

3-D seismic velocity model of the Eastern Mediterranean region using body-wave tomography

Theme 1: The Earth as a complex system

Topic 1.2: Solid Earth structure

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TEL AVIV UNIVERSITY
אוניברסיטת תל אביב



משרד העלייה והקליטה
Ministry of Aliyah and Integration



Outline

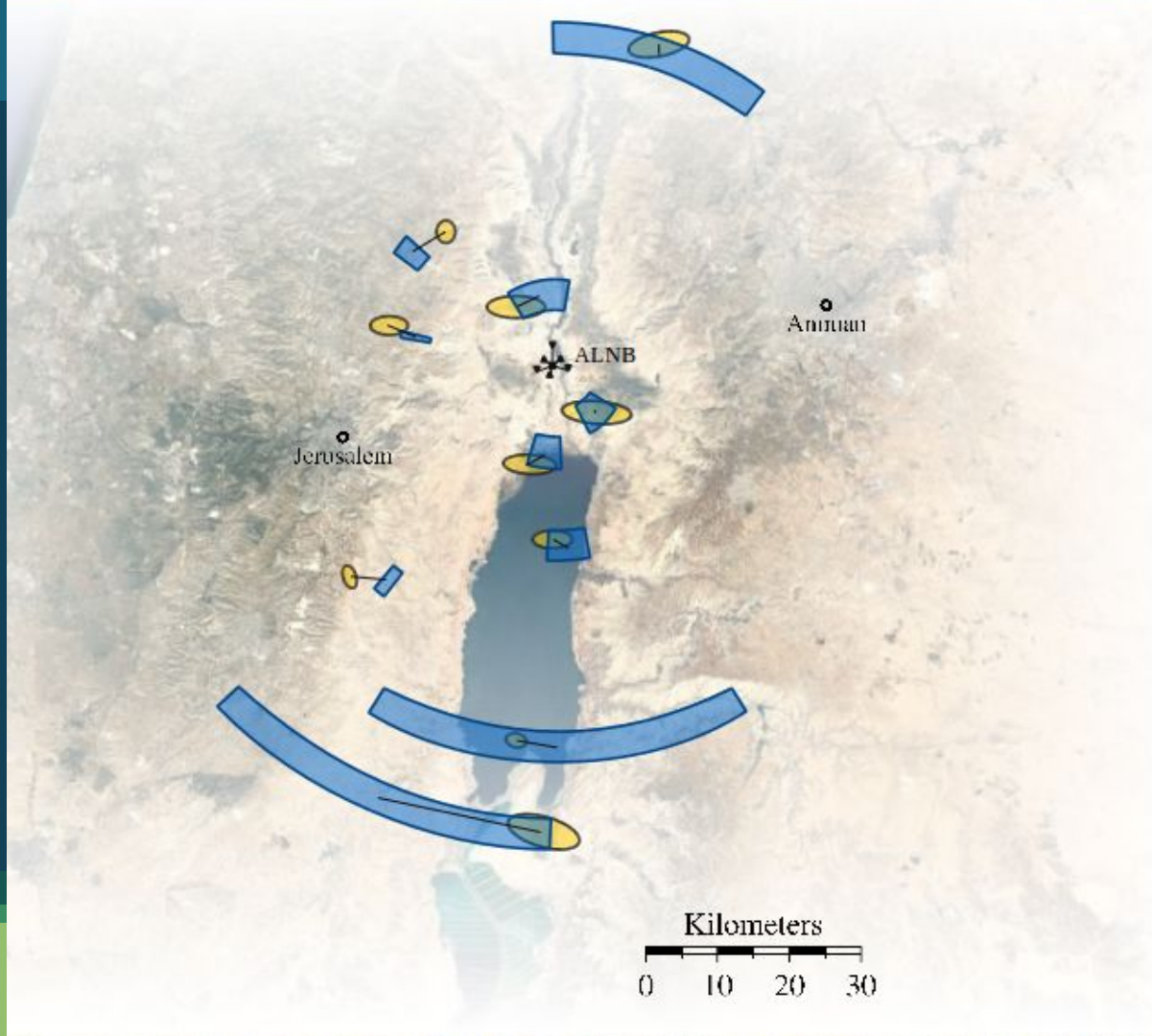
- 1) Introduction
- 2) The Israeli seismic bulletin
- 3) Local seismic tomography
- 4) A tomographic model for the CTBTO
- 5) Conclusions & outlook



after Eisermann *et al.* (2018)



Introduction





- Earthquake location accuracy is everything
EEWS, application of the CTBT, ...
- Depends on theory and technique ...
ray theory, finite frequency, single-event, multiple-event, ...
- ... but mostly on the **velocity model** used
1-D, 3-D, resolution, coverage, ...

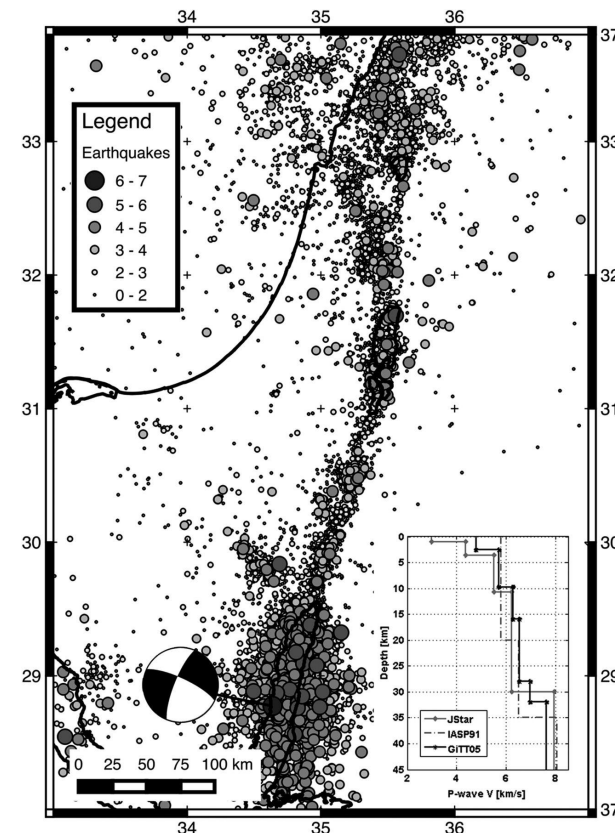
Table 1
Median Values of Locations and Relocations Misfits

Distribution Type	Events	Location (JStar)			Events	Relocation (IASP91)			Events	Relocation (GIT05)		
		Error x (km)	Error y (km)	Error z (km)		Error x (km)	Error y (km)	Error z (km)		Error x (km)	Error y (km)	Error z (km)
All	15,856	8.4	4.0	6.0	15,150	0.77	1.05	1.30	15,181	0.72	1.00	1.26
In-Network*	6576	2.3	1.3	2.2	5909	0.44	0.56	0.78	6223	0.43	0.55	0.76
Off-Network-N	1447	6.5	3.2	3.2	1783	0.71	0.86	1.14	1528	0.78	1.06	1.31
Off-Network-S	7833	135.0	17.0	30.0	7454	1.47	1.83	2.35	7430	1.39	1.74	2.27

Median values of locations and relocation misfits calculated for (a) the initial locations and for the Antelope relocations using

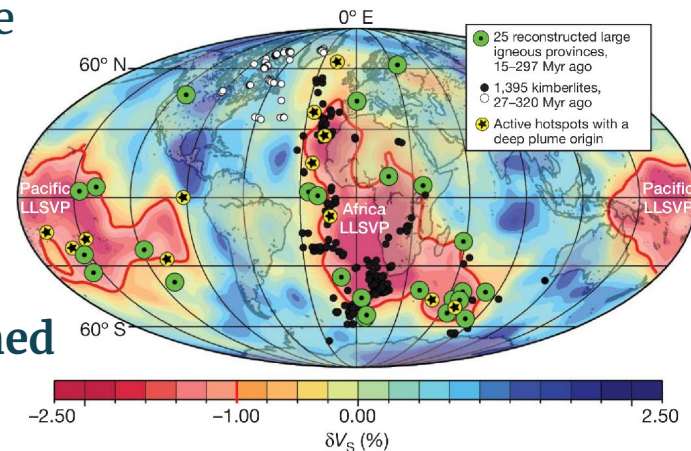
(b) IASP91 global velocity model and (c) 1.5 local velocity model (Gitterman et al., 2005) **IN USE** **OTHERS**

*The area of the In-Network events is presented by the rectangle in Figure 3.





- **Inversion technique** to retrieve **physical properties** of the Earth's interior
velocity, attenuation, anisotropy, ...
- **Inputs are seismic data** recorded at the surface
traveltimes, amplitudes, phase splitting, ...
- **Forward problem:** $G \cdot m = d$
 G : parameterisation & theory; m : velocity model; d : traveltimes
- **Inverse problem nonlinear & under-determined**
Iterative or probabilistic solving methods, regularisation
- **Interpreting tomographic images** helps linking **deep and surface observations**
Earth's evolution, seismic risk, ...



