

# SALSA3D

## A Global 3D P-Velocity Model of the Earth's Mantle For Improved Event Location in Nuclear Explosion Monitoring

Sandy Ballard<sup>1</sup>

Mike Begnaud<sup>2</sup>, Jim Hipp<sup>1</sup>, Chris Young<sup>1</sup>,  
Andre Encarnacao<sup>1</sup>, Scott Phillips<sup>2</sup>

<sup>1</sup>Sandia National Laboratories

<sup>2</sup>Los Alamos National Laboratory

# Nuclear Explosion Monitoring

Comprehensive Test Ban Treaty (CTBT)

Adopted by UN in 1996, ratified by 157 nations

China, Egypt, Iran, Israel, United States have signed, but not ratified

India, Pakistan and North Korea have not signed

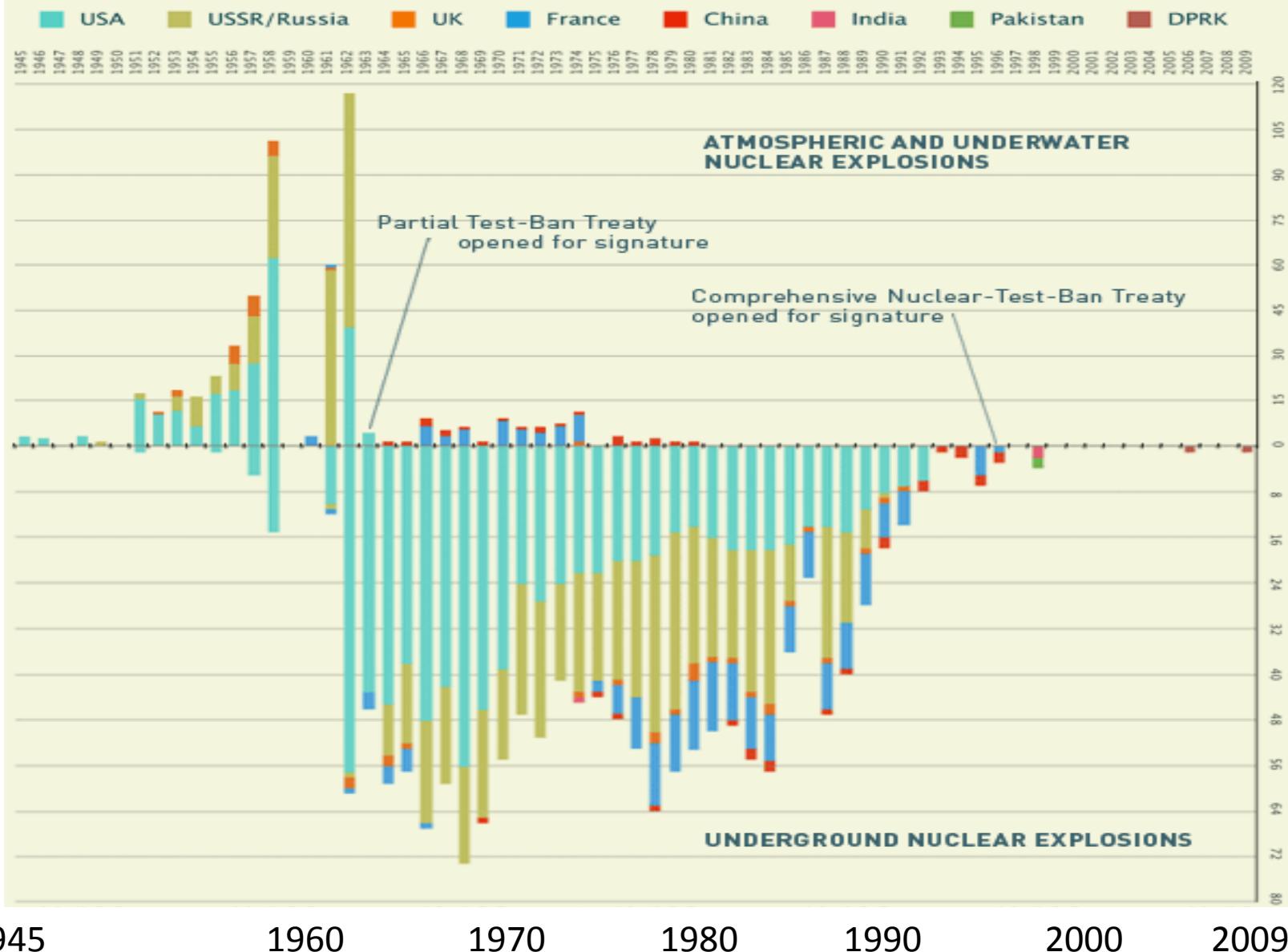


Comprehensive Test Ban  
Treaty Organization (CTBT)  
Vienna, Austria

US National Data Center,  
AFTAC, Patrick AFB, FL

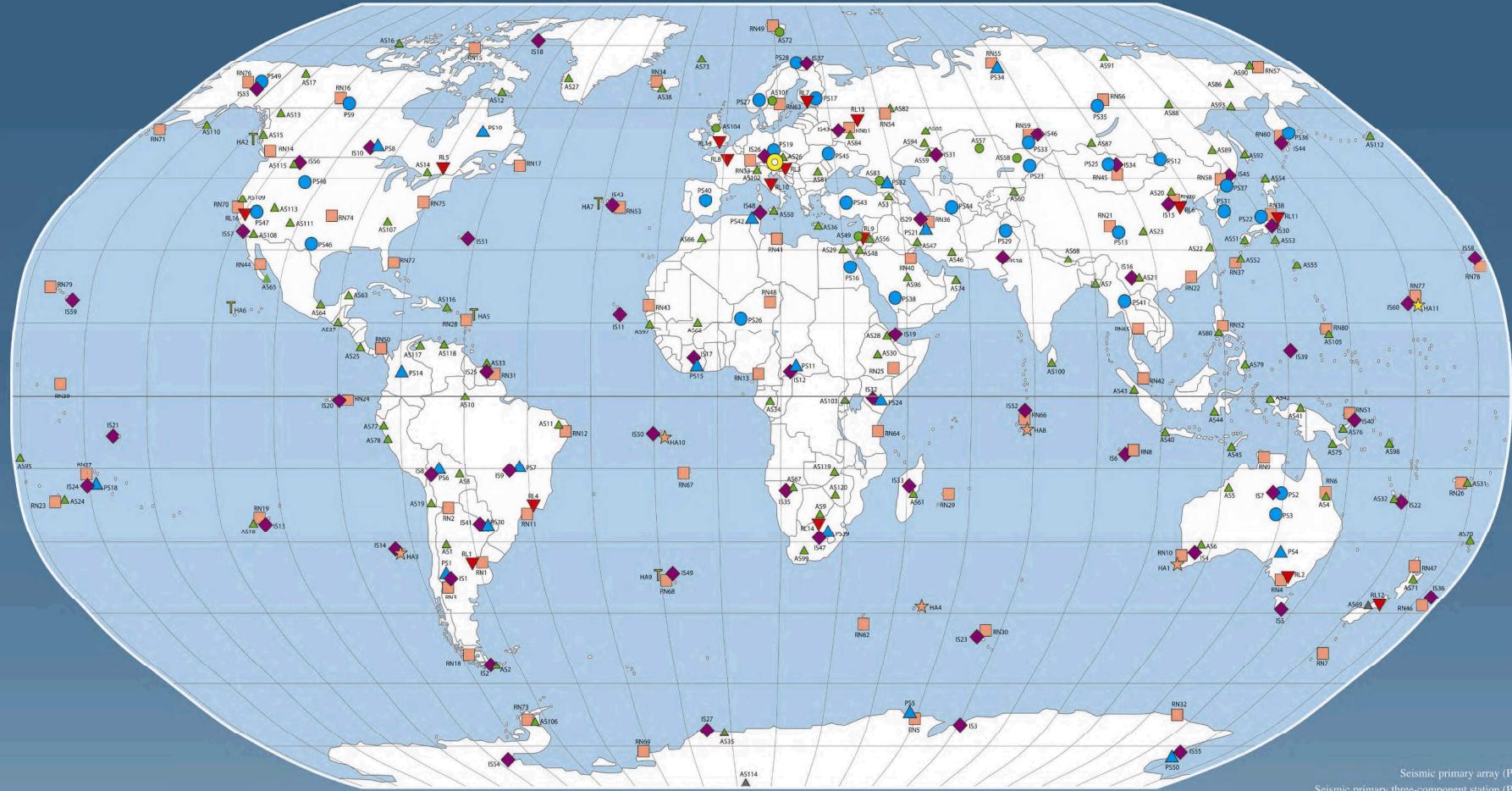
US Dept. of Energy  
provides R&D support

WORLDWIDE NUCLEAR TESTING:  
ATMOSPHERIC AND UNDERGROUND 1945-2009



