SAND2016-6884PE

Network Monitoring for Optimal Detection (NetMOD)

B. John Merchant

July/August, 2016

Sandia National Laboratories

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Motivation & Objective

Motivation:

Develop an improved tool to model the performance of global ground-based explosion monitoring systems. Network modeling is needed to be able to evaluate the potential effect of changes to the monitoring systems, to prioritize station deployment and repair, and to assess the overall monitoring capability currently and in the future

Objective:

The objective of this work is to provide CTBTO with a tool based upon relevant research we are able to identify, apply, and potentially improve upon.

Outline

- Why assess network performance
- Research basis
- Recent Improvements & examples
- Future work

Why Assess Sensor Network Performance?

1. Gauge effectiveness of an existing sensor network: what can we see and where do we need to improve?
   - Best approach is just to show actual monitoring results: how well has the network performed?

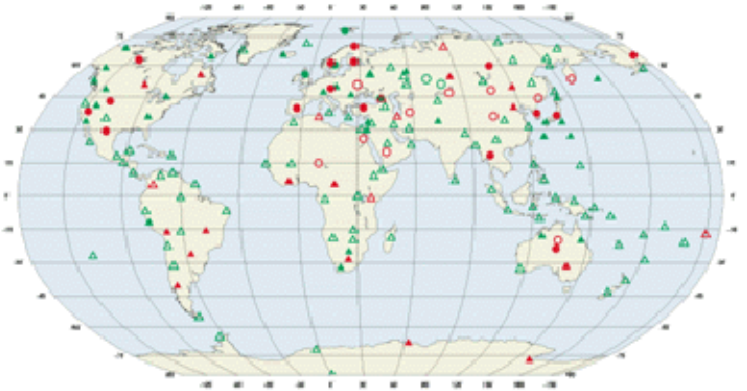
   <u>Problem:</u> limited source sampling (plate boundaries + nuclear test sites)

2. Plan a new/augmented sensor network (new stations) and/or new processing

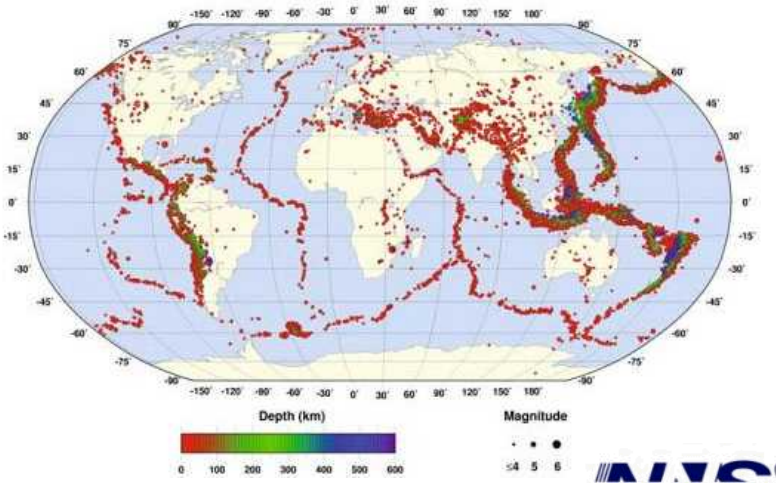
   <u>Problem:</u> no actual data from new sites or new algorithms

In both cases, we must make *assumptions* about what is expected, i.e. we must *model* expected behavior

CTBTO Seismic Sensor Network



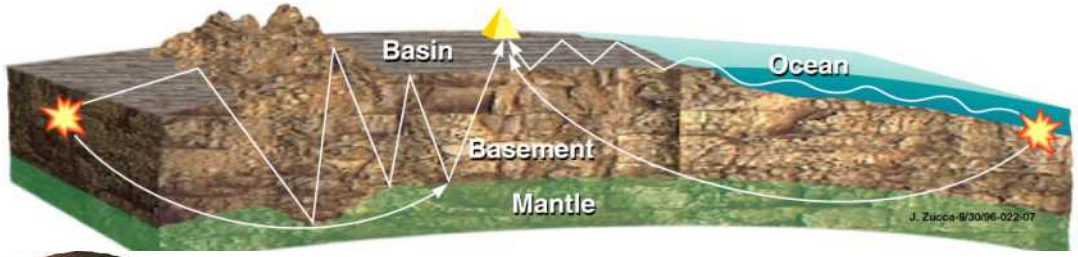
CTBTO Seismic Event Catalog

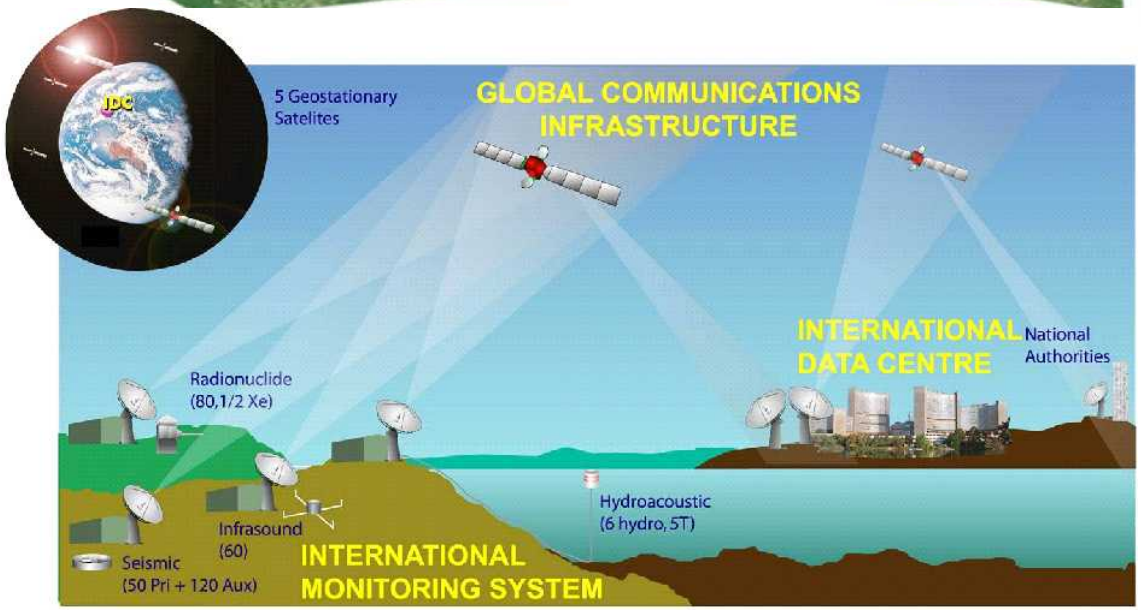


Sandia National Laboratories

NNSA National Nuclear Security Administration

What We Must Simulate





Earth Physics
- Source
- Signal Propagation

Sensor Network
- Seismic
- Hydroacoustic
- Infrasound
- Radionuclide

Data Reliability

Data processing

Our Goal: *simulate all of this to assess overall performance*

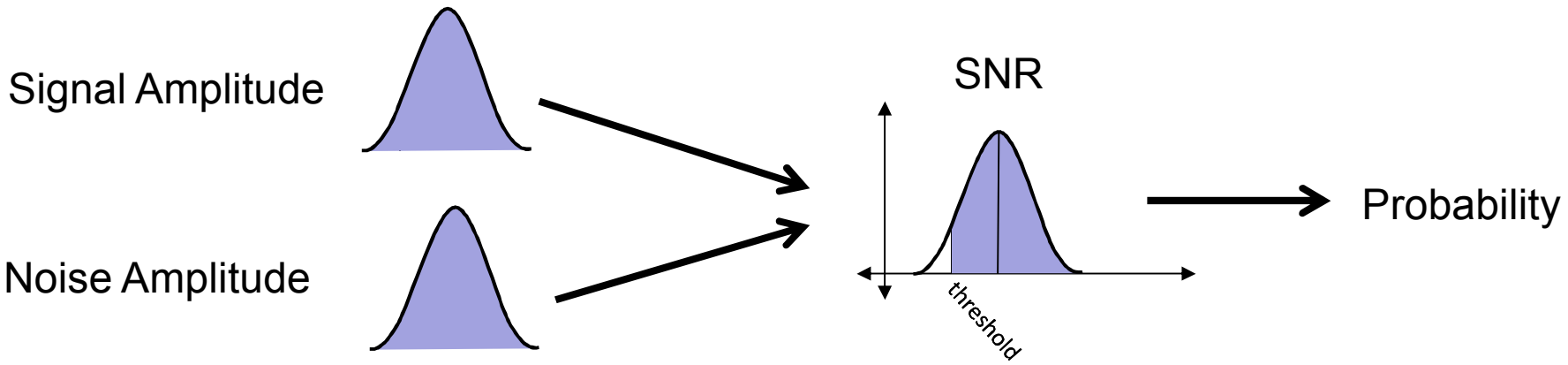
Sandia National Laboratories

Figures taken from LLNL GNEMRD Program and IMS/IDC Regional Technical Training Course: Pretoria-South Africa, 10-14 March 2008

NNSA National Nuclear Security Administration

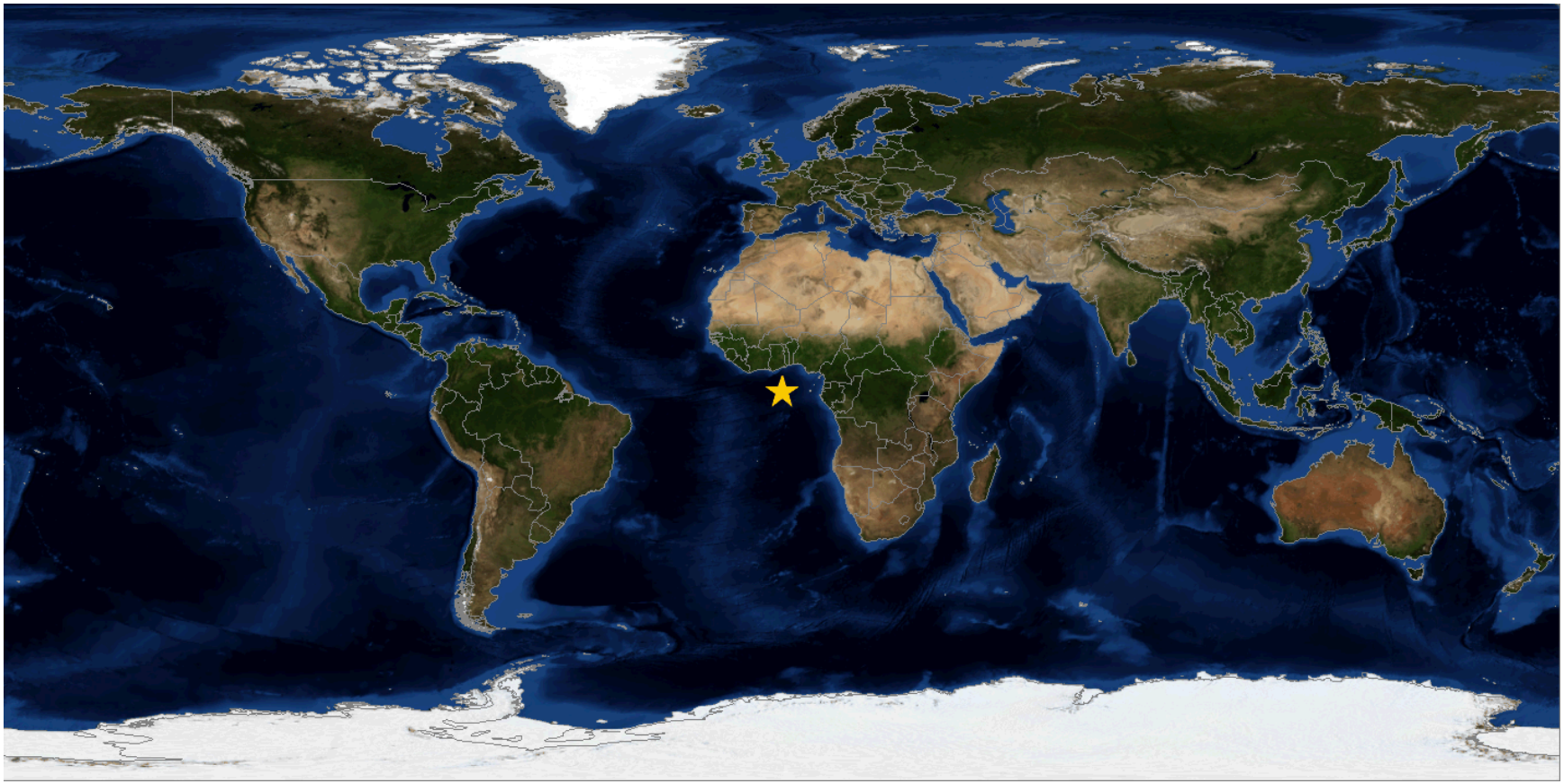
Research Basis

Primarily solving for the probability of detection by simulating the observed signal and noise amplitudes (Sereno, 1990).



