Two sets of twenty-five years of ISC Delay times and their newly estimated uncertainties

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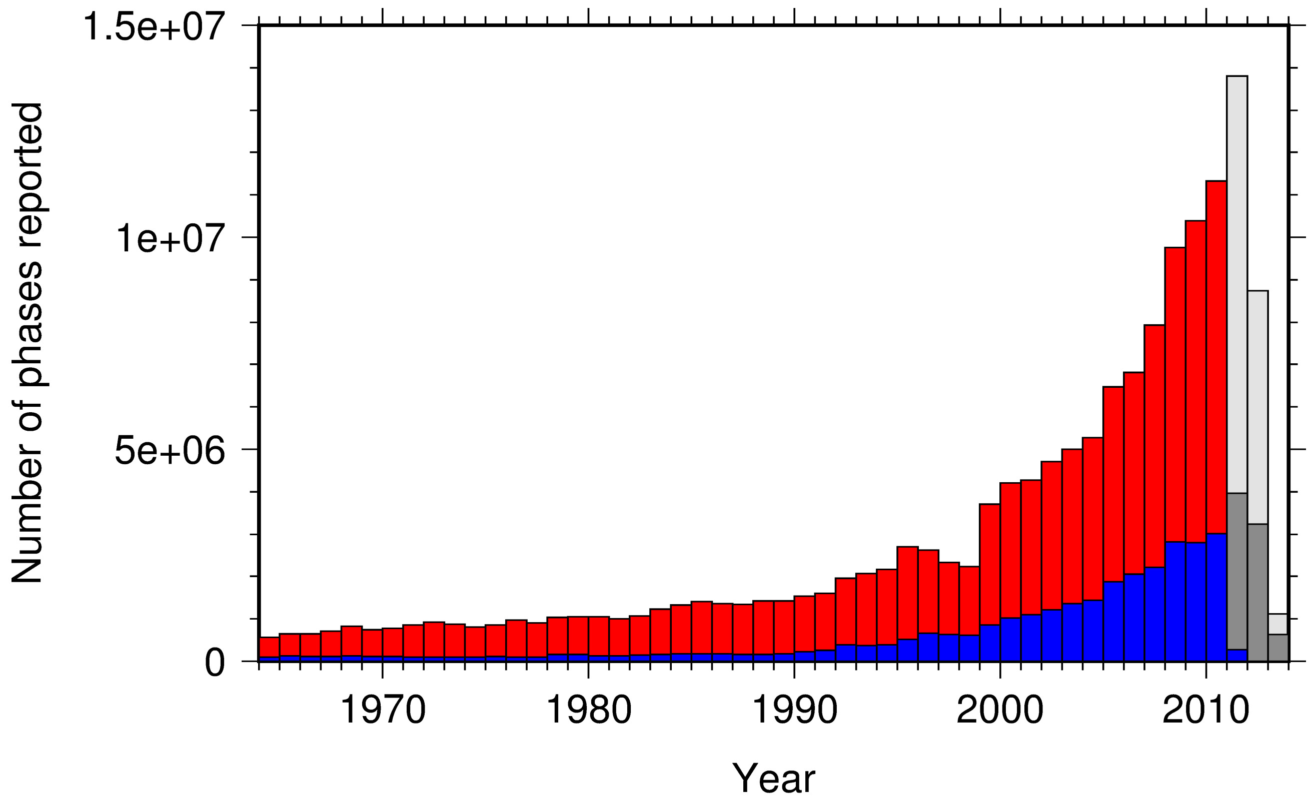
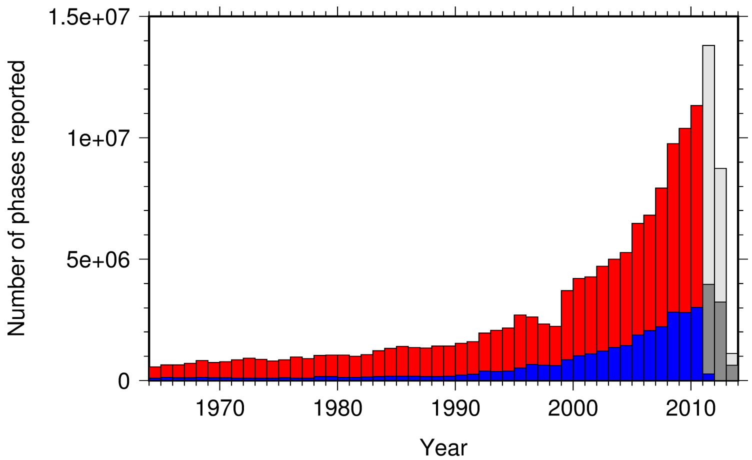


Figure 9.3: *Histogram showing the number of phases (red) and number of amplitudes (blue) collected by the ISC for events each year since 1964. The data in grey covers the current period where data are still being collected before the ISC review takes place and is accurate at the time of publication.*

International Seismological
Centre, On-line Bulletin, http://www.isc.ac.uk, Internatl. Seis. Cent., Thatcham, United Kingdom, 2010.

1964-2013 = 50 years of ISC

- 25 years, 1964-1988
- ~15 million phases reported
- nearly ***5 million*** EHB P delays



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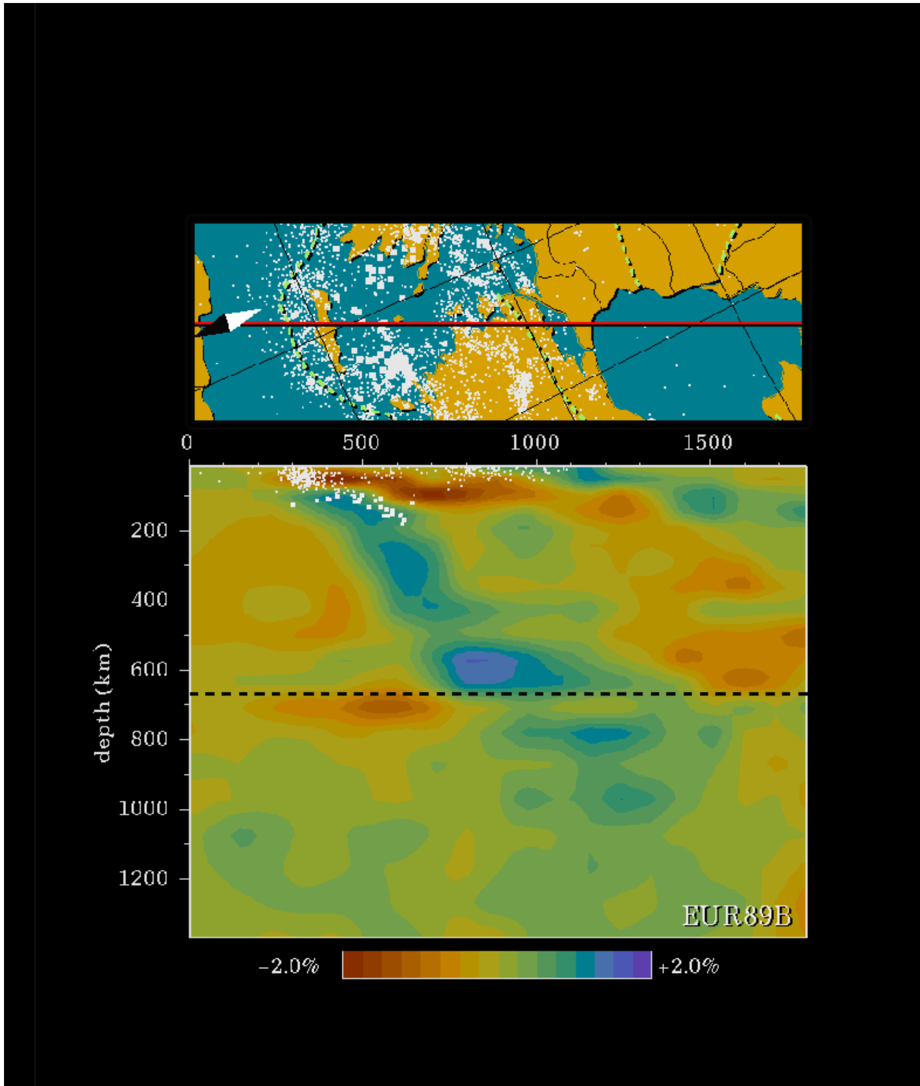
- 25 years, 1989-2013
- (20 years, 1989-2008)
- ~100 million reported, estimated 15 million EHB P, (over ***12 million*** in EHB till 2008)

