Finite Frequency Measurements of conventional and core-diffracted P-waves (P and Pdiff) for waveform tomography

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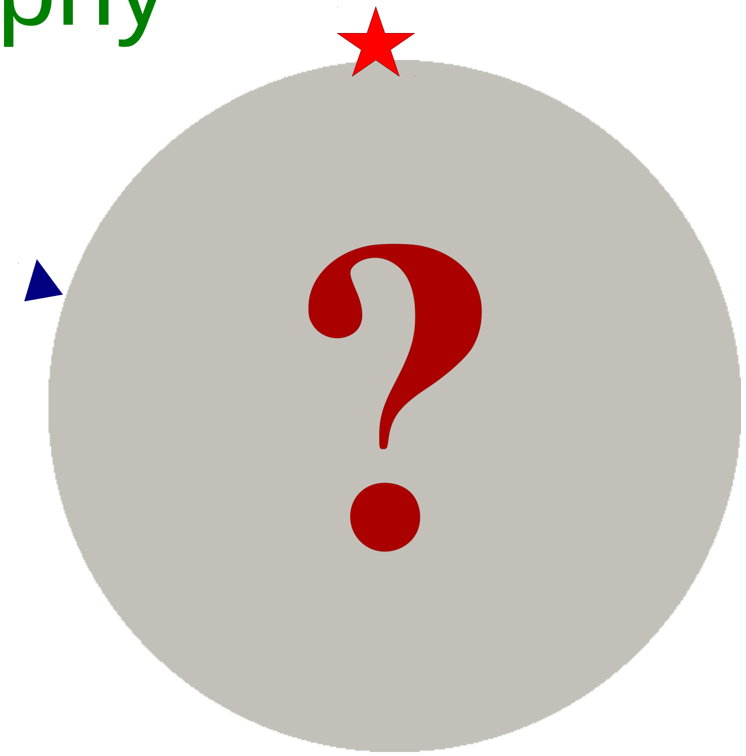
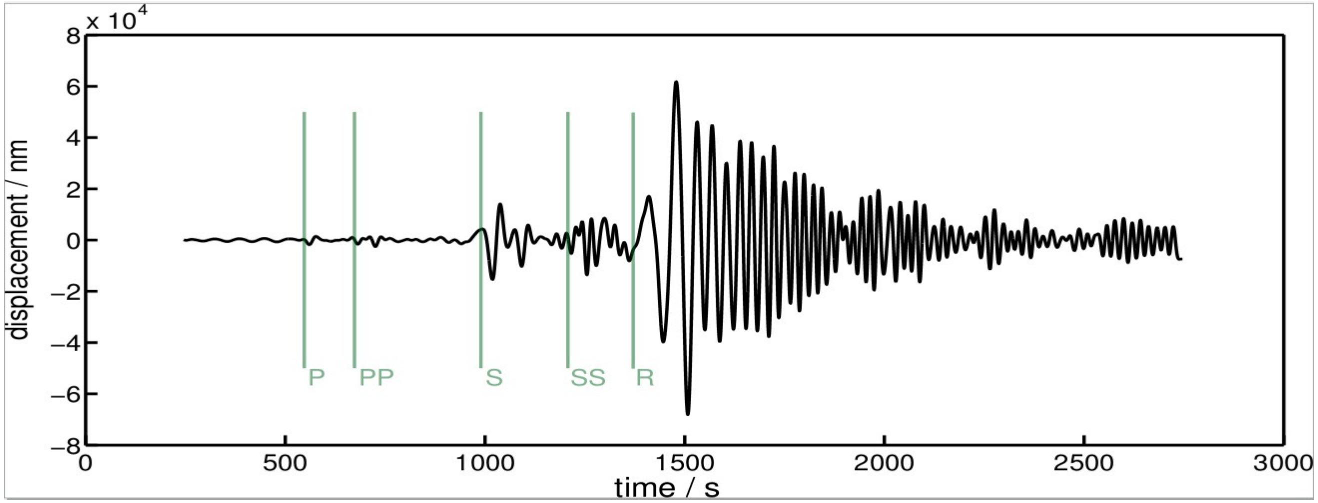
EGU2014, Vienna, April 2014

Global Seismic Tomography



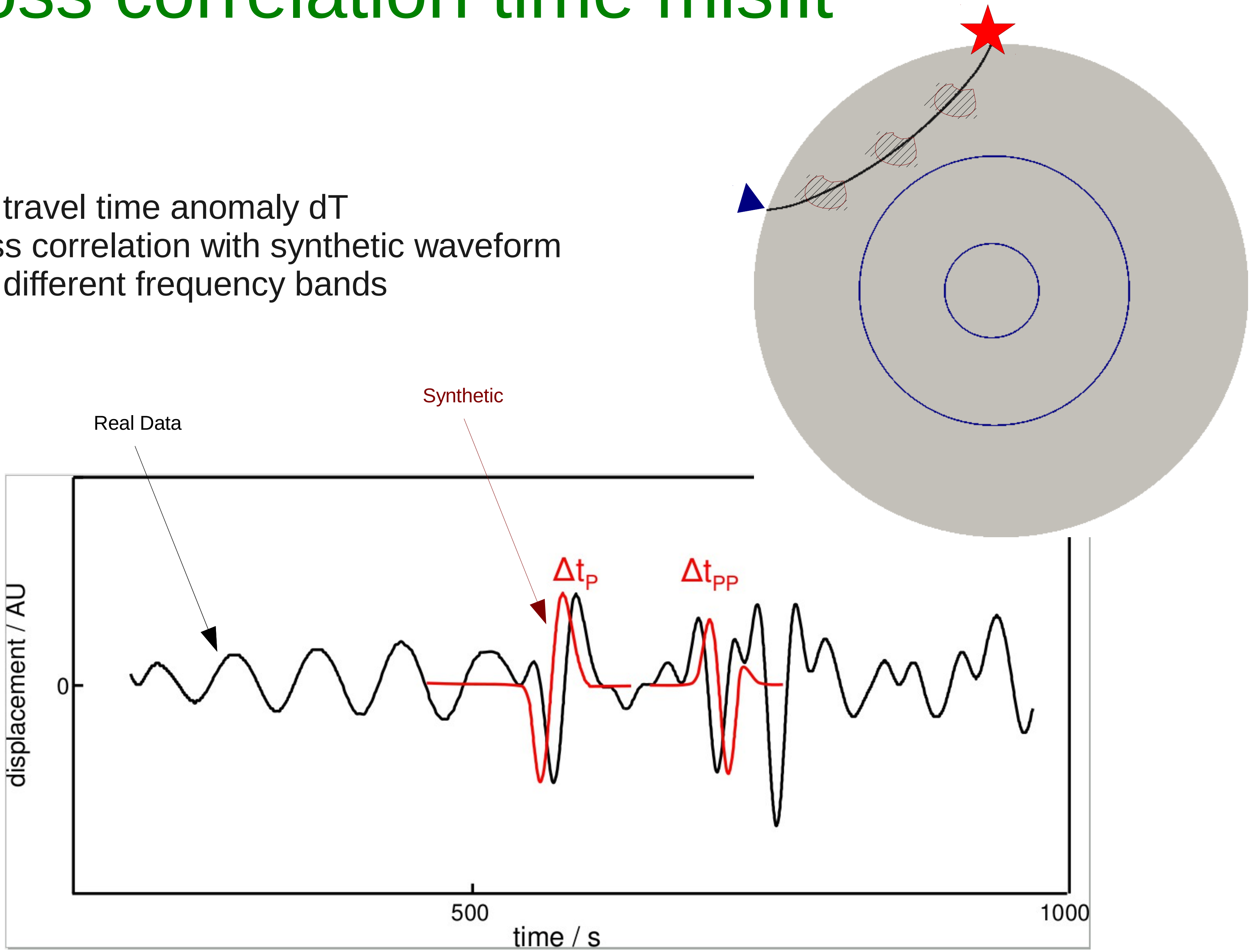
Use earthquakes to infer the Earth structure

- Real data (recorded signals by seismic stations)
- Calculate travel time (pick phases or generate synthetic waveforms)
- Compare with expected travel times (difference or cross-correlation, ...)
- Invert for velocities



Cross correlation time misfit

- Use travel time anomaly dT
- Cross correlation with synthetic waveform
- Use different frequency bands



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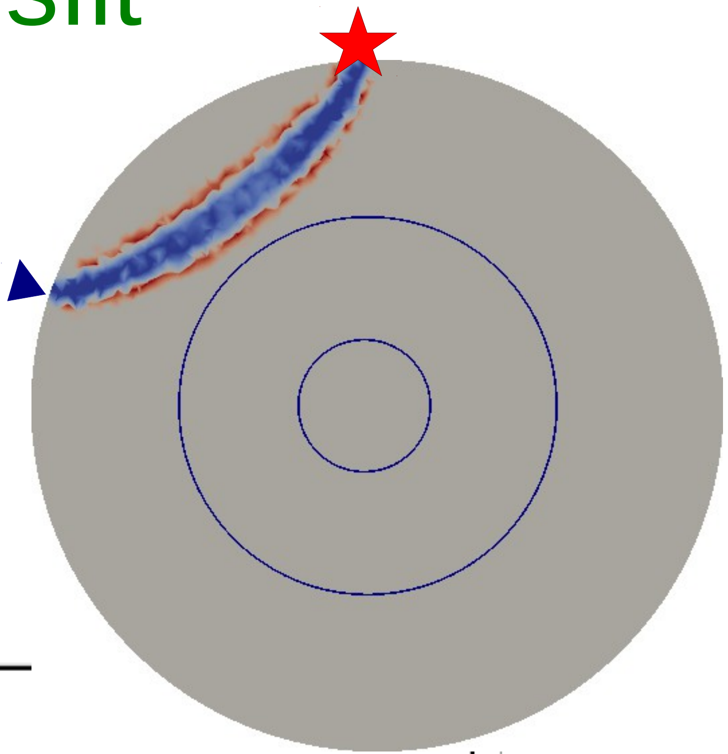

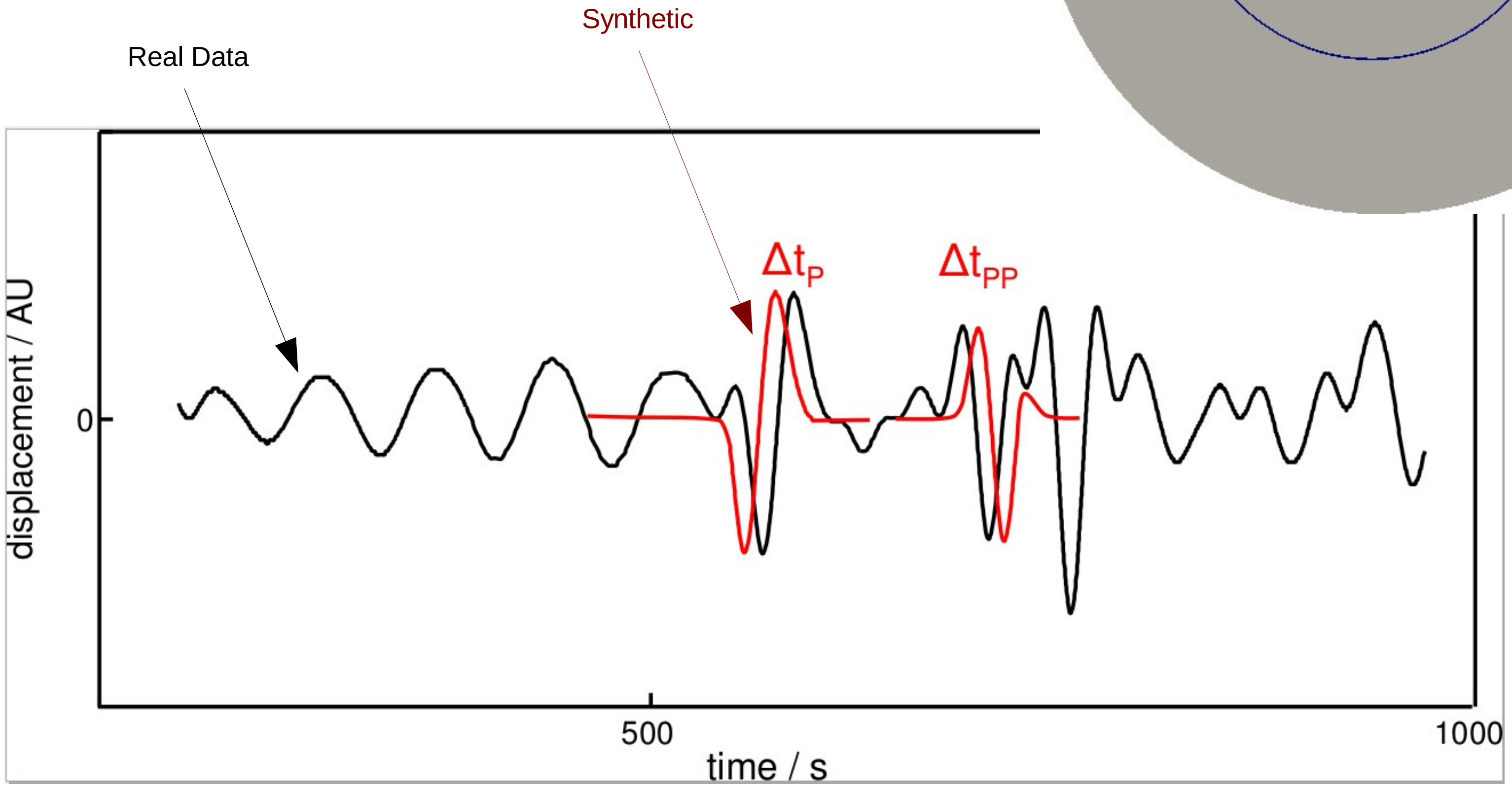

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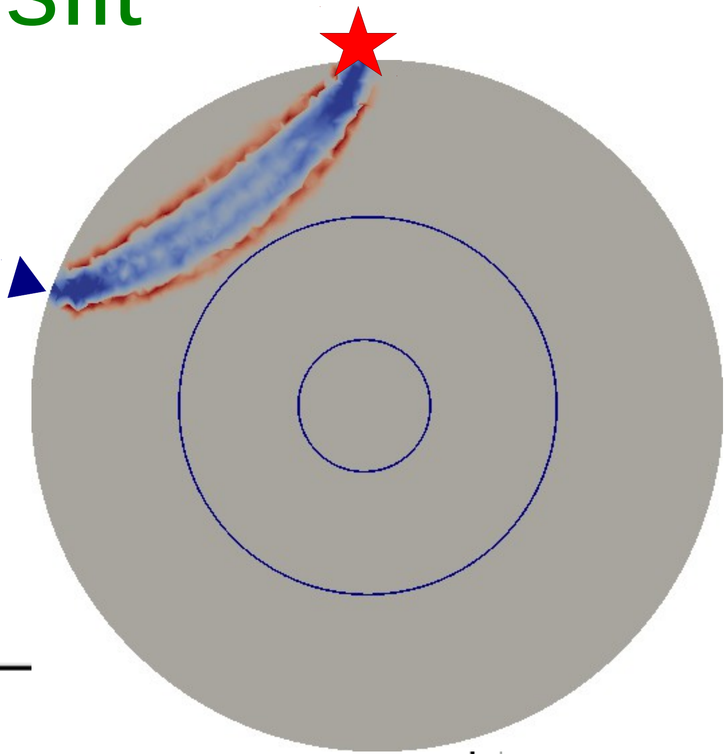

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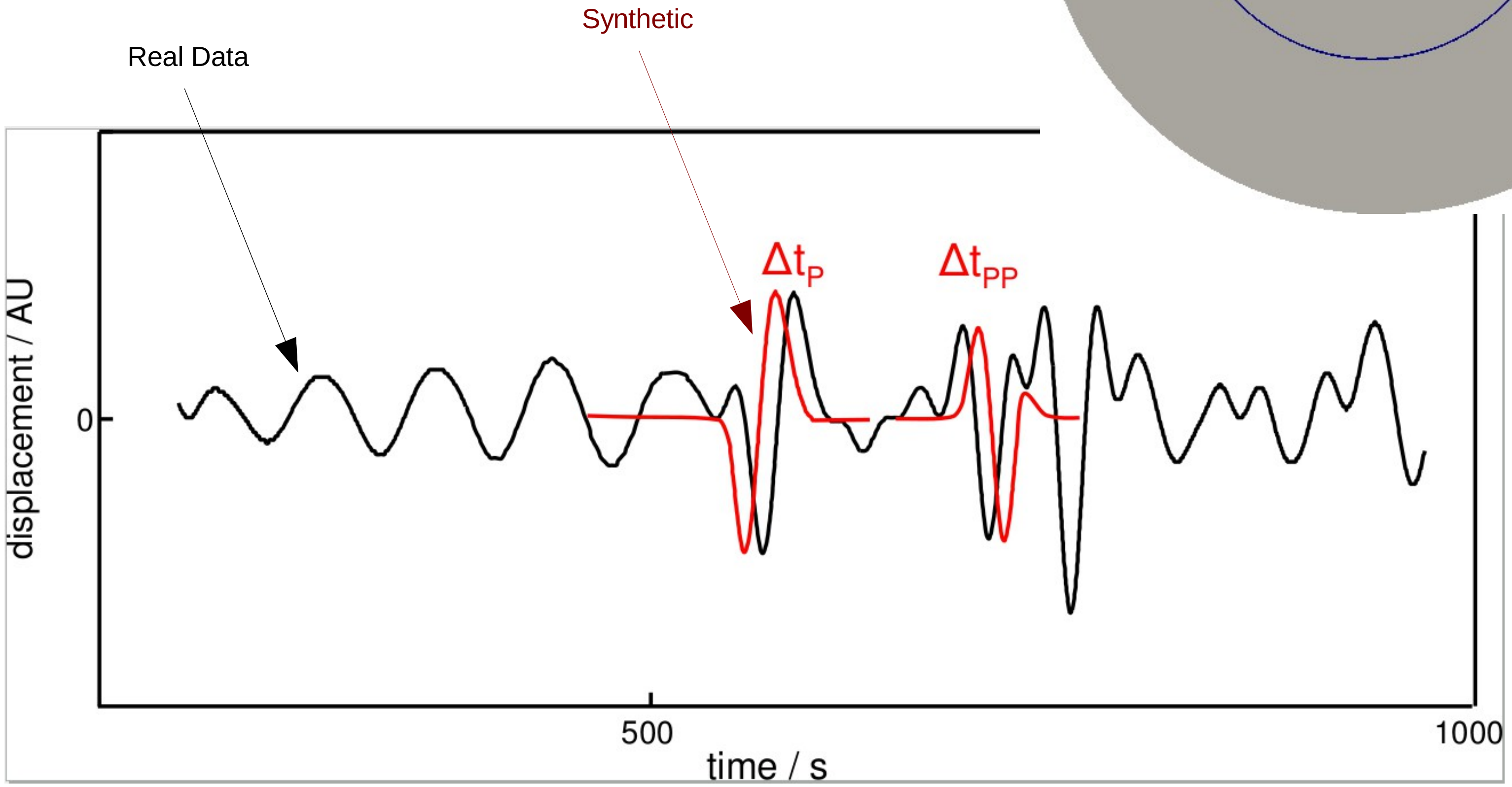
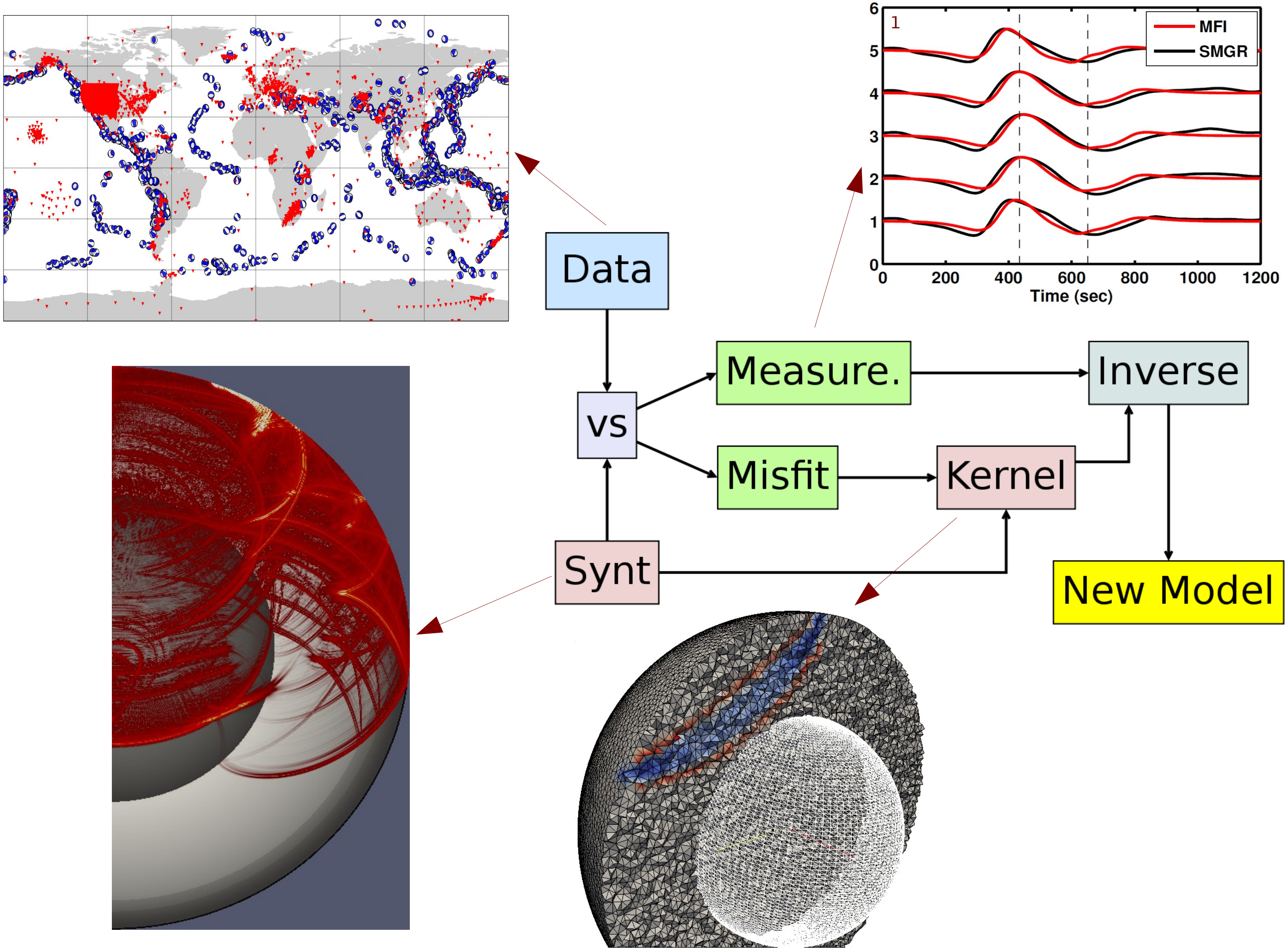


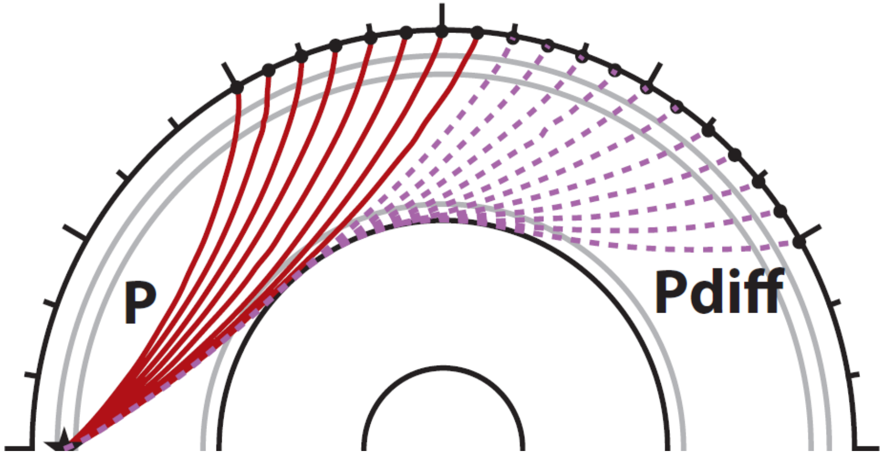
NDLB: No Data Left Behind

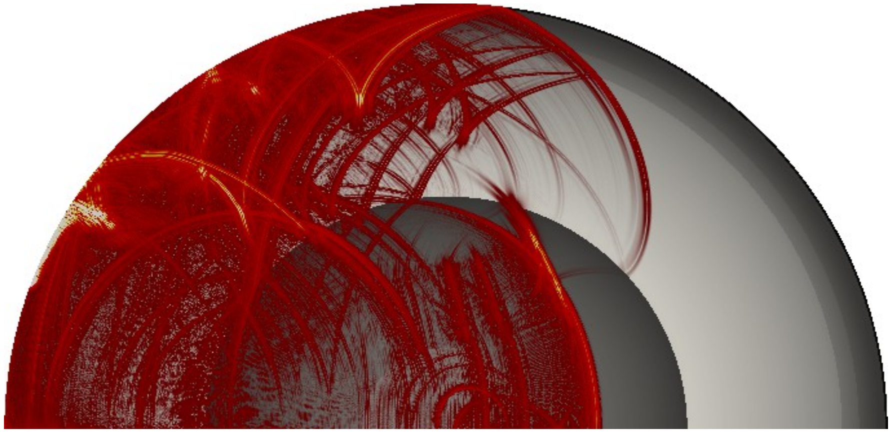


Core diffracted P-waves

Grazes the core:

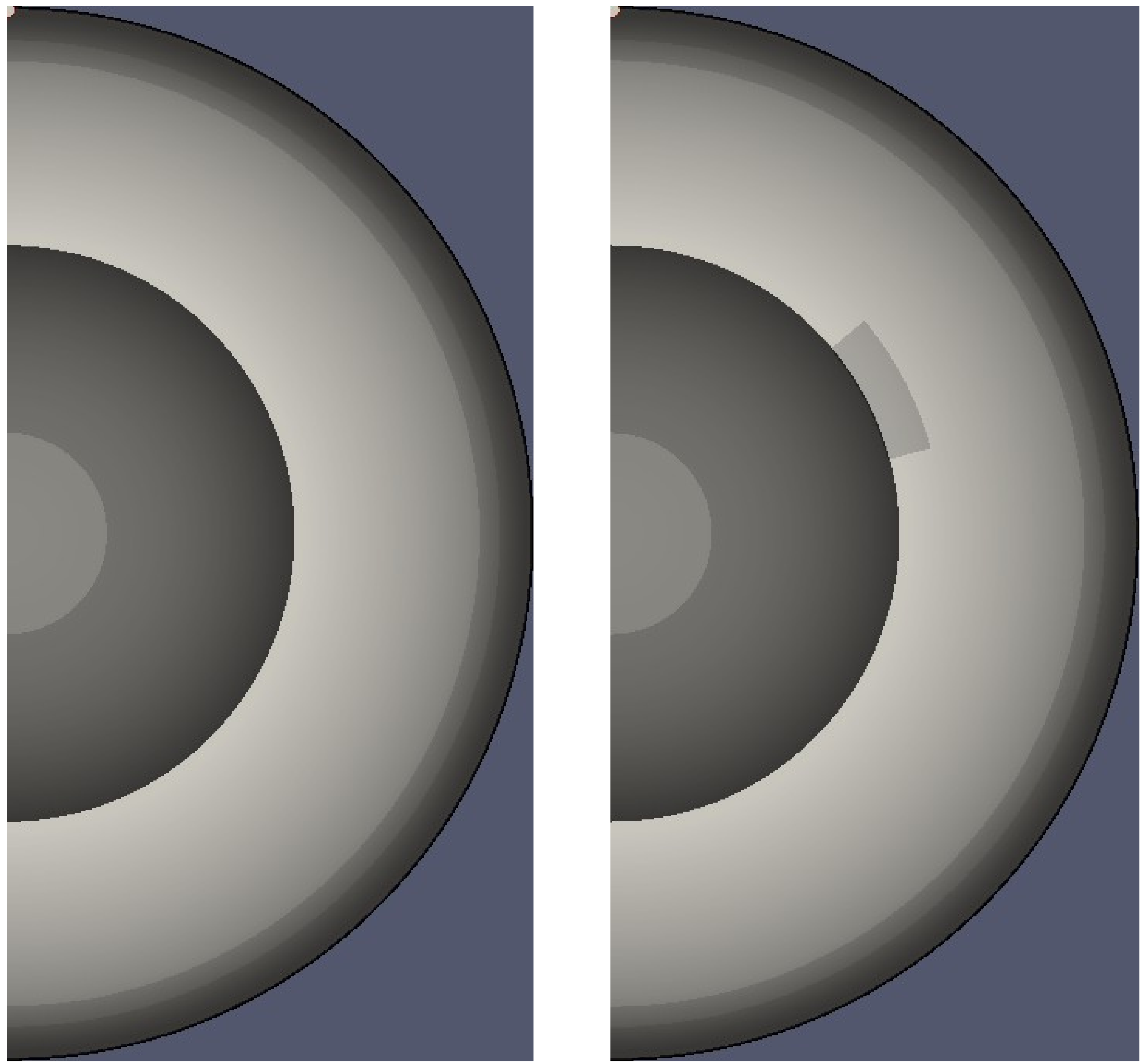
- Extensively samples the deepest part of the mantle
- Better information on the 'footing' of mantle plumes and internal structure of the anomalies on CMB
- ~~Ray theory~~



