Regional Seismic Travel Time (RSTT) Evaluation, Training, and Outreach

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T5.4-O5

CTBTO-PTS SnT2017
Vienna Austria
June 2017

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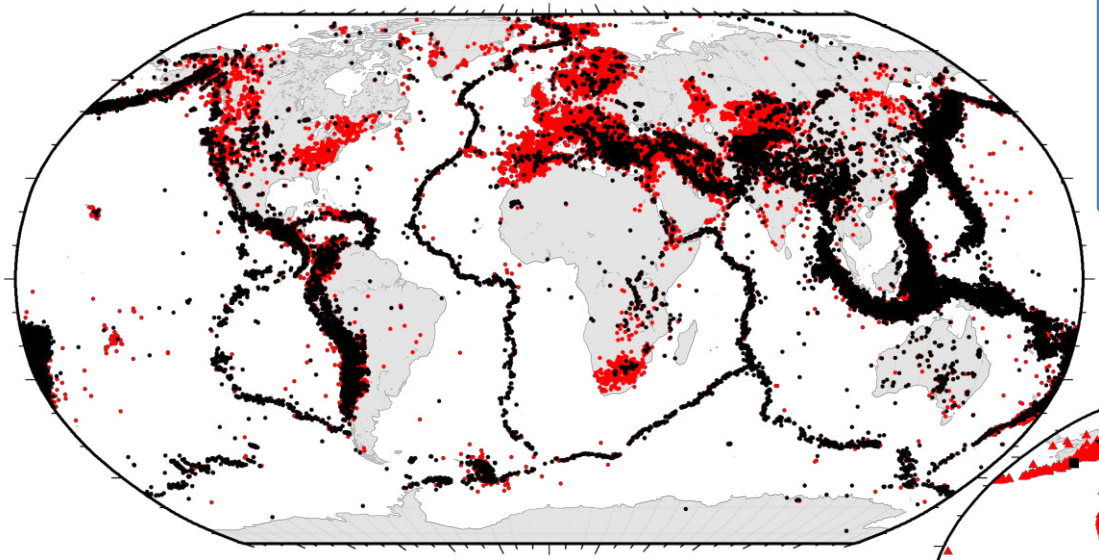
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

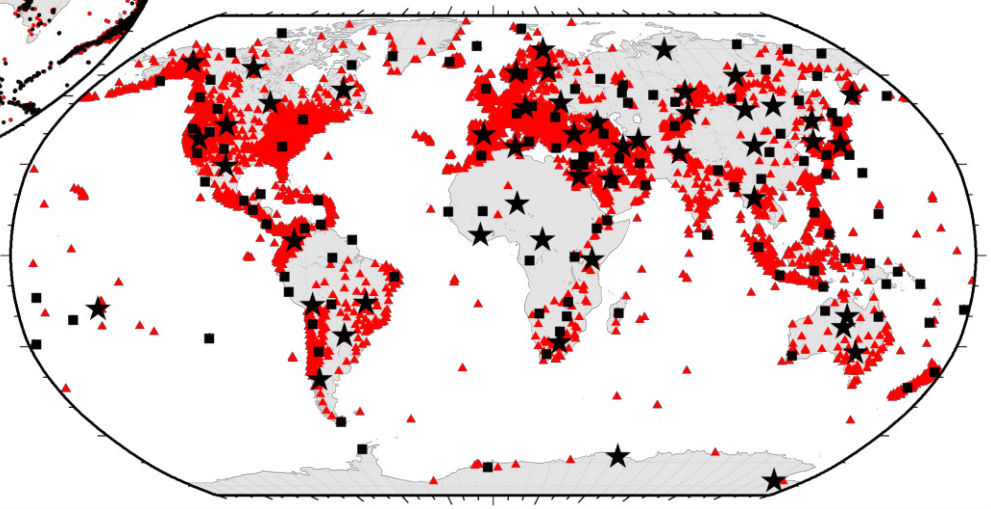
The REB and ISC event maps agree over much of the globe

2-years of seismicity: REB, ISC



- REB and ISC seismic events outline the major tectonic features (tectonic plate boundaries)
- ISC bulletin contains more events where regional network operators contribute their results

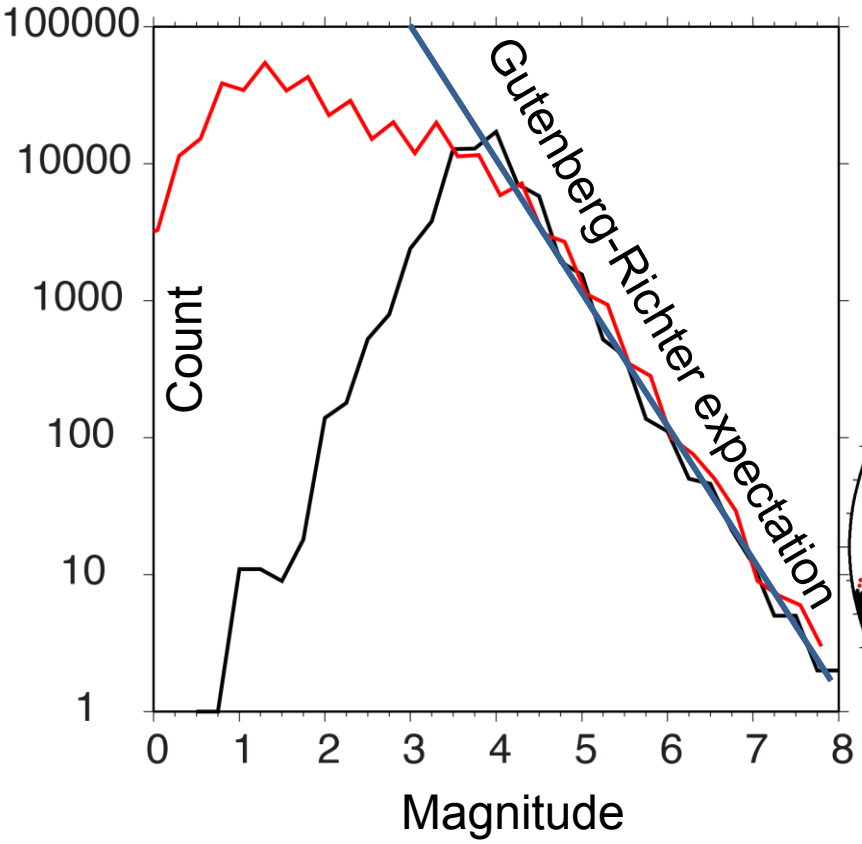
Seismic stations: REB, ISC



Reviewed Event Bulletin (REB)
International Seismologic Center (ISC)

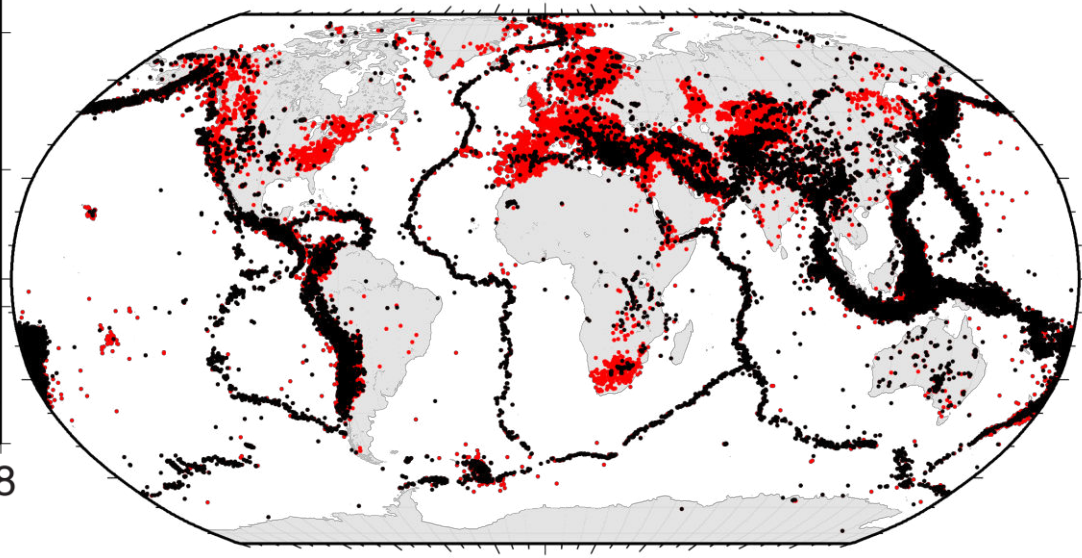
Significant differences between the REB and ISC bulletin are at low magnitudes