# CTBT International Monitoring System

## INTERNATIONAL MONITORING SYSTEM



The boundaries and presentation of material on this map do not imply the expression of any opinion on the part of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO PrepCom) concerning the legal status of any country, territory, city or area or its authorities, or concerning the delimitation of its frontiers or boundaries.

Chart 1, revised July 2003

The Comprehensive Nuclear-Test-Ban Treaty (CTBT) of 1996 bans nuclear explosions in all environments.

Explosions in the atmosphere, under water and in outer space were banned in 1963. CTBT prohibits them underground as well.

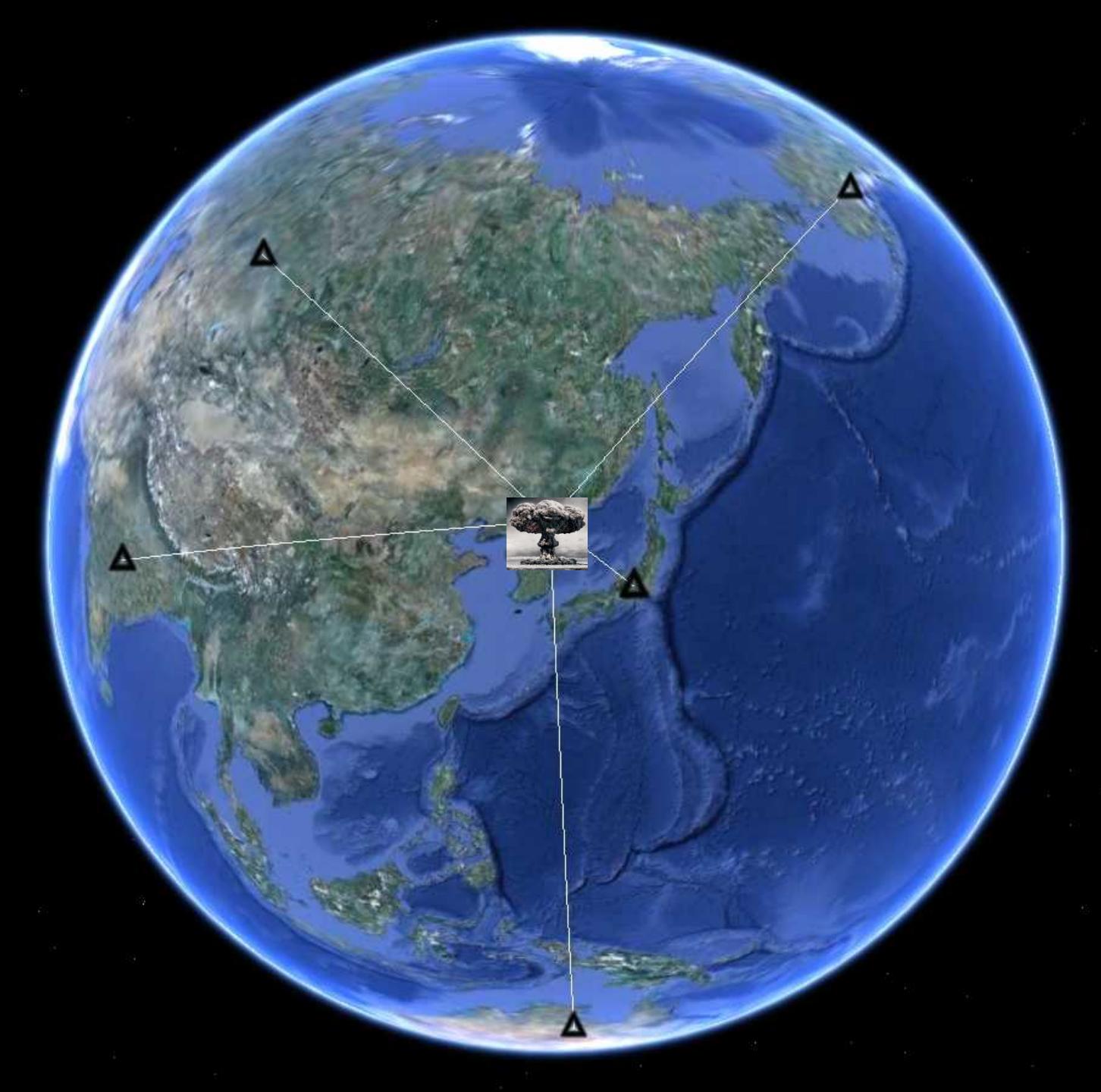
Under CTBT, a global system of monitoring stations, using four complementary technologies, is being established to record data necessary to verify compliance with the Treaty. Supported by 16 radionuclide laboratories, this network of 321 monitoring stations will be capable of registering shock waves emanating from a nuclear explosion underground, in the seas and in the air, as well as detecting radioactive debris released into the atmosphere. The location of the stations has been carefully chosen for optimal and cost-effective global coverage.

