Application of 3-D Empirical Travel Times to Routine Event Location

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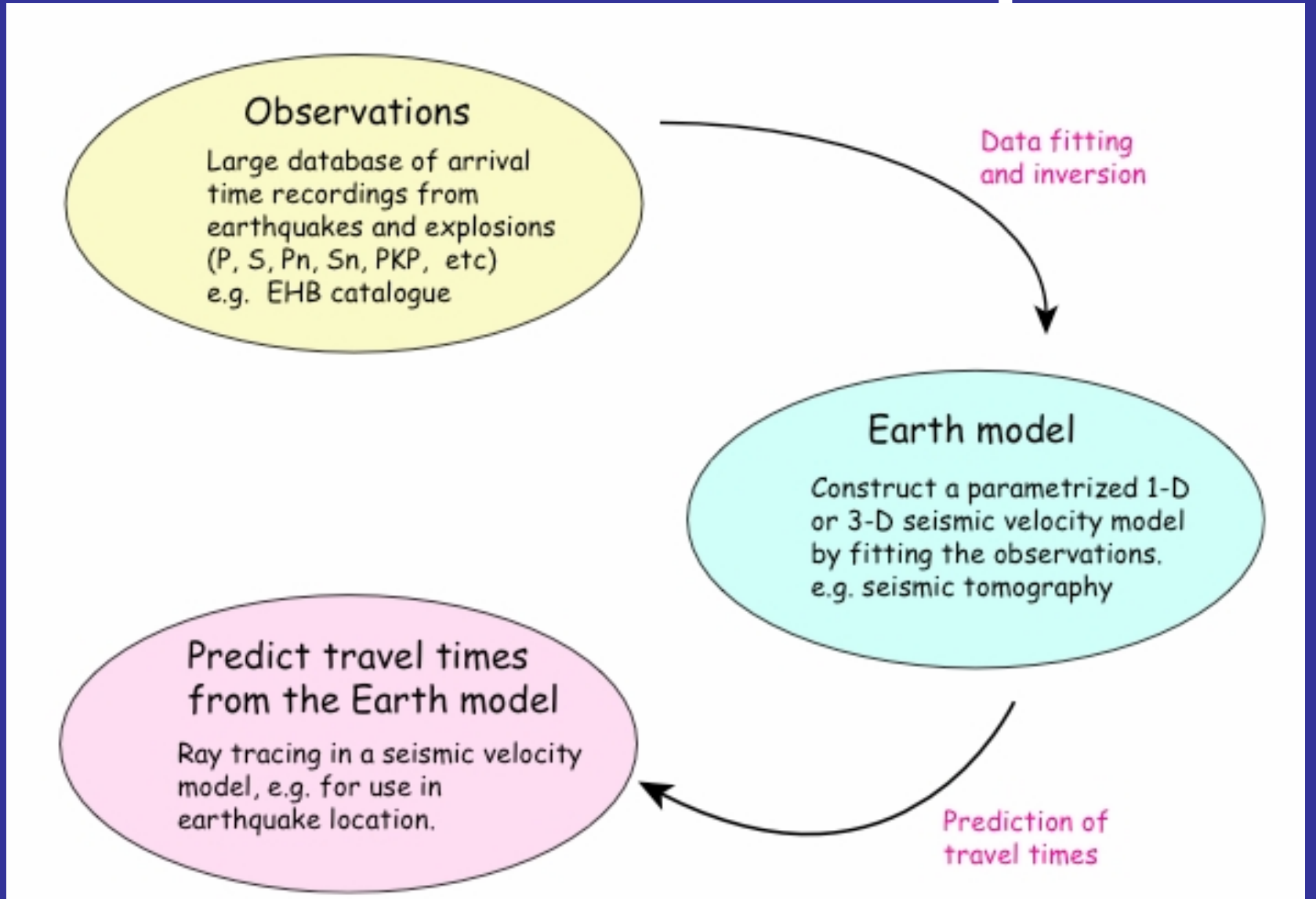
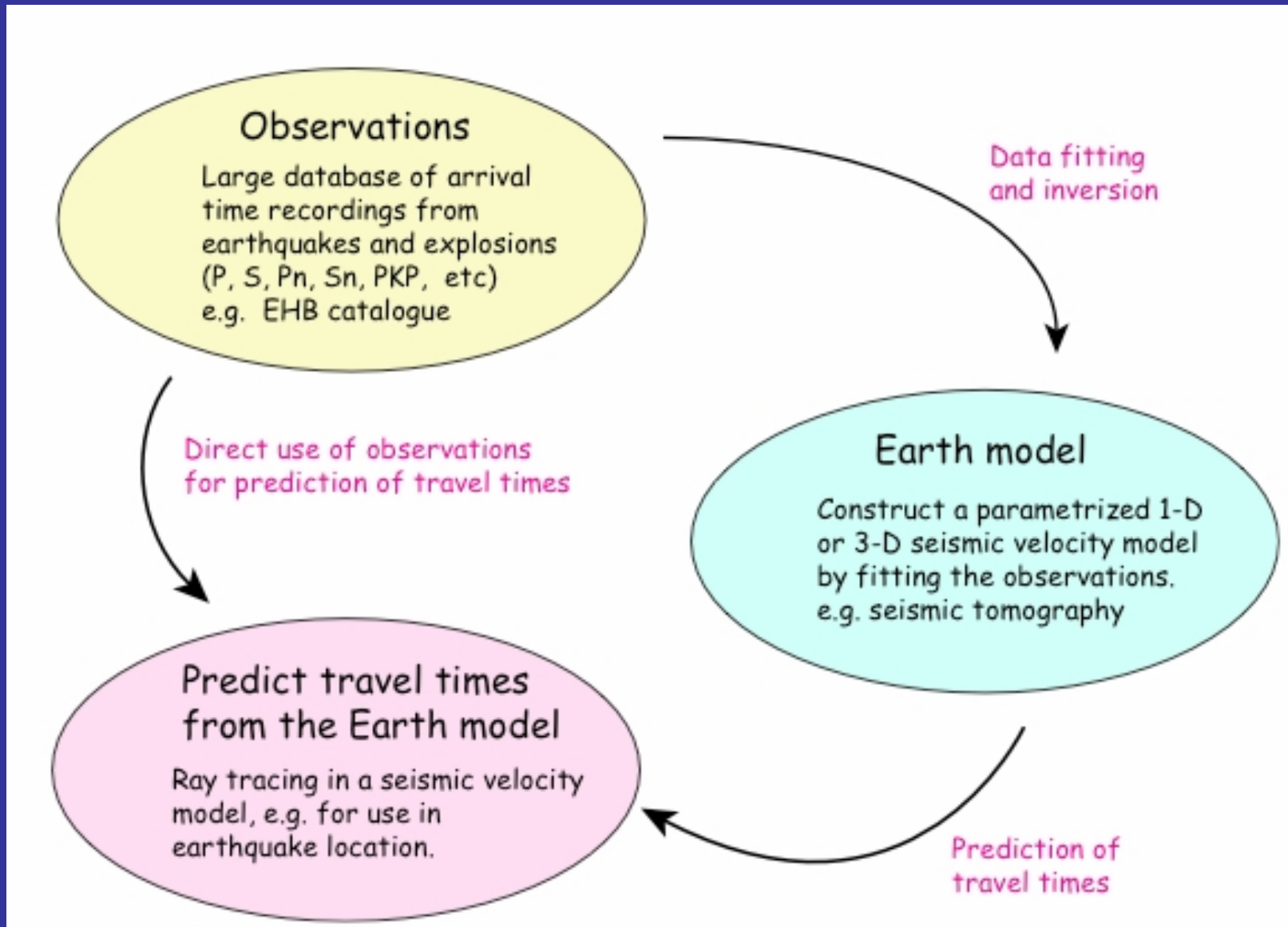
Key points

- Empirical Travel Times are designed to account for the 3-D effects of lateral heterogeneity on travel time.
- They ride on top of a 1-D model
- We are trying to improve the locations of small events

Approaches with an intermediate step



The Database Approach



- The database is made up of the best previous events (e.g. explosions, events with lots of observations including depth phases)
- The threshold for inclusion in the database varies geographically.
- The database is not perfect. It contains location and observation errors!

We use the information in the database to improve the locations of small events.

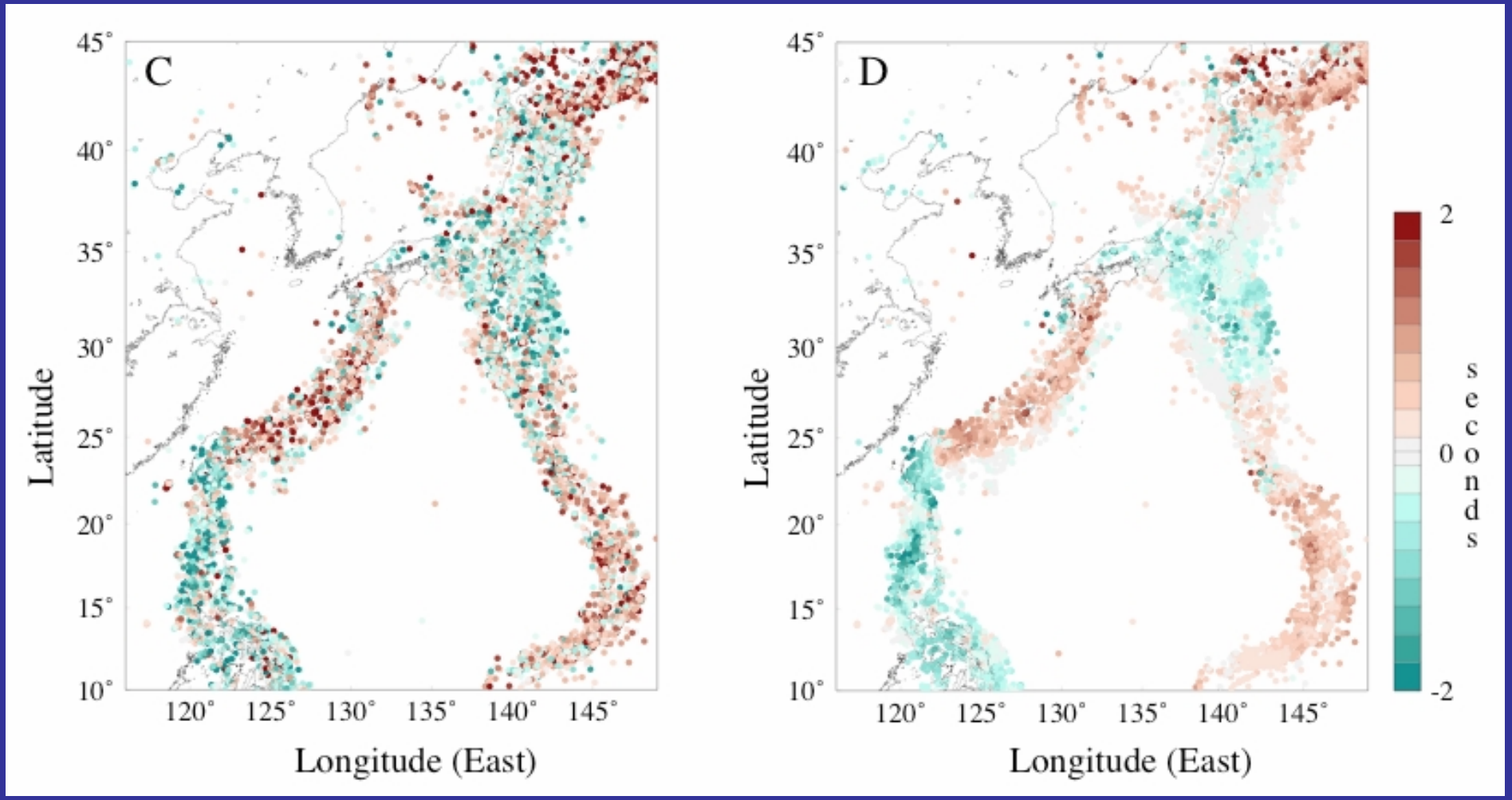
ETTs can be loosely thought of as master event location with 1000's of master events