2-years of seismicity: (REB, ISC)



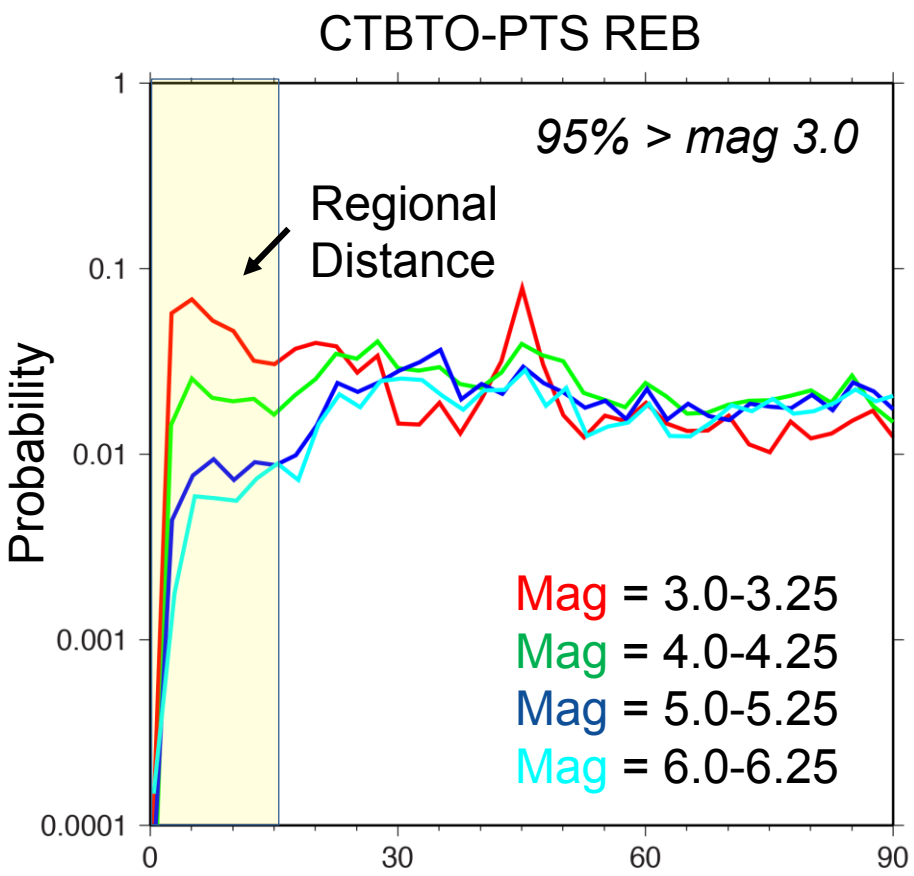
- The REB agrees with Gutenberg-Richter relationship to approximately mag. 4
- The ISC bulletin contains more low-magnitude events

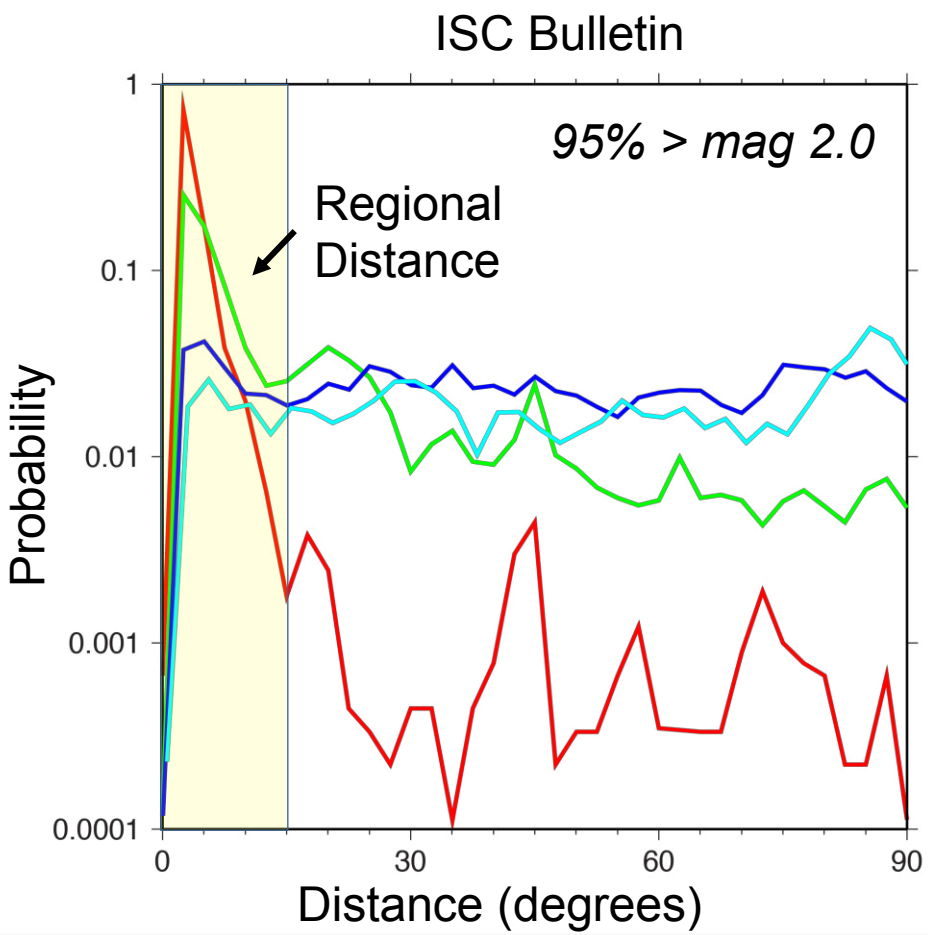
Seismic event locations (REB, ISC)



Small-magnitude events are predominantly detected at regional stations

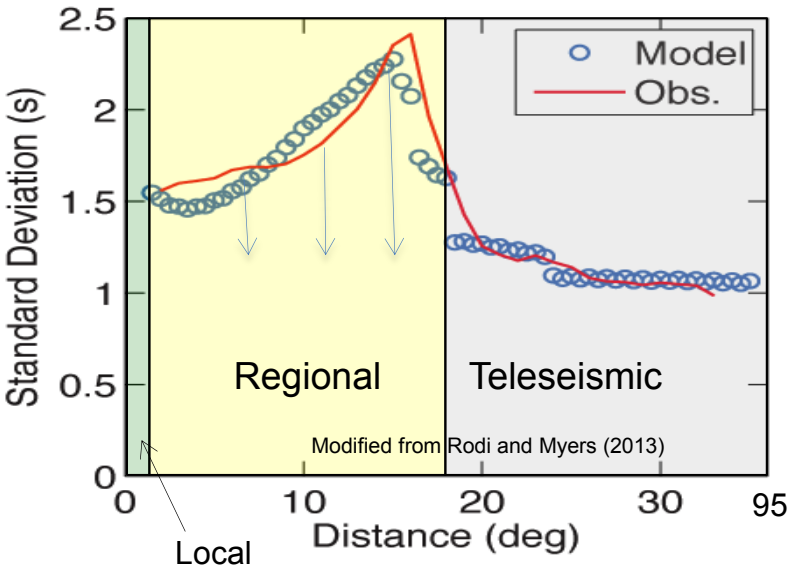
Lowering monitoring thresholds can be achieved by utilizing regional networks