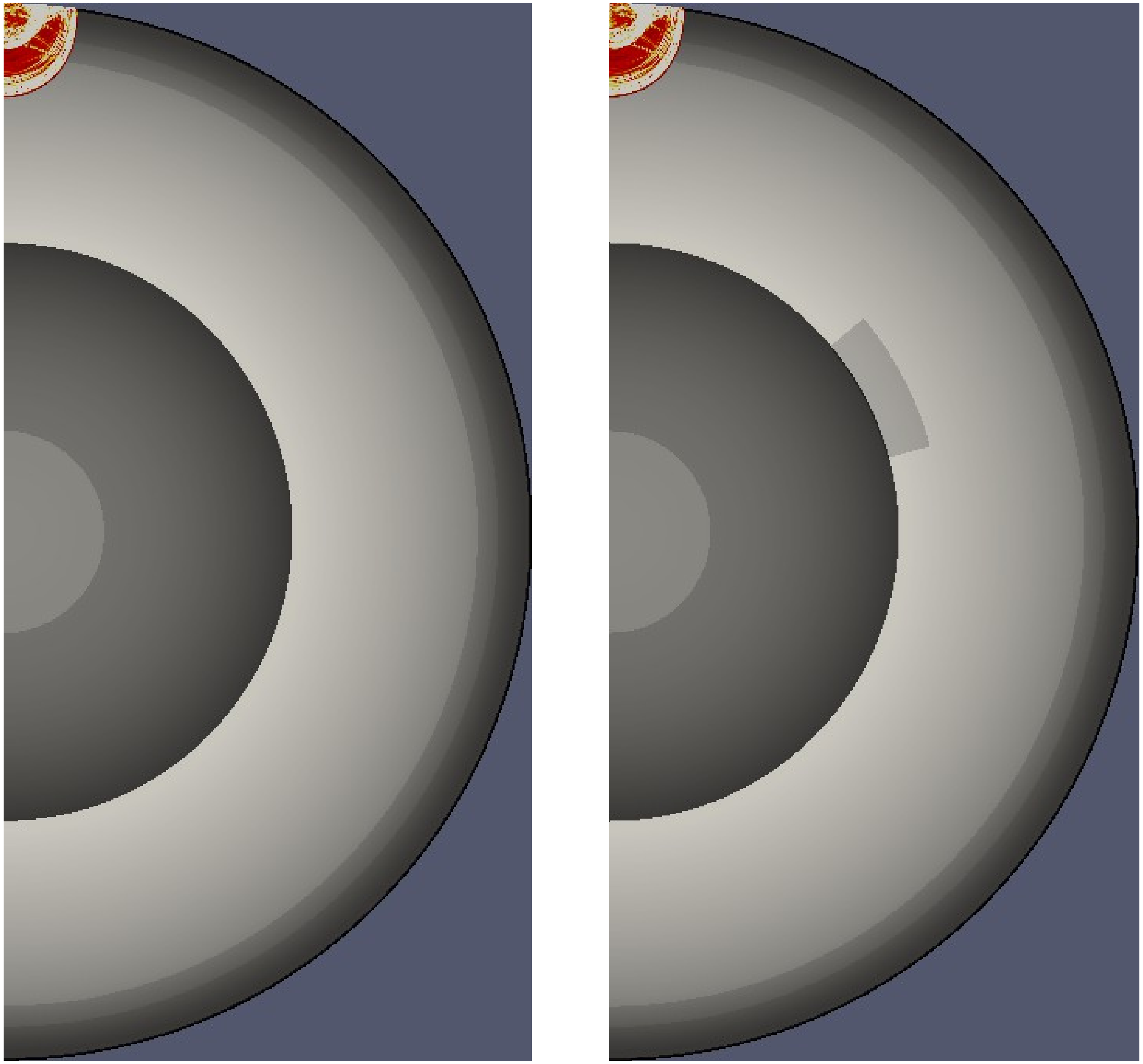


AXISEM, 2013

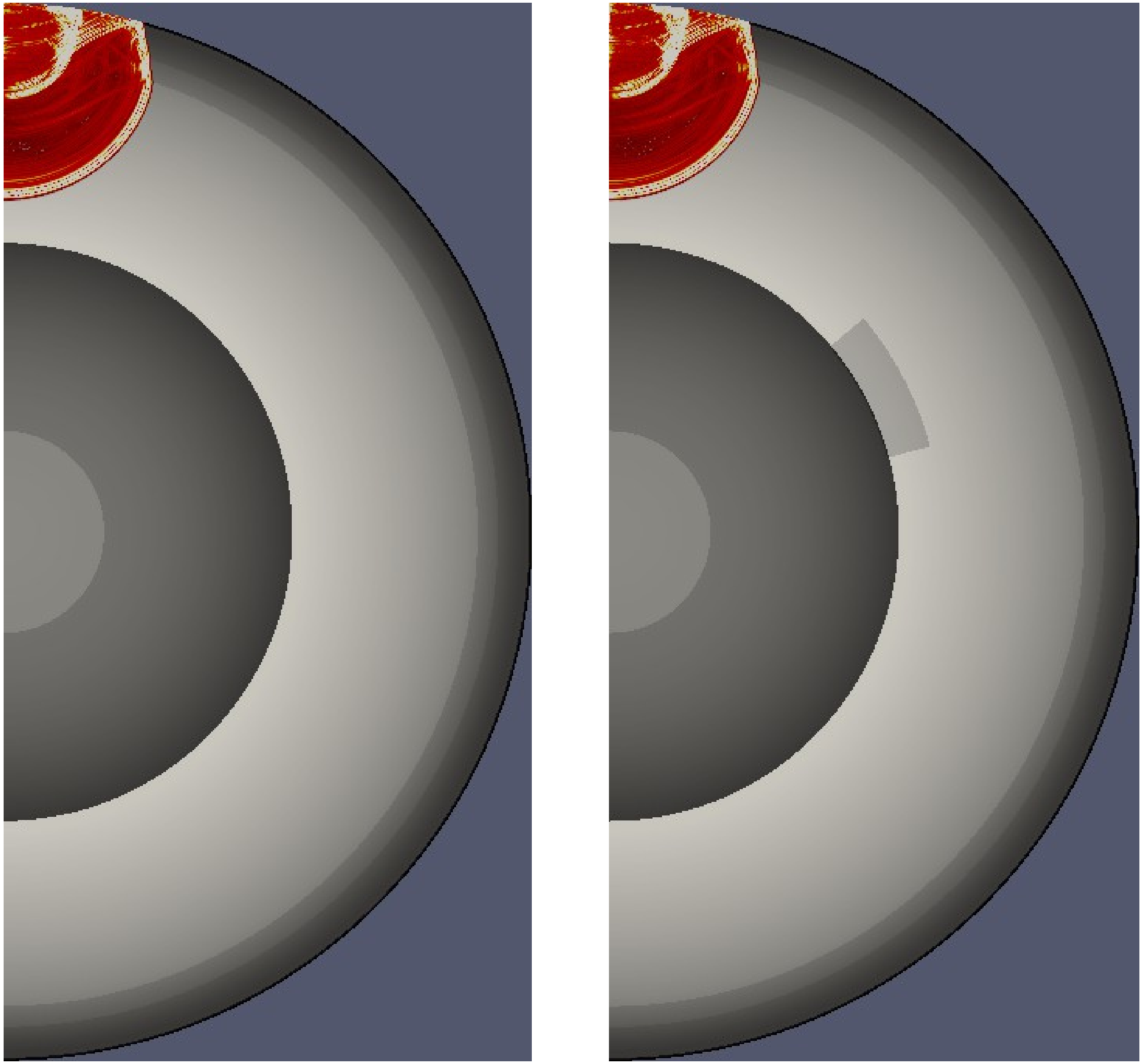
Core-diffracted waves



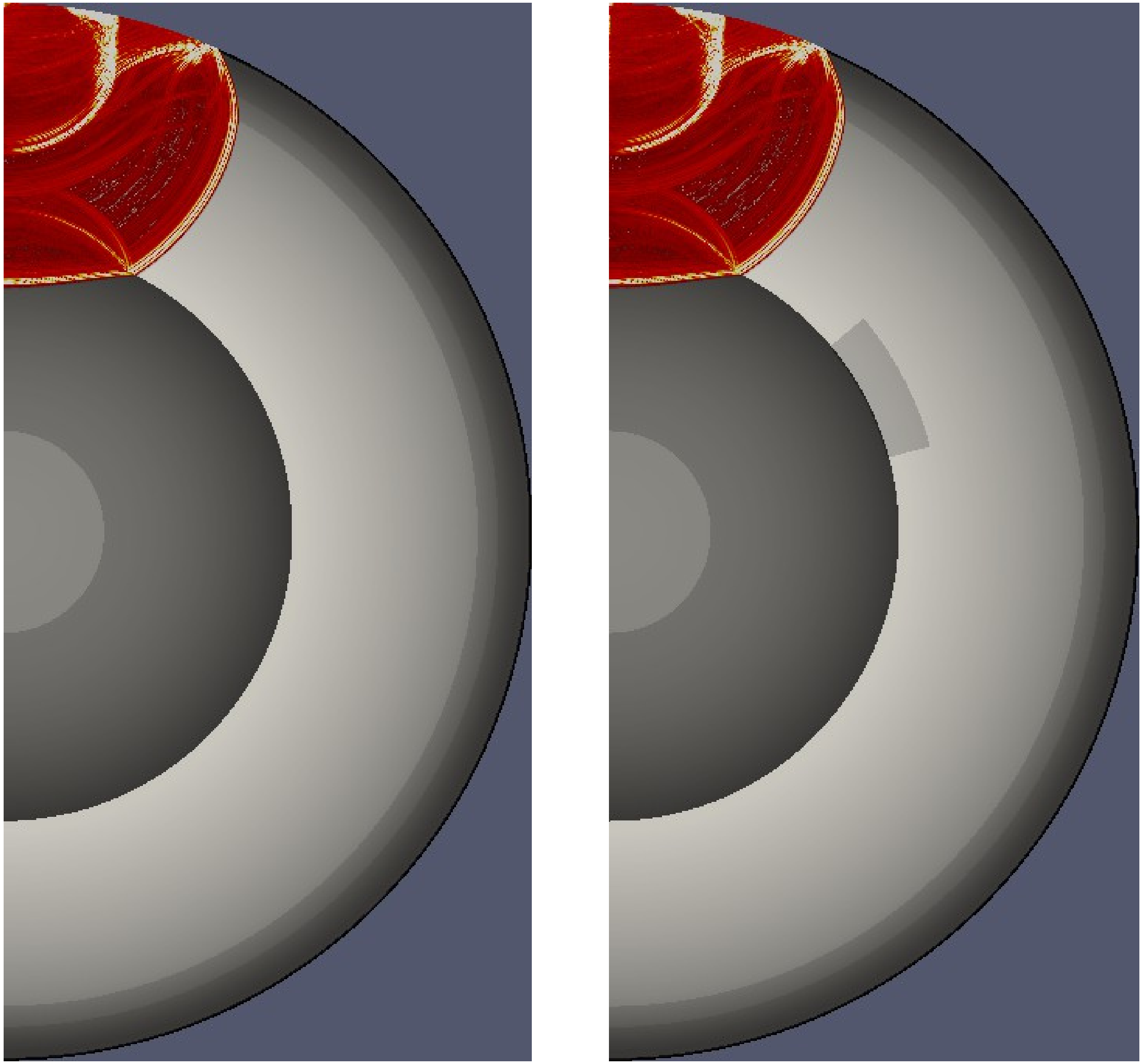
Core-diffracted waves



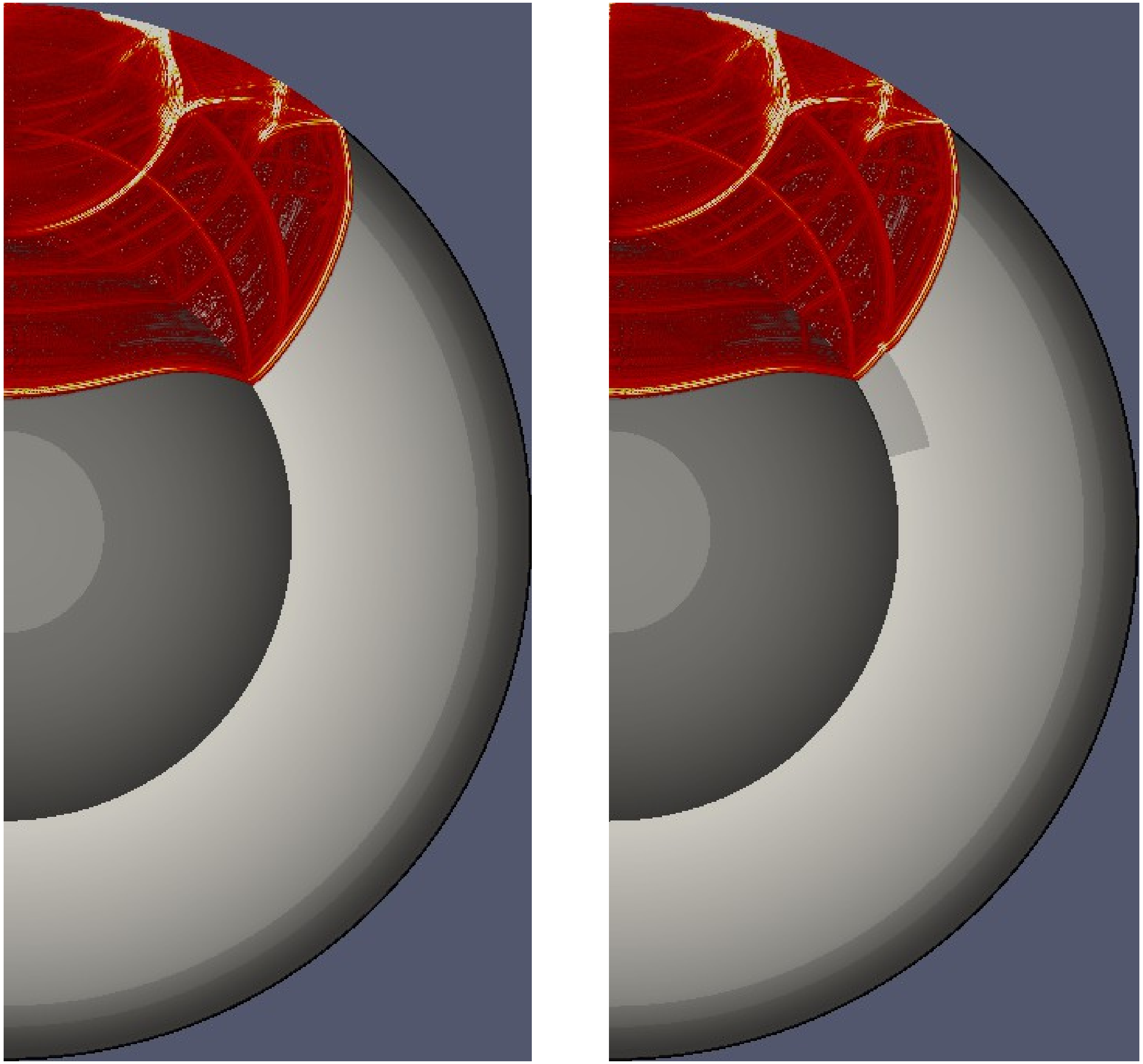
Core-diffracted waves



Core-diffracted waves



Core-diffracted waves



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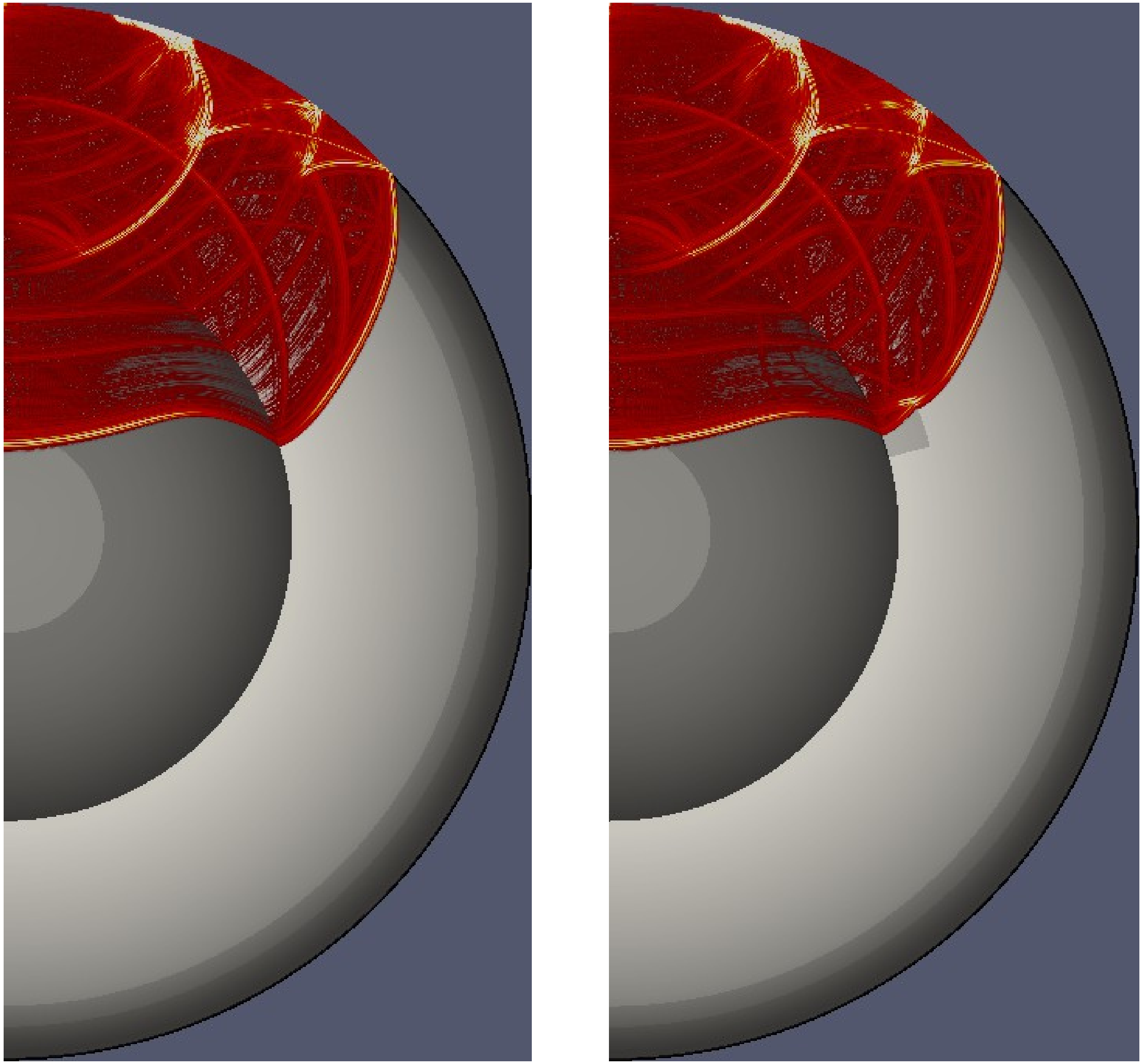

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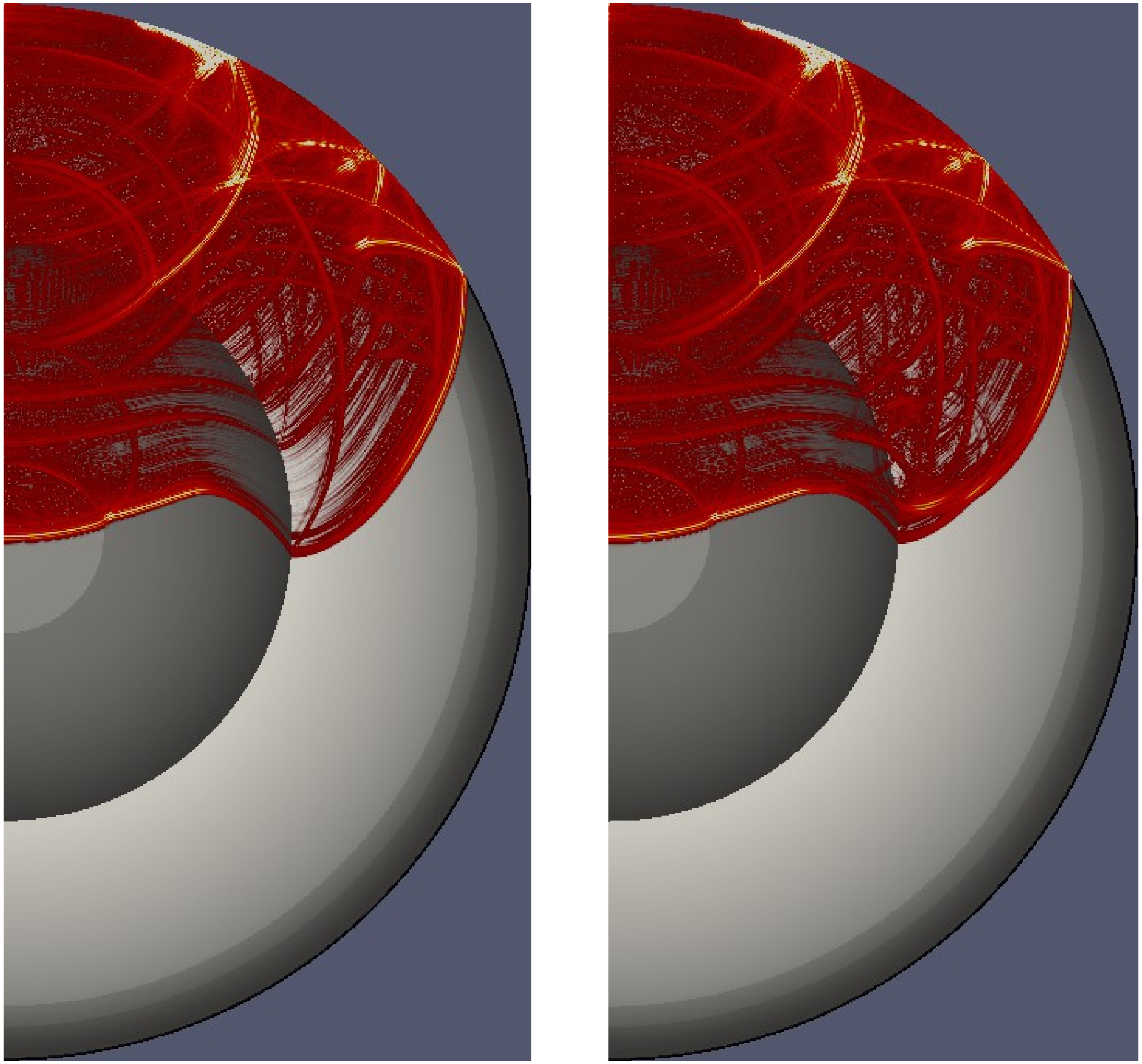

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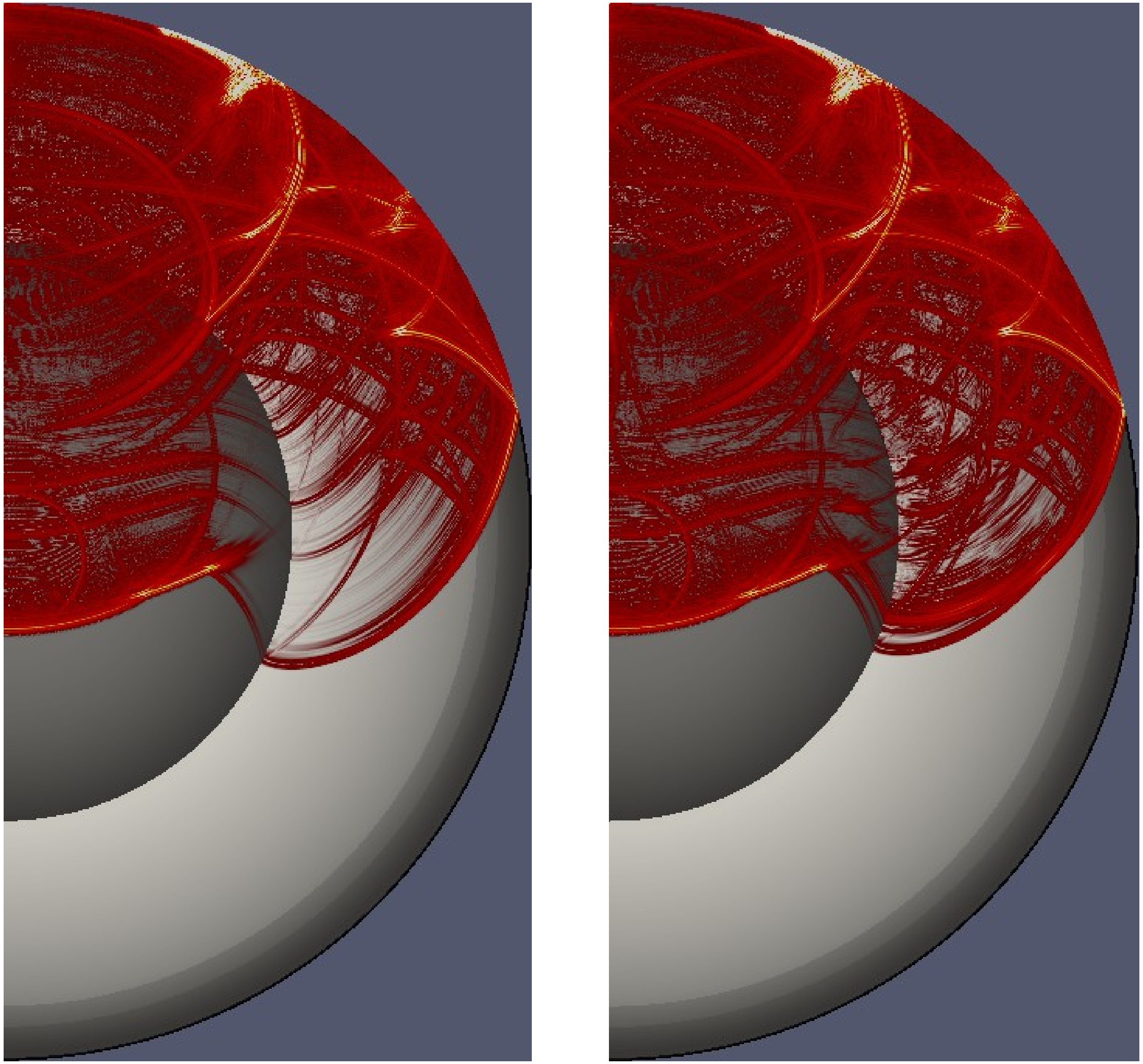

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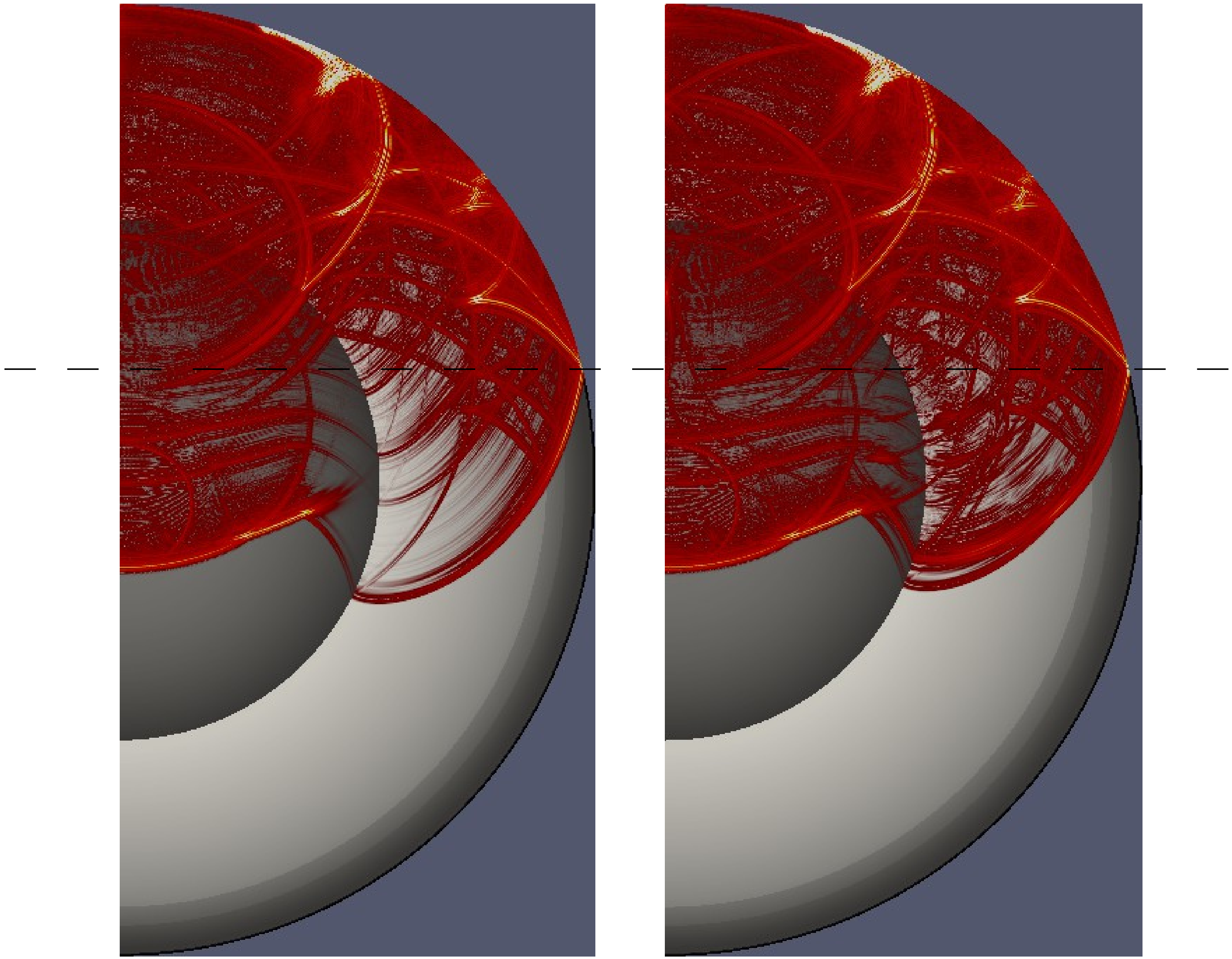
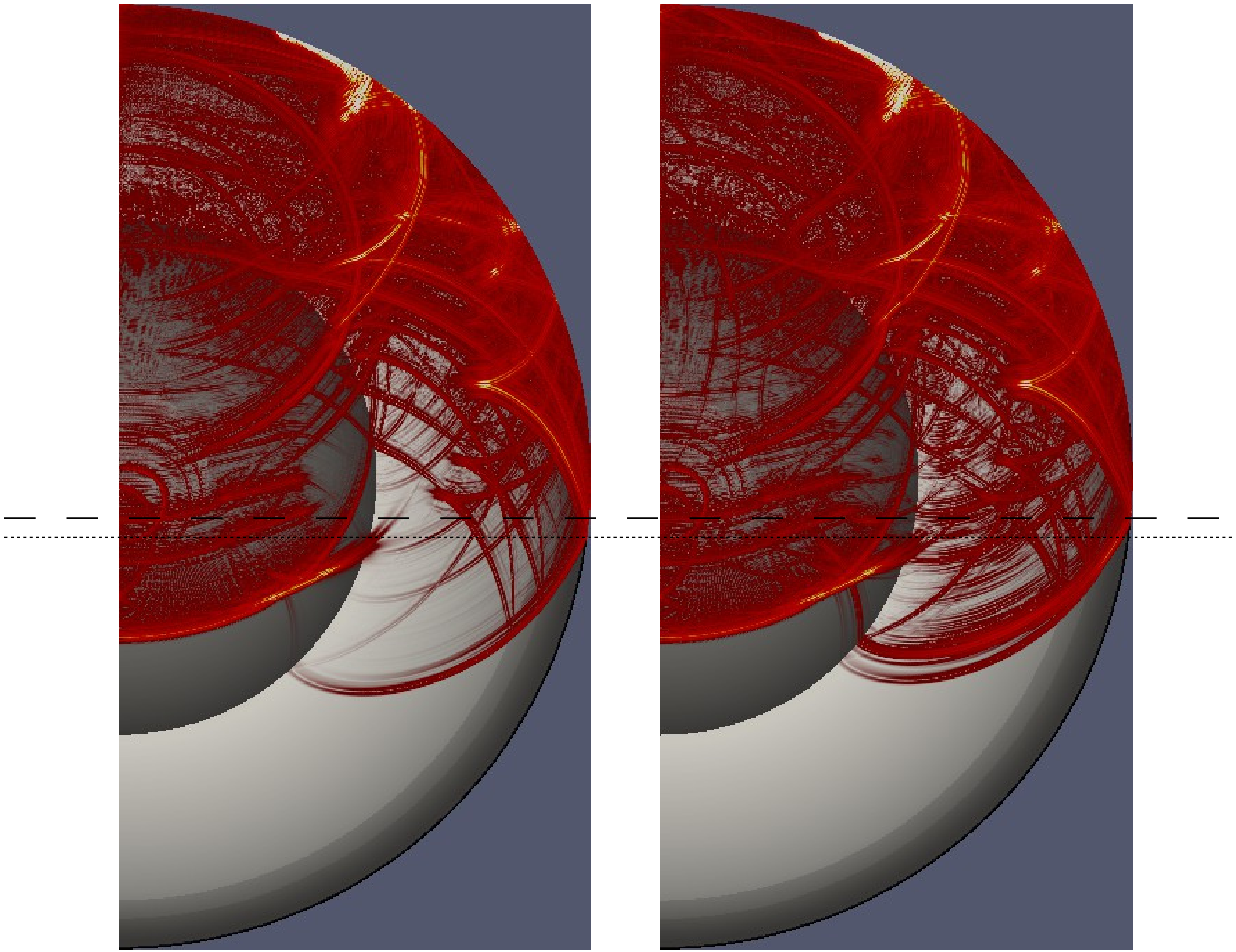
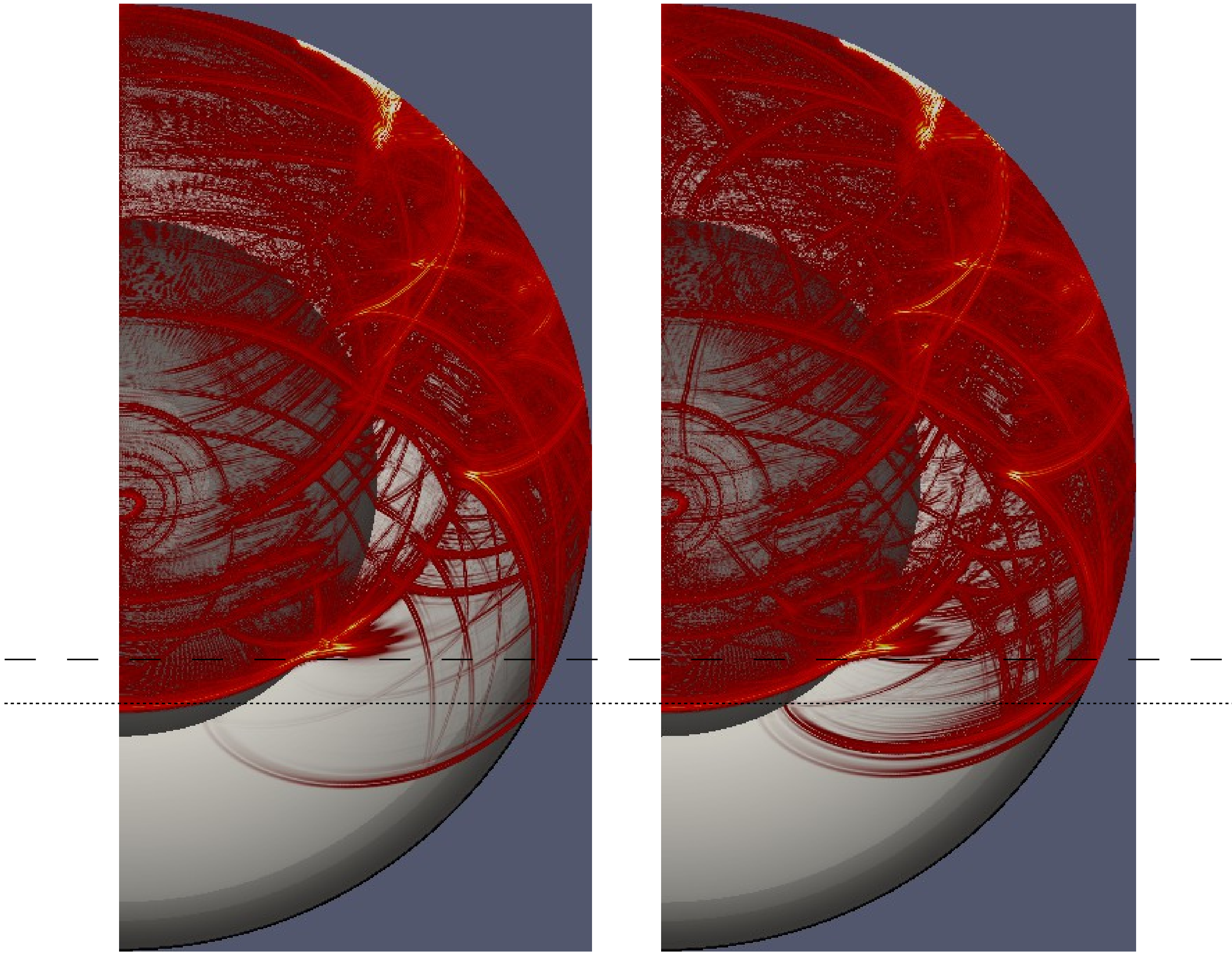


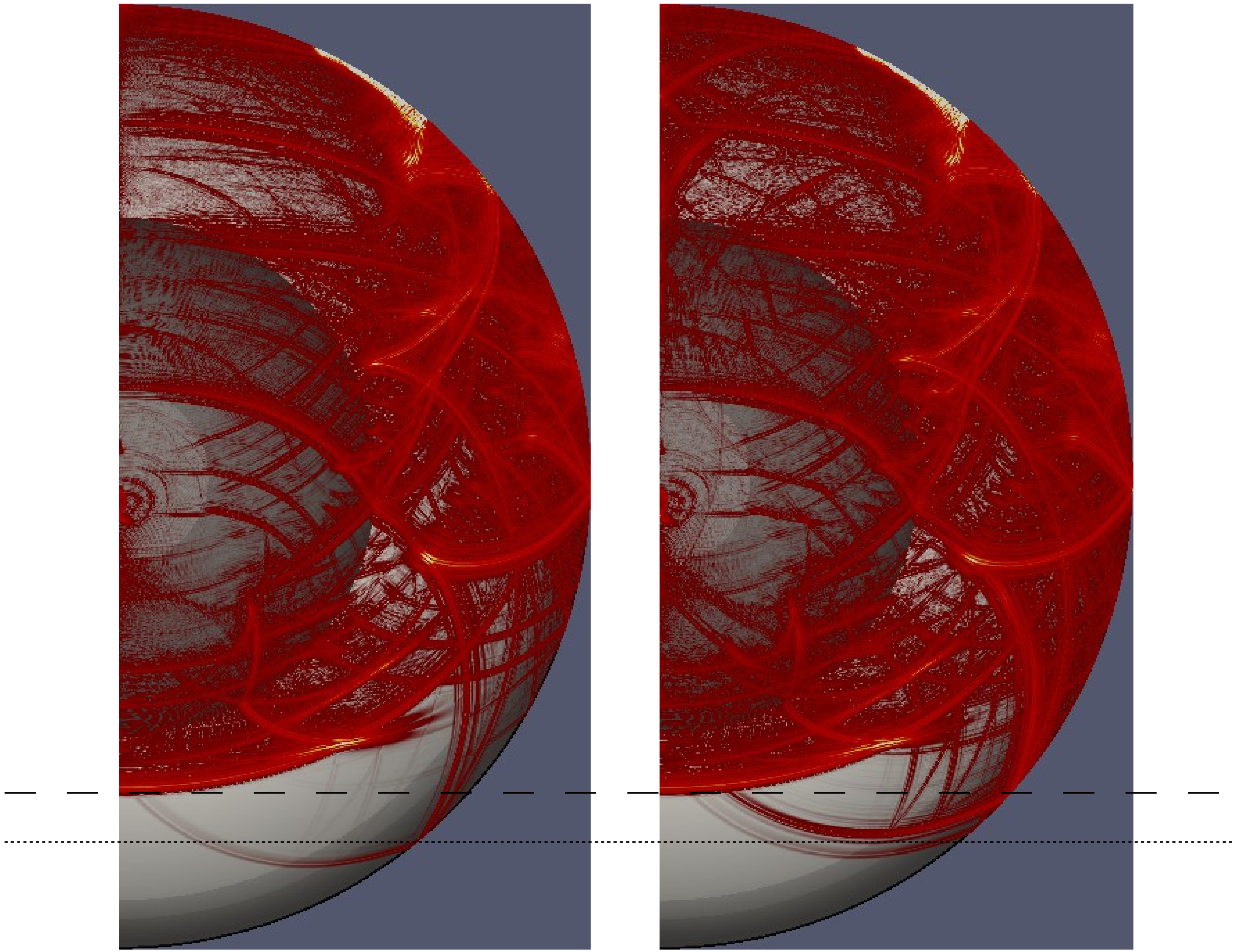
Core-diffracted waves



Core-diffracted waves



Core-diffracted waves



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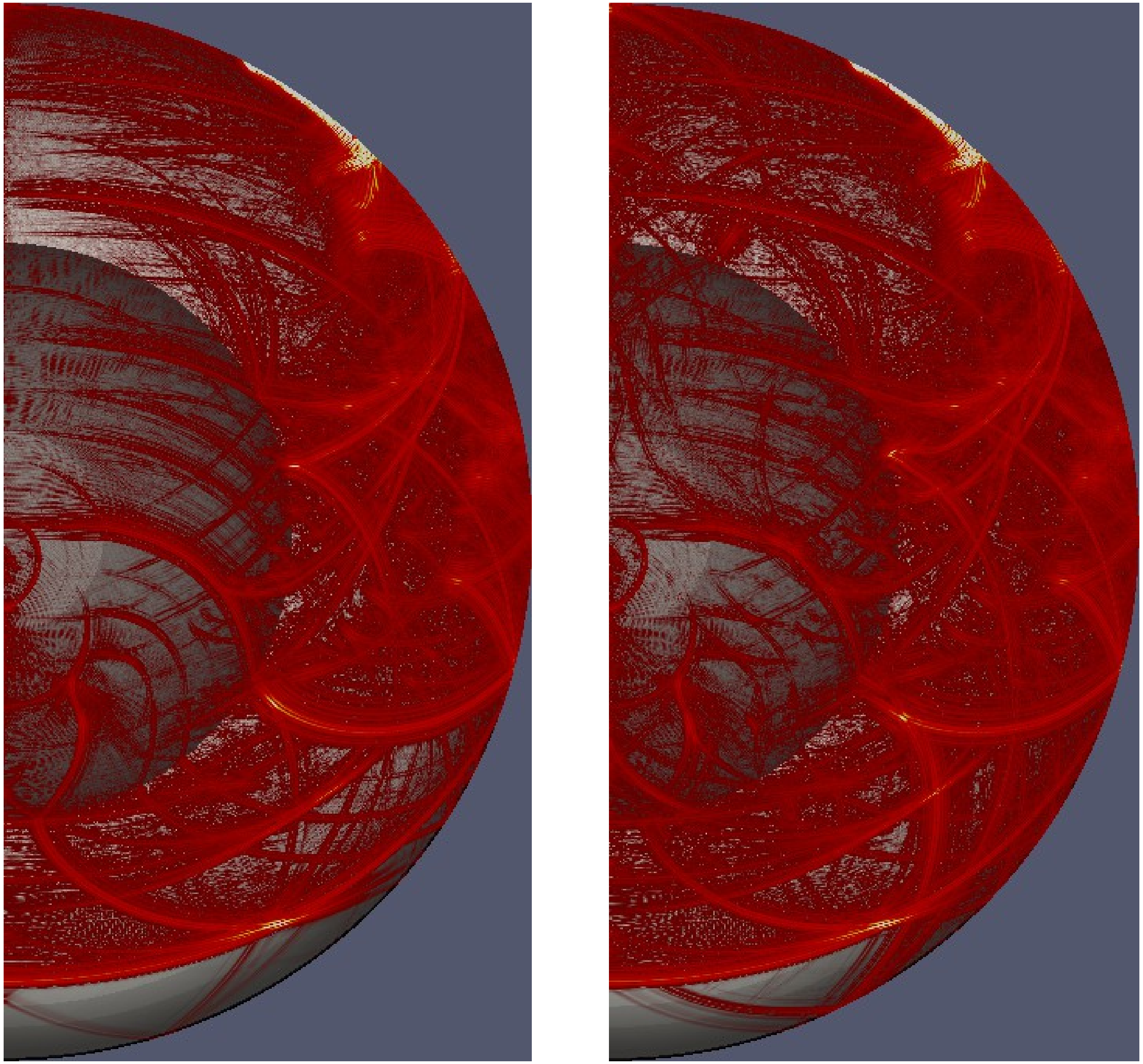