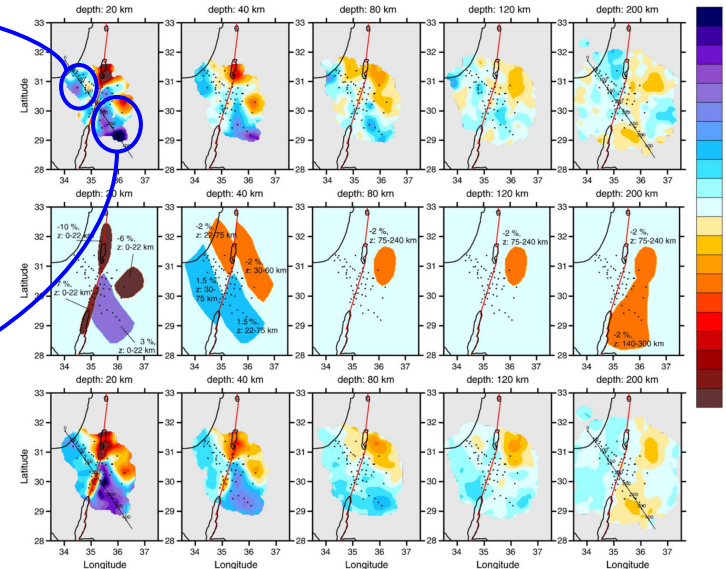
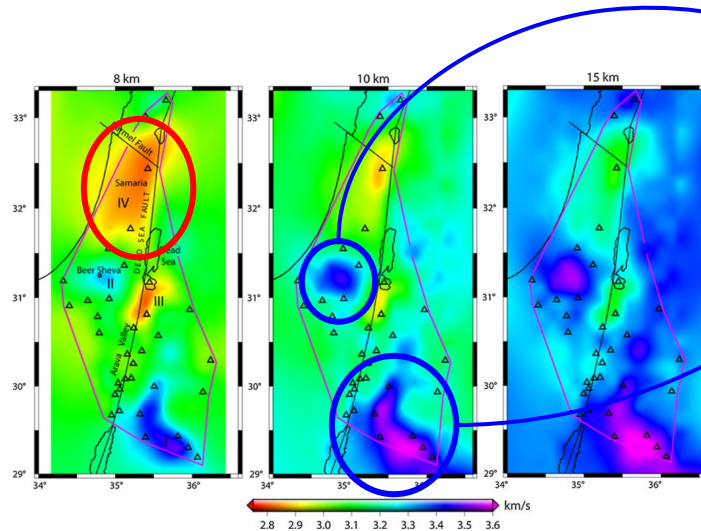


Previous tomographic studies of the EM



Pinsky et al. (2013)
Koulakov et al. (2006)

- **Local studies of the DSB and DST**
 - *Local earthquake seismic tomography:* Braeuer et al. (2012), Hofstetter et al. (2012)
 - *Active-data seismic tomography:* ten Brink et al. (2006); Haberland et al. (2007); Mechie et al. (2009)
 - *Ambient noise tomography:* Stankiewicz et al. (2012); Pinsky et al. (2013)
 - *Teleseismic tomography:* Hofstetter et al. (2000); Koulakov et al. (2006)
- **Regional study of the EM: Koulakov & Sobolev (2006)**

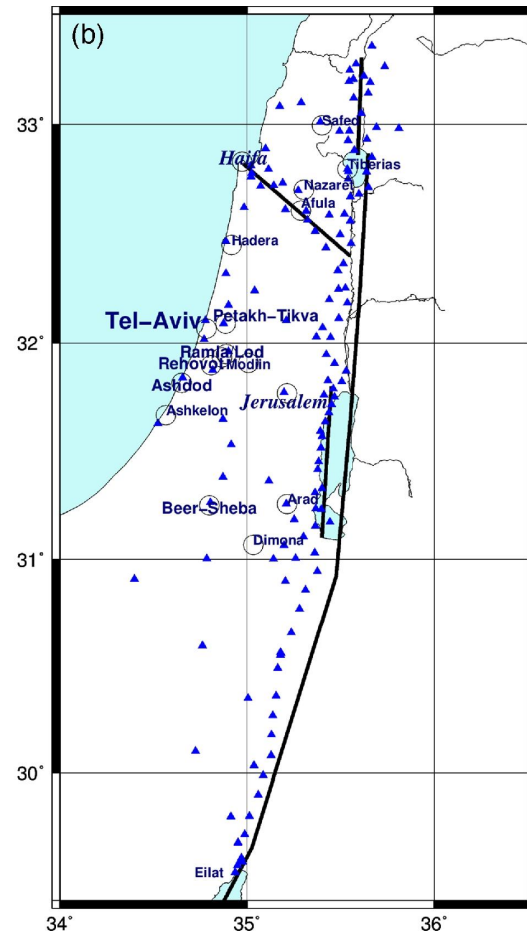
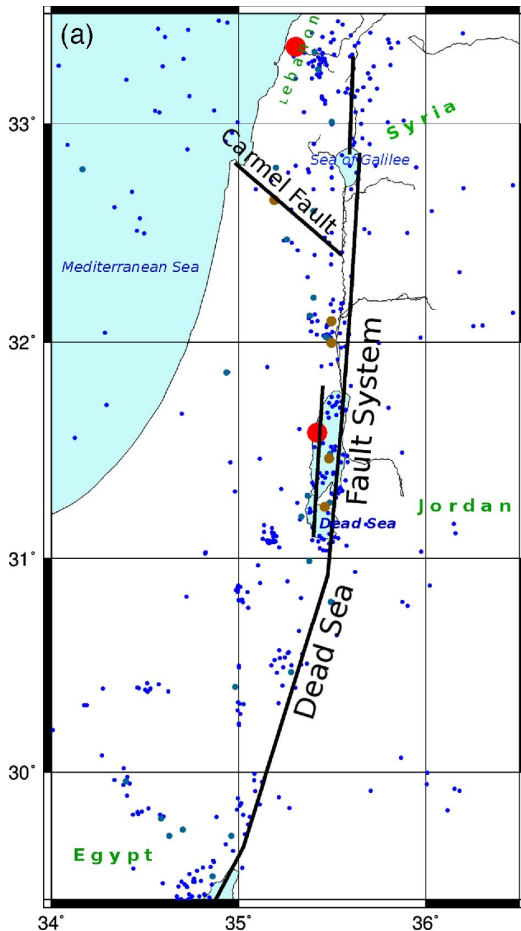




Pinsky (2017); $M > 3$



the Israeli seismic bulletin



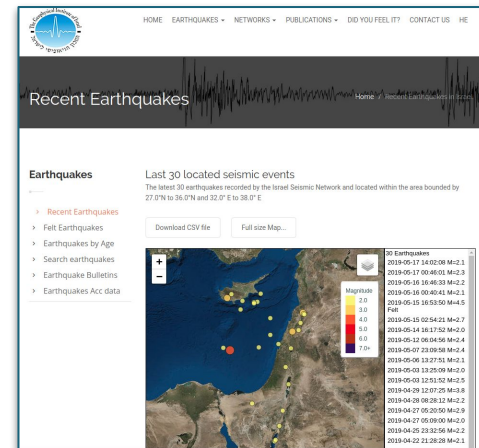


The Israeli seismic bulletin



Built by the GII's Seismology Division

- 24 seismic stations from ISN
- 2 seismic “stations” from the CTBTO’s IMS
- 6 seismic stations from the NDC’s CNF
- Also collects data from neighbouring countries
Cyprus, Lebanon, Syria, Turkey, Jordan, Saudi Arabia, Egypt, ...
- Database starts in the 1980’s
- Local, regional and teleseismic events
- Natural as well as man-made seismicity
quarry blasts, network calibration, ...



```
*** LOC2 ***
First Approximation: x 188.000 y 387.000 z 0.0
09/02/1994 O.T.= 08:12:33.54 *** Aragonese-Deep Region
***
Md= 3.6 +- 0.1 (6 st.)
Latitude= 28.742 N Longitude= 34.687 E R.M.S.= 0.14
X0= 168.906 +- 14.4 Y0= 295.252 +- 247.6 H= 2.0 +- 30.0
Reliability : ACCEPTABLE Stability
:02585.98

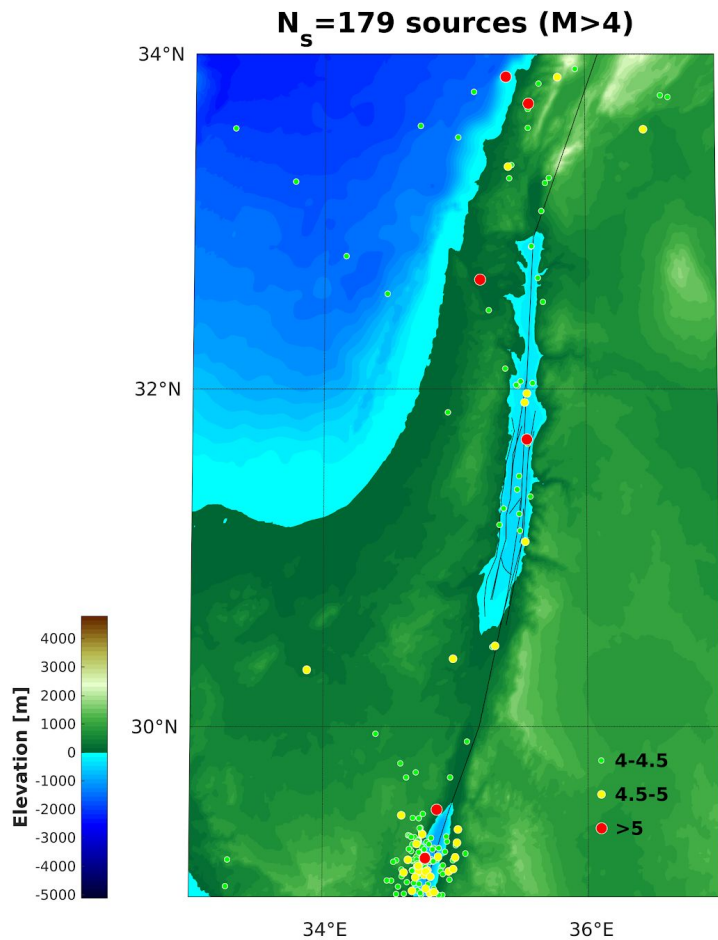
St. Phase Arr.Time Dist. Az. Wt. Ob-C1. Md
YASH Pg 08:12:50.07 95.4 11 1 0.05 3.7
MBH Pg 08:12:53.71 118.6 11 1 -0.18 3.7
MBH Sg 08:13:09.83 118.6 11 2 0.06
SAGI Pn 08:12:59.61 162.1 360 1 -0.04 3.6
PRNI Pn 08:13:02.26 181.1 10 3 0.31 3.6
RMN Pn 08:13:03.92 205.7 2 3 -0.16 3.6
K111 Pn 08:13:09.85 241.6 353 3 0.03
KER Pn 08:13:10.86 250.9 355 3 0.07 3.5
NST Pn 08:13:19.53 293.2 12 4 -0.01
```



The Israeli seismic bulletin



ETOPO1: Amante & Eakins (2009)
Bird *et al.* (2003)

