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Title: Development of global stochastic models for infrasound

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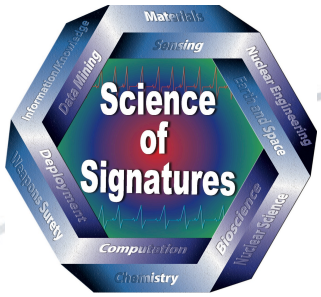

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Development of global stochastic models for infrasound

Stephen Arrowsmith
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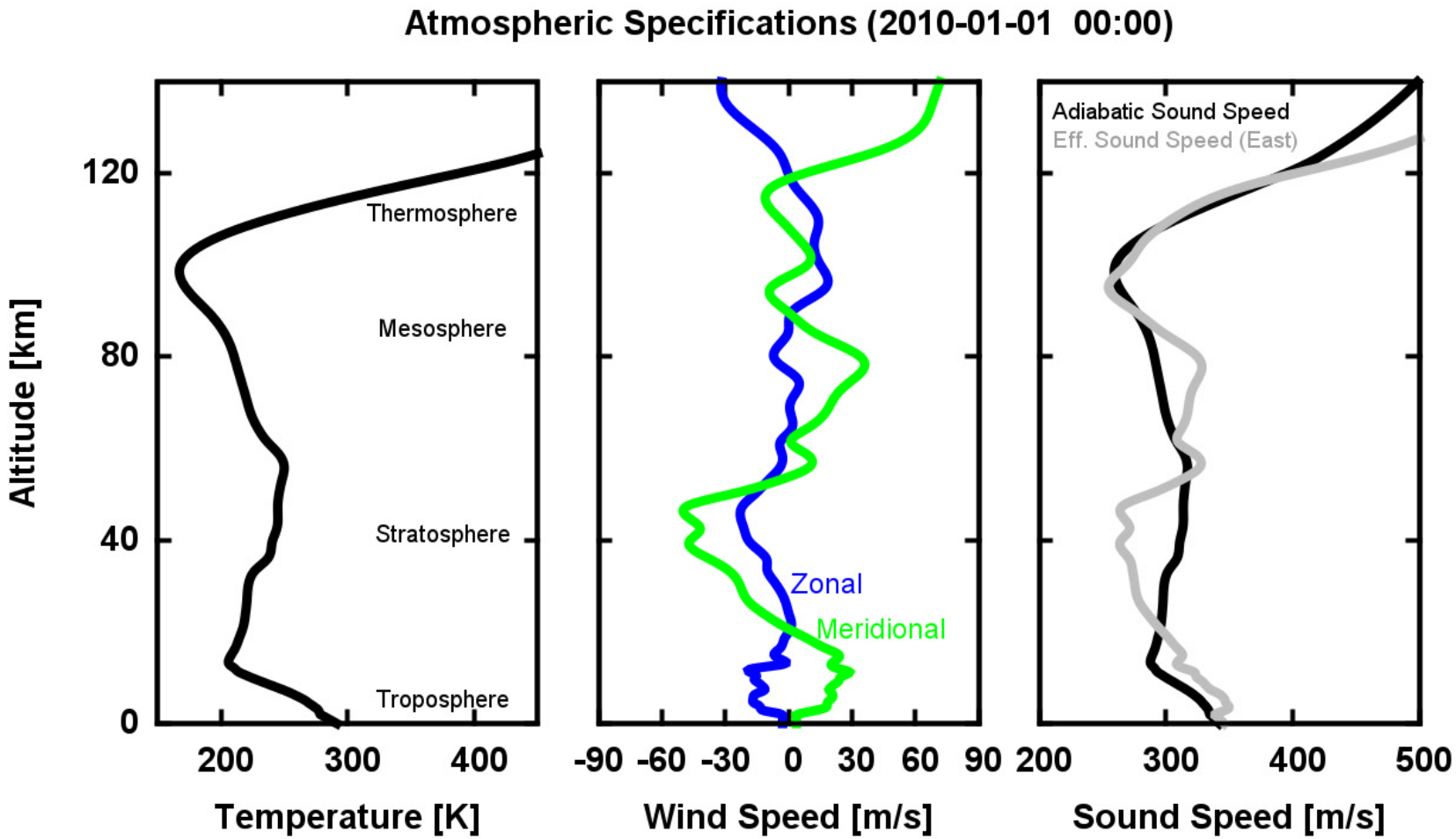
Emily Morton
Dale Anderson

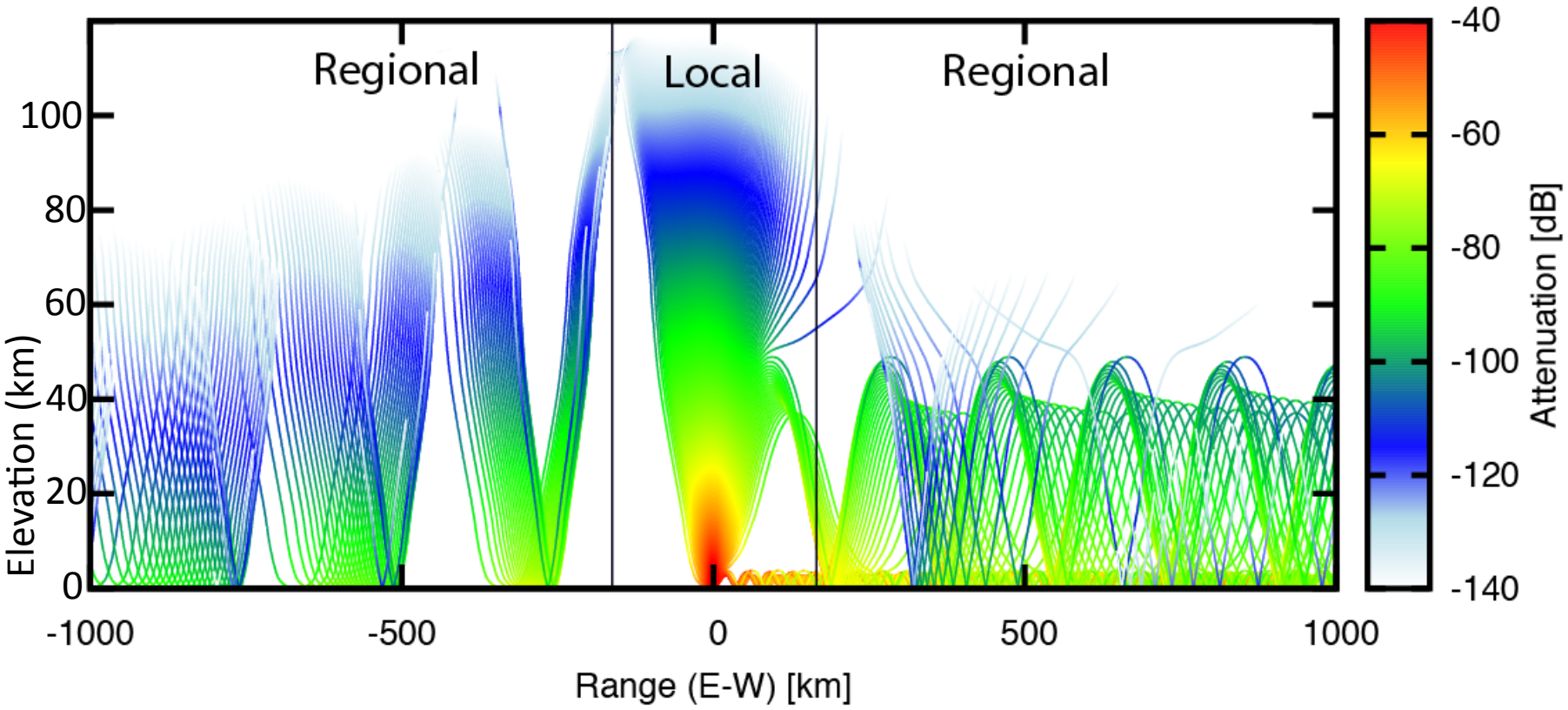
Relevance to Science of Signatures

- Infrasound is a 'signature' of energetic events in the atmosphere and shallow crust
- Infrasound is the component of the CTBT monitoring framework dedicated to monitoring atmospheric explosions
- Infrasound is also used by U.S. monitoring agencies for source characterization and yield estimation