Tomography with ISC delays

- 25 years, 1964-1988

EUR89B



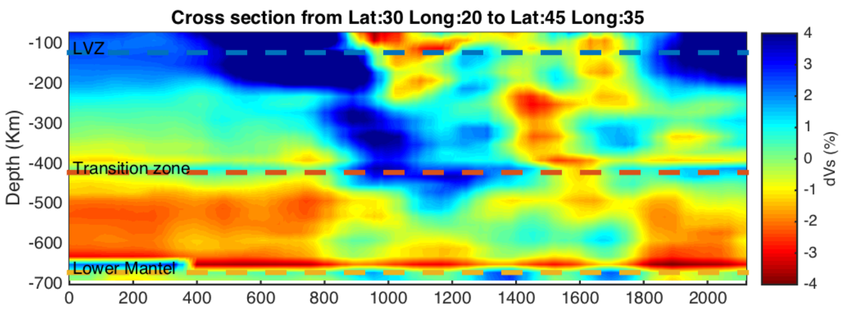
- nearly ***5 million*** EHB P delays
- ***2 million*** (impulsive-onset, European stations) selected for tomography study:

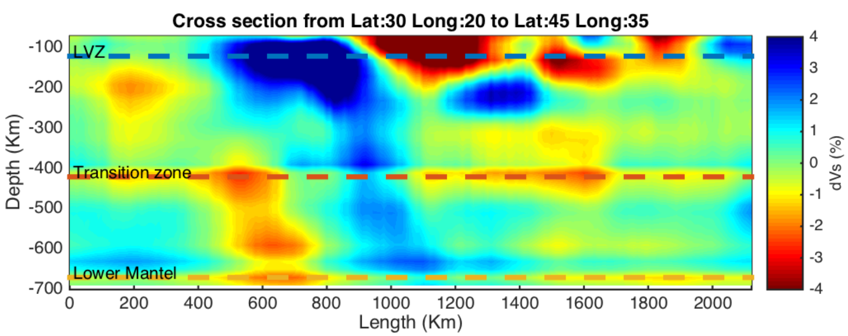
Spakman, W., Van der Lee, S., & Van der Hilst, R. (1993). Travel-time tomography of the European-Mediterranean mantle down to 1400 km. *Physics of the Earth and Planetary Interiors*, *79*(1), 3-74.

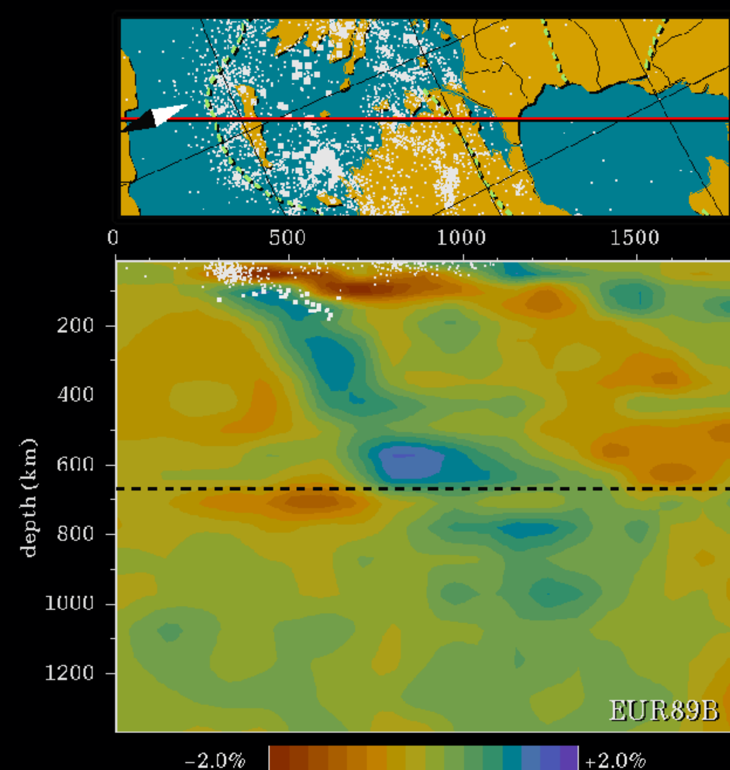
Tomography with ISC delays ...and more

Zhu, H., Bozdağ, E., & Tromp, J. (2015). Seismic structure of the European upper mantle based on adjoint tomography. *Geophysical Journal International*, *201*(1), 18-52.

EUR89B







Chang, S. J., van der Lee, S., Flanagan, M. P., Bedle, H., Marone, F., Matzel, E. M., ... & Schmid, C. (2010). Joint inversion for three−dimensional S velocity mantle structure along the Tethyan margin. *Journal of Geophysical Research: Solid Earth (1978–2012)*, *115*(B8).

Comparisons by A. Pladys & J.Thurin

50 years of ISC data

115 million phases reported, of which~ 50 million P phases

17 million P delays in EHB catalog

- Too much for tomography?
- Perfect for statistical analysis

17 million P delays

Chang, S. J., van der Lee, S., Flanagan, M. P., Bedle, H., Marone, F., Matzel, E. M., ... & Schmid, C. (2010). Joint inversion for three‐dimensional S velocity mantle structure along the Tethyan margin. *Journal of Geophysical Research: Solid Earth (1978–2012)*, *115*(B8).

Because the group velocities are measured at up to 21 periods between 7 and 100 s per seismogram, the dU measurements are significantly redundant. To reduce this redundancy and increase the validity and efficiency of the least squares inversion, we performed singular value decomposition [Dongarra et al., 1979] of (6) for each seismogram and discarded constraints with singular values less than 10% of the maximum singular value.

