SnT 2021

CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

CTBTO

PREPARATORY COMMISSION

InfraPy, InfraGA/GeoAc, & stochprop: open-source software tools for infrasound signal analysis and propagation modeling at Los Alamos National Laboratory

Philip Blom & Jeremy Webster

T1.1-215

POSTER

Los Alamos

NATIONAL LABORATORY

LA-UR-21-24432

InfraPy, InfraGA/GeoAc, & stochprop:
open-source software tools for infrasound signal analysis and propagation modeling

Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

ABSTRACT

Infrasound research conducted at Los Alamos National Laboratory (LANL) in recent years has included development of tools for signal analysis, propagation modeling, and uncertainty quantification. Many of these tools have been licensed as open-source software, made available for download at the LANL Seismoacoustics Github page, and are utilized by scientists across the globe for a variety of national security, civil, and scientific applications. The InfraPy signal analysis suite includes state-of-the-art detection, association, localization, and yield estimation algorithms accessible through Python-based scripting and notebooks, a command line interface, as well as the InfraView graphical user interface. The InfraGA/GeoAc software is a propagation modeling tool capable of simulating the propagation of infrasonic signals through the atmosphere in the limit of geometric acoustics and includes a number of unique features such as eigenray identification, weakly non-linear waveform calculation, and propagation over realistic terrain. The stochprop library is an in-development tool that includes methods enabling quantification and reduction of propagation uncertainties for infrasound analysis. The capabilities of these tools and their application to a recent seismoacoustic event of interest are presented here.

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE
Poster No.: T1.1-215

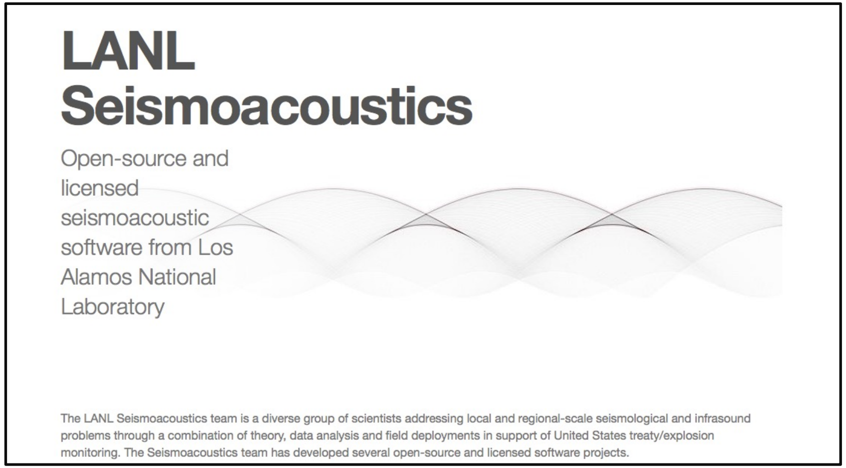
InfraPy, InfraGA/GeoAc, & stochprop:
open-source software tools for infrasound signal analysis and propagation modeling

Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

CTBTO PREPARATORY COMMISSION

INTRODUCTION

- Researchers on the LANL SeismoAcoustics (SA) Team have made an effort to share new algorithms and methods following peer reviewed publication through open-source software licensing
- Several infrasound-specific software tools are summarized here (bold below); though, they are only a subset of the tools developed by the SA Team



https://github.com/LANL-Seismoacoustics

- bulletproof
- EZpick
- **InfraGA/GeoAc**
- InfraMonitor
- **InfraPy**
- particleman
- pisces
- PyGeoTess
- RSTT
- SASM
- **stochprop**
- …

InfraPy, InfraGA/GeoAc, & stochprop:
open-source software tools for infrasound signal analysis and propagation modeling

Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

CTBTO PREPARATORY COMMISSION

InfraPy

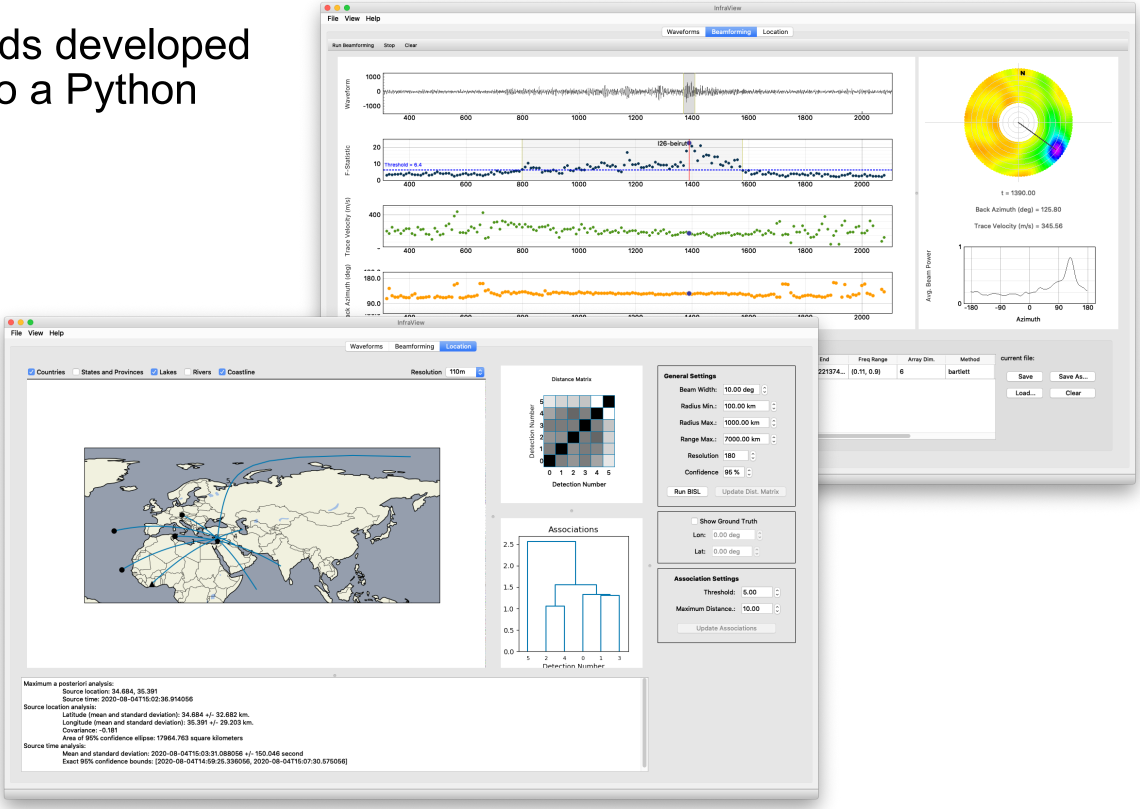
Infrasonic signal analysis methods developed at LANL have been collected into a Python library called "InfraPy"

Features

- Beamforming and Detection
- Event Identification
- Localization
- Yield Estimation

Interface options

- InfraView GUI
- Command Line Interface (CLI)
- Python Notebook



SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Poster No.: T1.1-215

InfraPy, InfraGA/GeoAc, & stochprop:
open-source software tools for infrasound signal analysis and propagation modeling

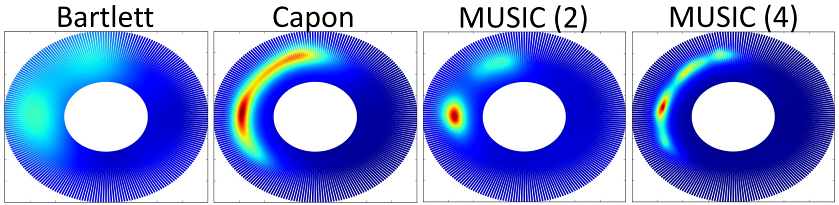
Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

CTBTO PREPARATORY COMMISSION

InfraPy

Beamforming and Detection

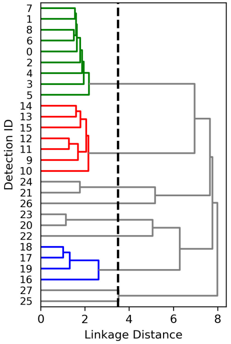
- Includes standard (Bartlett) beamforming as well as Capon and MUSIC
- Detection uses adaptive Fisher-statistics

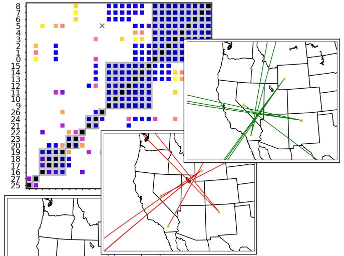


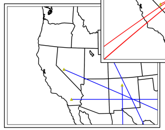
Beamforming results for persistent sources demonstrates the improved resolution of Capon and MUSIC algorithms for identifying multiple, co-incident signals

Event Identification

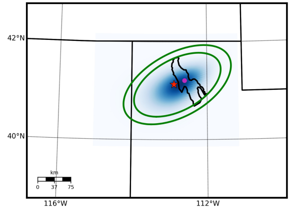
- Pair-based, joint-likelihood analysis and clustering analysis of the resulting distance matrix to identify events







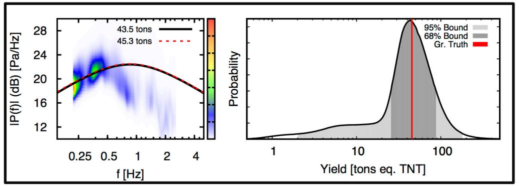
Event identification for 3 events in the western US identified in a clustering dendrogram analysis of the distance matrix (note: synthetic example)