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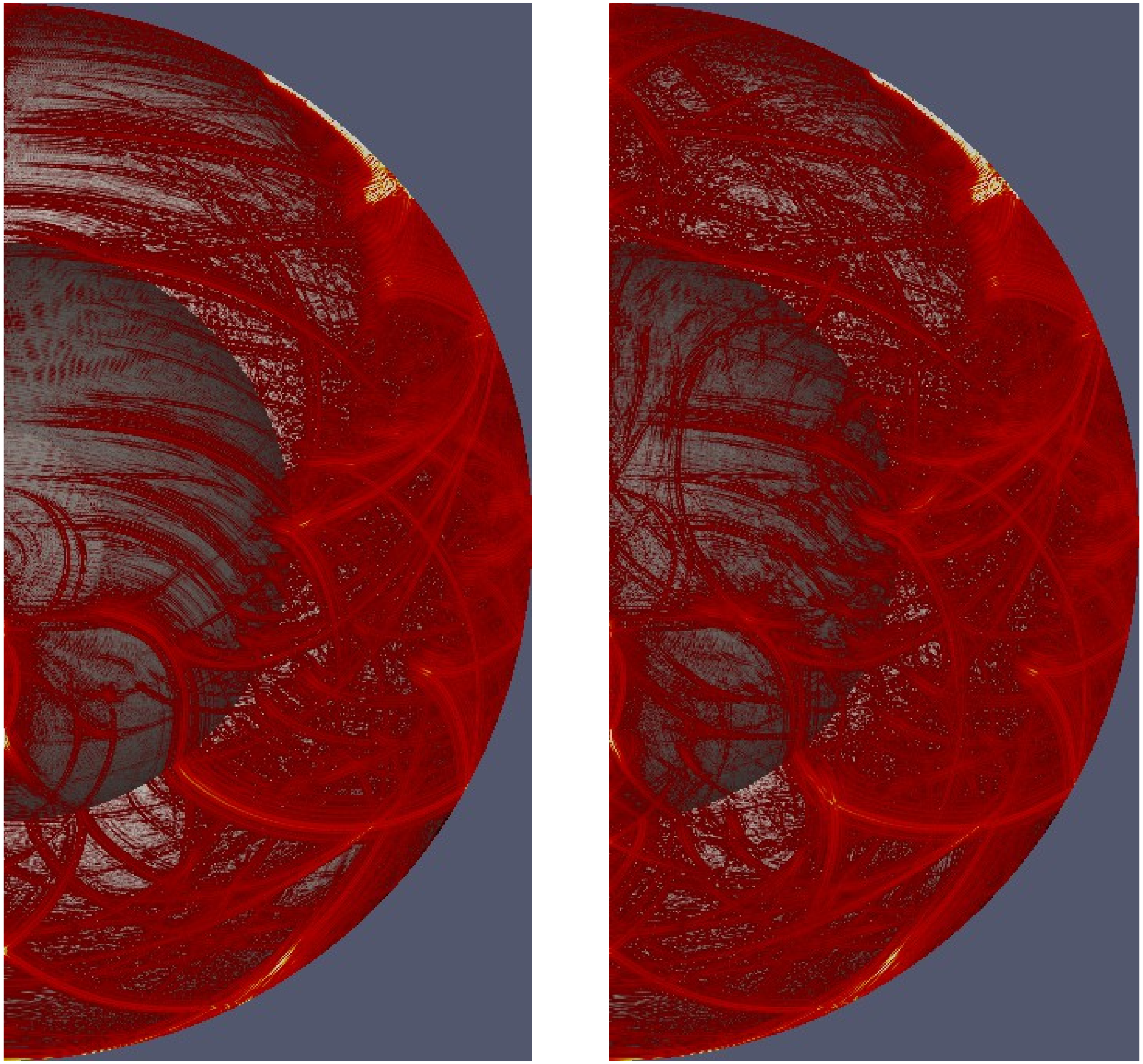

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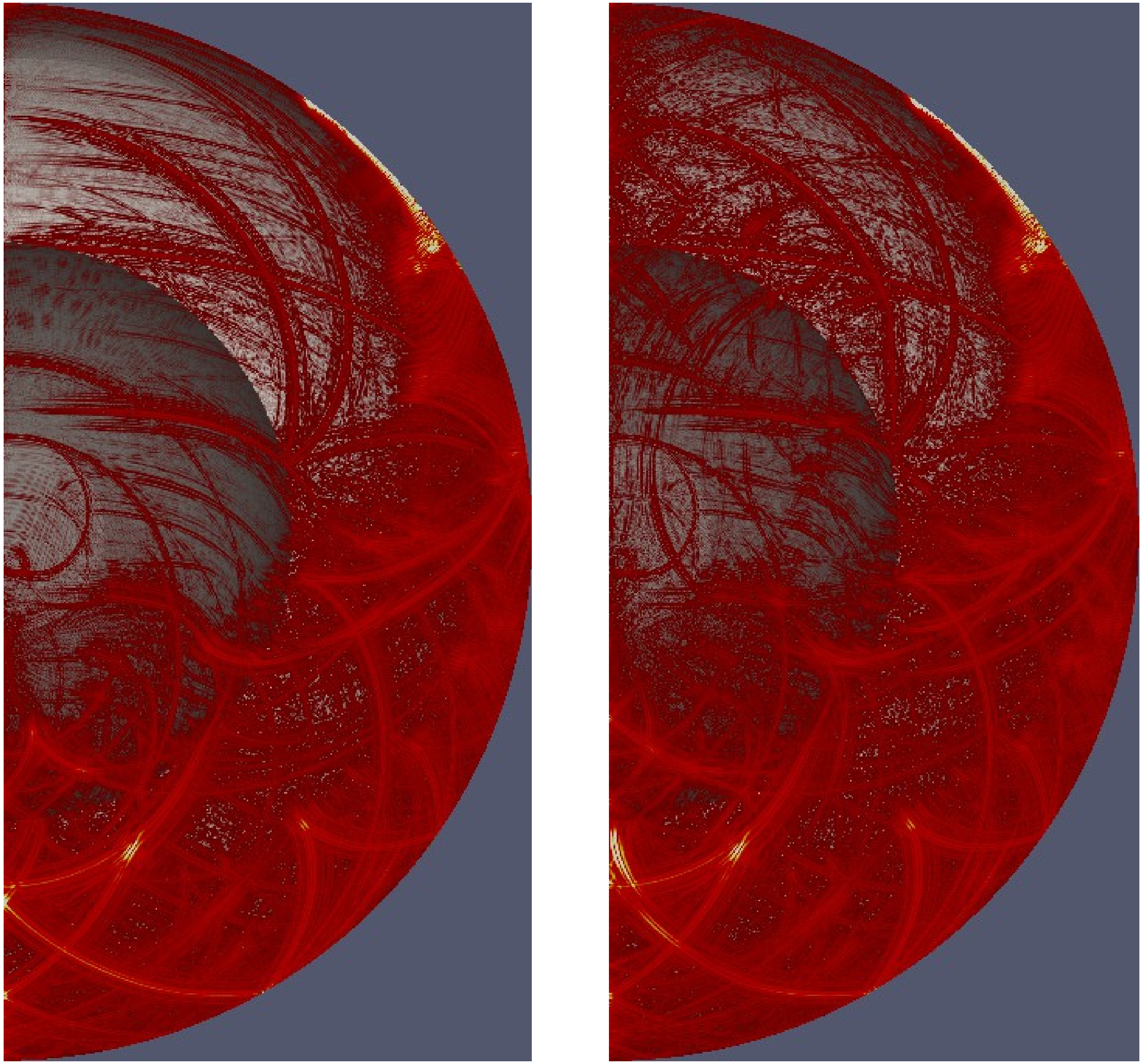
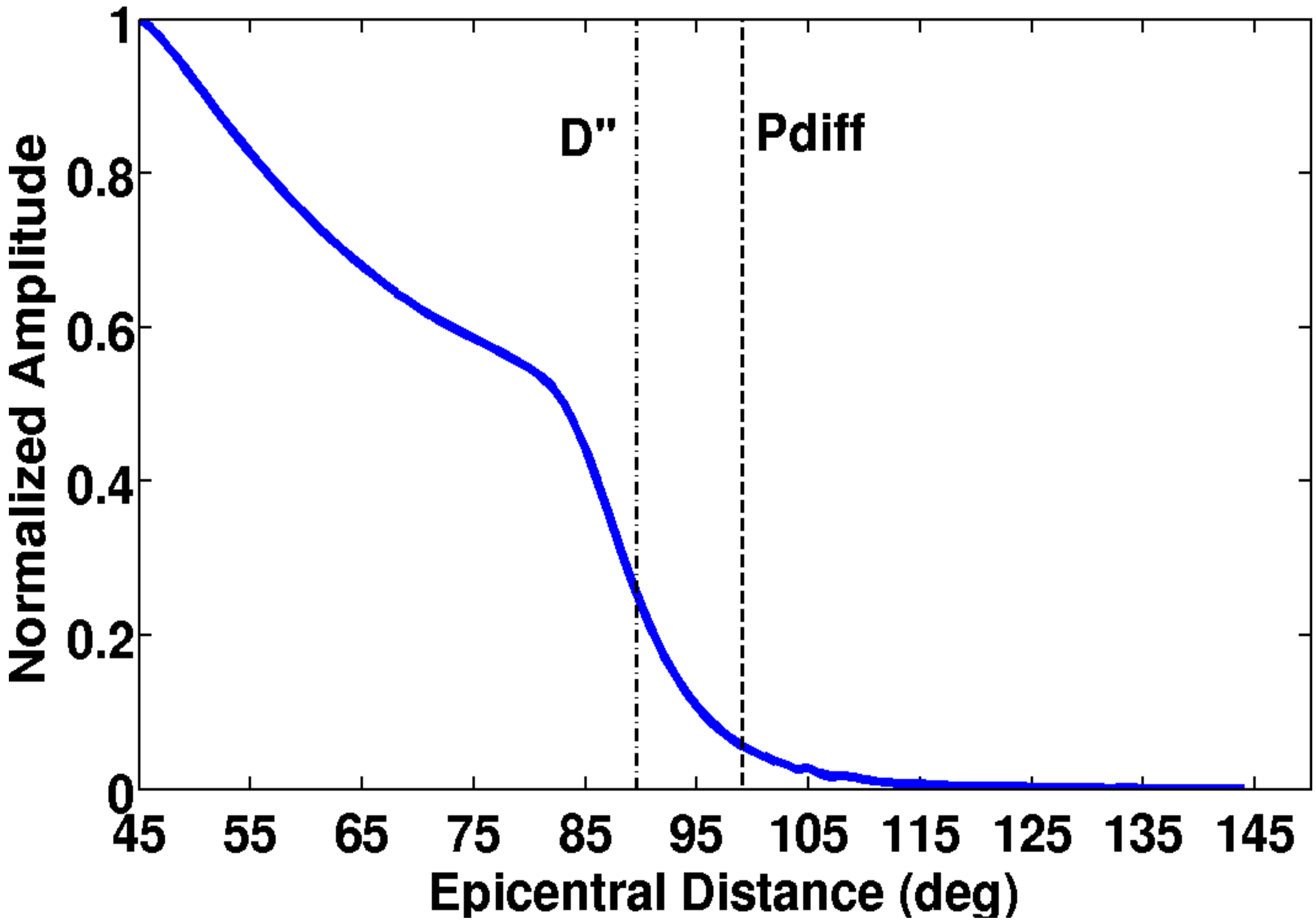


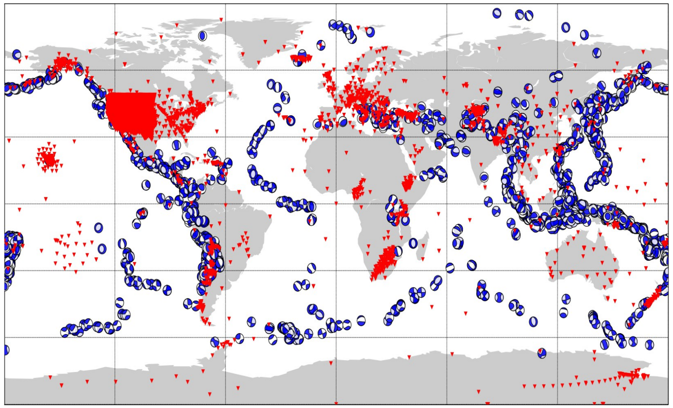
Nissen-Meyer, T., Van Driel, M., Staehler, S. C., **Hosseini**, **K.**, Hempel, S., Auer, L., Colombi, A., & Fournier, A., 2014. **Axisem: Broadband 3d seismic wavefields in axisymmetric media**, Solid Earth Discussions, 6, 265–319.

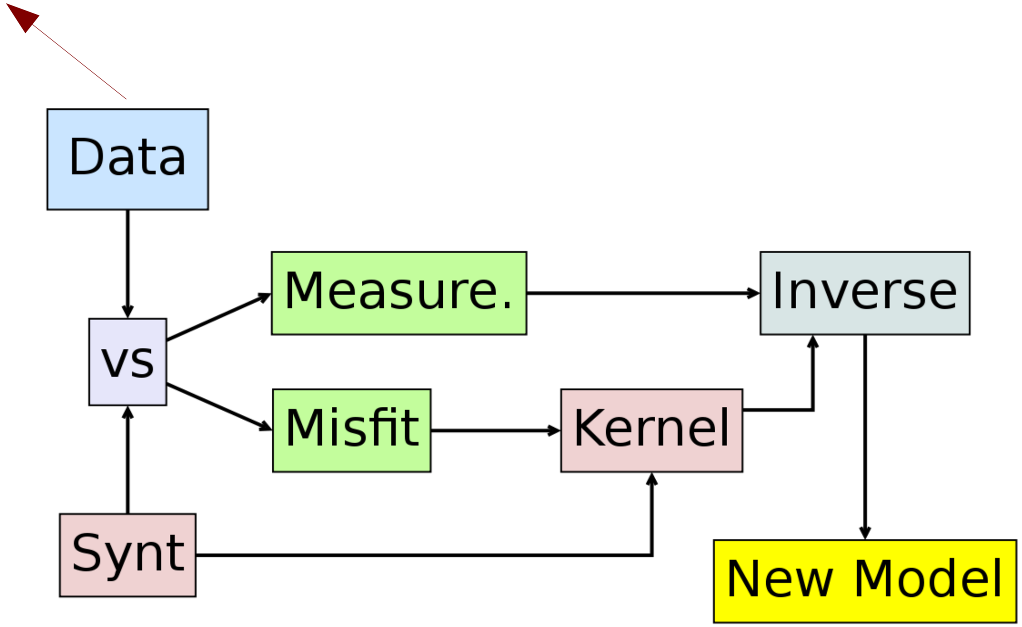
Amplitude vs Epicentral distace



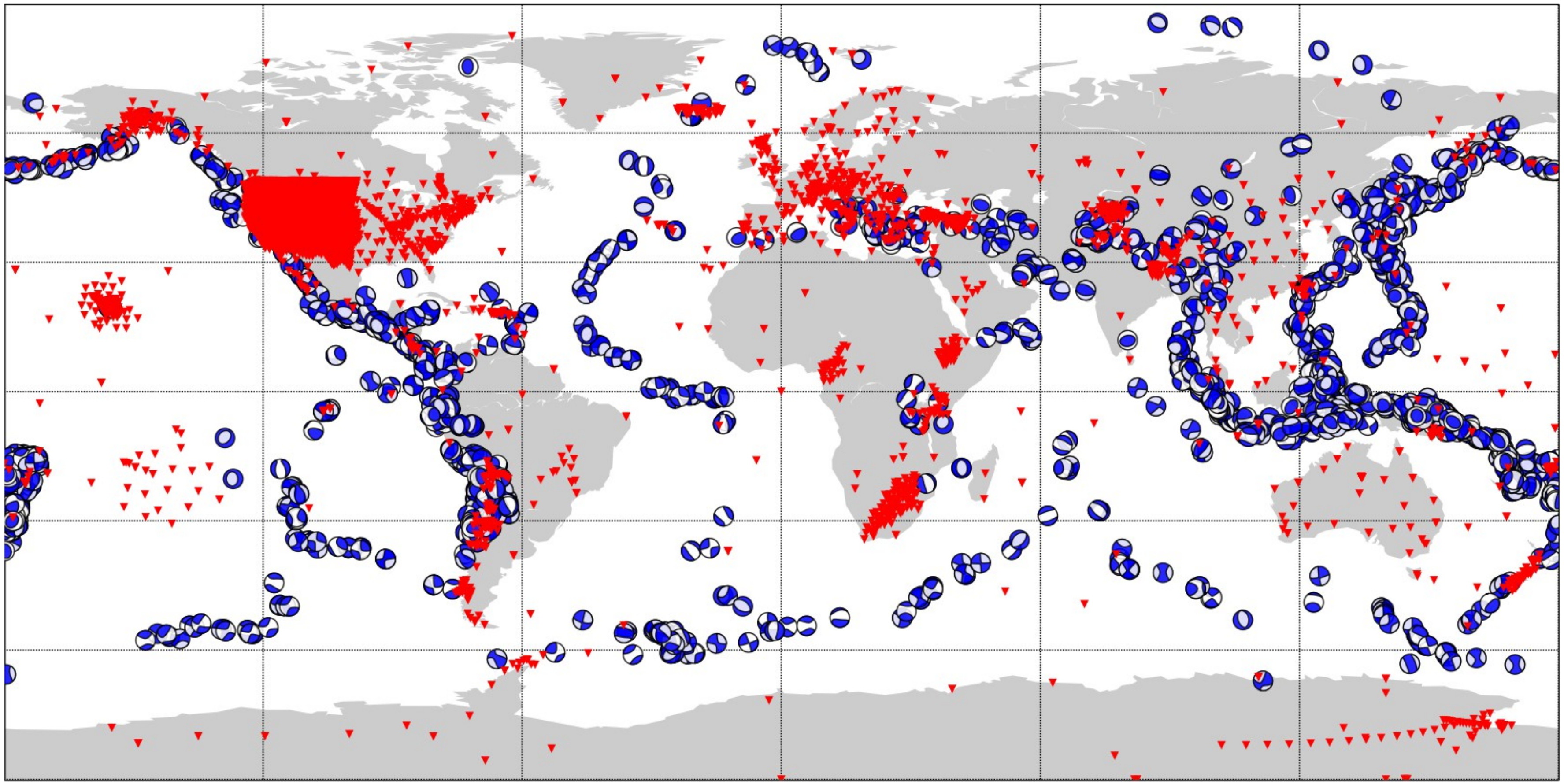
Synthetic test, IASP91
Seismograms are all filtered 5-40sec

NDLB: No Data Left Behind





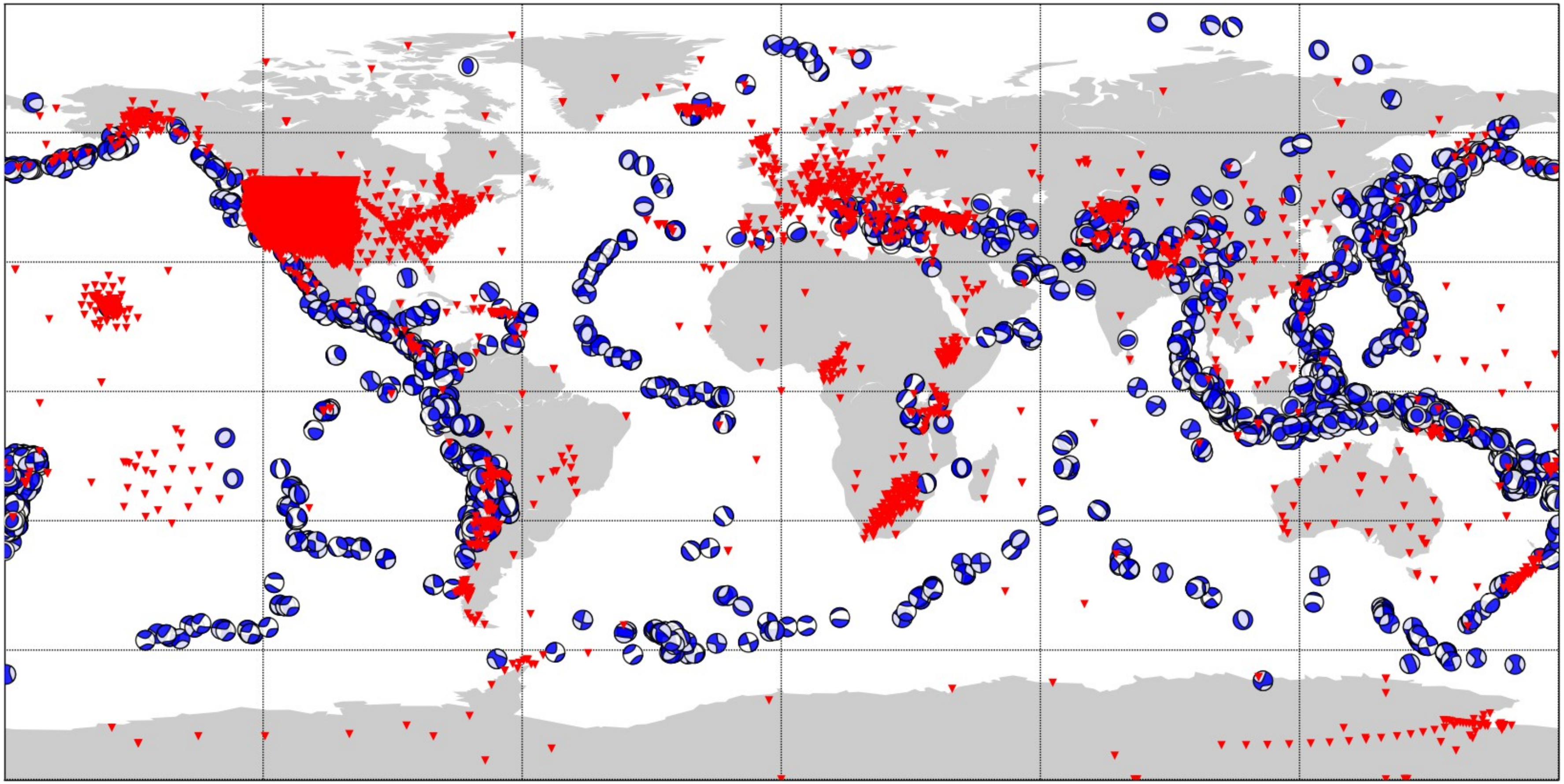
Data Archive for Pdiff



~2000 events

~640,000 P and ~580,000 Pdiff 'potential' source-receiver pairs

Data Archive for Pdiff



obspyDMT
Parallel retrieving, processing and management of massive seismological datasets.

Scheingraber, C., **Hosseini, K.**, Barsch, R., & Sigloch, K., 2013. **ObsPyLoad: A tool for fully automated retrieval of seismological waveform data**, Seismological Research Letters, 84(3), 525–531.

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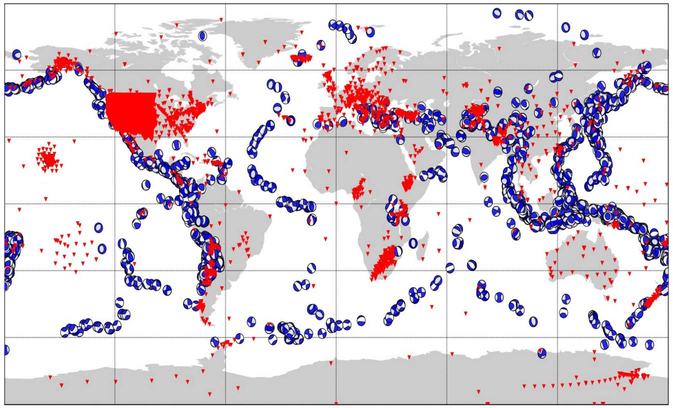
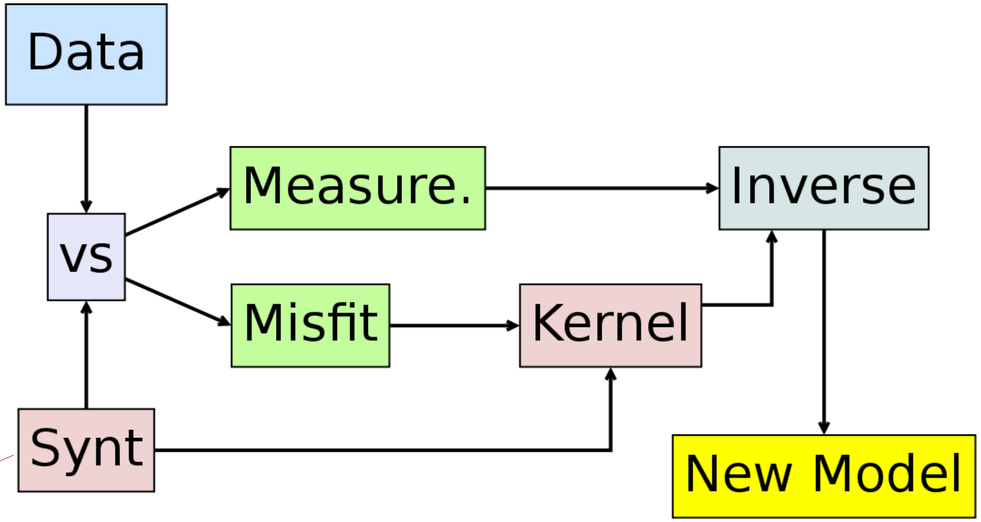
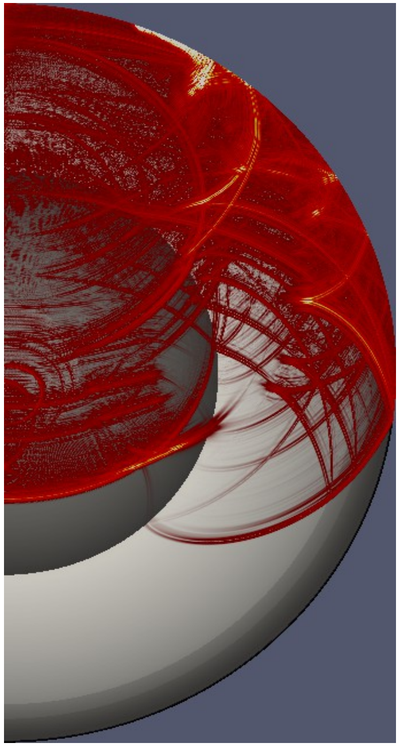
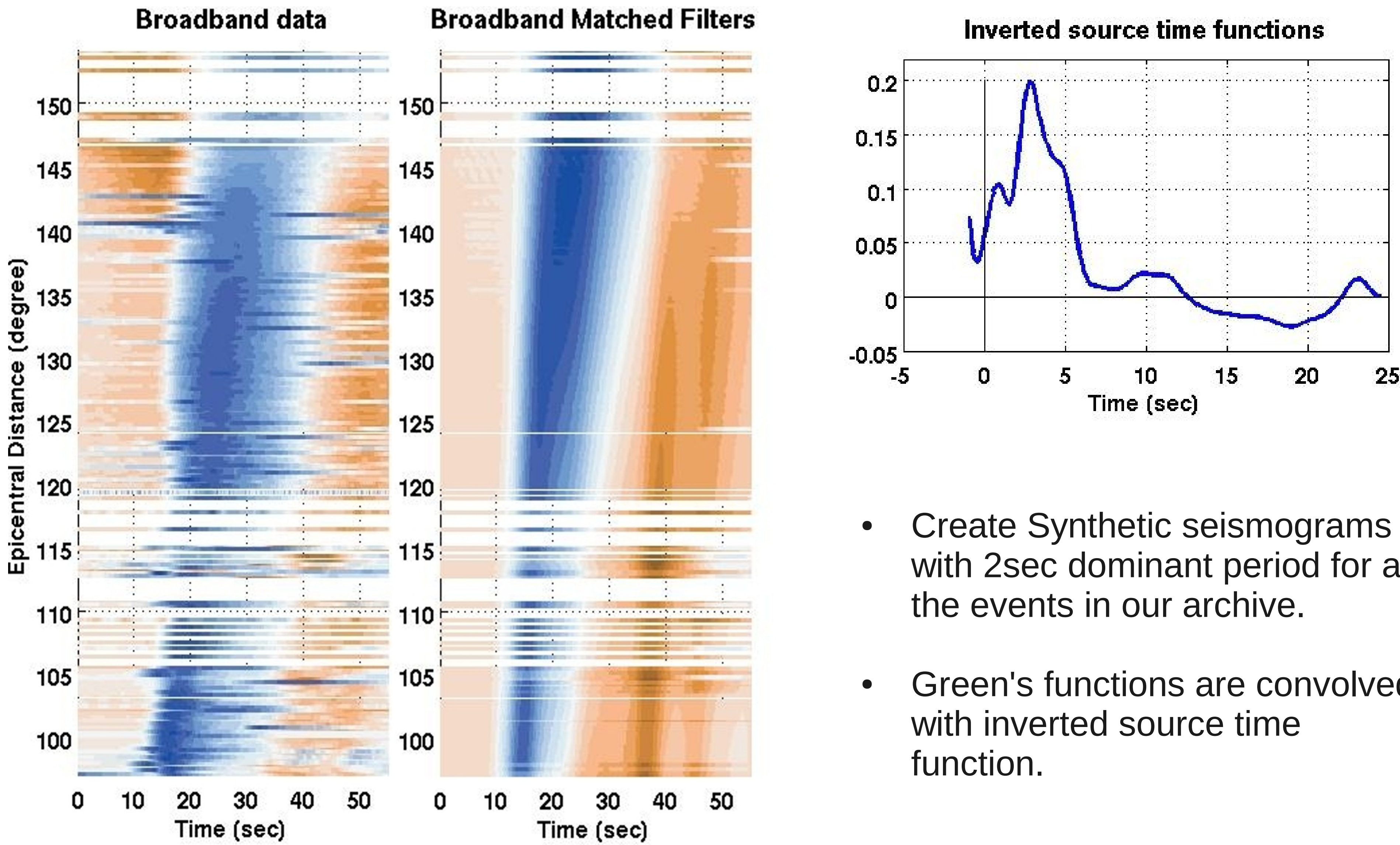




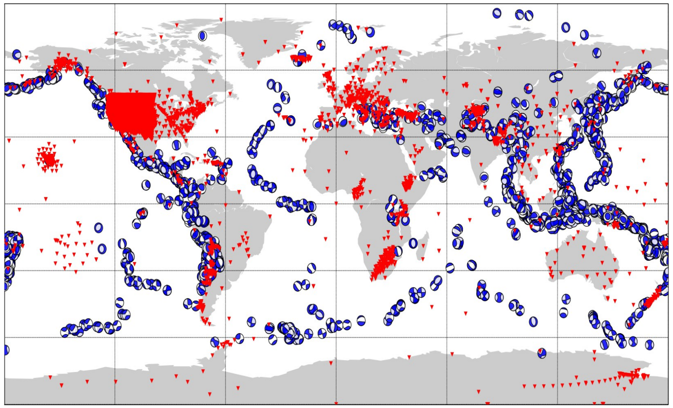


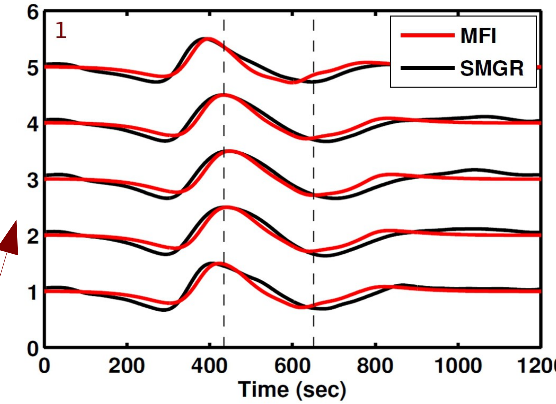
Synthetic Archive for Pdiff

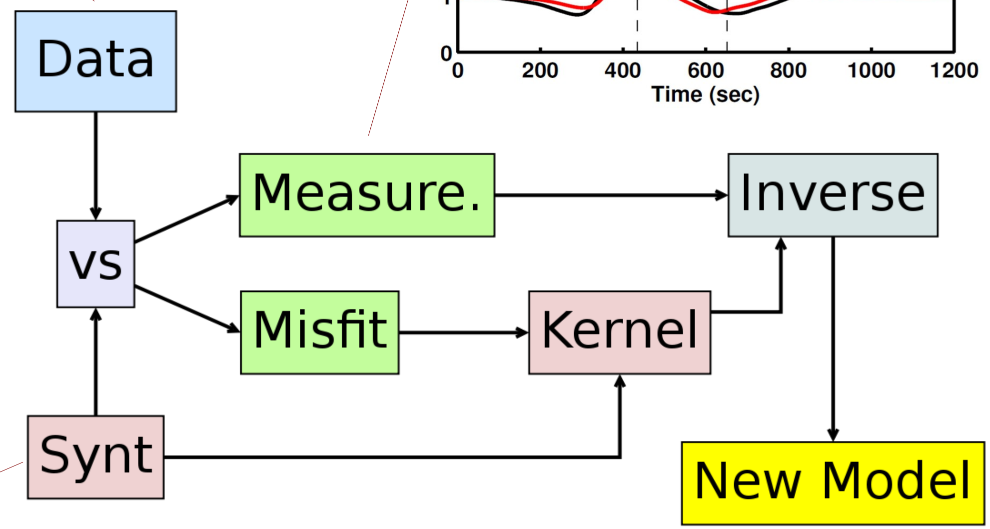


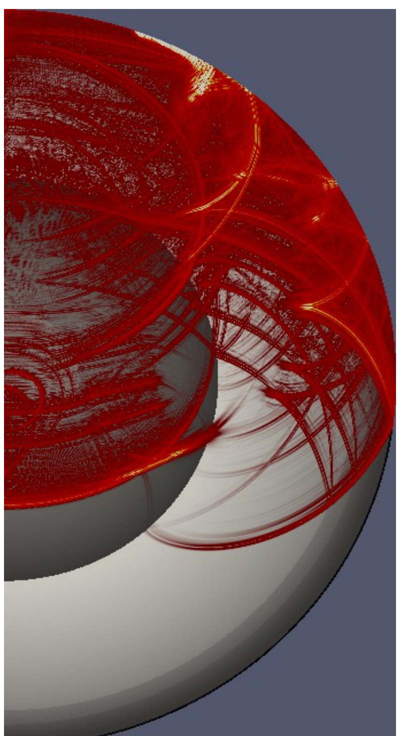
- Create Synthetic seismograms with 2sec dominant period for all the events in our archive.
- Green's functions are convolved with inverted source time function.