The Key Idea

In this sense we trying to pull the quality of the locations of the poor events up to the level of the database events

How ETTs work:

Each station and phase is considered separately

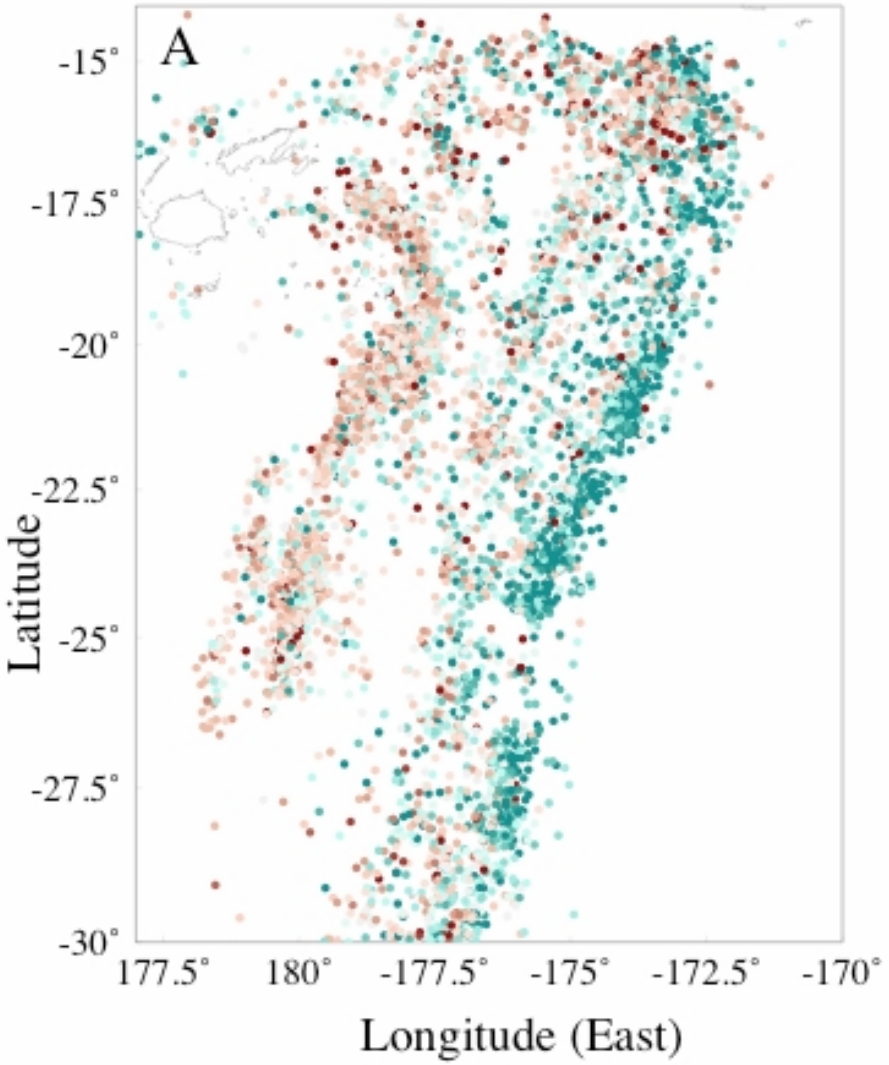


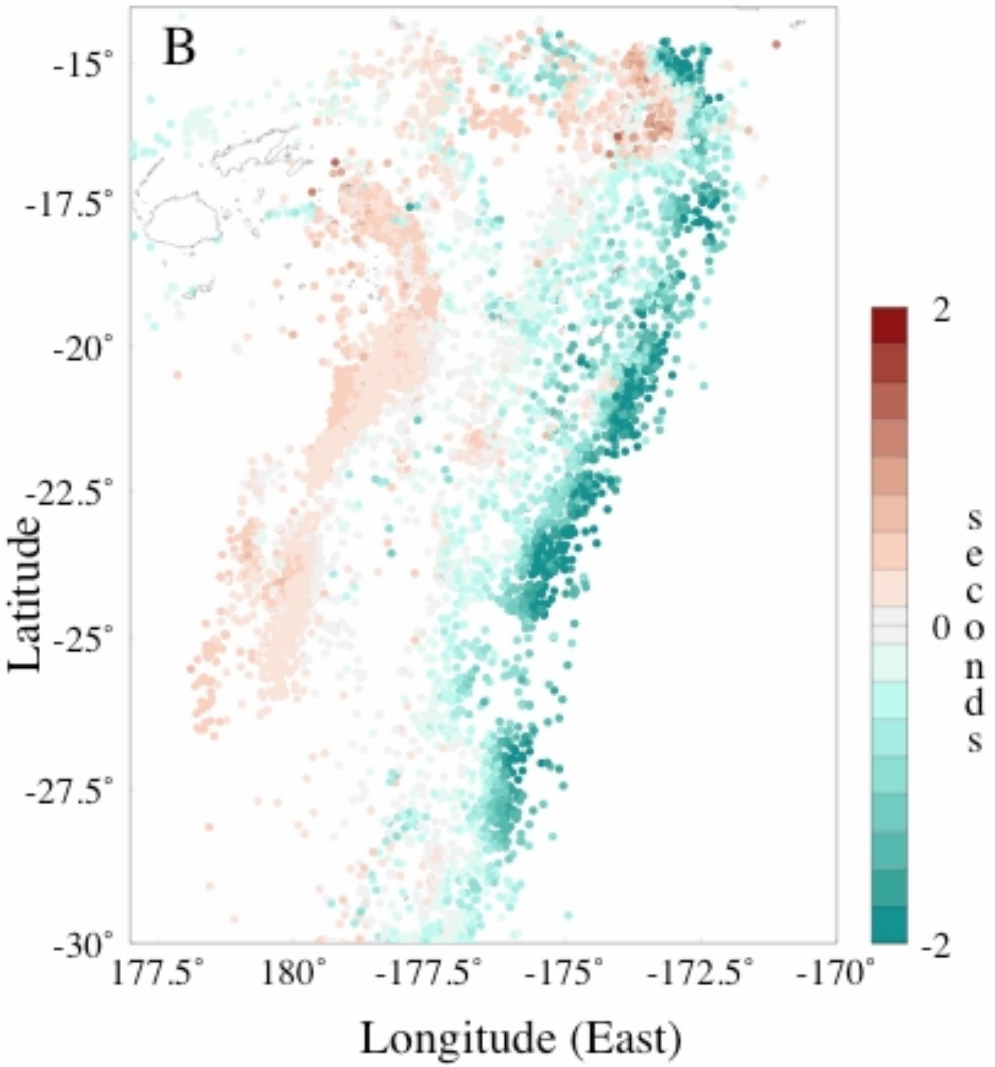
Observed travel time residuals

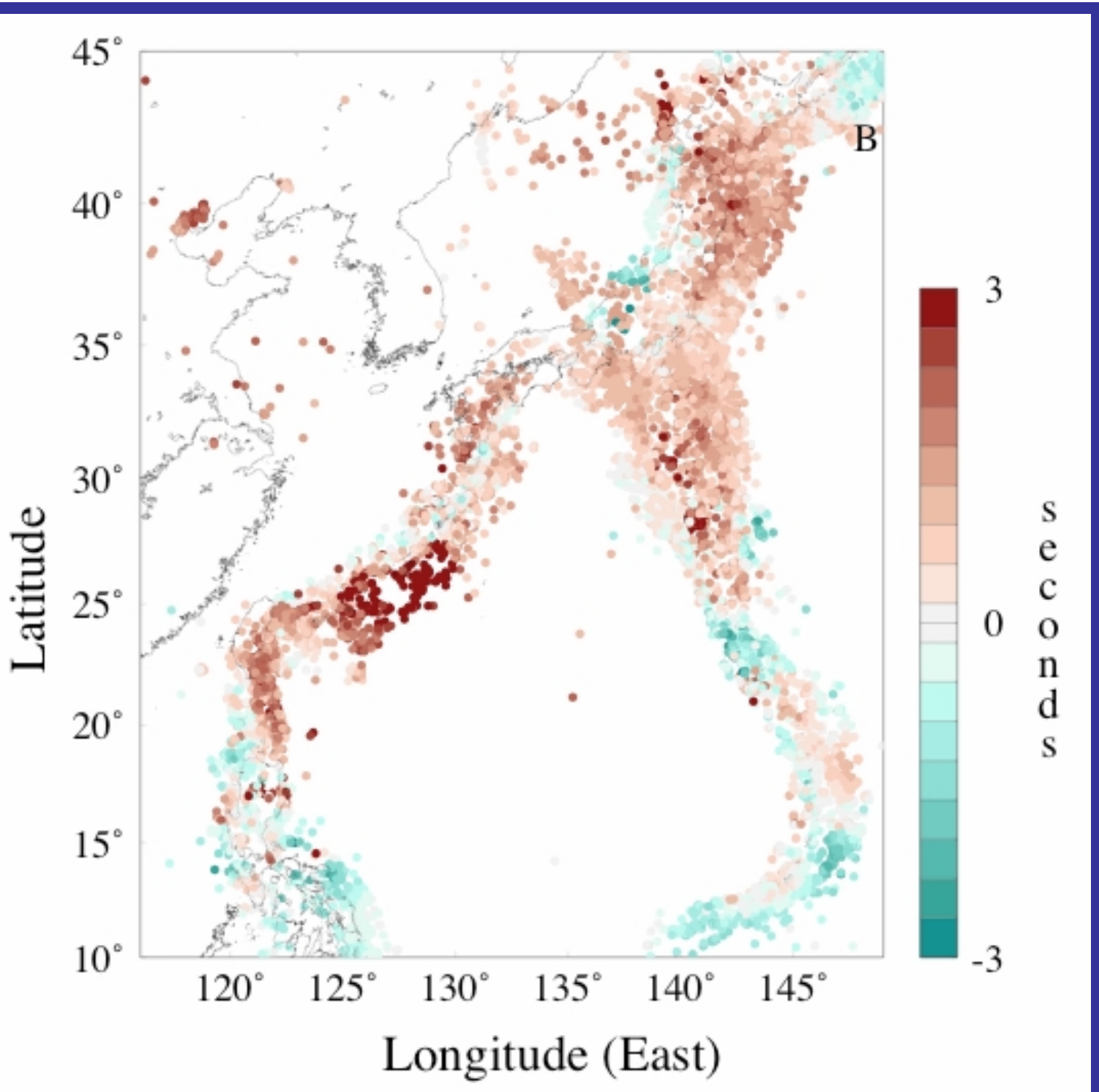
Empirical Travel Times (ETT)