Accounting for the dynamic atmosphere is the challenge we are addressing

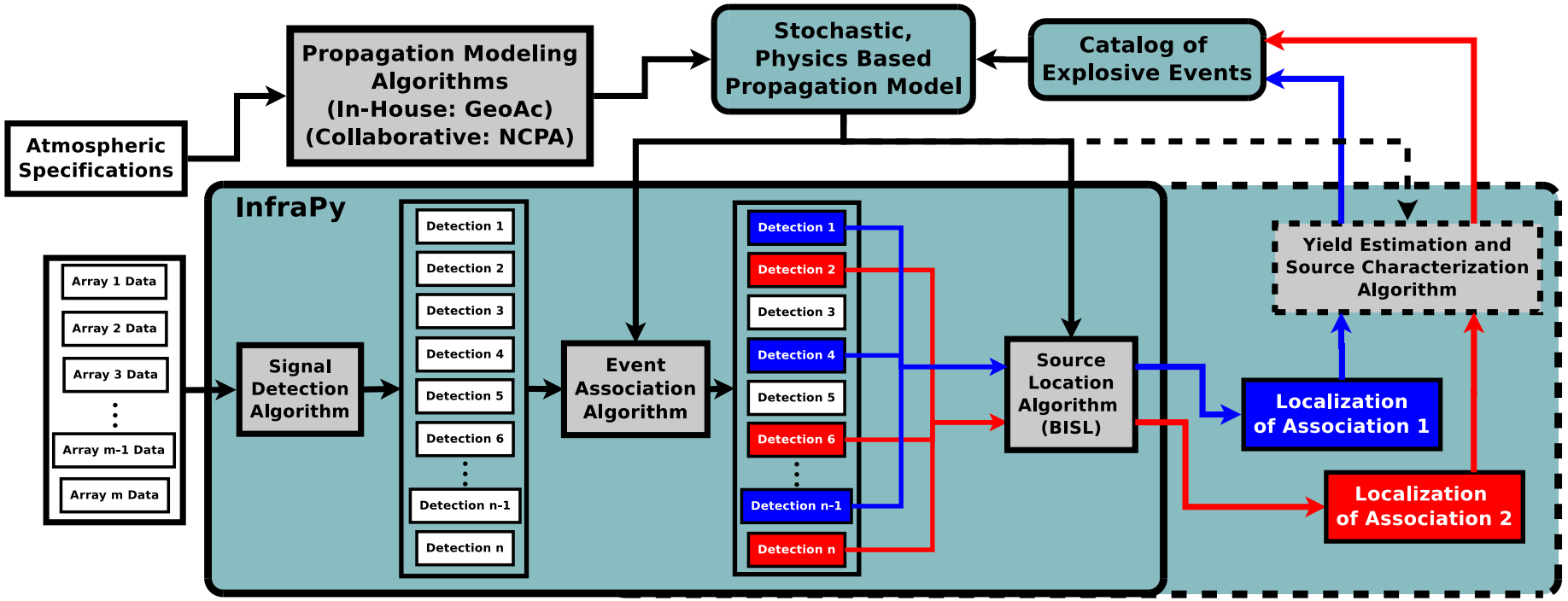


Stochastic Models should be used for regional and global scales



- Deterministic methods can work at local scales
- At regional and global scales, atmospheric propagation should be modeled stochastically

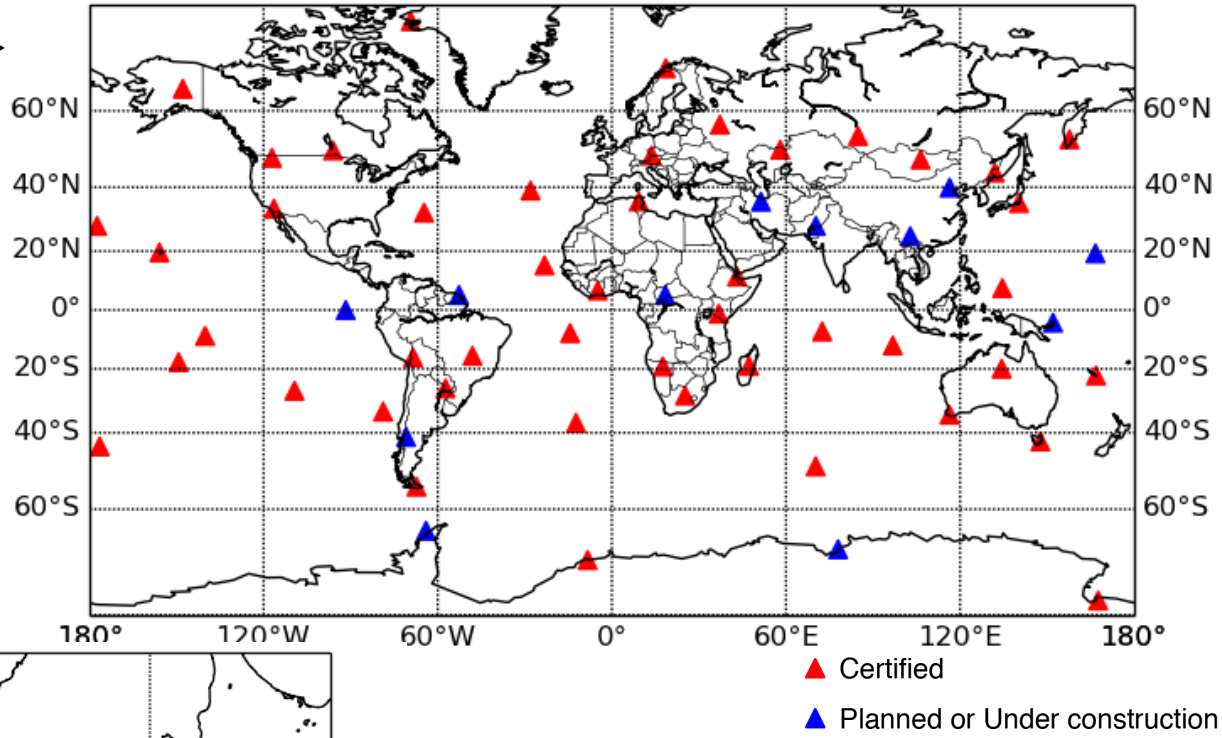
The Utility of Global Stochastic Models

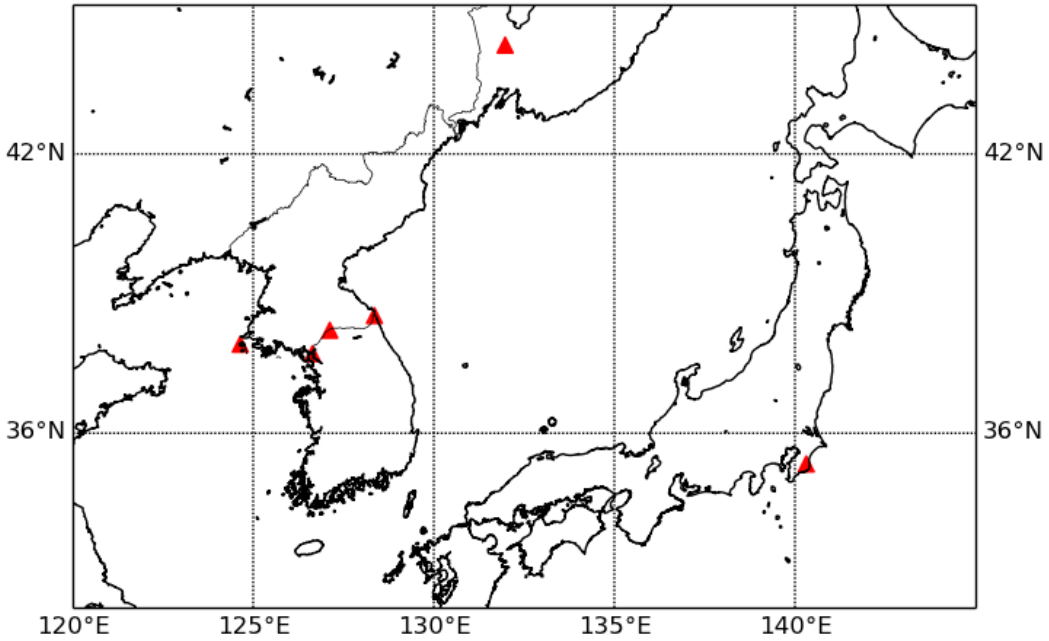


- Global Stochastic Models enable improvements to association, location, discrimination, and yield estimation using infrasound data
- Our LANL-developed tool, *InfraPy*, and associated products are enabling the CTBTO monitoring mission and the missions of multiple U.S. monitoring agencies