Localization estimate for a surface explosion at the Utah Test and Training Range using regional infrasound (red star denotes ground truth, magenta point is max likelihood, and ellipses show 95 and 99% bounds)

Localization

- Location and origin time estimated using a Bayesian framework



Yield estimation for a surface explosion via computation of the near-source spectral characteristics (left) and comparison with a blastwave model (right)

Yield Estimation

- Statistical propagation models to estimate near-source characteristics
- Comparison with a source model to estimate yield

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Poster No.: T1.1-215

InfraPy, InfraGA/GeoAc, & stochprop:
open-source software tools for infrasound signal analysis and propagation modeling

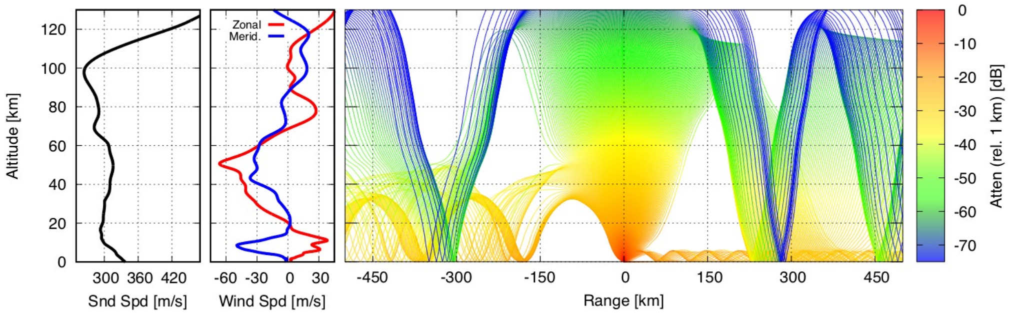
Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

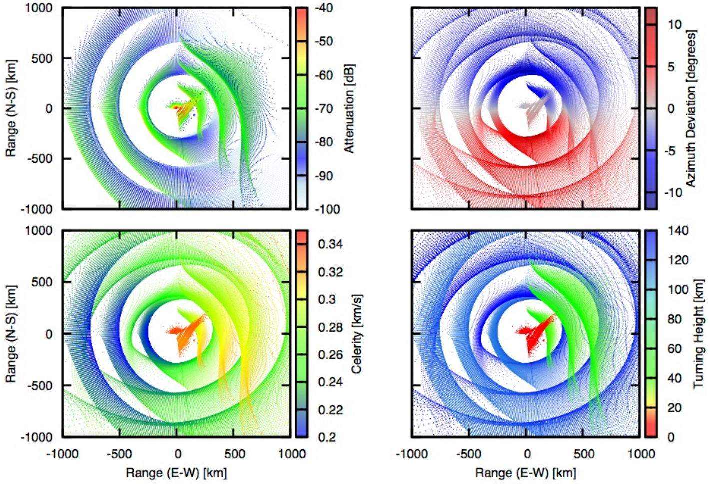
CTBTO
PREPARATORY COMMISSION

InfraGA/GeoAc

InfraGA/GeoAc is a suite of numerical tools for modeling **Infra**sound propagation in the limit of **Geo**metric **Ac**oustics

- Used and referenced in 25+ publications since 2014
- Models propagation in Cartesian coordinates or through a spherical atmospheric layer





Calculates arrival characteristics:

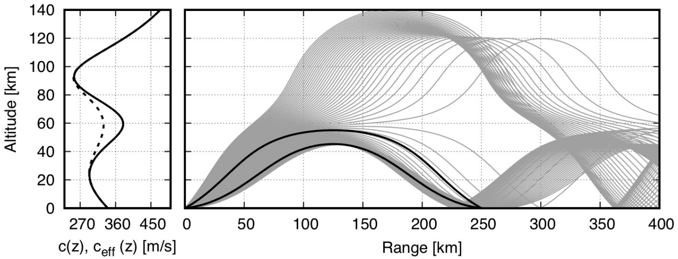
- Propagation time
- Arrival geometry (back azimuth, inclination)
- Turning height
- Geometric spreading, thermo-viscous losses

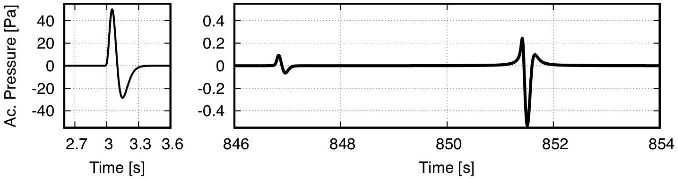
InfraPy, InfraGA/GeoAc, & stochprop:
open-source software tools for infrasound signal analysis and propagation modeling