The monitoring stations will transmit, via satellite, the data to the International Data Centre (IDC) within CTBTO PrepCom in Vienna, where the data will be used to detect, locate and characterize events.

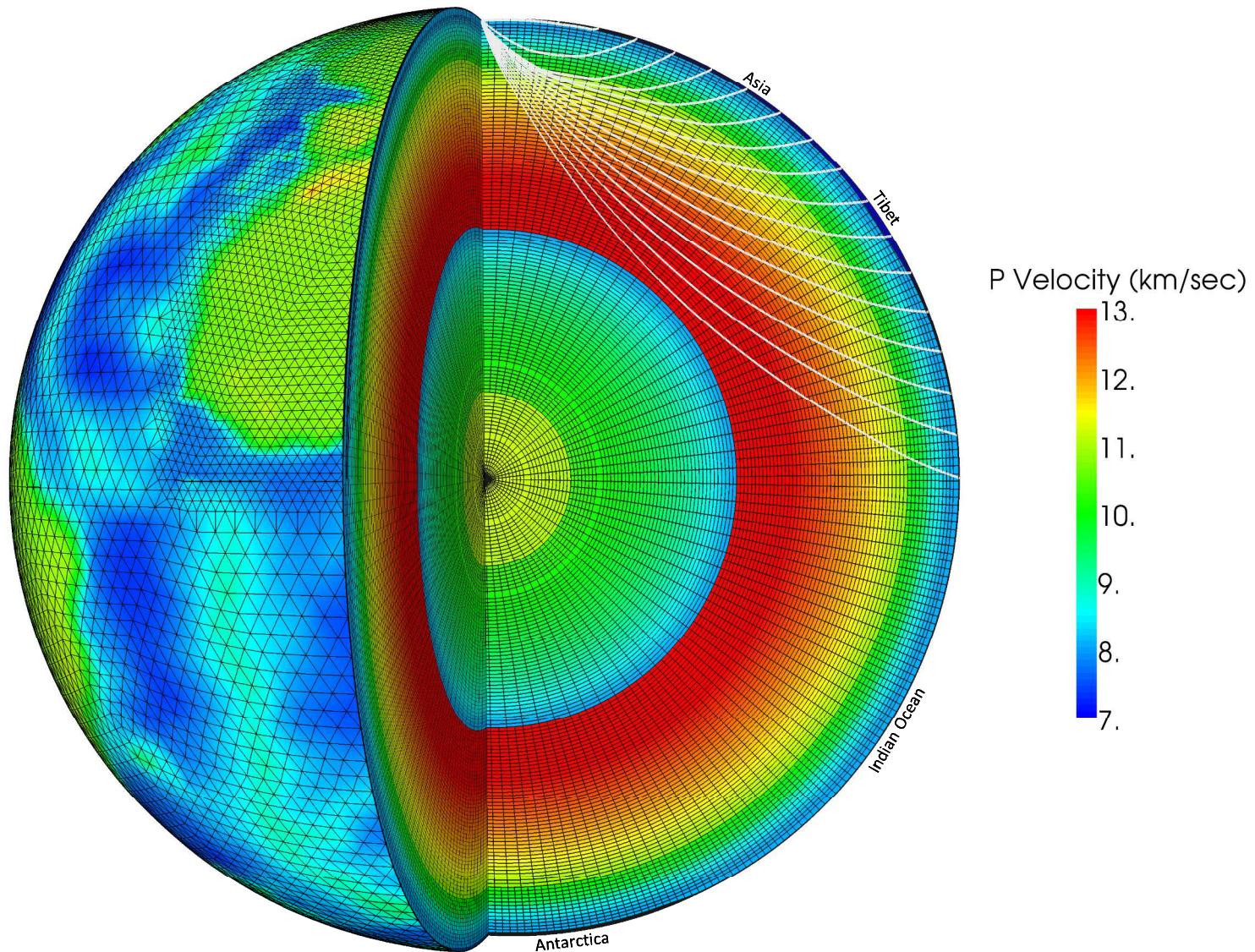
These data and IDC products will be made available to the States Signatories for final analysis.

Overleaf is a listing of the 337 facilities of the international monitoring system and brief descriptions of their characteristics and capabilities.

