LA-UR-16-24234
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Title: InfraPy: Python-Based Signal Analysis Tools for Infrasound

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Intended for: Presentation for EIVR visit with AWE Blacknest (week of June 20th).

Issued: 2016-06-16

InfraPy

Python-Based Signal Analysis Tools for Infrasound

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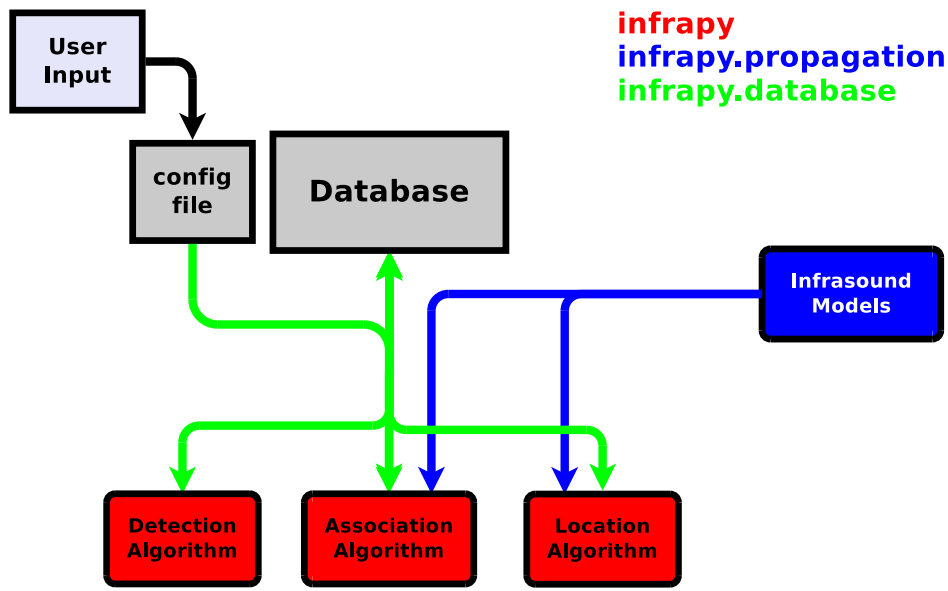
May 31, 2016

Outline

1. Algorithms
   - Array Level
   - Network Level
2. Propagation Models
   - General Models
   - Propagation-Based Stochastic Models
   - Multi-Phenomology Models
3. Usage & Interface
4. Future Plans for InfraPy

Overview

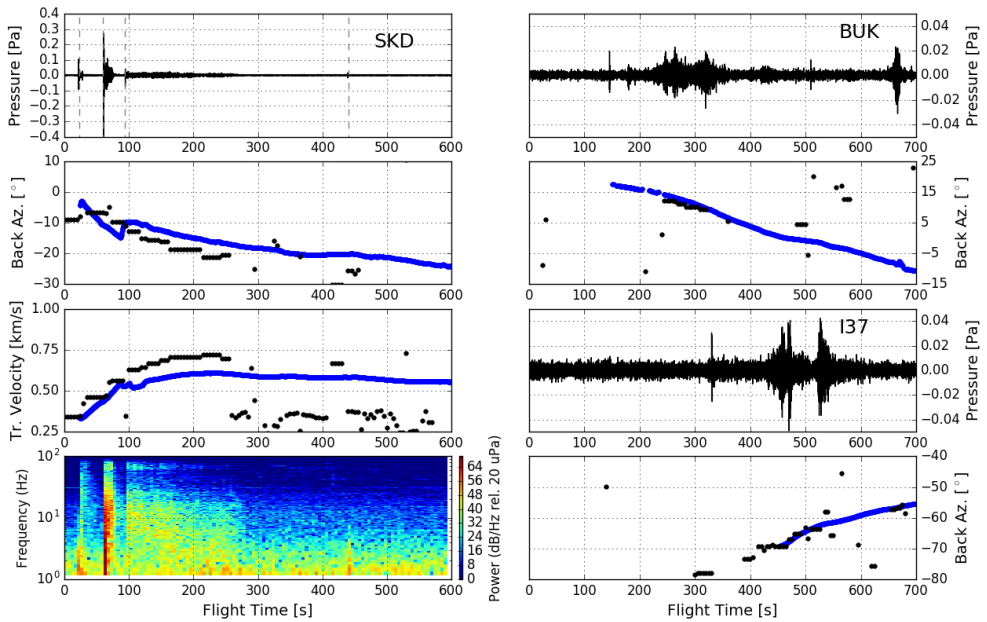
- InfraPy is a Python-based analysis toolkit being development at LANL.
- The algorithms are intended for ground-based nuclear detonation detection applications to detect, locate, and characterize explosive sources using infrasonic observations.
- The implementation is usable as a stand-alone Python library or as a command line driven tool operating directly on a database.