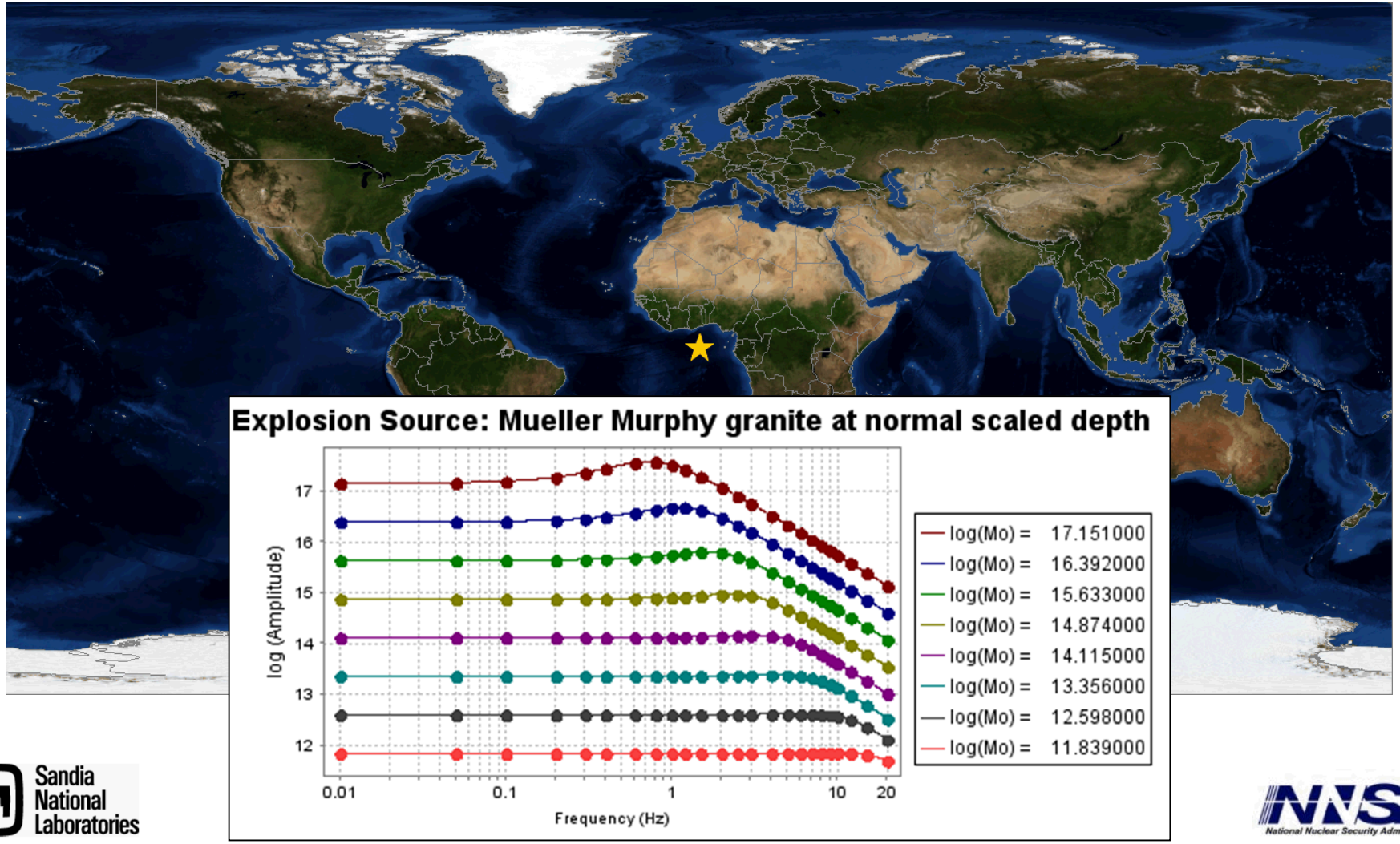
Research Basis

Hypothesize an event location on the earth



Research Basis

Source Model, based on type (eq, ex), coupling, and geographic region

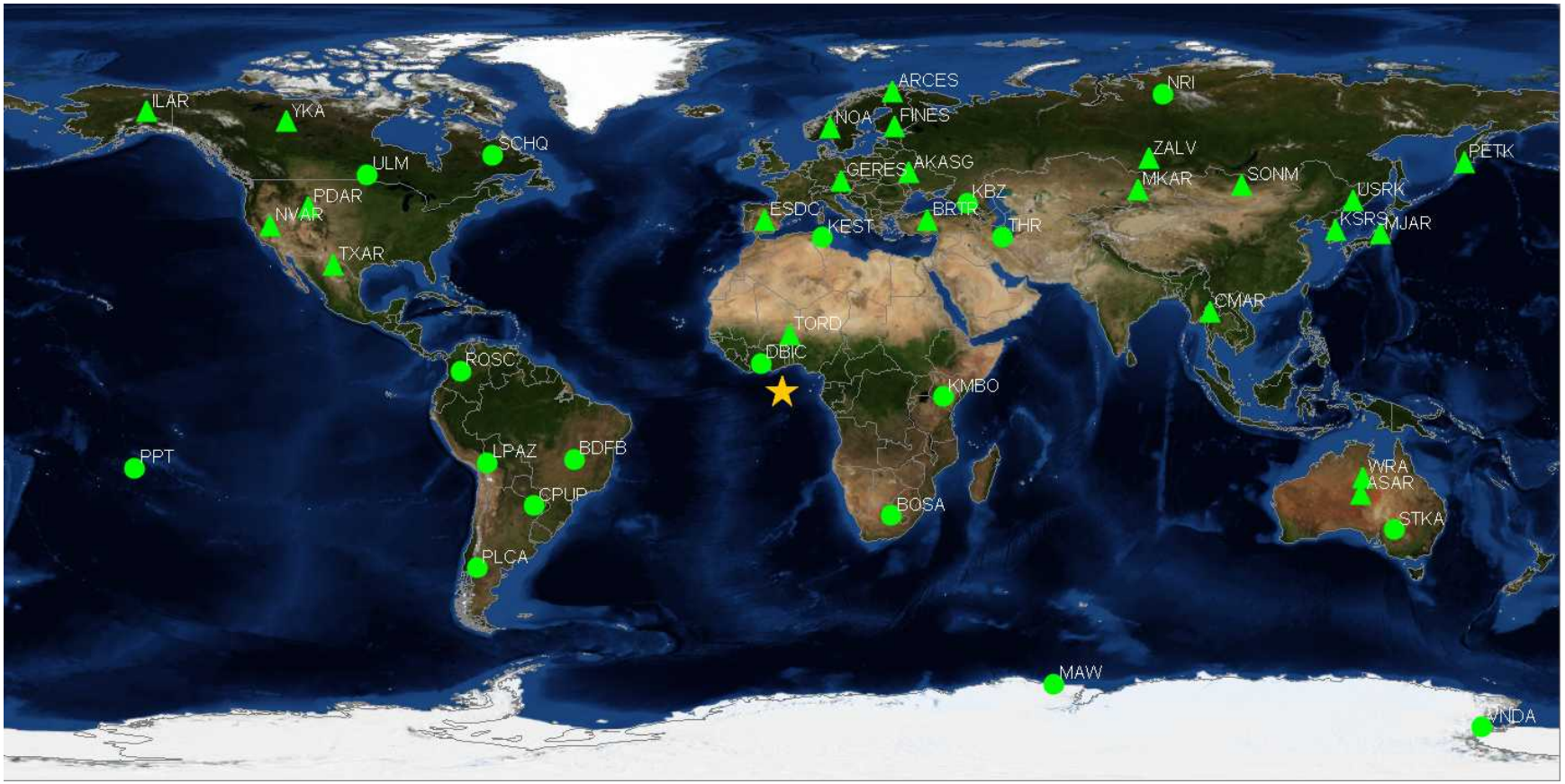


Sandia National Laboratories

National Nuclear Security Administration

Research Basis

Define a network configuration to simulate

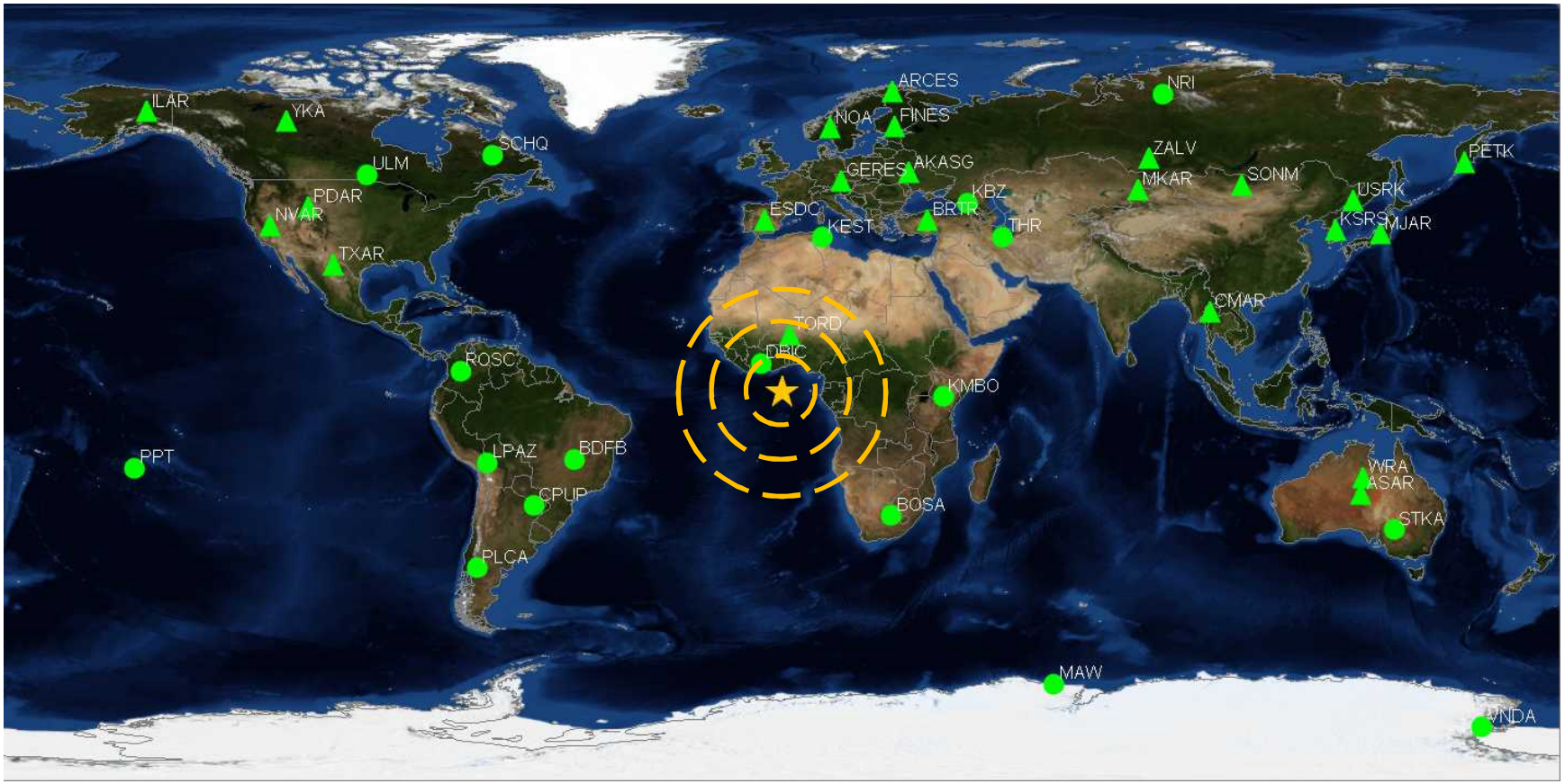


Sandia National Laboratories

National Nuclear Security Administration

Research Basis

Simulate path attenuation as the signal propagates

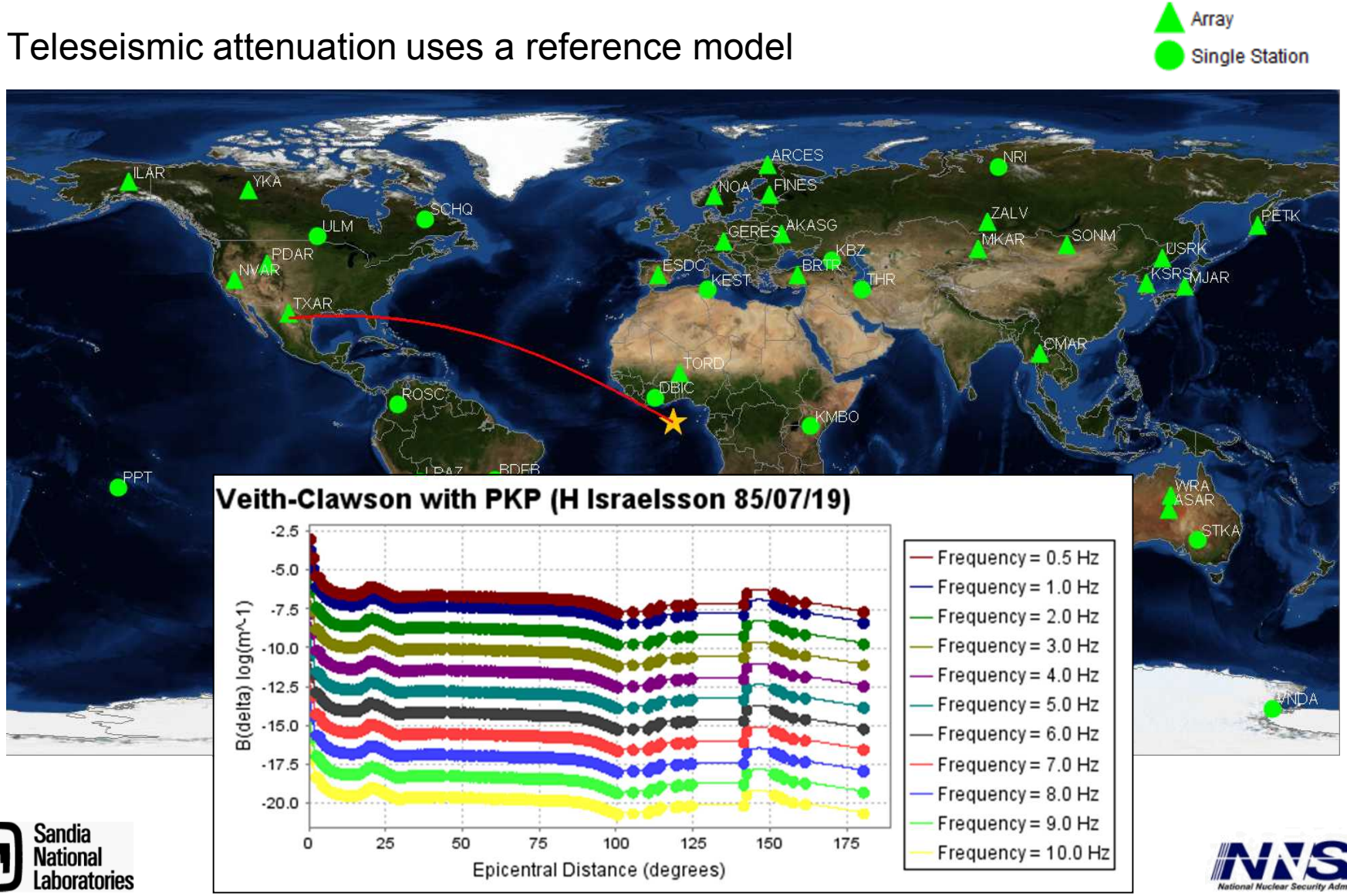


Sandia National Laboratories

National Nuclear Security Administration

Research Basis

Teleseismic attenuation uses a reference model

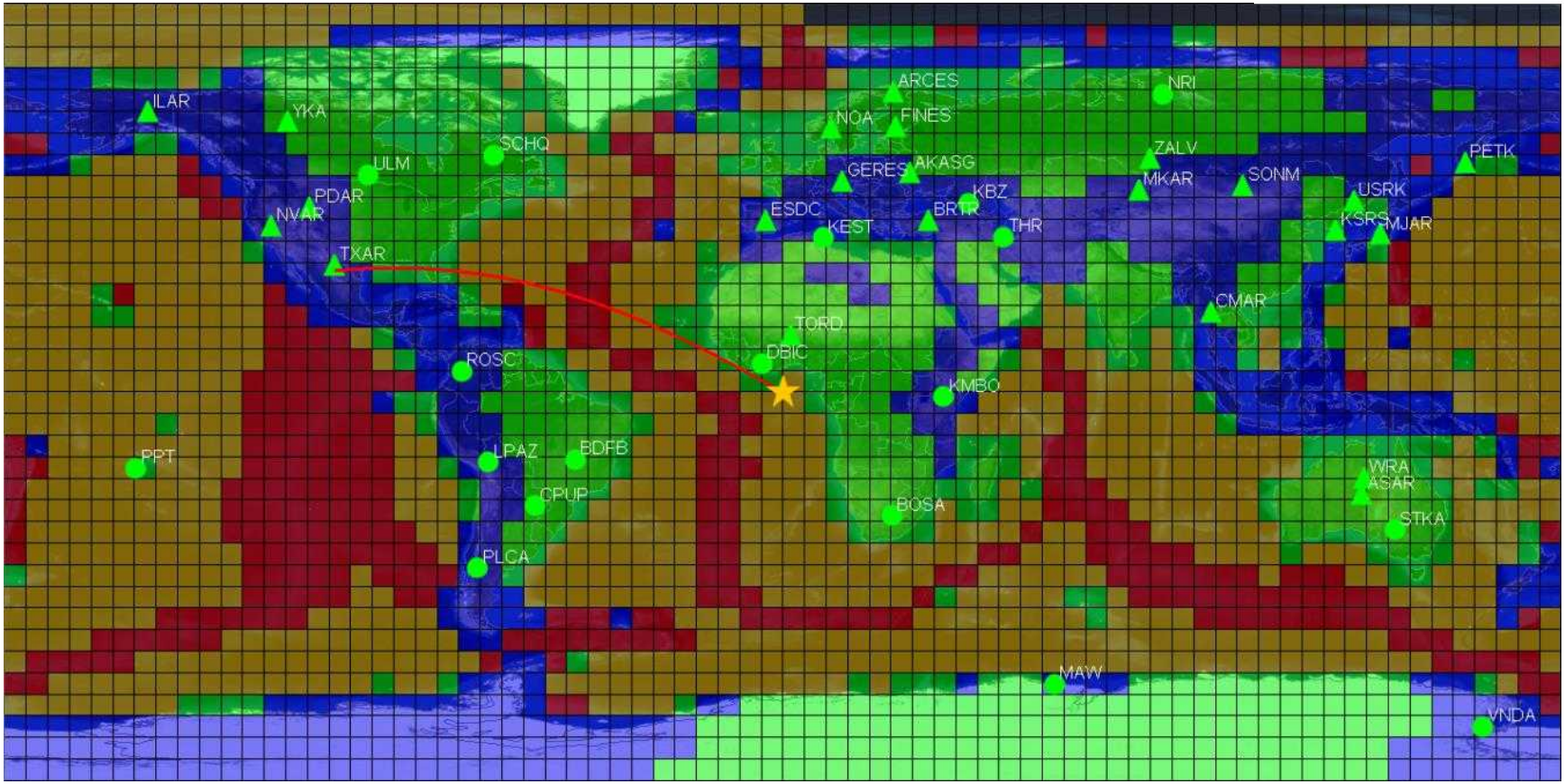


Sandia National Laboratories

NNSA National Nuclear Security Administration