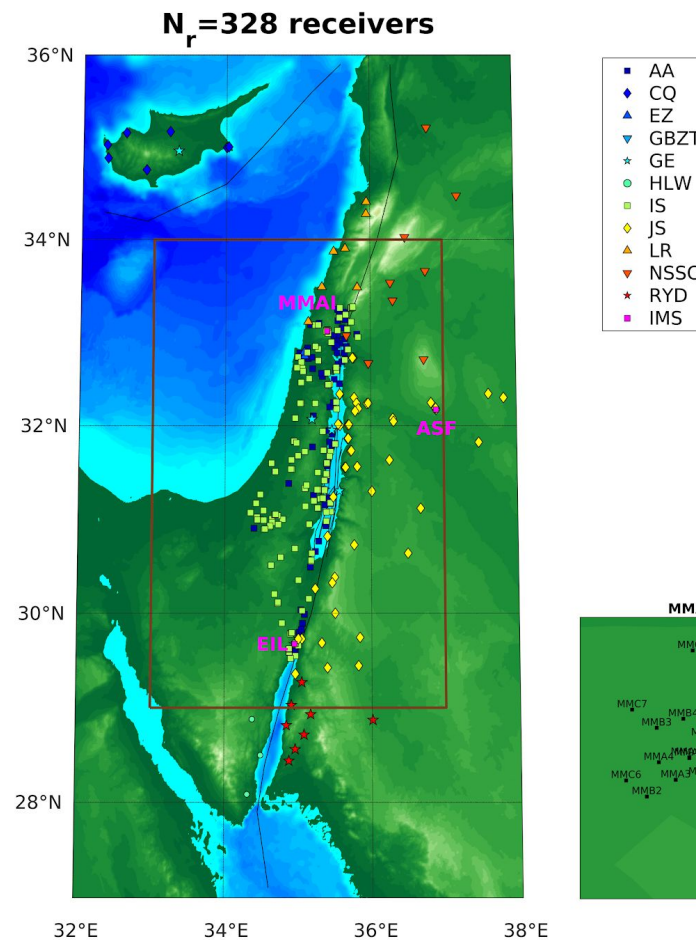
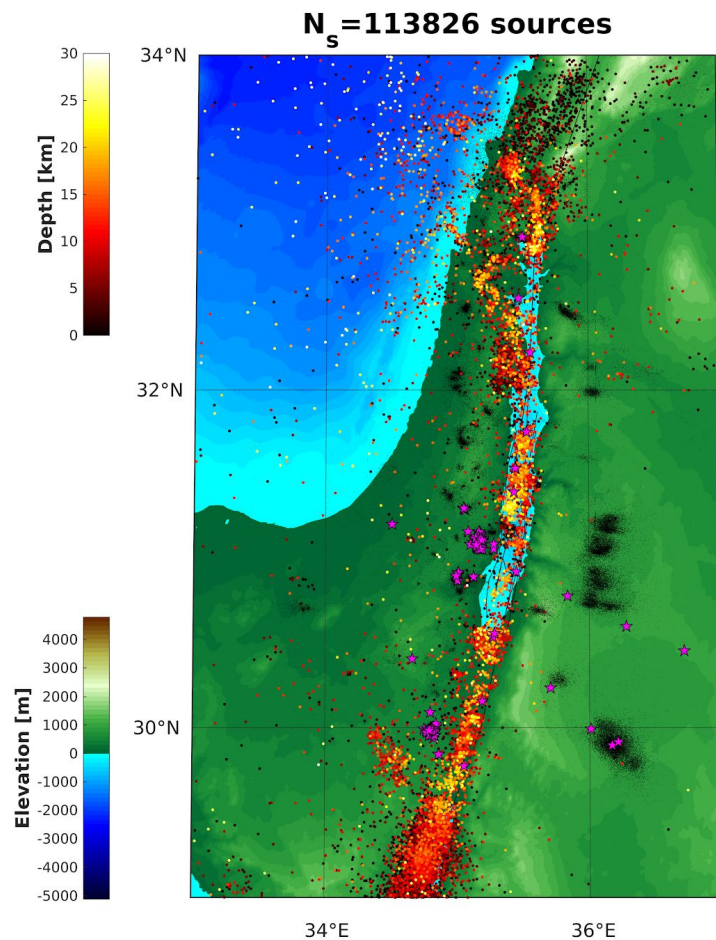




The Israeli seismic bulletin



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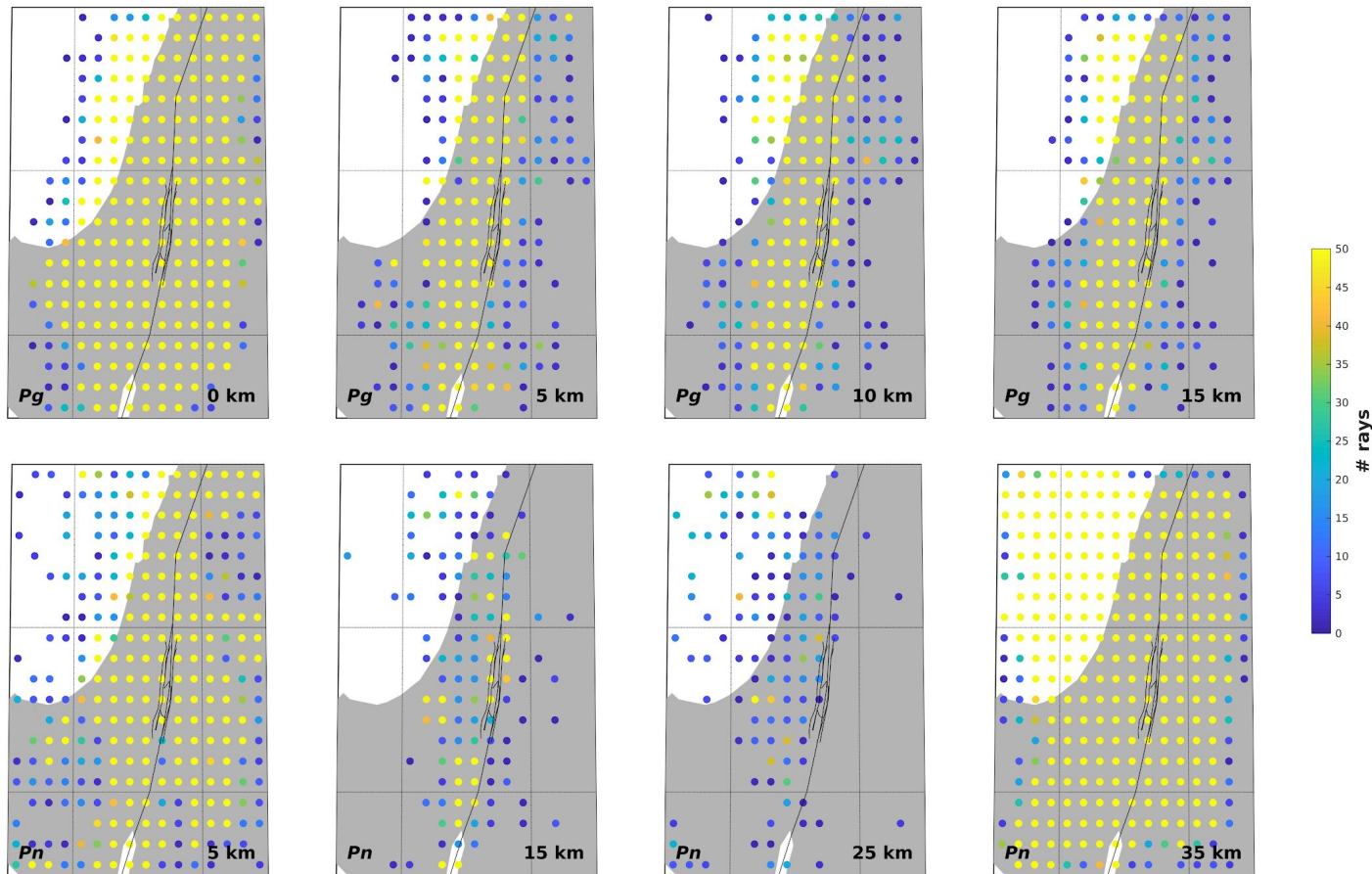




The Israeli seismic bulletin



ak135: Kennett *et al.* (1995)
TauP: Crotwell *et al.* (1999)