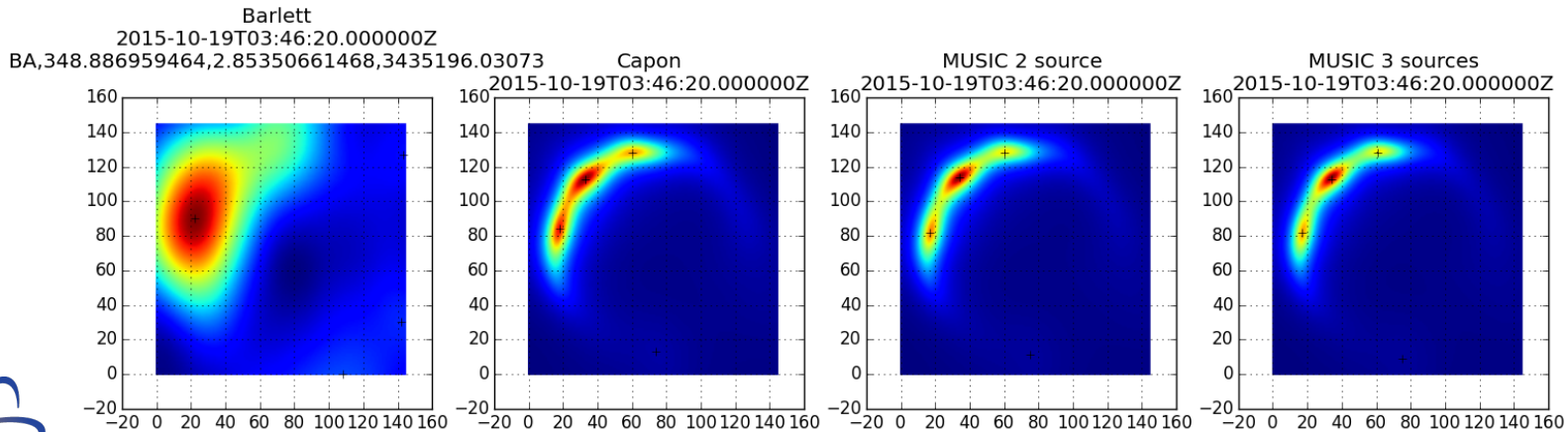


- With multiple scientists working on the project, we've begun using a LANL git repository for collaborative development and version control.

infrapy.detection

- The detection algorithm utilizes an adaptive F-detector to account for variable background noise.
- Current efforts are aimed at improving the beam-forming capabilities to identify multiple signals coincident on an array (microbaroms + transient).





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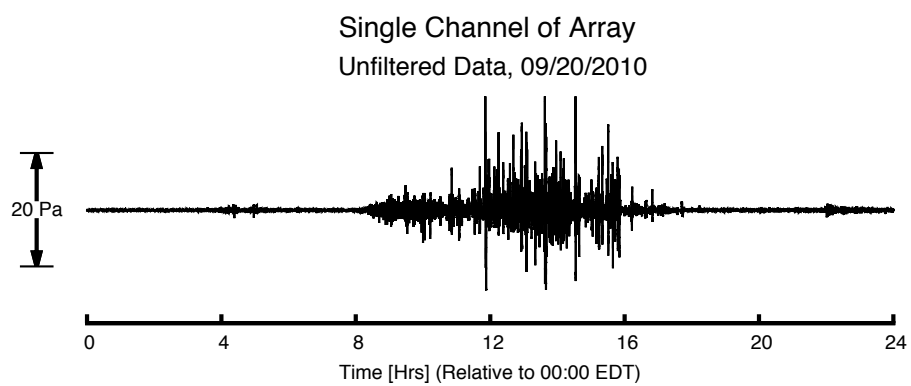
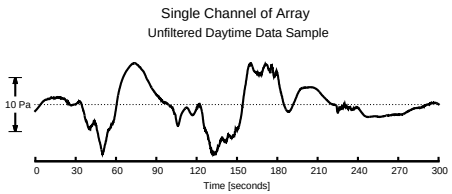
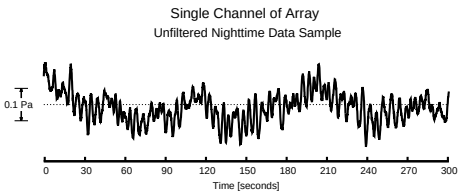
infrapy.soh - Future Development