Research Basis

Regional attenuation modeled based on geographic regions

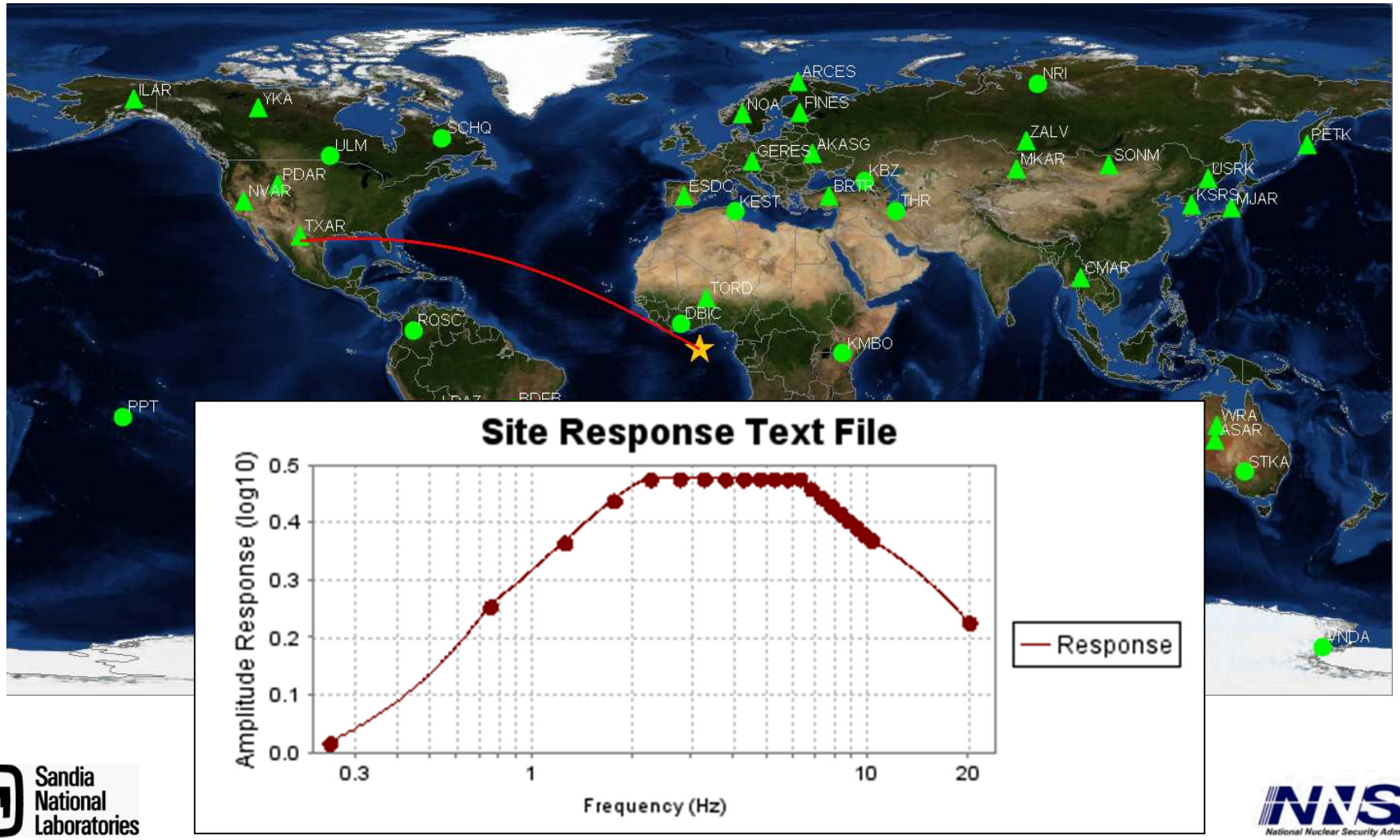


Sandia National Laboratories

National Nuclear Security Administration

Research Basis

Site response, instrument passband, array gain

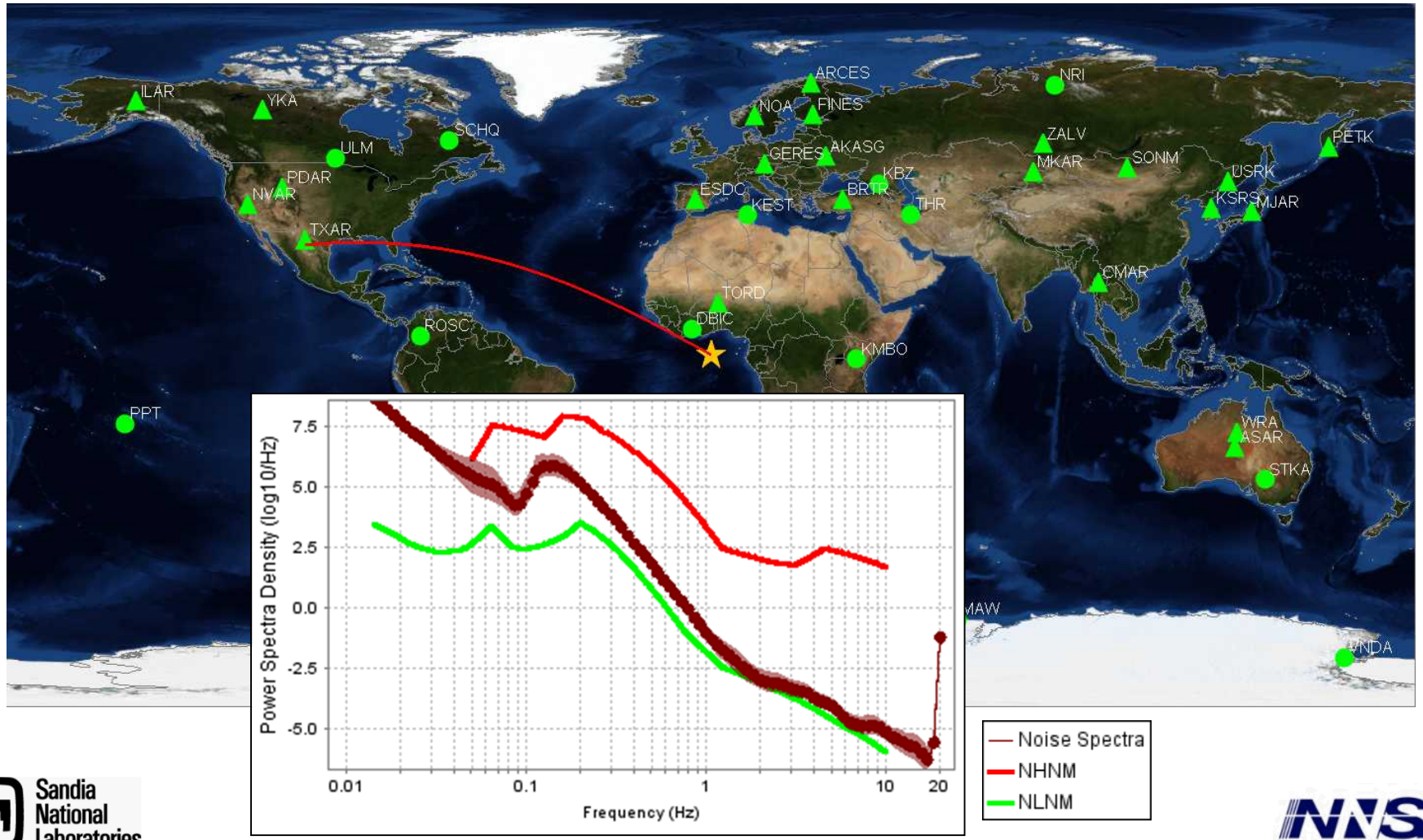


Sandia National Laboratories

National Nuclear Security Administration

Research Basis

Noise includes empirical site noise and earlier phases

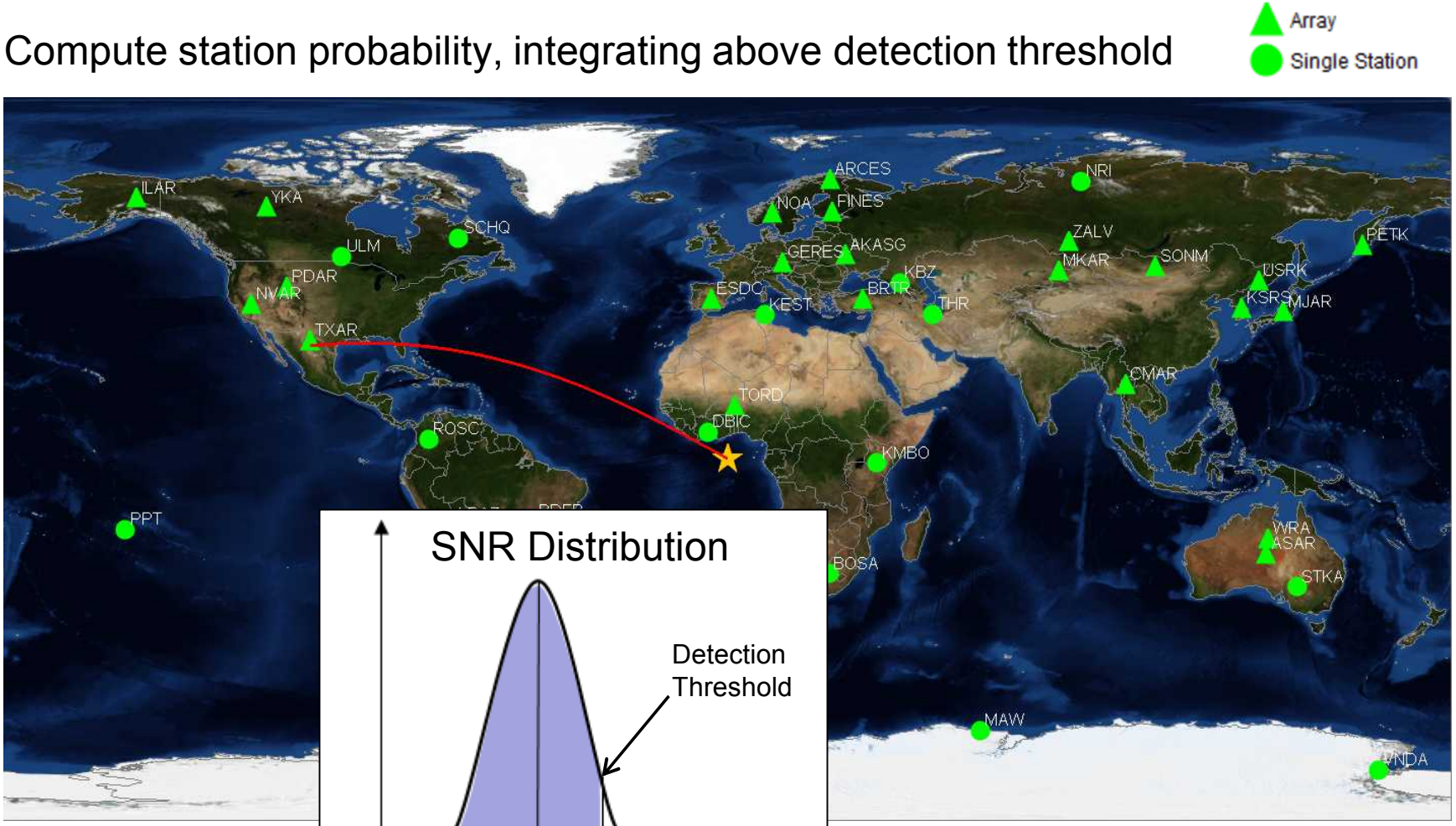


Sandia National Laboratories

National Nuclear Security Administration

Research Basis

Compute station probability, integrating above detection threshold



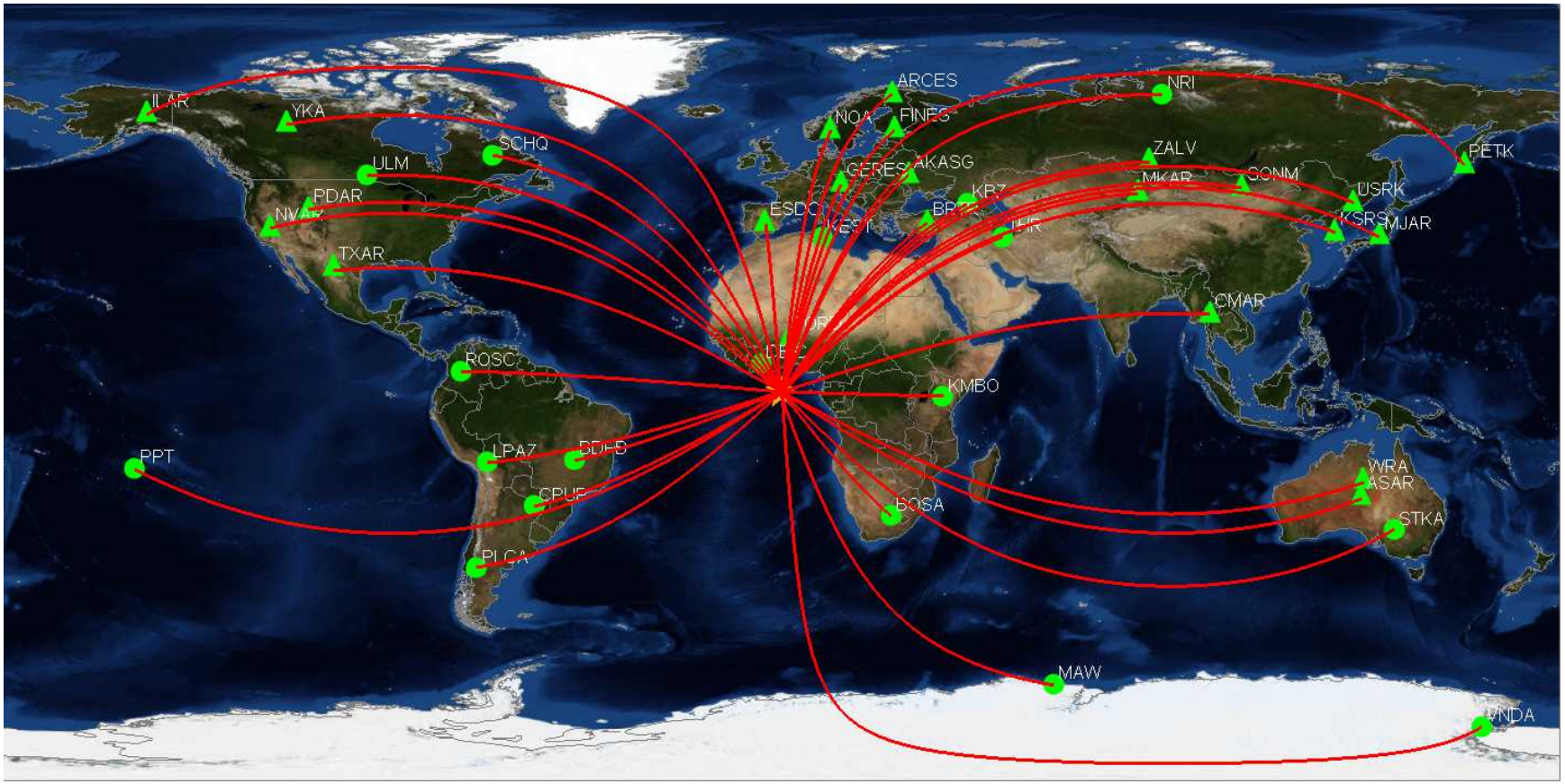
Sandia National Laboratories

National Nuclear Security Administration

Research Basis

Compute probabilities at every station in the network

Combine, using combinatorics, to get a network probability