Voronin, S., Mikesell, D., Slezak, I., & Nolet, G. (2014). Solving large tomographic linear systems: size reduction and error estimation. *Geophysical Journal International*, *199*(1), 276-285.

Singular value decomposition of each subset allows us to project the data onto a subspace associated with the largest eigenvalues of the subset. After projection we reject those data that have a signal-to-noise ratio (SNR) below a chosen threshold. Clustering in this way assures that the sparse nature of the system is minimally affected by the projection. Moreover, our approach allows for a precise estimation of the noise affecting the data while also giving us the ability to identify outliers.

Use method of Voronin et al. (2014) in 9 different categories of IS/EHB P delays:

Singular Value Decomposition

$$Am = d$$

NxM Mx1 Nx1

$$A = U \Lambda V^T \approx U_k \Lambda_k V_k^T$$

NxM NxN NxM MxM Nxk kxk kxM

Small and zero eigenvalues removed

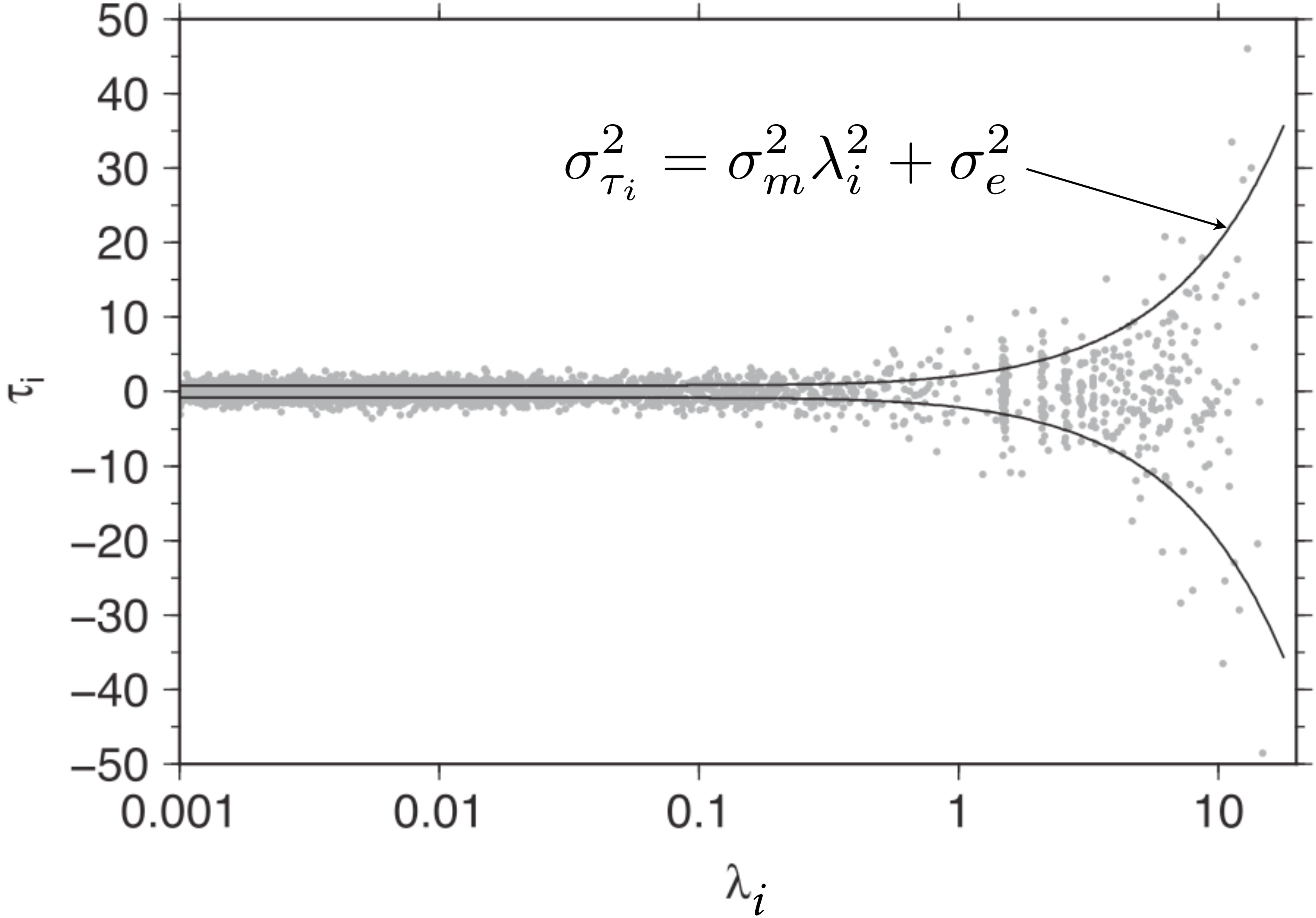
Projecting the system

$$Am = d + e$$

$$U^T Am = U^T d = \tau$$

$$\boxed{\text{if } \lambda_i = 0 \text{ then } \tau_i = 0 + u_i^T e}$$

where u_i^{T} is the *i*-th column of U

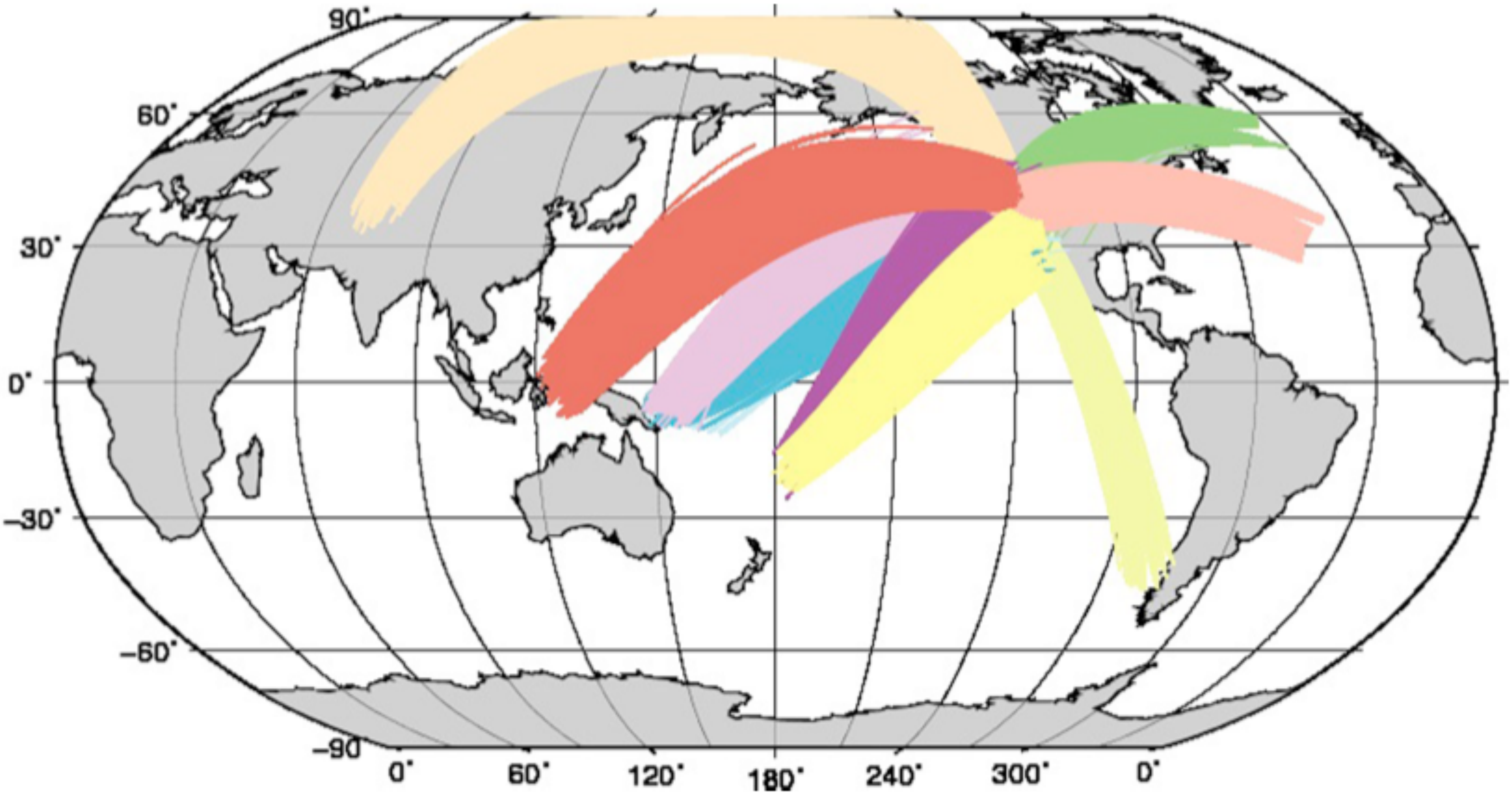

50
40
30
20
10
0
−10
−20
−30
−40
−50
τ_i
0.001
0.01
0.1
1
10
λ_i
$\sigma^2_{\tau_i} = \sigma^2_m \lambda^2_i + \sigma^2_e$

The role of (1) the Earth *m* and (2) errors e

$$\underbrace{\sigma^2_{\tau_i} = \sigma^2_m}_{\text{Signal}}\lambda^2_i + \underbrace{\sigma^2_e}_{\text{Noise}}$$

(Voronin et al, Geophys. J. Int. *199*, 276-285, 2014)

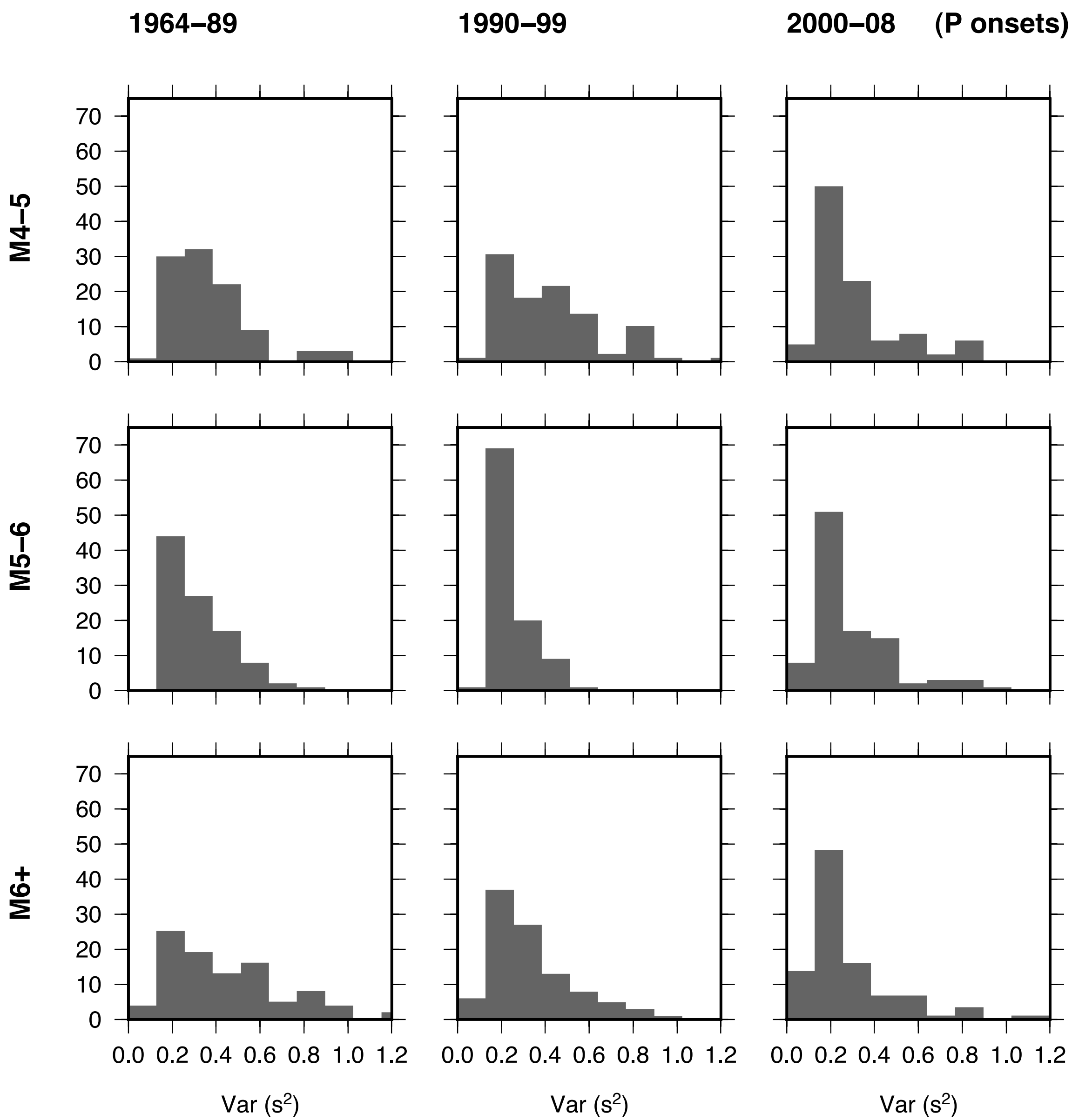
Clustering of raypaths gives many zero eigenvalues



We analyzed 881 clusters of EHB delays and looked for:

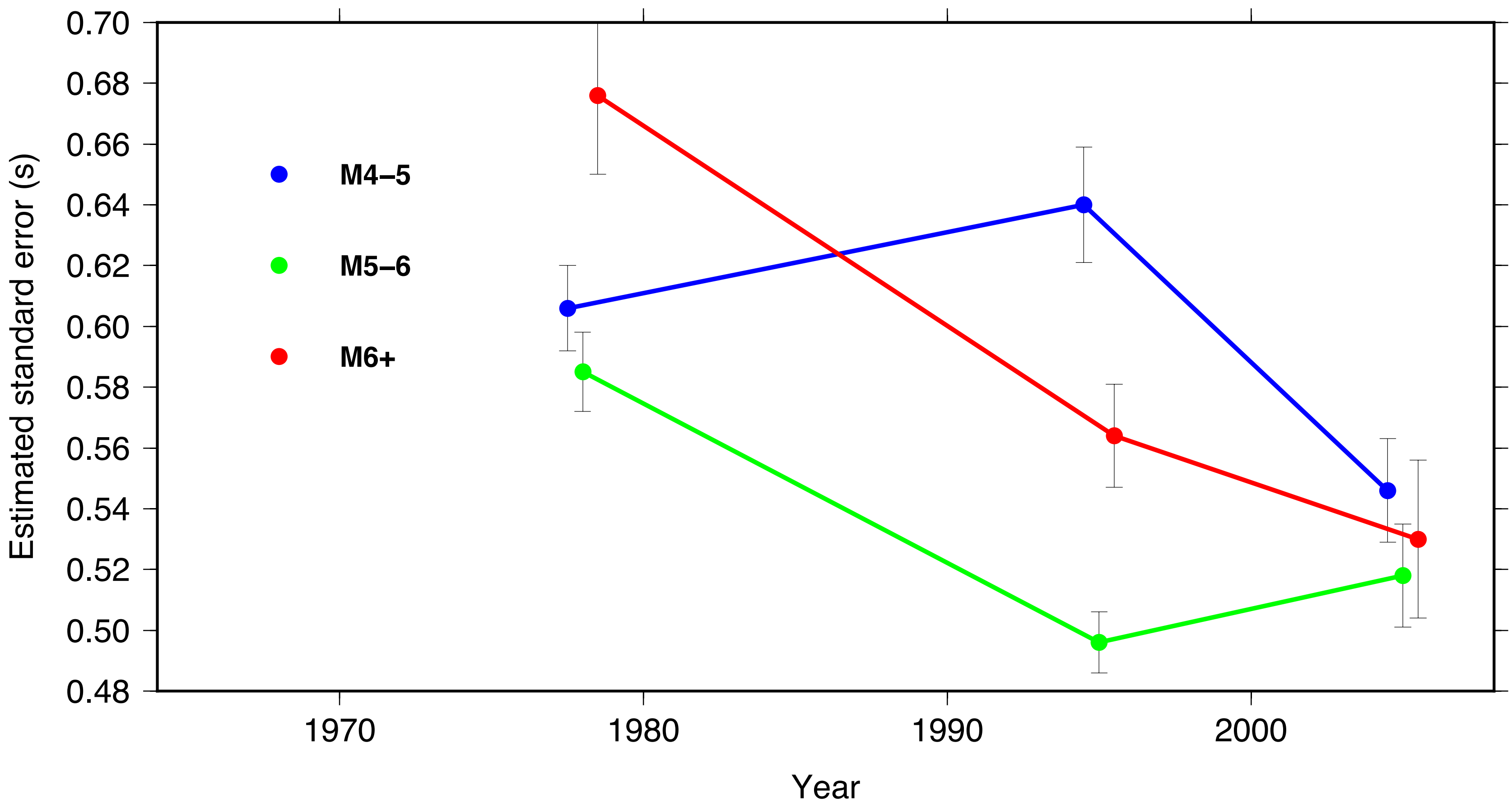
- Dependence of standard error σ on magnitude
- On year (periods: 1964-89, 1990-99, 2000-2008)
- On epicentral distance
- On location of the stations in the cluster
- And location of the earthquakes in the cluster

Variance as function of magnitude and year

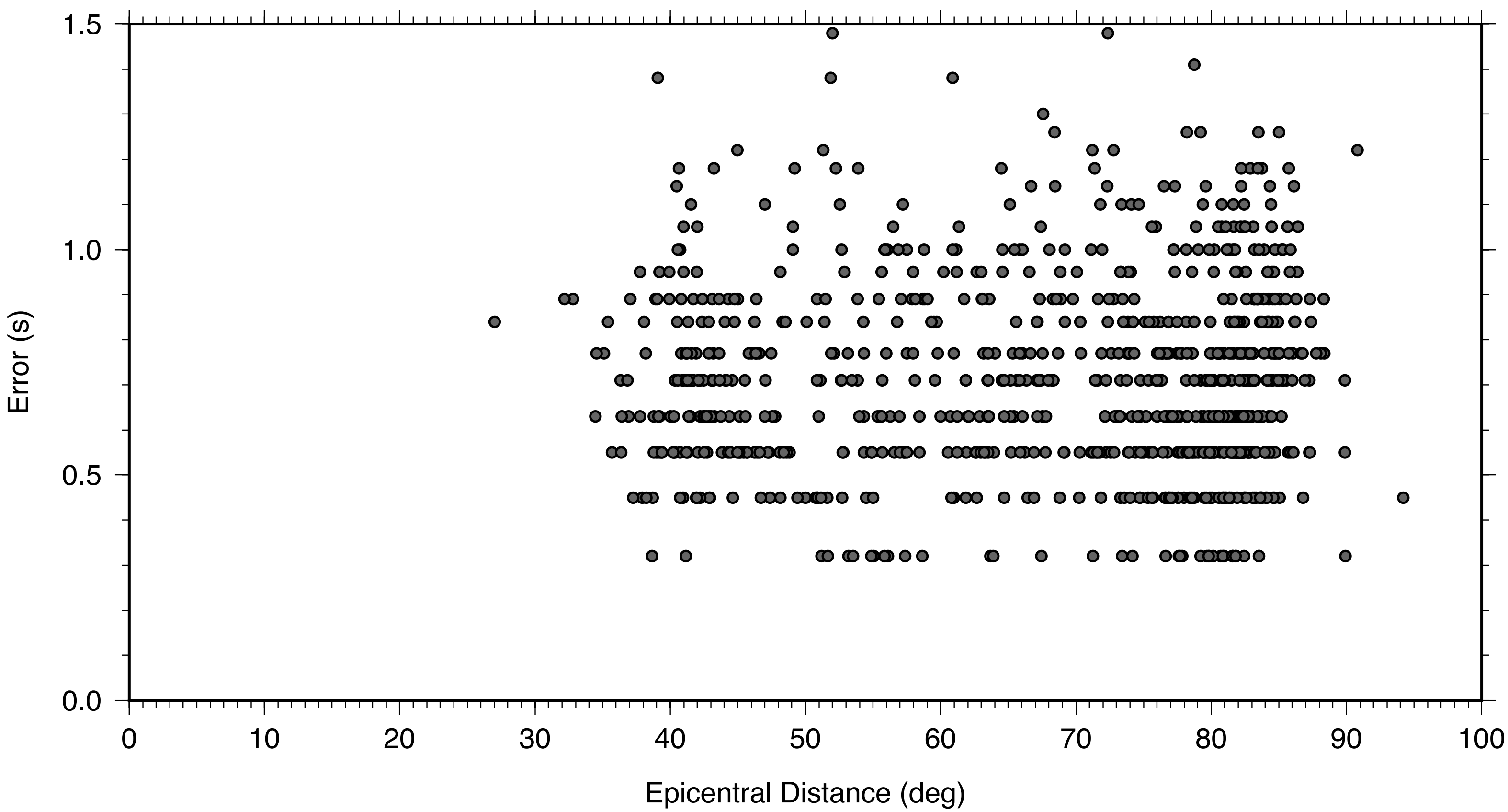


Most are between 0.2 and 0.4 s^2 (standard errors between 0.44 and 0.63 s)