Our LANL team is utilizing regional and global networks

International Monitoring System (IMS) infrasound network →

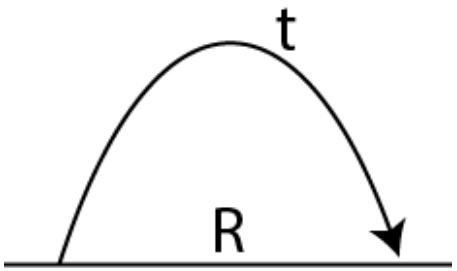




← Korea network

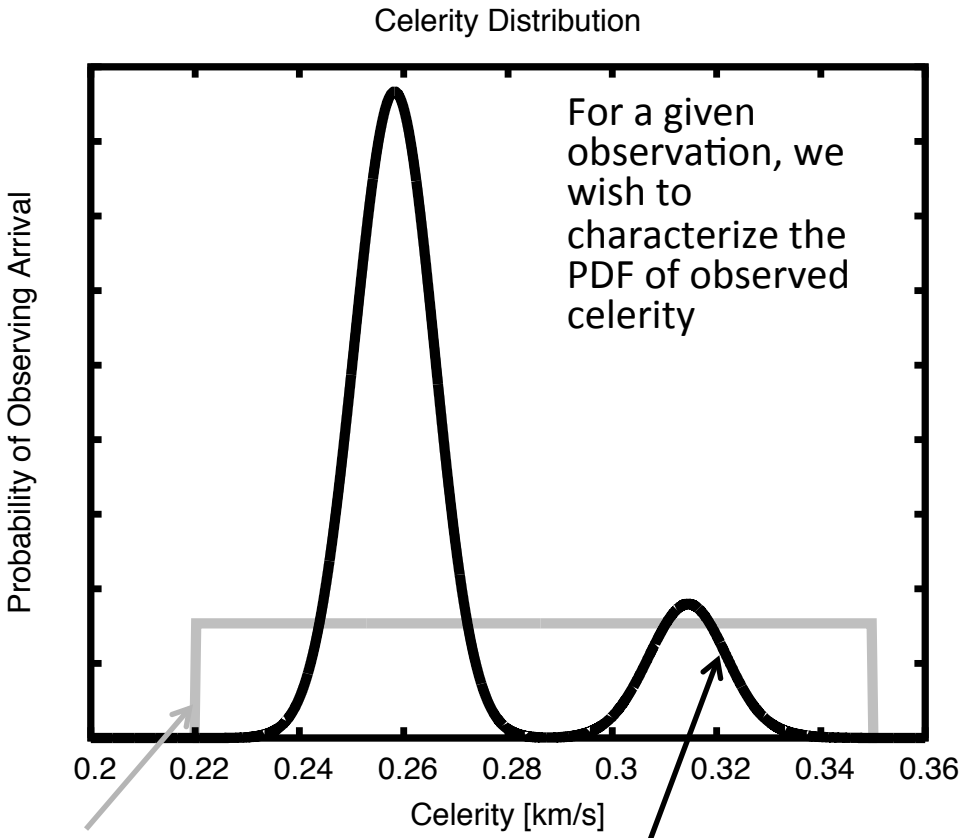
What do we mean by a Stochastic Model?

A statistical model representing the prediction of an important propagation property that formally captures the uncertainty of that property



$v = R/t$

Celerity (v) is representative of the 'phase' or propagation path

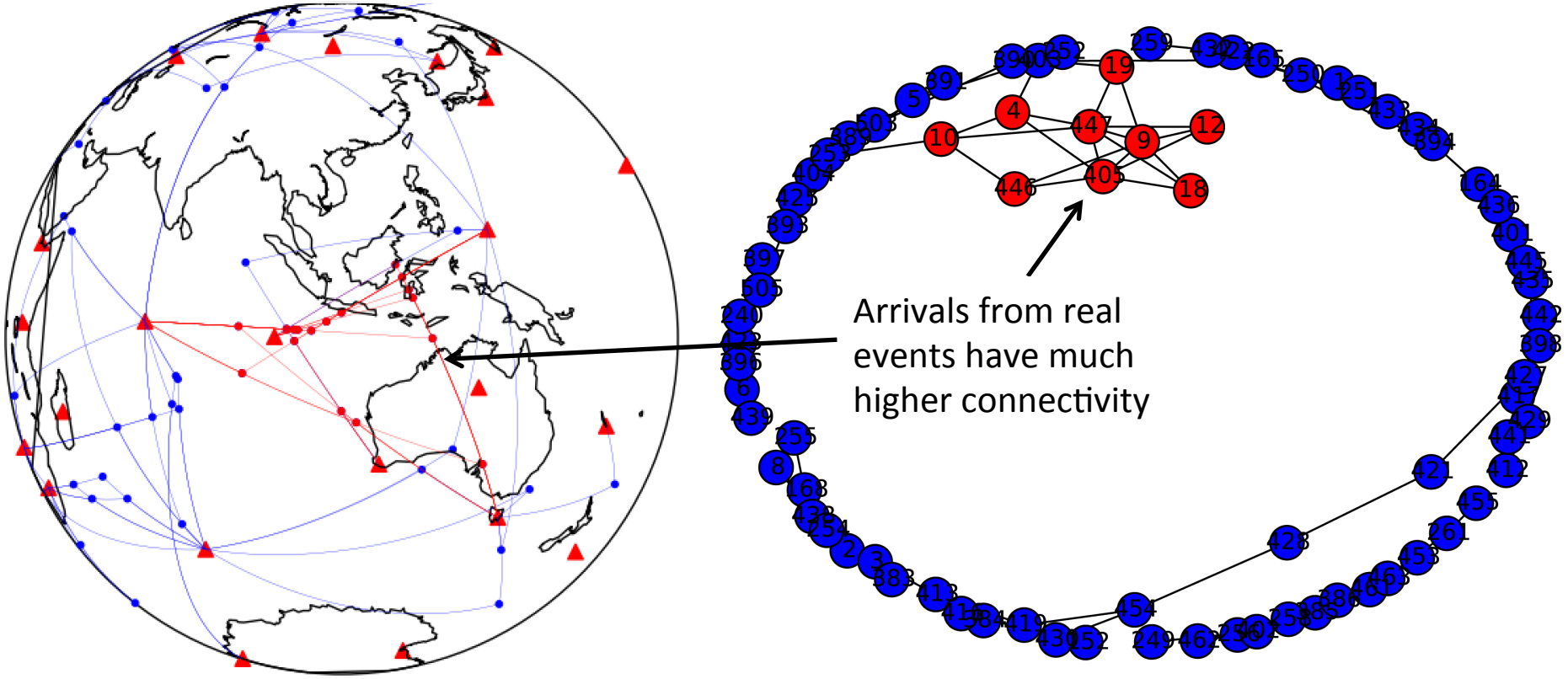


Previous capability used a simple uniform distribution

We are building improved models that use atmospheric and propagation models

LANL-developed association method uses a novel combination of physics and graph theory

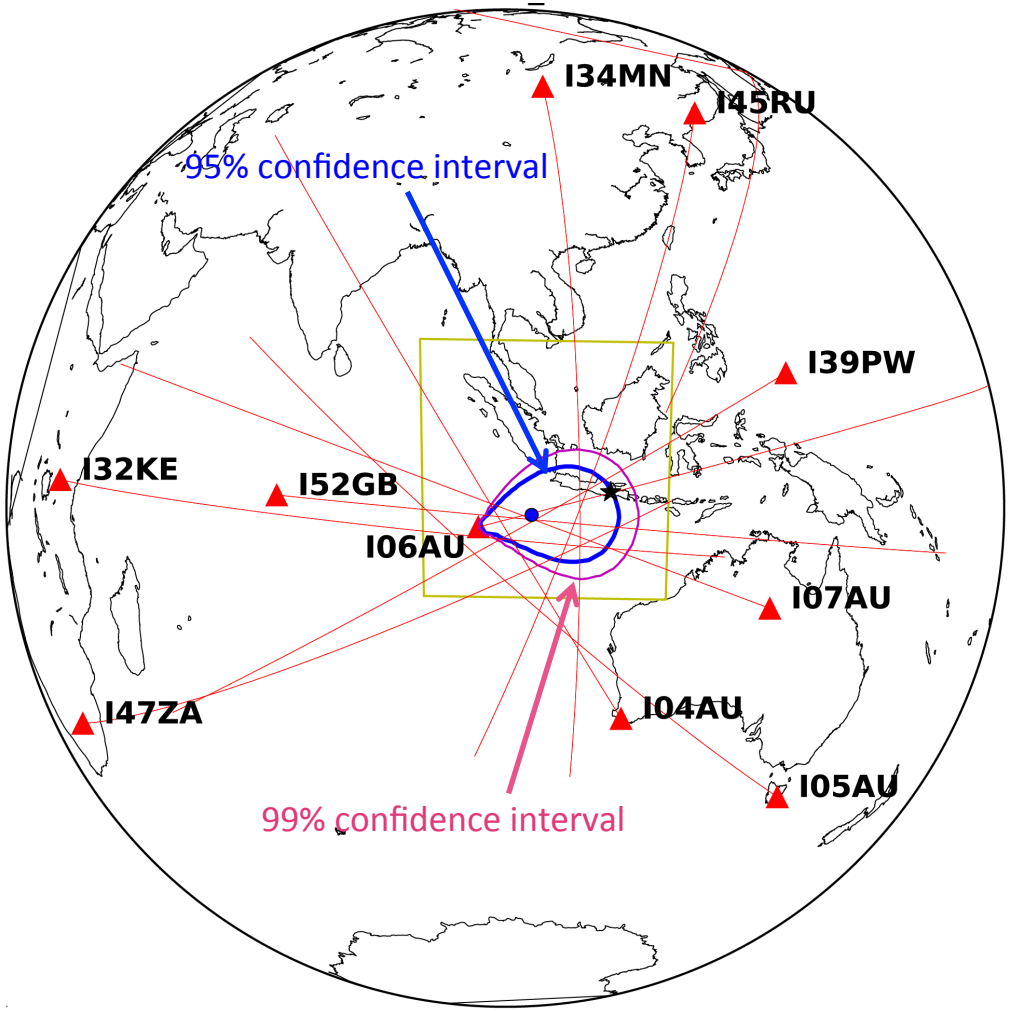
- Association: Identifying detections at different arrays from the same causative event
- Current analysis using crude priors is good for big events but poor for small events detected at <6 arrays