NDLB: No Data Left Behind

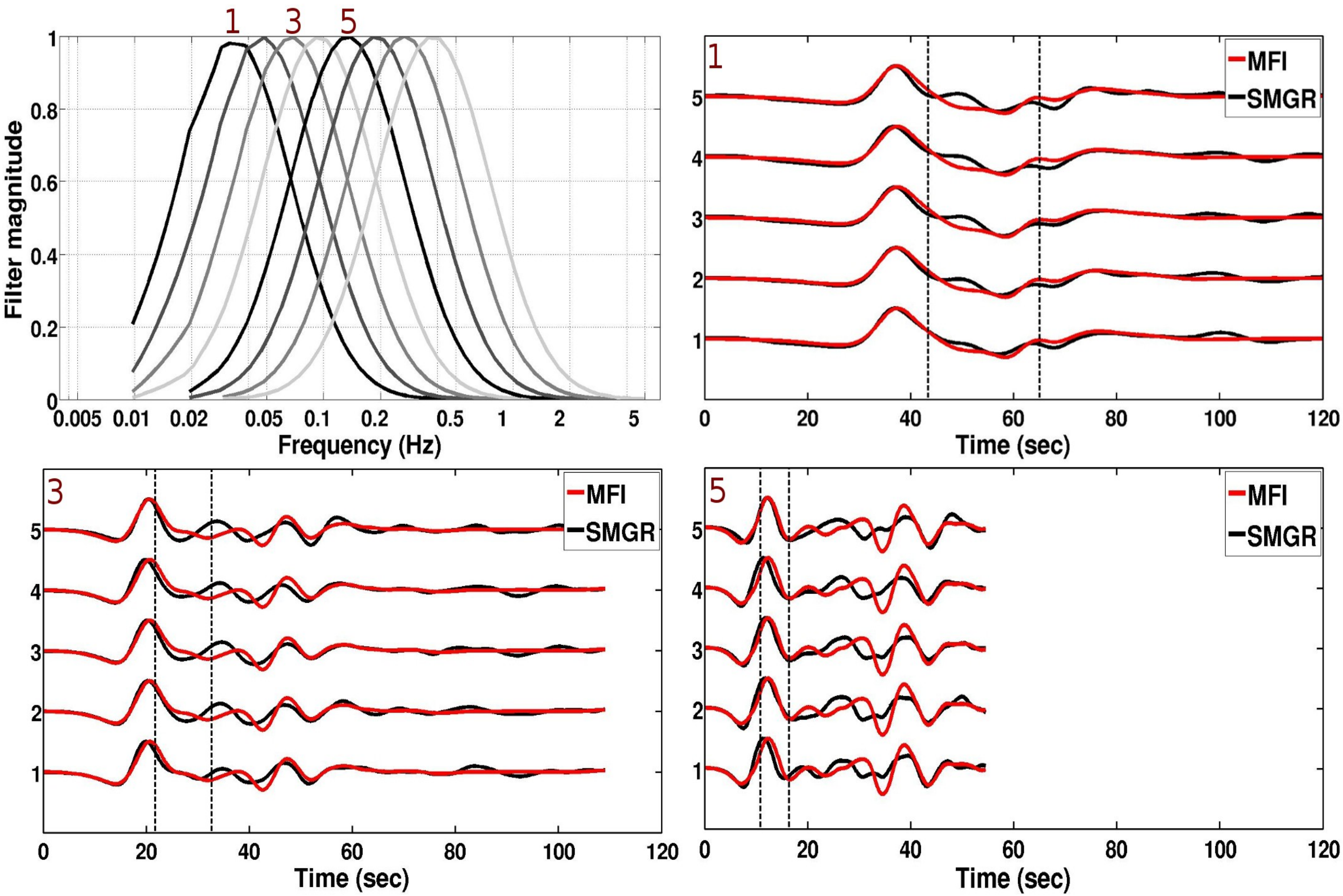








Finite Frequency Measurements



P and Pdiff travel-time measurements

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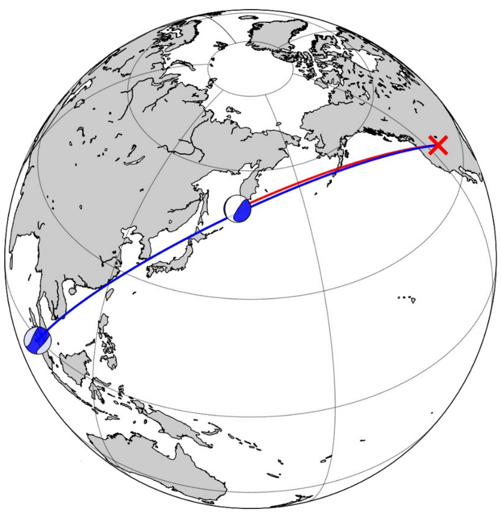
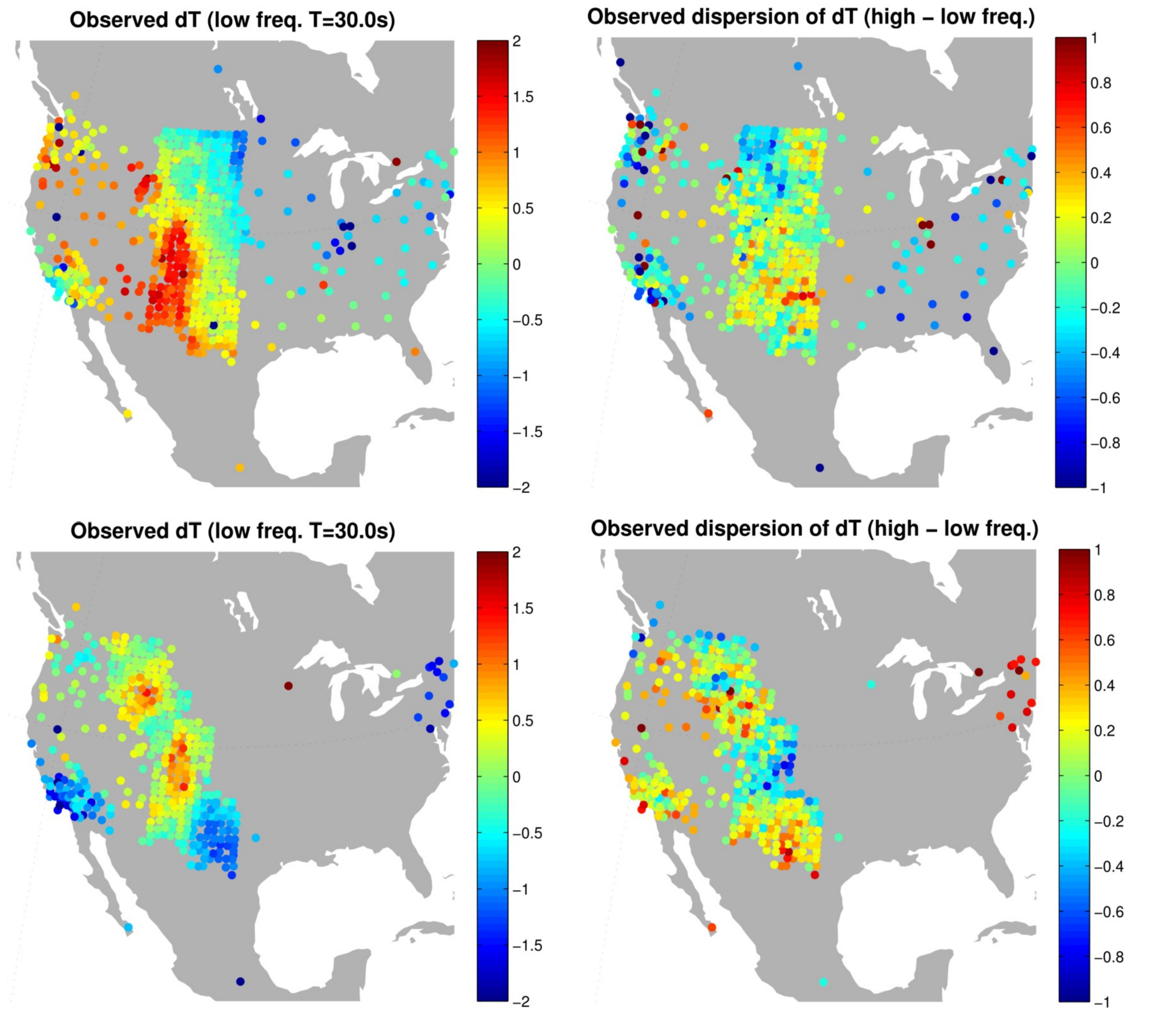
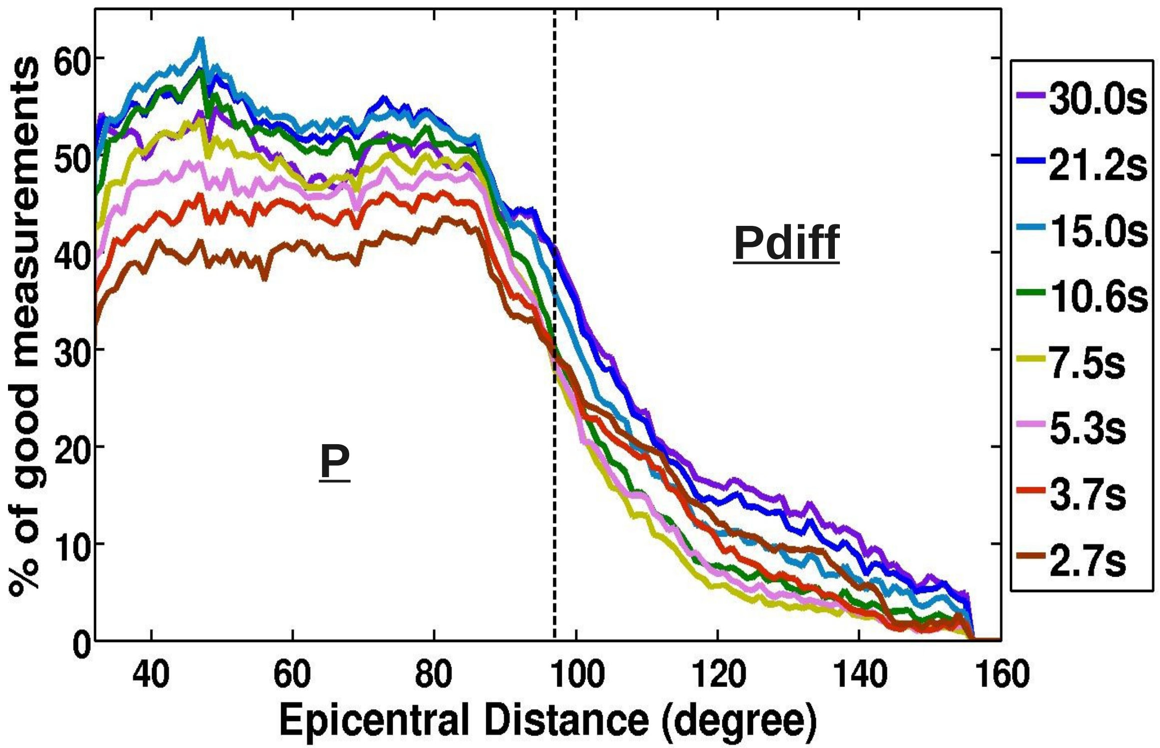


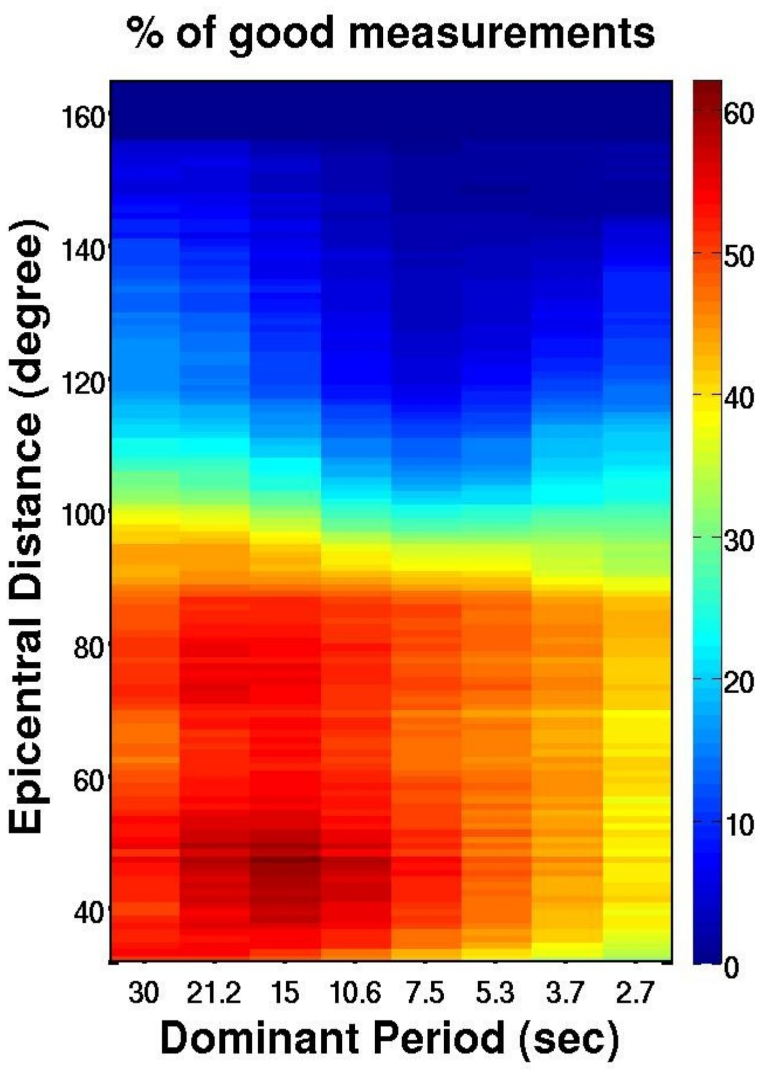
Pdiff

P



Statistical analysis (epicentral distance)

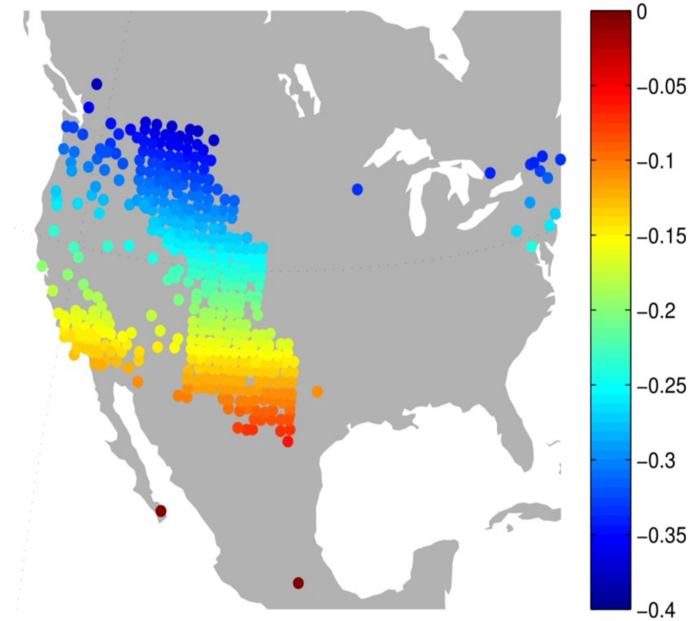


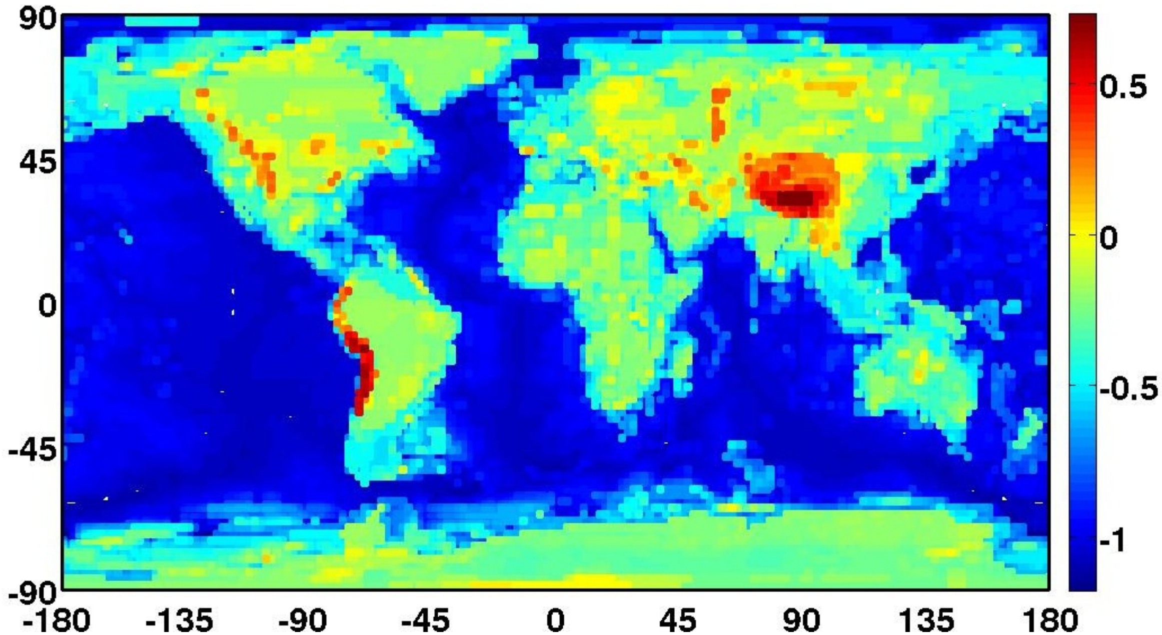


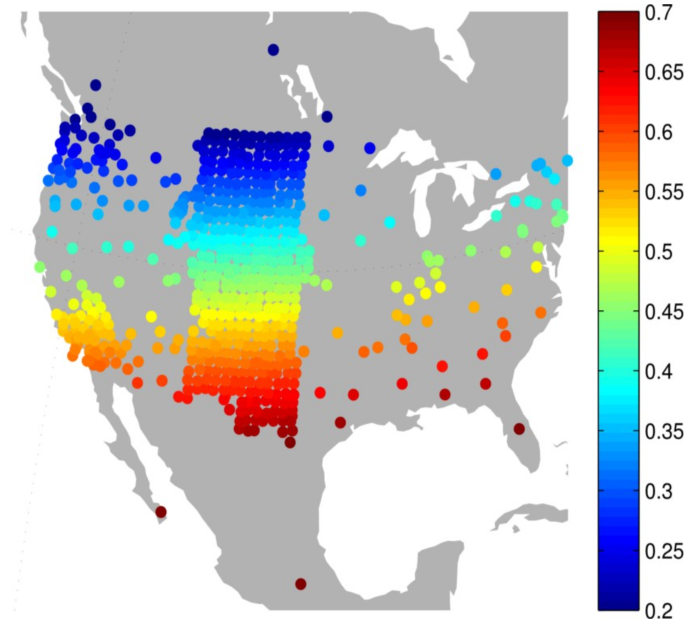
Common Corrections

We have used a spherically symmetric Earth model, so we need some corrections:

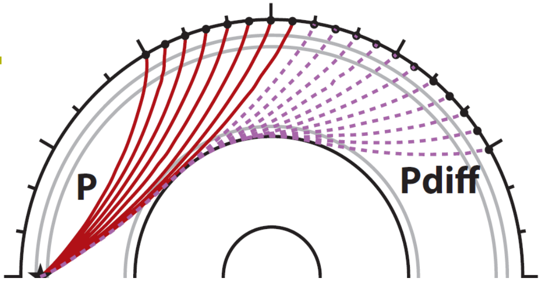
1. Ellipticity
2. Topography
3. Crustal time

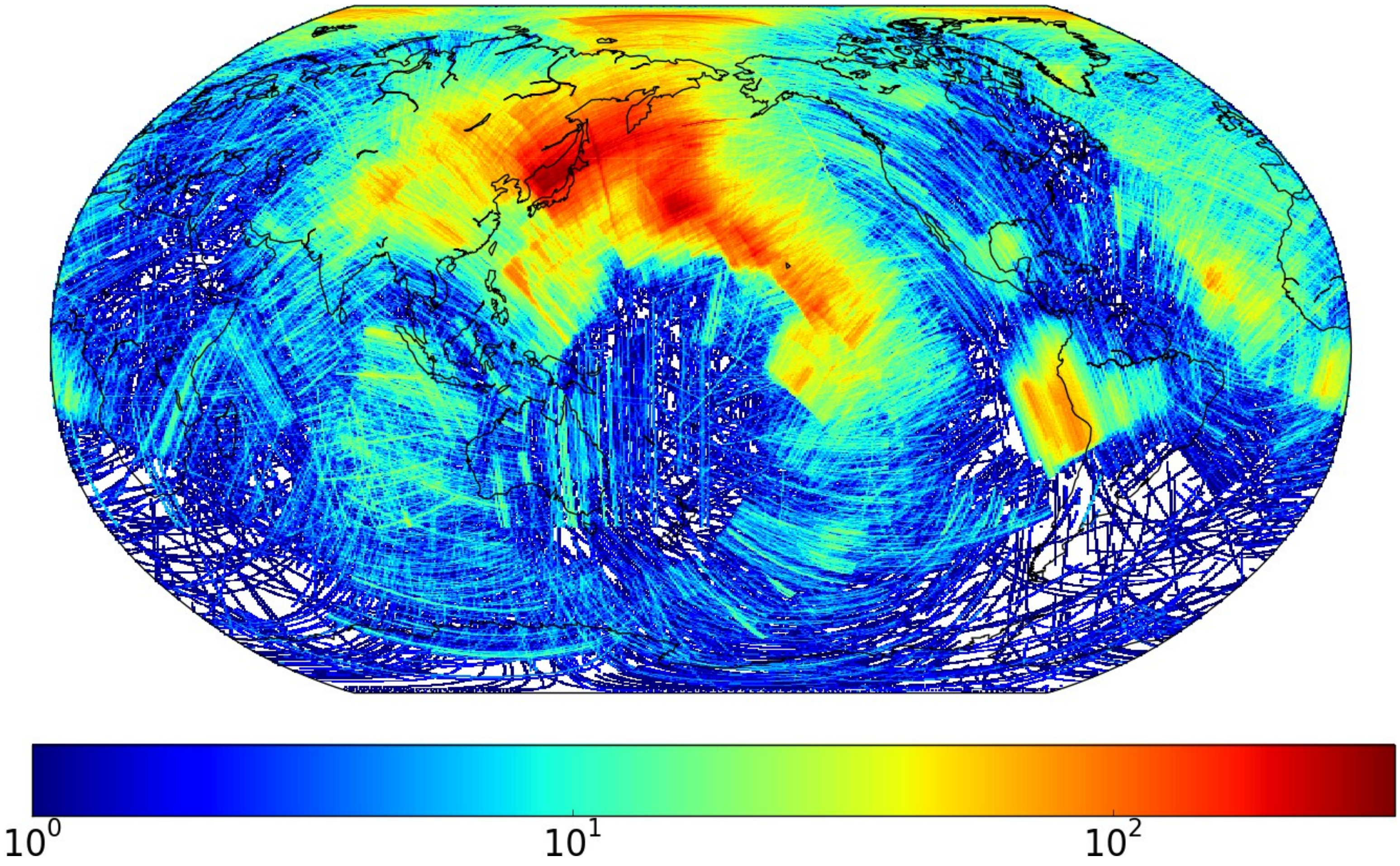






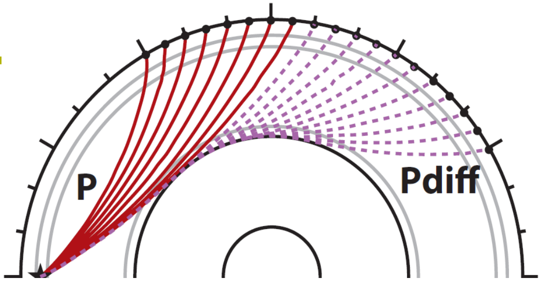
Ray coverage

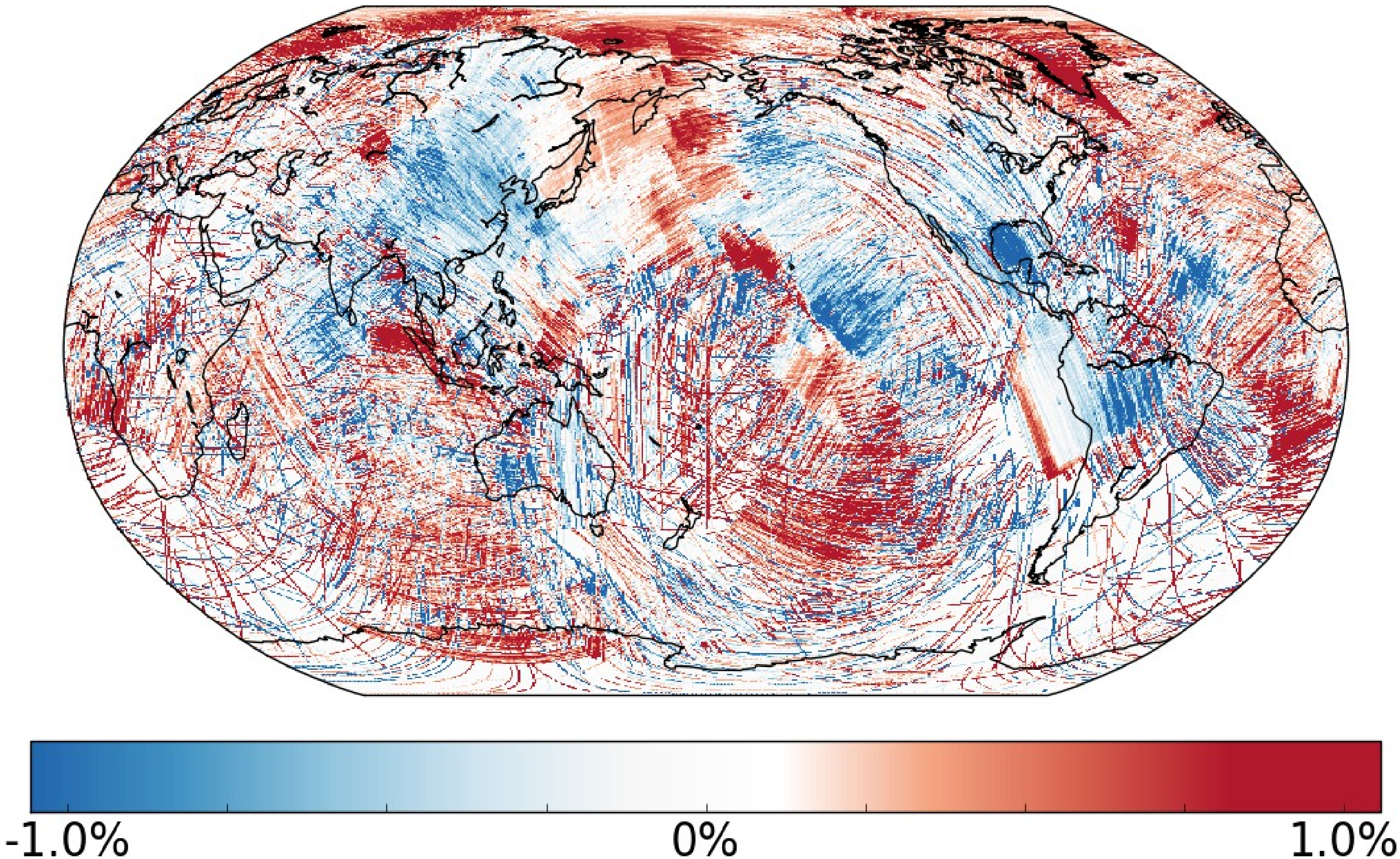




Dominant period: 30sec
137,887 source-receiver pairs
Maximum value: 330

Travel Time Anomaly





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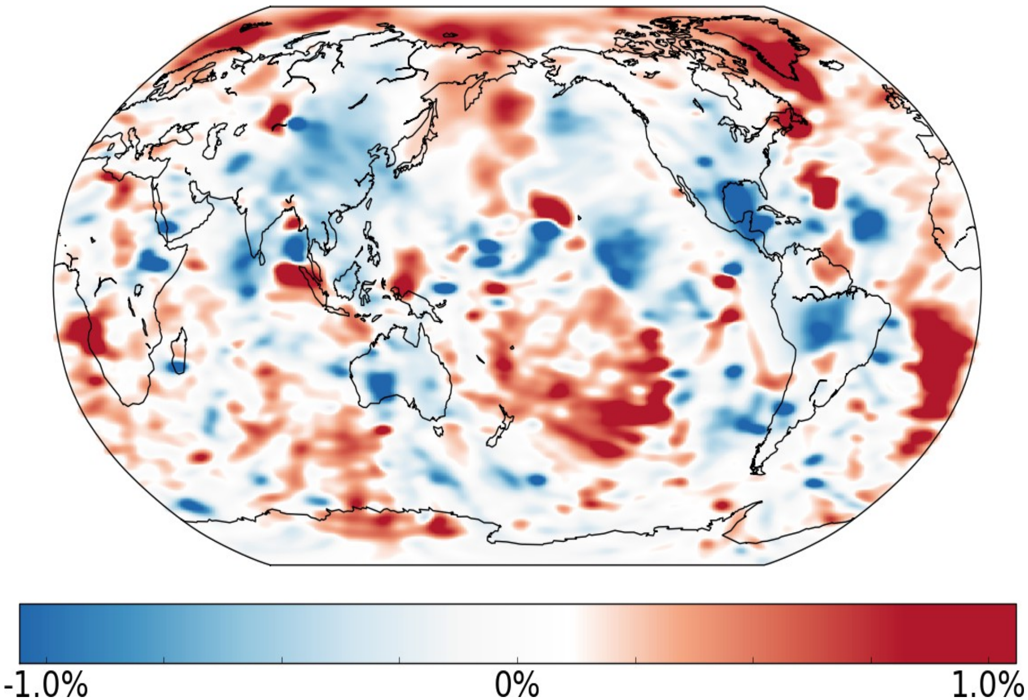
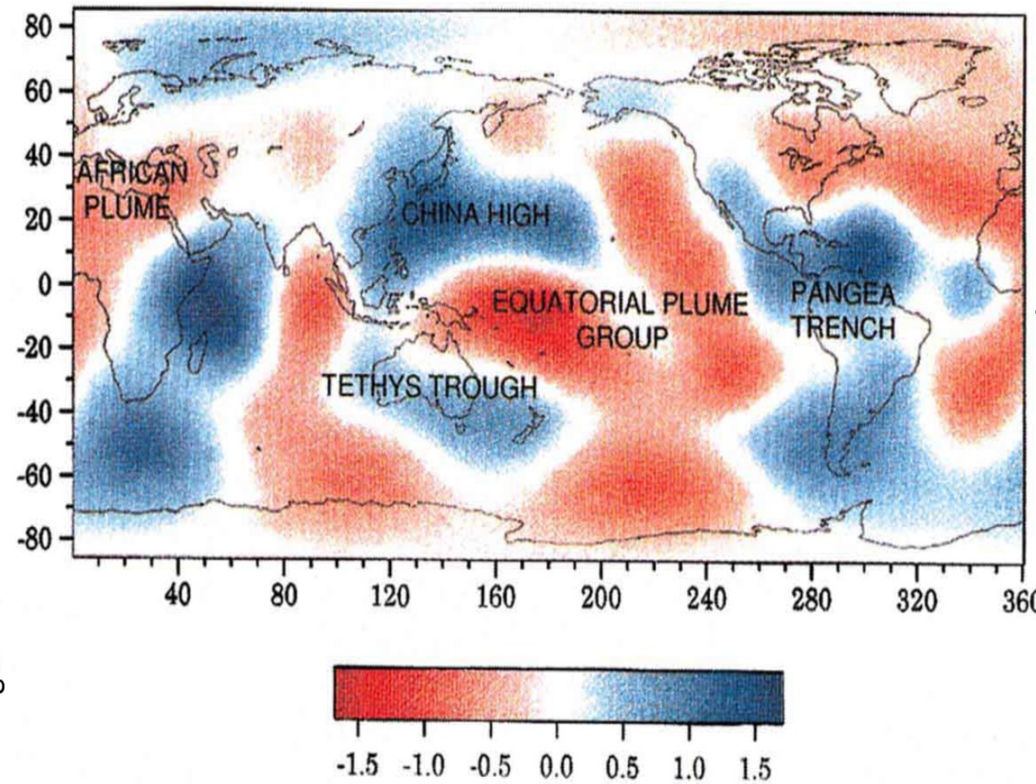


