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InfraPy
An open-source signal analysis toolkit for infrasound research

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Overview

Infrasound researchers at Los Alamos National Laboratory have been actively developing and evaluating signal analysis tools for detecting, associating, localizing, and further analyzing infrasonic signals and sources. The algorithms developed during these efforts have been combined into a suite of Python libraries and recently made available as an open-source software toolkit. The detection methods are based on adaptive Fisher detection methods previously developed for inclusion in the InfraMonitor tool, while the association, localization, and yield estimation methods leverage Bayesian algorithms and statistical propagation models to accurately identify and analyze infrasonic events. A number of interface options have been developed including a command line interface (CLI) for large-scale, batch processing and a graphical user interface (GUI) for interactive analysis of infrasonic data.

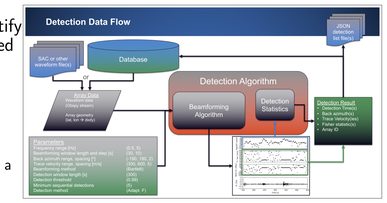
Analysis Algorithms

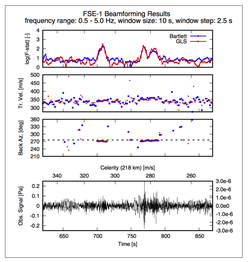
Analysis Overview

- Analysis methods are modular so that results from other tools can be used in at later analysis steps (e.g., detections from PMCC analyzed using InfraPy association or localization)
- Algorithms are written to be data agnostic so analysis can be performed regardless of data source once IO method is established
- Time series and detection objects can be populated from database or local files, and results can be written with the same options

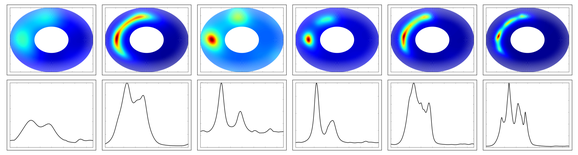
Detection

- Array processing to identify detections is accomplished in two step process:
  - Beamform to estimates parameters of coherent signals
  - Adaptive Fisher statistics determine when to declare a detection



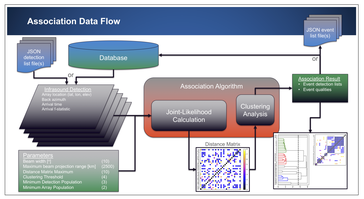


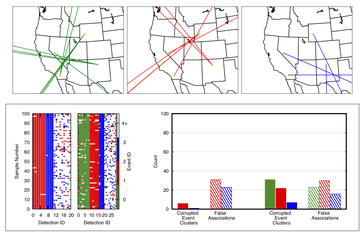
- Beamforming capabilities include methods for transient and persistent signals
- Transient signals are identifying using standard Bartlett beaming
  - Active research investigating the use of Generalized Least Squares (GLS) analysis to adaptively account for noise covariance
- Persistent signals can be investigated using Minimum Variance Distortionless Response (MVDR) or MUltiple Signal Classification (MUSIC) algorithms



Association

- Events are identified using a pair-based Bayesian algorithm that leverages joint-likelihood between detection pairs from their and identifies events via hierarchical clustering

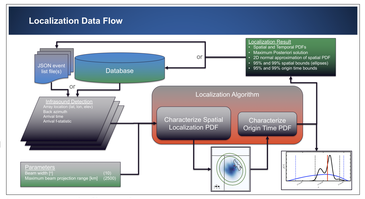




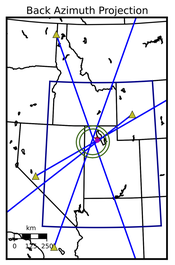
- Current implementation utilizes only spatial/temporal coincidence, but additional information will improve event identification
- Evaluated using a synthetic data set to quantify performance at regional distances

Localization

- Event analysis uses the Bayesian Infrasonic Source Localization (BISL) to estimate the spatial location of the event as well as the origin time with quantified uncertainty

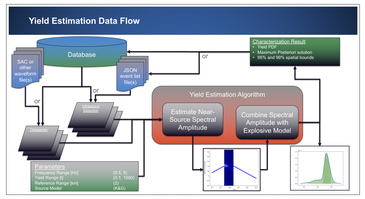


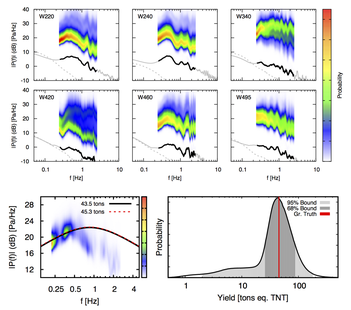
- Analysis of the back projections can define the spatial region of interest or it can be specified
- BISL analysis identifies:
  - maximum posteriori solution
  - marginalized spatial distribution with 95 and 99% confidence ellipse bounds (approximated as 2d-normal)
  - marginalized temporal distribution with exact 95 and 99% confidence bounds
- Likelihood definitions are shared between association and localization analysis for consistency



Yield Estimation

- Bayesian spectral yield estimation (SpYE) has been investigated that estimates near-source spectra from regional observations and marginalizes against an explosive model for yield



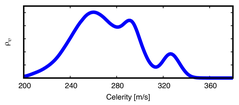


- Preliminary evaluation against surface explosions found the method able to estimate accurate explosive yield for the source but the source model can be improved
- Models for non-explosive sources are being investigated to extend the applicability of the method
- This algorithm is not implemented as part of the current InfraPy release, but will be included in a future version
- The Friedlander waveform and Kinney & Graham parameterization utilized here may be added to the suite as part of a set of source models or may be implemented as a stand alone tool