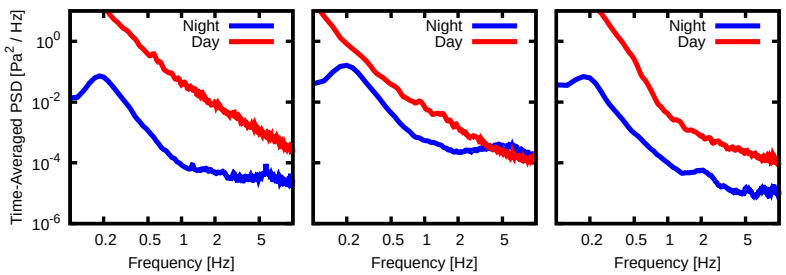
State of Health

- The variable wind noise recorded on a microbarometer can cause significant temporal variability in the background noise.
- Identifying excessively noisy channels on arrays can assist in improving detection capabilities, network/array design, and passively monitor the state of health of an array or network.



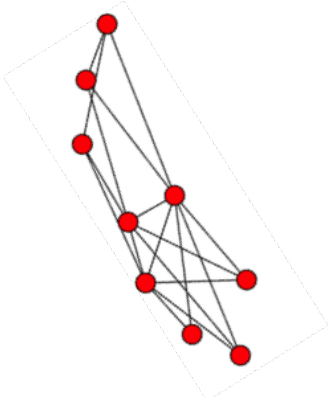


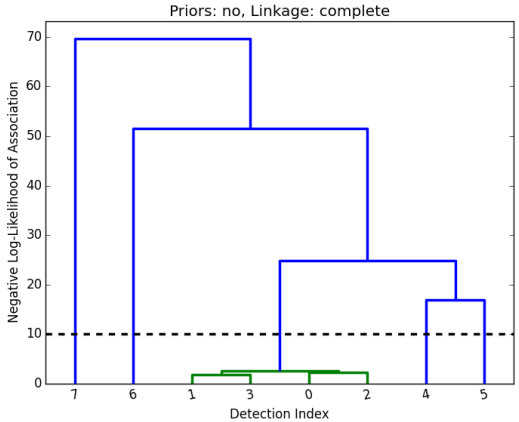


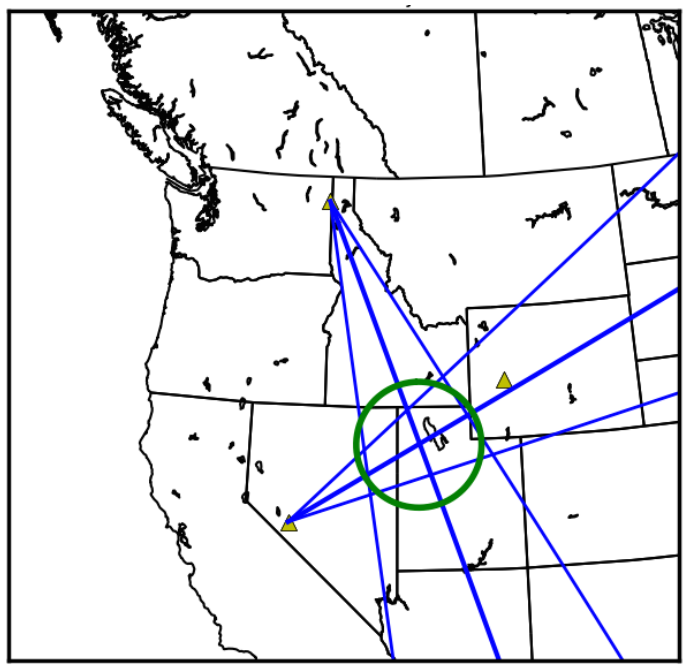


infrapy.association

- Association is based on a Hierarchical Joint-Likelihood (HJL) analysis leveraging cluster analysis methods.
- The propagation model in the likelihood definition leverages those used in the Bayesian Source Localization (BISL) methods.
- Current methods utilize a user-defined region of interest, but work is underway to automatically identify relevant regions for analysis.