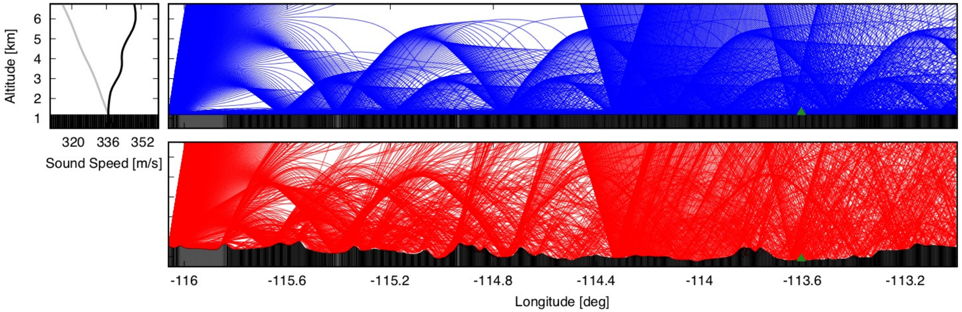
Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

InfraGA/GeoAc

- Able to simulate propagation over realistic terrain







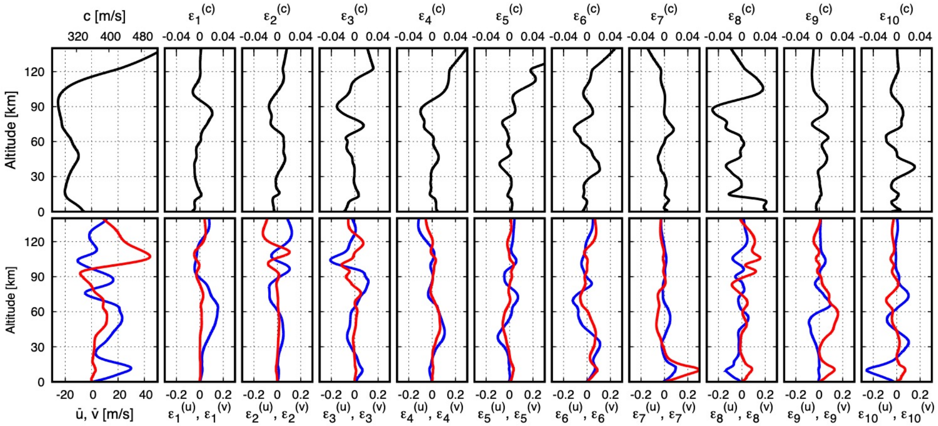
- Uses auxiliary parameters to compute geometric spreading as well as identify propagation paths connecting specific source/receiver geometry (eigenrays)
- Weakly non-linear waveform calculations along ray paths provide a means to estimate arrival signals
- OpenMPI features allow for parallelized calculations

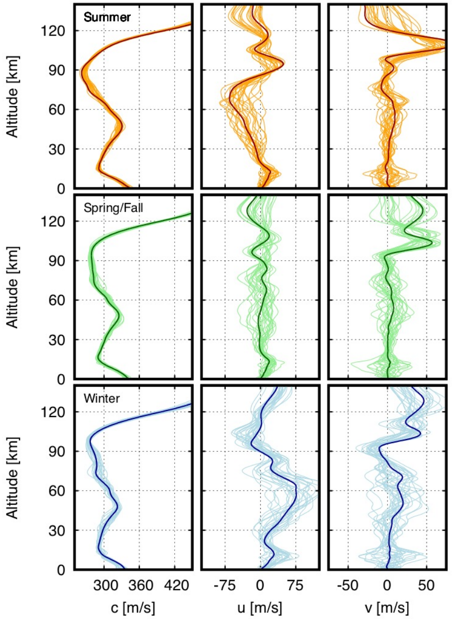
InfraPy, InfraGA/GeoAc, & stochprop:
open-source software tools for infrasound signal analysis and propagation modeling

Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

stochprop

- The atmosphere is dynamic and relatively sparsely sampled, particularly the middle- and upper atmosphere
  - → Variability/uncertainty in the propagation medium leads to variability/uncertainty in infrasound propagation predictions
- Python library, stochprop, uses empirical orthogonal function (EOF) analysis to quantify this uncertainty and variability and construct **stoch**astic **prop**agation models