Increased travel time prediction error at regional distances leads directly to increased event location error

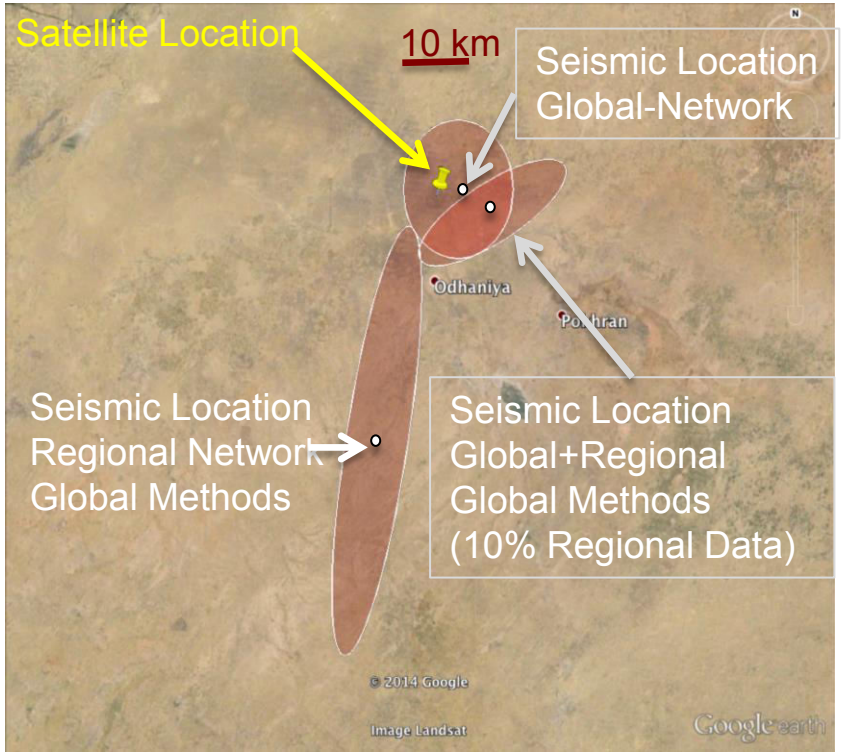
Average Pn Travel Time Error



	Median Mislocation*
Regional	11 km
Teleseismic	8.5 km

From Myers et al., 2015

Example from India Announced nuclear test 1998



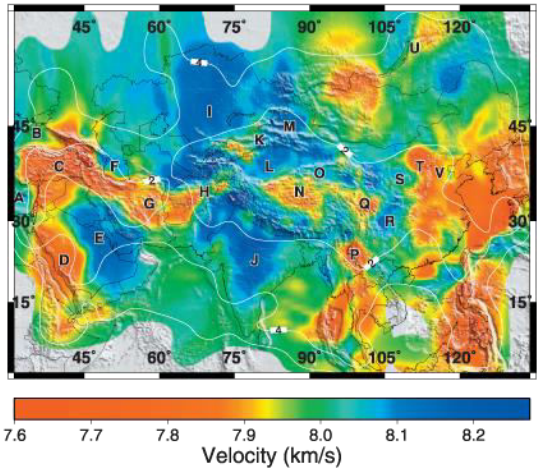
* Fifty station network surrounding event

The RSTT project originated from a need at the U.S. NDC

Steve Myers
Project Leader

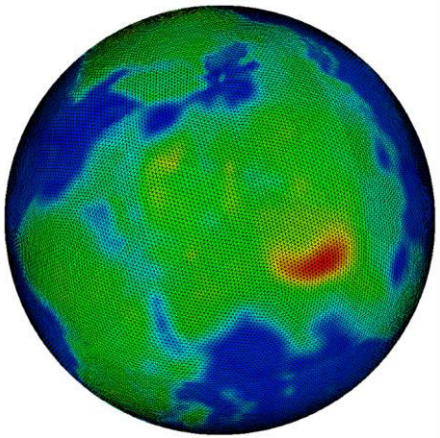
LANL	LLNL	SNL	USNDC
Mike Begnaud	*Steve Myers*	*Sandy Ballard*	John Dwyer
Scott Phillips	Michael Pasyanos	Chris Young	Greg Wagner
Char Rowe	Abe Ramirez		Mark Woods