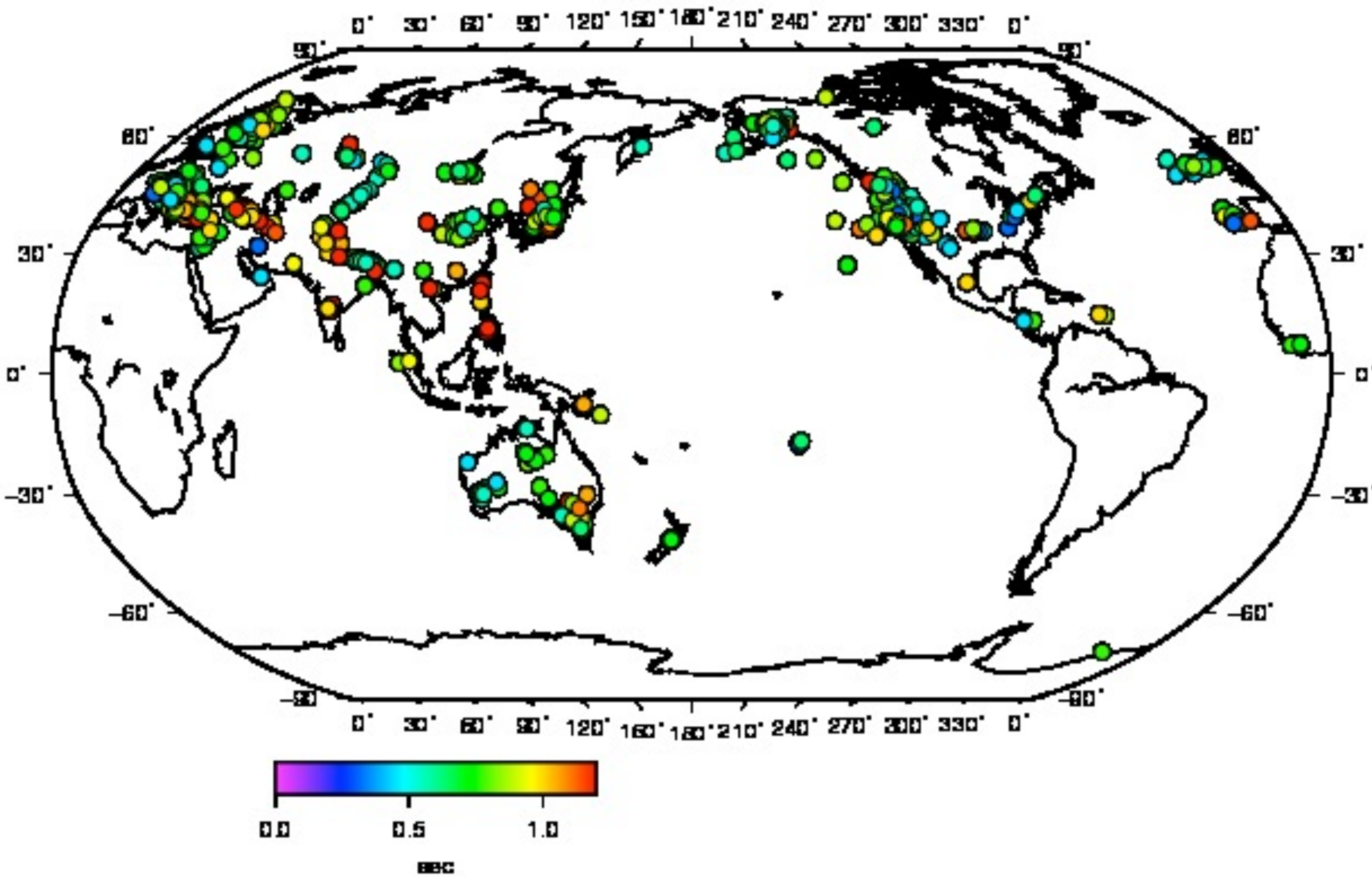
Standard error vs time indicates slight improvement with time