- Seismic primary array (PS) ●
- Seismic primary three-component station (PS) △
- Seismic auxiliary array (AS) ○
- Seismic auxiliary three-component station (AS) △
- Hydroacoustic (hydrophone) station (HA) ★
- Hydroacoustic (T-phased) station (HA) △
- Infrasound station (IS) ◆
- Radionuclide station (RN) □
- Radionuclide laboratory (RL) ▼
- International Data Centre, CTBTO PrepCom, Vienna ○



# Seismic Ray Tracing Through 3D Earth Models

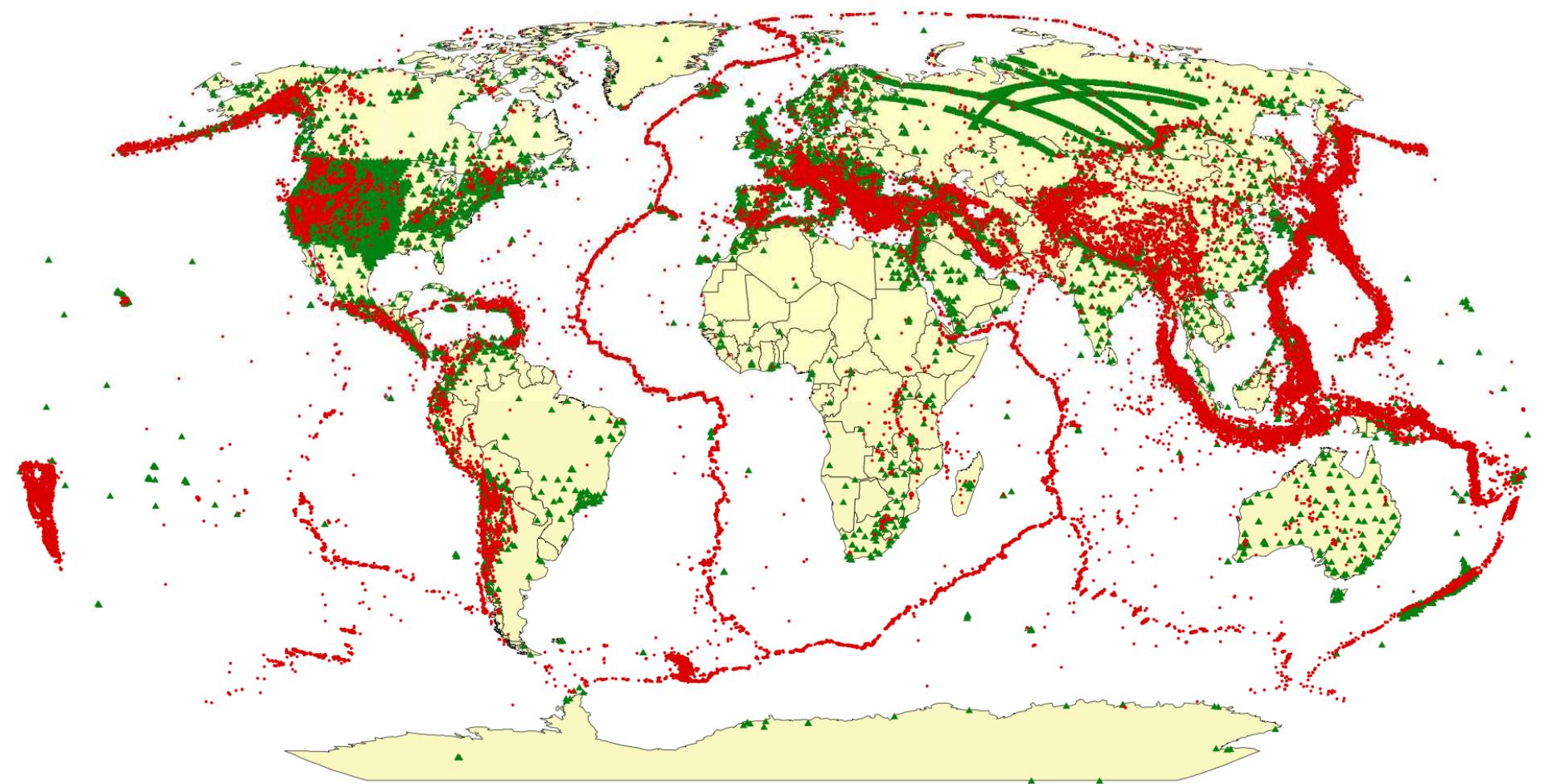


# Tomography Data

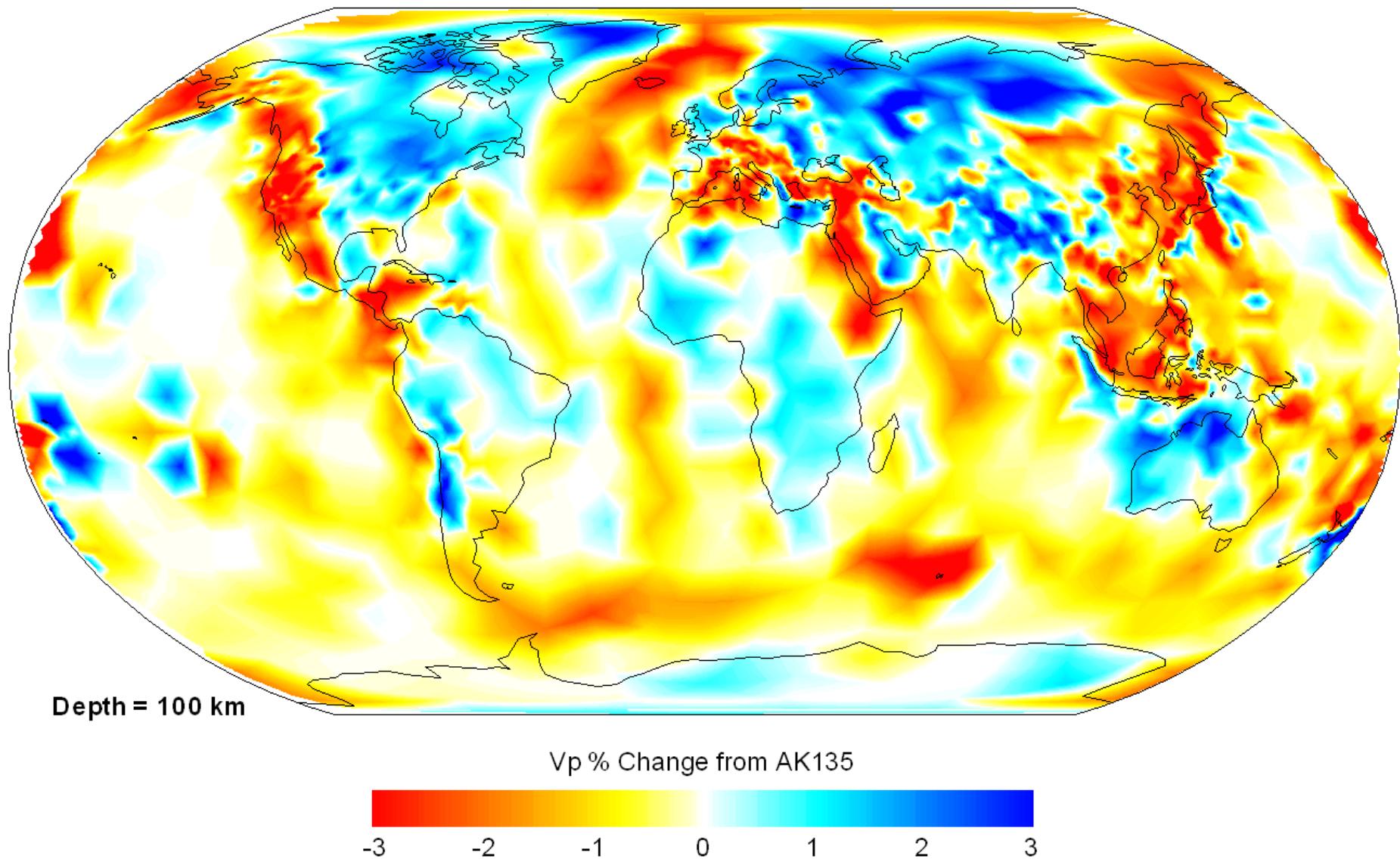
**117K events**

**12K stations**

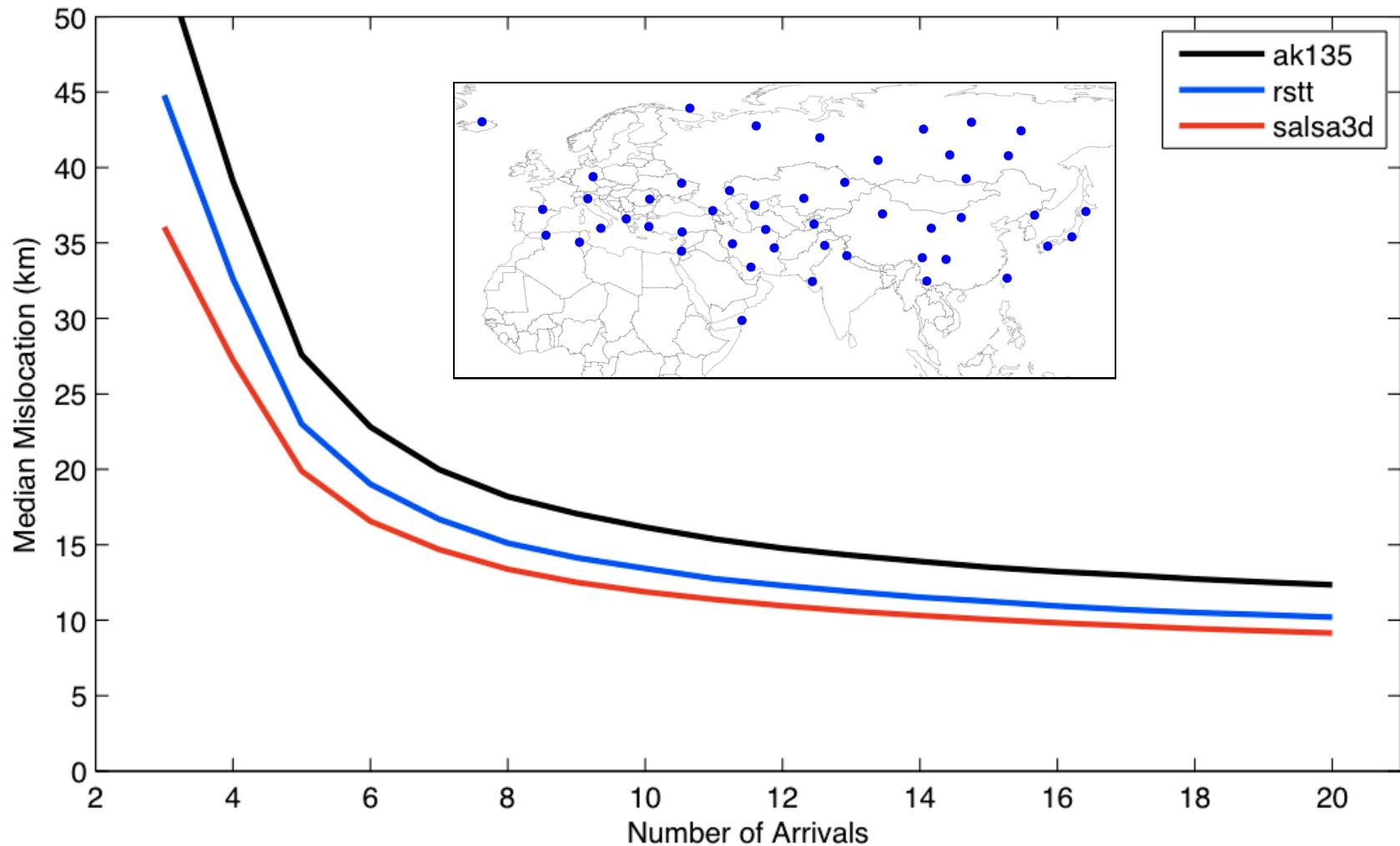
**12M ray paths**



# SALSA3D



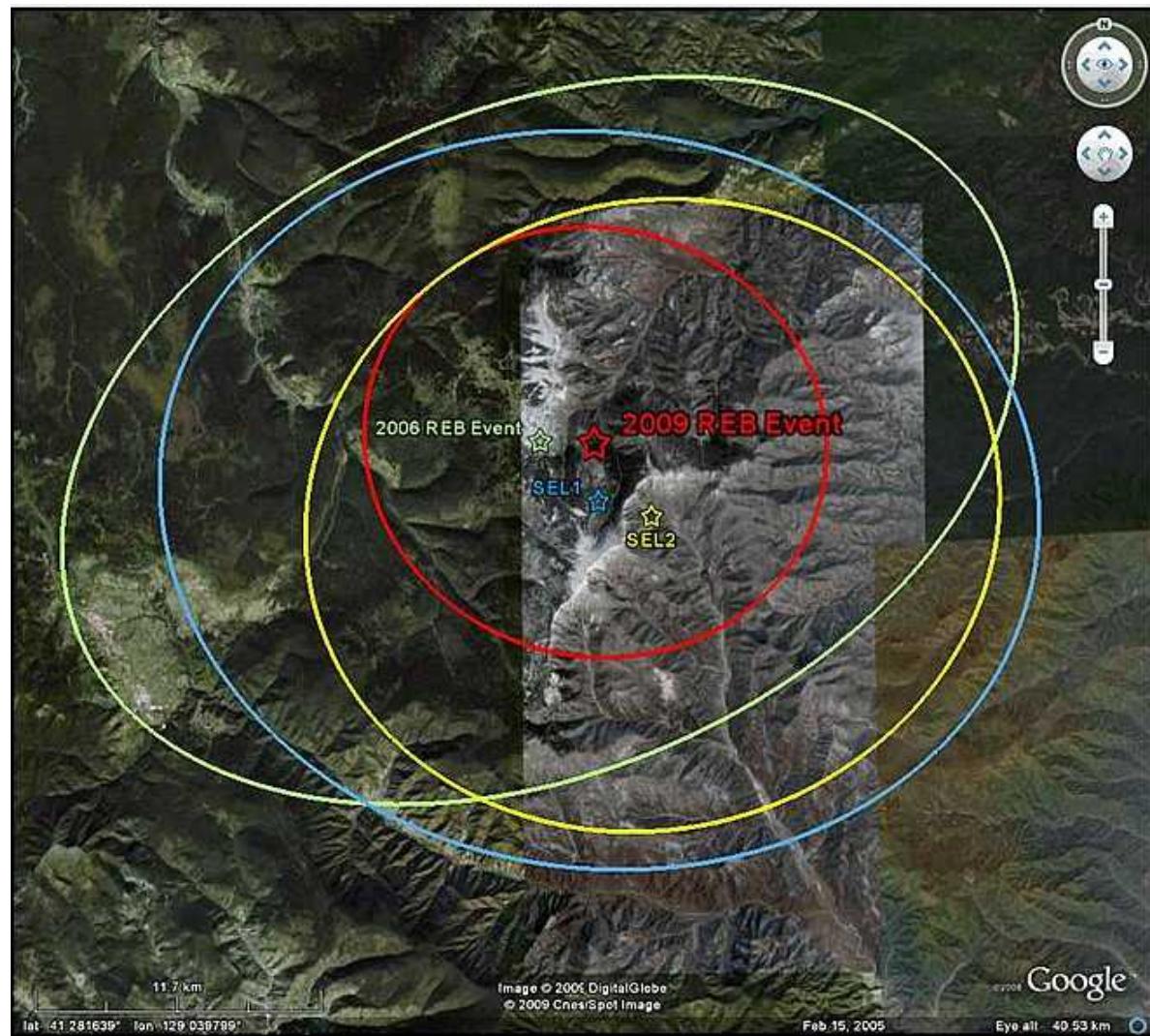
# Mislocation vs. Number of Observations



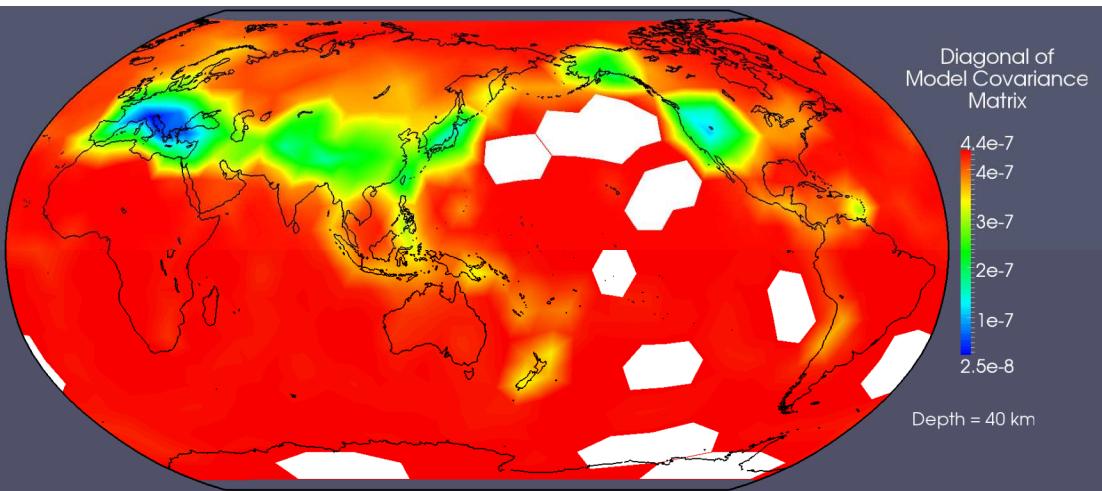
# CTBTO Location of 2006 and 2009 North Korean Tests

- Origin of 2009 event (red) is much more precise than the 2006 origin (green)
- Blue and yellow ellipses show the first and second automatic location estimates
  - Sel1 = primary stations
  - Sel2 = primary + auxiliary
- 2009 bigger event, seen at more stations, error ellipse is circular due to better station coverage