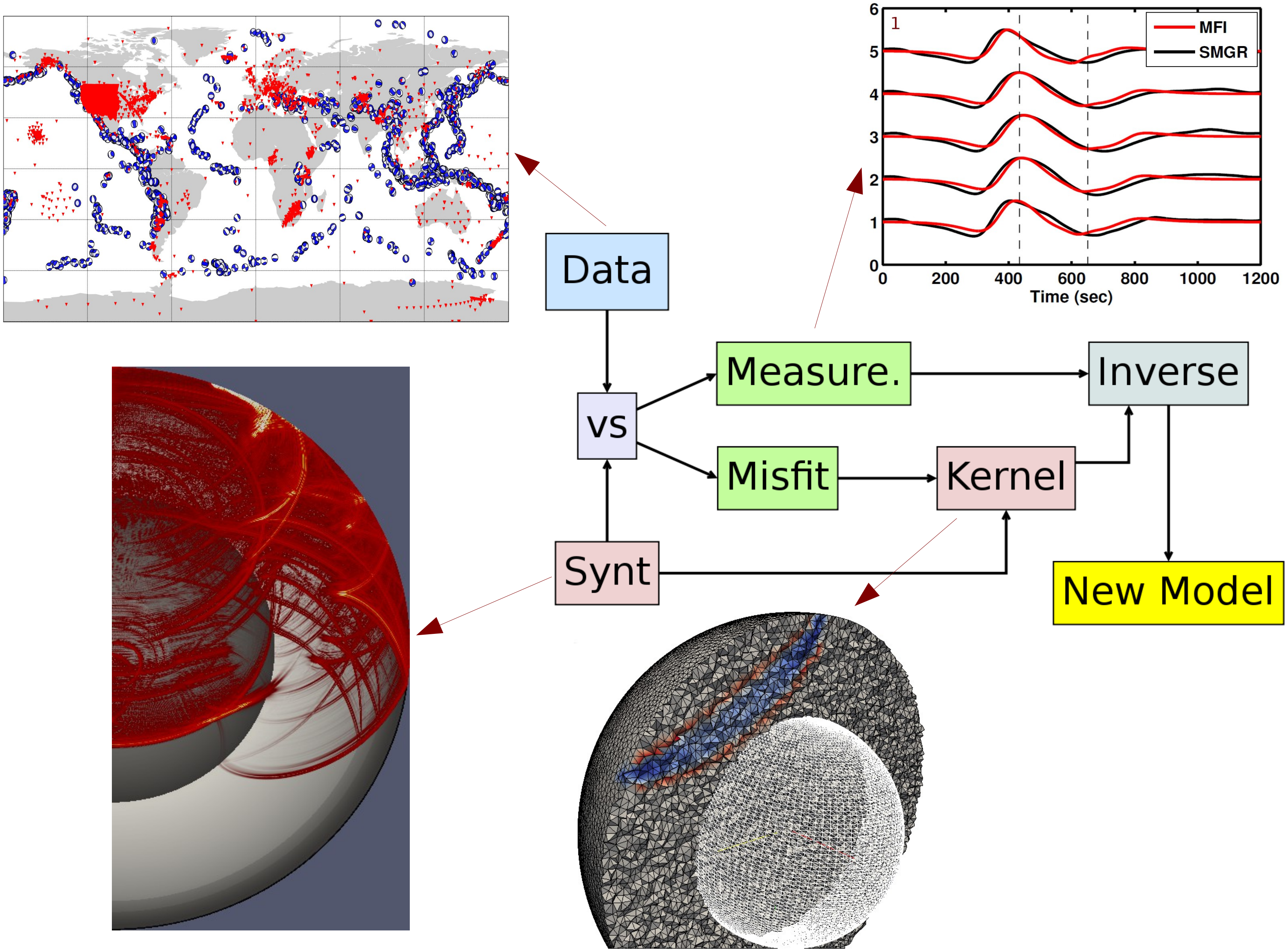


Wysession, 1996

Travel-Time anomaly map

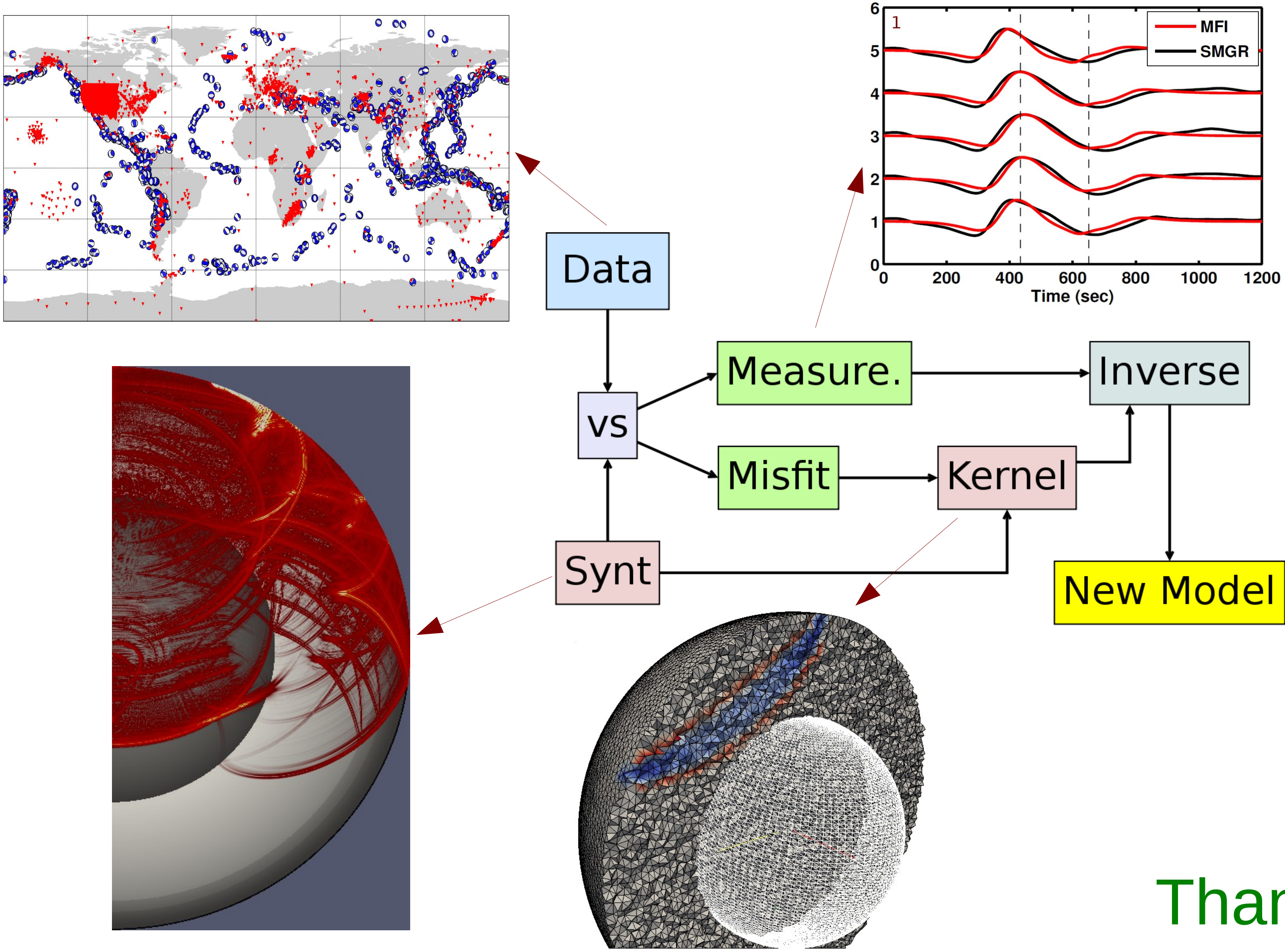
Tomography model (seismic velocity)

Conclusion

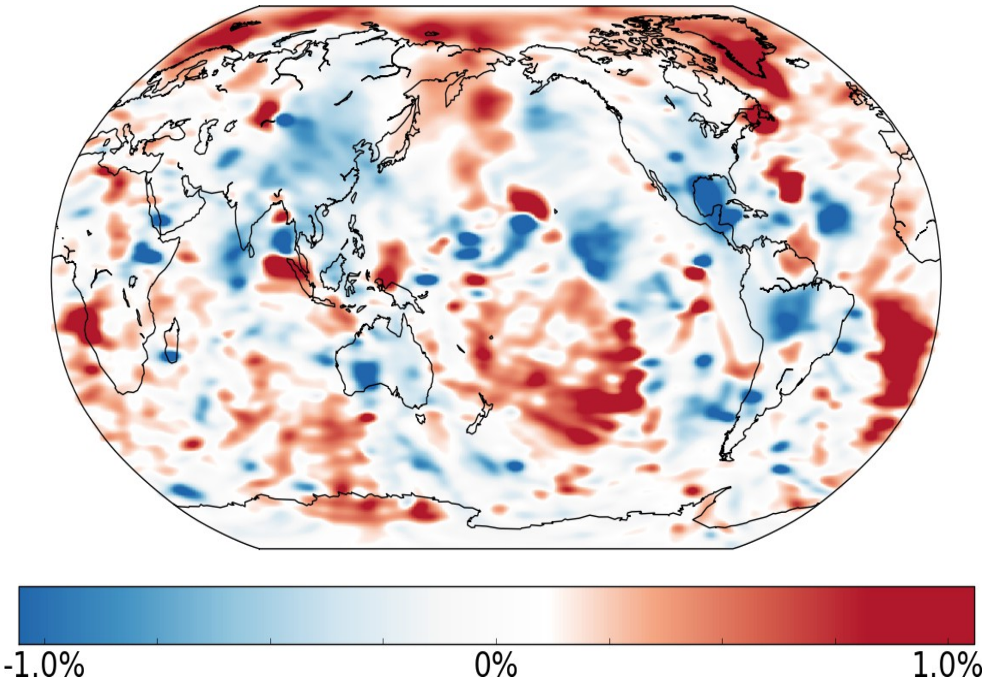


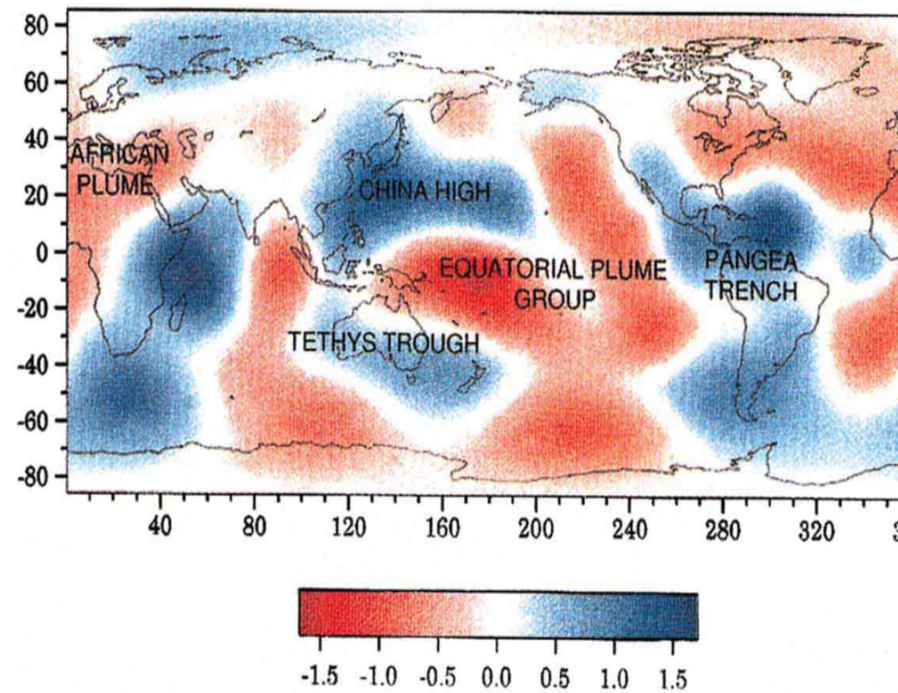
1
MFI
SMGR
0
1
2
3
4
5
6
0
200
400
600
800
1000
1200
Time (sec)
Data
vs
Measure.
Inverse
Misfit
Kernel
Synt
New Model

Conclusion

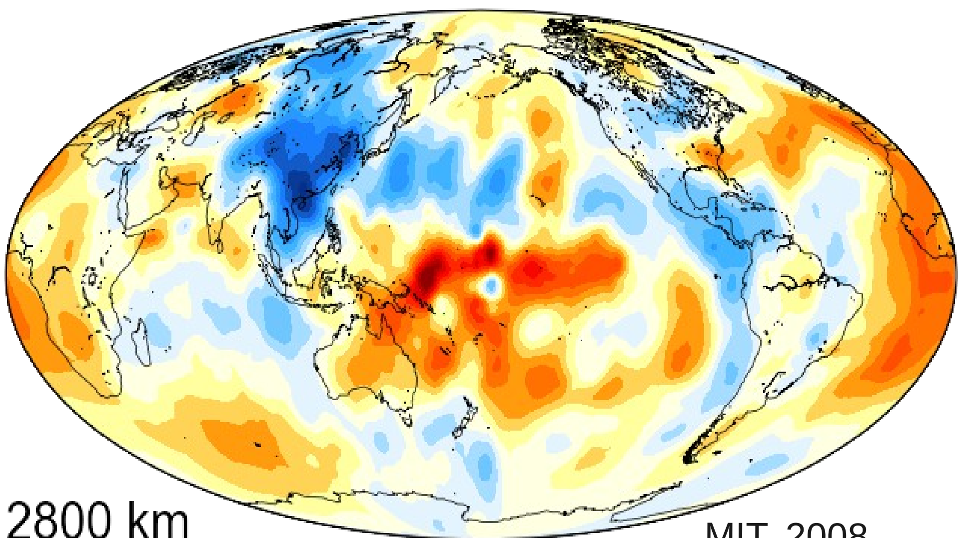


Thank You!

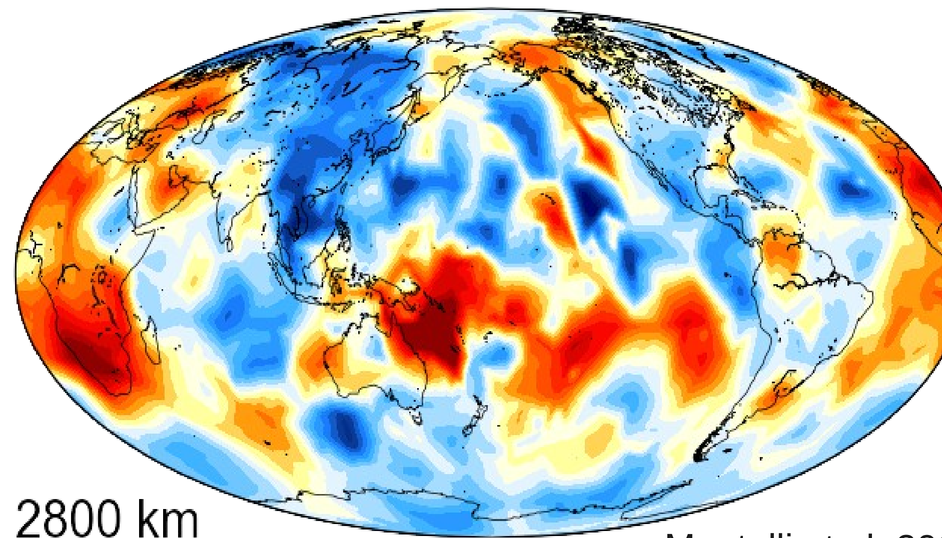




Wysession, 1996

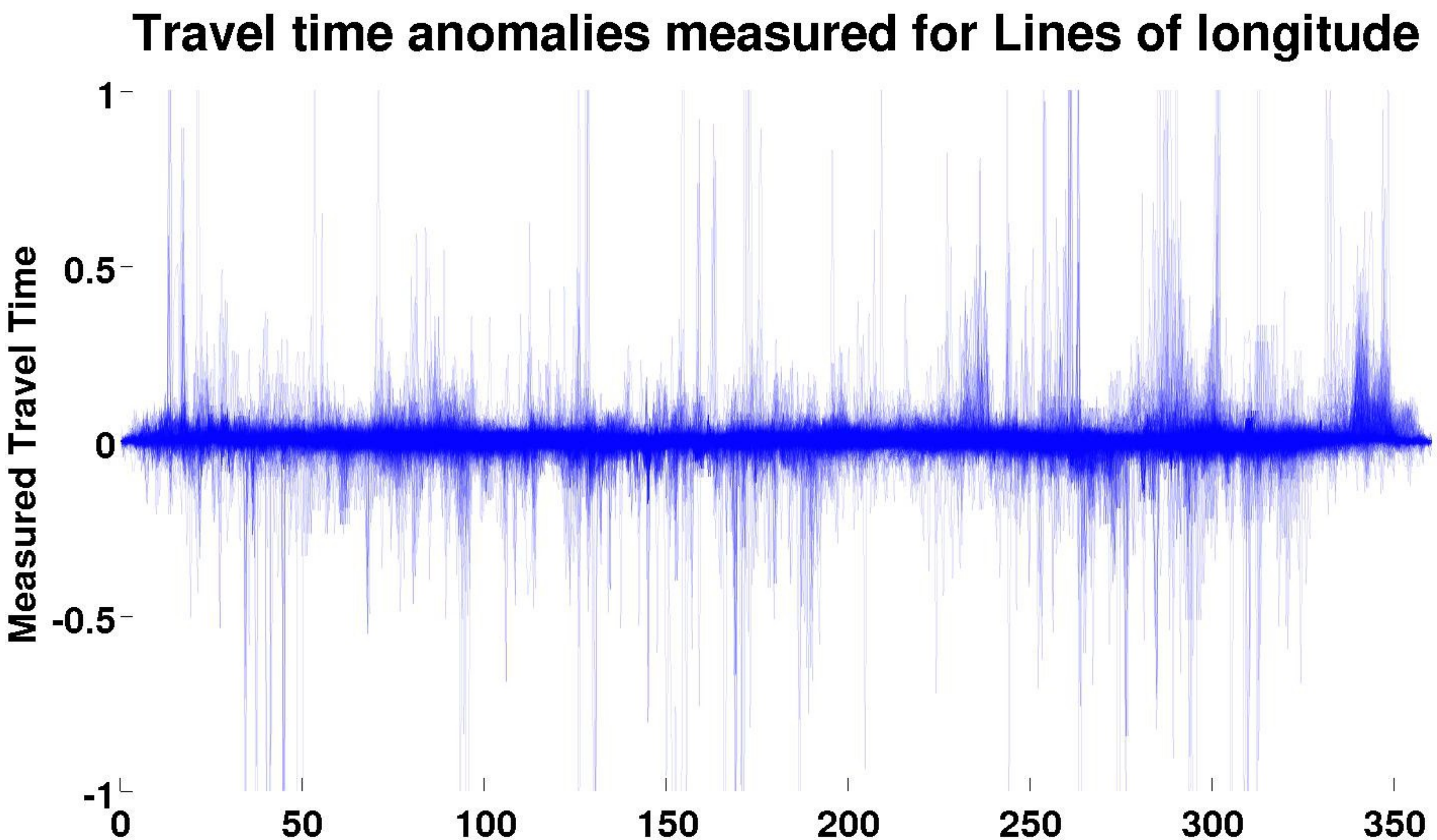


MIT, 2008



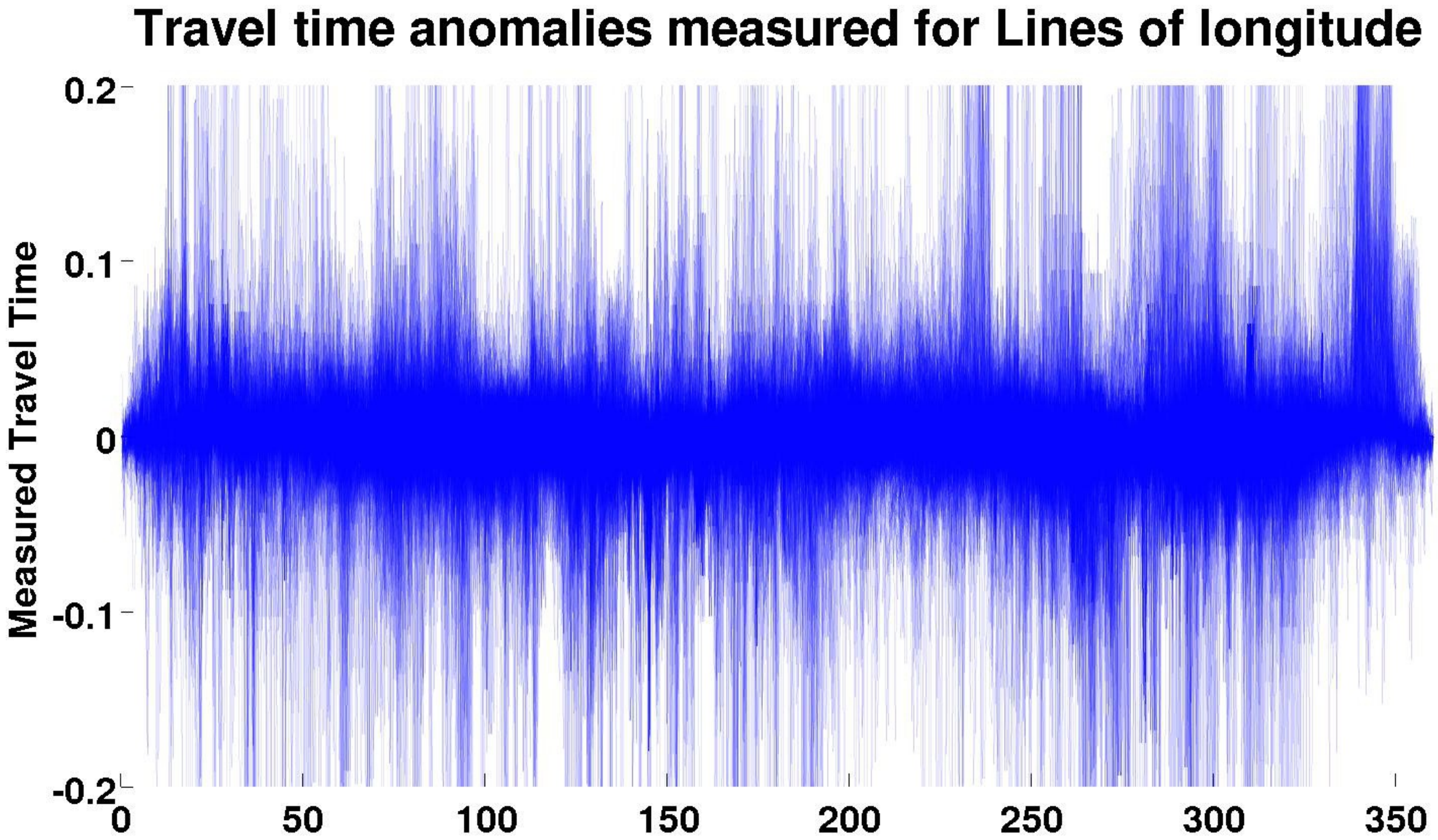
Montelli et al, 2005

Travel time anomalies after projection on CMB



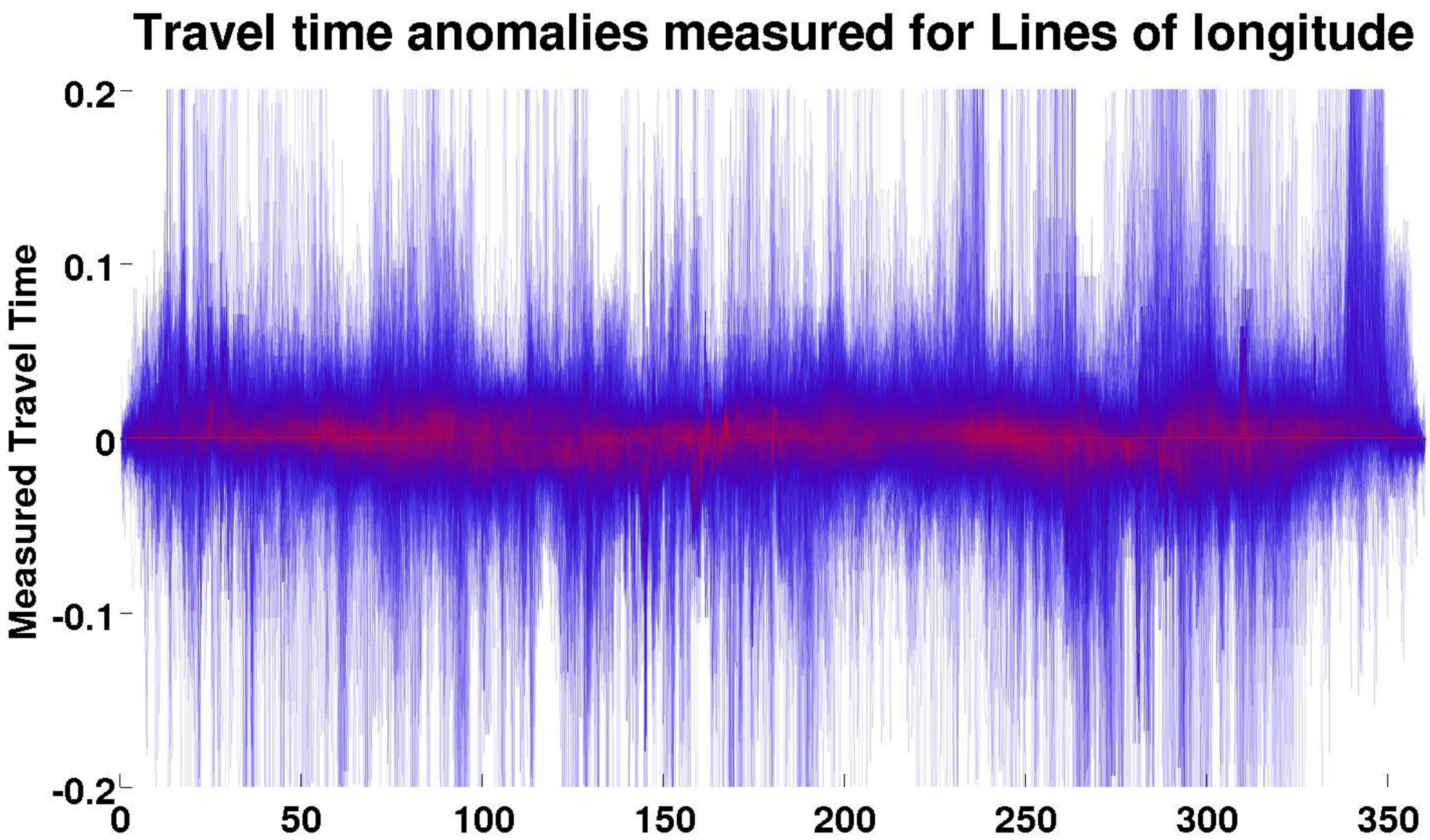
39.4% Compare to the defined reference time on the grid

Travel time anomalies after projection on CMB



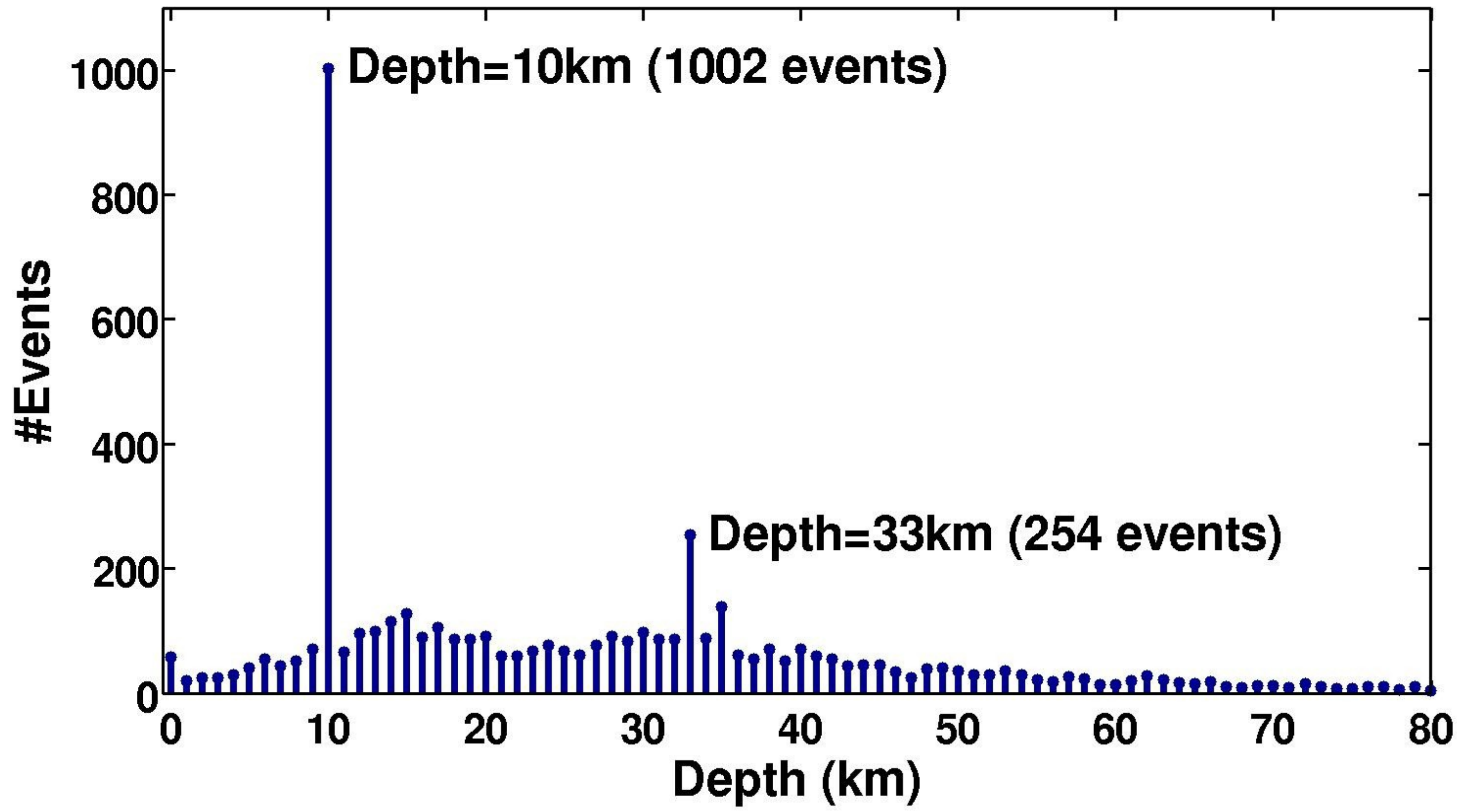
7.9% Compare to the defined reference time on the grid

Travel time anomalies after projection on CMB



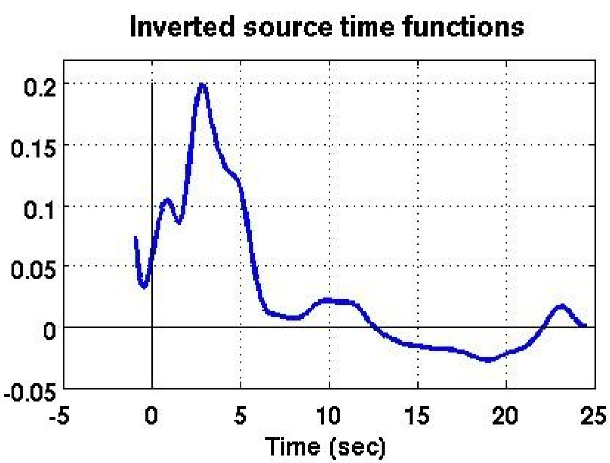
7.9% Compare to the defined reference time on the grid

Distribution of Events as a function of depth



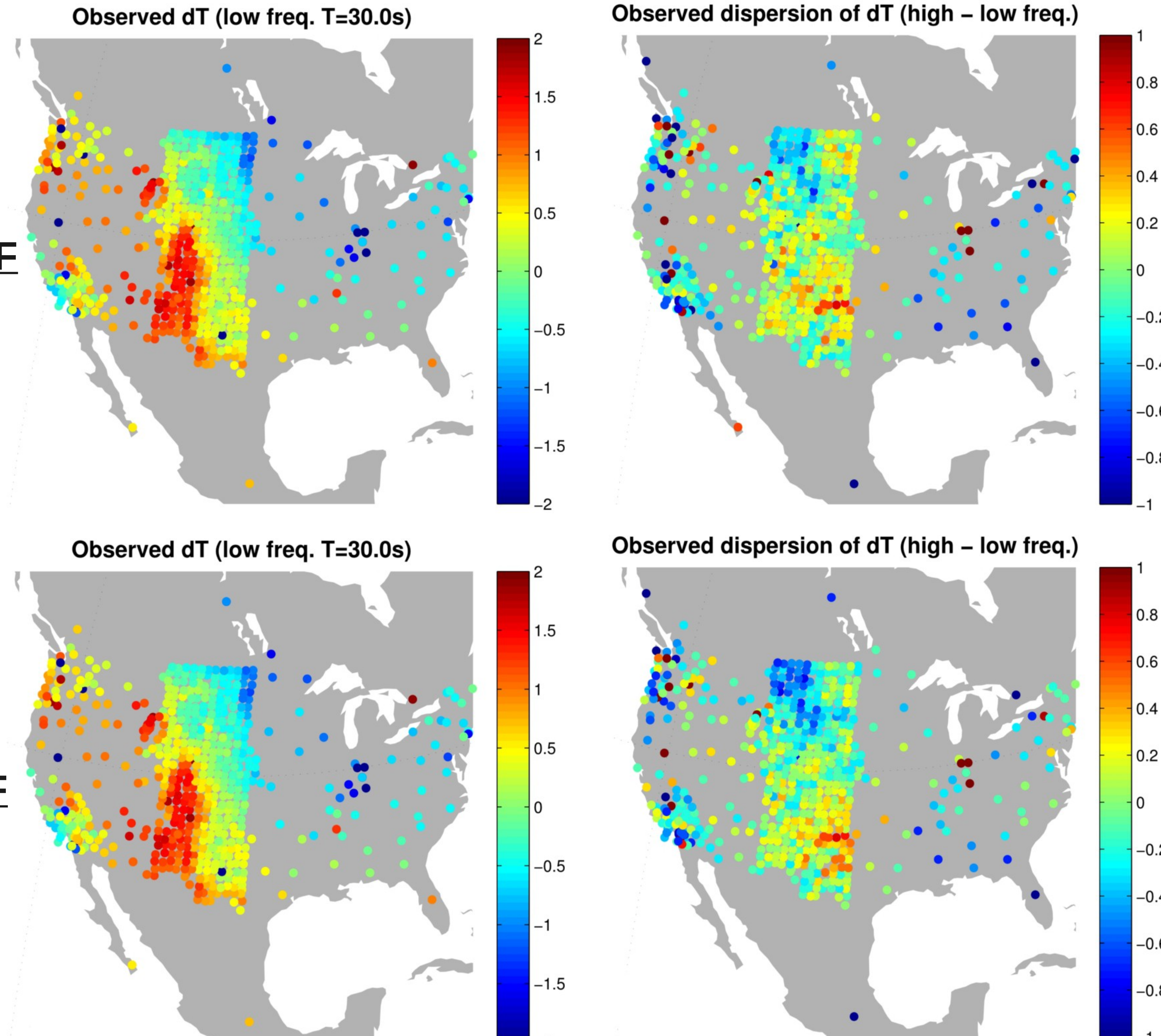
All events with magnitude more than 5.5 occurred in 2000-2012
Event information is retrieved from IRIS
10km ---> 16% and 33km ---> 4% of total amount

Pdiff travel-time measurements (w/wo STF)