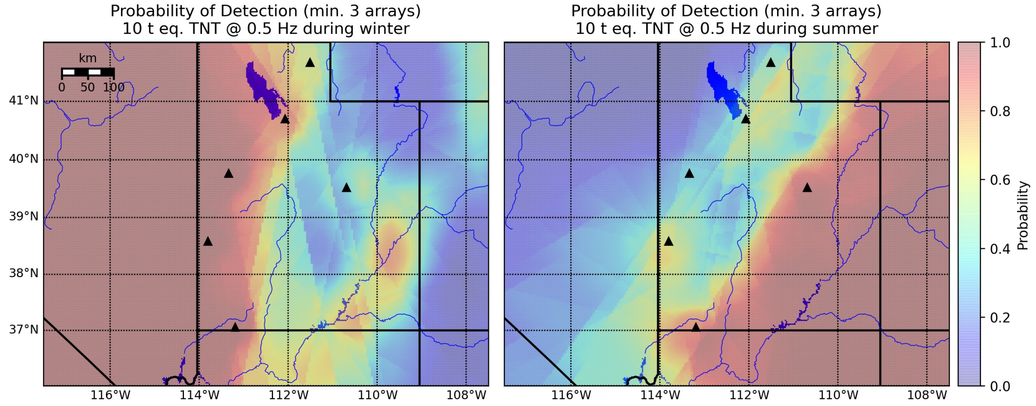
- Identifies seasonal trends and generates “typical” atmospheric and propagation characteristics

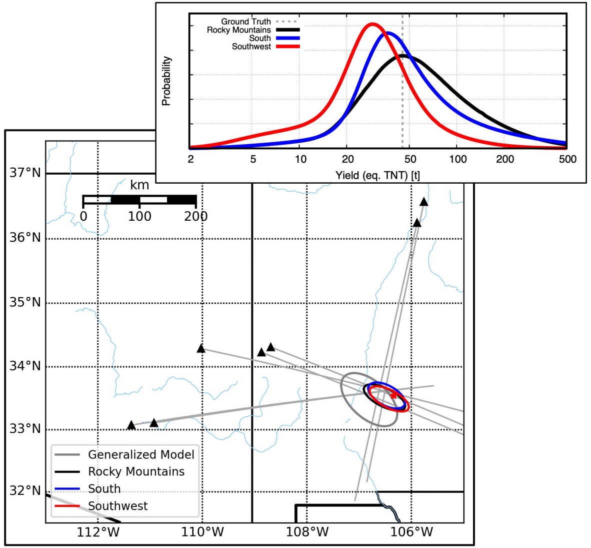
InfraPy, InfraGA/GeoAc, & stochprop:
open-source software tools for infrasound signal analysis and propagation modeling

Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

stochprop

- Region- and season-specific models can be used with localization and yield estimation methods in InfraPy
- Detection probabilities can be computed by combining the propagation statistics with source and background noise models





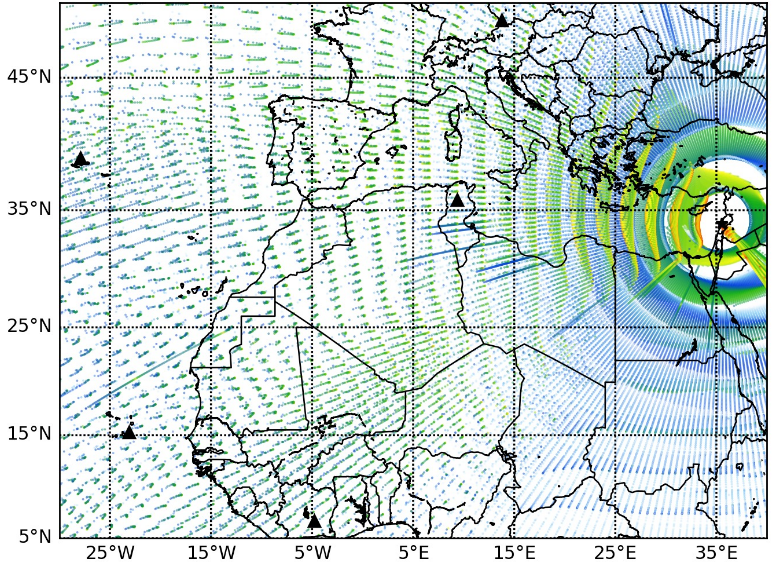
- Propagation statistics for several locations across the continental US have been constructed for evaluation of the method

InfraPy, InfraGA/GeoAc, & stochprop:
open-source software tools for infrasound signal analysis and propagation modeling

Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

APPLICATION

- A large chemical explosion occurred in Beirut, Lebanon in early August, 2020 and produced infrasonic signals observed 6,000+ km away
- This event provides a useful example to demonstrate InfraGA/GeoAc and InfraPy
  - InfraGA/GeoAc analysis of regional propagation as well as more detailed simulations for propagation towards I26 (Germany) and I48 (Tunisia)
  - InfraPy detection of signals on several IMS stations to the west as well as a nearby non-IMS station, IMA (Israel), to the south
  - Detections used for localization of the event
- Propagation simulations show a stratospheric waveguide to the west typical of summer in the northern hemisphere