Tomography



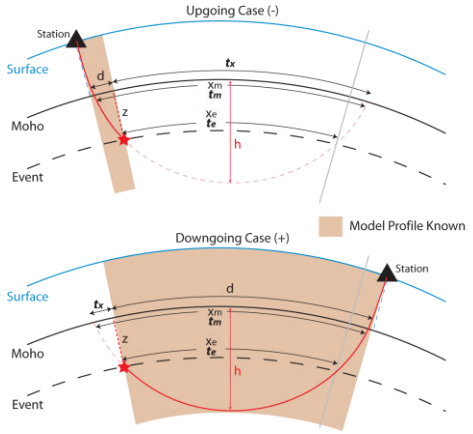
From Phillips et al., 2007

Global Tessellation



From Ballard, 2011

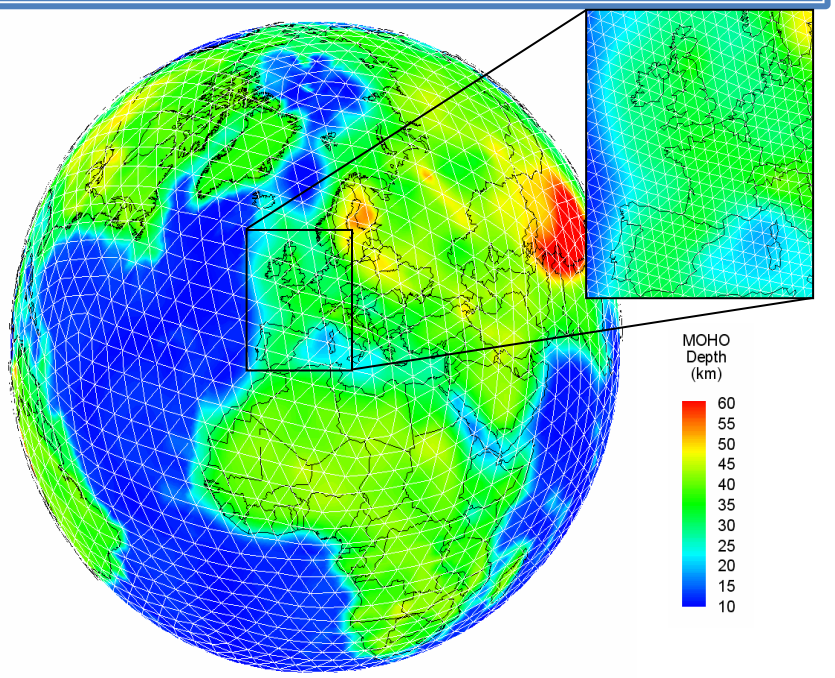
Operationalization



From Myers et al., 2010

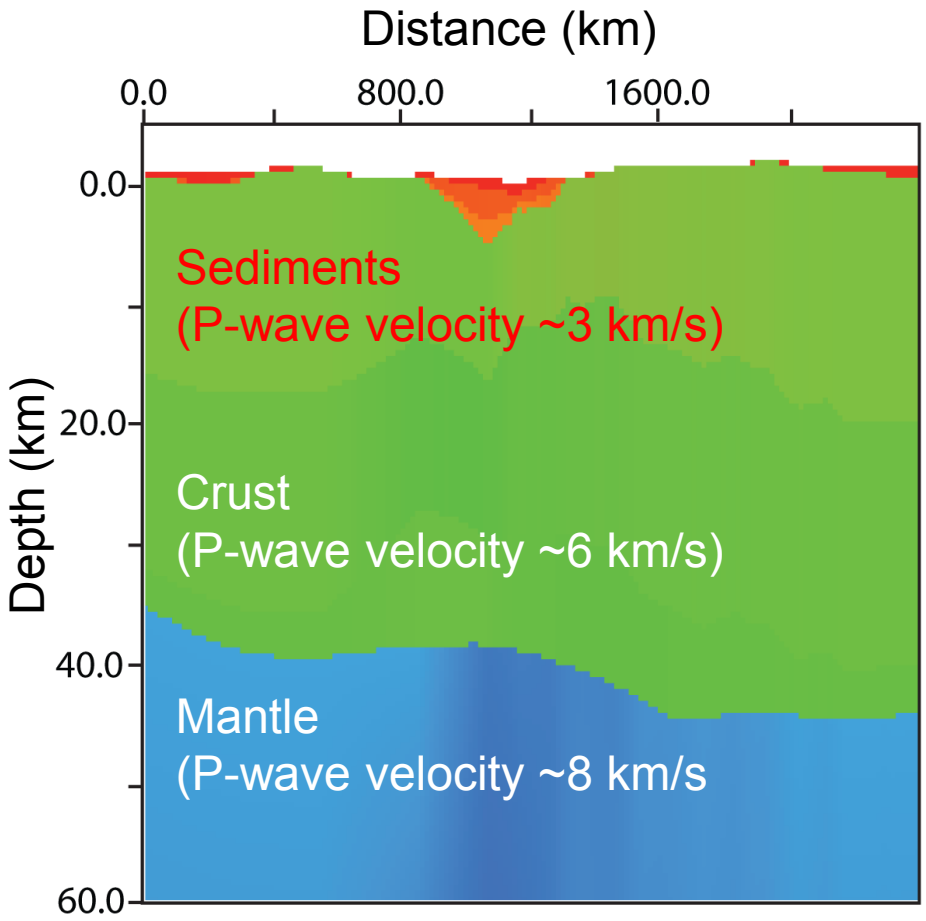
RSTT reduces travel time prediction error by taking 3-dimensional structure of Earth's crust and upper mantle into account

- Vertical velocity provide at each tessellation node
- Interpolation renders 3D crust and laterally varying upper mantle velocity



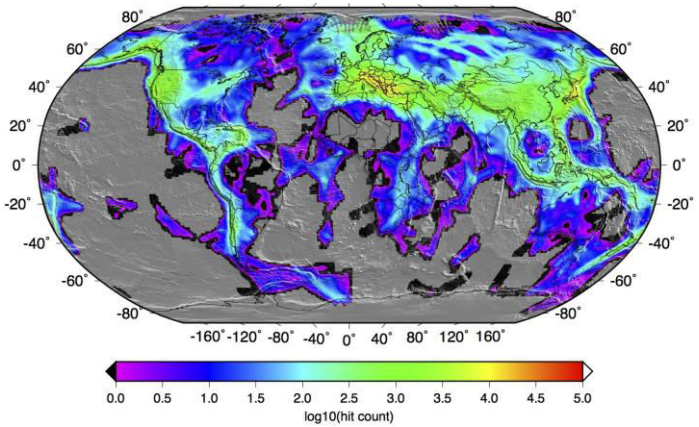
Spherical Tessellation

RSTT model: example cross section

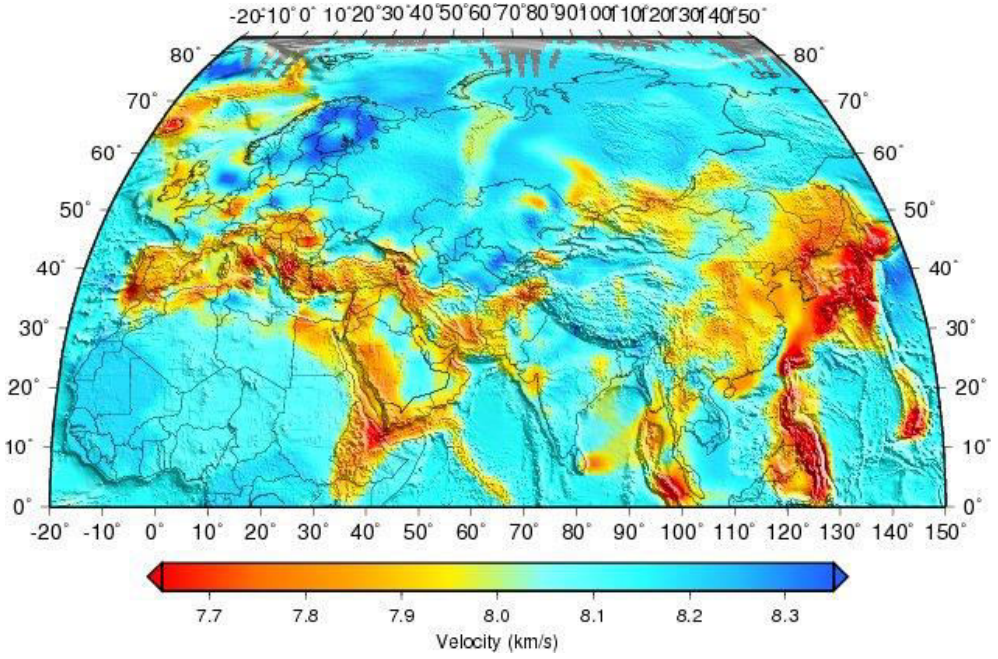


Data-driven tomographic imaging optimizes our best estimate of crustal and upper mantle structure for travel time prediction

Tomographic data set



Updated Map of P-wave velocity



Tomographic system of equations

$$\begin{bmatrix} x_1^1 & \cdots & x_N^1 & -\frac{x_1^1(X_m)^3}{24V_oX_m} & \cdots & -\frac{x_N^1(X_m)^3}{24V_oX_m} & \sum_{p=1}^{Q}\frac{l_{1p}^1}{v_{1p}} & \cdots & \sum_{p=1}^{Q}\frac{l_{Np}^1}{v_{Np}} \\ \vdots & & & & \ddots & & & & \vdots \\ x_1^K & \cdots & x_N^K & -\frac{x_1^K(X_m)^3}{24V_oX_m} & \cdots & -\frac{x_N^K(X_m)^3}{24V_oX_m} & \sum_{p=1}^{Q}\frac{l_{1p}^K}{v_{1p}} & \cdots & \sum_{p=1}^{Q}\frac{l_{Np}^K}{v_{Np}} \\ & & & & & \text{Regularization} & & & \end{bmatrix} * \begin{bmatrix} s_1 \\ \vdots \\ s_N \\ c_1^2 \\ \vdots \\ c_N^2 \\ a_1 \\ \vdots \\ a_N \end{bmatrix} = \begin{bmatrix} t^1 \\ \vdots \\ t^K \\ \text{Regularization} \end{bmatrix}$$