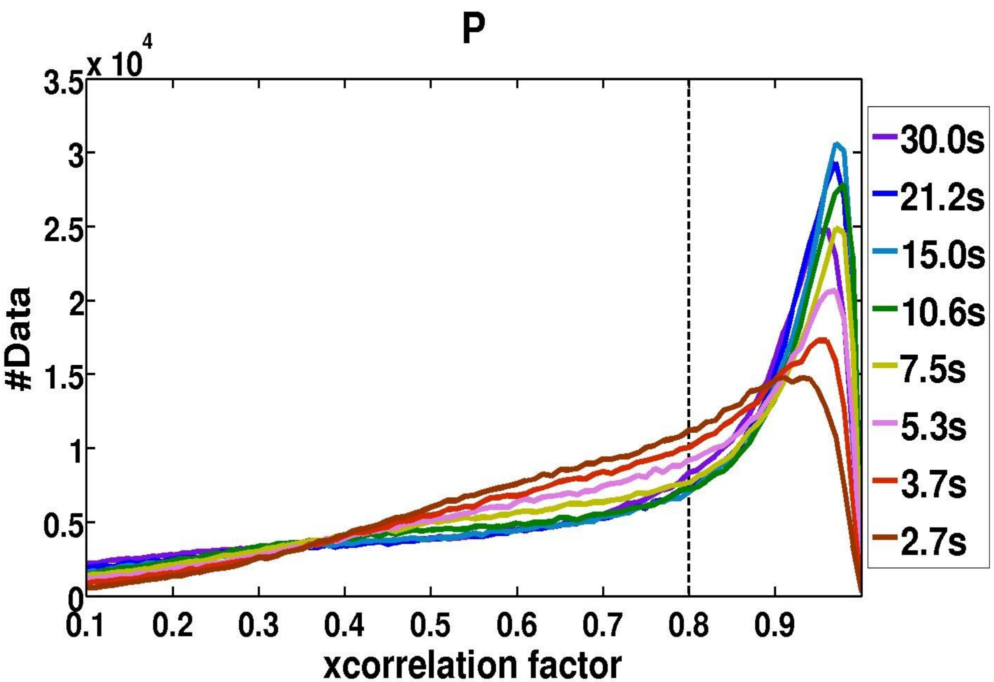


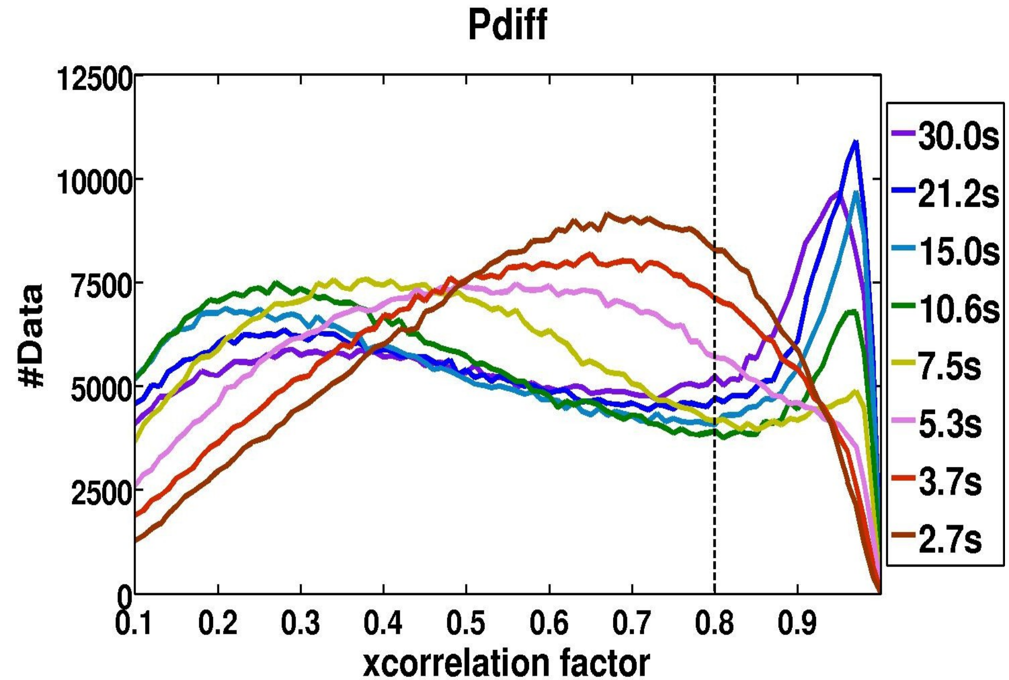
+STF

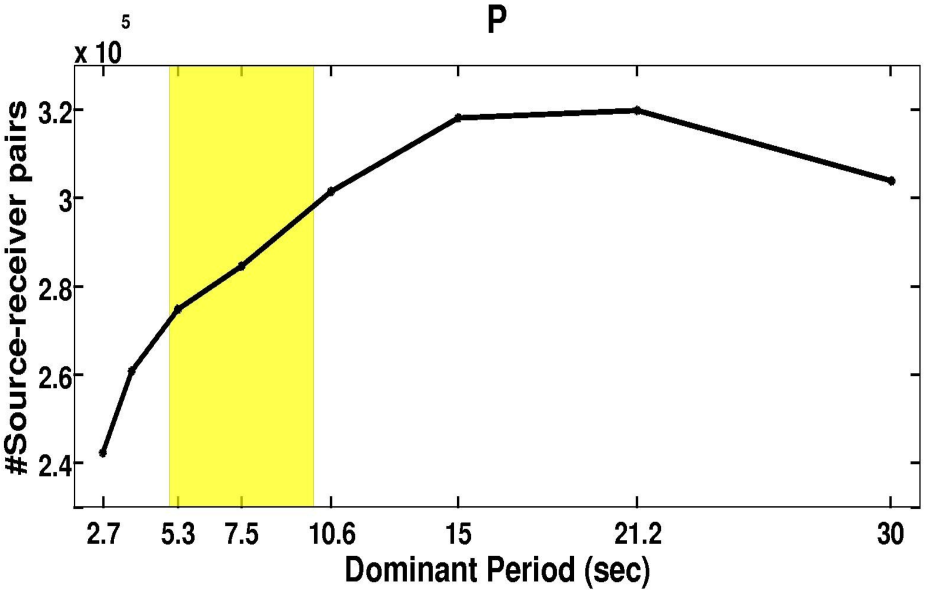
-STF

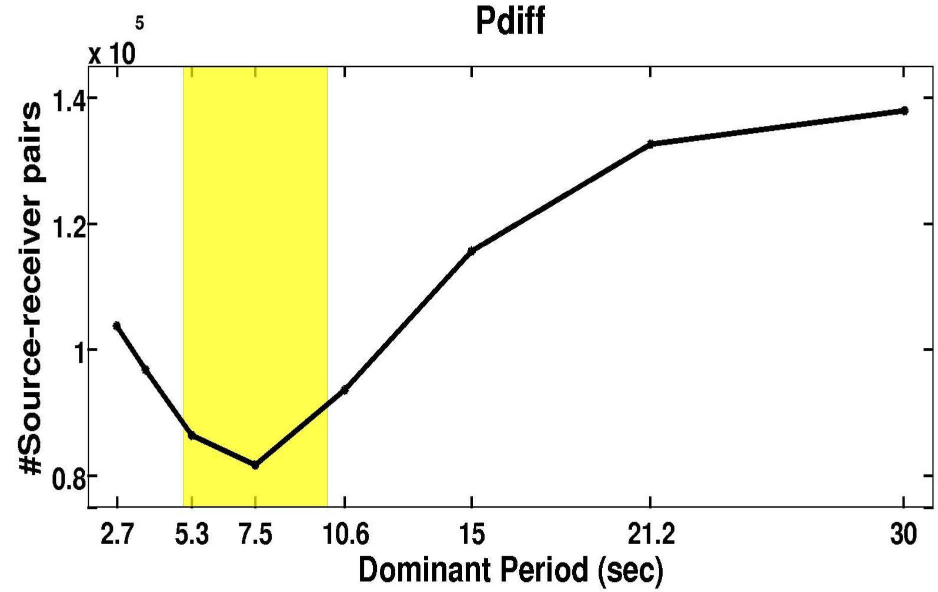


#Data vs xcorr-factor

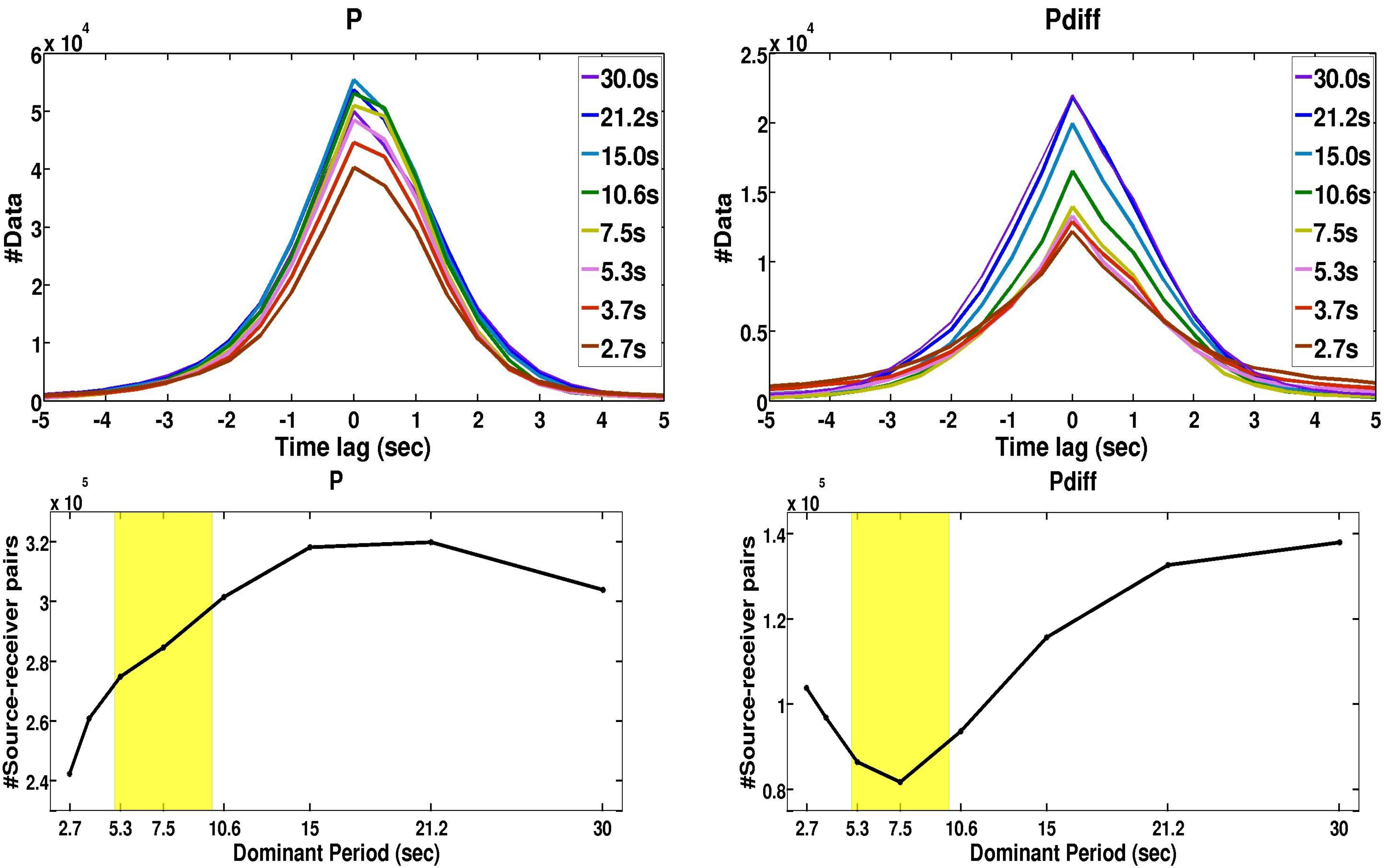




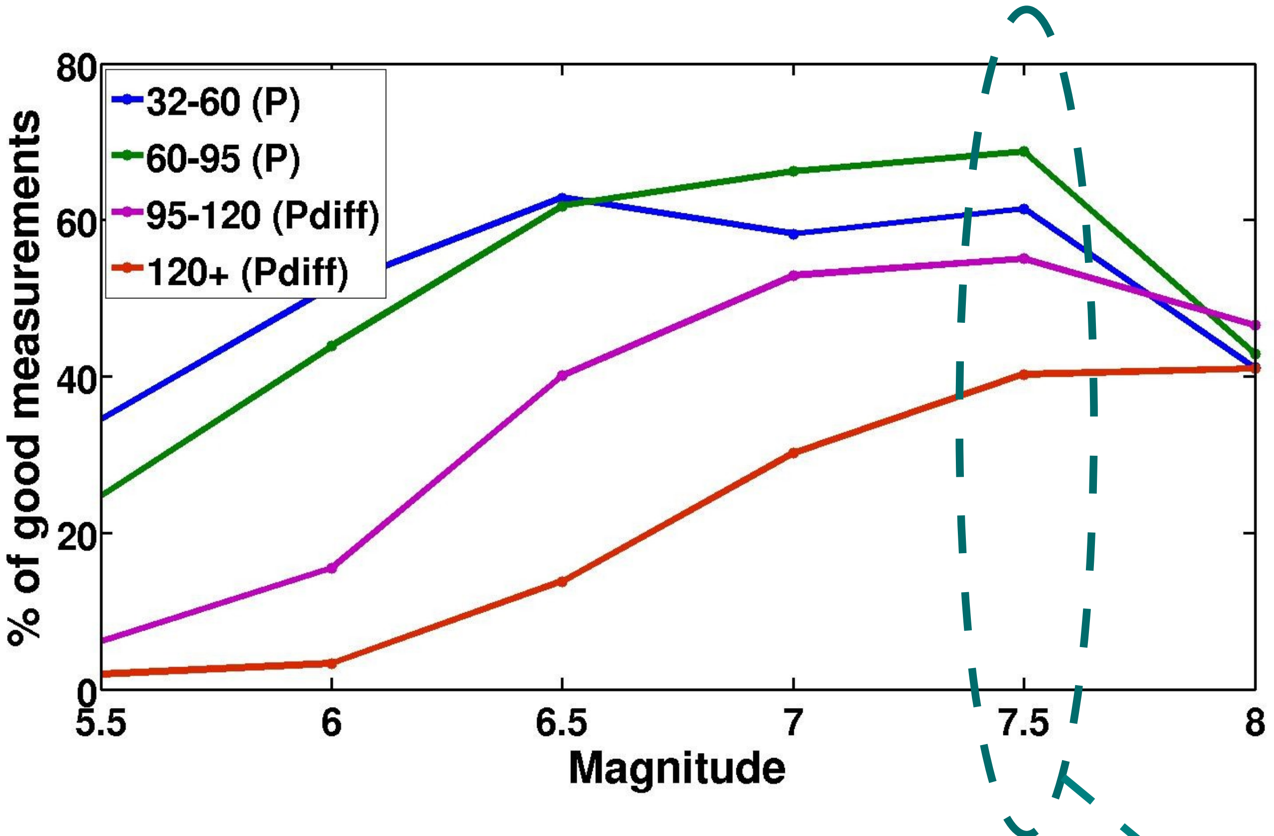


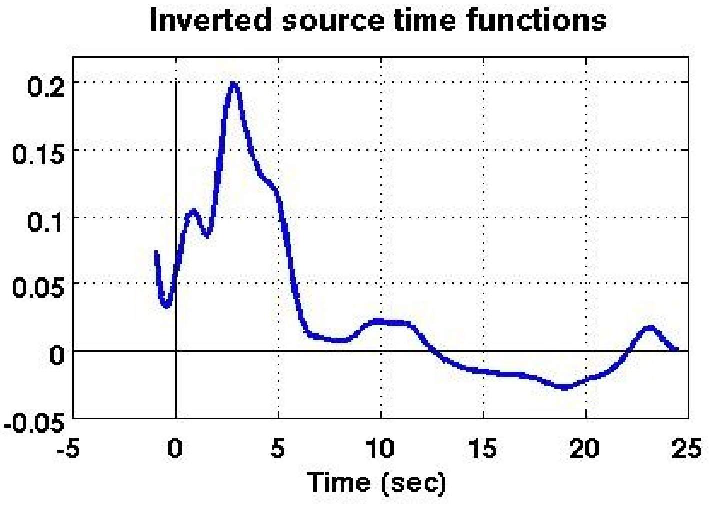


#Data vs Measured travel-time



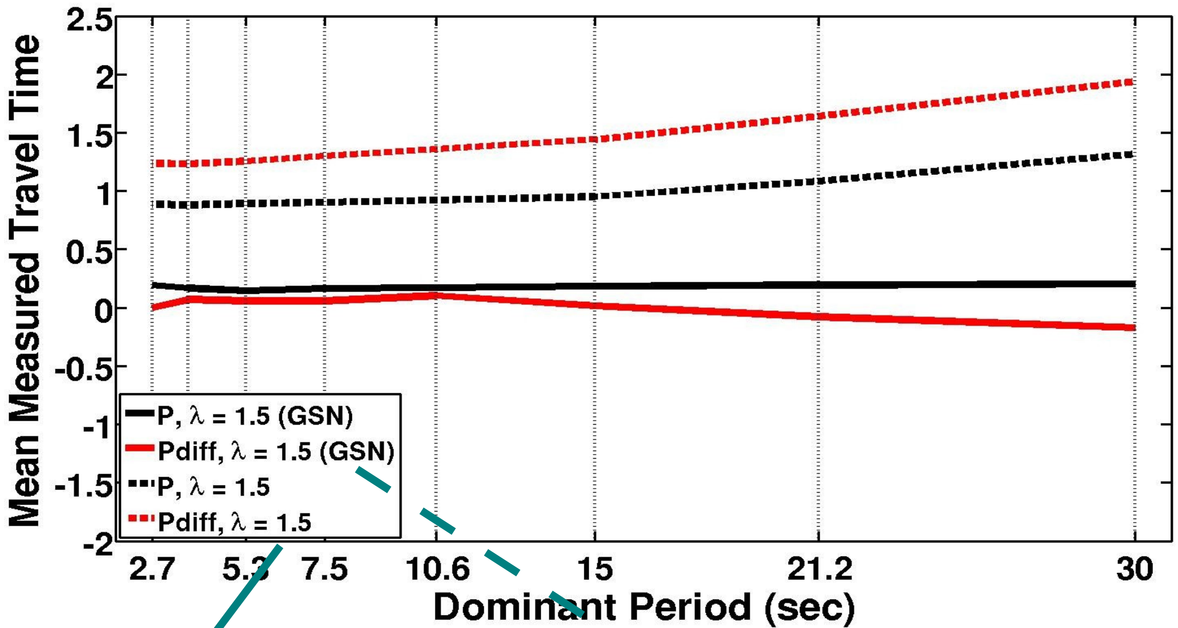
%Usable data vs Magnitude

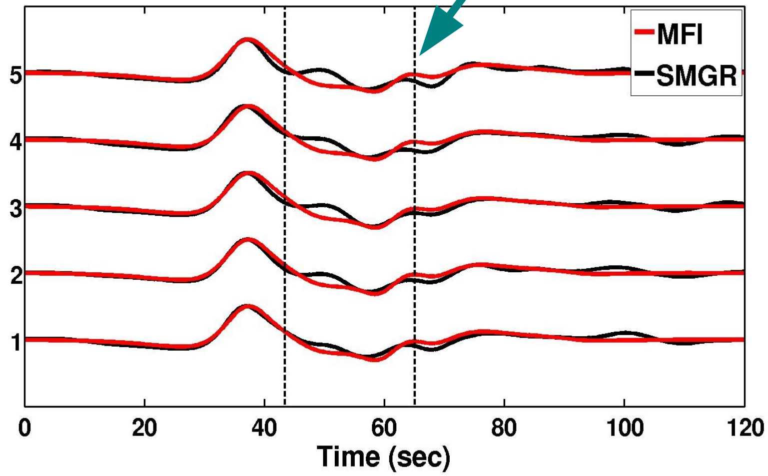


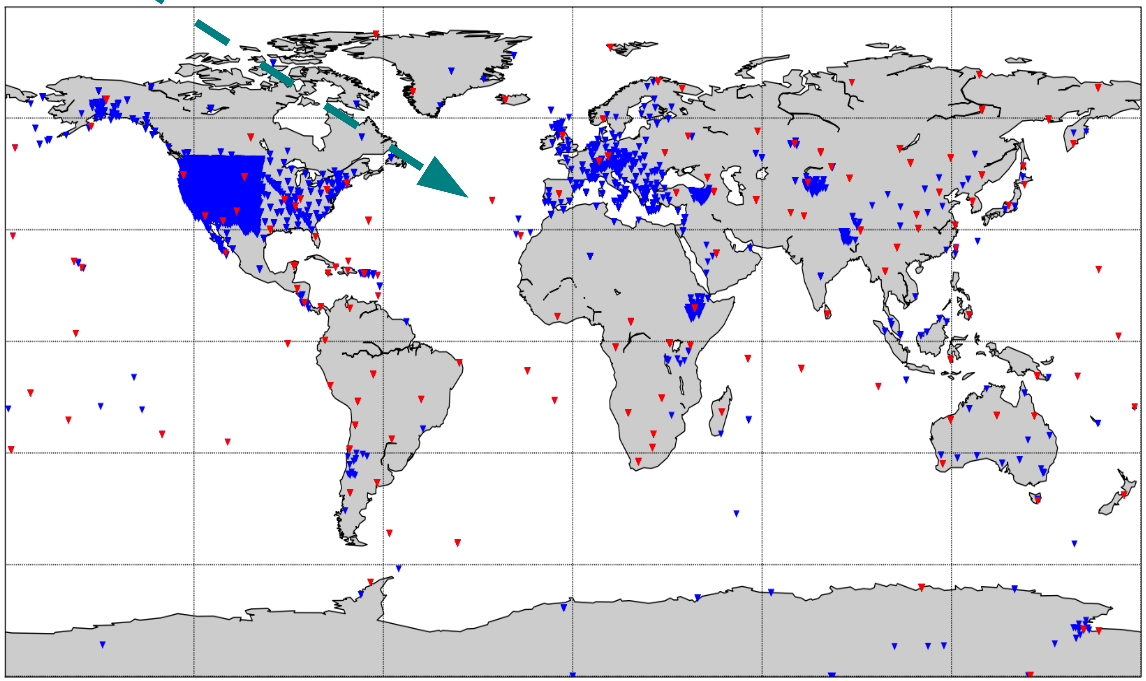


- Percentage of usable data vs magnitude, for different epicentral distances.
- Only those events with good STF to avoid finite-source effects.

Dispersion curve (frequency-dependent behavior of measurements)







Common Corrections

- We have simplified the Earth model, so we need some corrections:

  1. Ellipticity
  2. Dispersion
  3. Topography
  4. Crustal time

  - Geometrical spreading
  - Mantle correction
  - radiation pattern

Common Corrections

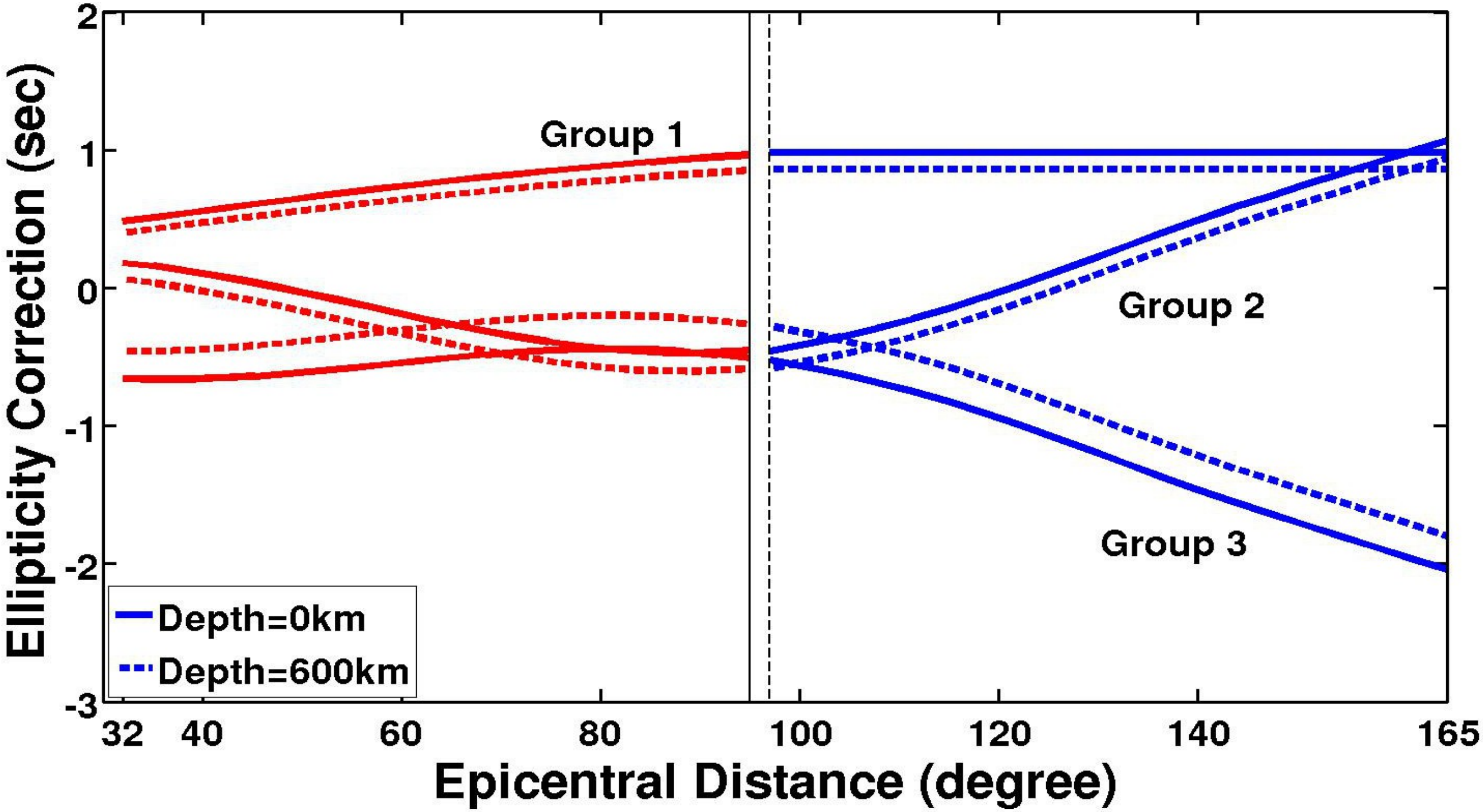
- We have simplified the Earth model, so we need some corrections:

1. Ellipticity
2. ~~Dispersion~~
3. Topography
4. Crustal time

$$c(\omega) = c(\omega_0)\left[1 + \frac{1}{\pi Q}\ln\left(\frac{\omega}{\omega_0}\right)\right]$$

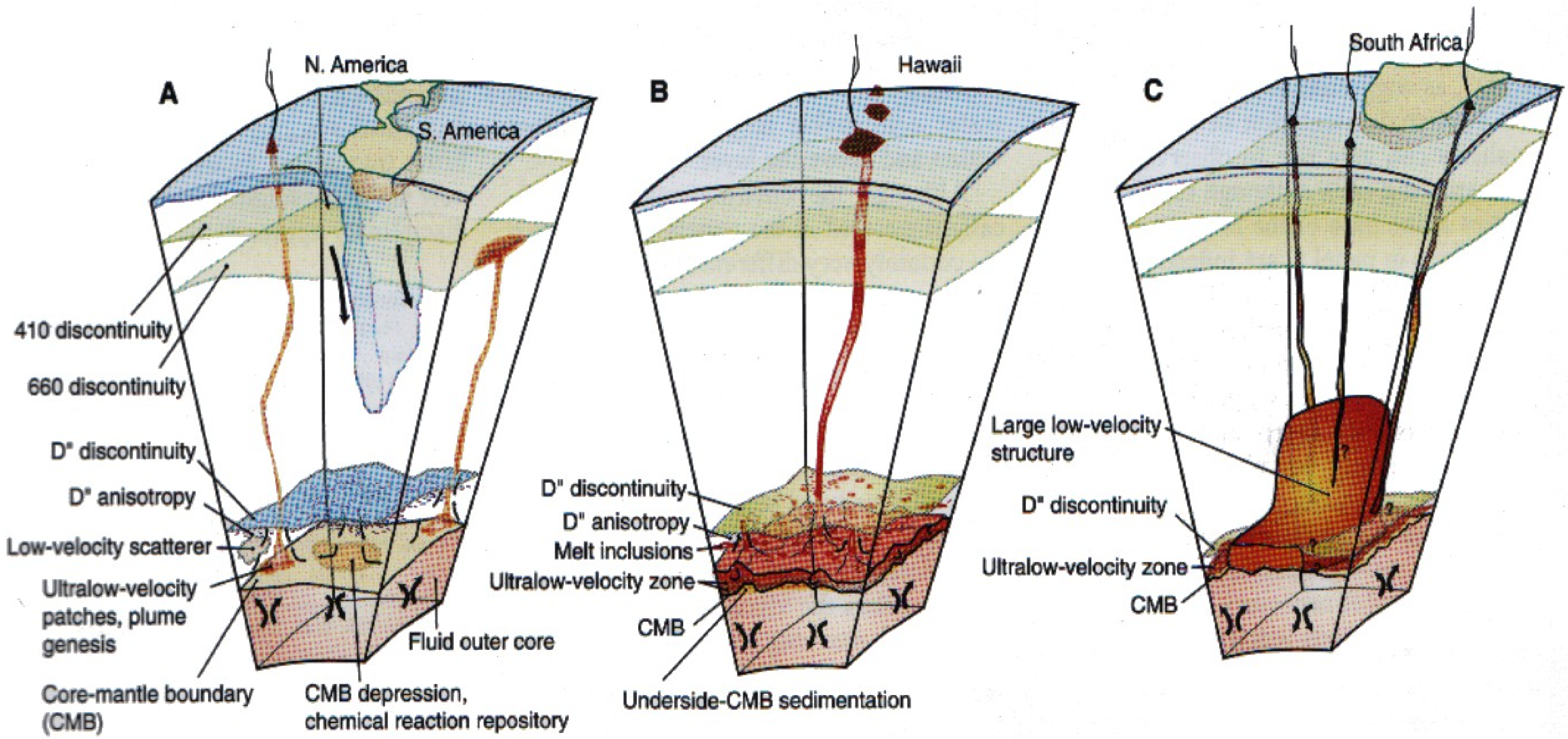
- ~~Geometrical spreading~~
- ~~Mantle correction~~
- ~~radiation pattern~~

Ellipticity Correction



Group1: event on latitutde=longitude=0, and the stations are distributed on the Equator.
Group2: event is in the same location as Group1 (latitude=longitude=0), but the stations are distributed on longitude=0 line.
Group3: stations are distributed similar to Group2 (longitude=0 line), but the event is on the North pole.

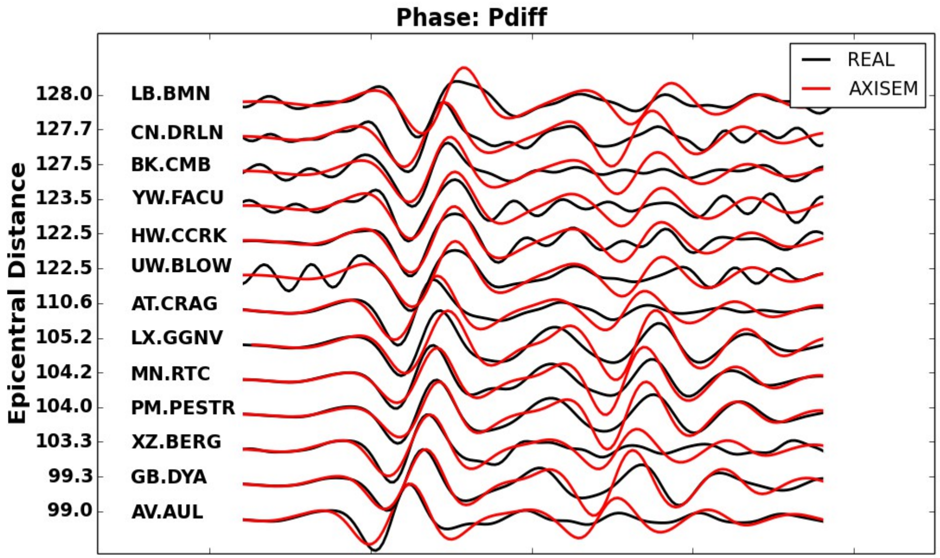
Core Mantle Boundary

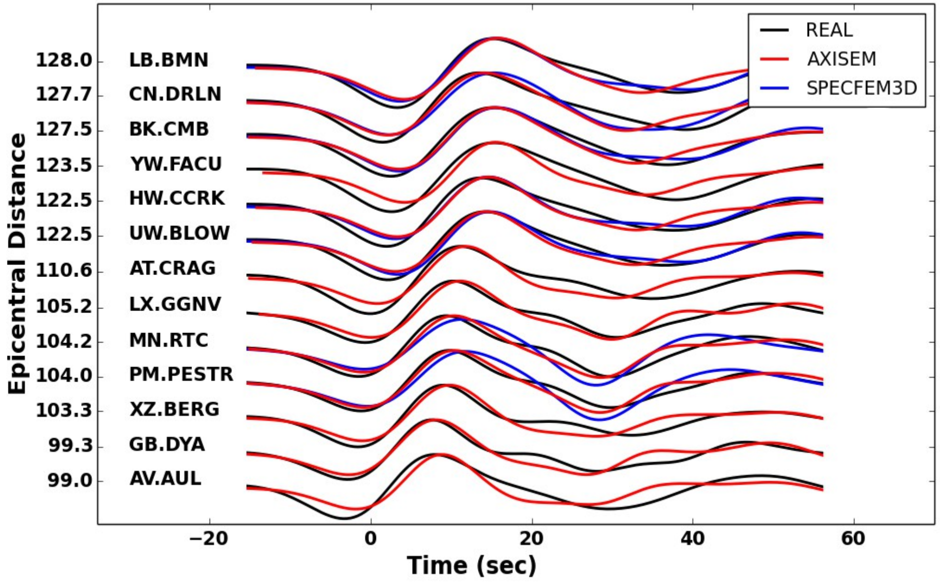


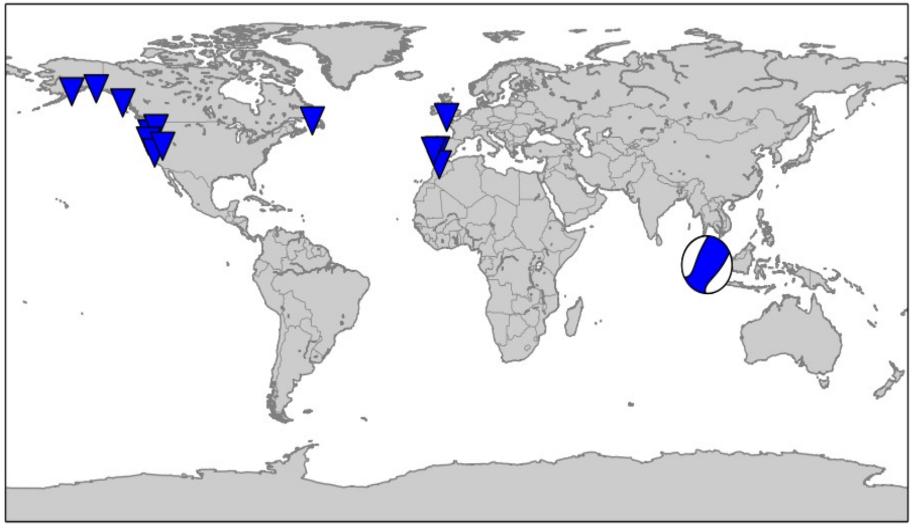
Garnero, 2004

Deep mantle complexities for three regions: (A) Beneath Central America, (B) Central Pacific and (C) South Atlantic and Southern Africa.