From CTBTO website

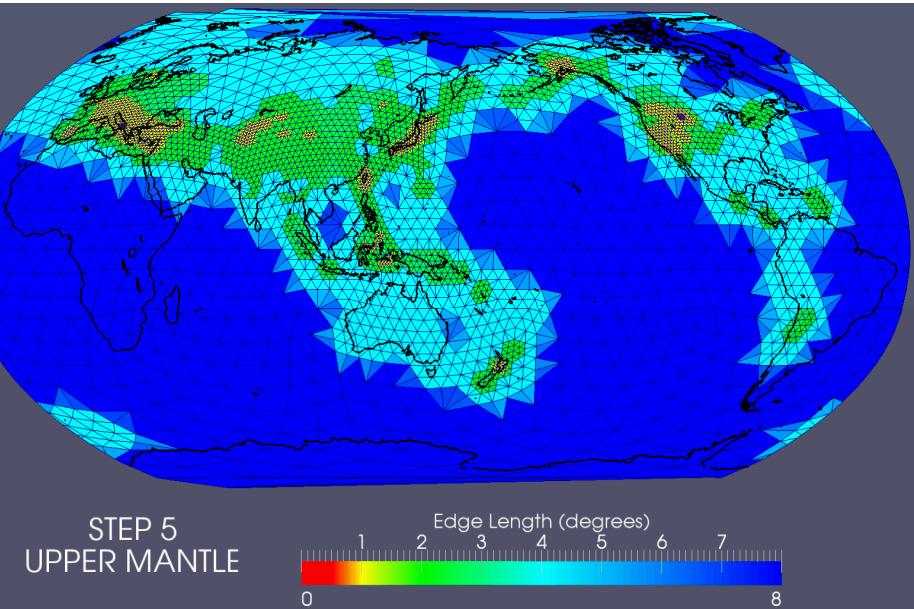
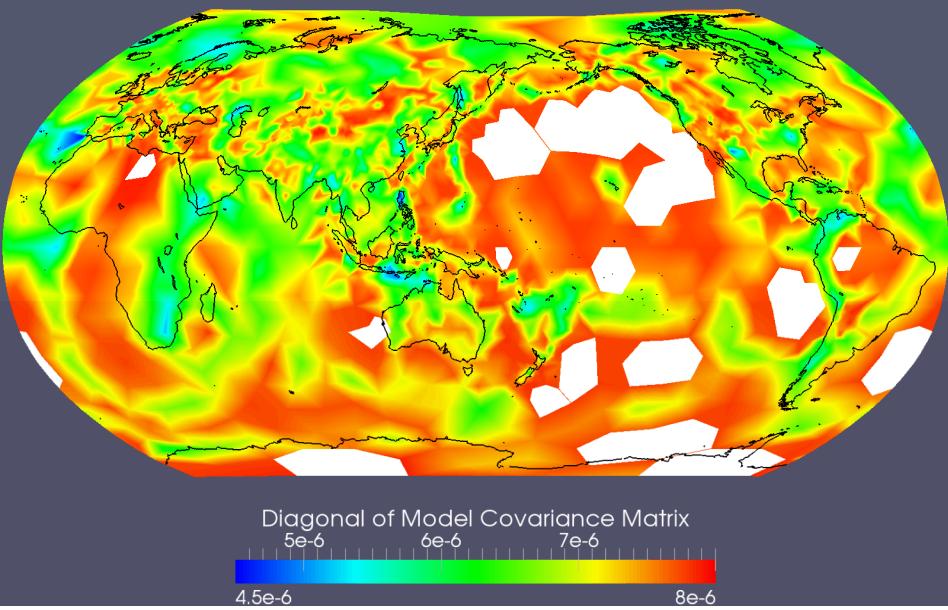


# Model Covariance Matrix

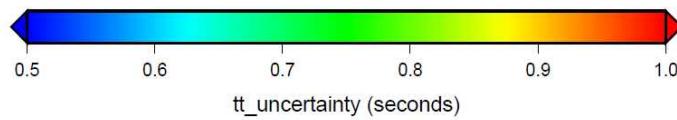
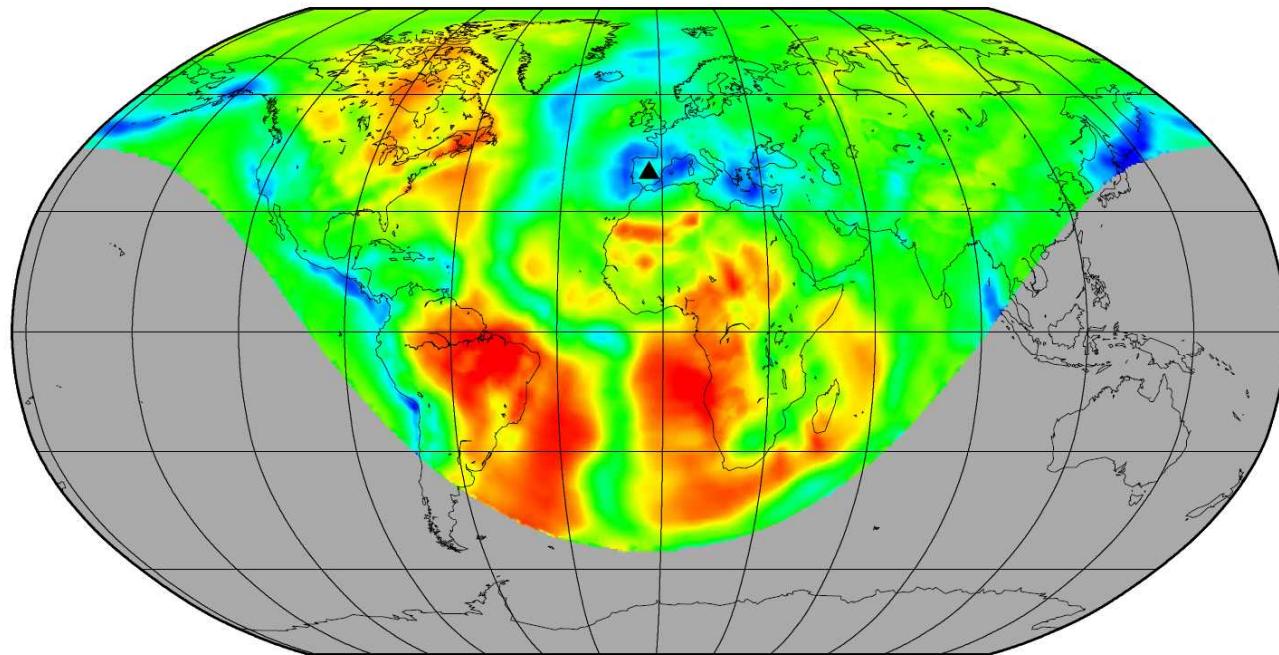


$$C_M = (G^T G)^{-1} G^T \begin{bmatrix} C_{\Delta d} & 0 \\ 0 & C_{\Delta s} \end{bmatrix} G (G^T G)^{-1}$$