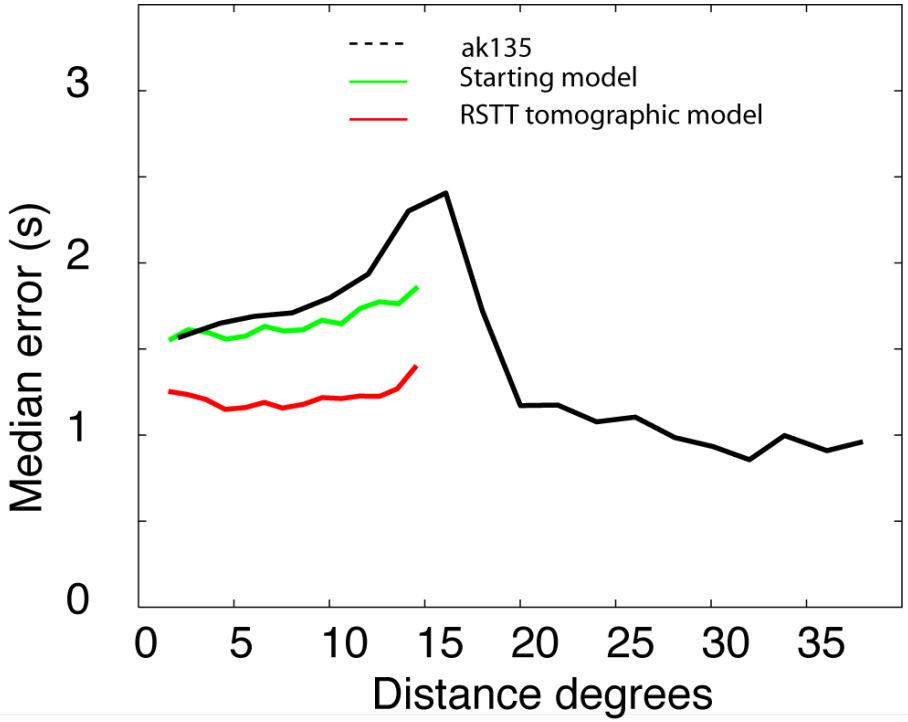
RSTT tomography adjusts

- Mantle velocity
  - At the Moho
  - Gradient
- Crustal slowness

The RSTT model reduces travel-time prediction error and event epicenter error

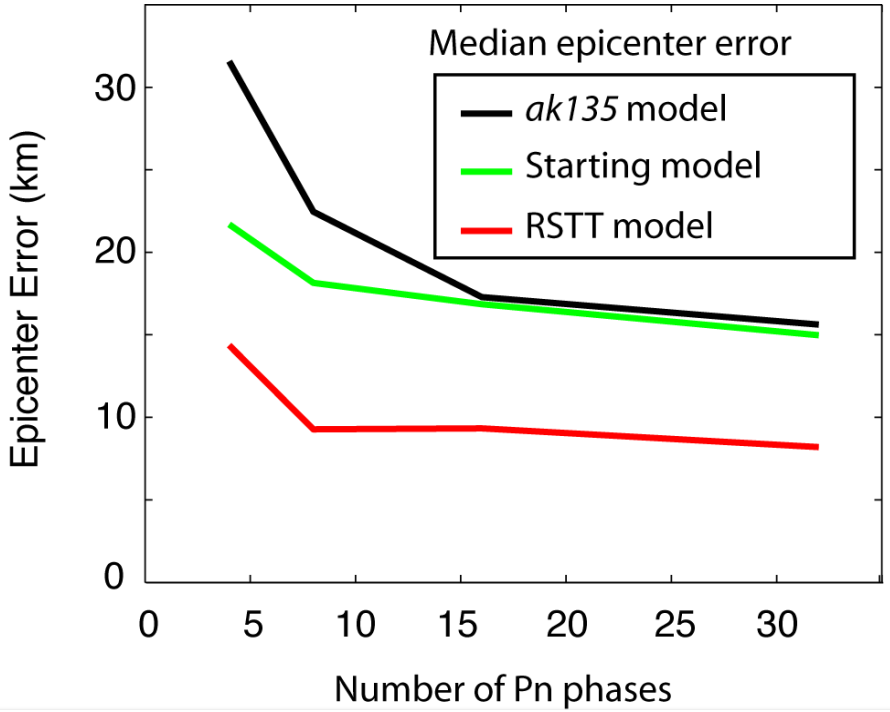
Travel-time error reduction

- Regional prediction error is reduced to teleseismic level



Epicenter error reduction

- Epicenter error is reduced by approximately a factor of 2.
- Largest improvement for sparse networks.



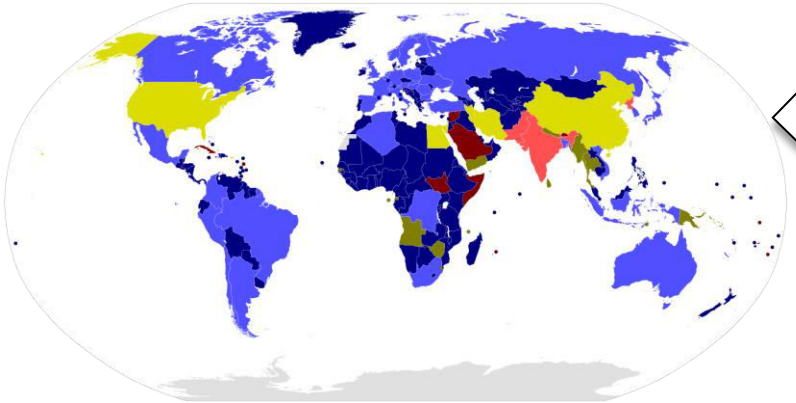
The U.S. contributed RSTT to the CTBTO-PTS for use by the International Data Center and CTBT national data centers

US National Data Center

Using the same travel time model enables all states parties to determine a consistent event location.

U.S. Department of State

International Community



CTBTO PREPARATORY COMMISSION

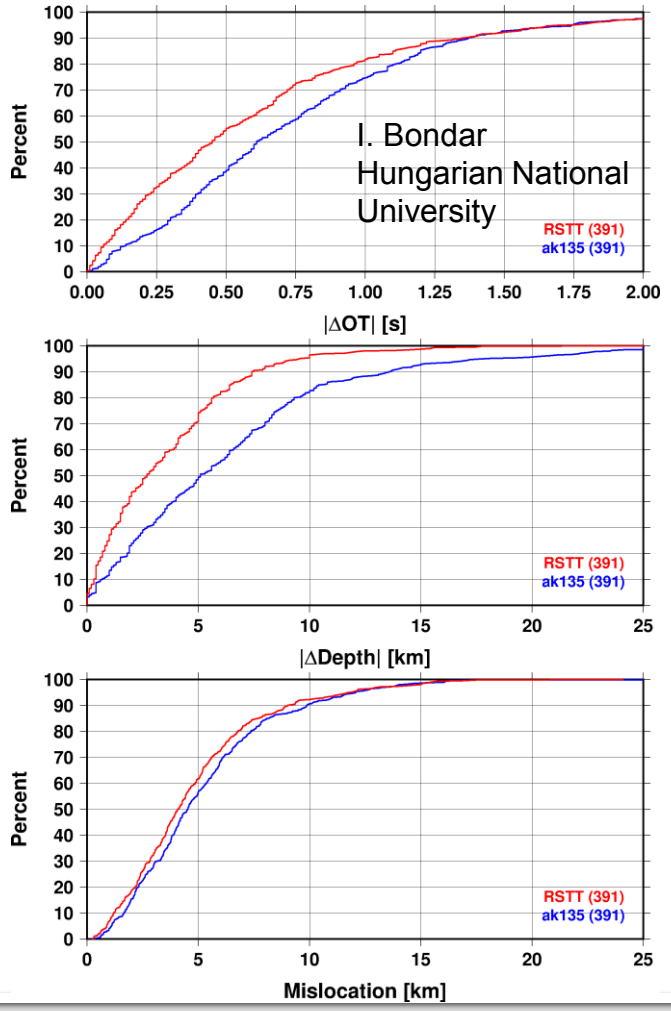
RSTT has been tested by the IDC and CTBT National Data Centers