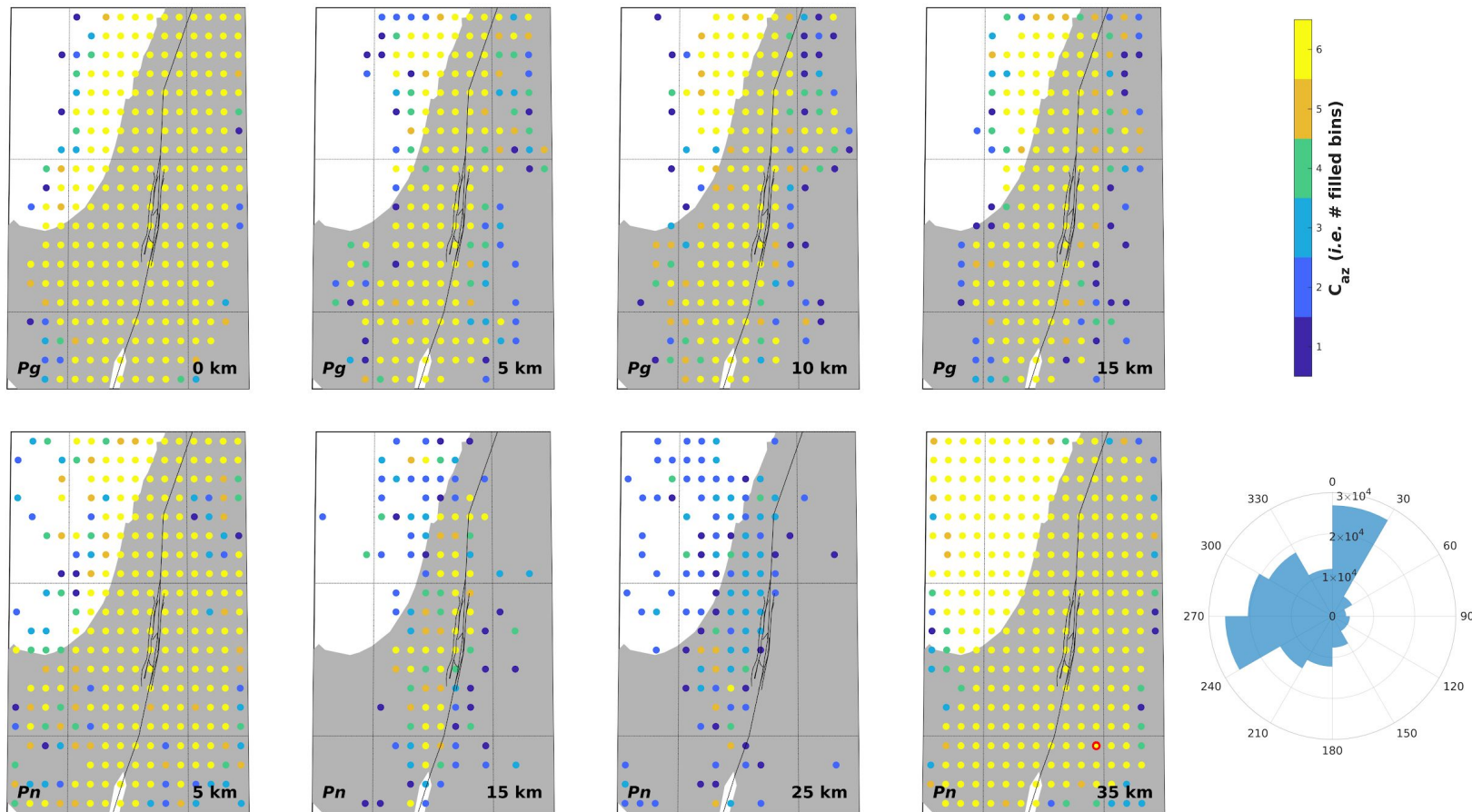




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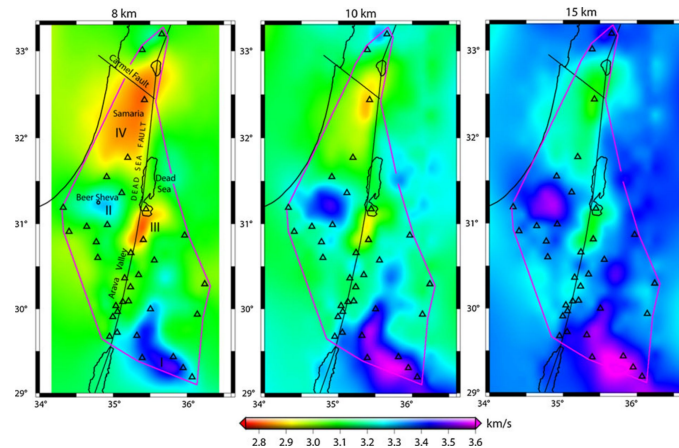
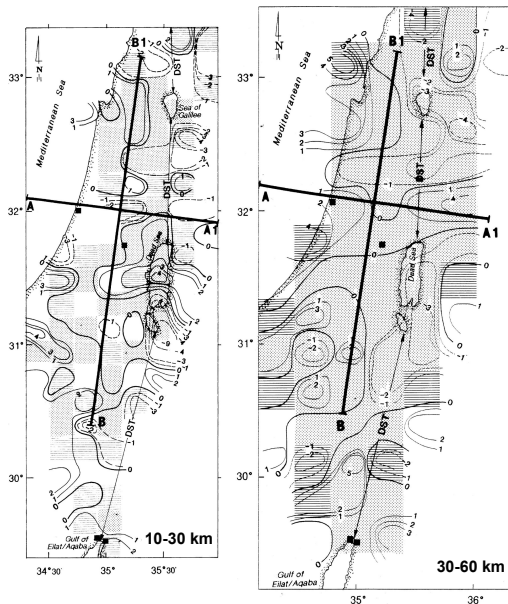




Hofstetter et al. (2000)
Pinsky et al. (2013)



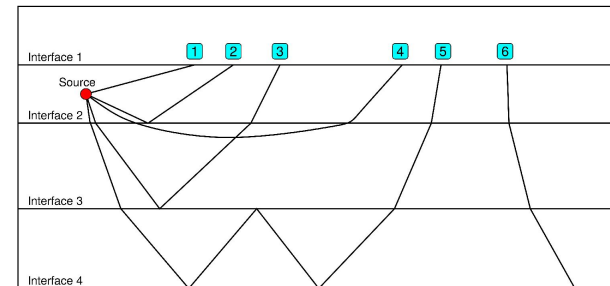
local seismic tomography



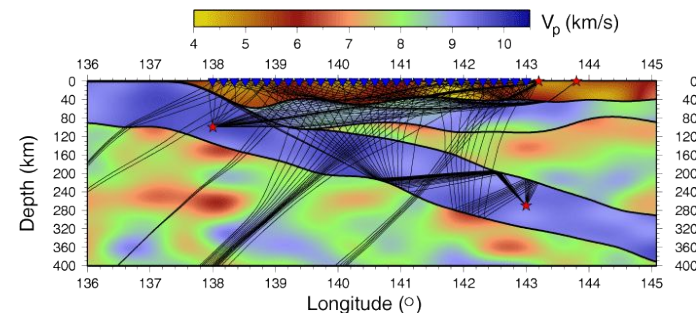


Fast Marching Tomography (FMTOMO)

- Forward modelling uses **Fast Marching Method (FMM)**
- Wide variety of **data types** and **seismic phases**
- Model parameterisation allows **complex structures**



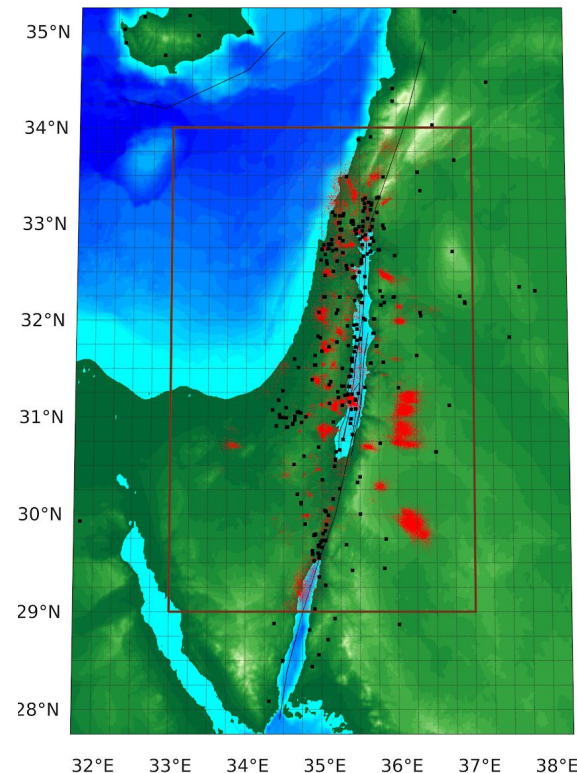
Ray ID	Path signature
1	0 1
2	0 2 2 1
3	0 2 2 3 3 2 2 1
4	0 2 2 3 2 1
5	0 2 2 3 3 4 4 3 3 4 4 3 3 2 2 1
6	4 3 3 2 2 1





Fast Marching Tomography (FMTOMO)

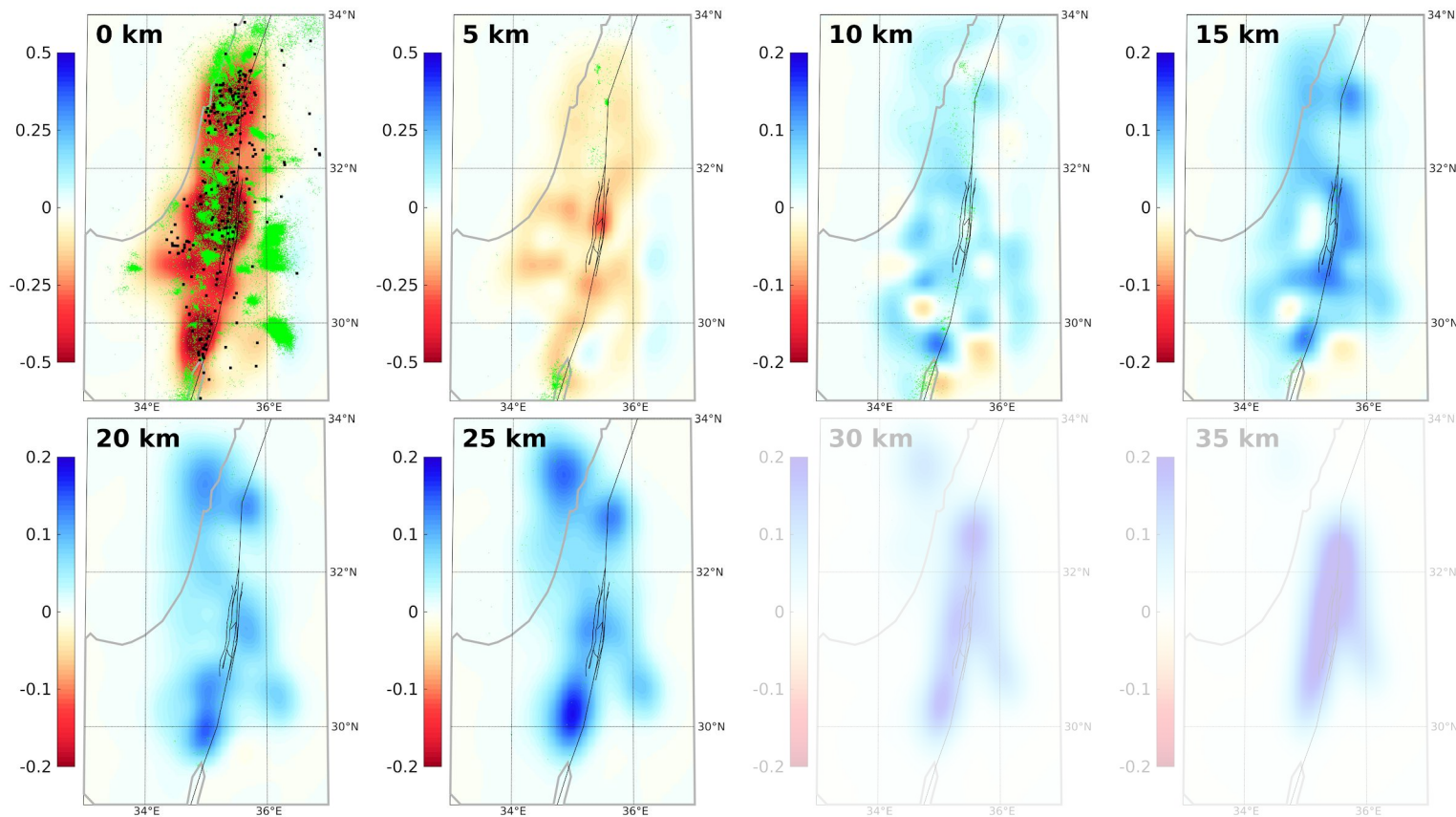
- Forward modelling uses **Fast Marching Method (FMM)**
- Wide variety of **data types** and **seismic phases**
- Model parameterisation allows **complex structures**
- **Vertical** grid spacing of 5 km (-35 to +5 km)
- **Horizontal** grid spacing of 0.25° ($7.5^\circ \times 6.5^\circ$)
- Inverting for v_p , constant Moho depth, no event relocation