Association for 48 hour period including eruption of Kelud volcano, Indonesia on February 13, 2014

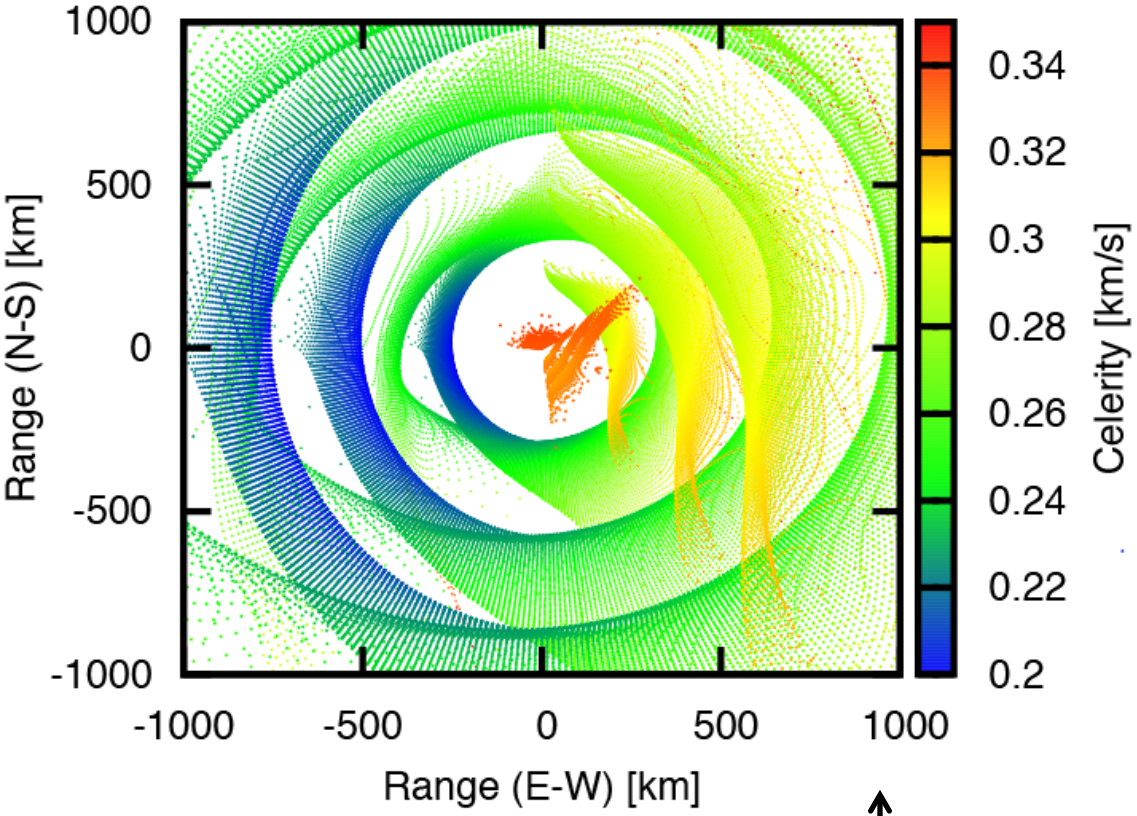
Locating infrasonic sources with BISL

- Bayesian location framework developed to formally utilize probabilistic models for celerity and backazimuth deviation
- Enables estimation of confidence intervals



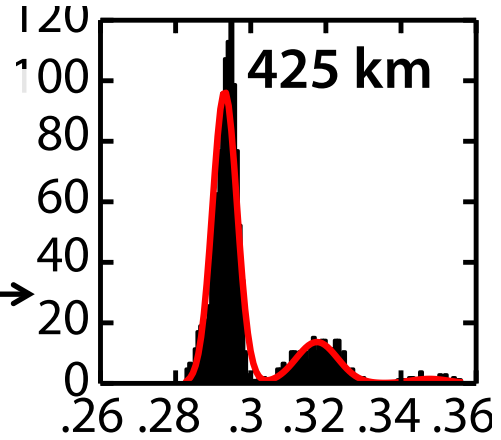
Location for eruption of Kelud volcano, Indonesia

Global Stochastic Models: Enabling infrasound as a viable capability for the CTBT