Presentations at CTBTO-PTS Working Group B

- ✓ U.S.
- ✓ U.K.
- ✓ France
- ✓ Hungary
- ✓ PTS

- ✓ Measurably reduces epicenter error
- ✓ Can be implemented in Source-Specific-Station-Correction format at the IDC
  - ✓ No software modification needed
  - ✓ Available for all IMS stations
- ✓ RSTT does not break other components IDC processing (e.g. association)

Summary results of global RSTT tests

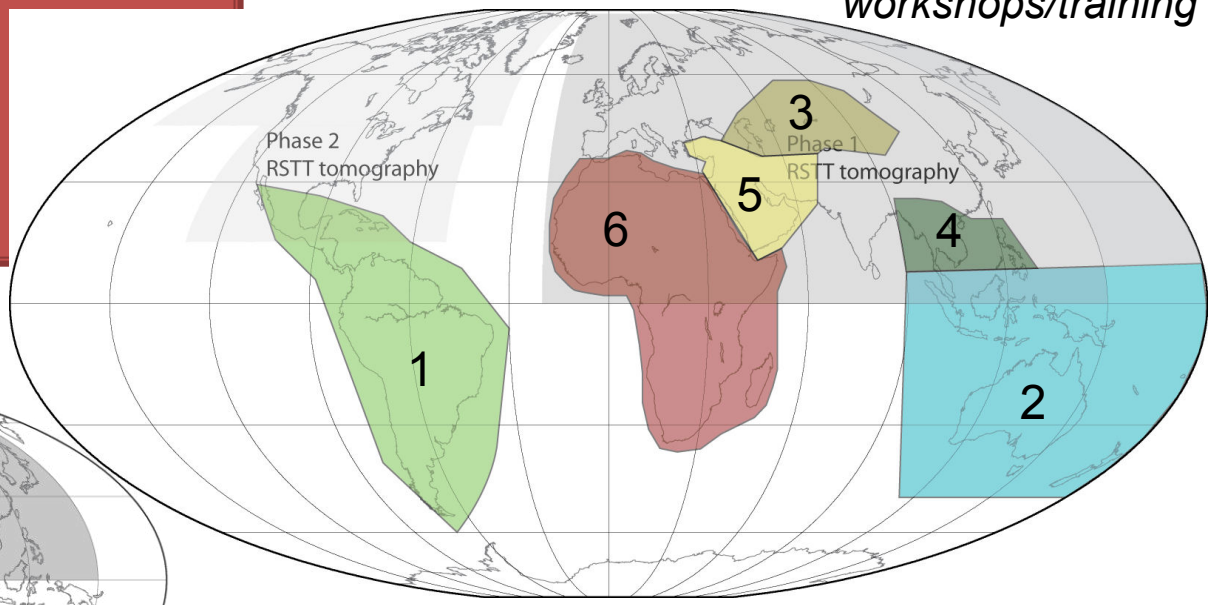


The U.S. national laboratories and CTBTO-PTS partner to conduct RSTT training

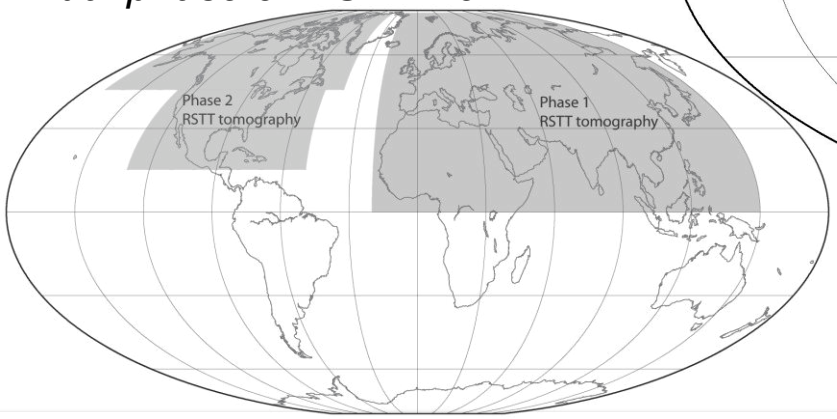
CTBTO workshops and training draws on NDCs and the broader scientific community to strengthen the verification effort.

RSTT workshop regions
1) South America/Caribbean
2) Oceania
3) Central Asia
4) South Asia
5) Middle East
6) Africa

Geographic coverage of CTBTO-related RSTT workshops/training



Tomographic model domain in the initial phase of RSTT work



RSTT workshops introduce regional experts to the RSTT model and methods

Participating Countries to date (67)

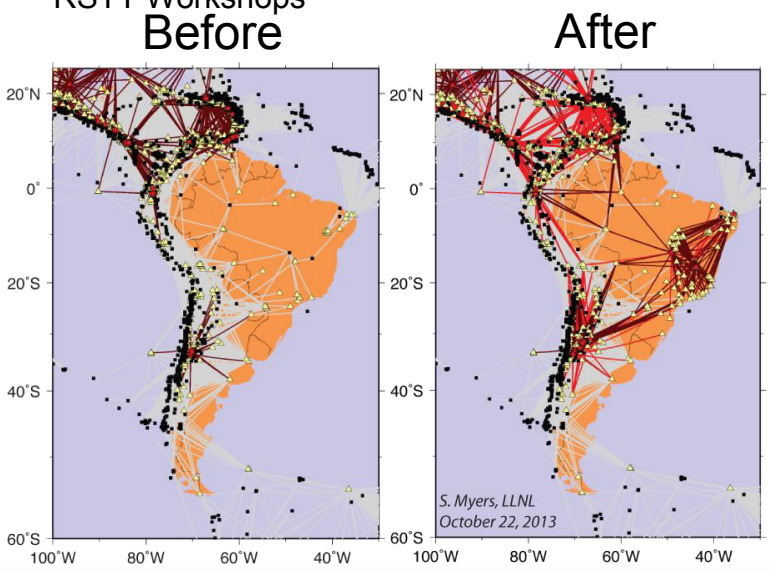
Algeria	**Congo**	**Haiti**	Micronesia	**South Africa**
Argentina	Cook Islands	**Hungary**	**Mongolia**	**South Korea**
Armenia	**Costa Rica**	**Iraq**	**Morocco**	**Tajikistan**
Australia	**Djibouti**	**Ireland**	**Mozambique**	**Tanzania**
Azerbaijan	**Dominican Republic**	**Italy**	Nauru	**Tonga**
Bahamas	**Ecuador**	**Jamaica**	New Zealand	**Tunisia**
Bolivia	**Egypt**	**Jordan**	Norway	**Turkmenistan**
Botswana	**Ethiopia**	**Kazakhstan**	**Panama**	**Uganda**
Brazil	Fiji	**Kyrgyzstan**	**Papua New Guinea**	**United Kingdom**
Cameroon	France	**Libya**	**Peru**	**United States**
Chad	**Georgia**	Malaysian	**Philippines**	**Uzbekistan**
Chile	**Ghana**	**Madagascar**	**Samoa**	**Vanuatu**
Columbia	**Guatemala**	**Mexico**	**Solomon Islands**	**Venezuela**
Comoros				**Zambia**