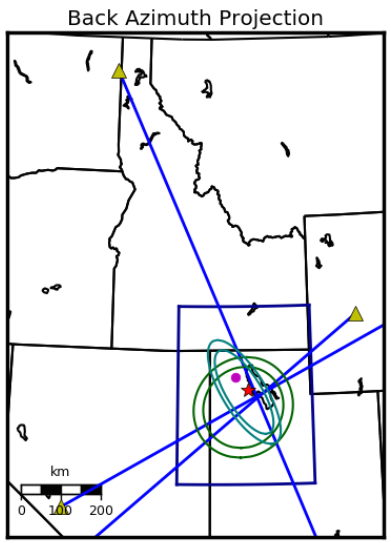


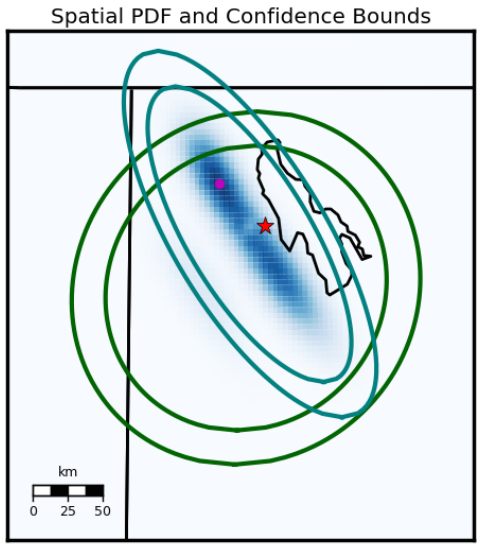


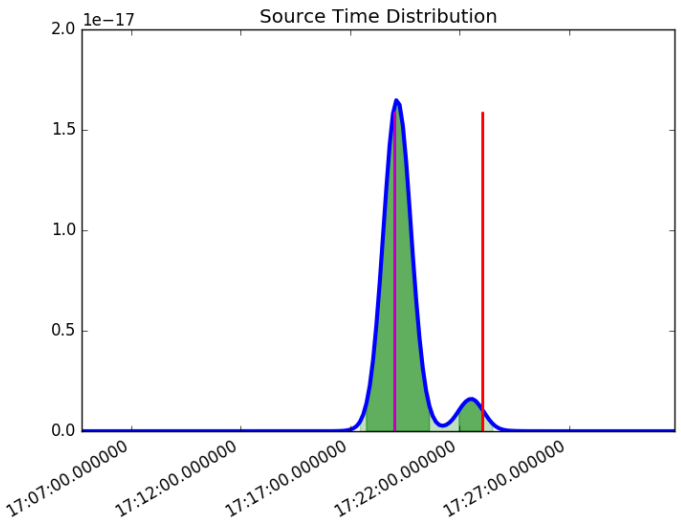


infrapy.localization

- Localization is performed using the Bayesian Infrasonic Source Localization (BISL) method.
- The posterior spatial distribution is fit with a 2-dimensional normal distribution to approximate the 95% and 99% confidence regions
- Exact confidence bounds are identified for the posterior temporal distribution.







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infrapy.characterization - Future Development

Yield Estimation

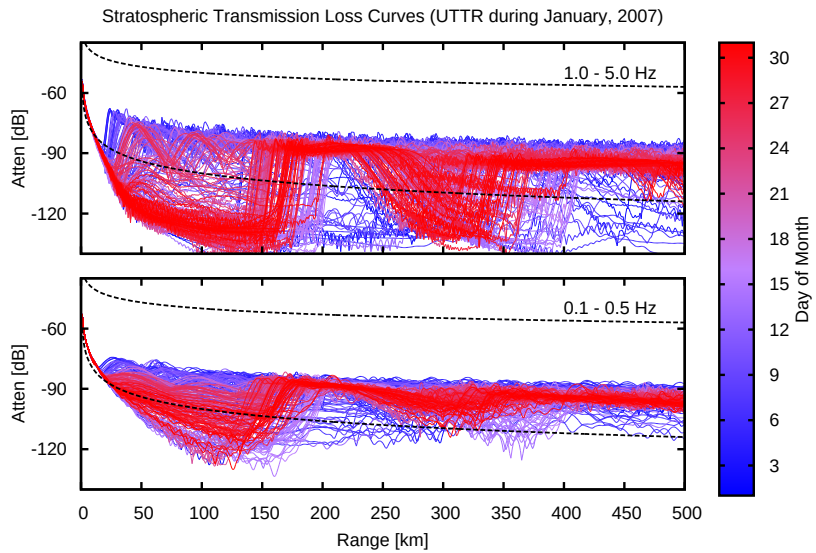
- The presence of infrasonic signals can assist in seismo-acoustic discrimination.
- Infrasonic signals at regional distances (stratospheric and thermosphere) are of a current area of interest for yield estimation.