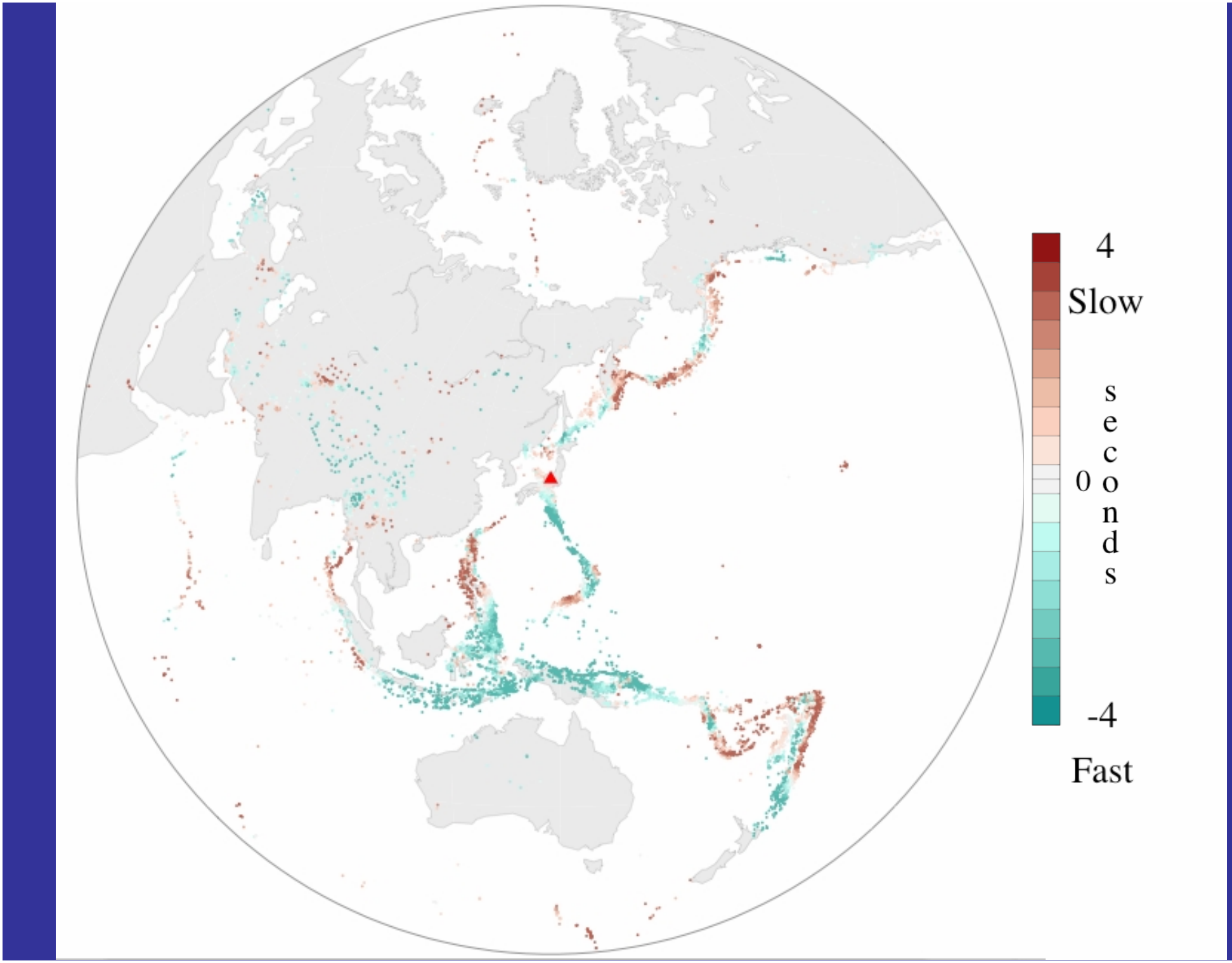
Observed travel time perturbations

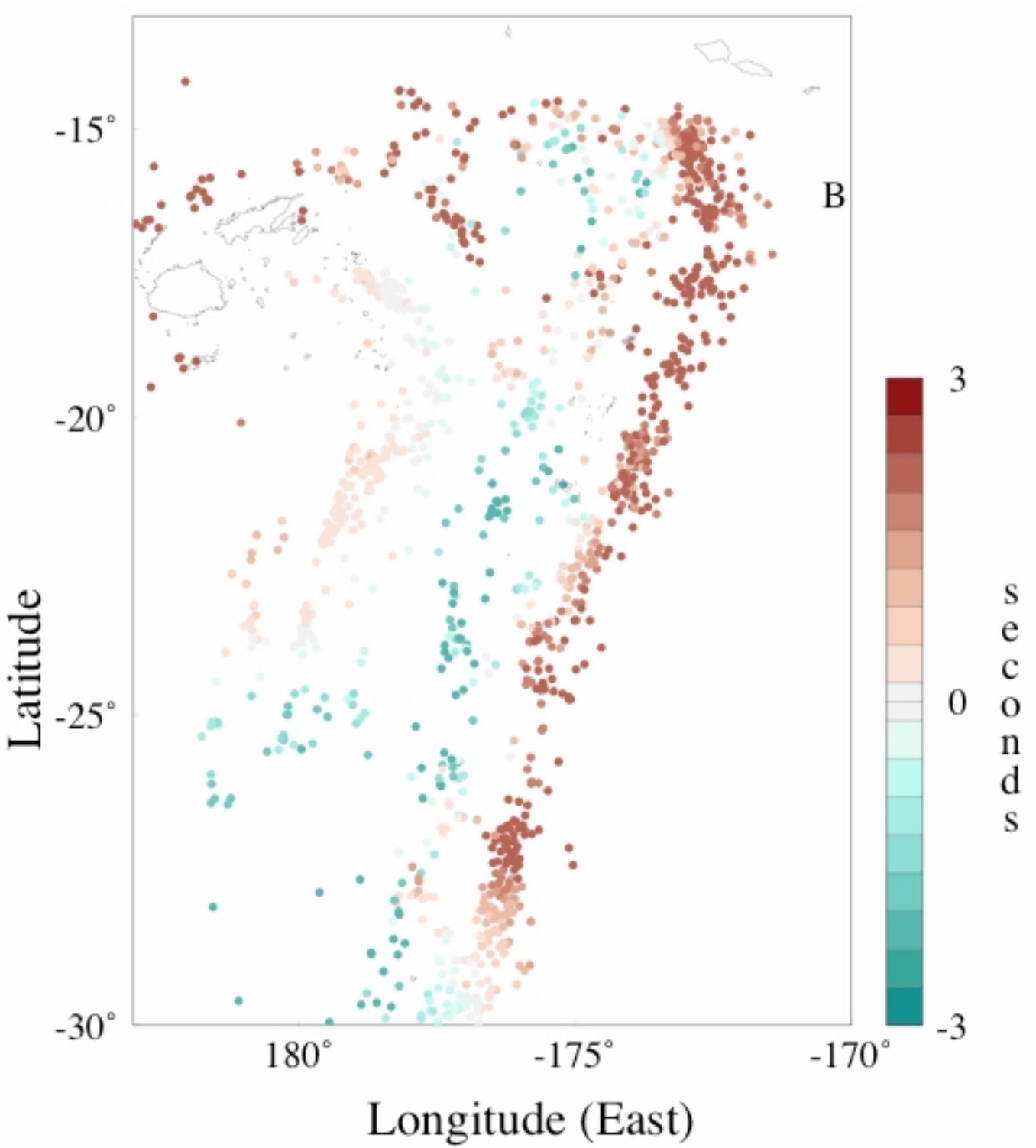
Empirical Travel Times



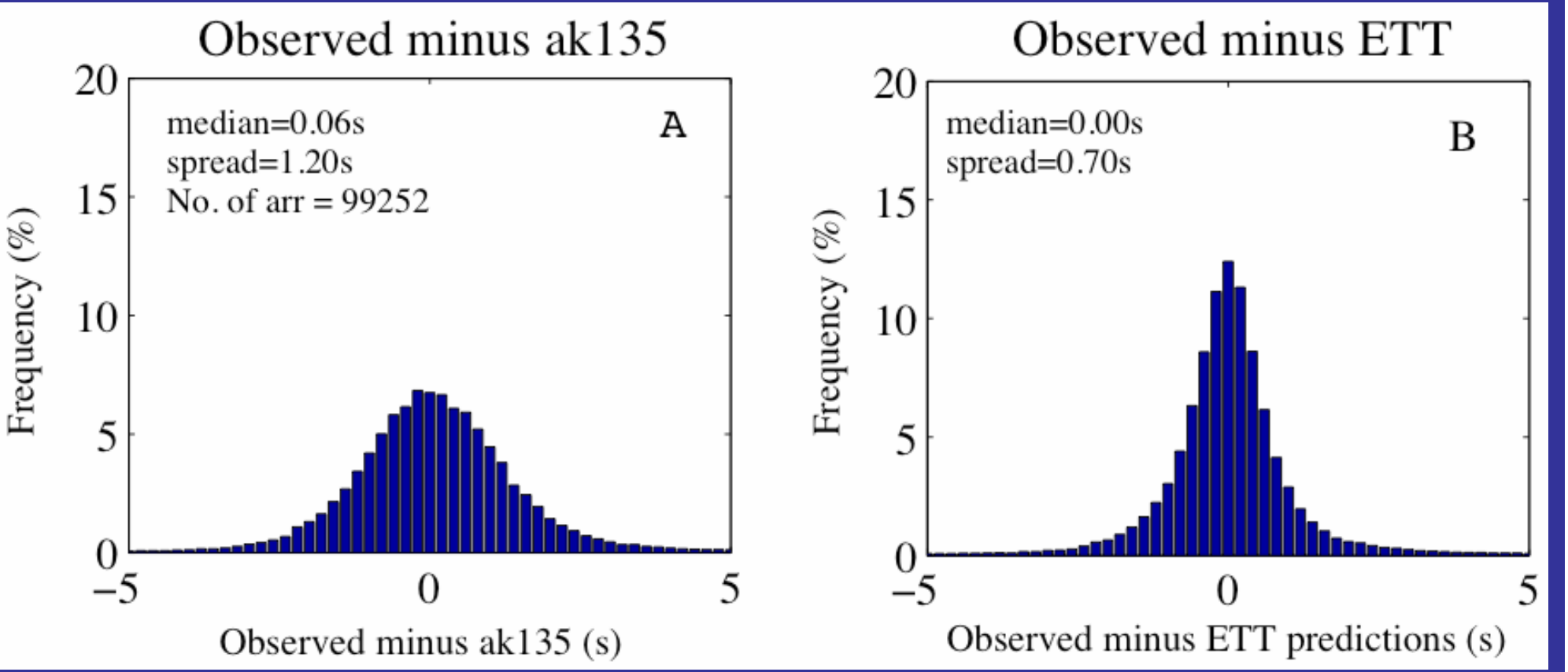



45°
40°
35°
30°
25°
20°
15°
10°
Latitude
120°
125°
130°
135°
140°
145°
Longitude (East)
B
3
0
-3
seconds