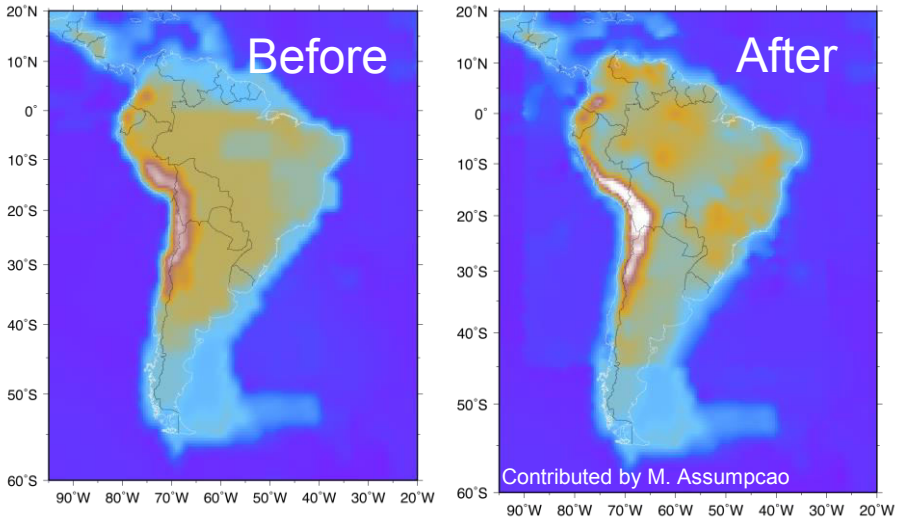
Typical training agenda

- Introduction to the RSTT model and method
- Utility of RSTT to CTBTO, NDCs and national networks
- The need for model and data contributions
- Location examples using the ISC locator

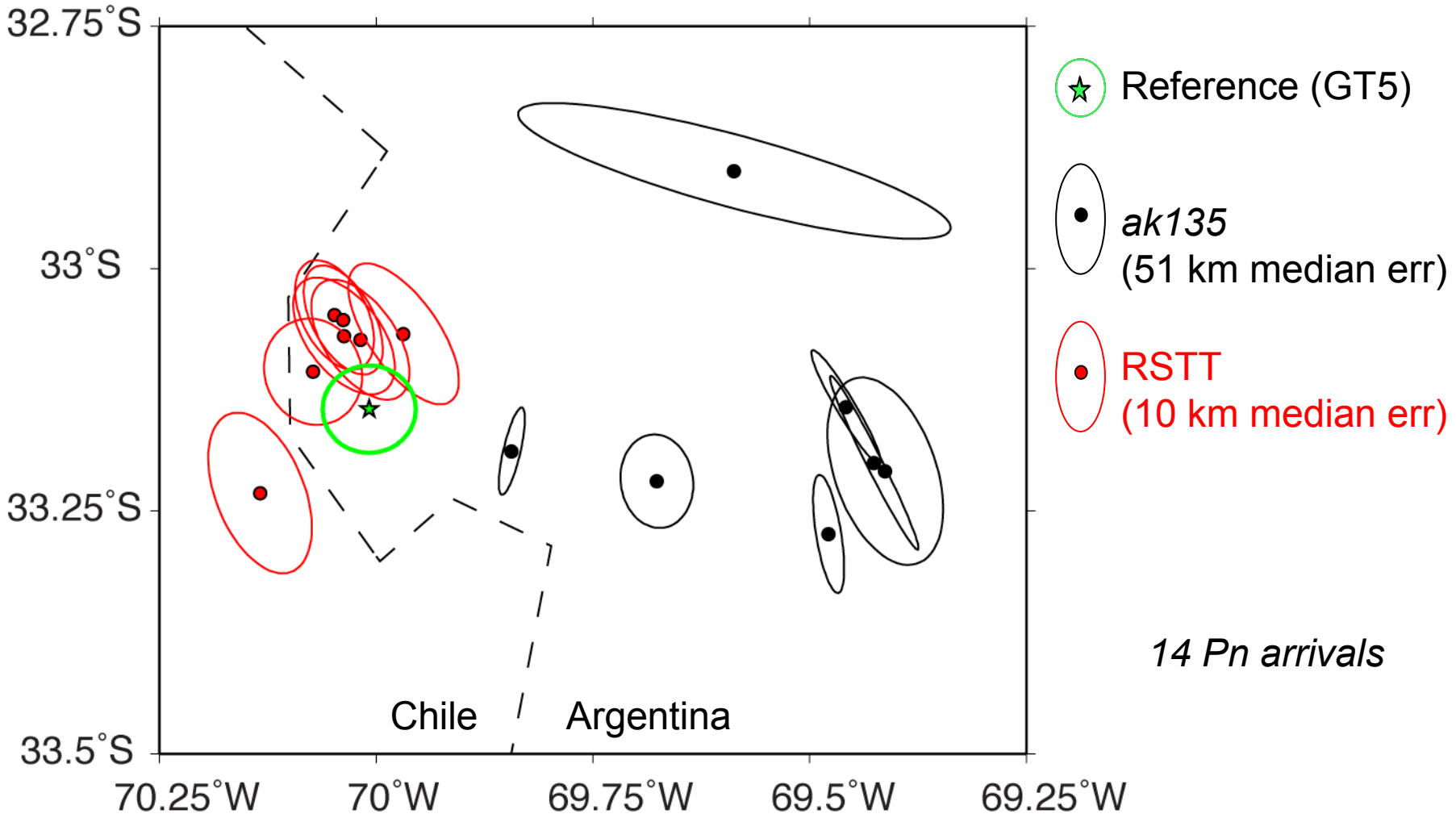
- Instruction in how to extract and modify RSTT model parameters
- Hands-on exercises involving
  - Calculation of travel times using the RSTT code
  - Extraction and modification of RSTT model parameters
  - Event relocation
- Review of data contributed during the workshop

