykal/AnakKrakatauEWSFinal/data/raw/ASSOC_TEST/IM.I52H_2018.12.03.00.00.17.00.00.00'
```



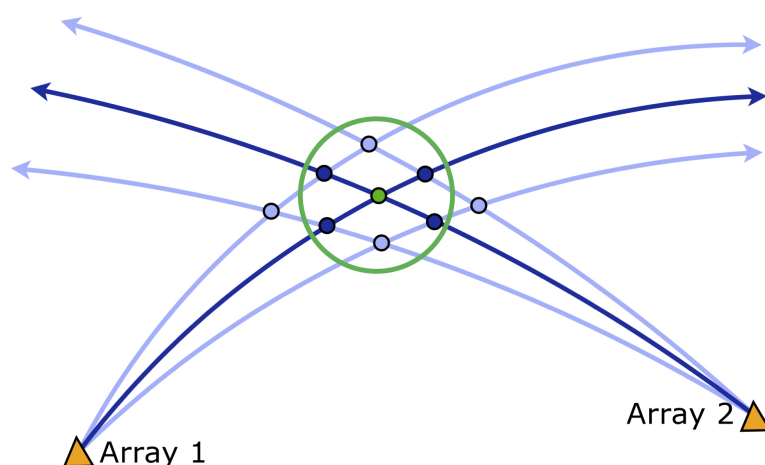
Association

InfraPy uses a pair-based, joint-likelihood method to identify those detection sets with high likelihood of originating from a common source. Events are identified using a pair-based Bayesian algorithm that defines the association between detection pairs from their joint-likelihood and identifies events via hierarchical clustering analysis

- The current implementation utilizes only spatial and temporal coincidence, but additional detection information can further improve event identification
- Evaluation using a synthetic data set has shown some mixing of spatially similar events poorly resolved by network geometry and occasional inclusion of "noise" detections in event clustering

Integration Region Analysis

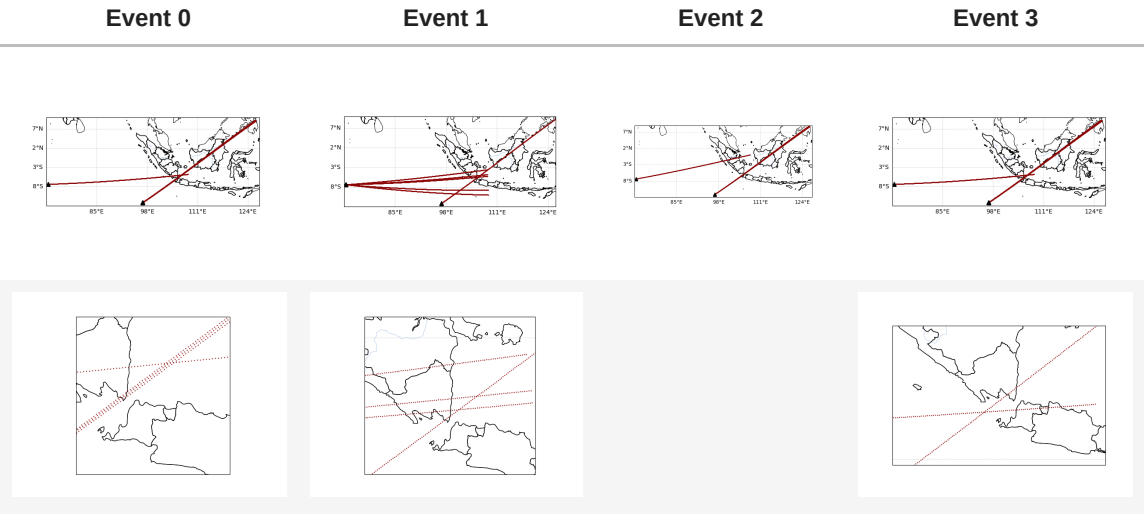
The joint-likelihood calculation used to quantify the probability that a pair of detections originated from a common source includes a pre-computation step to identify an integration region for the joint-likelihood. The identification of this integration region can be complicated and is controlled by several parameters in InfraPy. Consider the figure below showing a pair of detecting infrasound arrays (orange triangles). The direction-of-arrival information from beamforming (fk) analysis is used to compute a back projection from each station out some maximum distance to identify intersections. In InfraPy, this projection distance is controlled by `range_max` parameter (`--range-max` on the CLI). In addition to this maximum projection range, the integration region analysis is dependent on the lighter blue projections that bound the central great circle path. These bounding projections are defined by the `back_az_width` parameter (`--back-az-width` on the command line). These values default to 2000 km and $\pm 10^\circ$ and are intended for regional analysis. In the case of local or global scale analysis, the maximum range should be modified to be 10's of km or 1000's of km, respectively, depending on the likely source-receiver ranges.