Local seismic tomography

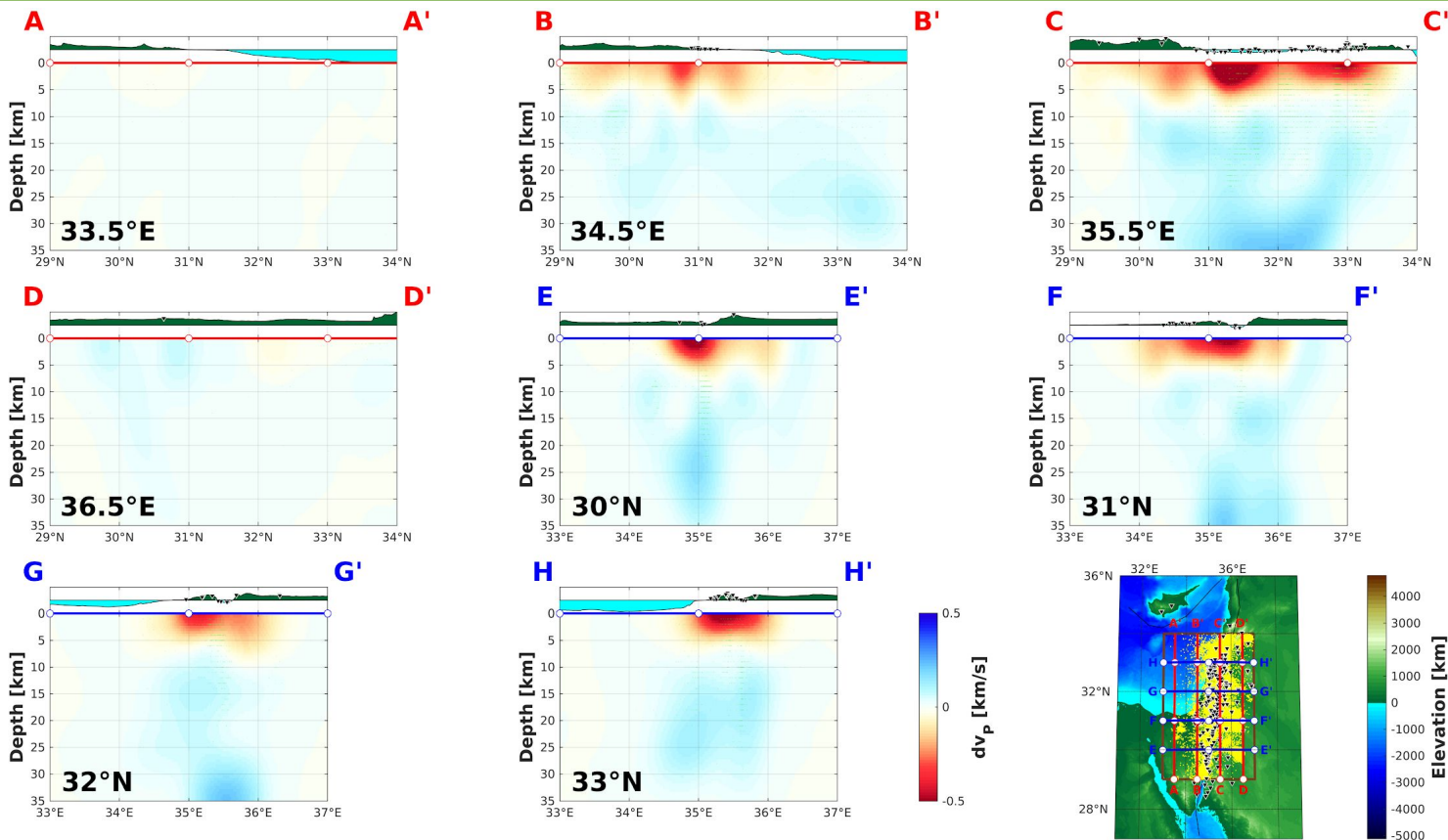
Horizontal depth sections





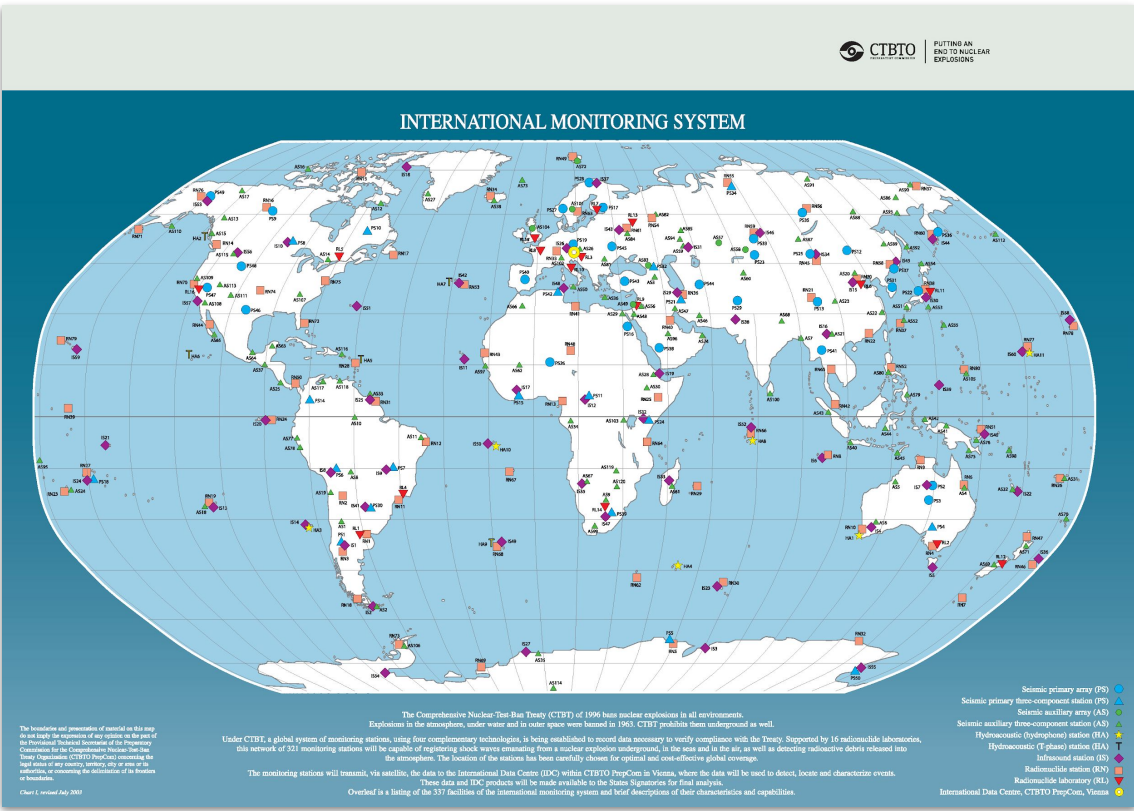
Local seismic tomography

Vertical cross-sections





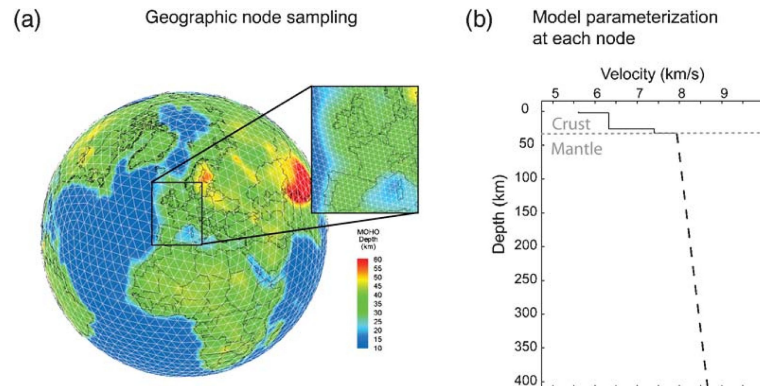
a tomographic
model for the
CTBTO





The RSTT framework

- Software and regional model specifically built for **real-time event-location**
- Software package initially designed for **regional ray tracing**
- Model is based on a **global tessellation** of nodes every $\sim 1^\circ$
- **1-D velocity profiles** at each node are interpolated to build a 3-D model of the **crust and upper mantle**



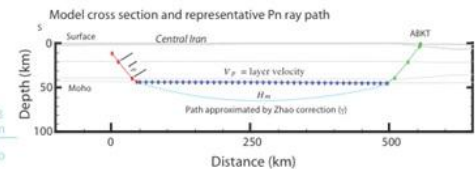
Travel Time Calculation

$$T = \sum_{i=1}^N x_i s_i + \alpha + \beta + \gamma$$

Source and Receiver Crustal Travel Times (α and β)

$$\alpha = \sum_{j=1}^Q \frac{L_j}{V_j} \quad \beta = \sum_{l=1}^Q \frac{L_l}{V_l} \quad \gamma = -\frac{c^2 X_m^3}{24 V_0^3}$$