Ray Paths before/after Contributions from RSTT Workshops



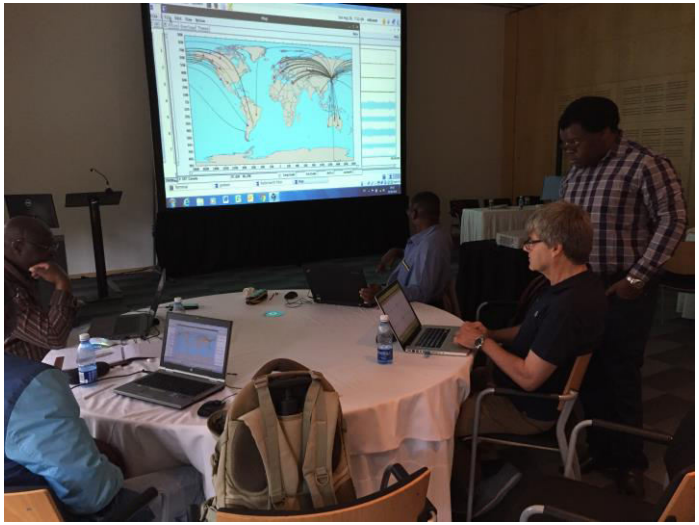


Example results in South America



Most recent training: Cape Town, South Africa

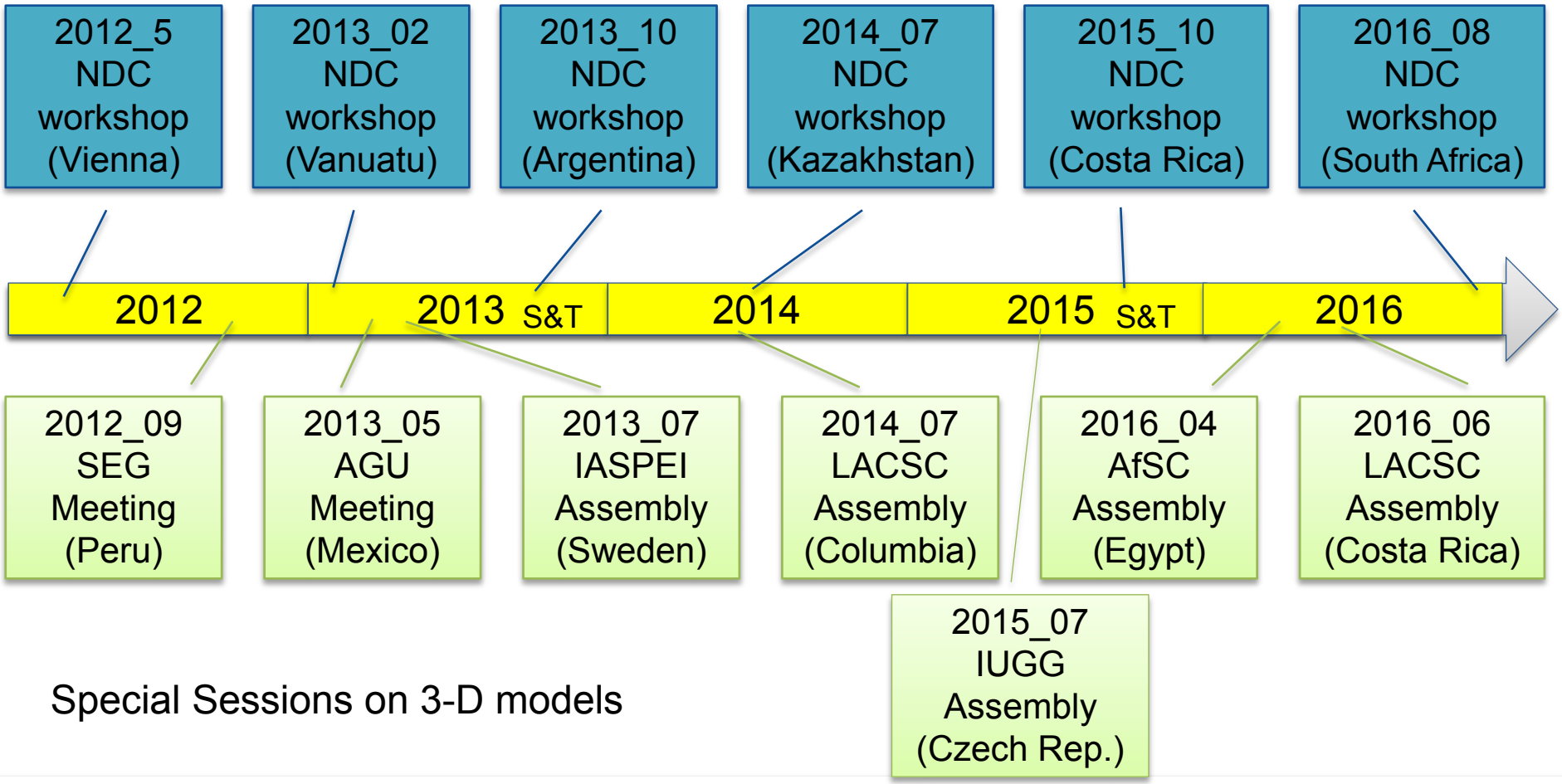
- Participants from 9 African countries
- RSTT/iLoc installed on all participant's computers
- Participants relocated African events and learned to interrogate/modify the RSTT model



Cape Town, South Africa 27-28 August, 2016

CTBTO outreach efforts are augmented by special sessions at professional meetings

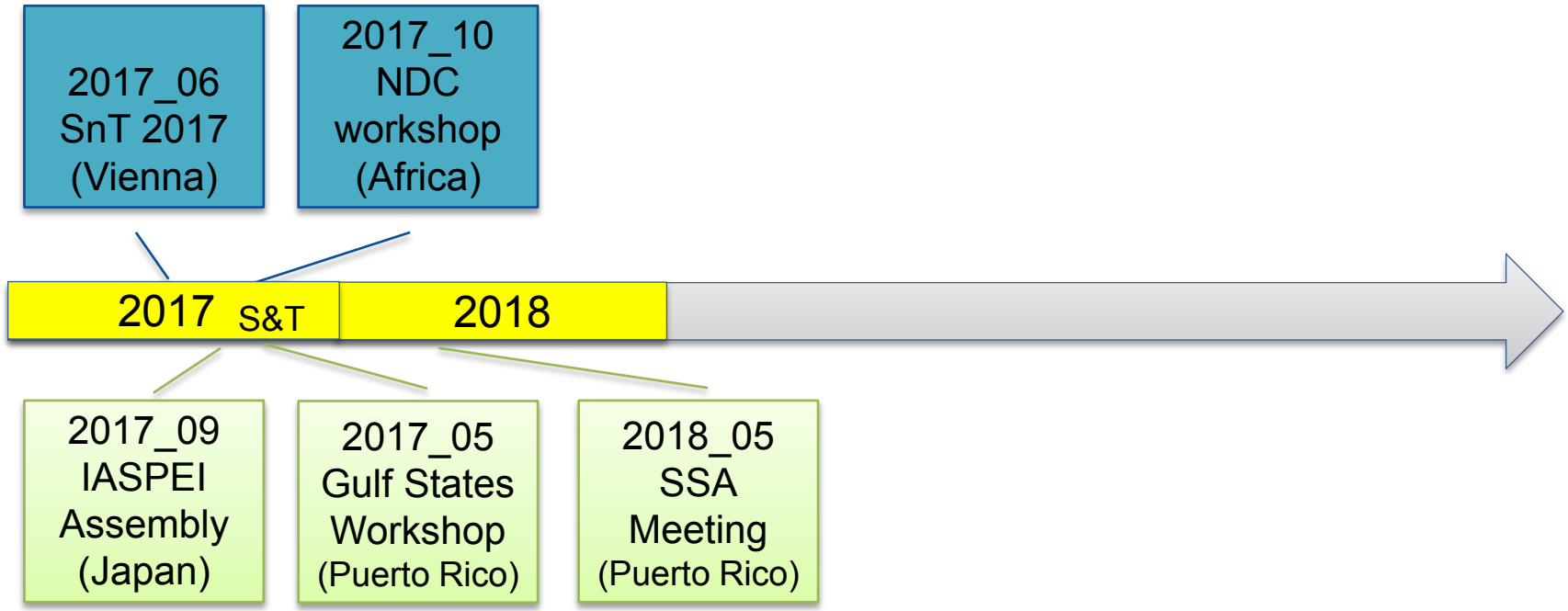
CTBTO workshops/training



Special Sessions on 3-D models

Continued RSTT activities are planned into 2018

CTBTO workshops/training



Special Sessions on 3-D models

Summary

- Utilization of regional seismic stations leads to detection of lower-magnitude events
- Increased travel time prediction error at regional distances causes increased event location error
- RSTT reduces regional travel time error by developing an efficient travel-time calculation method and a 3-dimensional model of Earth's crust and upper mantle
- CTBTO outreach efforts and workshops
  - Provide RSTT training, including use with the iLoc locator (both open source)
  - Contribute local and regional studies that improve the RSTT crustal model
  - Contribute data for improved tomography
  - Contribute to the ISC ground-truth database
- IUGG/IASPEI working group and professional-society special sessions
  - Engage with the academic community
  - Demonstrate that advances in verification and basics science are complementary or synonymous.