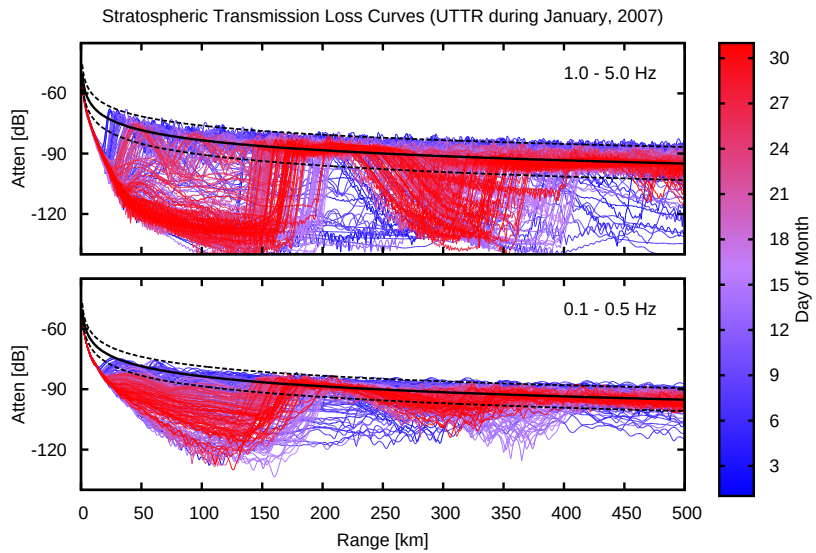
$$\mathcal{P}(r) = \mathcal{P}_0 r^{-\alpha}$$

$\alpha = 1$ for spherical spreading,
$\alpha = \frac{1}{2}$ for cylindrical spreading,

$\alpha = 0.83 \pm 0.07$ for 0.1 – 0.5 Hz,

$\alpha = 0.84 \pm 0.05$ for 1.0 – 5.0 Hz.





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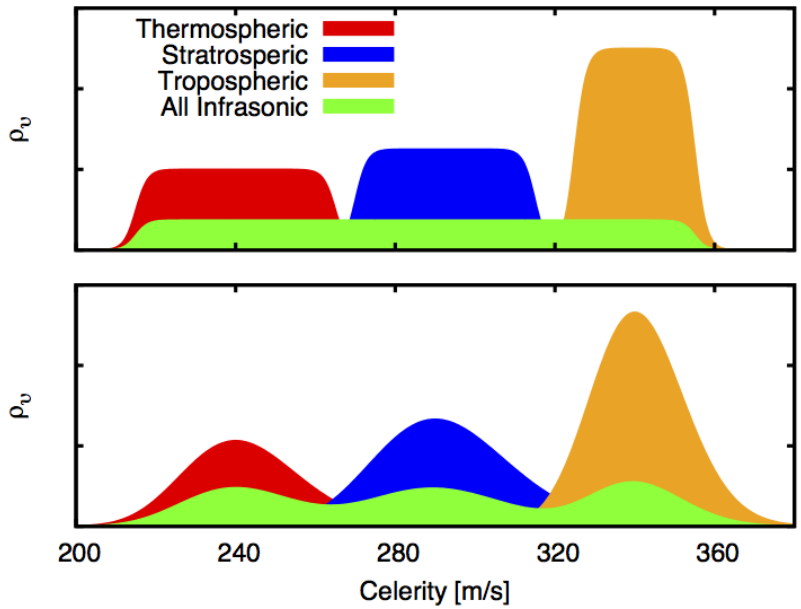
infrapy.propagation.infrasound

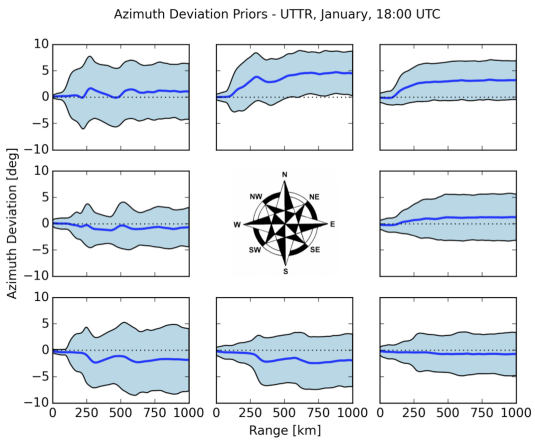
- Infrasonic signals propagate at tropospheric, stratospheric, and thermosphere celerities.
- Initial developments utilized tapered boxcar distributions.
- Recent worked investigated gaussian mixture models in reciprocal celerity for analytic integration of the source time.