4
Slow
seconds
0
-4
Fast

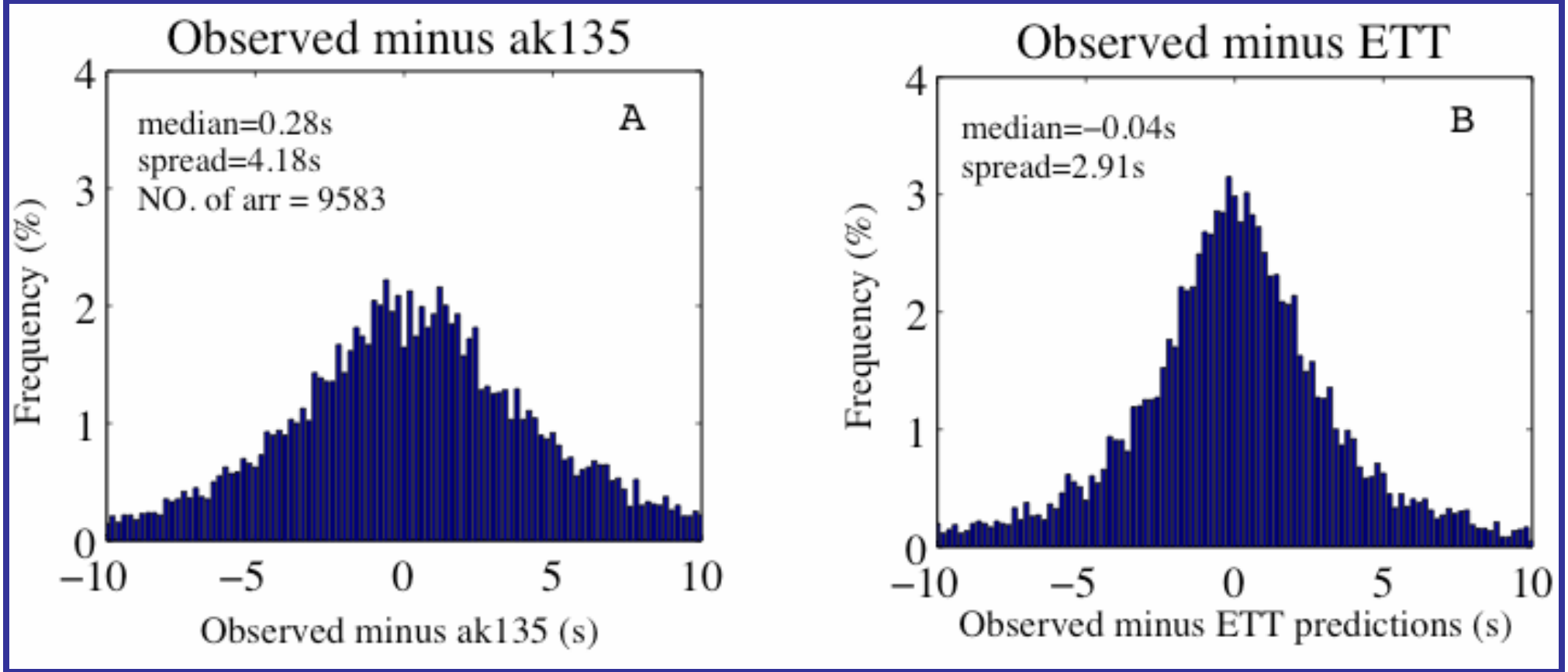

B
-15°
-20°
-25°
-30°
Latitude
180°
-175°
-170°
Longitude (East)
3
0
-3
seconds

The error distribution is no longer Gaussian

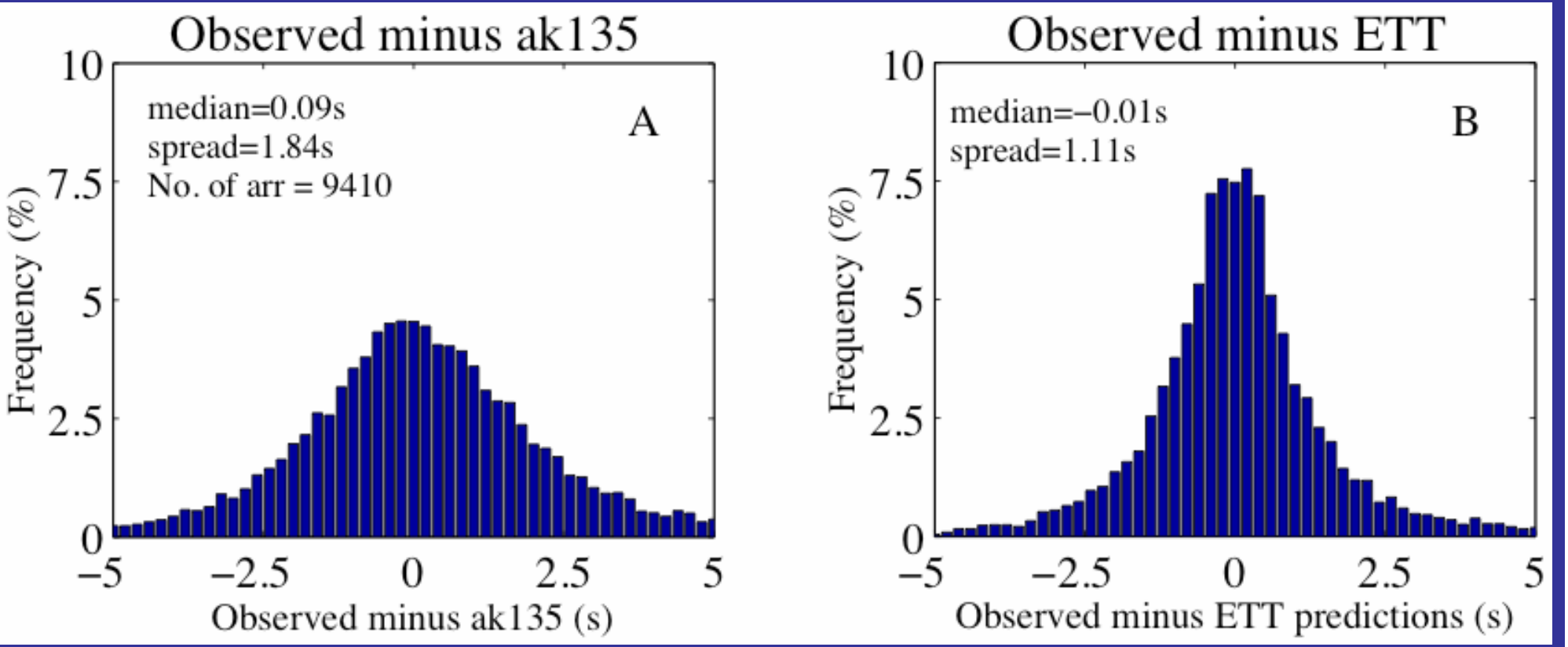


It's a double exponential distribution!