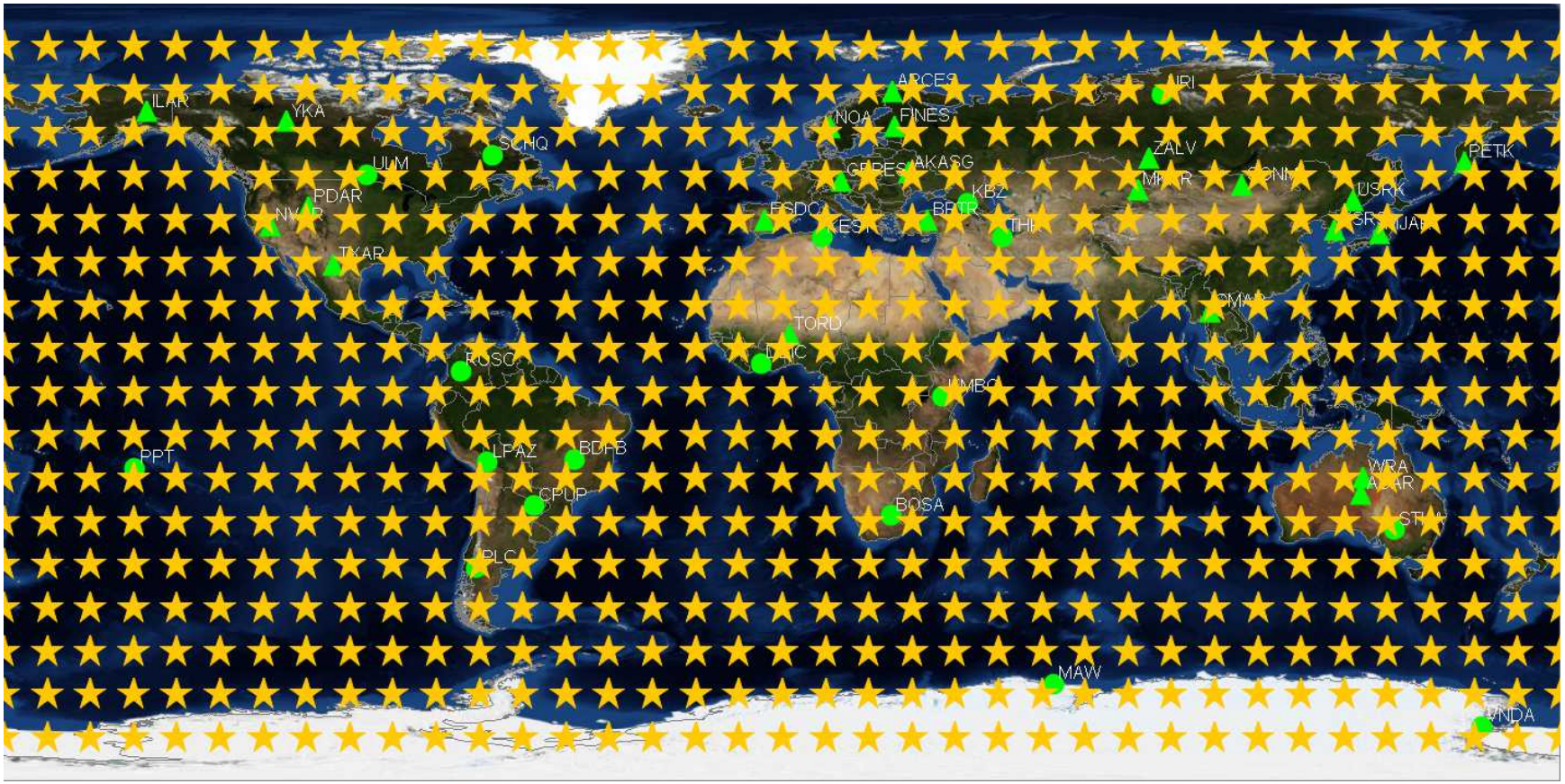


Sandia National Laboratories

National Nuclear Security Administration

Research Basis

Simulation repeats for any number of source locations



Sandia National Laboratories

National Nuclear Security Administration

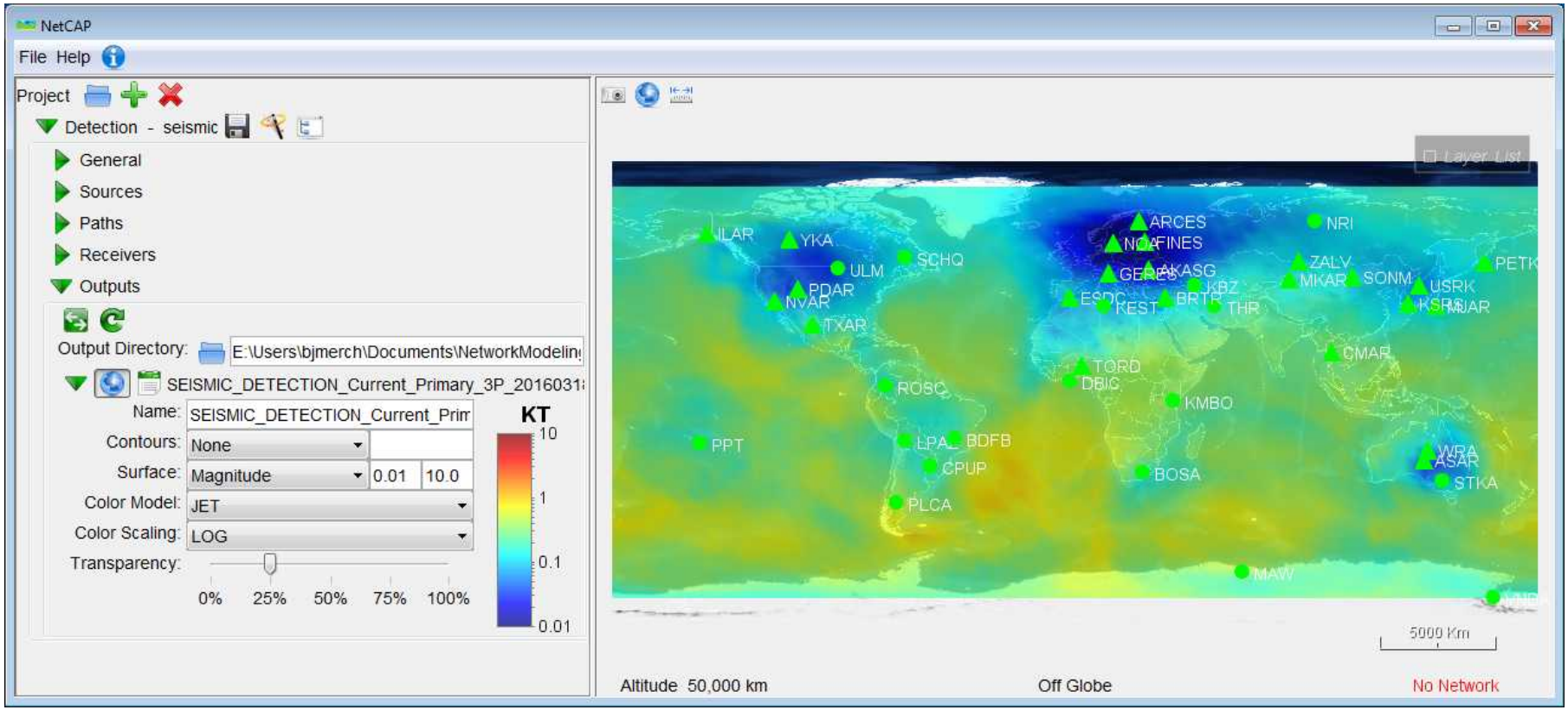
Network Capabilities that may be modeled

- Detection
  - Probability of detecting a given magnitude
  - Magnitude that may be detected with a given probability

- Location
  - Location uncertainty, given the predicted detecting stations?

Seismic - Example

- Minimum detectible size with 90% probability
- Current IMS Primary Seismic Network, 3-station detection



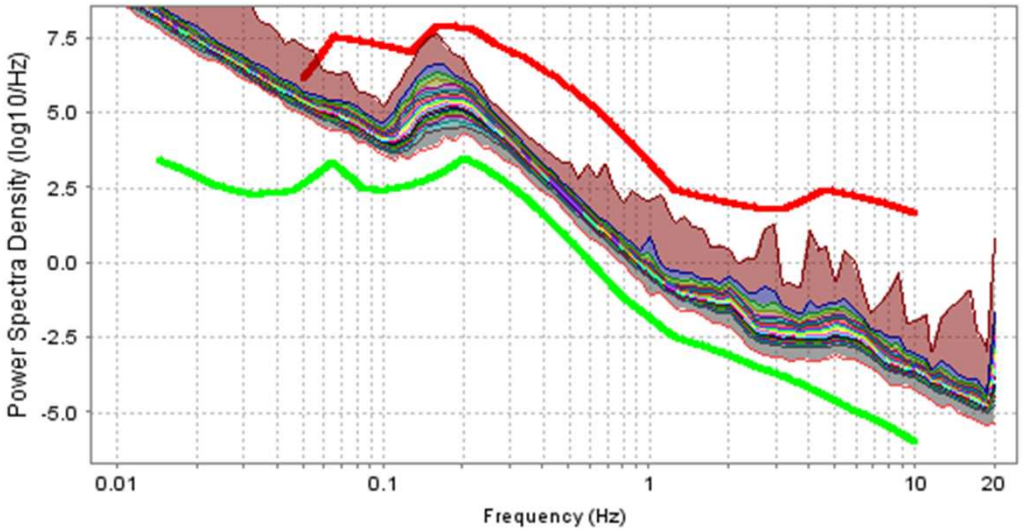
Sandia National Laboratories

National Nuclear Security Administration

Improvements upon earlier research

- Monte Carlo simulations