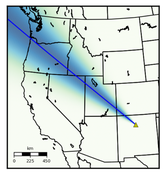
Propagation Models

General Models

- A set of general propagation models for celerity (horizontal group velocity) and azimuth projection have been defined for use in the association and localization analyses



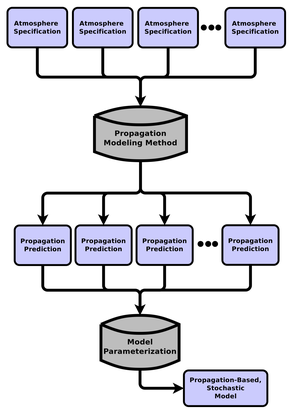
- A Gaussian mixture model (GMM) is defined in terms of inverse celerity
  - Three components of the GMM correspond to typical tropospheric (327 m/s), stratospheric (293 m/s), and thermospheric (260 m/s) celerities
  - The GMM is defined in terms of inverse celerity, $\nu^{-1} = \frac{\delta t}{r}$, so that marginalization of the event origin time can be completed analytically

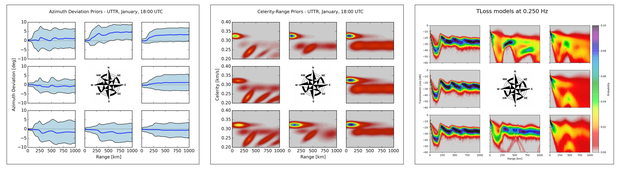


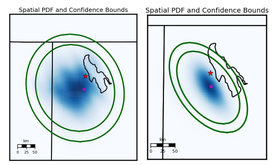
- Back azimuth projection is completed using the von Mises distribution commonly utilized in directional statistics to account for the finite bound of azimuth values
- The beamwidth is defined from the detection quality (Fisher statistics, SNR, coherence, or other measure) and provides a means to weight higher quality detections more heavily

Propagation-Based Stochastic Models

- Propagation-based, stochastic models for path geometry have been investigated as a means of improving localization estimates
  - Propagation range and celerity as well as back azimuth bias and variance are quantified by large scale ray tracing simulation campaigns using archived atmospheric specifications
  - Models are defined for specific locations and seasons (e.g., the western US during winter)
- Similarly constructed transmission loss models were developed for use in the estimation of near-source spectral amplitude in the yield estimation methodology







- Preliminary evaluation of the methods using surface explosions in the western US as ground truth found that propagation-based, stochastic path geometry models reduced the area of the confidence ellipses for spatial localization estimates by 25 – 40%
- Research is ongoing to develop a means of constructing semi-empirical models combining observed infrasonic signals from known sources with propagation predictions using archived atmospheric specifications
- Preliminary investigations have been made into defining a specific set of atmospheric states needed to construct a high precision model for an event of interest

Interface Options

Scripting Interface

- The algorithms in InfraPy can be directly accessed in a Python script for prototyping
- Similarly, algorithms can be accessed in a Python interpreter or notebook for rapid analysis of local data

```
from infrapy.association import hjl
from infrapy.propagation import likelihoods as lkhds

# Read in detections and define run parameters...
det_list = lkhds.json_to_detection_list('data/detection_set1.json')
width = 10.0
rng_max = 2500.0
dist_max = 10.0
threshold = 4.0

# Run Hierarchical Joint-Likelihood (HJL) association...
dists = np.array(hjl.build_distance_matrix(det_list, bm_width=width, rng_max=rng_max))
dists[dists > dist_max] = dist_max

# Run clustering...
links, labels, sorted_dists = hjl.cluster(dists, threshold)

# Summarize clusters...
hjl.summarize_clusters(labels, dists)
```

Command Line Interface (CLI)

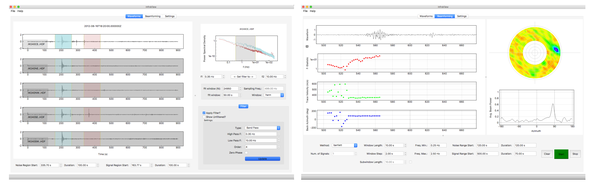
- Large batch processing work can more easily be accomplished using the command line interface (CLI) to define parameters and run analysis
- Waveform or detection data from a database (Oracle, SQLite, etc.) can be accessed and analyzed quickly and results written back into the database
- For this and other database interaction, InfraPy uses the Pisces tool and a modified CSS 3.0 schema

```
[GeneralParams]
database=sqlite:///example.sqlite
year=2019
dayofyearini=1
dayofyearend=2
station=array1
name=example
sitetable=None
wfdisctable=None

[DetectParams]
filtertype=bandpass
minfreq=0.1
maxfreq=1.0
beamwinlen=30
beamwinstep=10
minbackaz=180.0
maxbackaz=180.0
stepbackaz=3.0
mintrvel=300.0
maxtrvel=600.0
steptrvel=5.0
beammethod=barlett
detwinlen=600
detthresh=0.99
detmethod=adaptf
numcores=10
name=det example
detresults=det.example
```

Graphical User Interface (GUI) - InfraView

- A graphical user interface (GUI) has been developed for interactive waveform viewing and detection analysis
- Spectral features of a noise and signal window can be compared to identify time windows and frequency bands for analysis
- Transient and persistent signals can be identified using the beamforming analysis and written to local (json) files or into a database



Summary

- The InfraPy toolkit provides **state-of-the-art algorithms** for infrasonic signal analysis including detection, association, and localization
- The association and localization methodologies leverage **physically informed propagation models** to produce high precision, accurate estimates for events
- InfraPy methods can be accessed through a number of **interfaces** include directly in Python notebooks, the command line or an interactive GUI.
- InfraPy and other LANL software tools can be downloaded from github.com/LANL-Seismoacoustics

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