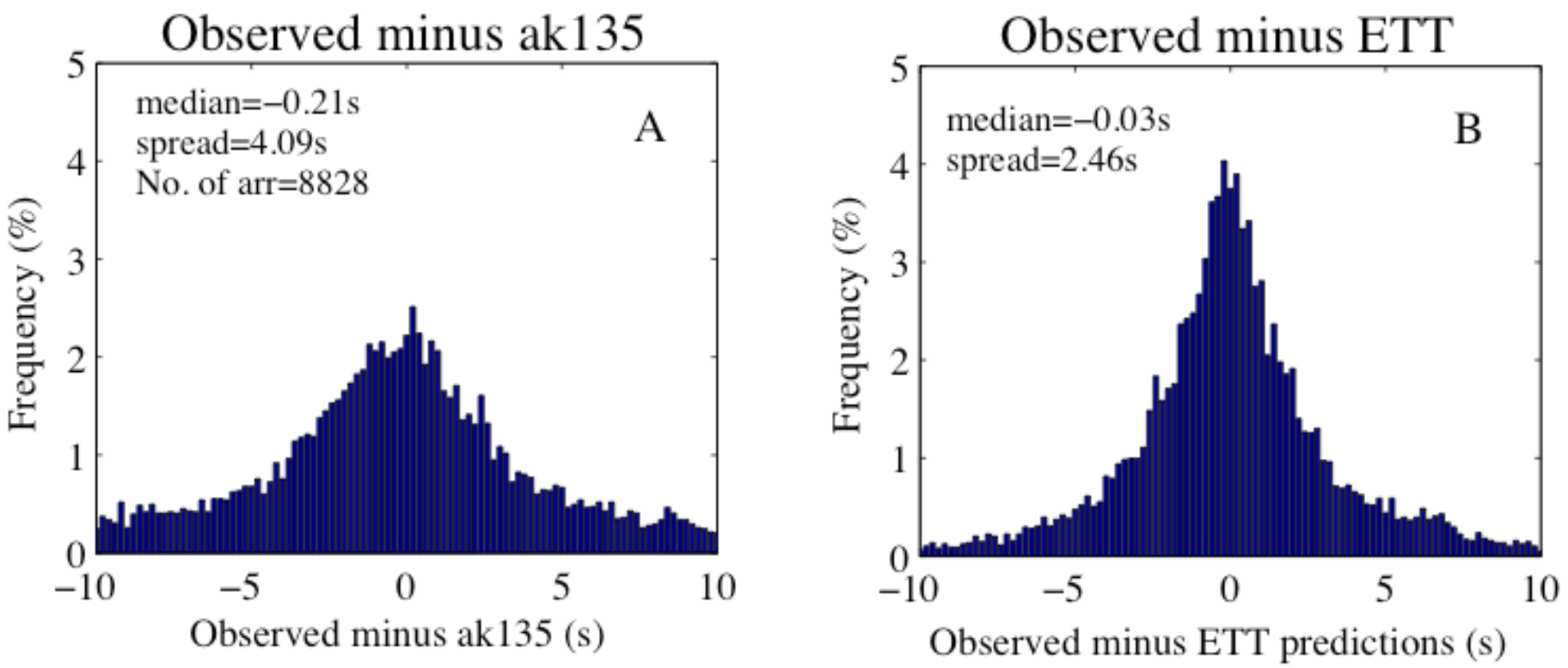
The same is true for S arrivals



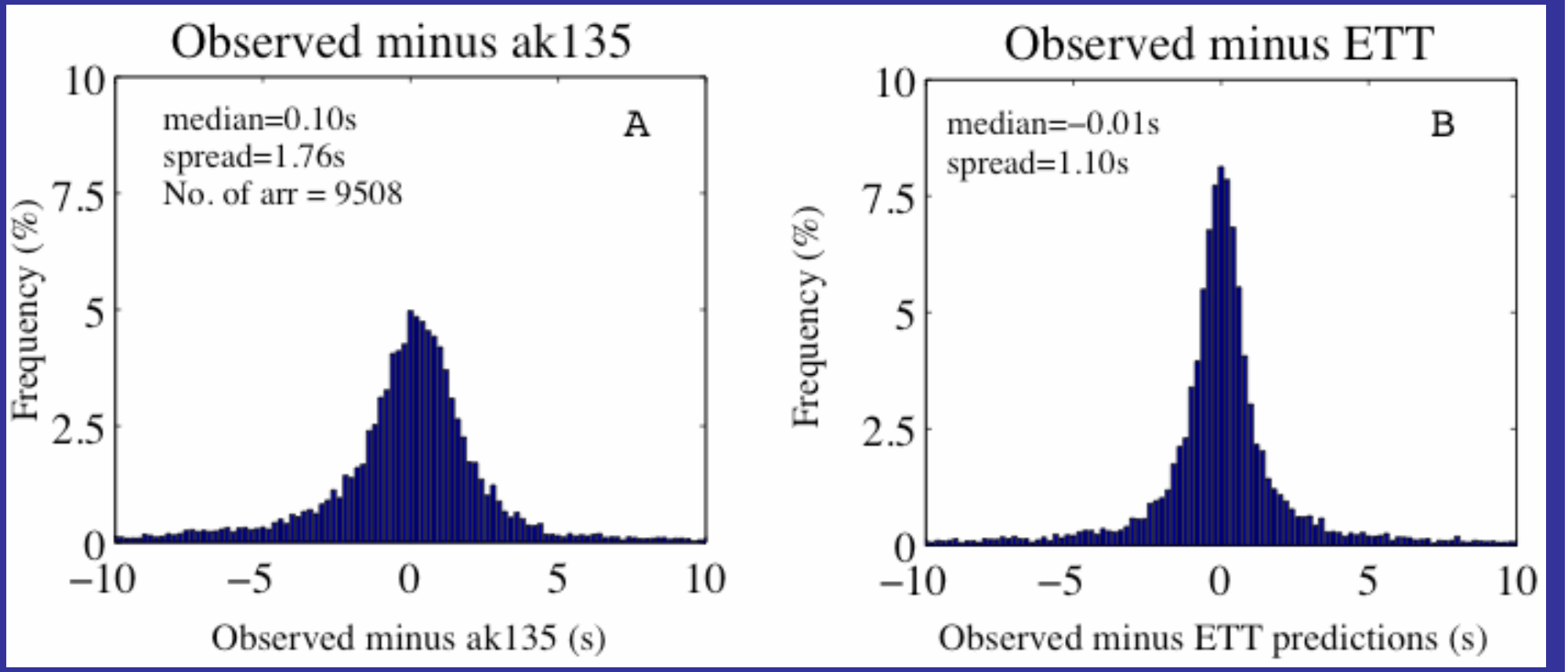
And Pn


Observed minus ak135
median=0.09s
spread=1.84s
No. of arr = 9410
A
Frequency (%)
10
7.5
5
2.5
0
−5
−2.5
0
2.5
5
Observed minus ak135 (s)
Observed minus ETT
median=−0.01s
spread=1.11s
B
Frequency (%)
Observed minus ETT predictions (s)

And Sn


Observed minus ak135
median=–0.21s
spread=4.09s
No. of arr=8828
A
Frequency (%)
Observed minus ak135 (s)
Observed minus ETT
median=–0.03s
spread=2.46s
B
Frequency (%)
Observed minus ETT predictions (s)

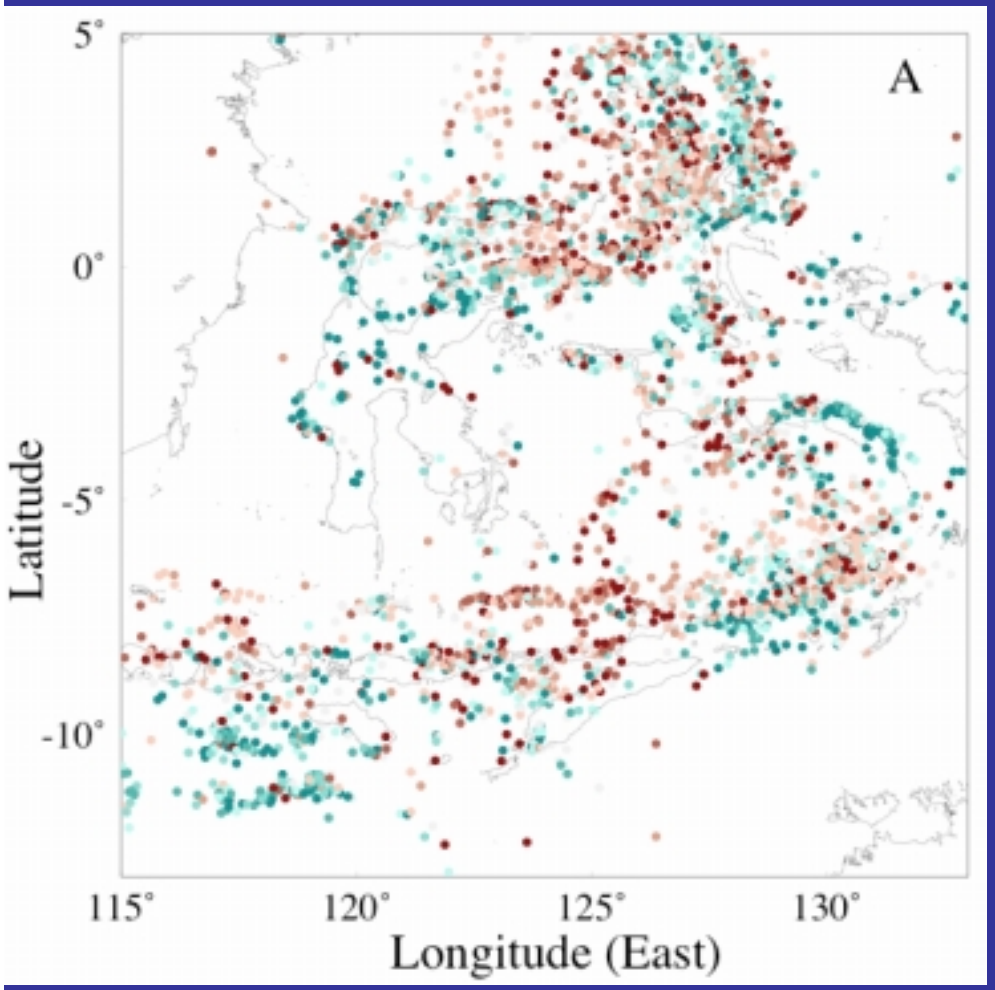
And other phases too

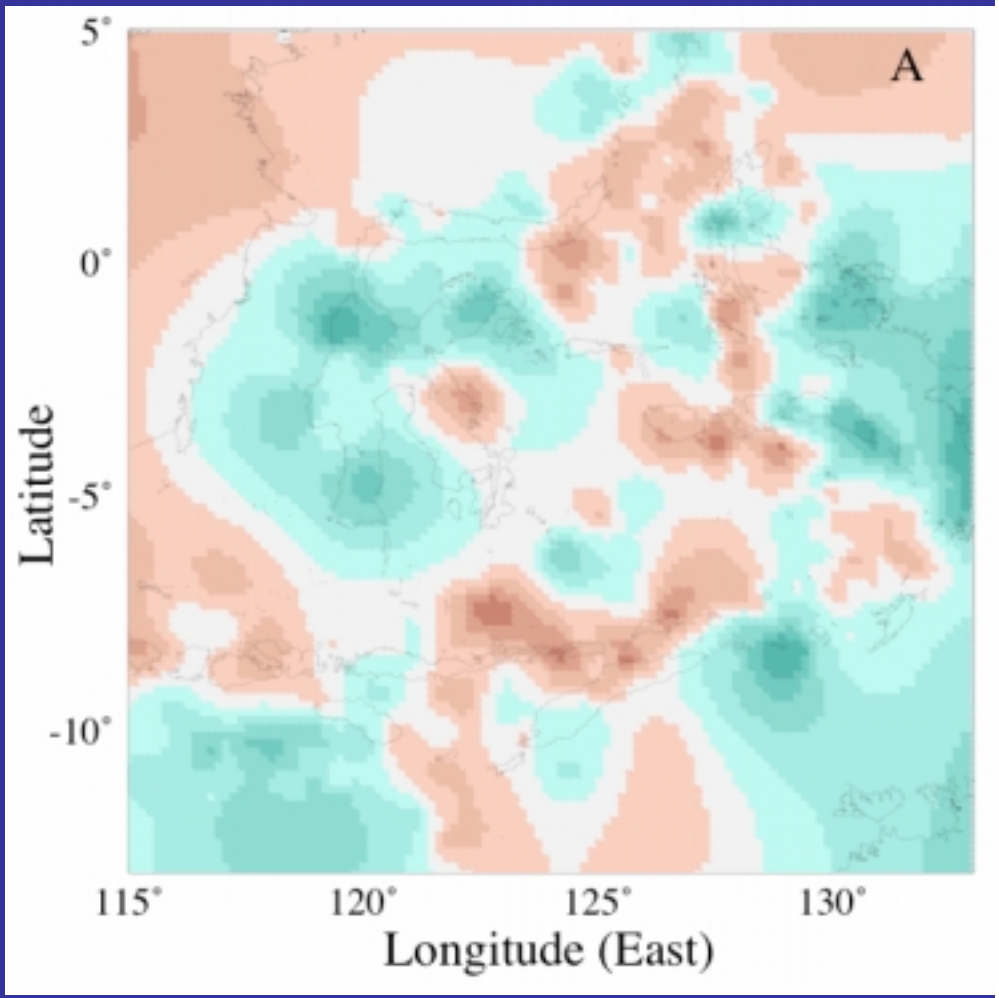


Implications for earthquake location using ETTs

- The L2 norm misfit function is not appropriate.
- Instead we use the L1 misfit.
- We use a grid search in the optimization.
- No static, elevation or ellipticity corrections are used. They are all included in the ETTs