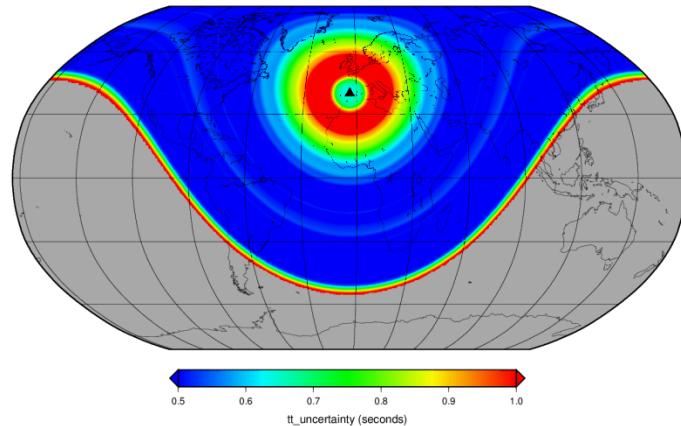
15 petaflops to compute  
180GB of RAM to store  
computed in distributed mode



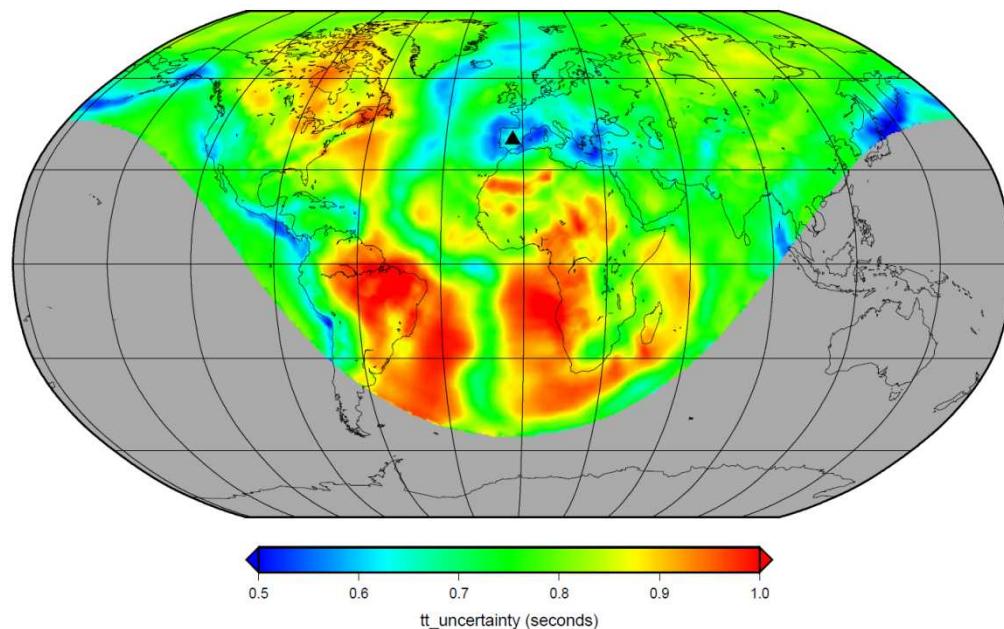
ESDC, depth=0km



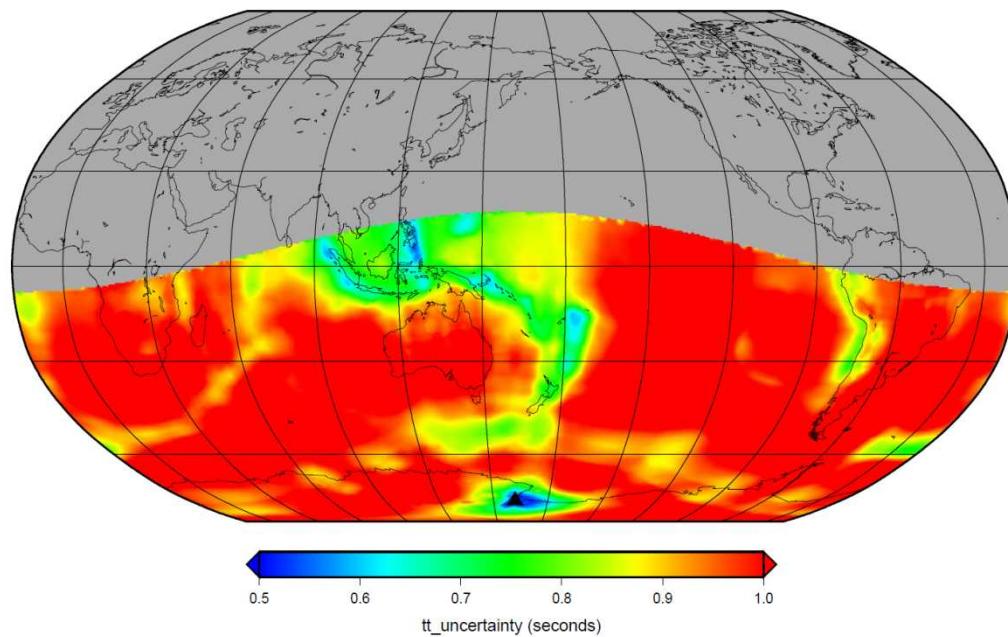
$$\sigma_T^2 = W \begin{bmatrix} C_M & 0 \\ 0 & C_{NR} \end{bmatrix} W^T$$



ESDC, depth=0km



VNDA, depth=0km



# Summary

- We have developed a global 3D model of the compressional wave speed distribution in the Earth's crust and mantle.
- We successfully computed the model covariance matrix for our model which allows us to calculate path-dependent travel time uncertainty estimates.
- The model significantly improves the accuracy and precision and seismic event locations.
- We delivered 3D travel time lookup tables for USNDC network to mitigate performance issues related to the use of 3D models in operational systems
- System is currently being tested on USNDC pipeline testbed.