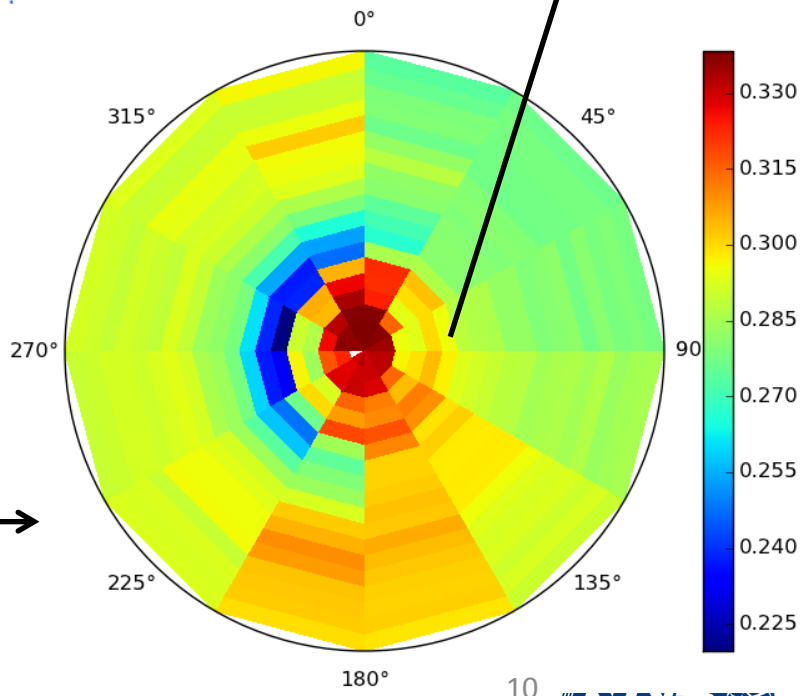


Ray bounce points for one atmosphere over UTTR in January 2010

Gaussian Mixture Model for range/ azimuth bin →

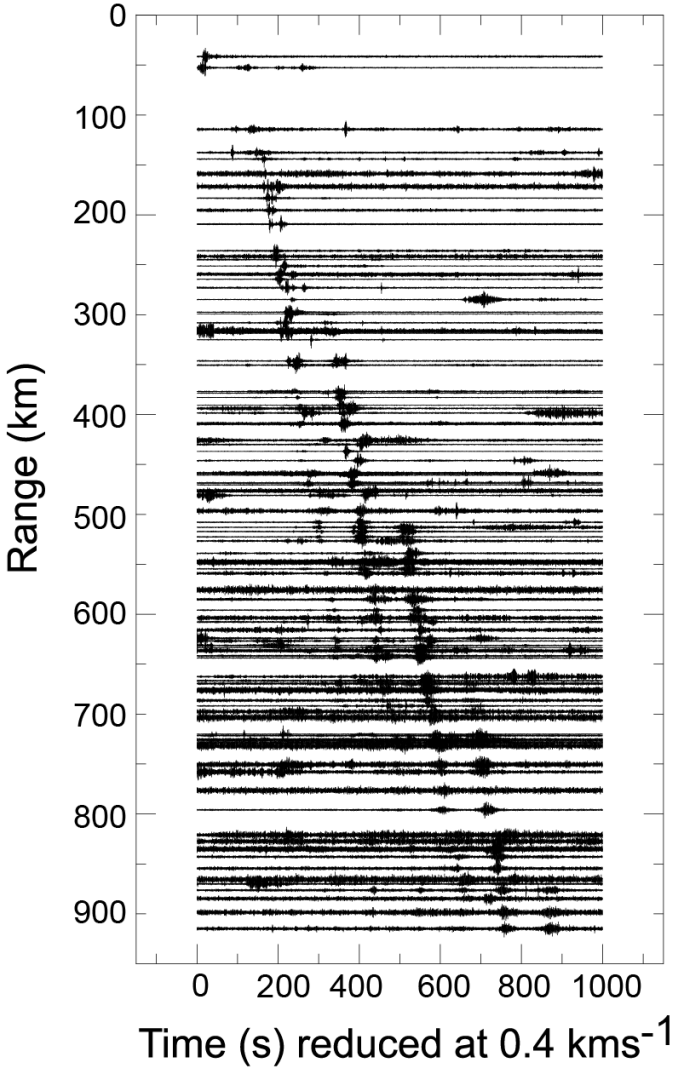


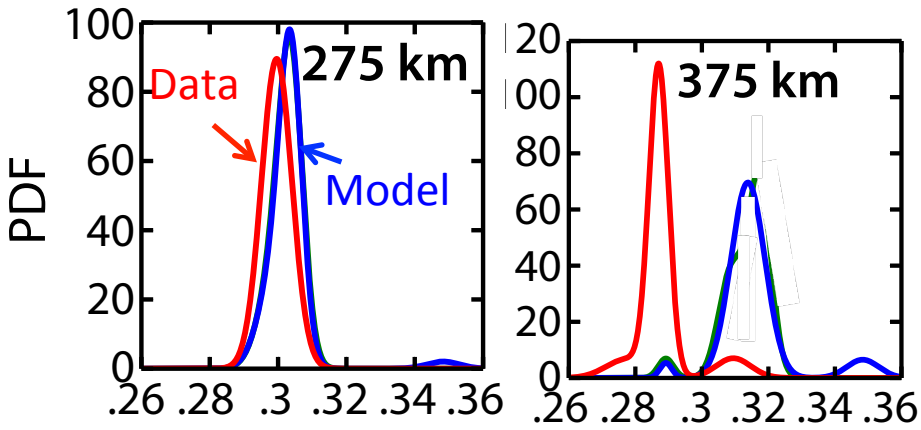
Catalog of propagation simulations for UTTR during January over multiple years →