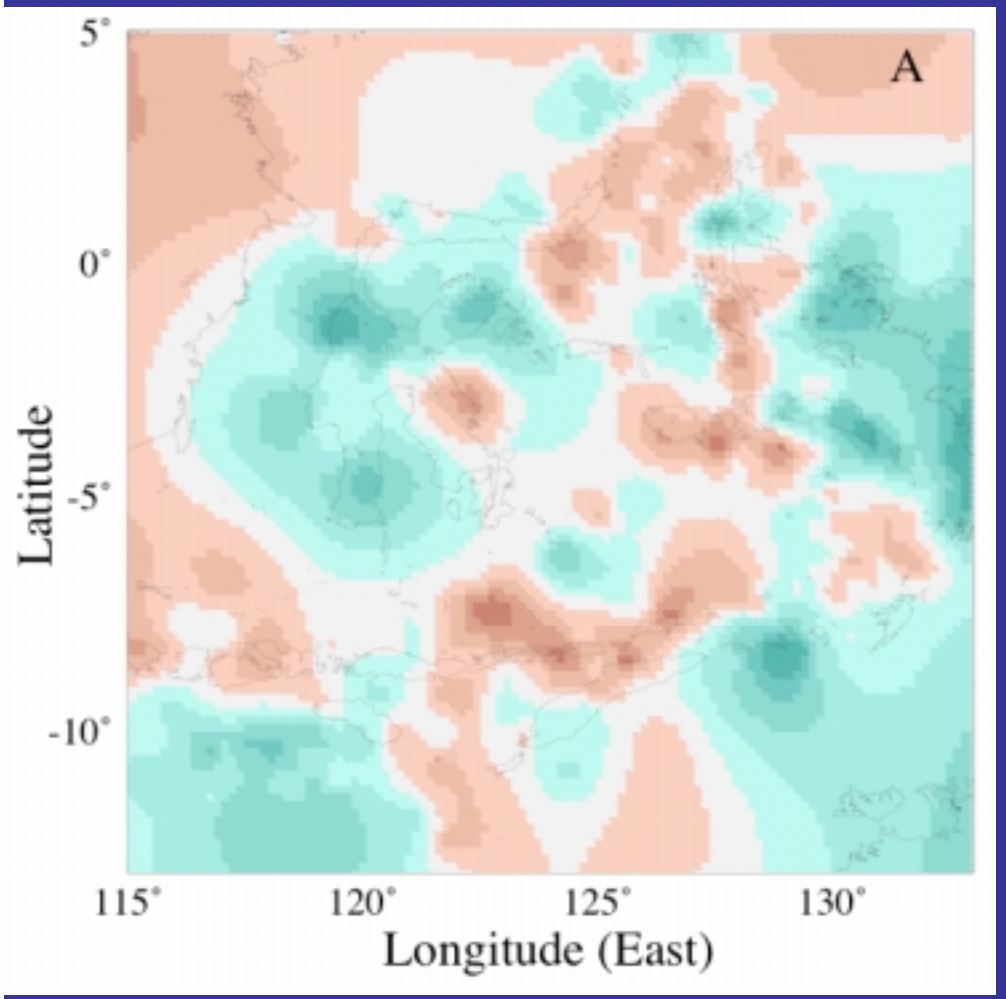
ETTs as a station correction

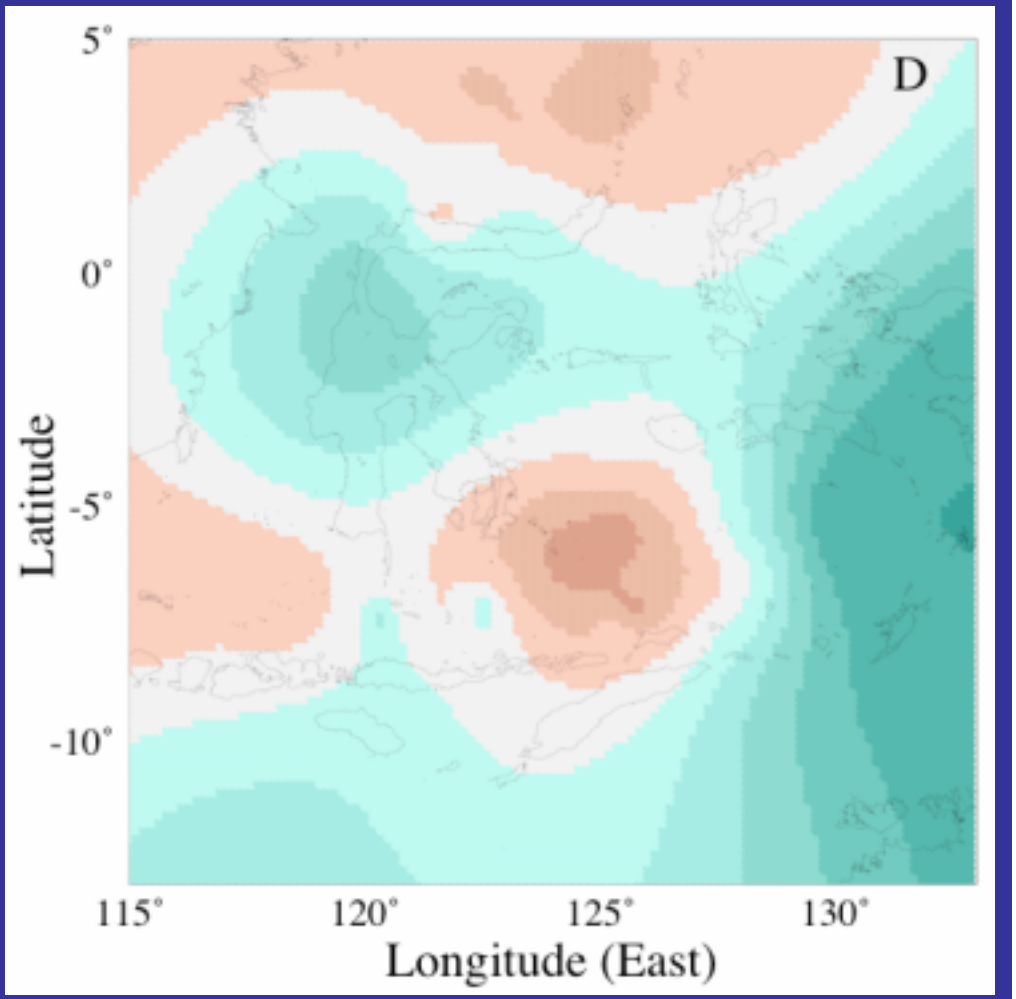




Advantages of using ETTs

- Automatic adaptation to data density





Advantages (continued)

- Automatic adaptation to the amount of noise in the data
- Accurate, detailed uncertainty estimates
- Easy to update - you just add to the database
- Fast - each correction surface can be calculated in less than 1 second

Advantages (continued)

- No information about the ray path is used
- Anisotropy is taken into account
- The same framework can be used for a variety of phases

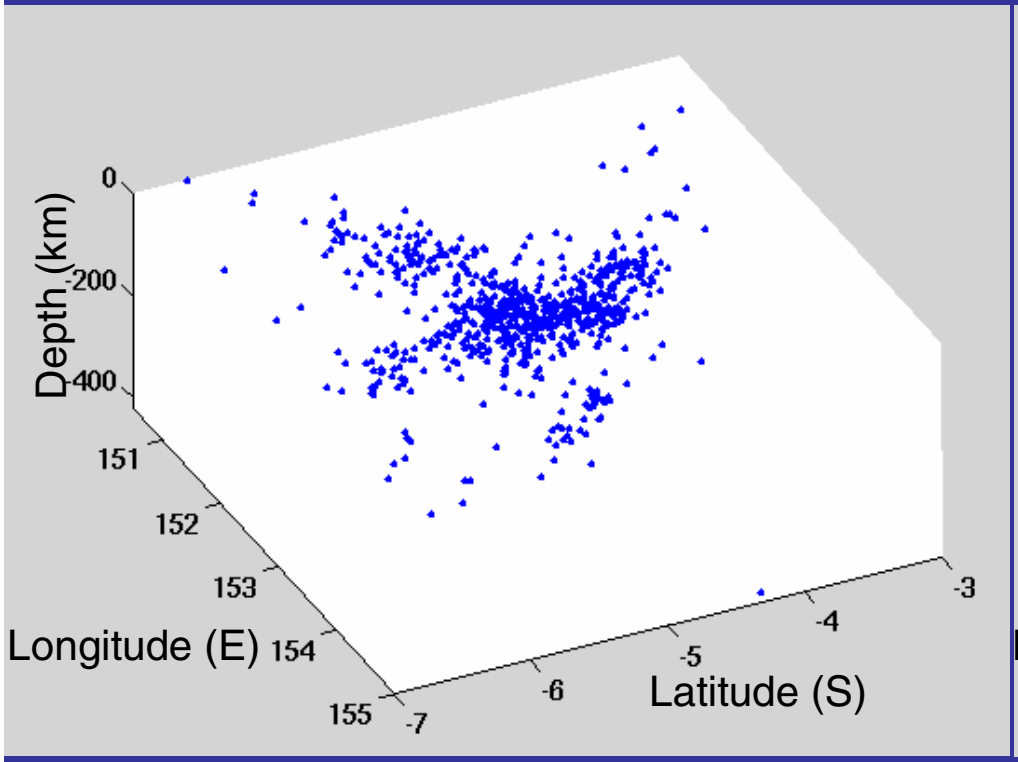
Limitations

- Any systematic error in the database events maps into errors in new locations
- Can only be used once a station has made some observations

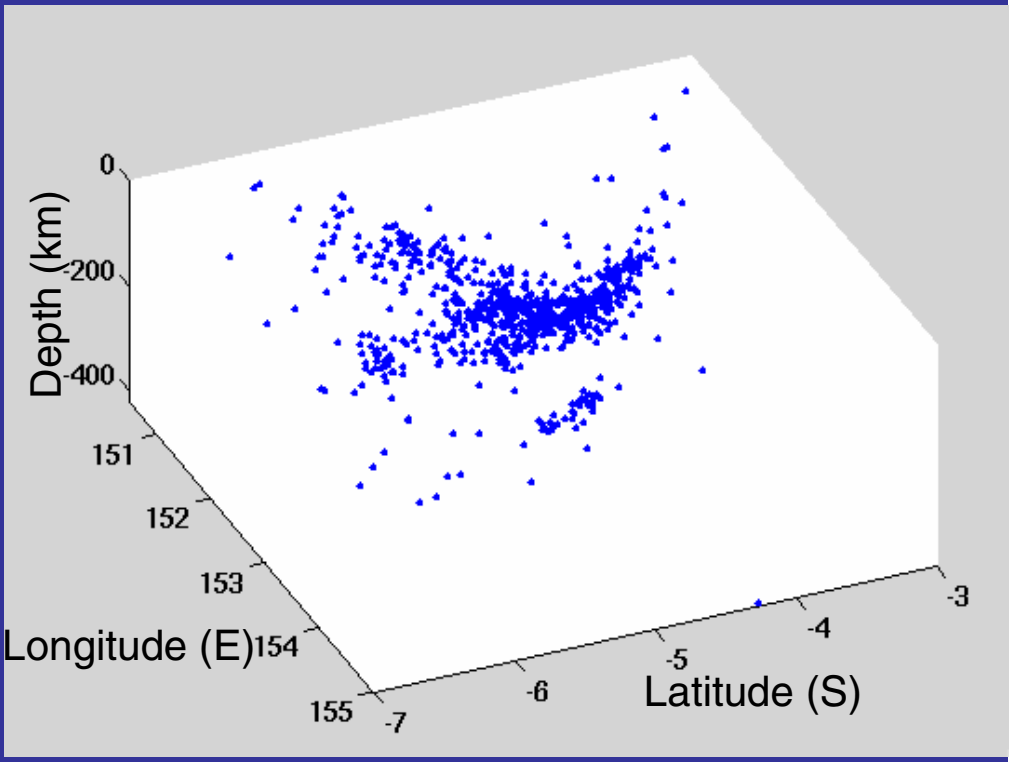
Remember, the database events aren't perfect, but they are the best information we have!