```
In [ ]: !infrapy run_assoc --local-detect-label '/run/media/viblab/Markov2/Haykal/Ar
```


Cleaning up and merging clusters...

Identified 4 events.



Event 3

Time (UTC)	["F Stat."]	["Trace Vel. (m/s)"]	Start	End	Freq Range[0]	Freq Range[1]	Method	Event	Network
2018-12-03T13:38:45.500000	1.5761	364.22	-150.0	150.0	0.7	4.0	bartlett	3	IM
2018-12-03T15:10:35.300000	1.5901	390.72	0.0	75.0	2.0	10.0	bartlett	3	IM

Localization

Event analysis in InfraPy uses the Bayesian Infrasonic Source Localization (BISL) methodology to estimate both the spatial location of the event as well as the origin time with quantified uncertainty. Preliminary analysis of the back projections can be used to define the spatial region of interest. The analysis identifies the maximum posteriori solution and also marginalizes a subset of the parameters to produce spatial and temporal distributions for the source. Likelihood definitions relating detection parameters to spatial and temporal source characteristics are shared between association and localization analysis for consistency.

```
In [ ]: !infrapy run_loc --local-detect-label '/run/media/viblab/Markov2/Haykal/Anal
```

```
#####
##                               ##
##           InfraPy           ##
##       Localization Analysis   ##
##                               ##
#####
```

Data summary:

```
local_detect_label: /run/media/viblab/Markov2/Haykal/AnakKrakatauEWSFinal/data/raw/ASSOC_TEST/Assoc_Results/Event_Population_2/assoc_out_2-ev3.dets.json
local_loc_label: /run/media/viblab/Markov2/Haykal/AnakKrakatauEWSFinal/data/raw/ASSOC_TEST/Assoc_Results/Event_Population_2/Local_ev3
```

Parameter summary:

```
back_az_width: 10.0
range_max: 4000.0
resolution: 180
src_est: [-6.102, 105.423, 300.0]
```

Loading detections from file: /run/media/viblab/Markov2/Haykal/AnakKrakatauEWSFinal/data/raw/ASSOC_TEST/Assoc_Results/Event_Population_2/assoc_out_2-ev3.dets.json

Running Bayesian Infrasonic Source Localization (BISL) Analysis...

```
Identifying integration region...
Computing marginalized spatial PDF...
Computing confidence ellipse parameters...
Computing marginalized origin time PDF...
```

BISL Summary:

Maximum a posteriori analysis:

```
Source location: -2.836, 104.959
Source time: 2018-12-03T12:06:37.955000
```

Source location analysis:

```
Latitude (mean and standard deviation): -4.801 +/- 104.877 km.
Longitude (mean and standard deviation): 105.654 +/- 137.217 km.
Covariance: -0.121.
Area of 95 confidence ellipse: 270877.003 square kilometers
```

Source time analysis:

```
Mean and standard deviation: 2018-12-03T12:09:33.050000 +/- 553.078
second
```

```
Exact 90% confidence bounds: [2018-12-03T11:54:06.387000, 2018-12-03T12:23:58.157000]
```

Writing localization result into /run/media/viblab/Markov2/Haykal/AnakKrakatauEWSFinal/data/raw/ASSOC_TEST/Assoc_Results/Event_Population_2/Local_ev3.loc.json

Event 0

Event 3