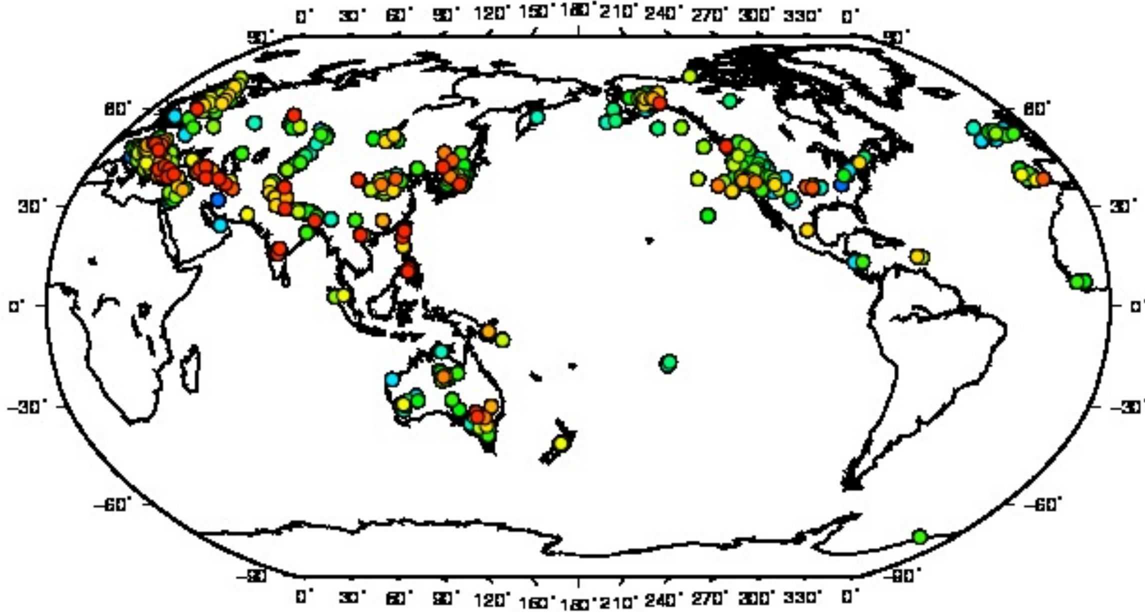


No dependance on distance

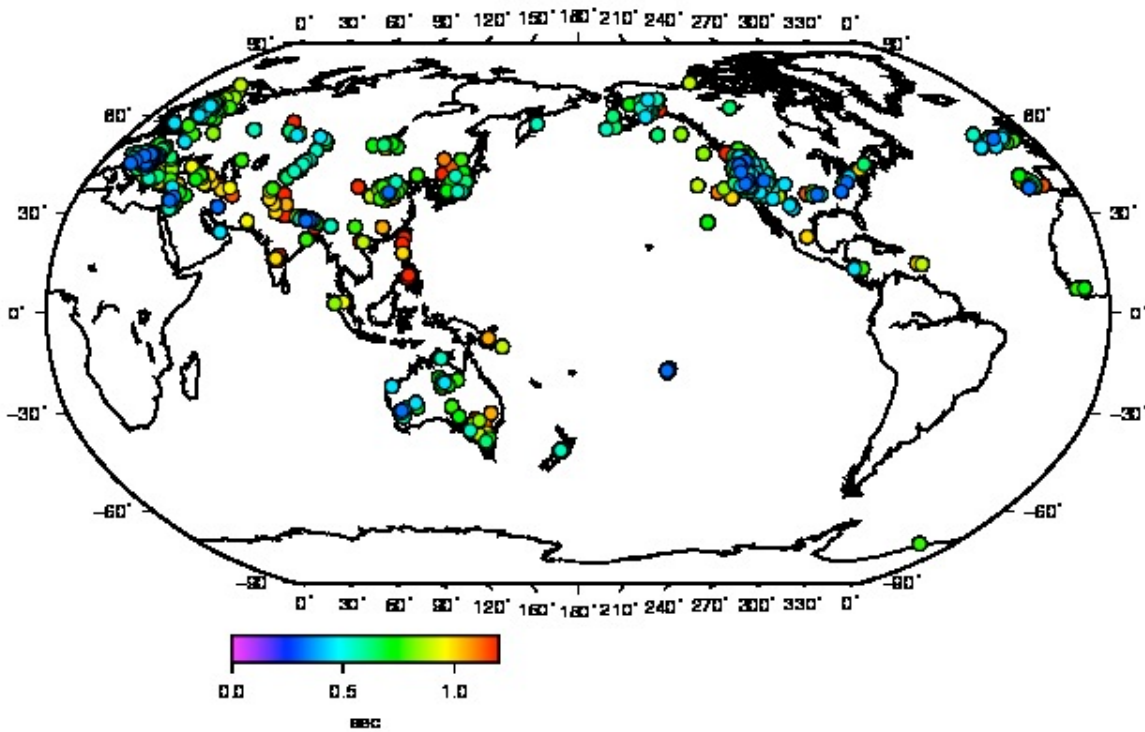


"station" σ's (not ordered)