Relocations of an aftershock sequence using Empirical Travel Times

ak135 locations



Empirical Travel Time locations



Relocations of an aftershock sequence using Empirical Travel Times

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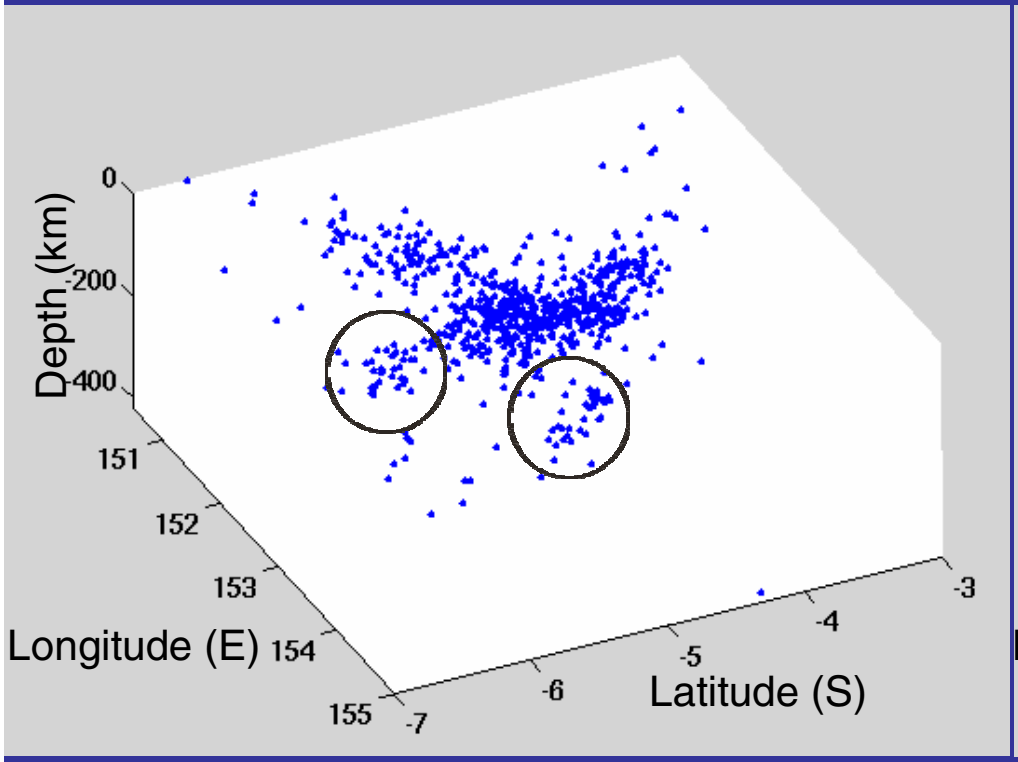
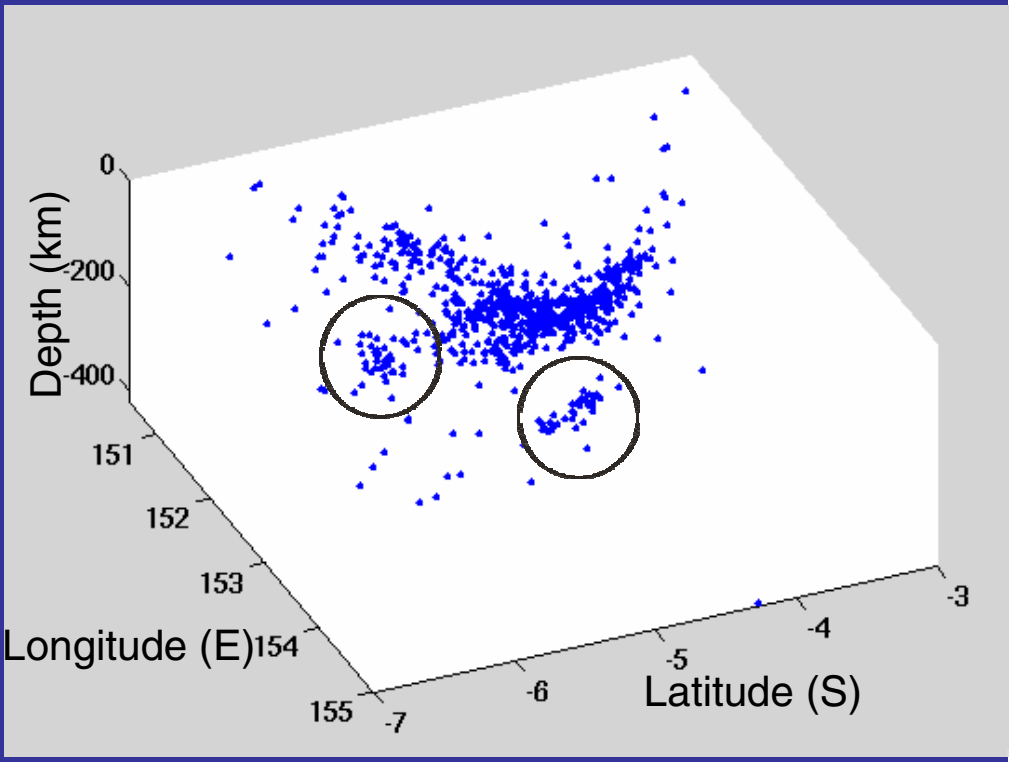
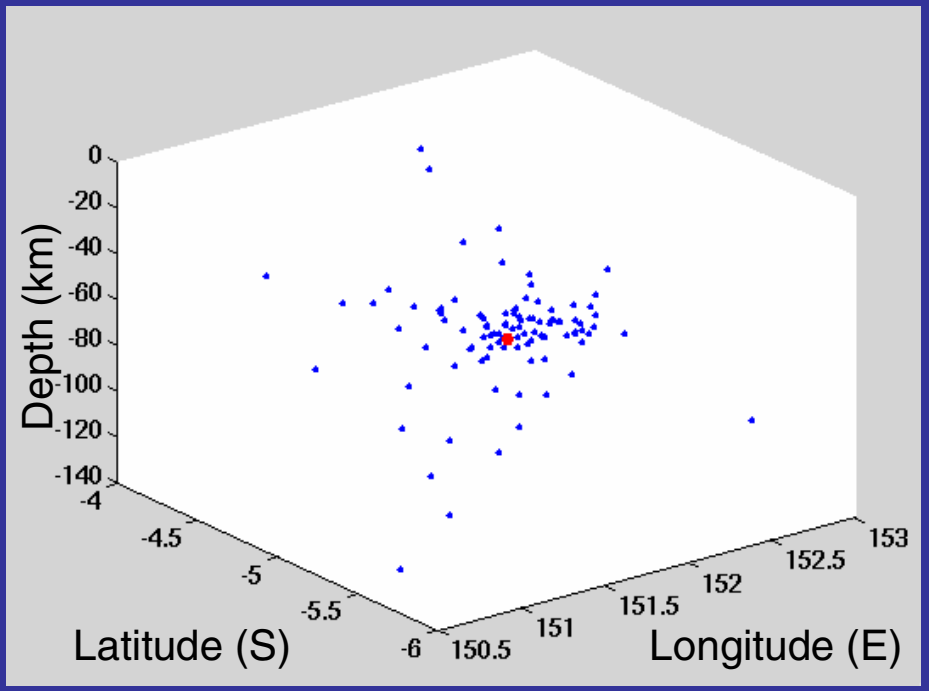