  - Bypass assumption of normal distributions

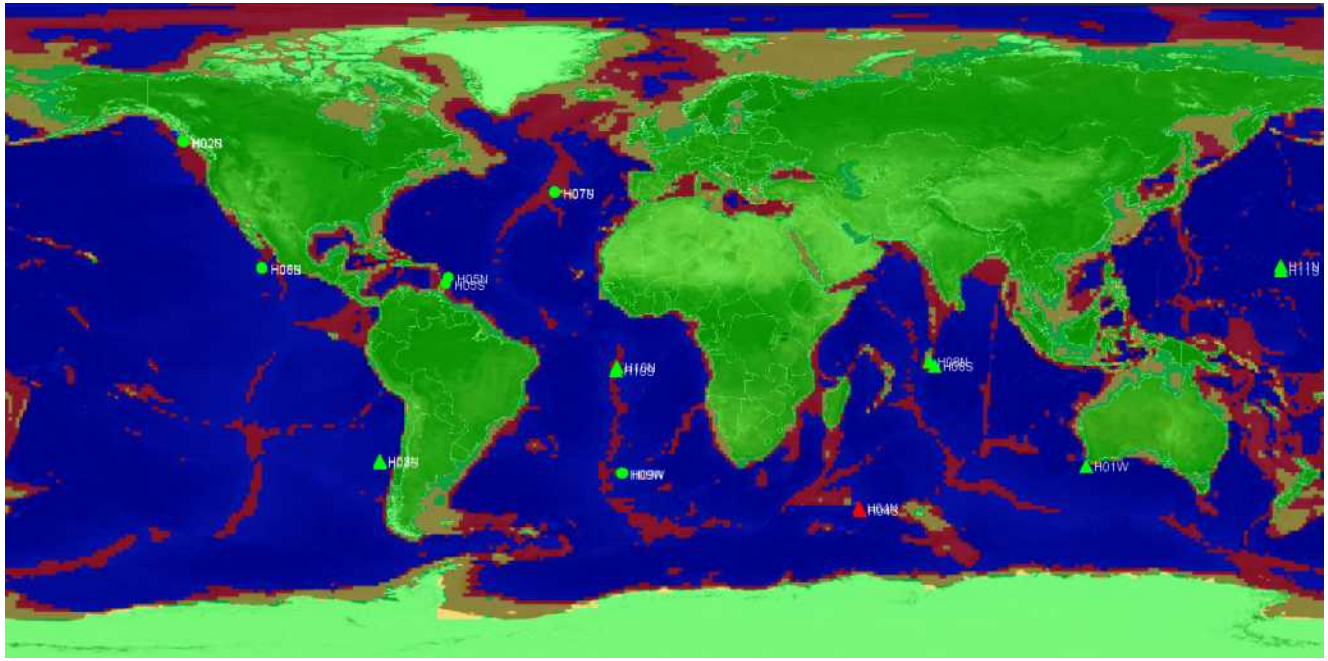
- Enhanced empirical site noise models:
  - Worked with IDC to obtain empirical site noise data
  - Models that vary with time of day and time of year
  - Cumulative Distribution Function, no assumption of a normal distribution



CDF of Site Noise

Hydroacoustic

- New simulation technology
- Path attenuation based on bathymetry model
- Line-of-sight blockage model.
- Does not model reflection / refraction of signal
  - Some small localized impact
  - large computational increase

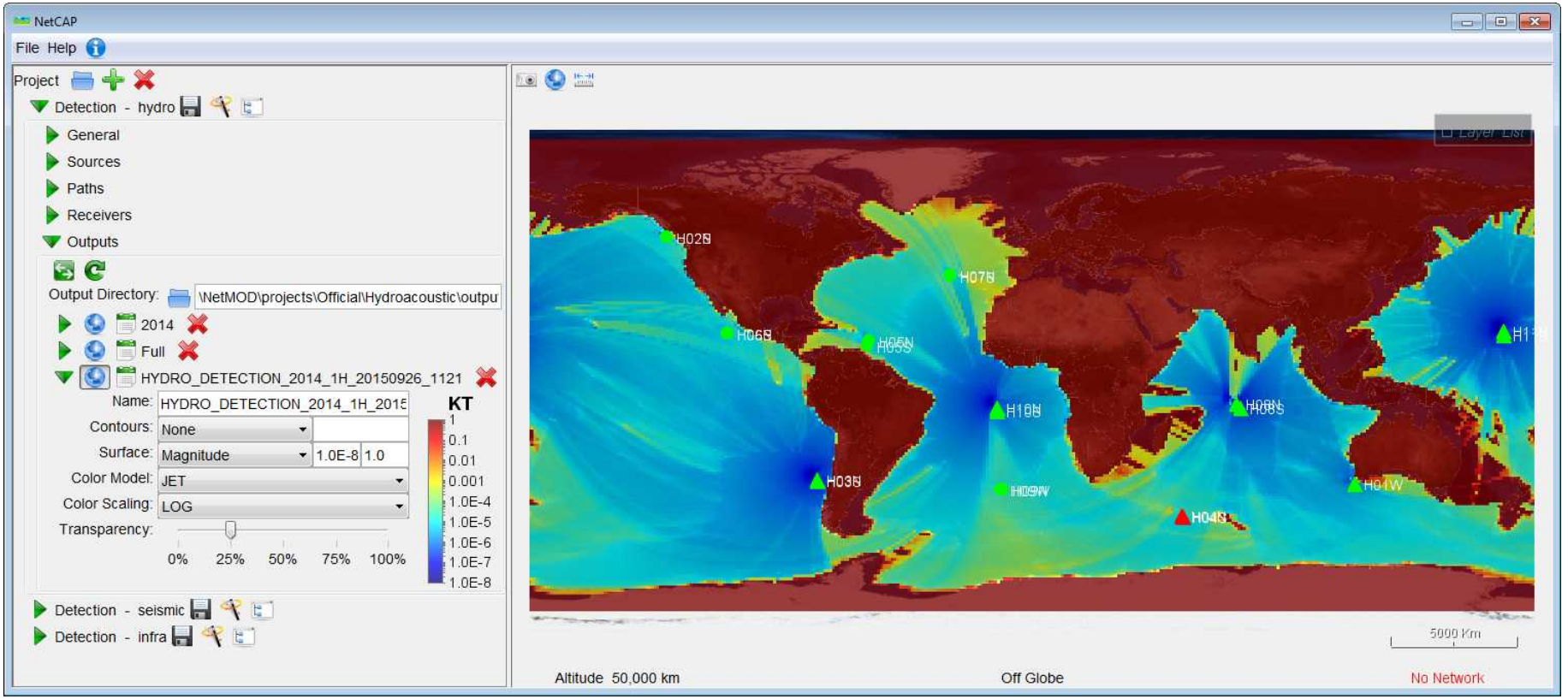


Sandia National Laboratories

NNSA National Nuclear Security Administration

Hydroacoustic - Example

- Minimum detectible size with 90% probability
- Current 10 station IMS network
  - H04 is offline
- 1-station detection