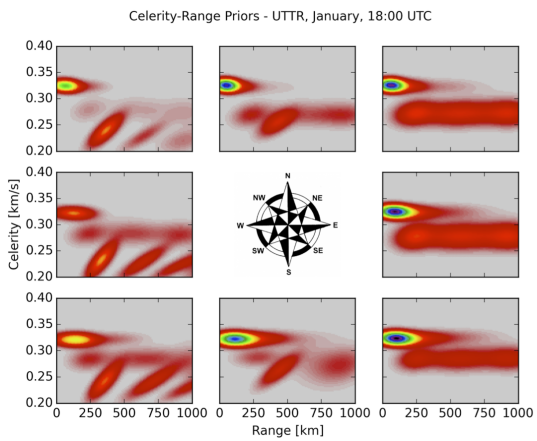


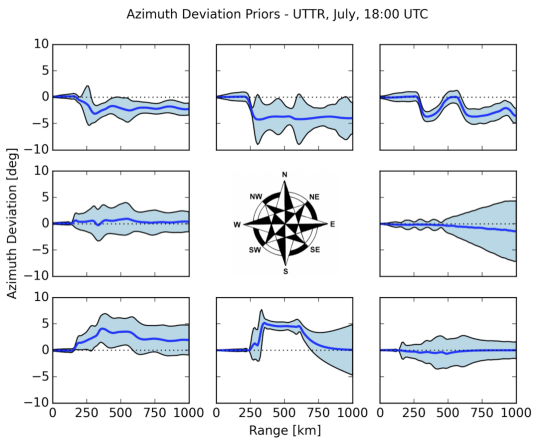
$$\int \frac{1}{\sqrt{2\pi\sigma_1^2}} e^{-\frac{1}{2}\left(\frac{x-x_1}{\sigma_1}\right)^2} \frac{1}{\sqrt{2\pi\sigma_2^2}} e^{-\frac{1}{2}\left(\frac{x-x_2}{\sigma_2}\right)^2} dx = \frac{1}{\sqrt{2\pi\left(\sigma_1^2+\sigma_2^2\right)}} e^{-\frac{1}{2}\frac{(x_1-x_2)^2}{\sigma_1^2+\sigma_2^2}}$$

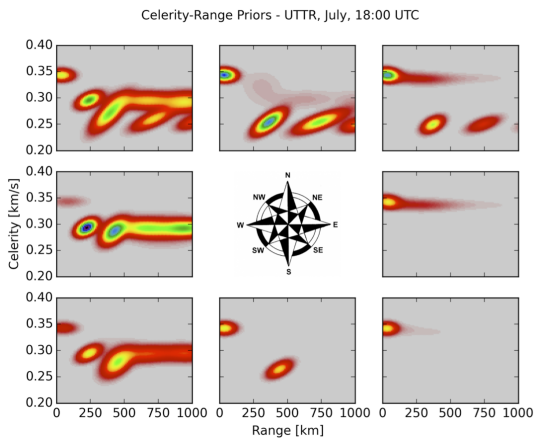
infrapy.propagation.infrasound

- Propagation-based, stochastic propagation models have been developed to improve localization estimates.
- Collaboration with SMU has shown a 25 – 40% decrease in the area of the confidence region with stochastic models.
- Continued work to construct hybrid semi-empirical models validated with ground truth data.