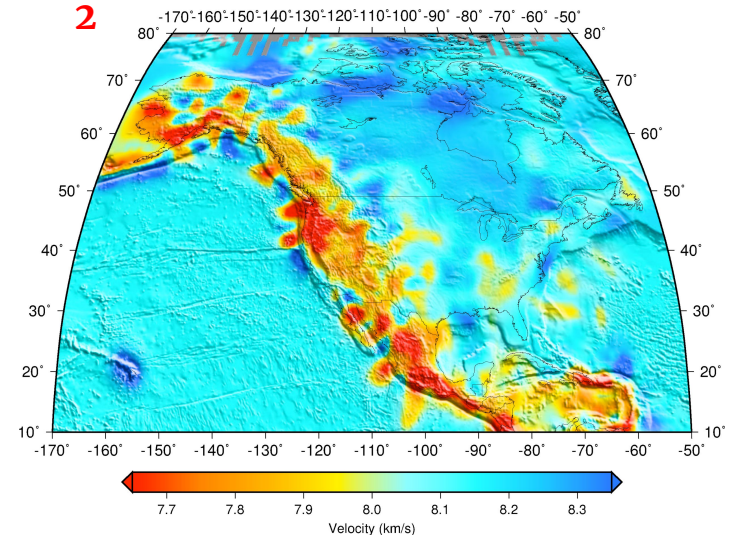
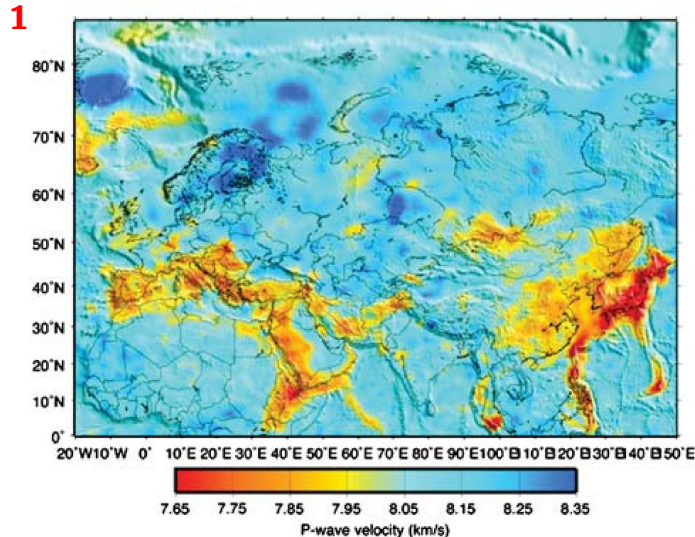
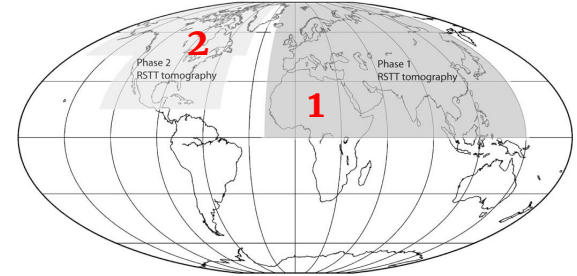
Q = number of crustal layers





The RSTT framework

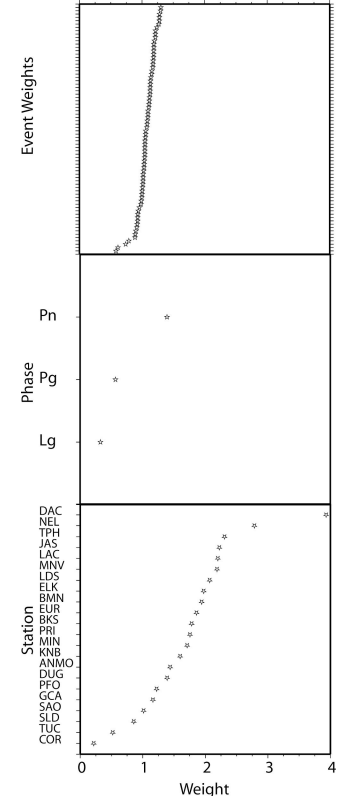
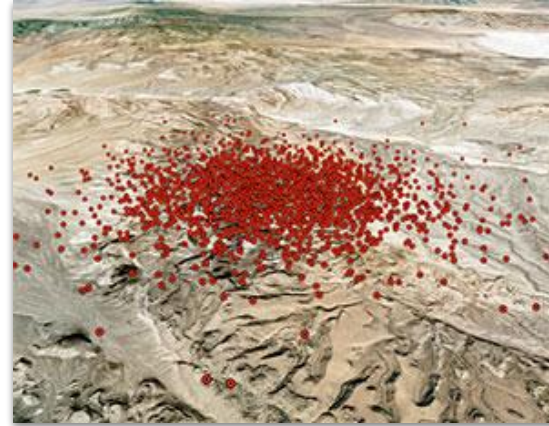
- RSTT studies have been conducted in Eurasia and North America
- Ultimate goal is global model designed to predict regional seismic phases





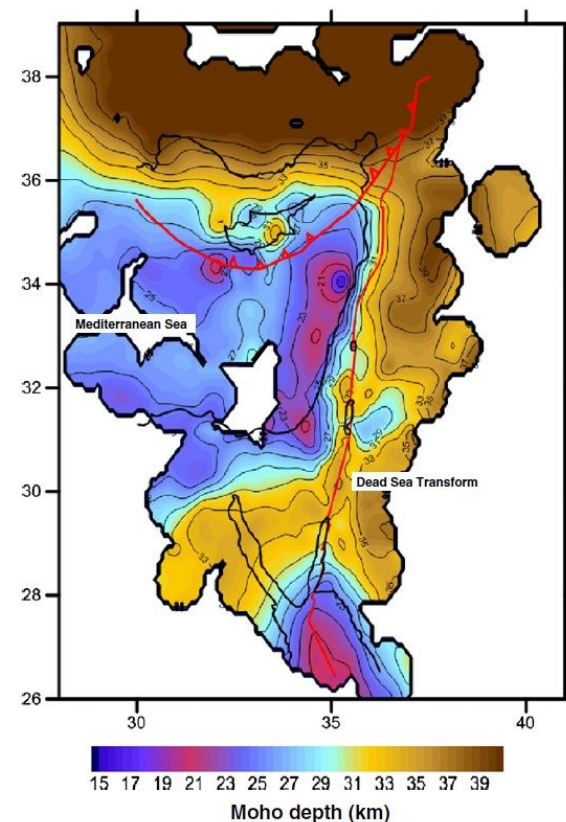
BayesLoc: Bayesian Hierarchical Seismic Event Locator

- Multiple-event seismic locator
 - Traveltime predictions
 - Arrival-time measurements
 - Stochastic phase labels
 - *A priori* statistical model
- Estimates event-, station- and phase-specific corrections that can be used as selection criteria
- Can also help reduce redundancy between seismic events in the input dataset





- Large data set with good coverage
more low-magnitude sources, more source coverage, ...
- New data with new network
new coverage, better quality/coherency
- BayesLoc will make cleaning-up easier
and reduce source redundancy
- Velocity model in agreement with literature
need to include Moho variations
- Only used P_g data
Pn for upper-mantle, Sn/Sg, ...
- Combine with other data
to increase depth coverage, sensitivity



THANKS!

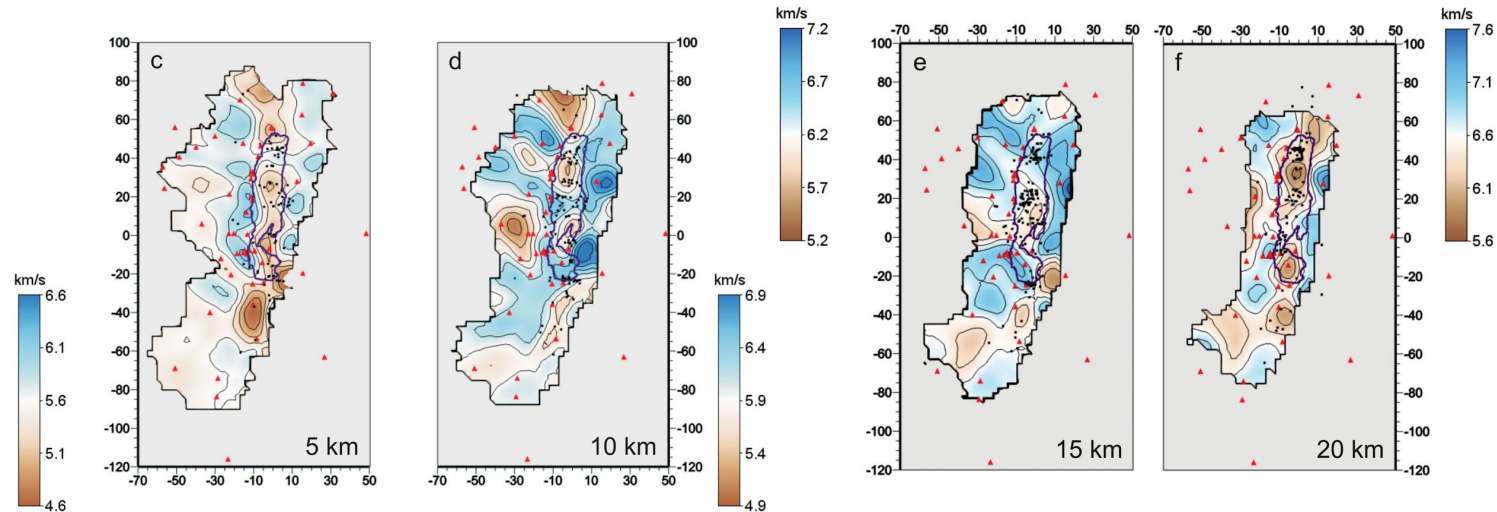
Any questions?