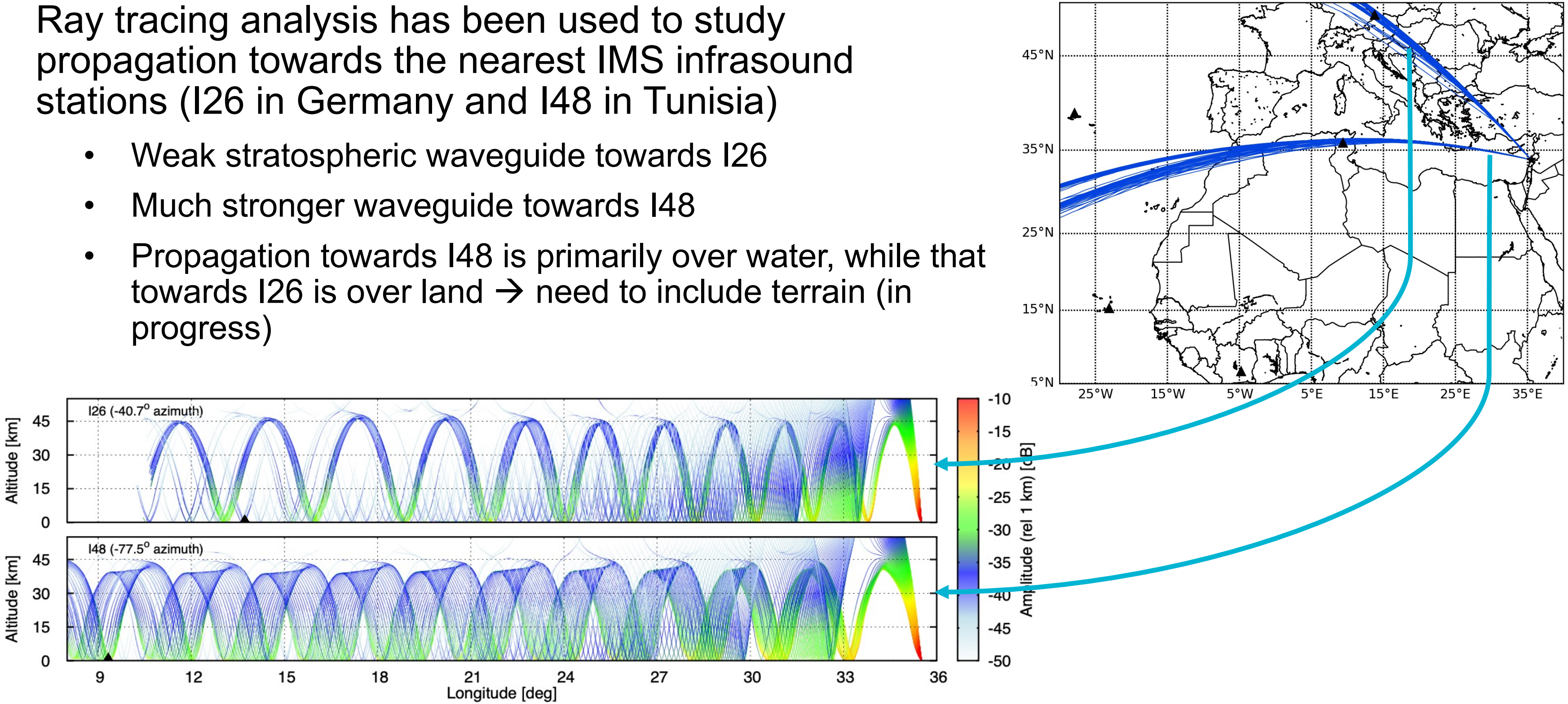


InfraPy, InfraGA/GeoAc, & stochprop:
open-source software tools for infrasound signal analysis and propagation modeling

Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

APPLICATION

- Ray tracing analysis has been used to study propagation towards the nearest IMS infrasound stations (I26 in Germany and I48 in Tunisia)
  - Weak stratospheric waveguide towards I26
  - Much stronger waveguide towards I48
  - Propagation towards I48 is primarily over water, while that towards I26 is over land → need to include terrain (in progress)