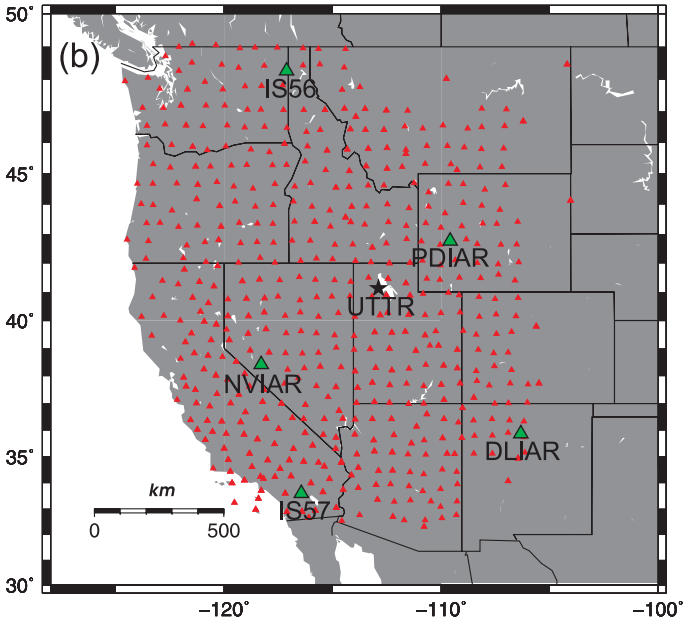
Validating Travel-time/Velocity Models

Infrasound from UTTR explosion recorded on USArray



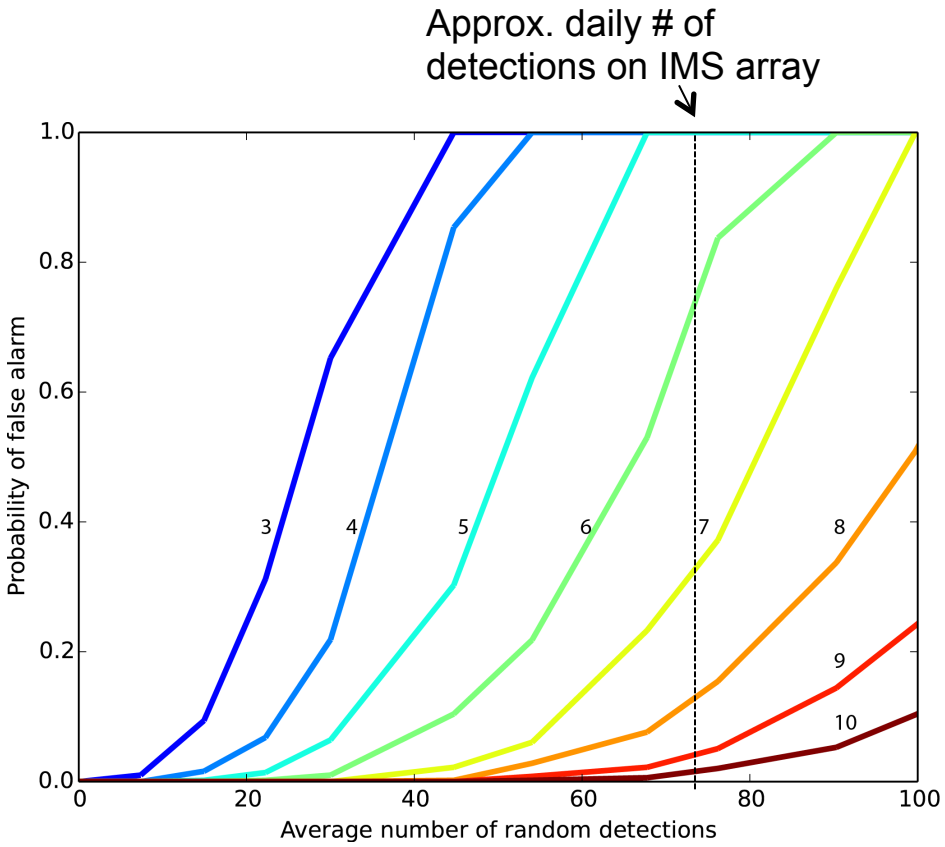


Comparisons with data identify scenarios where model improvements are needed

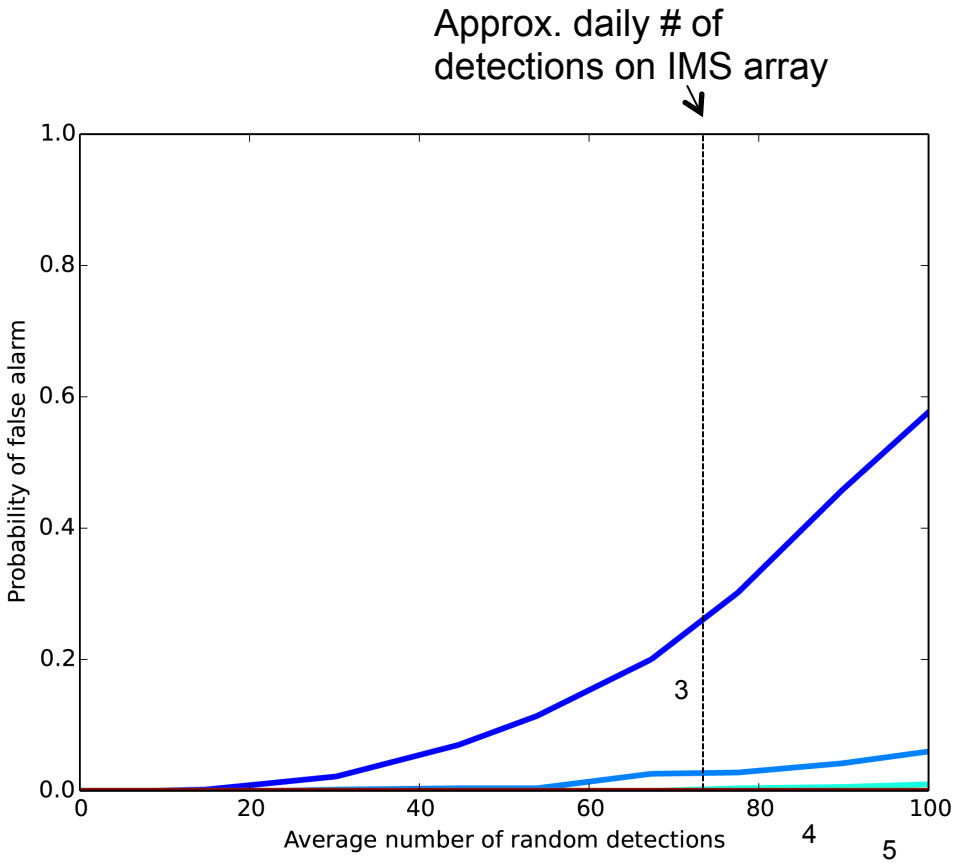


The data validation is a collaboration with AWE, UK

Stochastic Models improve Association false alarm rate



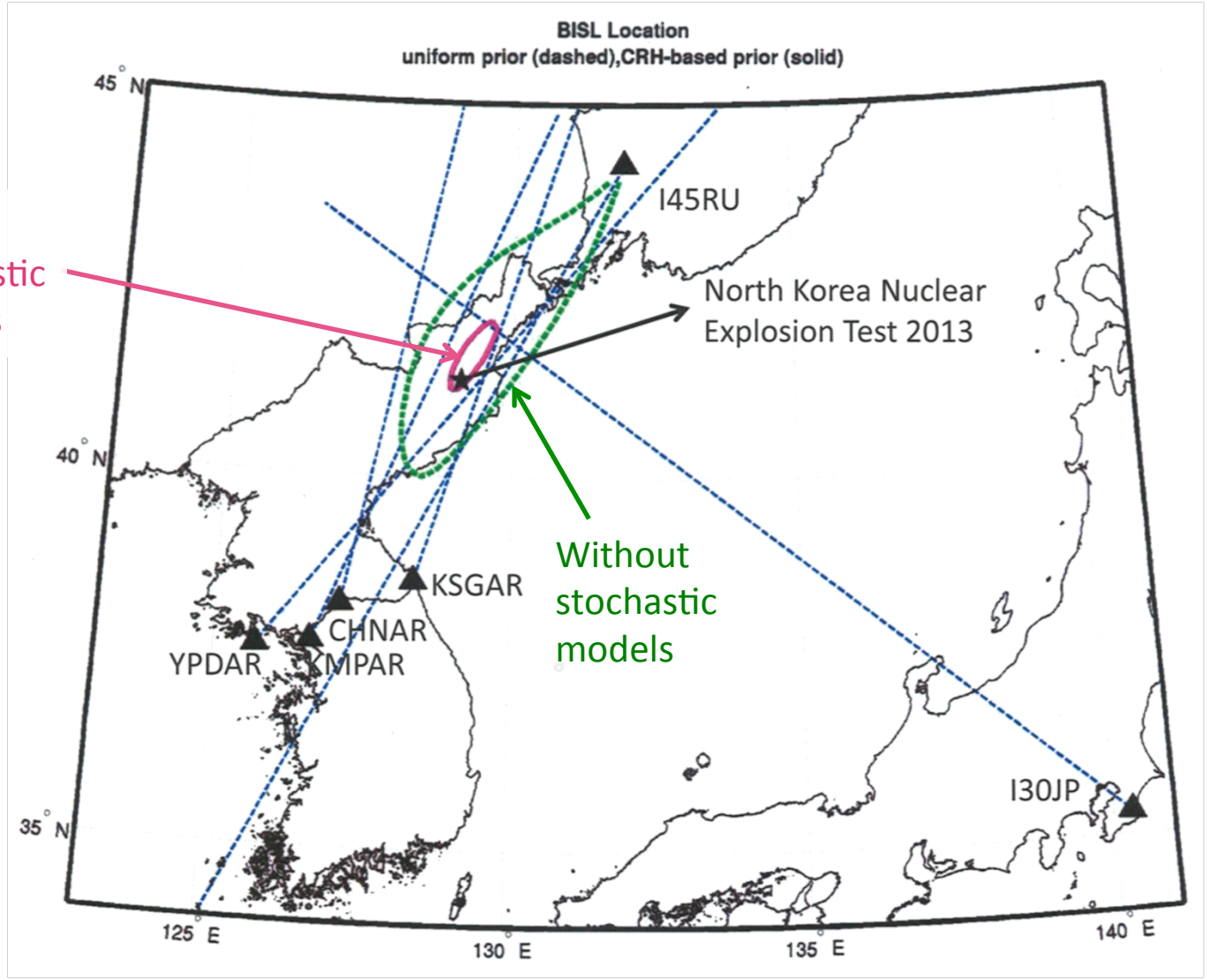
Without Stochastic Models



With Stochastic Models

- The 10-sensor false positive rate representing current capability is equal to that of 4 sensors using stochastic models

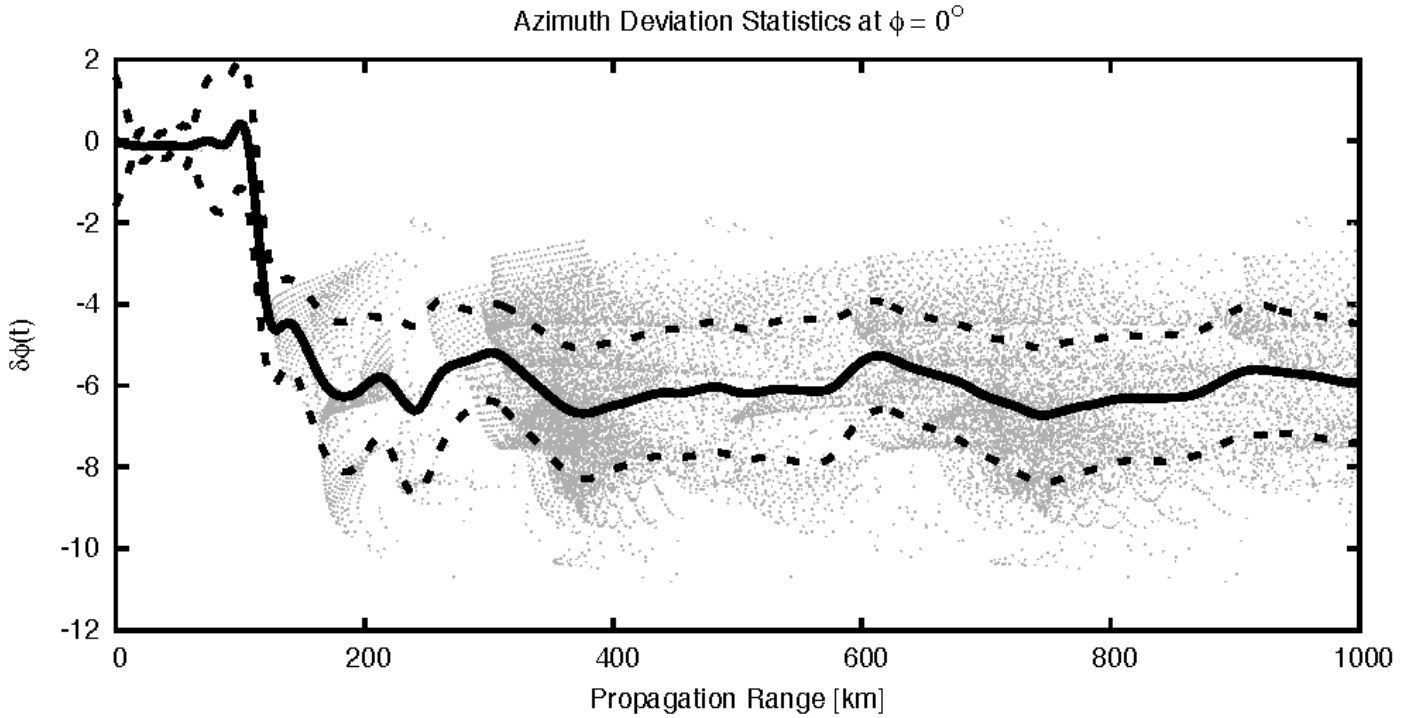
Stochastic Models Improve Location Precision



Modeling Additional Parameters will provide further enhancements to capability

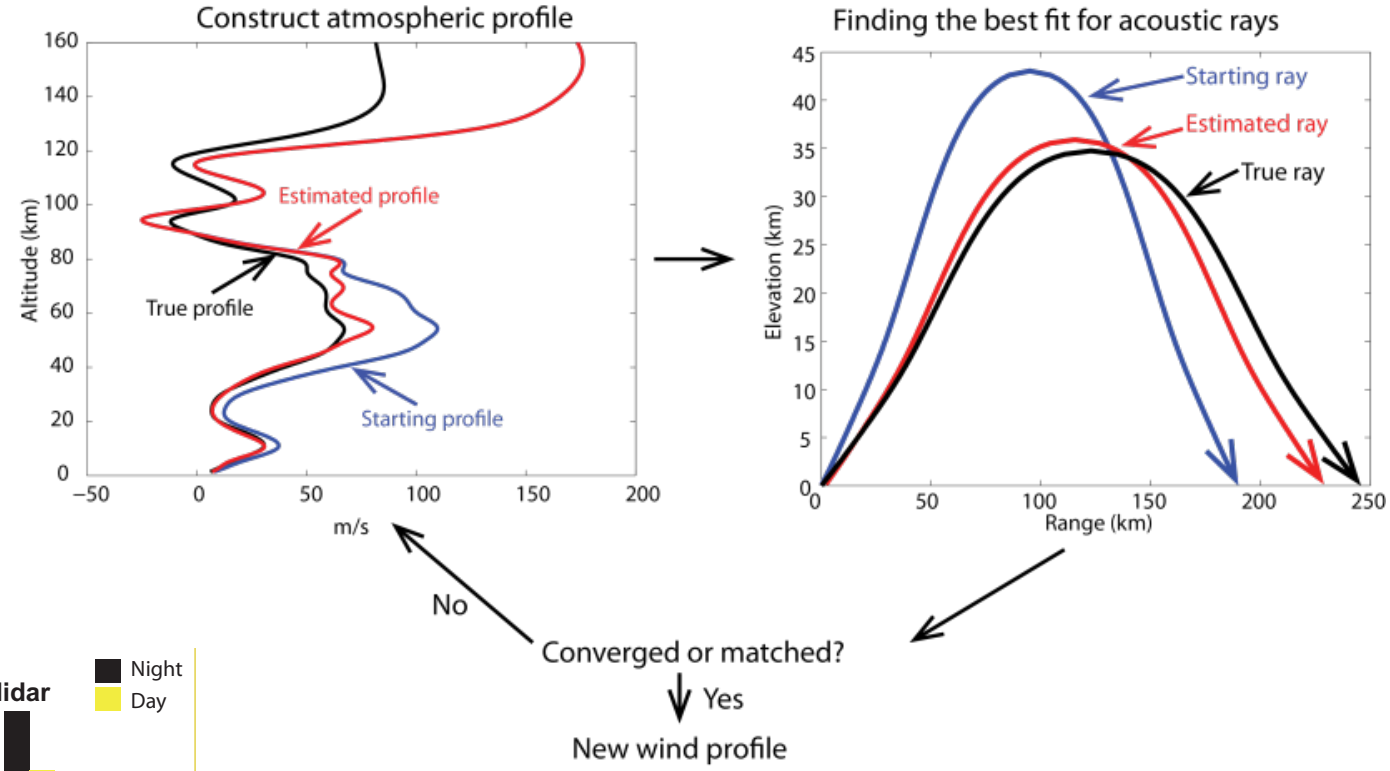
We are working on developing models for other parameters:

- Backazimuth deviation – would improve *location accuracy*
- Transmission loss as a function of frequency – would improve *association false alarm rate* and *yield estimation accuracy*
- Signal Duration – would improve *association false alarm rate* and *yield estimation accuracy*

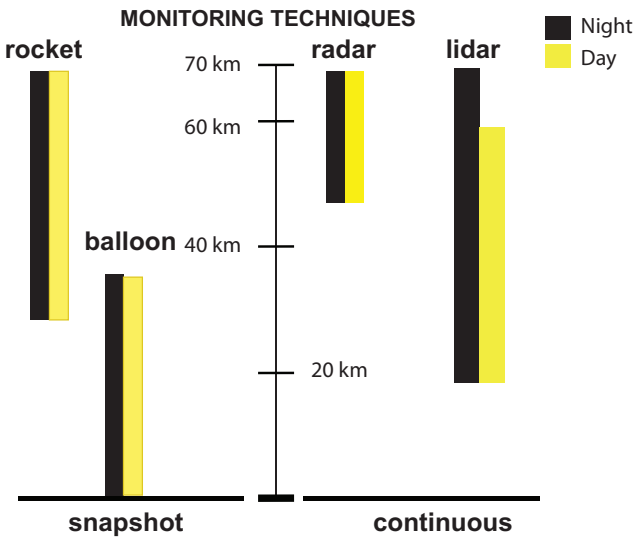


LANL-developed framework for using infrasound data to enhance Atmospheric Models

Iterative inversion schemes account for nonlinearity →

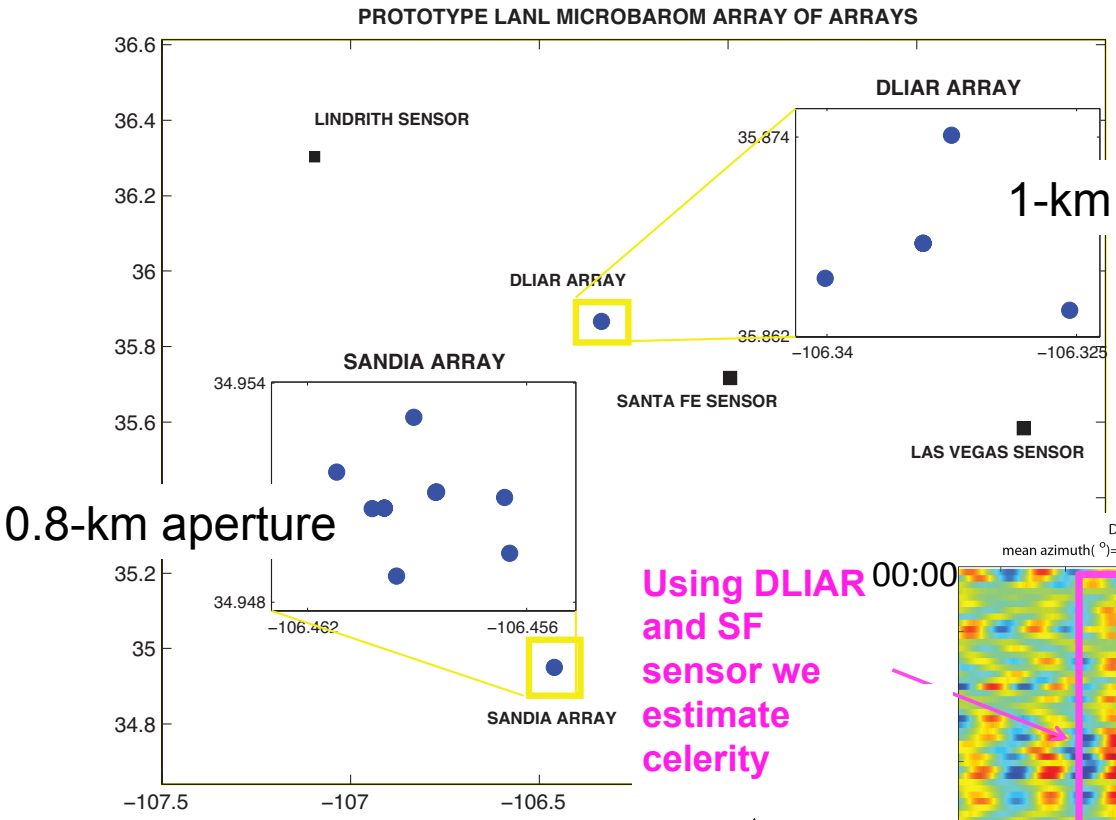


Winds at high altitude come from limited ground-based measurements ↓



- Research conducted under LDRD-ER project
- Key innovation: Mathematical framework for using infrasound from continuous sources with unknown location to update atmospheric models.
- A ubiquitous continuous source is caused by standing waves in the ocean (microbaroms)