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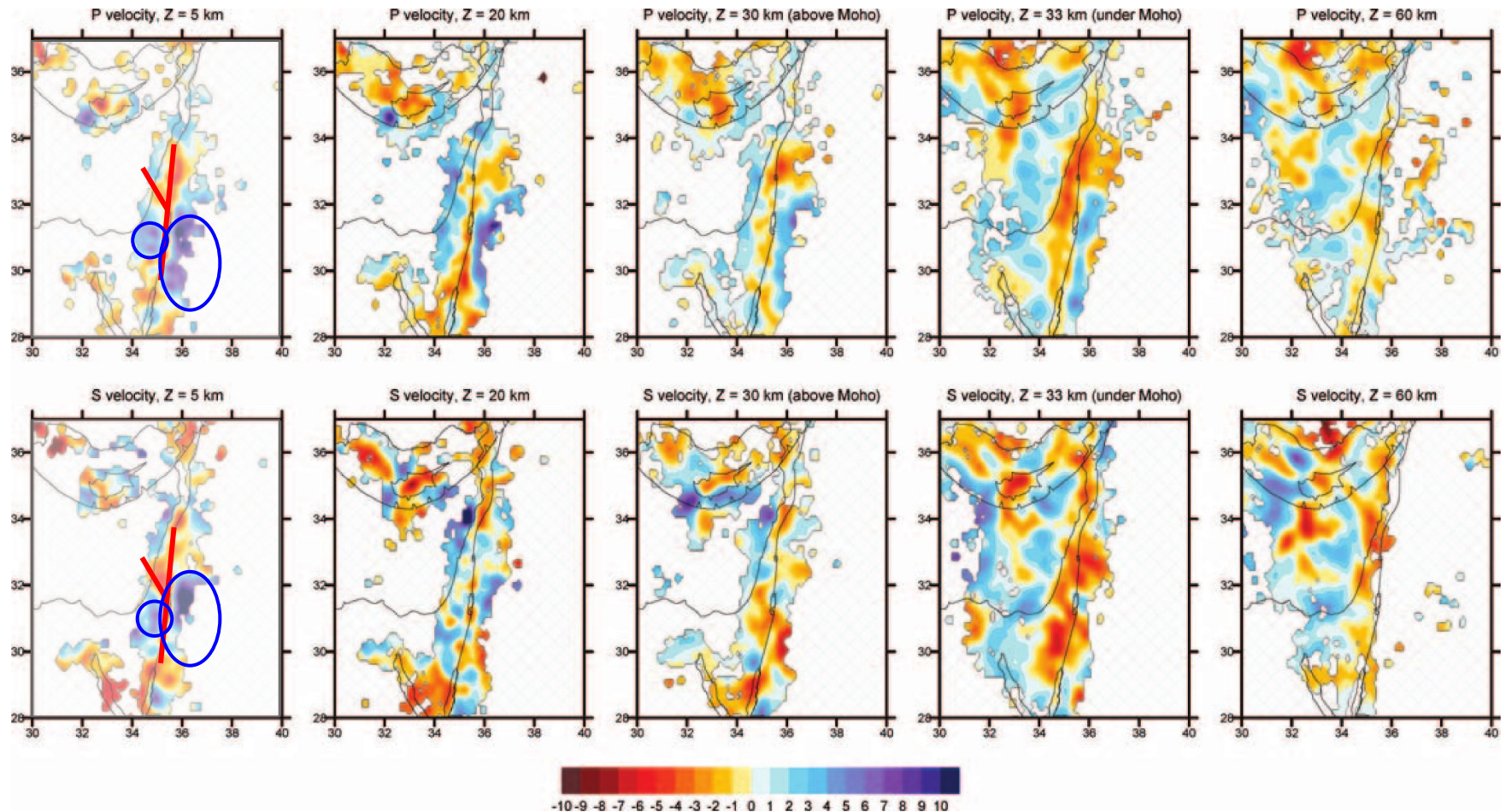




Regional model of the EMME

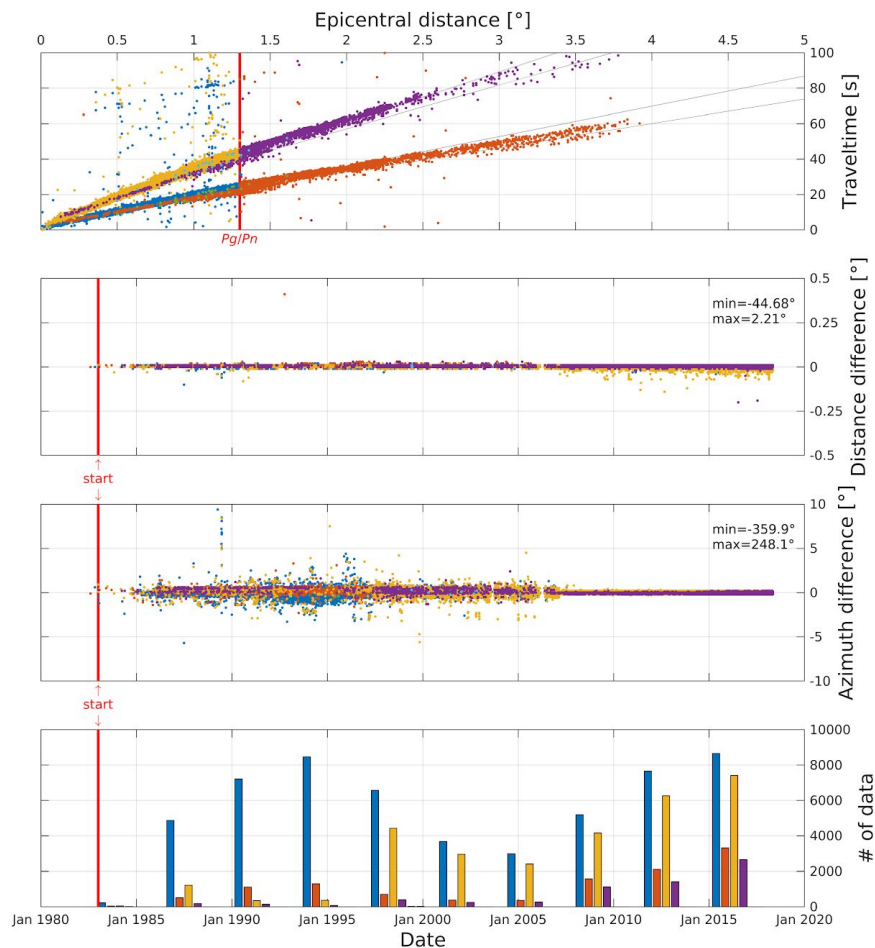
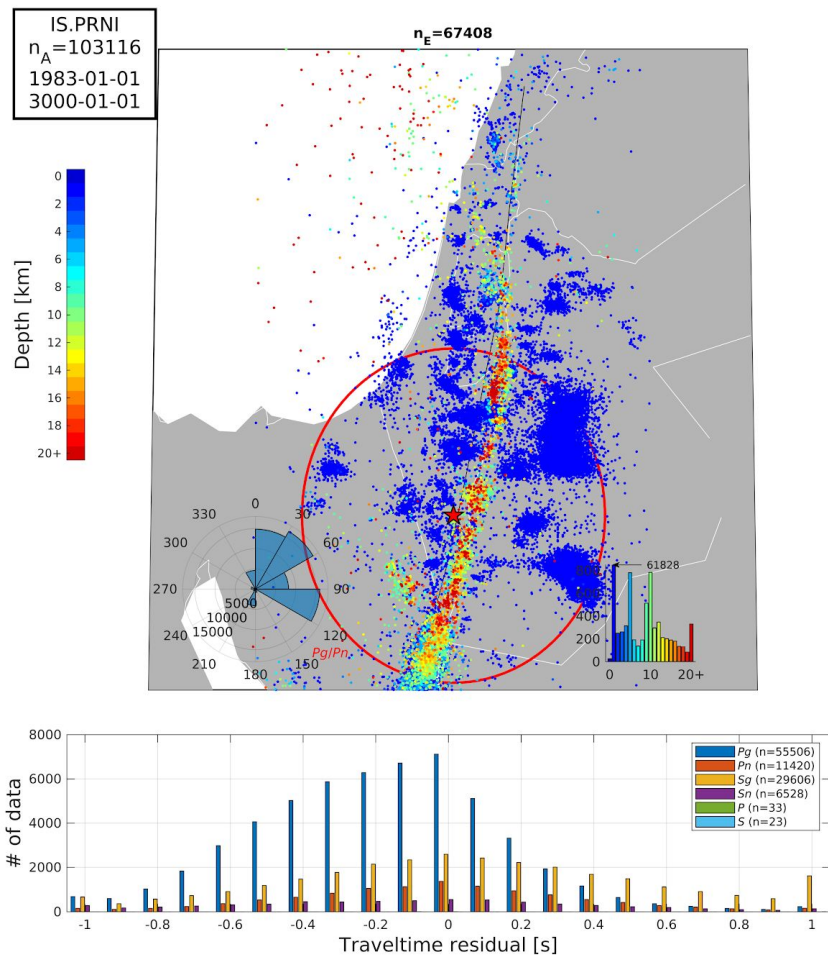


Koulakov & Sobolev (2006)



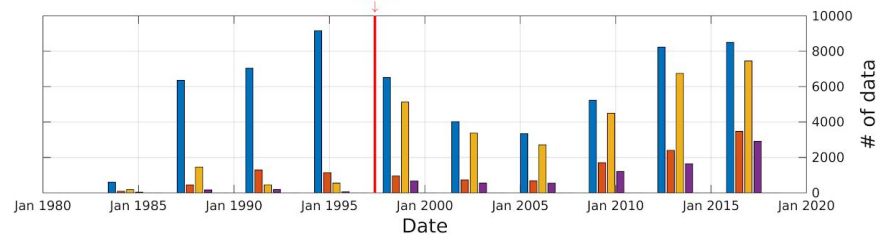
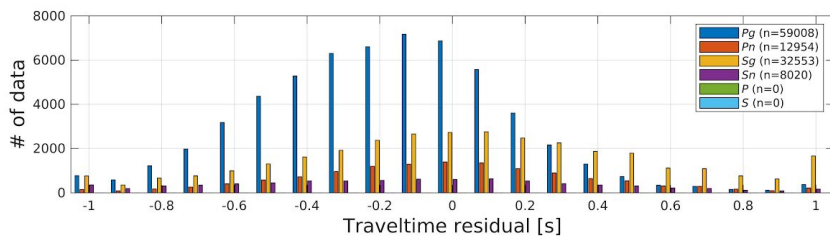
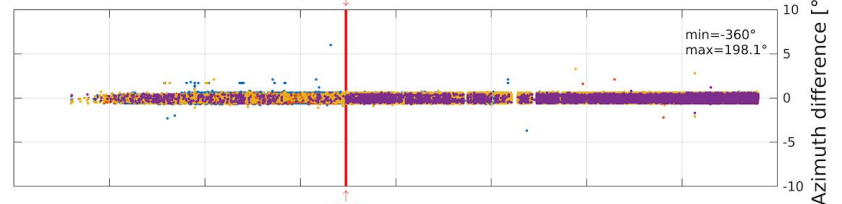
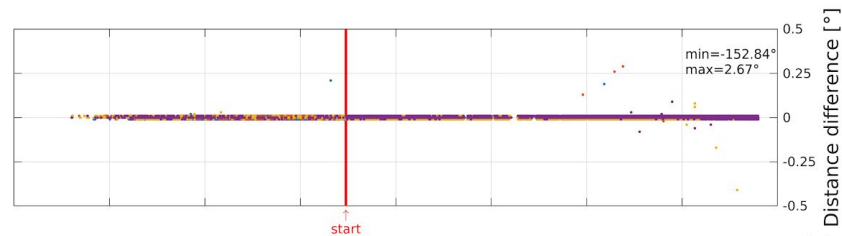
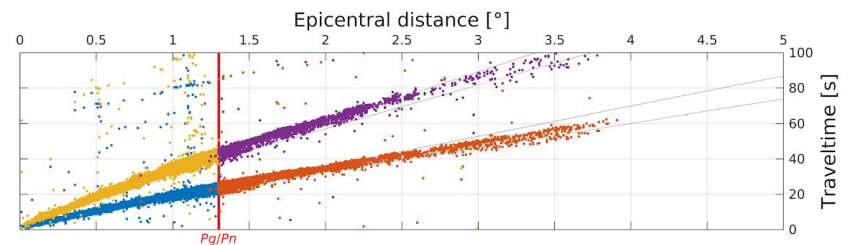
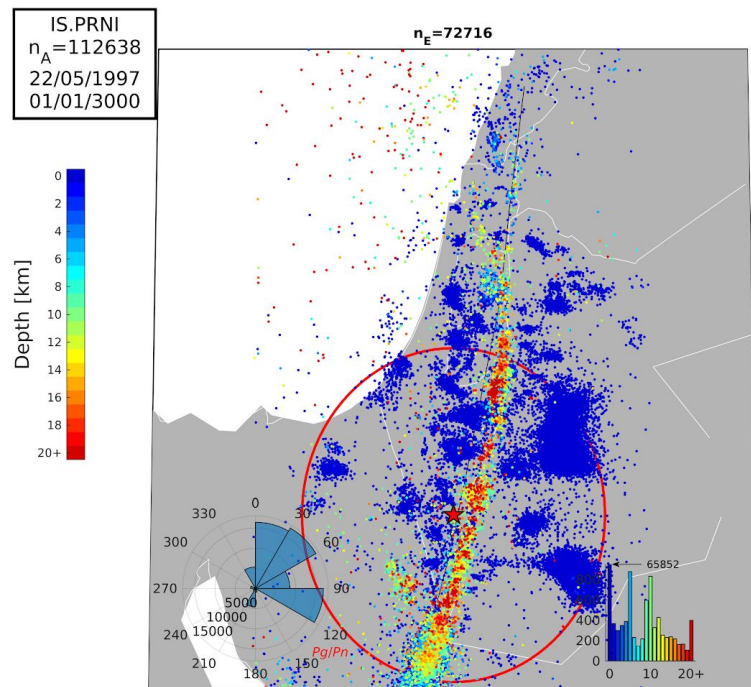