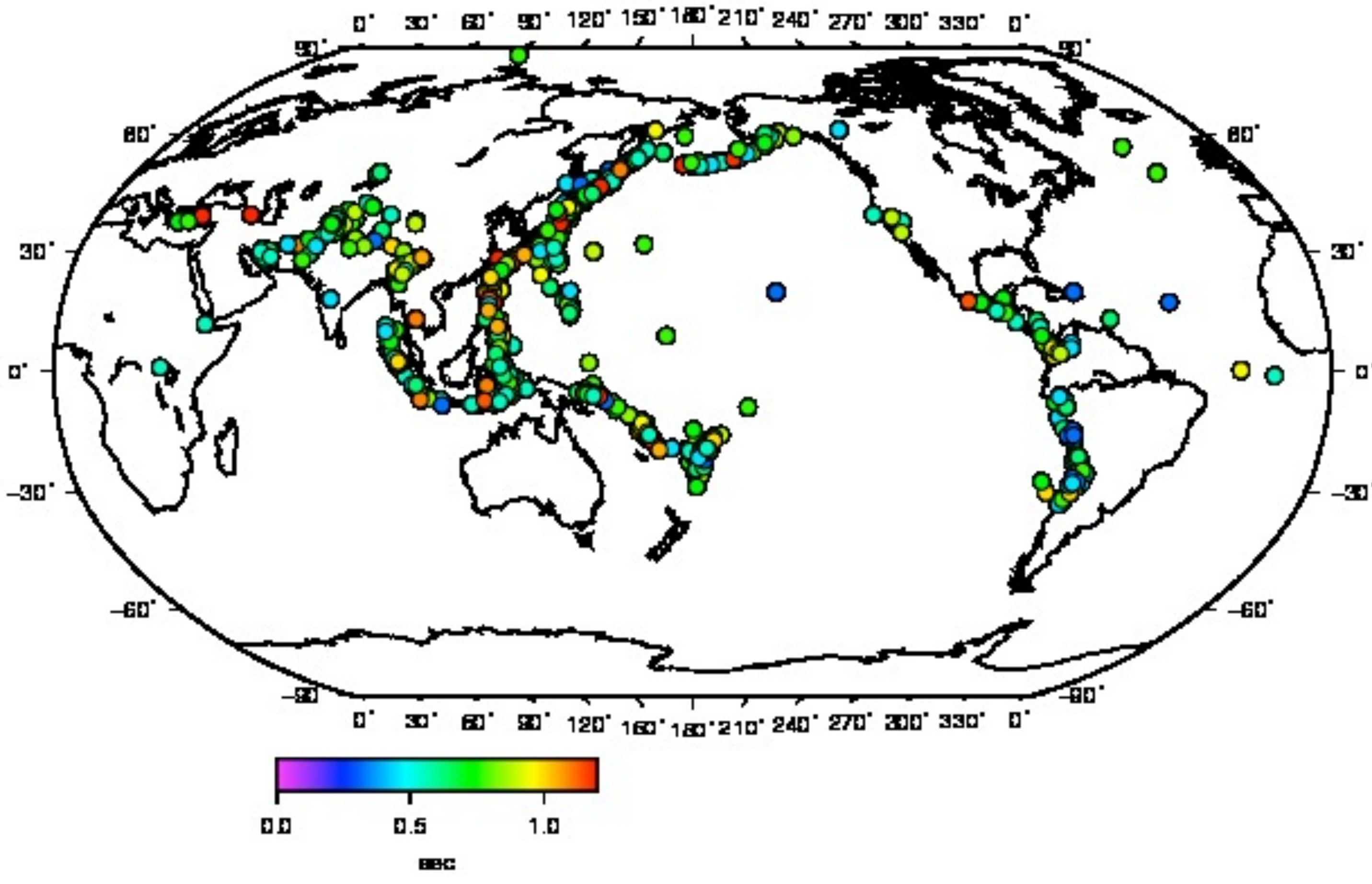


Largest errors plotted on top



Smallest errors plotted on top

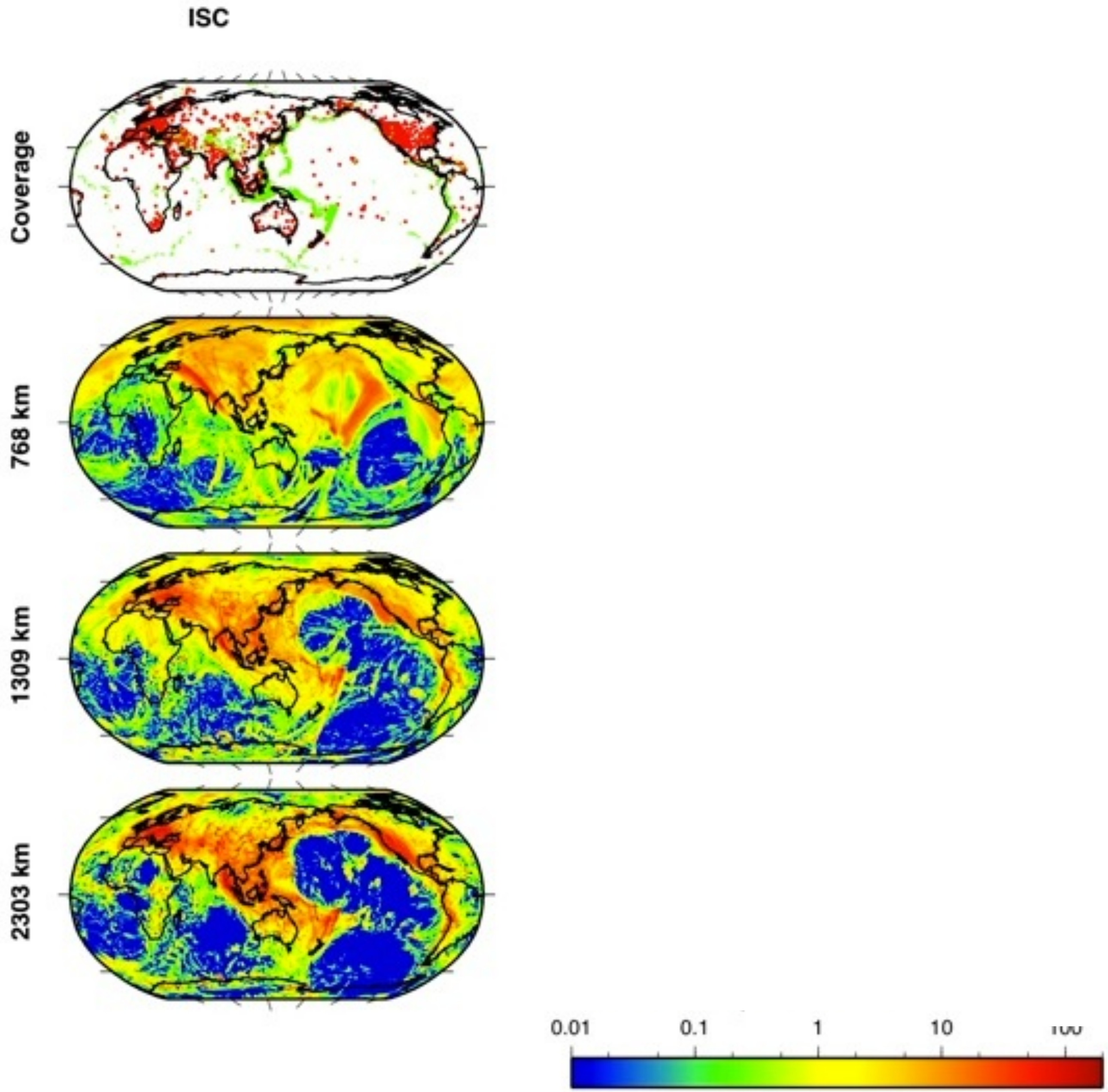
“source” σ’s (not ordered)



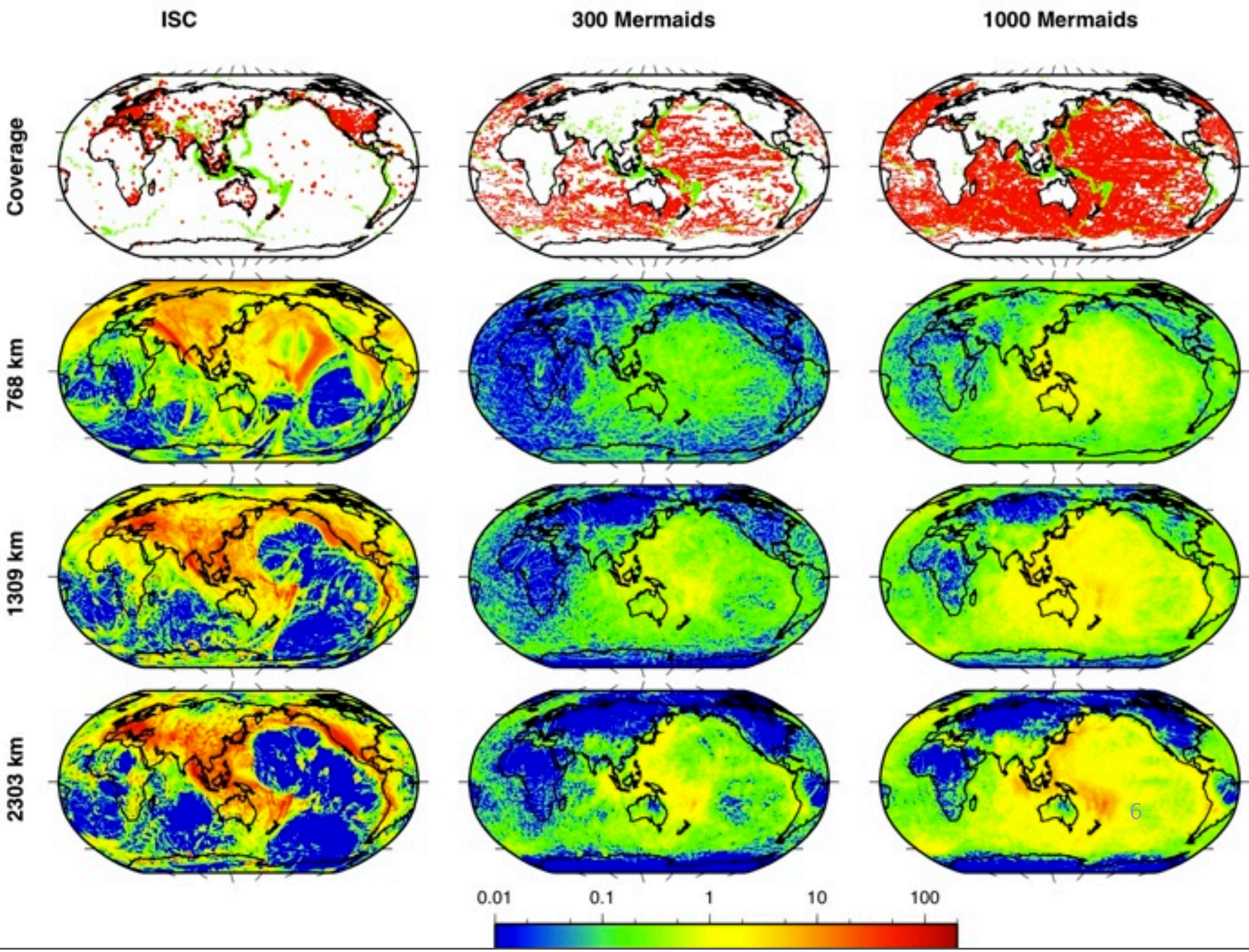
CONCLUSIONS

- Standard error in EHB P arrivals for first 25 years of ISC are 0.63 s
- More recently, it decreased to 0.53 s
- Errors are not uniformly distributed over geographic regions

Ray coverage: extending what ISC can do



Ray coverage in oceans limits resolution



modeling result: 5 years of Mermaids allows us high-resolution imaging of mantle plumes