Empirical Travel Time locations

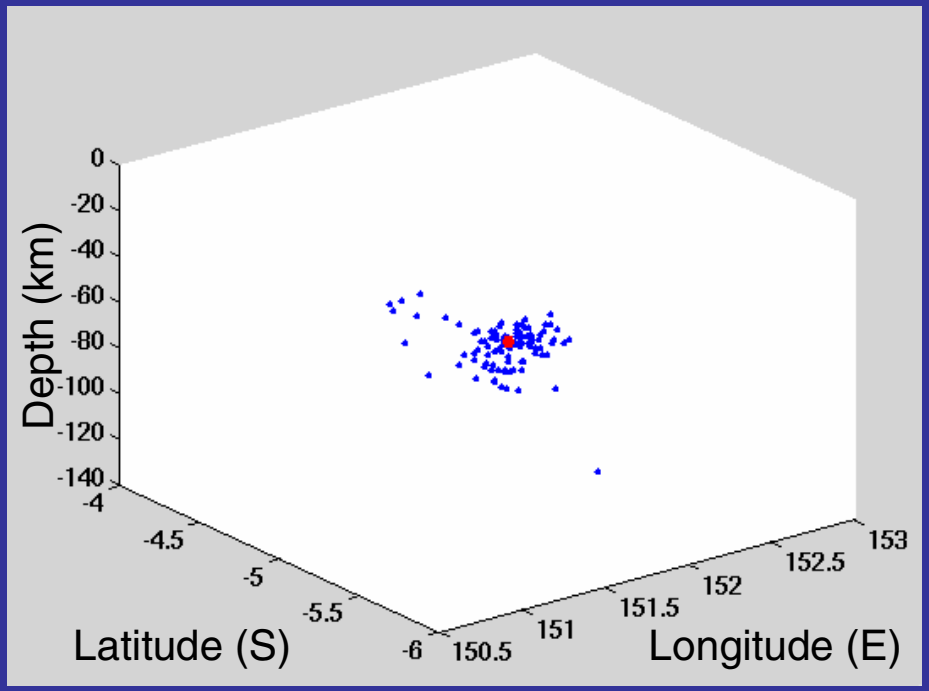


100 relocations of a large event using random subsets of the observations

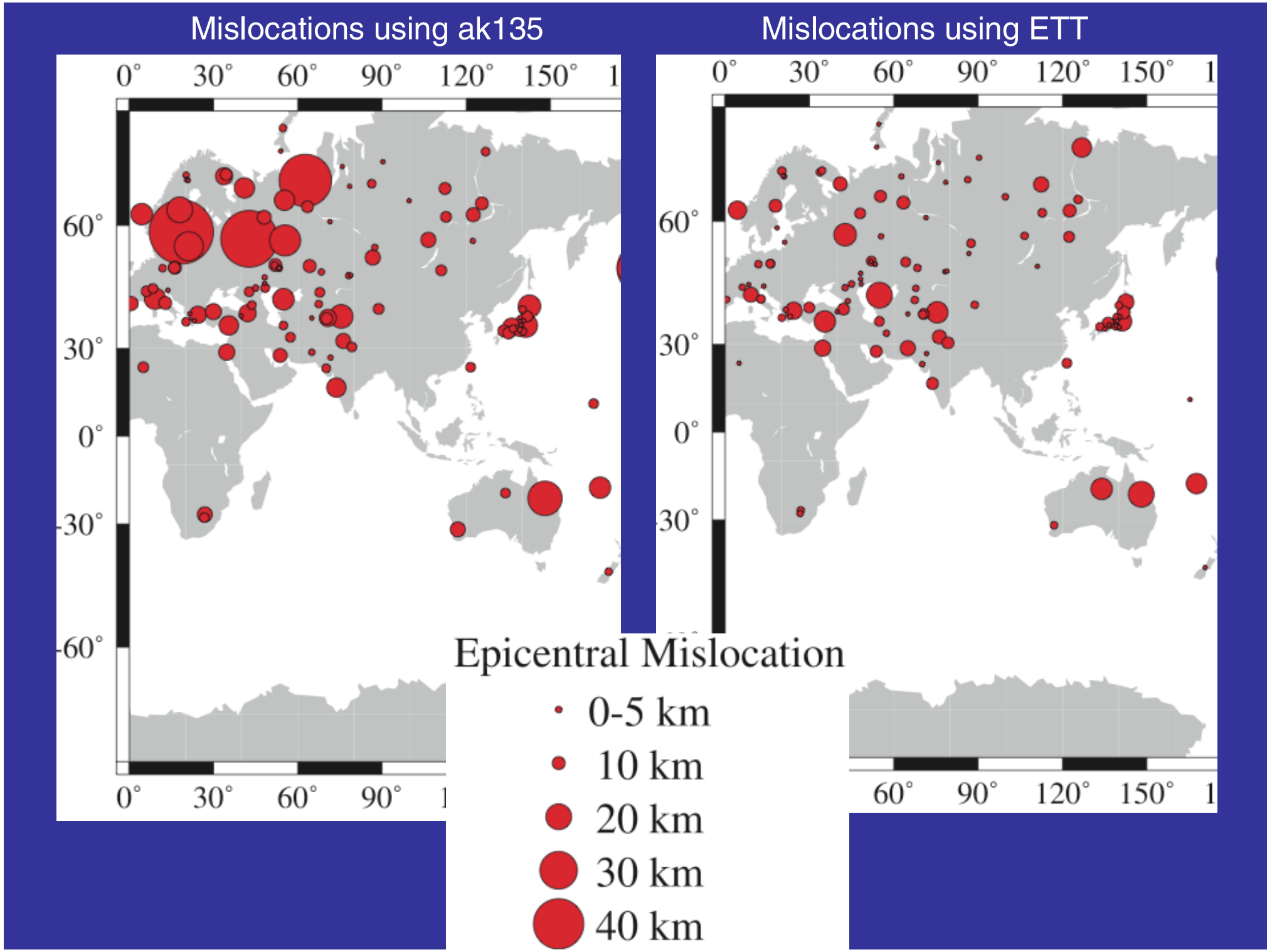
ak135 locations

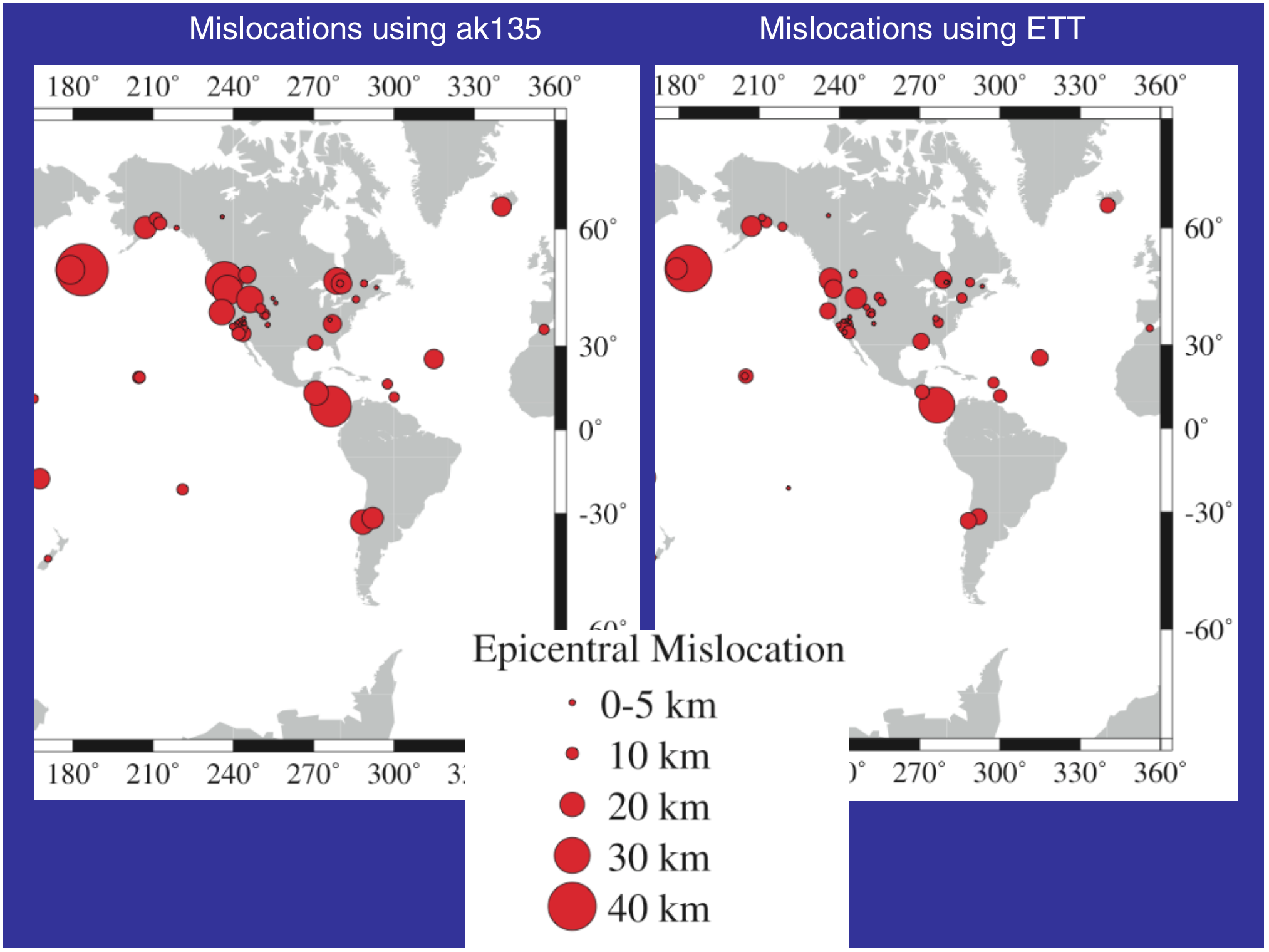


Empirical Travel Time locations



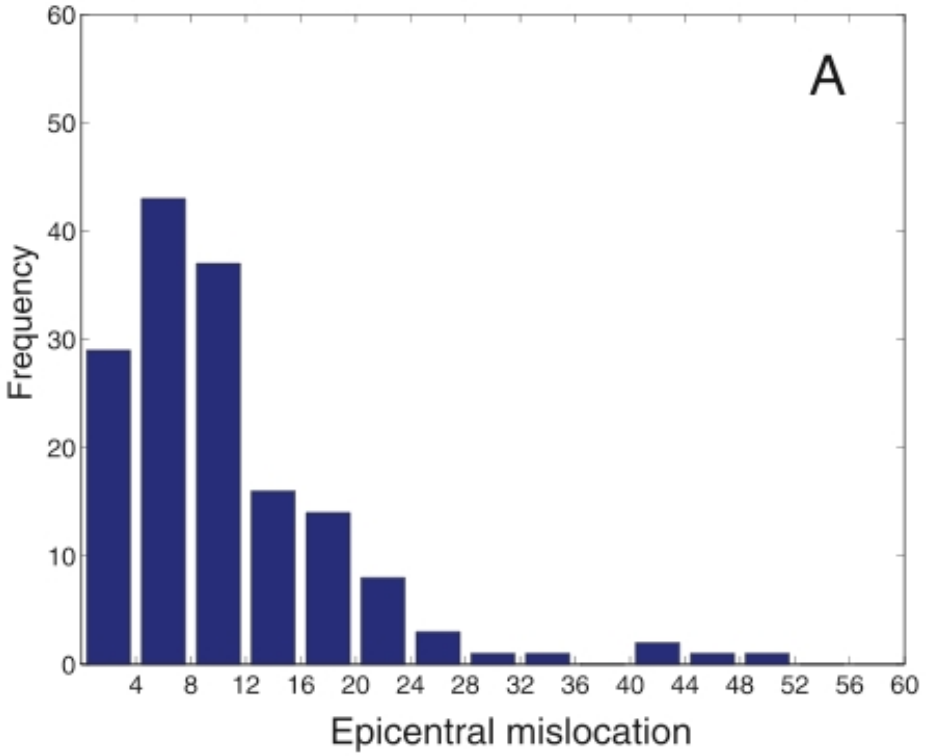
	ak135	ETT
Median Epicentral Error (km)	24.55	11.97
Median Depth Error (km)	6.04	3.65


Mislocations using ak135
Mislocations using ETT
0°
30°
60°
90°
120°
150°
60°
30°
0°
-30°
-60°
Epicentral Mislocation
0-5 km
10 km
20 km
30 km
40 km

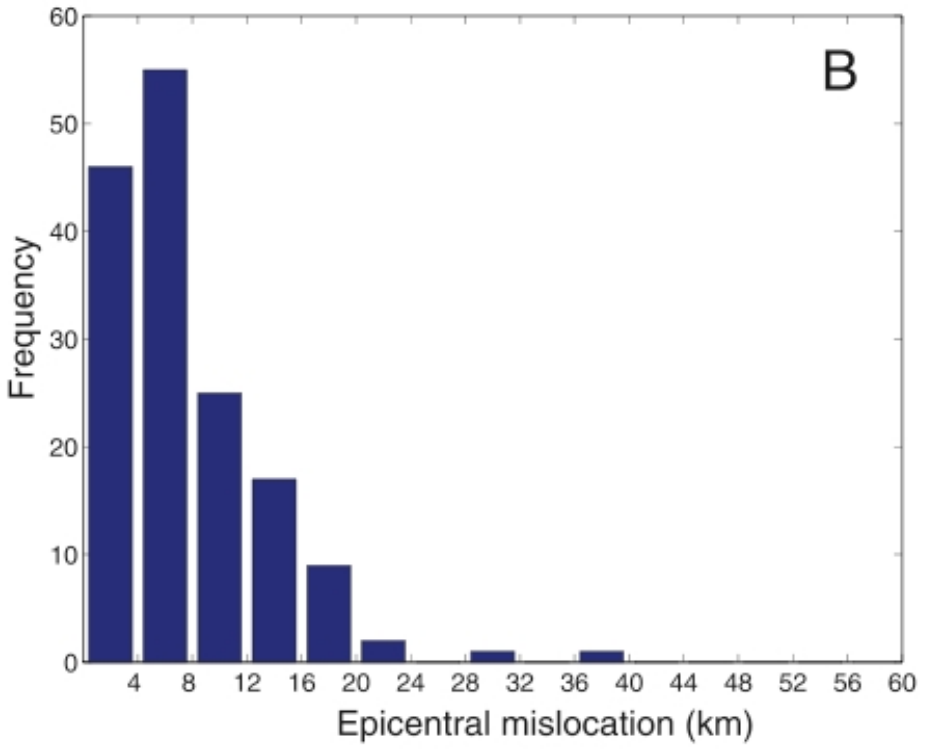

Mislocations using ak135
Mislocations using ETT
180° 210° 240° 270° 300° 330° 360°
60°
30°
0°
-30°
-60°
Epicentral Mislocation
0-5 km
10 km
20 km
30 km
40 km

The median epicentral mislocation reduces by 30% to less than 6km. ETTs are particularly effective for events with large ak135 mislocations

using ak135



using ETT



Conclusions

- ETTs use the database of reliable previous observations directly.
- ETTs account for correlated 3-D structure.
- ETTs provide the greatest improvement for small events
- ETTs reduce mislocation in by 30% over ak135.

ETTs can be easily updated by adding to the database