Real data against synthetic waveforms

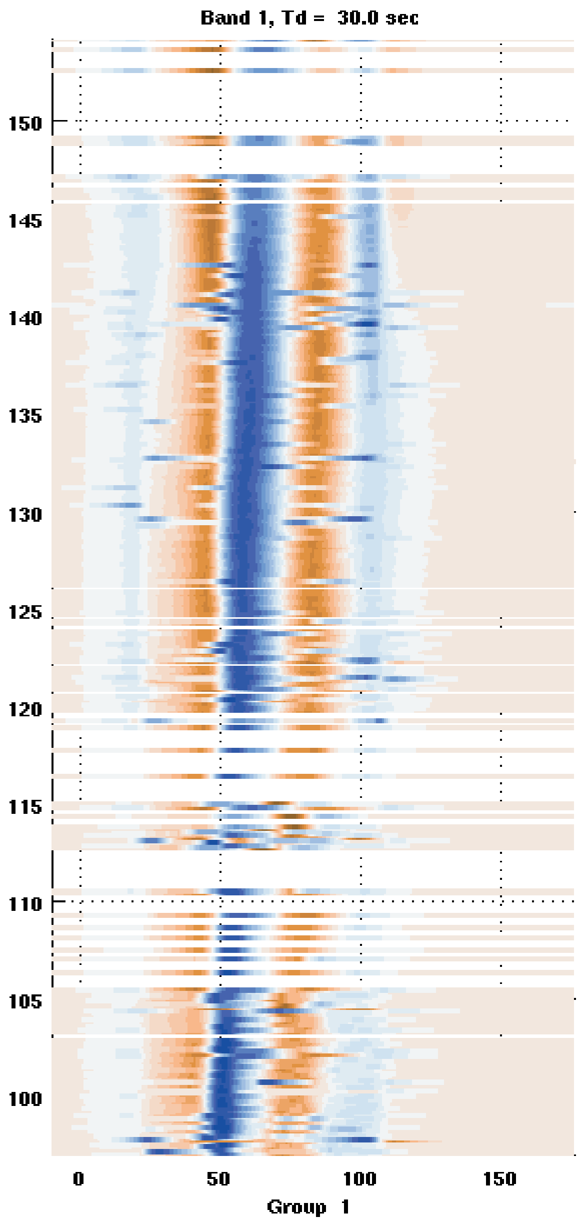


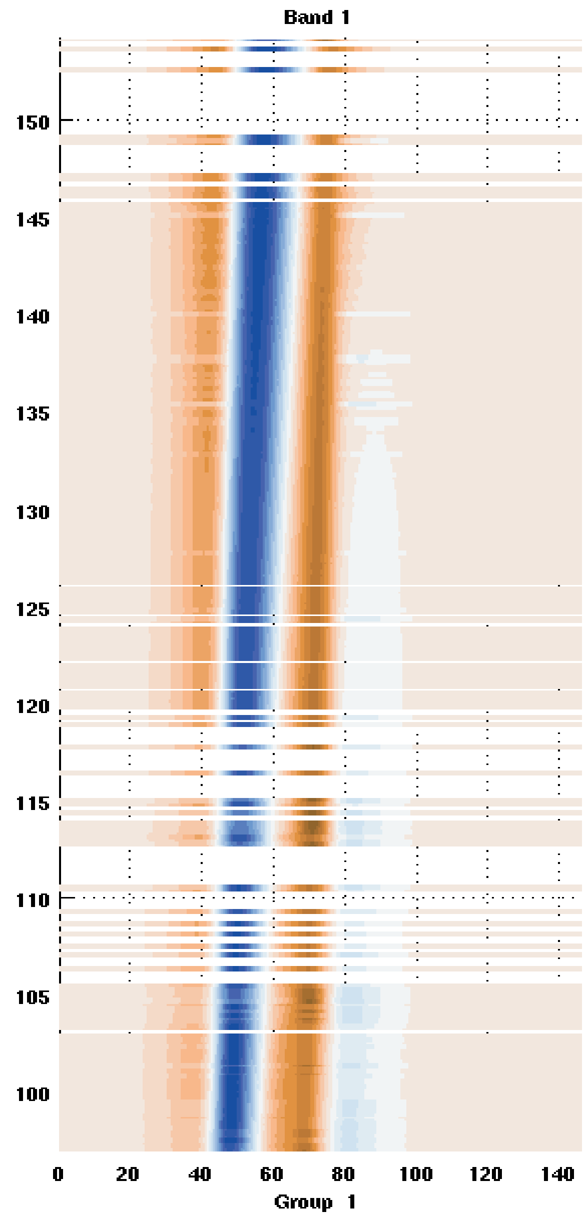


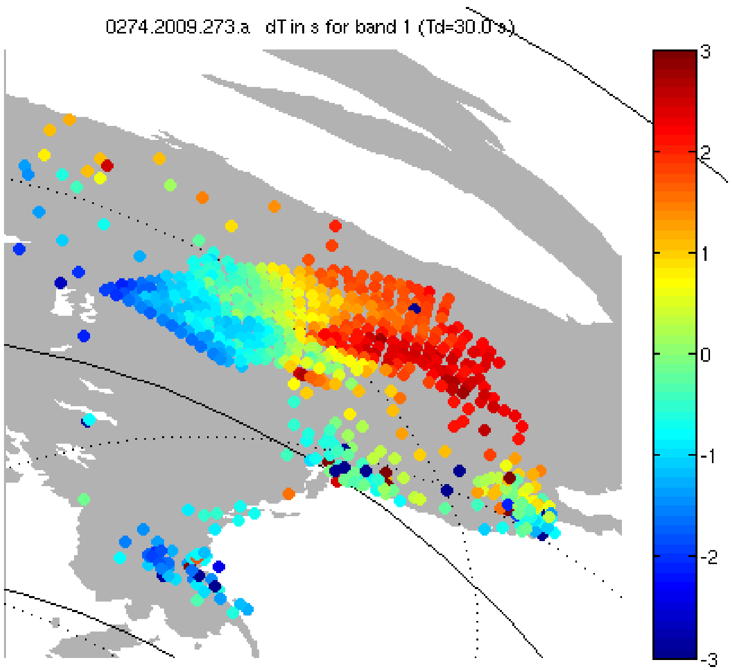


- Comparison between synthetic waveforms and real data for 5-15s and 15-45s pass bands.
- Sumatra 2009/09/30 10:16:09.249, Mag: 7.5, depth: 81.0km.

Measurements for Mag: 7.5, depth: 81.0, Sumatra 2009/09/30 10:16:09.249

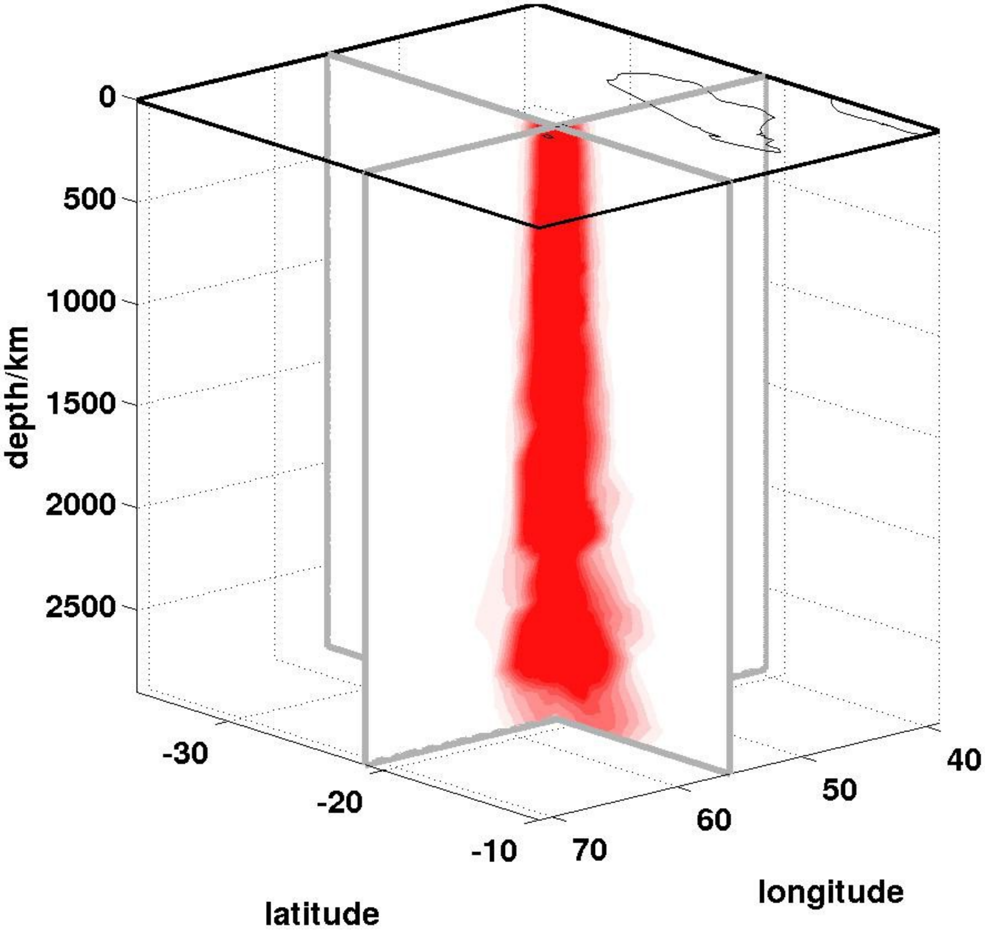


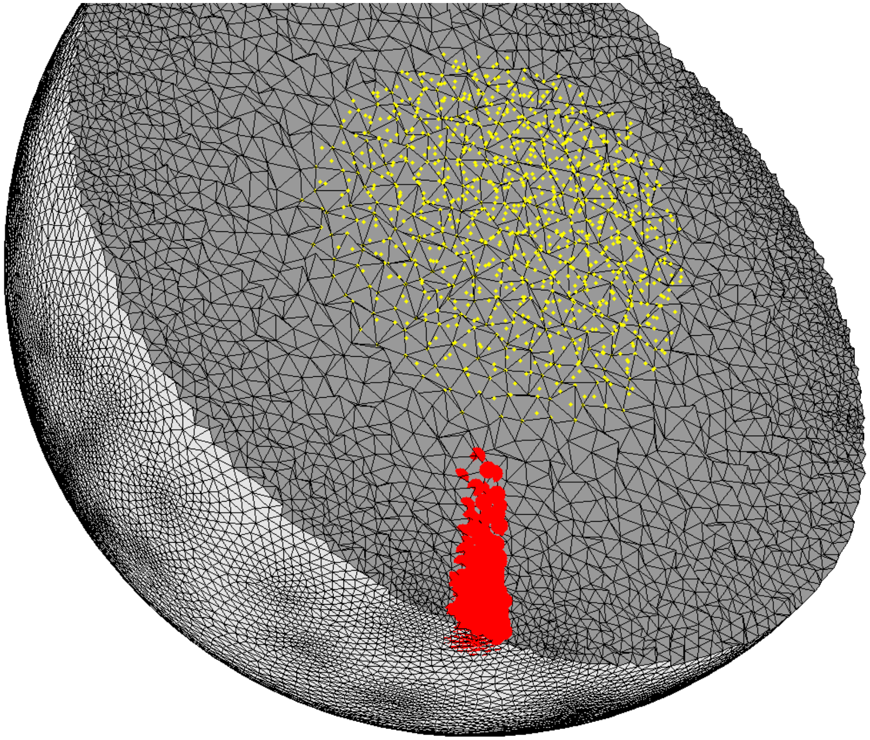




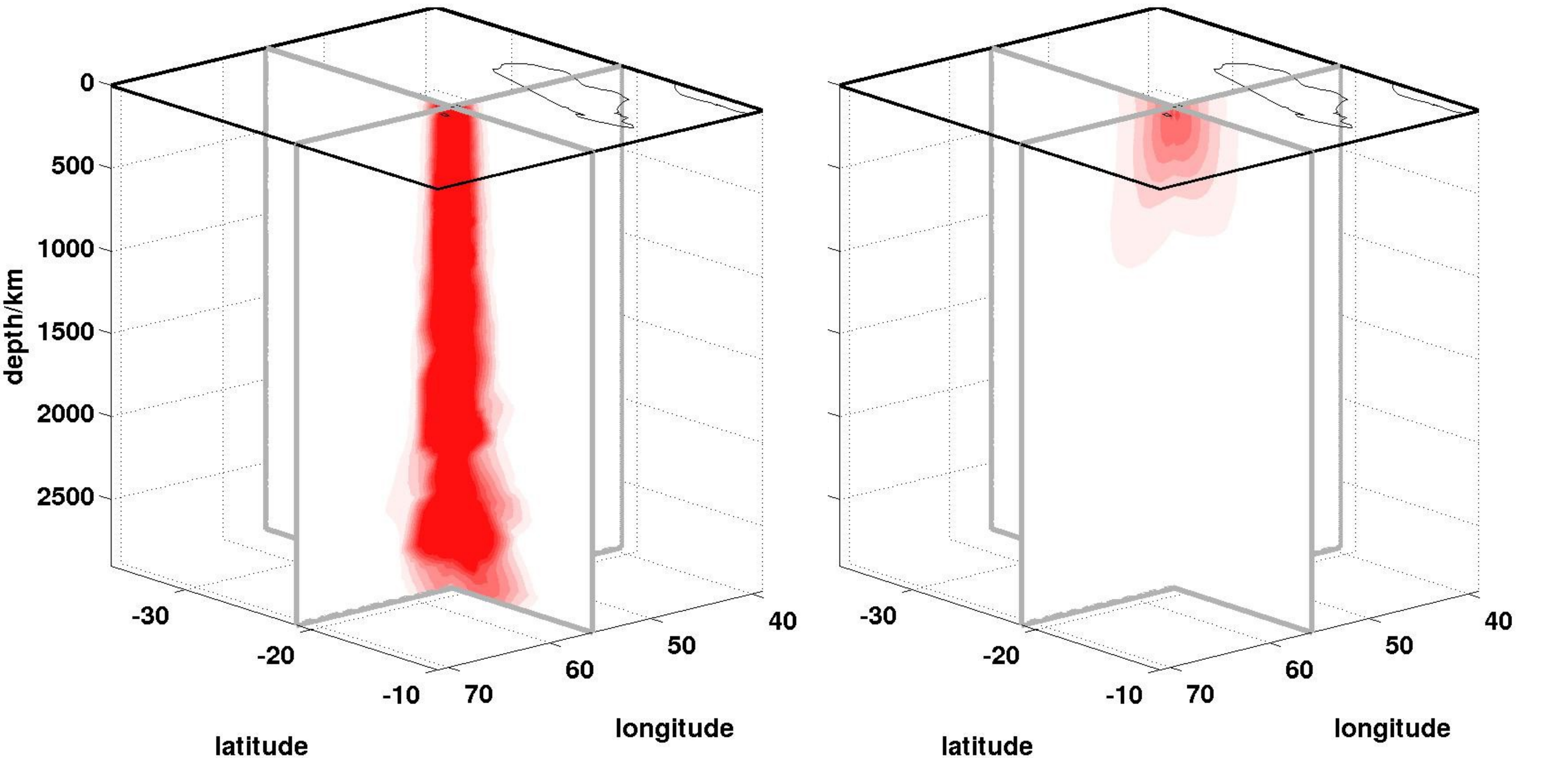
- Left: Broadband data and broadband matched filters are aligned on theoretical arrival time.
- Top: measured travel-time anomalies for stations in North America