Sandia National Laboratories

National Nuclear Security Administration

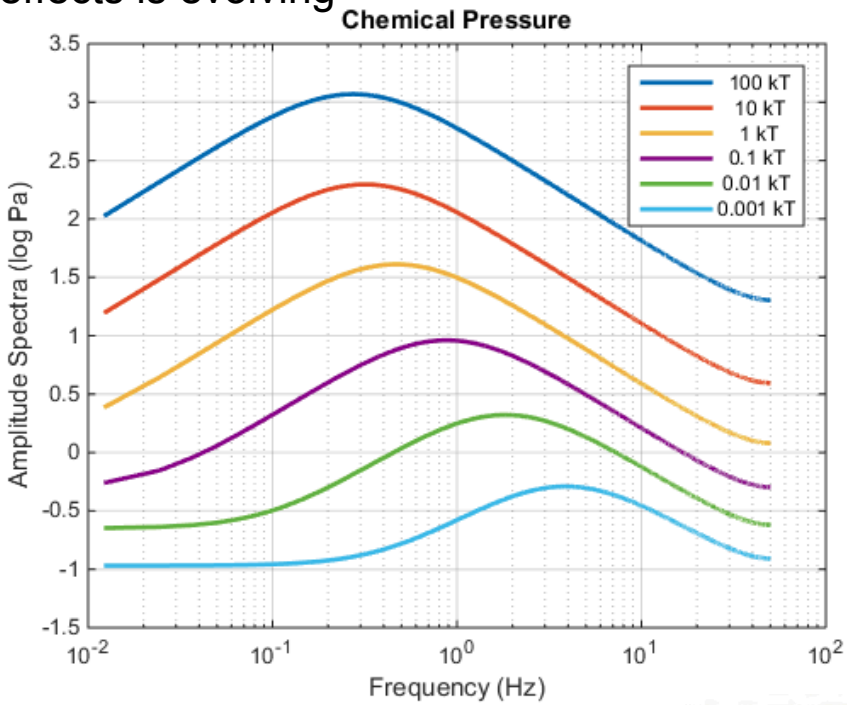
Infrasound

- New simulation technology
- Presumes that stratospheric signal path dominates detection

- Fundamental problems:
  - Atmosphere is a dynamic medium
  - Research on how to account for those effects is evolving
    - Attenuation
    - Travel Time

- Utilizes research from:
  - Whitaker, et al (2003)
  - Green & Bowers (2010)
  - Le Pichon, et al (2012)
  - Kinney & Graham (1985)

- Results are significantly different



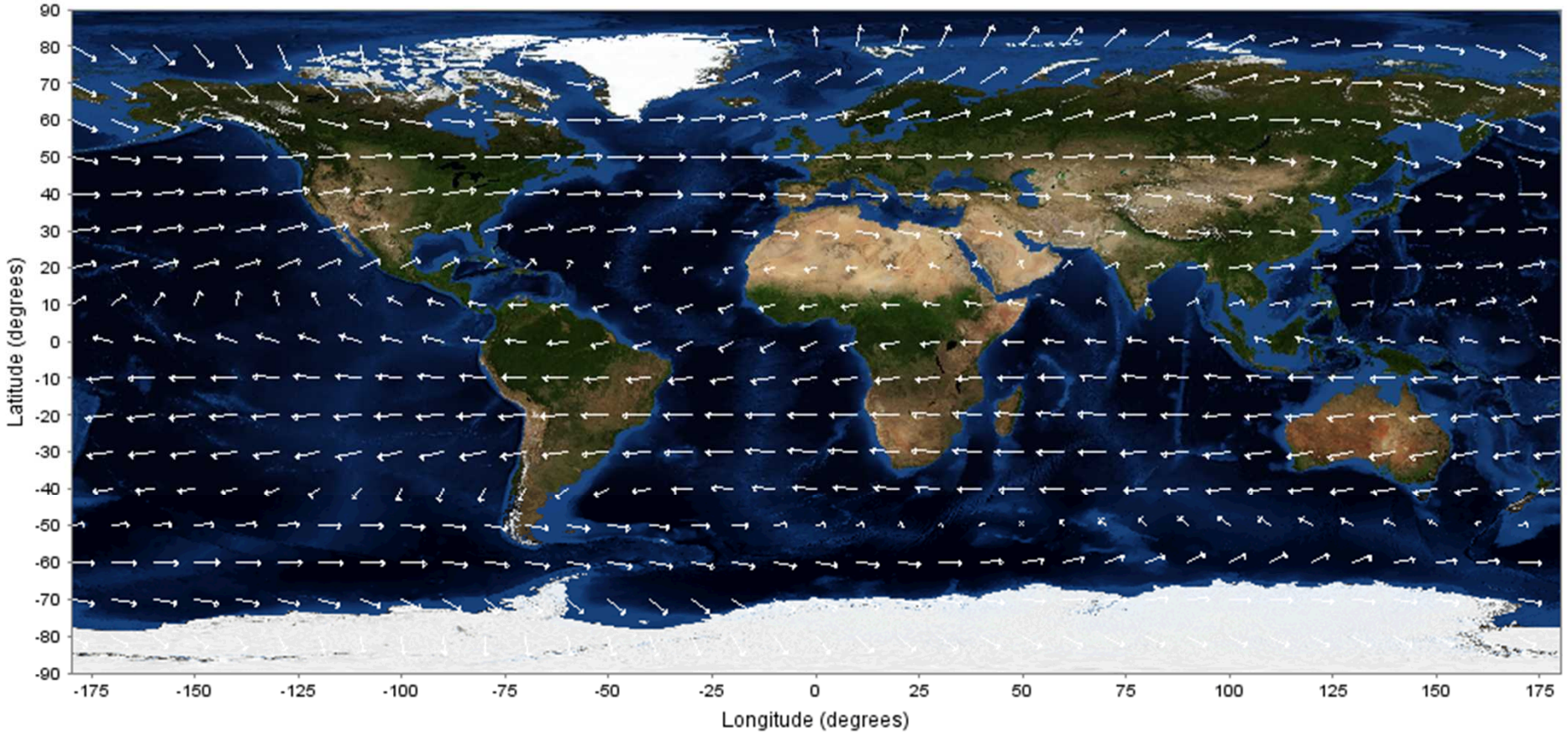
Kinney & Graham (1985)

Sandia National Laboratories

National Nuclear Security Administration

Infrasound – Wind Models

- Incorporated Climatological (seasonal) Horizontal Wind Model:
  - HWM07 and HWM14 from Navy Research Laboratory



Sandia National Laboratories

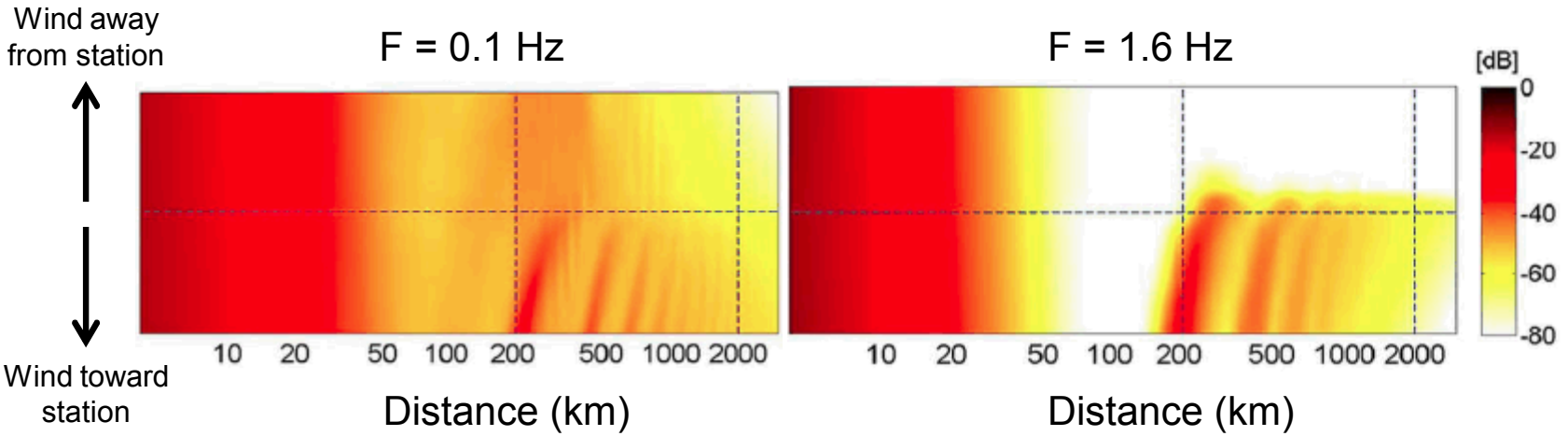
NNSA National Nuclear Security Administration

Infrasound – Wind Attenuation

- Variable wind conditions affect path attenuation
- Earlier attenuation models (Whitaker 2003), only accounted for wind speed and distance:

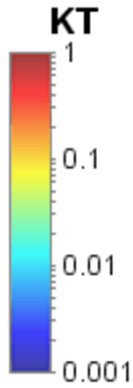
$$\log atn = 0.018 * \mathrm{v_s} - 1.4072 * \mathrm{R}$$

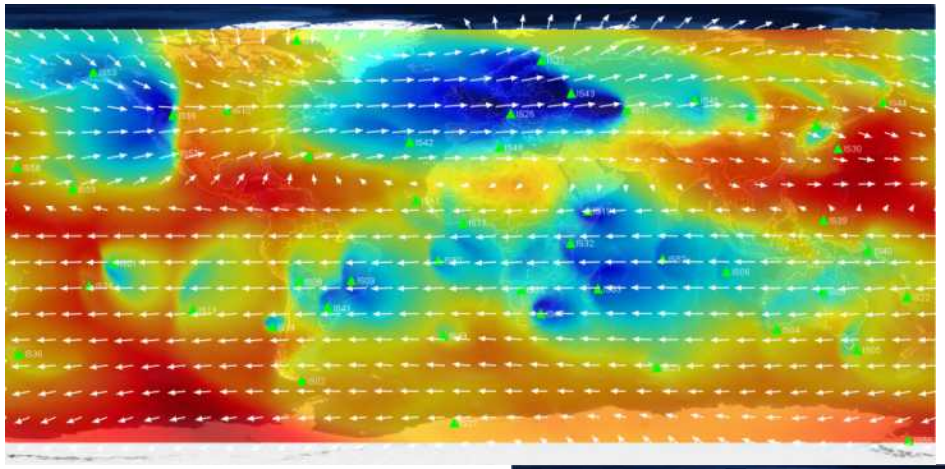
- More recent models (LePichon, 2012) incorporate dependence between wind speed, distance, and frequency:

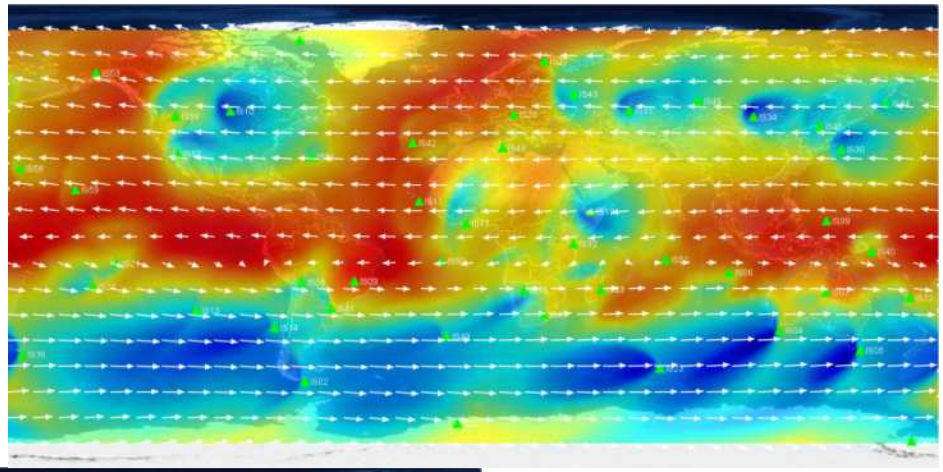


Infrasound – Example

- Minimum detectible size with 90% probability
- Current 48 station IMS network
- 2-station detection, HWM 2007 winds, 2013 IDC noise data