The Israeli seismic bulletin... BEFORE review





The Israeli seismic bulletin... AFTER review

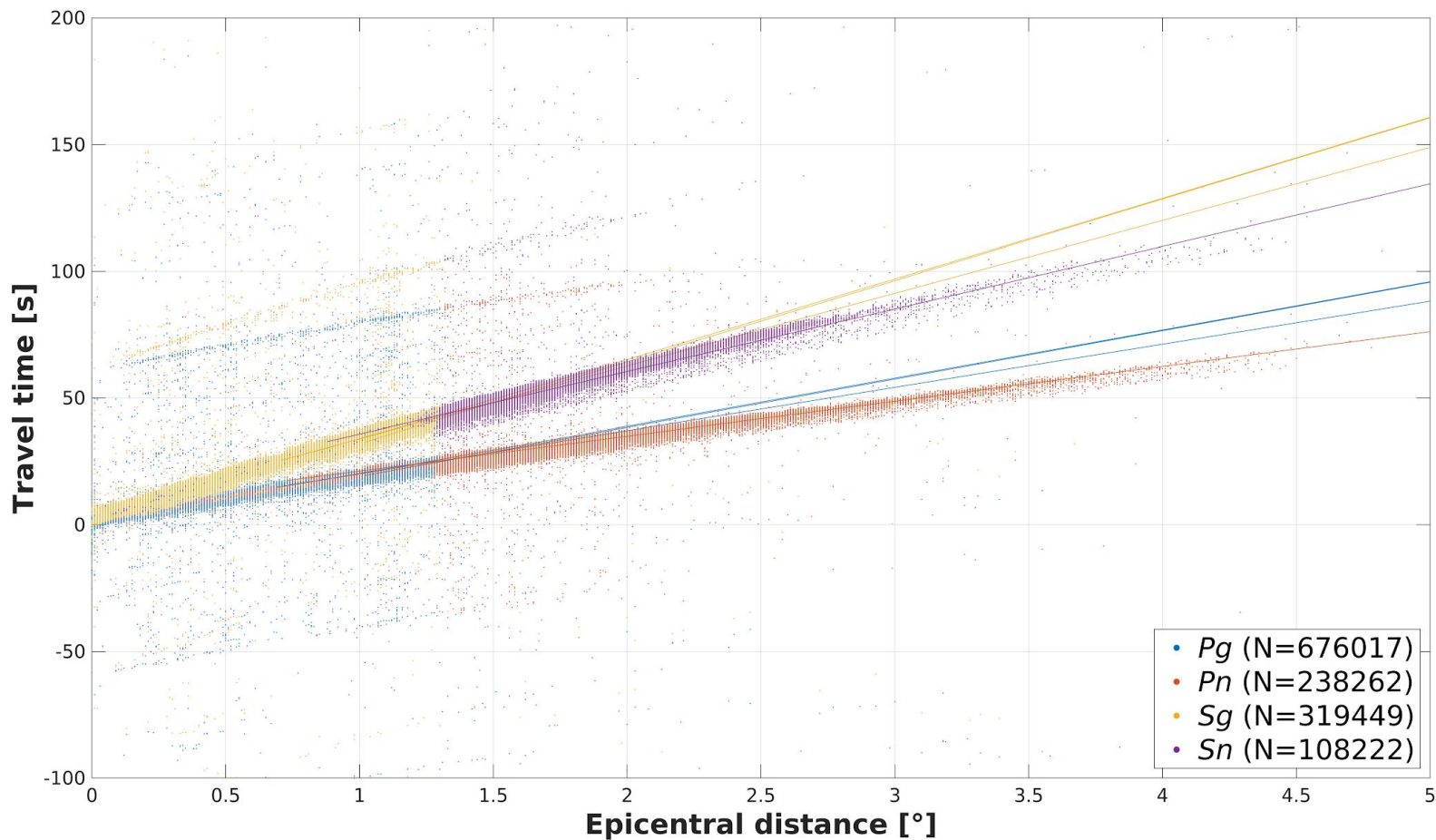




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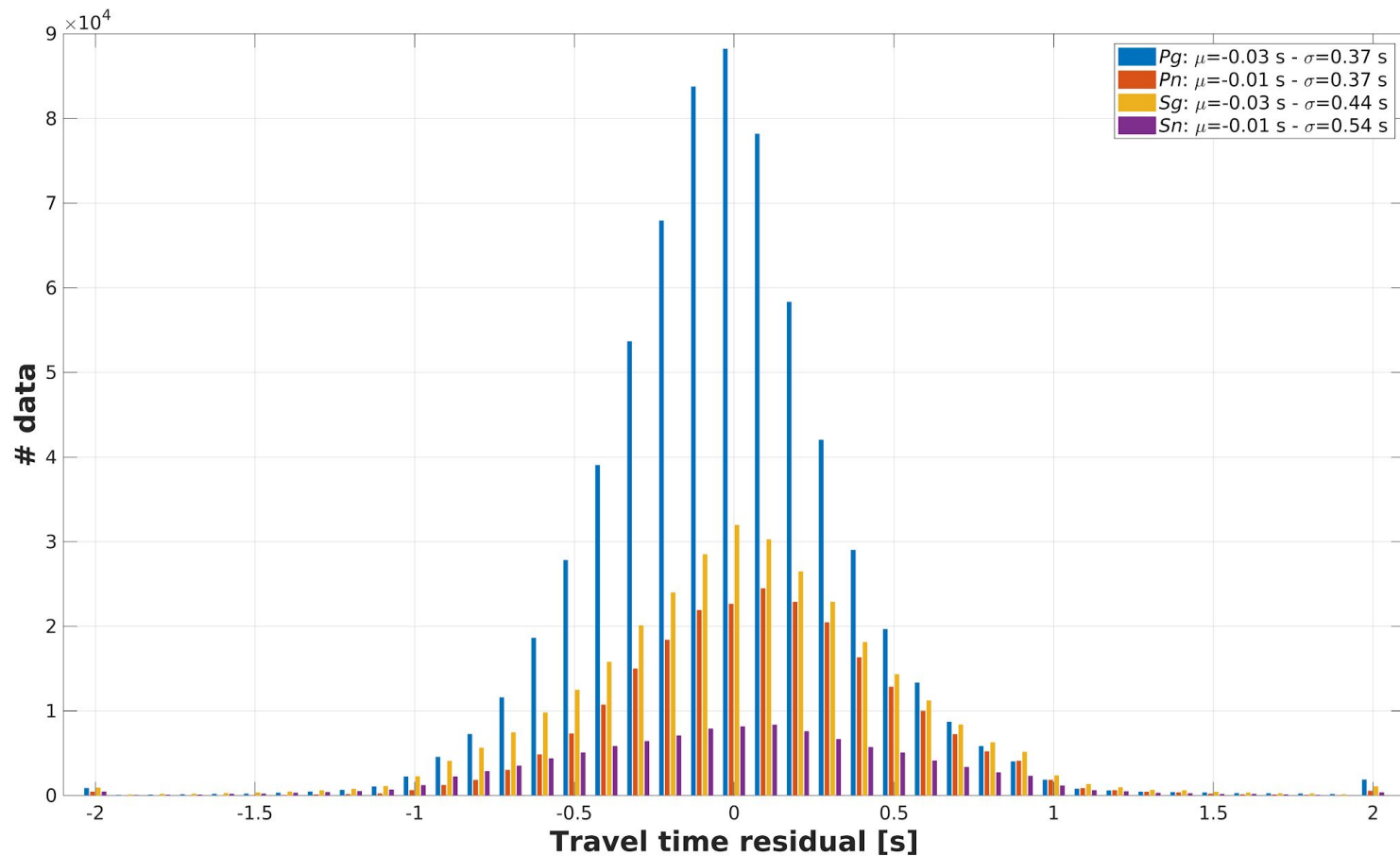


ak135: Kennett *et al.* (1995)
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The Israeli seismic bulletin





A tomographic model for the CTBTO



Simmons *et al.* (2011, 2012)
Myers *et al.* (2011, 2015)

Bringing RSTT studies together

- Global model *LLNL-G3Dv3* is built using *RSTT* studies as starting models
- Regional AND teleseismic seismic data
- *BayesLoc* is used to relocate events and select seismic data
- Global multi-level tessellation grid allows finer parameterisation in areas with better data coverage
- A higher resolution is still required in the EMME for local seismic location purposes