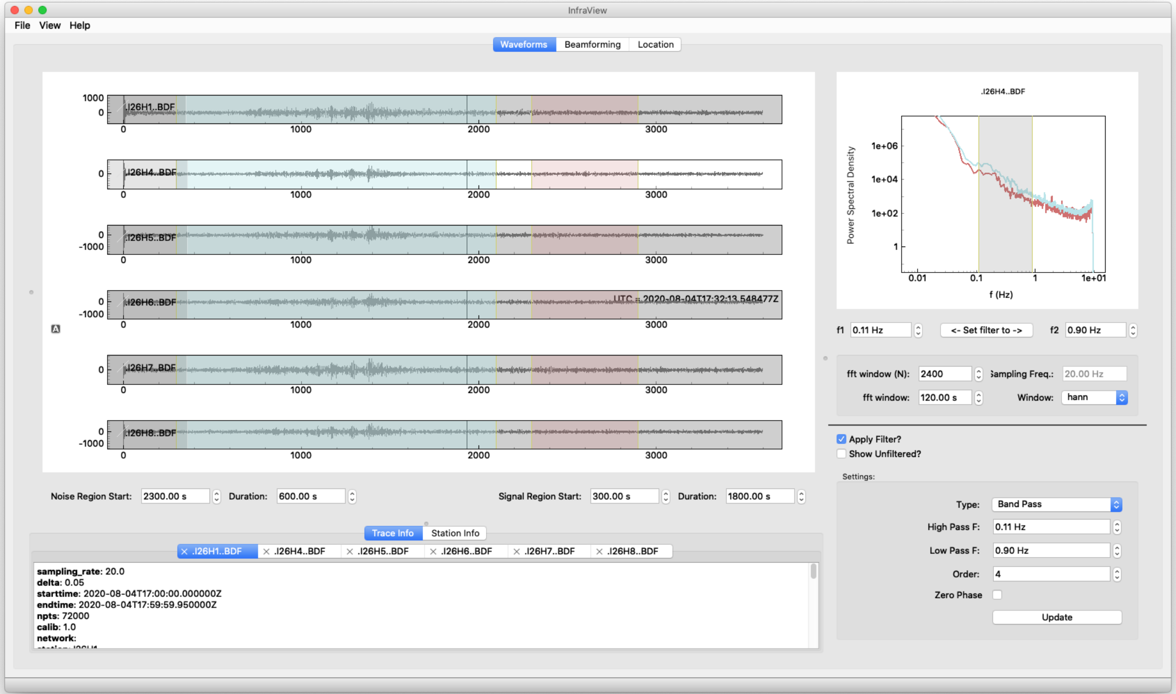
InfraPy, InfraGA/GeoAc, & stochprop:
open-source software tools for infrasound signal analysis and propagation modeling

Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

CTBTO PREPARATORY COMMISSION

APPLICATION

- InfraPy analysis at I26
  - *Expect infrasonic arrivals approximately 2.5 hours later (~1 hour per 1000 km)*
  - *Arrival band approximately 0.1 to 1.0 Hz*
  - Array processing identifies an extended arrival (almost 800 seconds) containing multiple arrival phases
- InfraPy localization
  - Estimated location is slightly north of Beirut
  - Origin time estimate is ~5 minute early



InfraPy, InfraGA/GeoAc, & stochprop:

open-source software tools for infrasound signal analysis and propagation modeling

Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

APPLICATION

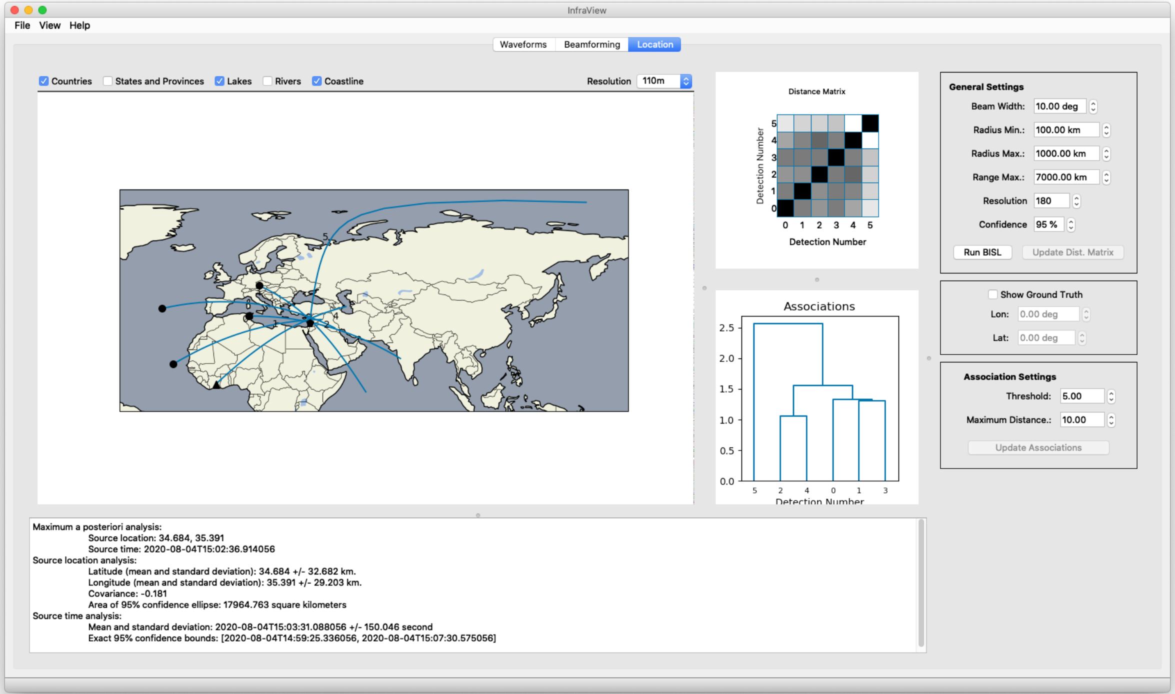
- InfraPy analysis at I26
  - Expect infrasonic arrivals approximately 2.5 hours later (~1 hour per 1000 km)
  - Arrival band approximately 0.1 to 1.0 Hz
  - *Array processing identifies an extended arrival (almost 800 seconds) containing multiple arrival phases*
- InfraPy localization
  - Estimated location is slightly north of Beirut
  - Origin time estimate is ~5 minute early