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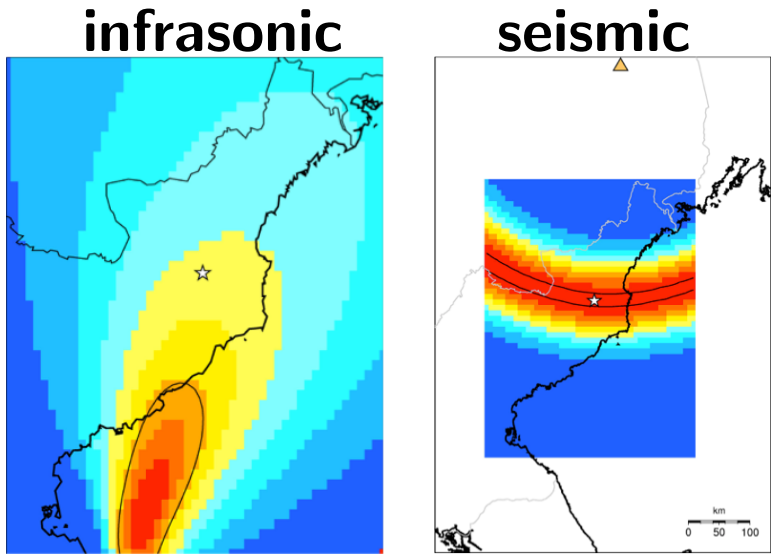
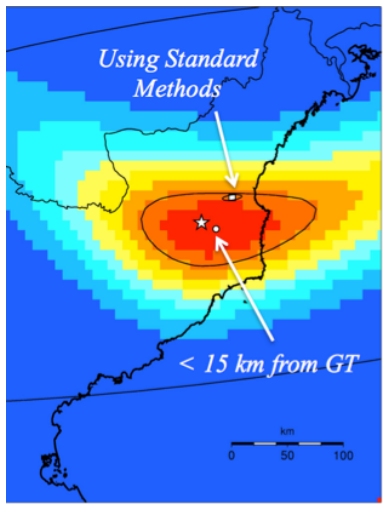
infrapy.propagation.seismic

- Infrasonic detections can be combined with those of other phenomenologies given appropriately defined likelihoods for each detection.
- Initial tests of seismo-acosutic localization utilize spatial distributions for infrasonic back azimuths and seismic (multi-phase) arrivals.
- Future work will utilize non-marginalized likelihoods (couple the source times).

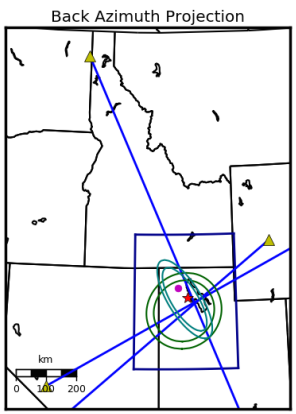


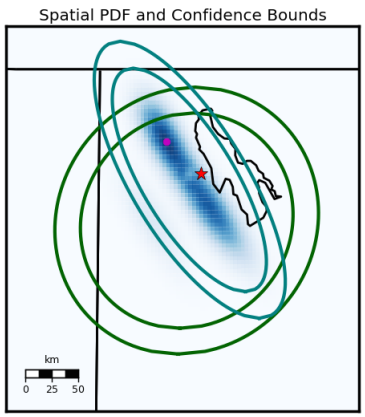


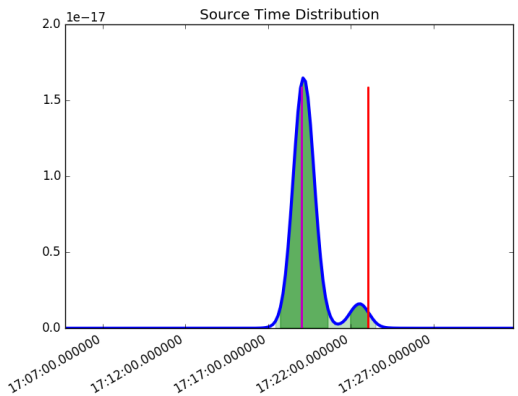
Library Usage

- The methods can be imported to Python scripts and used directly.
- Example: manually define detections and compute a location using the BISL algorithm.

```
from infrapy.location.bisl import *

# Set limits of integration and ground truth
lims = [[38.0, 44.0], [-117.0, -110.0]]
grnd_trth = [41.131, -112.896, datetime.datetime(2004, 6, 2, 17, 23, 4)]

# Define the list of detections
det1 = inf_det(42.7668, -109.5939, datetime.datetime(2004, 6, 2, 17, 42, 14), -125.6, 75.0, 4)
det2 = inf_det(38.4296, -118.3036, datetime.datetime(2004, 6, 2, 17, 50, 38), 56.6, 75.0, 4)
det3 = inf_det(48.2641, -117.1257, datetime.datetime(2004, 6, 2, 18, 9, 14), 157.5, 75.0, 4)
det_list = [det1, det2, det3]

# run BISL
result = run_bisl(det_list, lims, grnd_trth=grnd_trth, num_cores=7)
summarize_bisl_result(result)
```