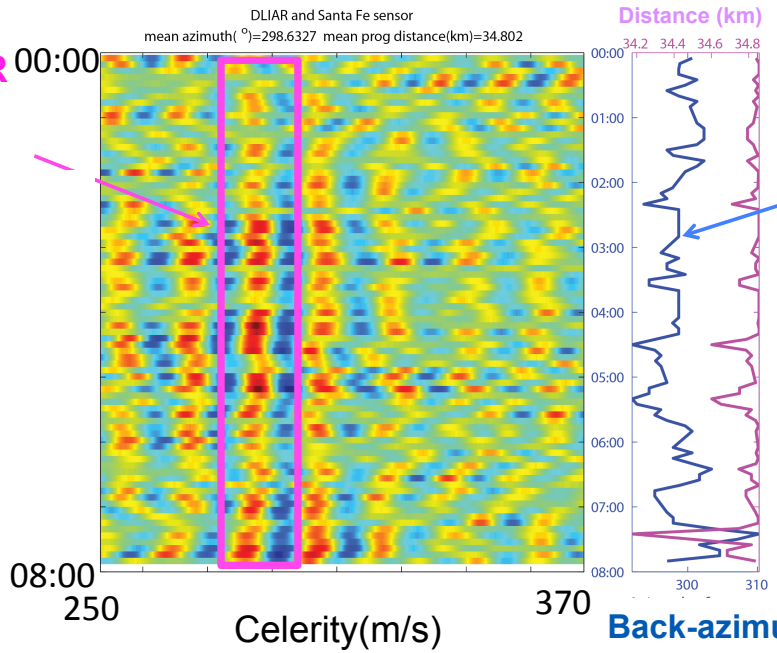
Exploring correlations of Microbaroms



1-km aperture

0.8-km aperture

Correlations indicate refracting energy in troposphere

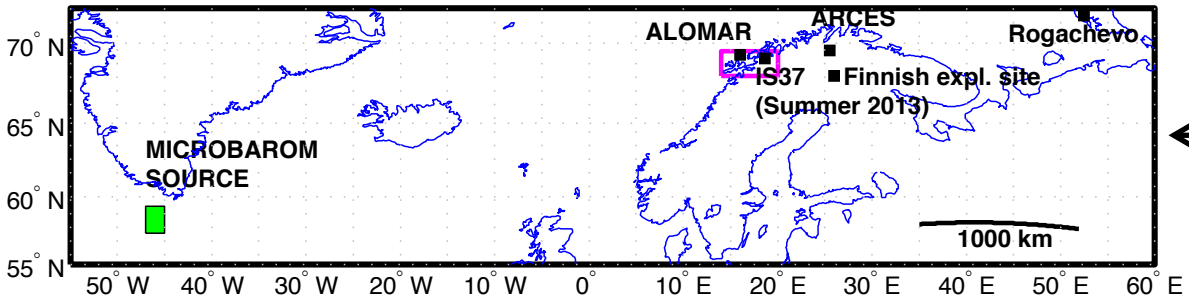


Using DLIAR and SF sensor we estimate celerity

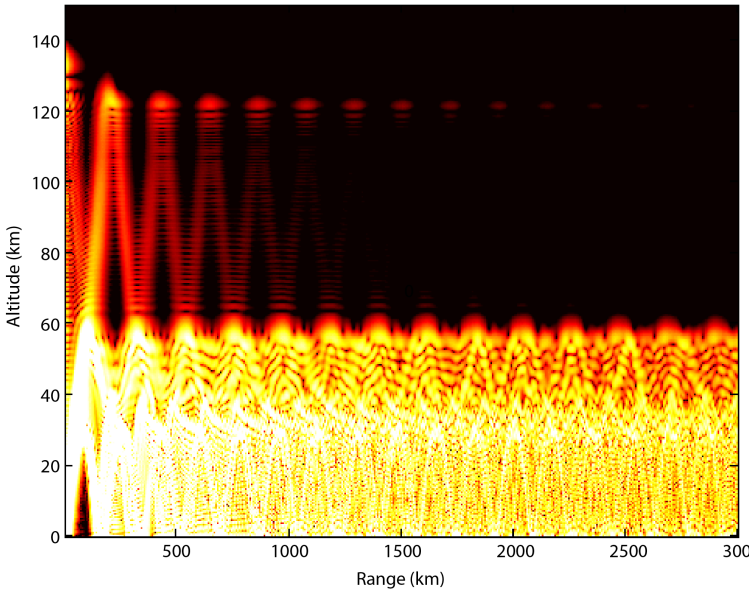
Using DLIAR we estimate back-azimuth

Prototype network of sensor arrays in Northern New Mexico designed to estimate microbarom time delays

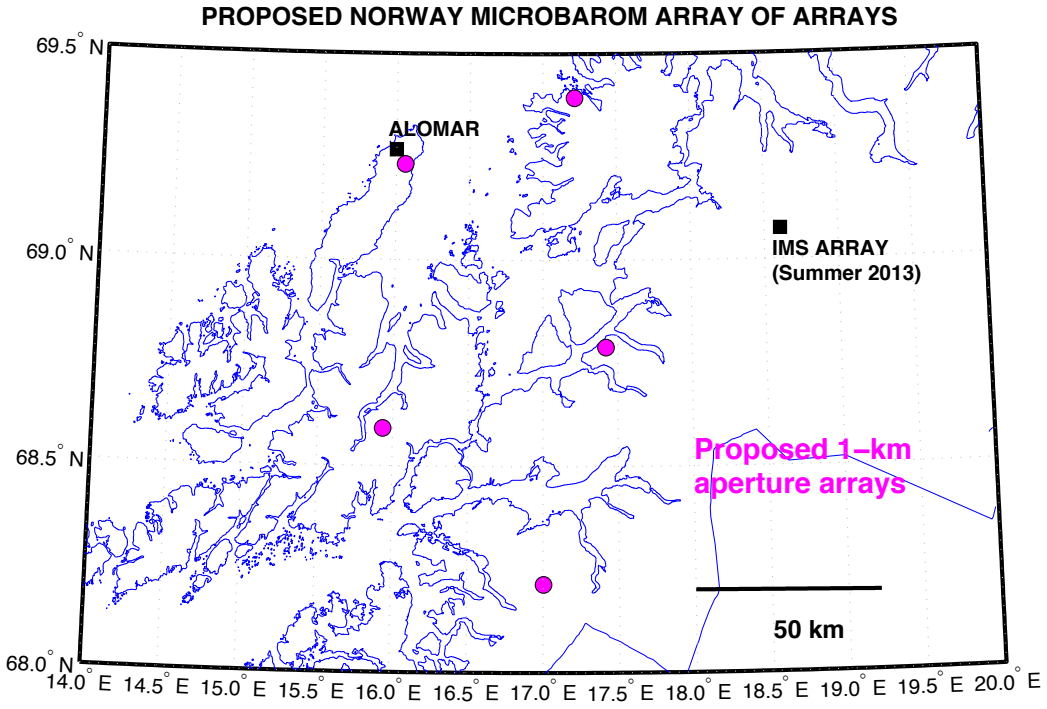
Our planned field experiment in Norway, 2015



Strong microbarom source offshore Southern Greenland



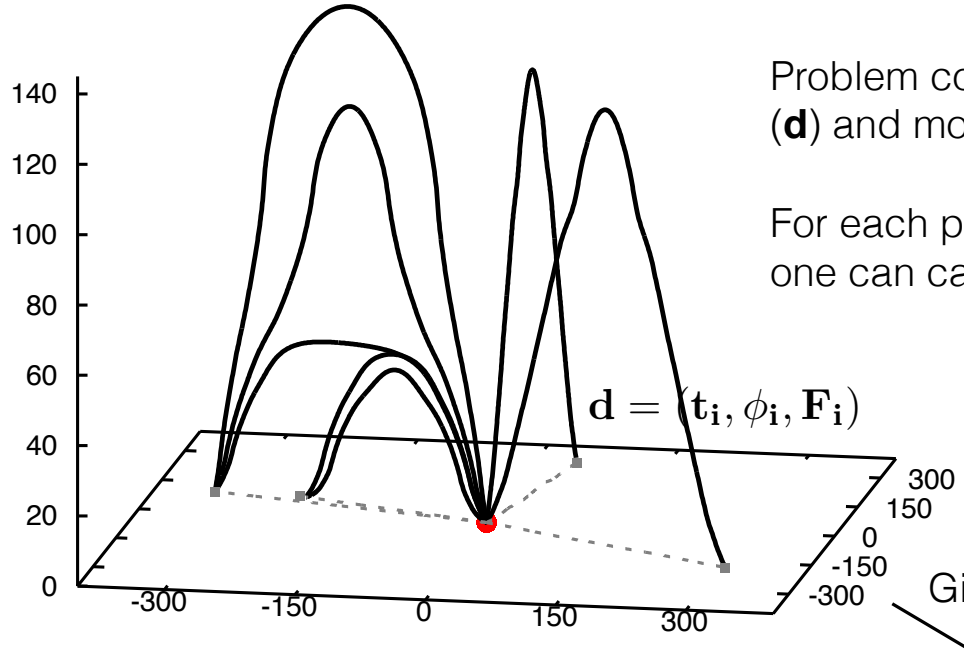
Modeling predicts strong propagation during wintertime



Planned array layout

Simultaneous Inversion of Source and Path

- In principle, an inverse approach for updating the atmosphere can be formulated in the BISL framework where adequate measurements exist
- Such an approach would enable the full quantification of the trade-offs in model parameters for the first time



$$\mathbf{d} = (\mathbf{t_i}, \phi_\mathbf{i}, \mathbf{F_i})$$

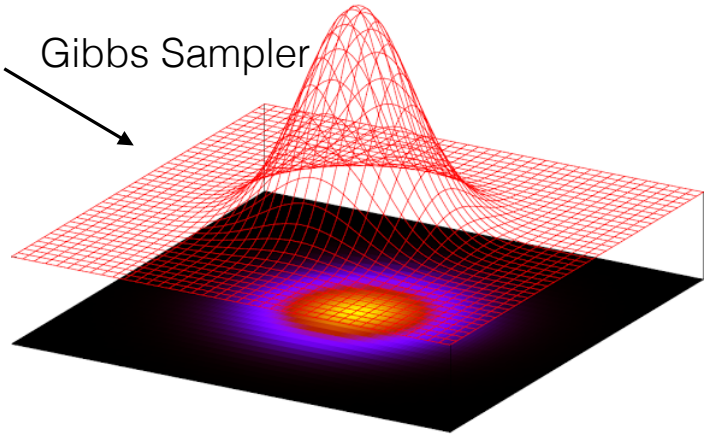
Problem consists of a series of data (**d**) and model (**m**) parameters

For each possible model parameter, one can calculate the fit to the data

$$\mathbf{m} = (x_0, y_0, z_0, t_0, W, \mathbf{\Psi})$$

Model parameters include location, yield, and some representation of atmospheric state

Gibbs Sampler



Multi-parameter PDF

Summary

- Global stochastic models are the only way currently developed to incorporate the dynamic atmospheric effects for automatic infrasound data processing
- Our LANL infrasound research team is leading the development of these models and their practical use
- For more details, see: 'Locating Infrasonic Sources at Regional and Global Distances' by Blom and Marcillo