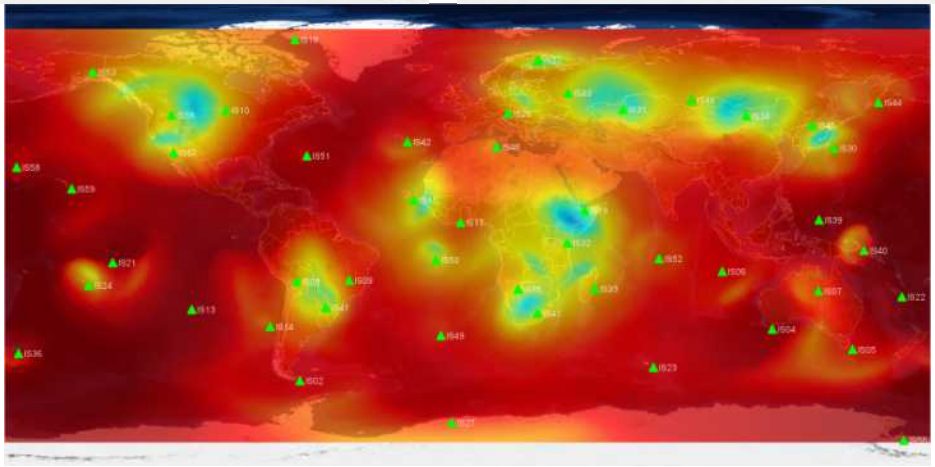




January 1

July 1

No Wind



Sandia National Laboratories

National Nuclear Security Administration

Summary

- Provided a usable tool that applies current modelling research
  - Version 1.0 delivery in 2013 with just Seismic.
  - Version 2.0, pending review completion, in 2016.

- Improved upon earlier capabilities to include:
  - Monte Carlo simulations
  - Enhanced empirical site noise models
  - Seismic Simulations
  - Hydroacoustic Simulations
    - Simple line-of-site attenuation model
    - Blockage models to prevent signals from passing through land
  - Infrasound Simulations
    - Several recent research models
    - Climatological wind models

Future work

Location Simulations

- Determine expected location accuracy
- Number of stations detecting
- Travel-time model & uncertainty

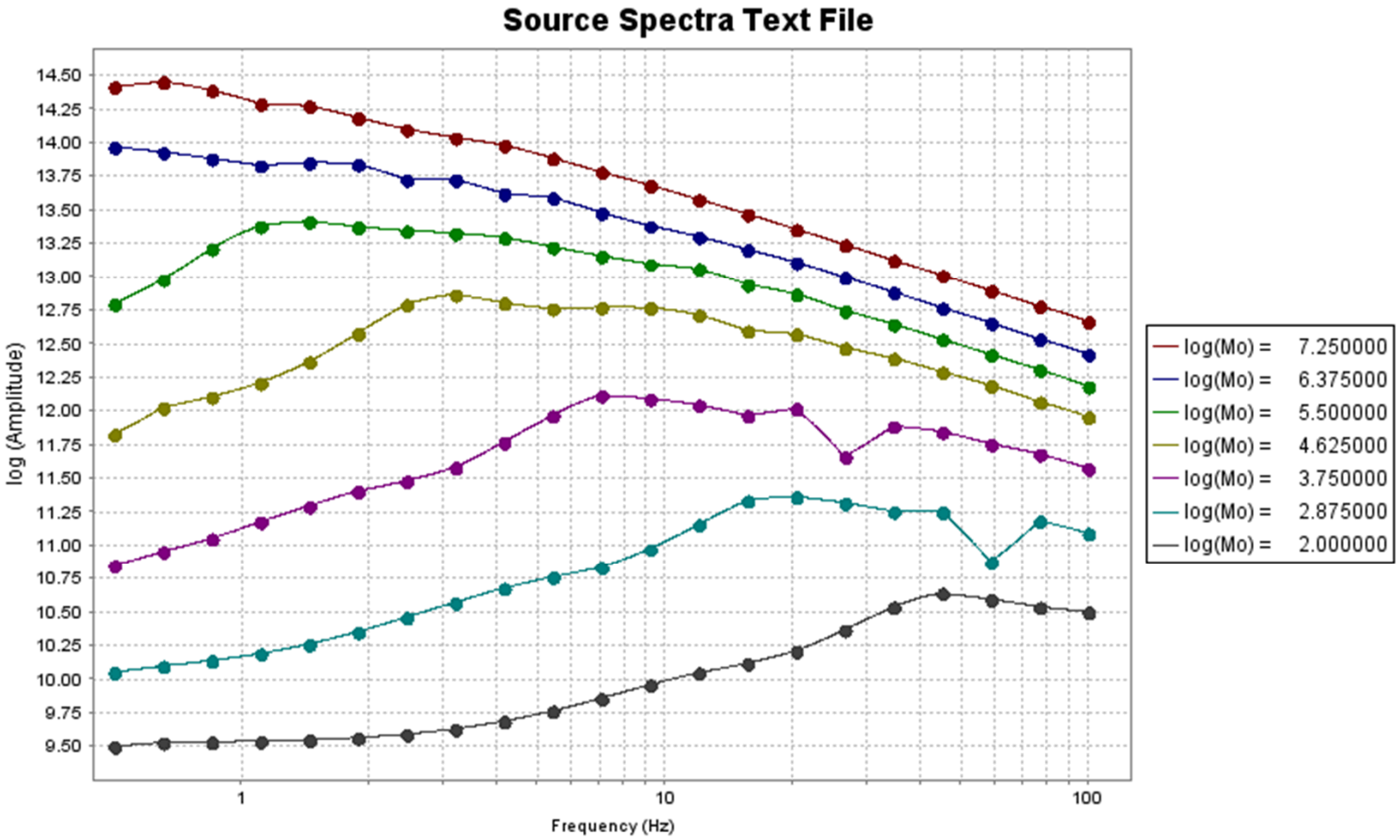
Infrasound

- Incorporate real-time Meteorological Wind Models:
  - Ground to Space (G2S)
  - European Center for Meteorological Weather Forecasting (ECMWF)

Questions?

Backup Slides

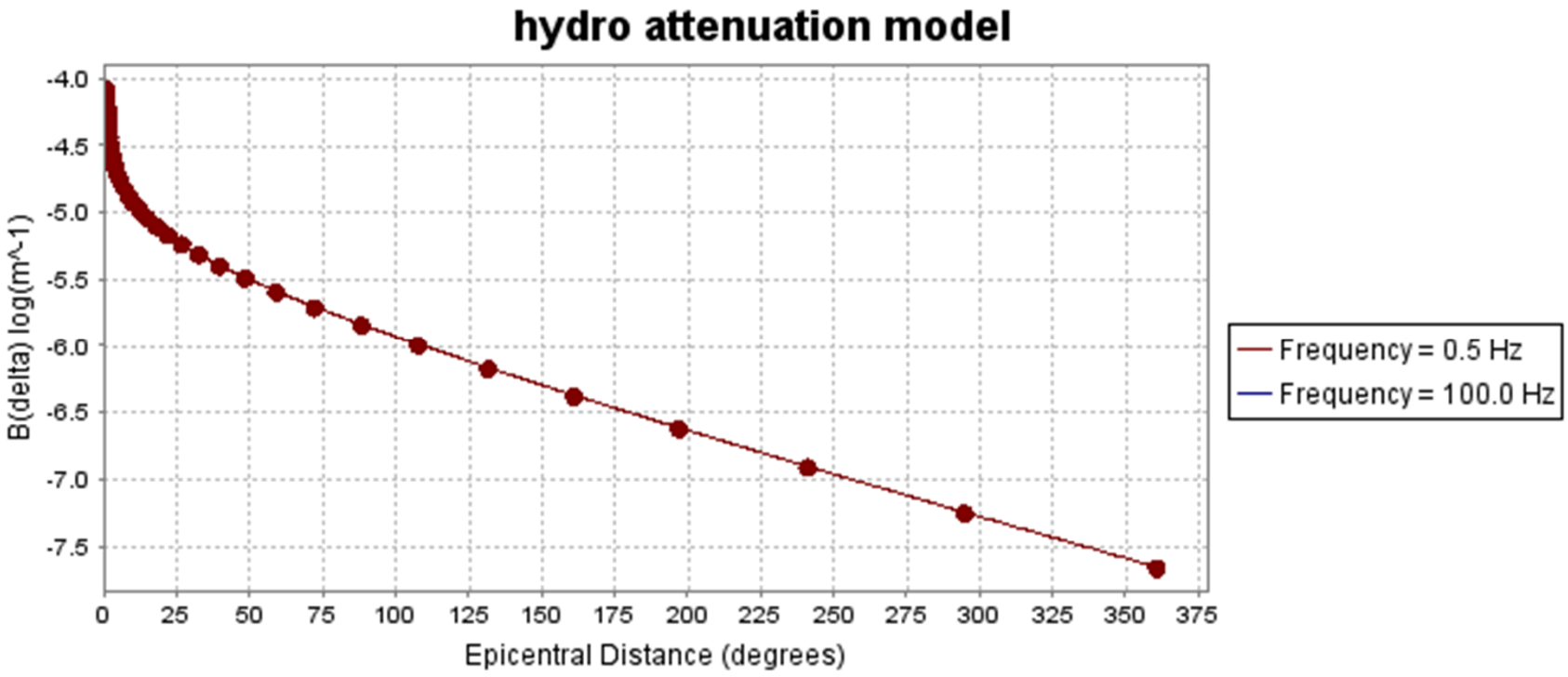
Backup – Hydro Source



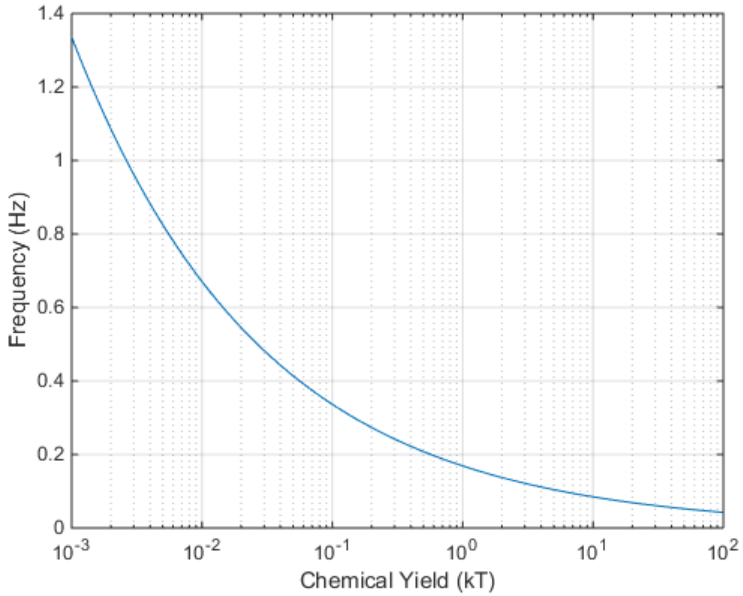
Sandia National Laboratories

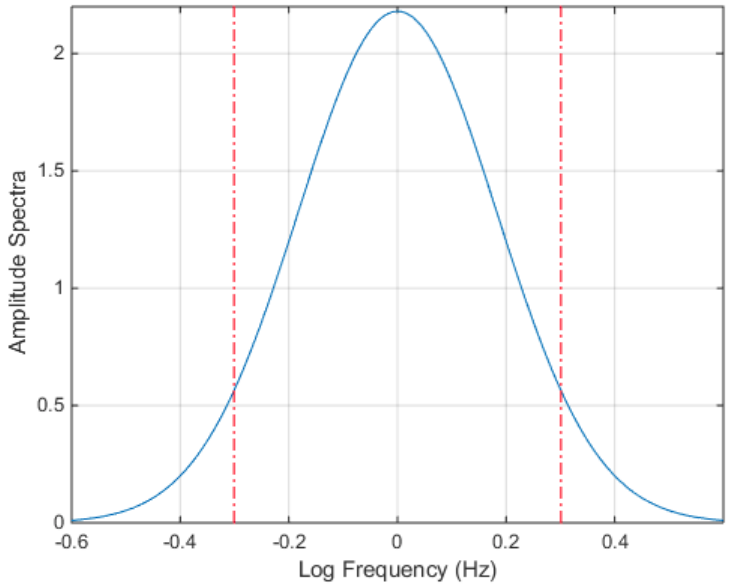
National Nuclear Security Administration