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Command Line Interface

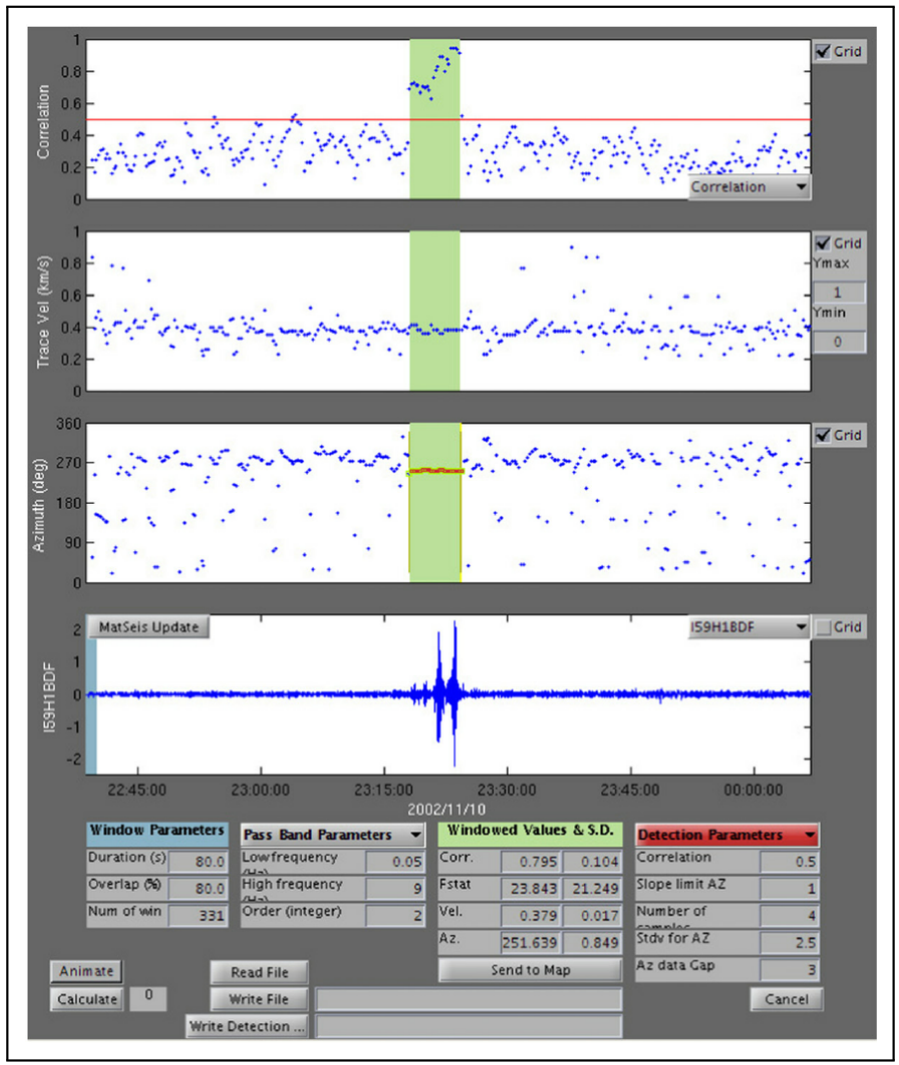
- The methods can also be run using a command line interface with a configuration file.
- Example: A day of data is run through the detection algorithm using the command line interface and an example database:

```
infrapy -run_fk example.config
infrapy -run_fd example.config
```

```
[GeneralParams]
database=sqlite:///example.sqlite
year=2014
dayofyearini=1
dayofyearend=2
station=array1
name=example
sitetable=None
wfdisctable=None
[FKParams]
name=fk example
filtertype=bandpass
filterl=0.1
filterh=1.0
wlen=30
overlapwlen=15
minslowness=-3.6
maxslowness=3.6
stepslowness=0.1
algorithm=barlett
fkresults=fk_example
numcores=6
[FDetectParams]
name=fd example
adaptivewlen=3600
pthreshold=0.01
corrthreshold=0.1
mineventlength=10
pfkid=0
fkresults=fk_example
fdresults=fd_example
```

Graphical User Interface - Future Development

- A graphical user interface (GUI) is a planned future development to attract users already familiar with software such as InfraTool (right).
- Unique GUI's will likely be needed for each processing task (-run_fk to process waveforms vs. -run_assoc to associate detections).



Future Plans

- Current and planned work on InfraPy focuses on the development of new algorithms and propagation models.
- Collaboration with Southern Methodist University (SMU) has helped identify bugs and limitations of the algorithms.
- The current focus of usage development is focused on library imports and CLI.