InfraPy, InfraGA/GeoAc, & stochprop:
open-source software tools for infrasound signal analysis and propagation modeling

Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

APPLICATION

- InfraPy analysis at I26
  - Expect infrasonic arrivals approximately 2.5 hours later (~1 hour per 1000 km)
  - Arrival band approximately 0.1 to 1.0 Hz
  - Array processing identifies an extended arrival (almost 800 seconds) containing multiple arrival phases
- InfraPy localization
  - *Estimated location is slightly north of Beirut*
  - *Origin time estimate is ~5 minute early*



InfraPy, InfraGA/GeoAc, & stochprop:
open-source software tools for infrasound signal analysis and propagation modeling

Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

SUMMARY

- LANL Seismoacoustic researchers are sharing their research with the wider geophysics community via **open-source software**
  - **InfraPy** is a signal analysis pipeline software package that includes detection, event identification, localization, and yield estimation capabilities that can be accessed via the InfraView GUI or a command line interface
  - **InfraGA/GeoAc** is a suite of numerical tools for modeling infrasound propagation in the limit of geometric acoustics including propagation through a spherical layer and interaction with terrain
  - **stochprop** is a collection of methods that allow researchers to quantify the variability and uncertainty in the atmospheric state relevant to infrasound propagation uncertainty quantification
- The large explosion that occurred in Beirut during August, 2020 provides a useful example to demonstrate InfraGA/GeoAc and InfraPy analysis

InfraPy, InfraGA/GeoAc, & stochprop:
open-source software tools for infrasound signal analysis and propagation modeling

Philip Blom (pblom@lanl.gov) & Jeremy Webster
Los Alamos National Laboratory, Earth and Environmental Science Division

REFERENCES

InfraPy

- Arrowsmith, S. J., et al. (2008). Regional monitoring of infrasound events using multiple arrays: application to Utah and Washington State. *Geophys. J. Int.*, **175**(1), 291 – 300. doi: 10.1111/j.1365-246X.2008.03912.x
- Arrowsmith, S. J., et al. (2009). The F-detector revisited: An improved strategy for signal detection at seismic and infrasound arrays. *Bull. Seismol. Soc. Am.*, **99**(1), 449 – 453. doi: 10.1785/0120080180
- Blom, P., et al. (2015). Improved Bayesian infrasonic source localization for regional infrasound. *Geophys. J. Int.*, **203**(3), 1682 – 1693. DOI: 10.1093/gji/ggv387
- Blom, P., et al. (2018). Bayesian characterization of explosive sources using infrasonic signals. *Geophys. J. Int.*, **215**(1), 240 – 251. DOI: 10.1093/gji/ggy258
- Blom, P., et al. (2020). Evaluation of a pair-based, joint-likelihood association approach for regional infrasound event identification. *Geophys. J. Int.*, **221**(3), 1750 – 1764. doi: 10.1093/gji/ggaa105

InfraGA/GeoAc

- Blom, P. & Waxler, R. (2012). Impulse propagation in the nocturnal boundary layer: Analysis of the geometric component. *J. Acoust. Soc. Am.*, **131**(5), 3680 – 3690. doi: 10.1121/1.3699174
- Blom, P. & Waxler, R. (2017). Modeling and observations of an elevated, moving infrasonic source: Eigenray methods. *J. Acoust. Soc. Am.*, **141**(4), 2681 – 2692. doi: 10.1121/1.4980096
- Blom, P. (2019). Modeling infrasonic propagation through a spherical atmospheric layer – Analysis of the stratospheric pair. *J. Acoust. Soc. Am.*, **145**(4) 2198 – 2208. doi: 10.1121/1.5096855
- Blom, P. (2020). The influence of non-flat ground on infrasonic propagation in the troposphere. *J. Acoust. Soc. Am.*, **148**(4), 1984 – 1997. doi: 10.1121/1.5096855
- Blom, P. & Waxler, R. (2021). Characteristics of thermospheric infrasound predicted using ray tracing and weakly non-linear waveform analysis. *J. Acoust. Soc. Am.*, **149**(5), 3174 – 3188. doi: 10.1121/10.0004949

stochprop

- Blom, P., et al. (2021). On the generation of statistical models for infrasound propagation from statistical models for the atmosphere: identifying seasonal and regional trends. *Geophys. J. Int.*, In Preparation.