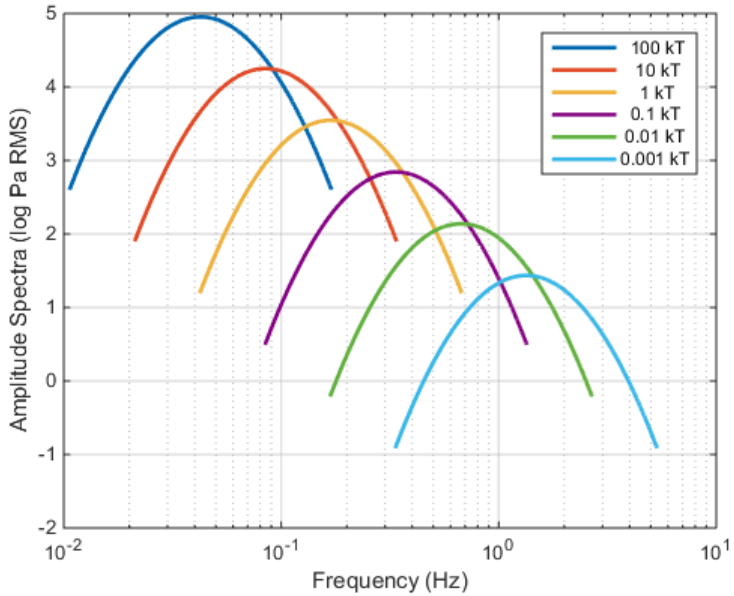
Backup – Hydro Attenuation



Backup – Whitaker Infrasound



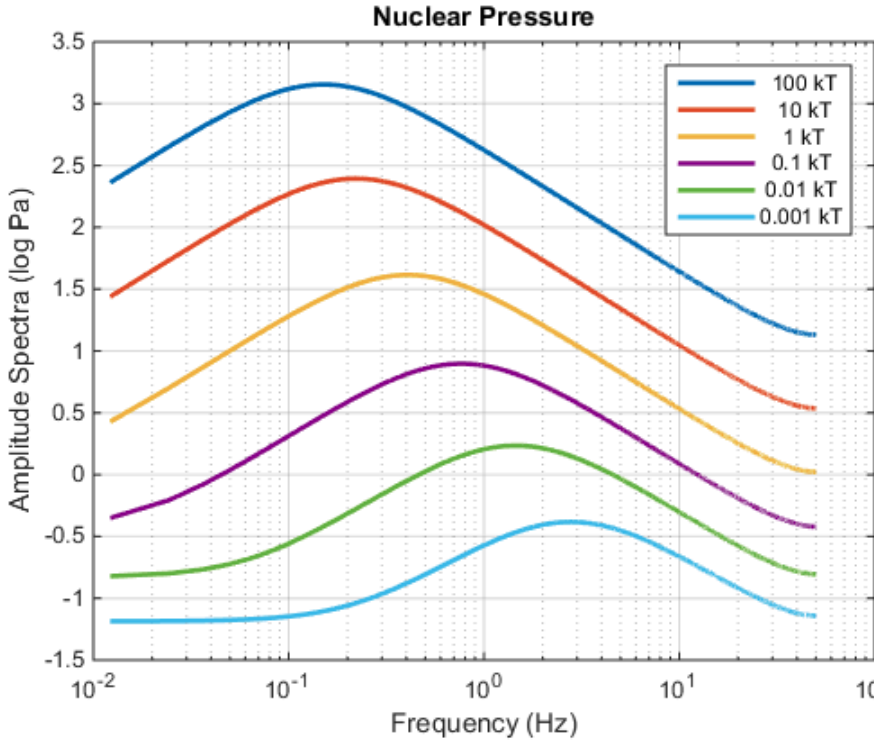


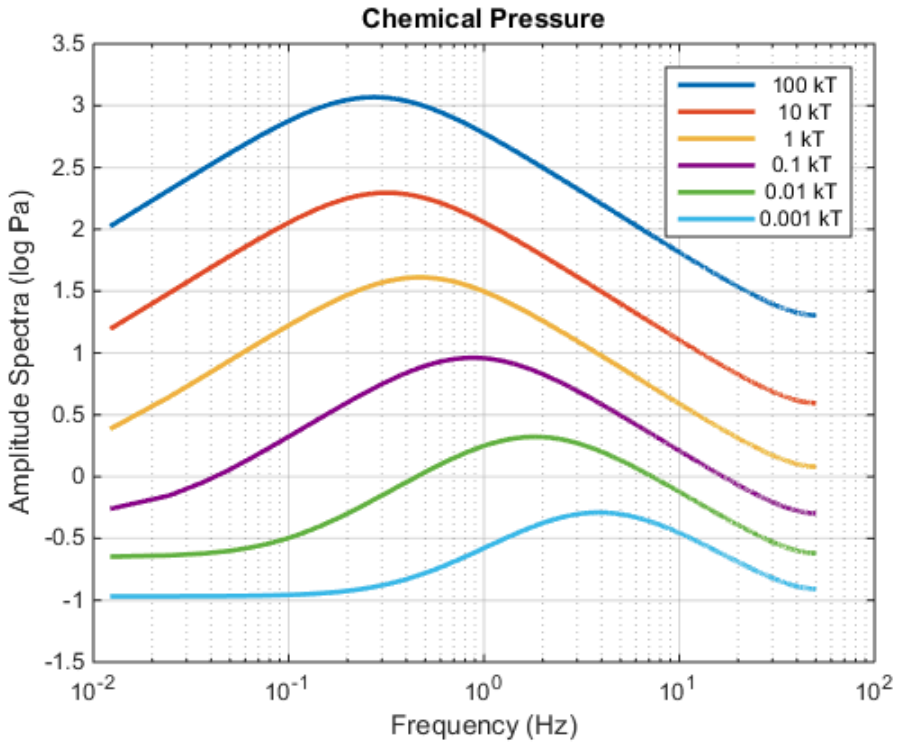


Sandia National Laboratories

National Nuclear Security Administration

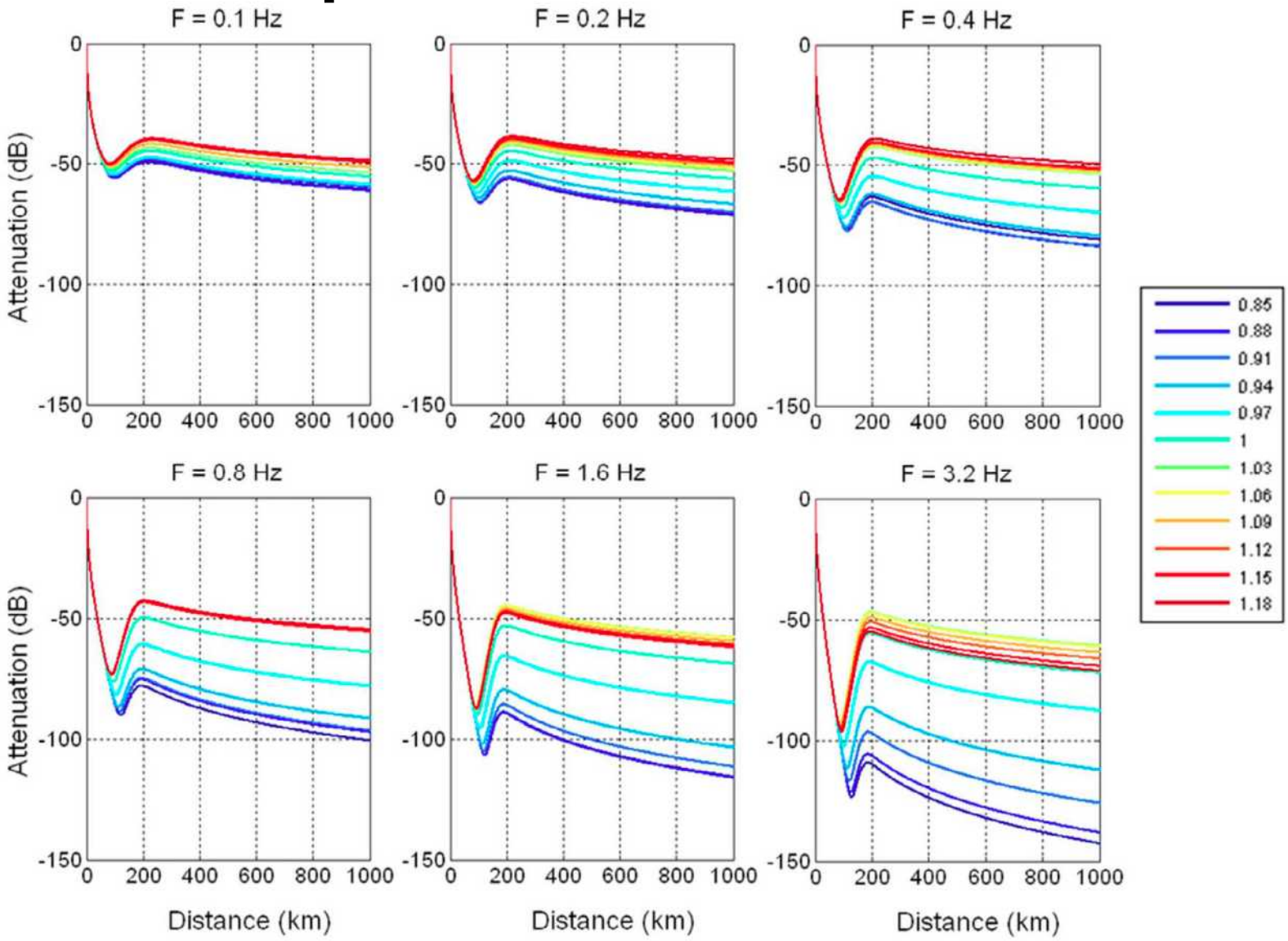
Backup – Kinney & Graham Source Model





Kinney & Graham (1985)

Backup – LePichon Path Model



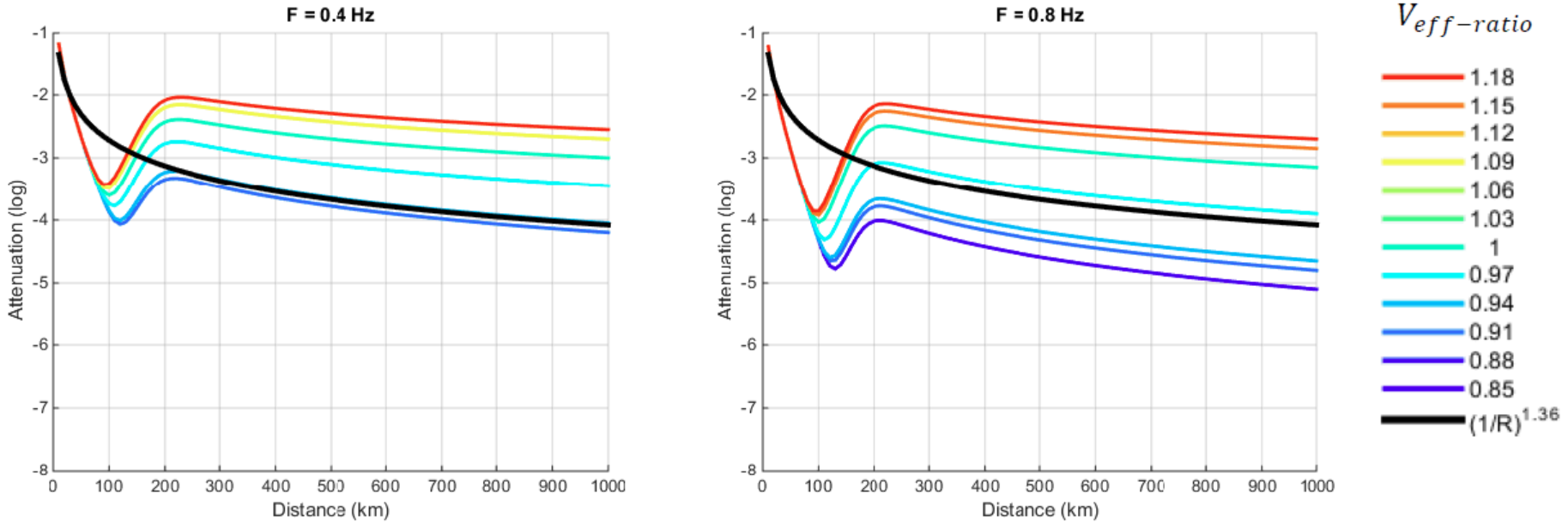
Le Pichon (2012)

Backup – Wind Attenuation

- Variable wind conditions affect path attenuation
- Earlier attenuation models (Whitaker 2003), only accounted for wind speed and distance:

$$\log atn = 0.018 * \mathrm{v_s} - 1.4072 * \mathrm{R}$$

- More recent models (LePichon, 2012) incorporate dependence between wind speed, distance, and frequency:



Le Picon (2012)

Backup – LePichon Path Model

Le Pichon (2012)