Inversion Grid and Resolution Matrix

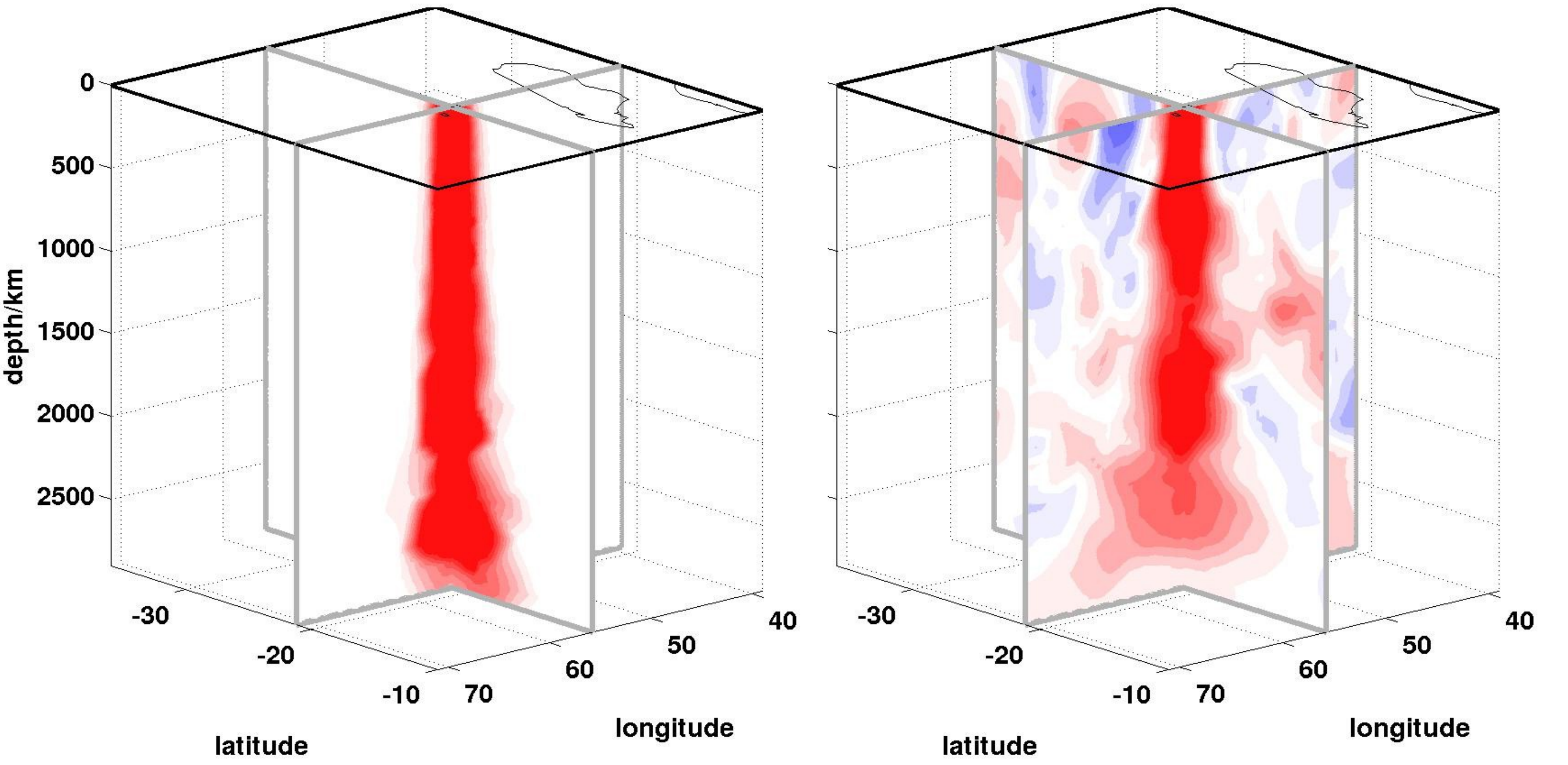




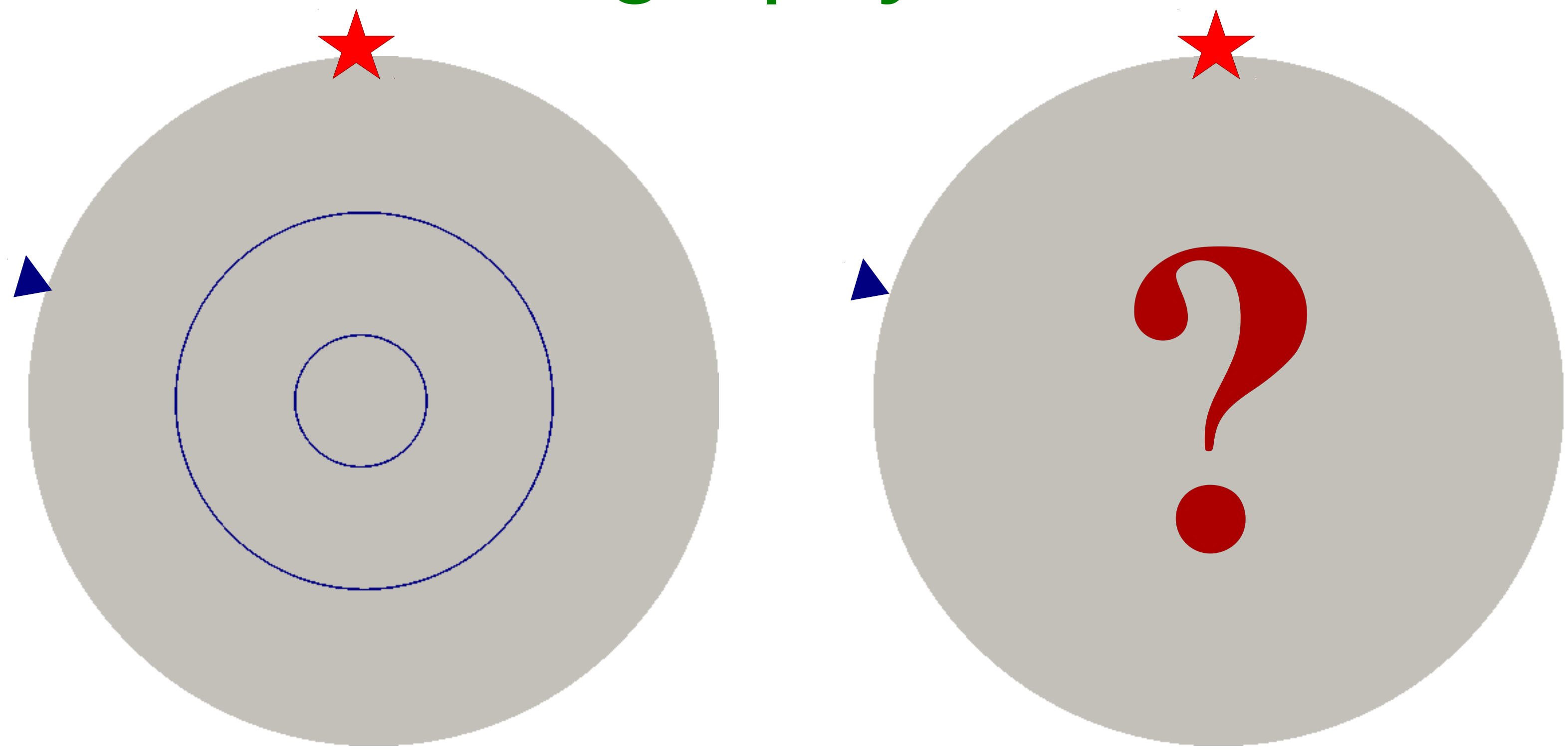
Inversion Grid and Resolution Matrix

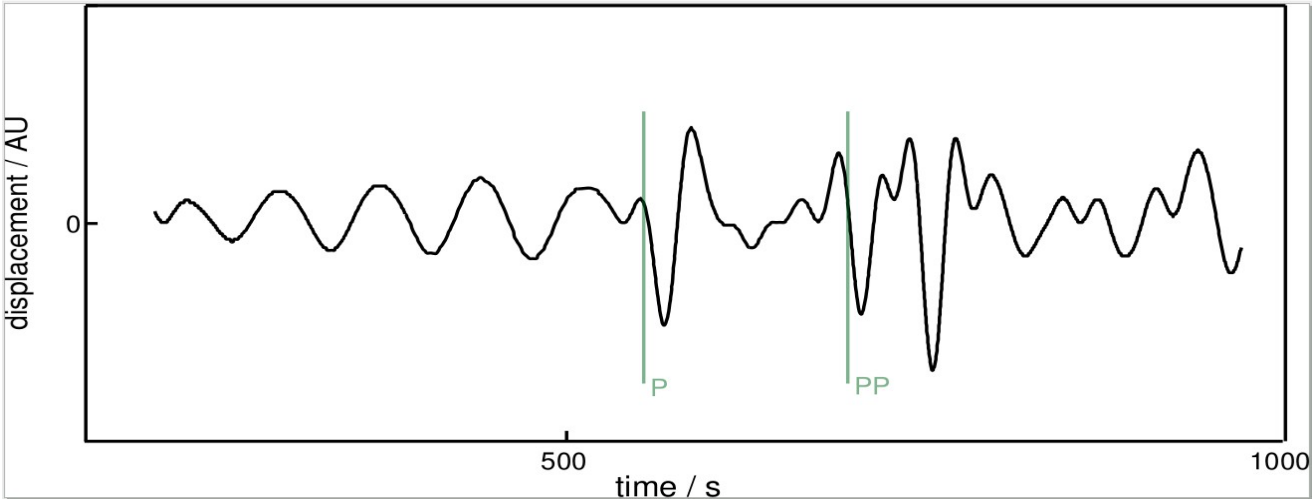


Inversion Grid and Resolution Matrix

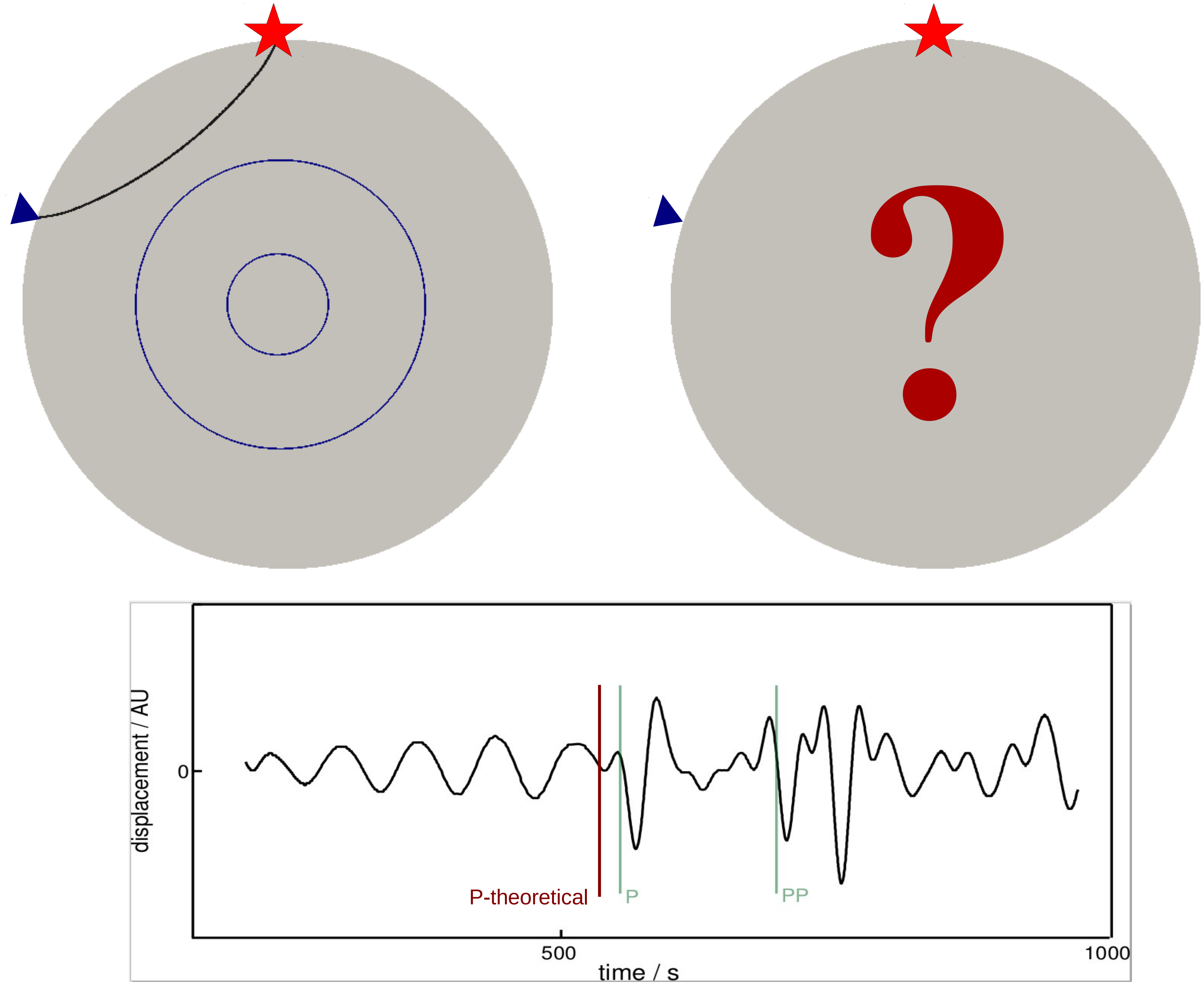


Ray based tomography

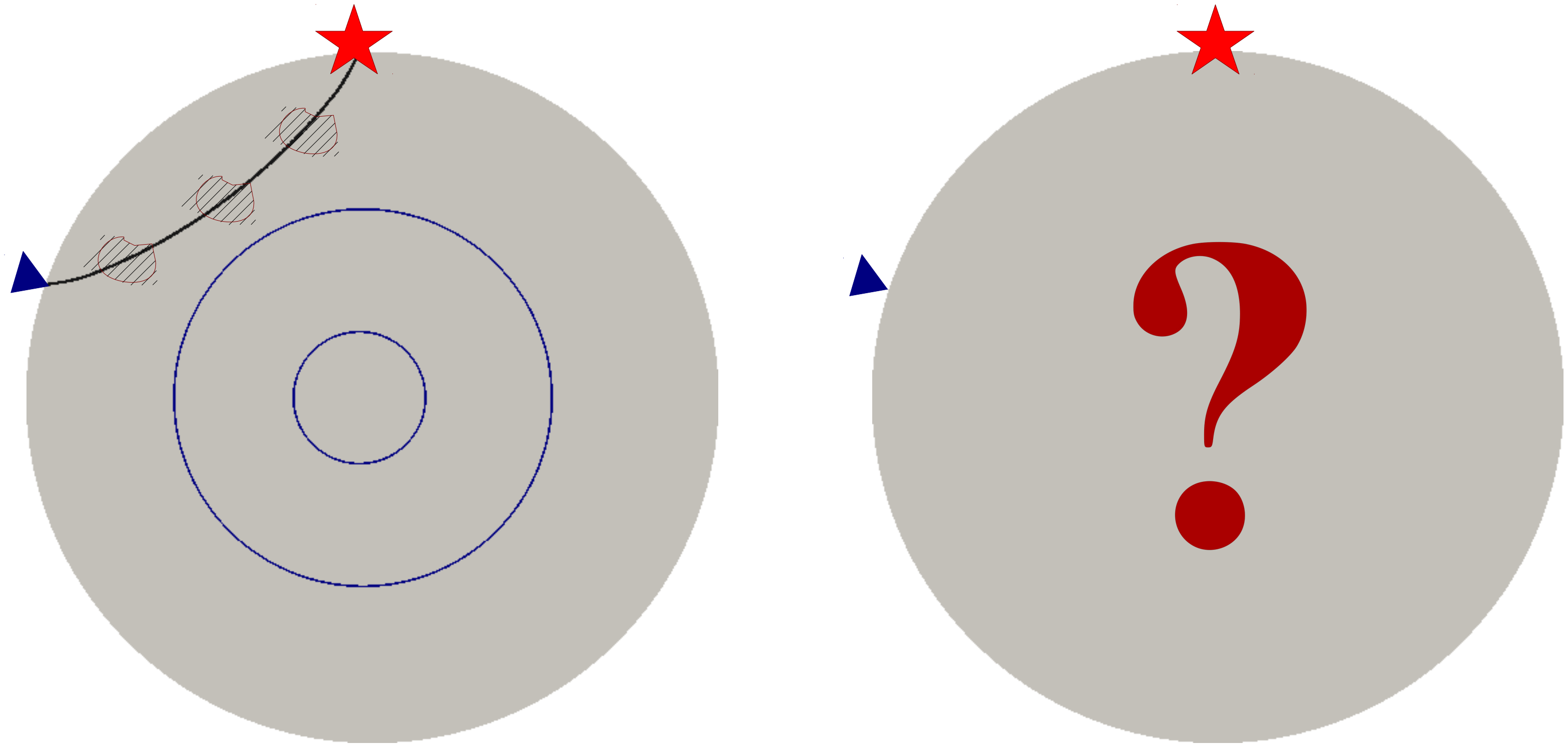


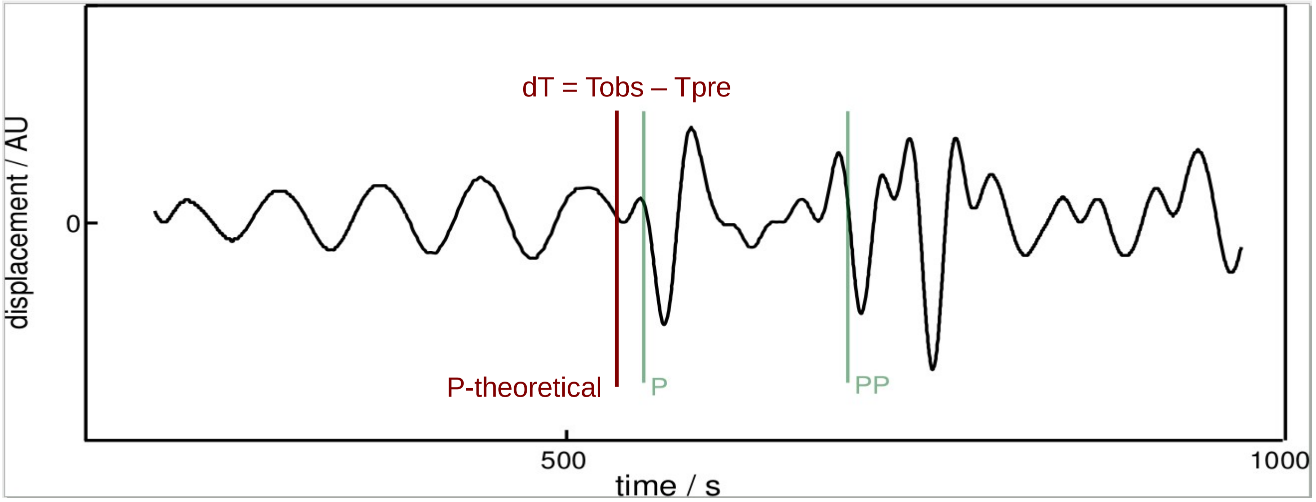


Ray based tomography

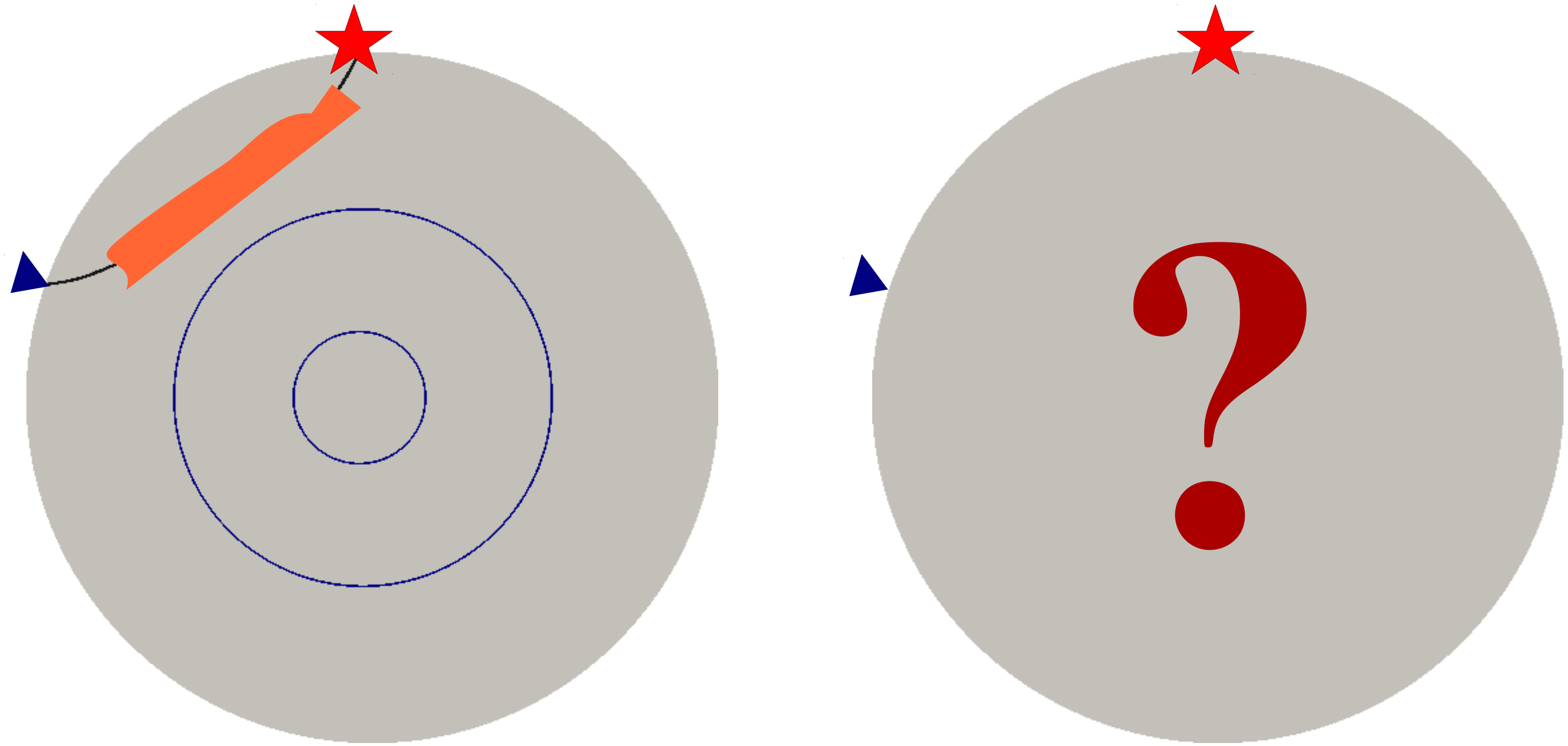


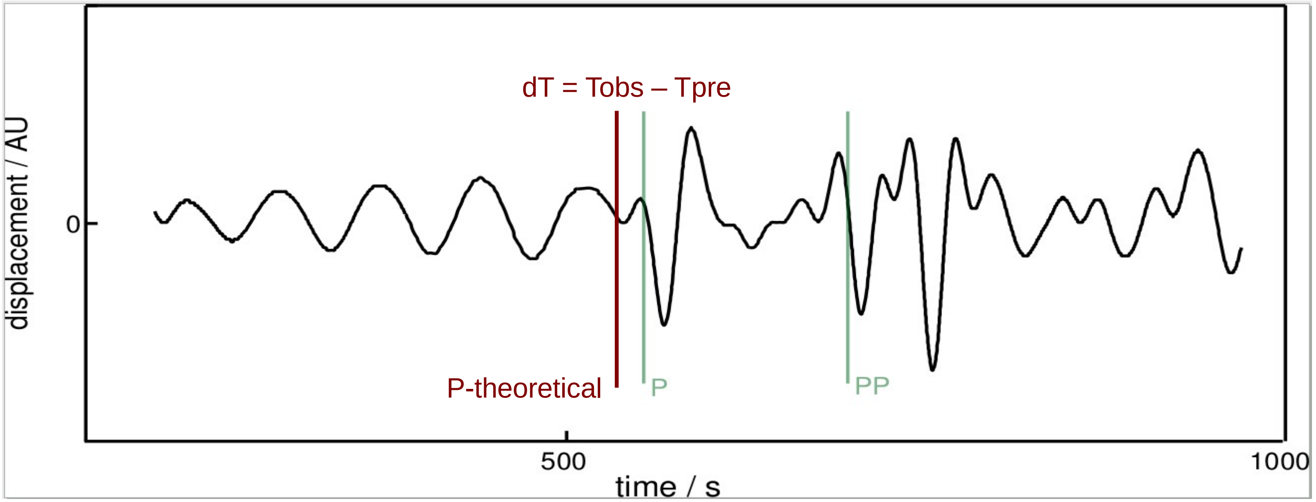
Ray based tomography





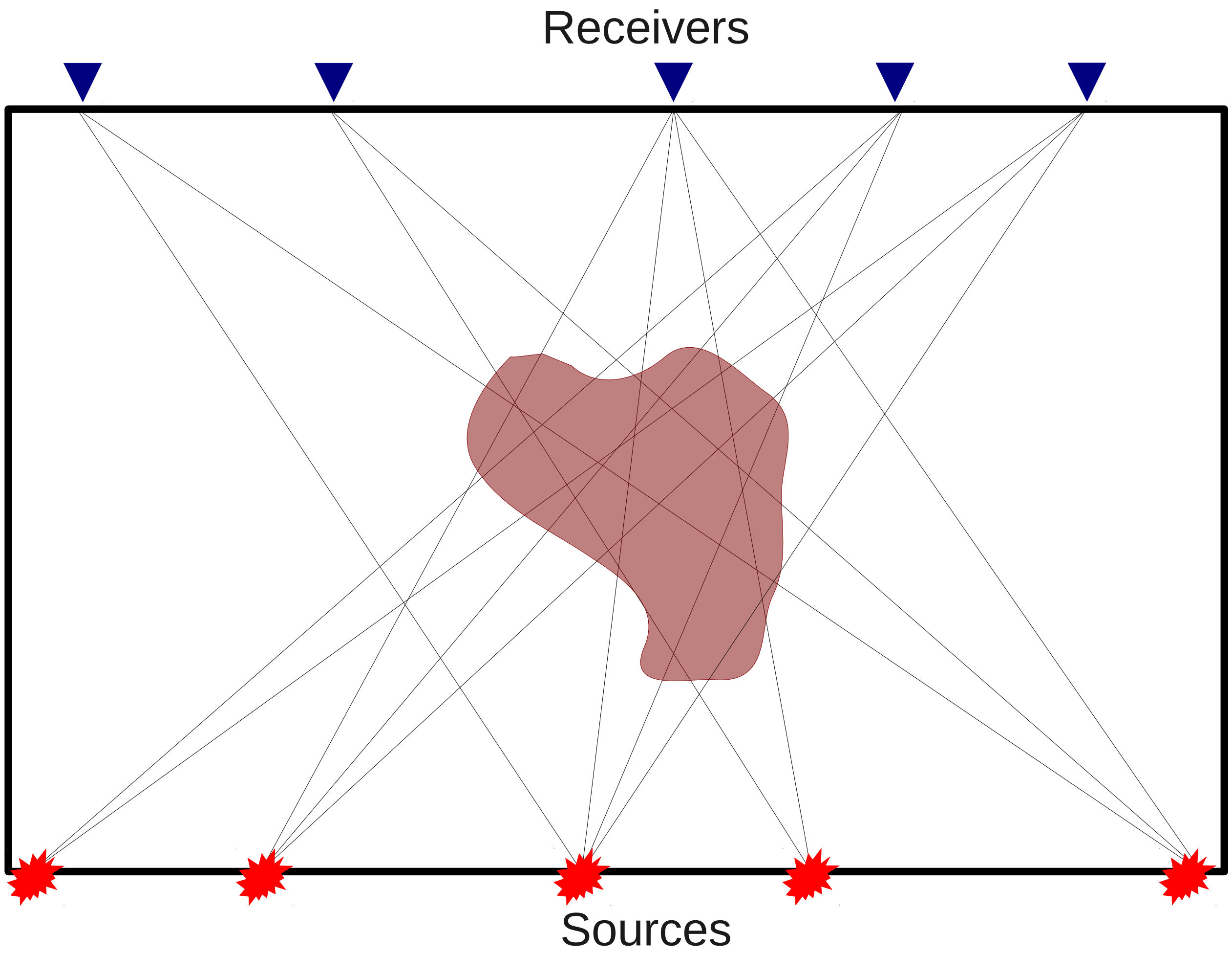
Ray based tomography





Ray based tomography

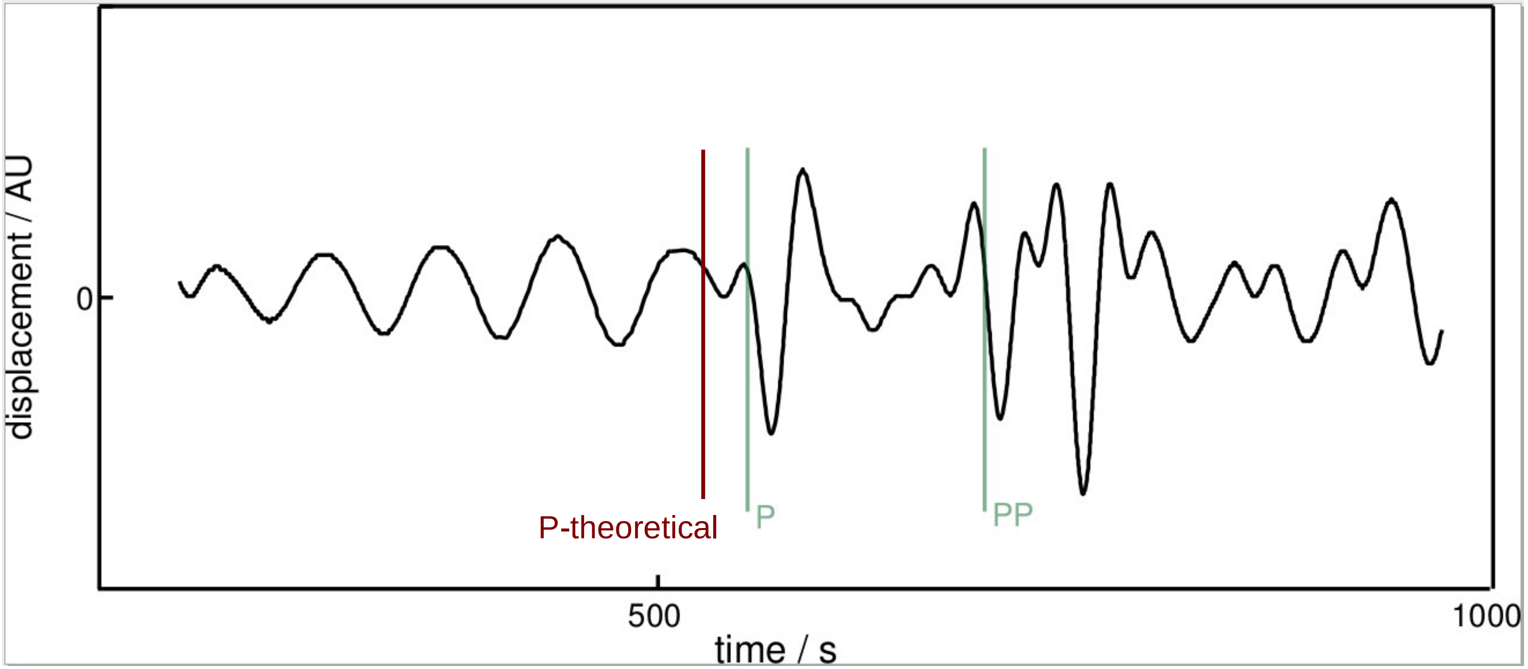
- Crossing rays



Ray based tomography

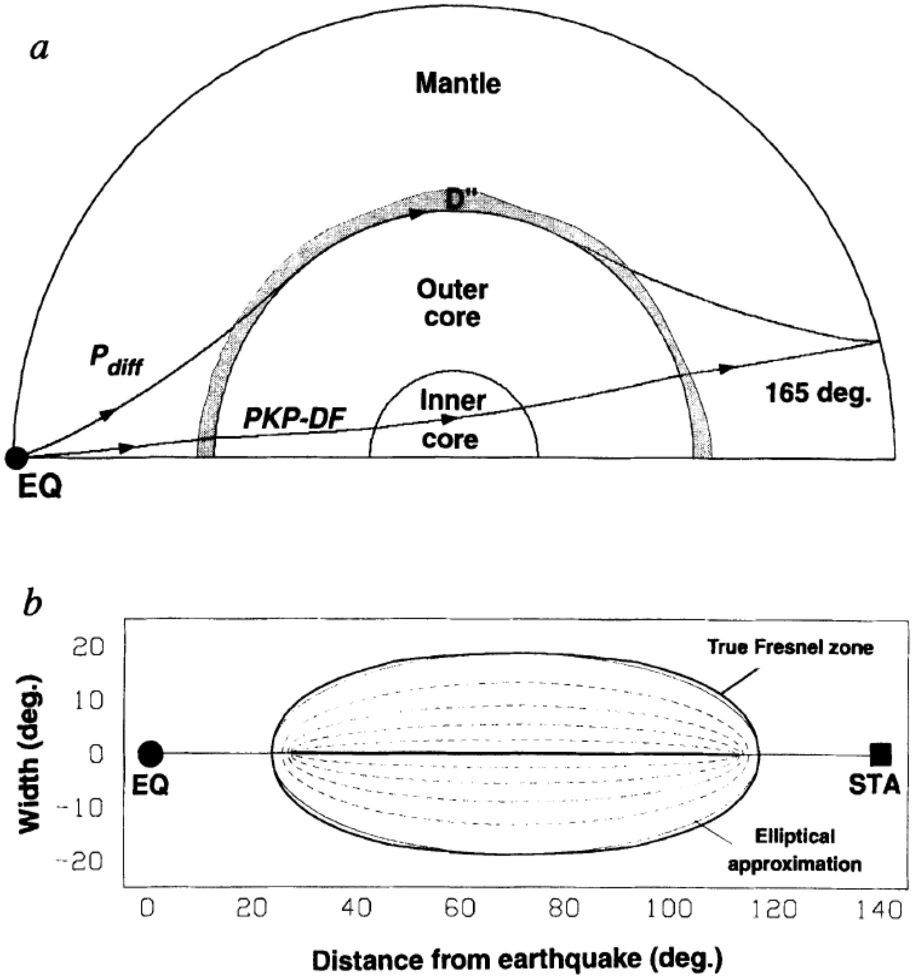
What is the arrival time?

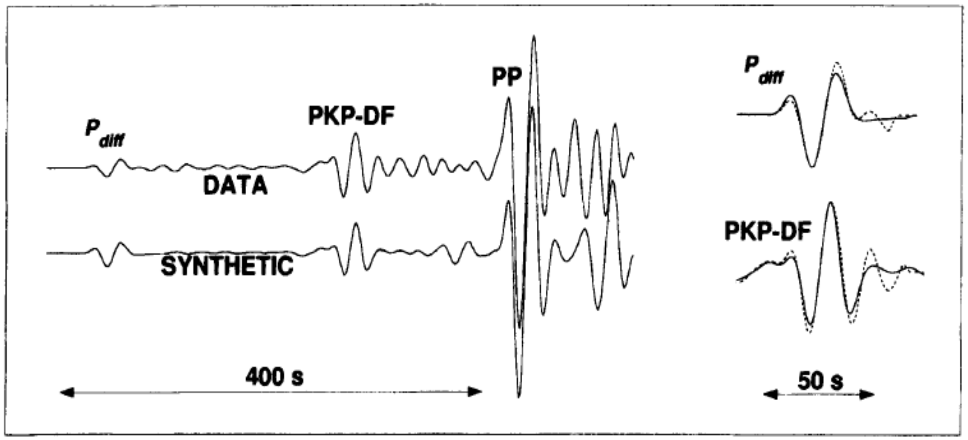
- Only defined for minimum-phase broadband signals (short time duration and a concentration of energy)
- Seismic sources are not minimum phased (spike)
- Earth's attenuation removes high frequencies
- Seismometers and noise!



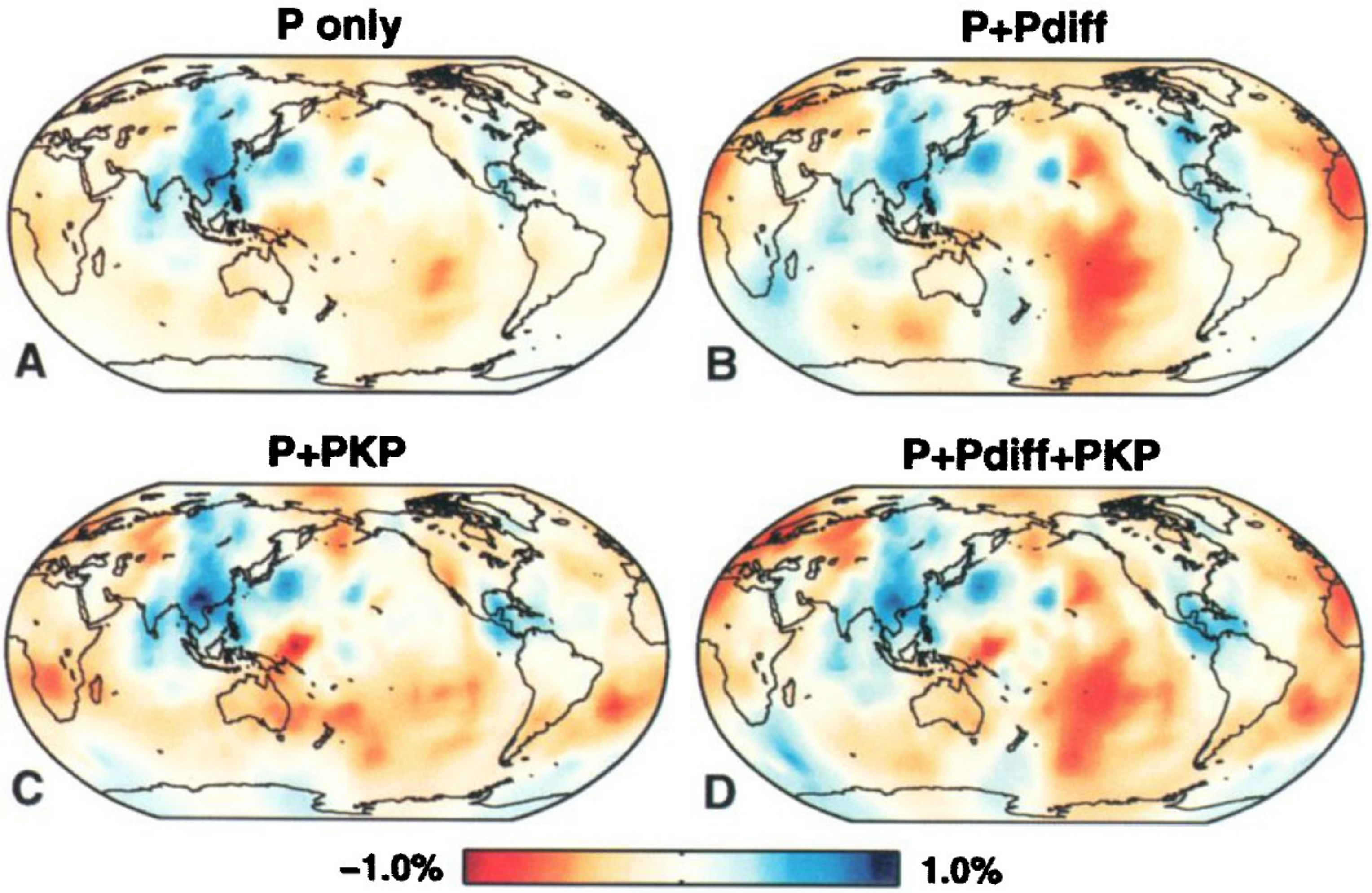
Large-scale structure at the core-mantle boundary from diffracted waves (Wysession, 1996)

- Differential travel time (PKP-Pdiff)
- 543 digital seismograms (120-165)
- 20s Fresnel zone

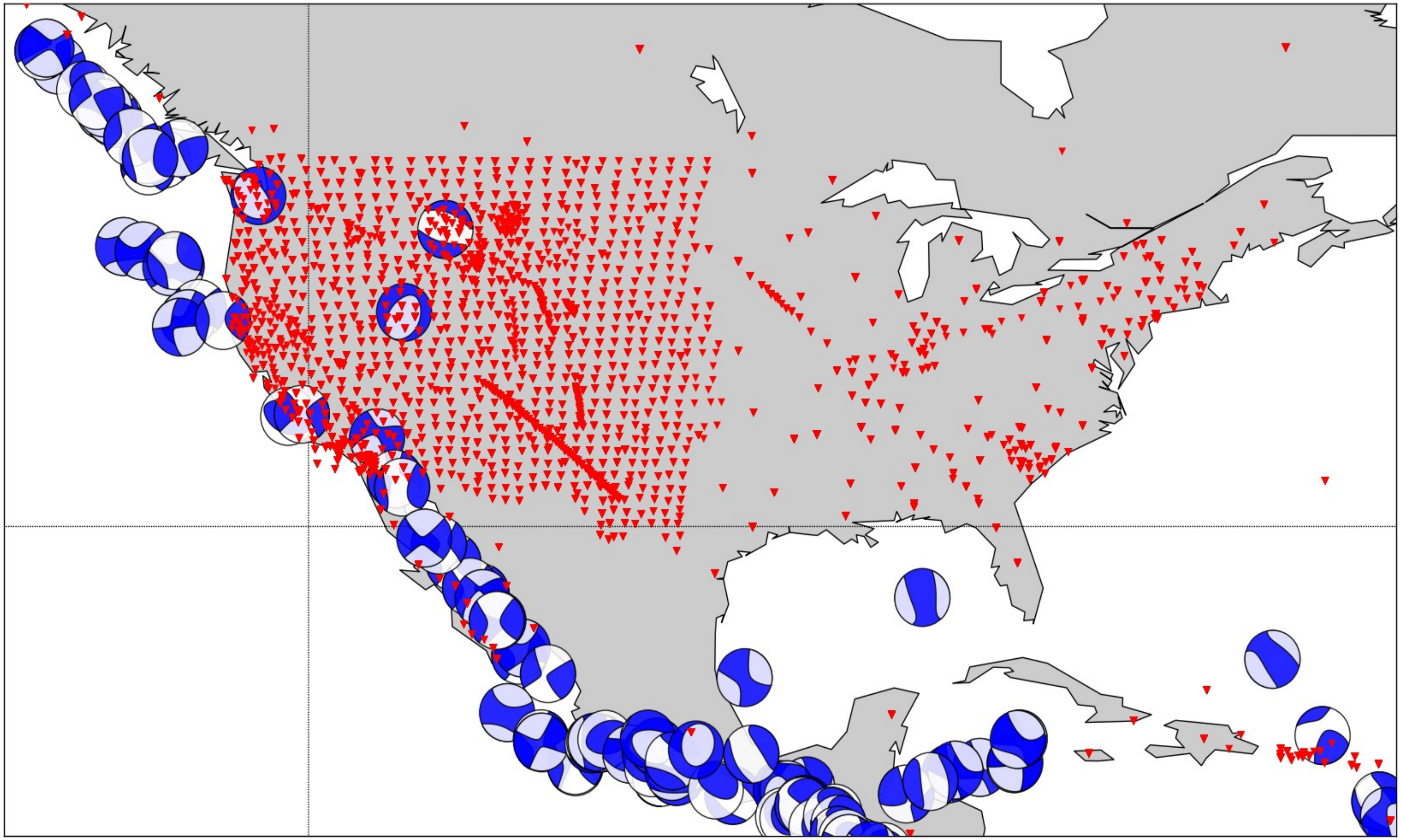




Tomographic imaging of the lowermost mantle with differential times of refracted and diffracted core phases (PKP, Pdiff) [Karason and van der Hilst, 2001]

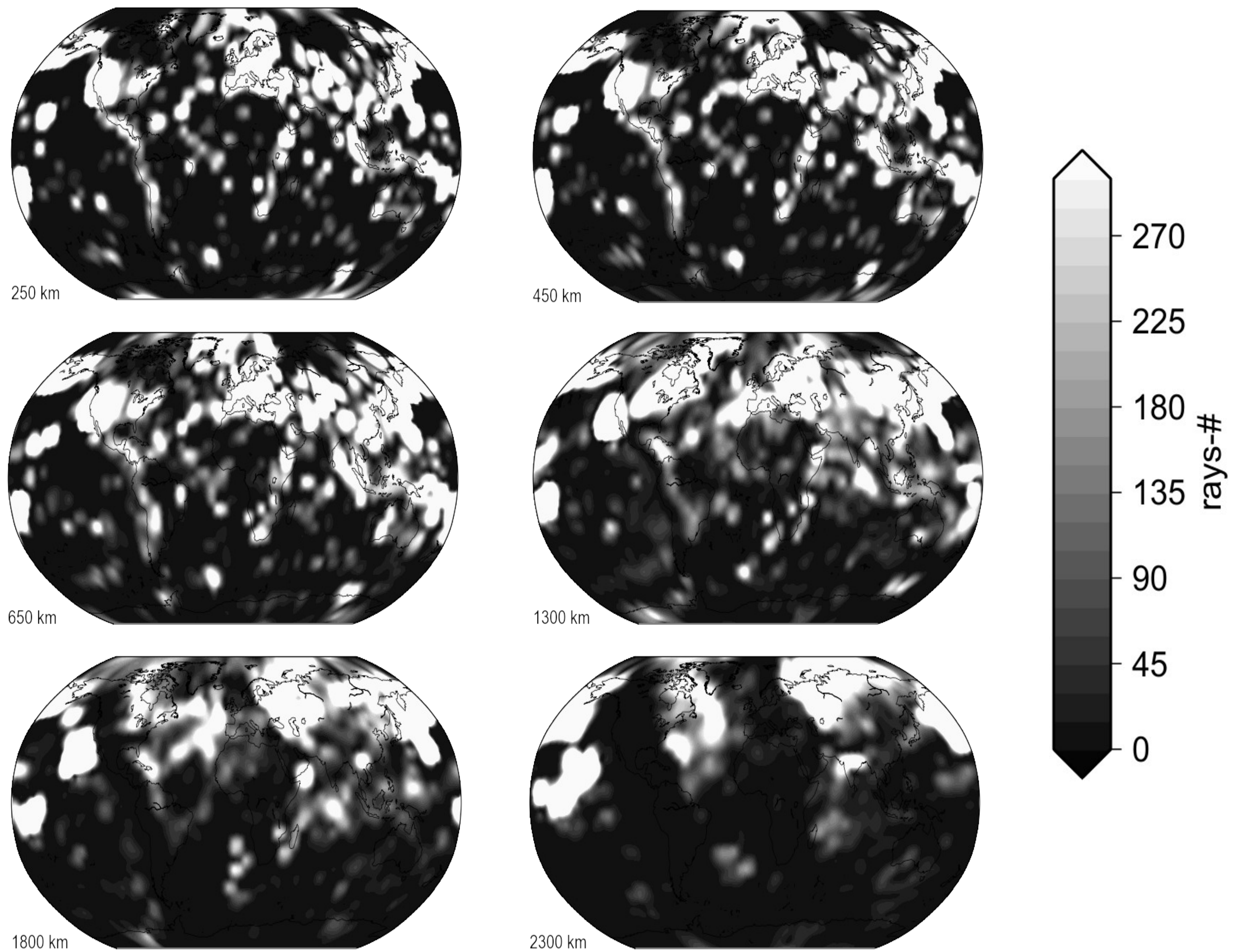


Data Archive for Pdiff

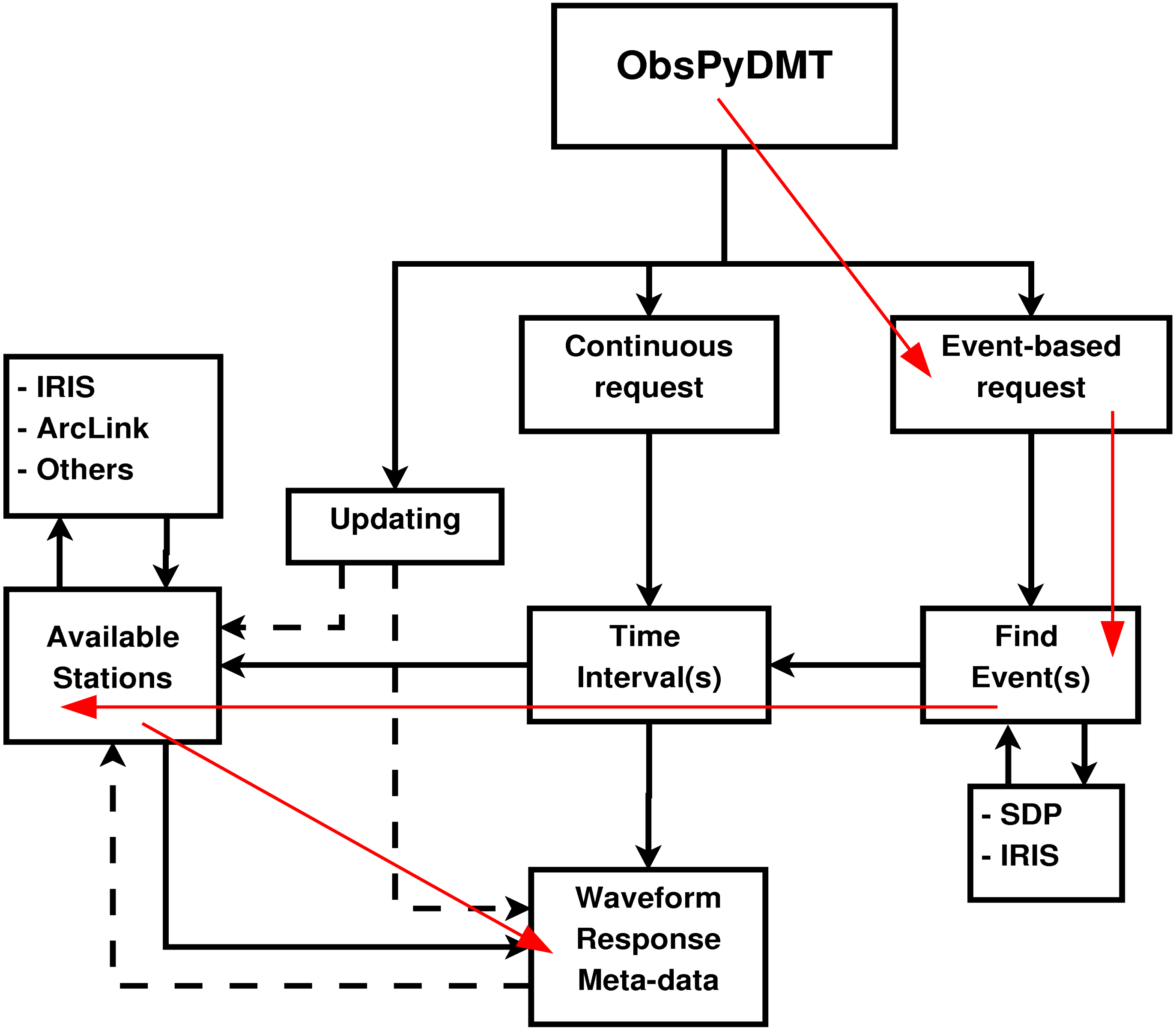


1856 events (out of 1884)
474311 'potential' source-receiver pairs

Hit-counts for P measurements

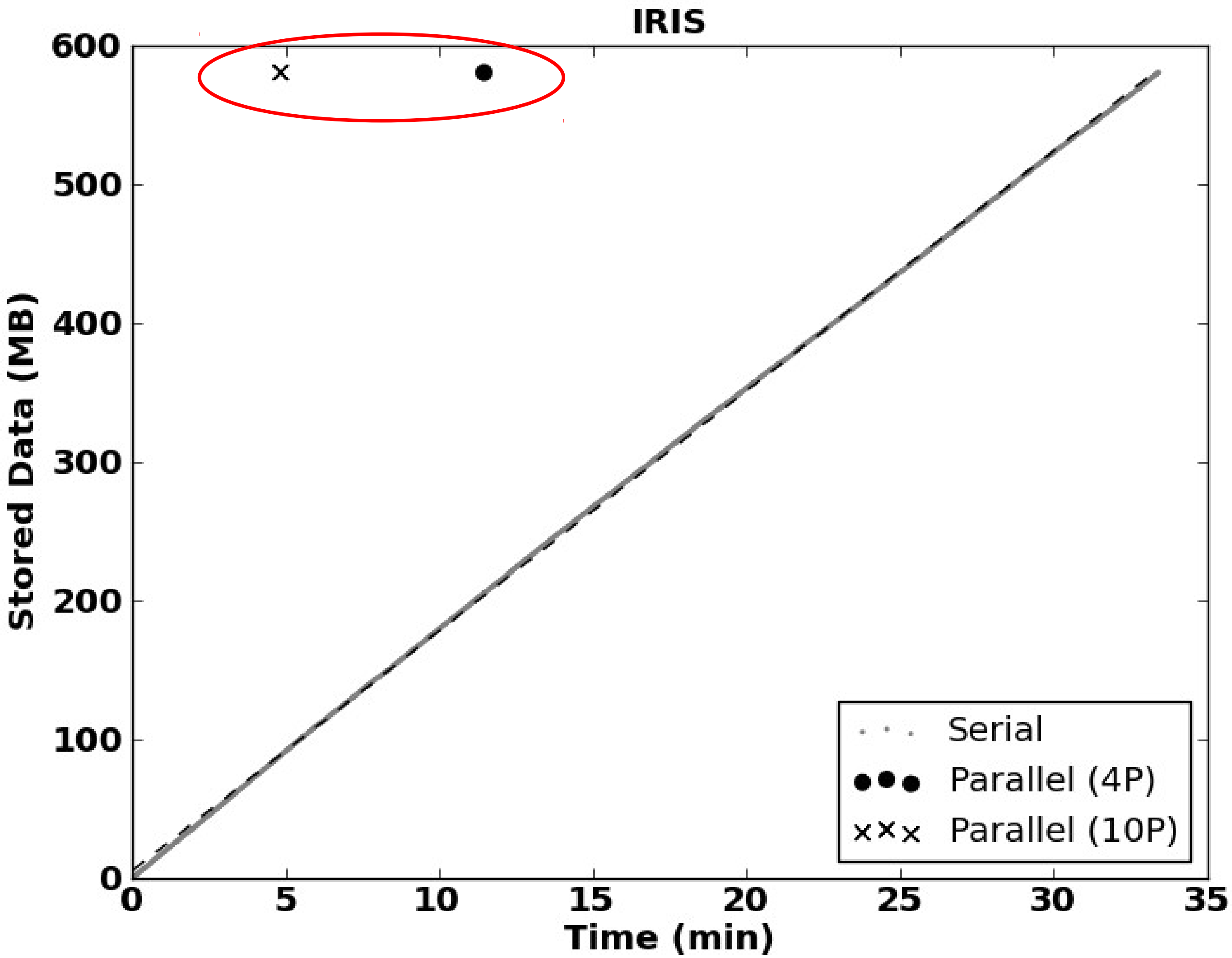


ObsPyDMT (Flowchart) – Event-based request



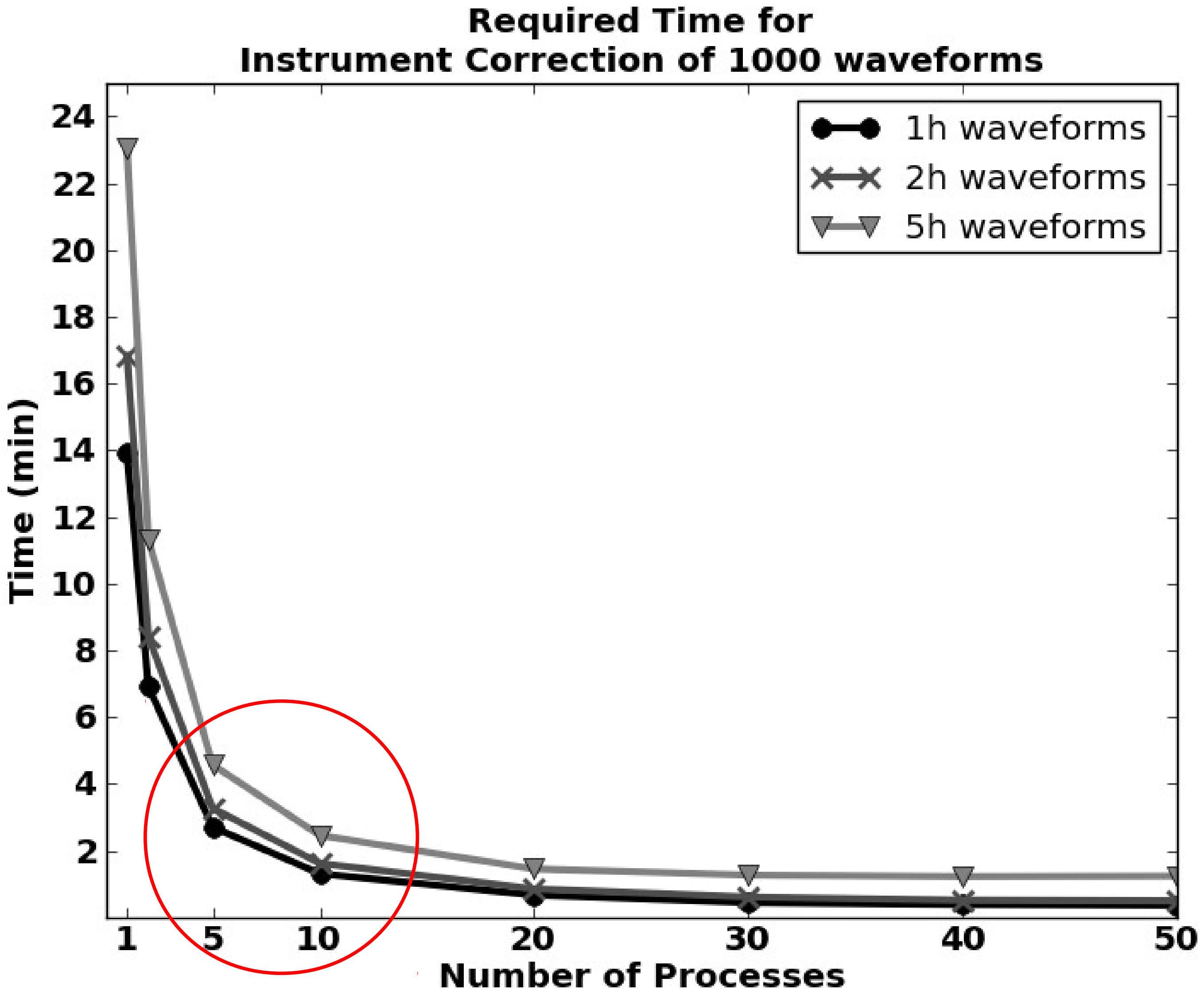
https://github.com/kasra-hosseini/obspyDMT

ObsPyDMT performance (retrieving)



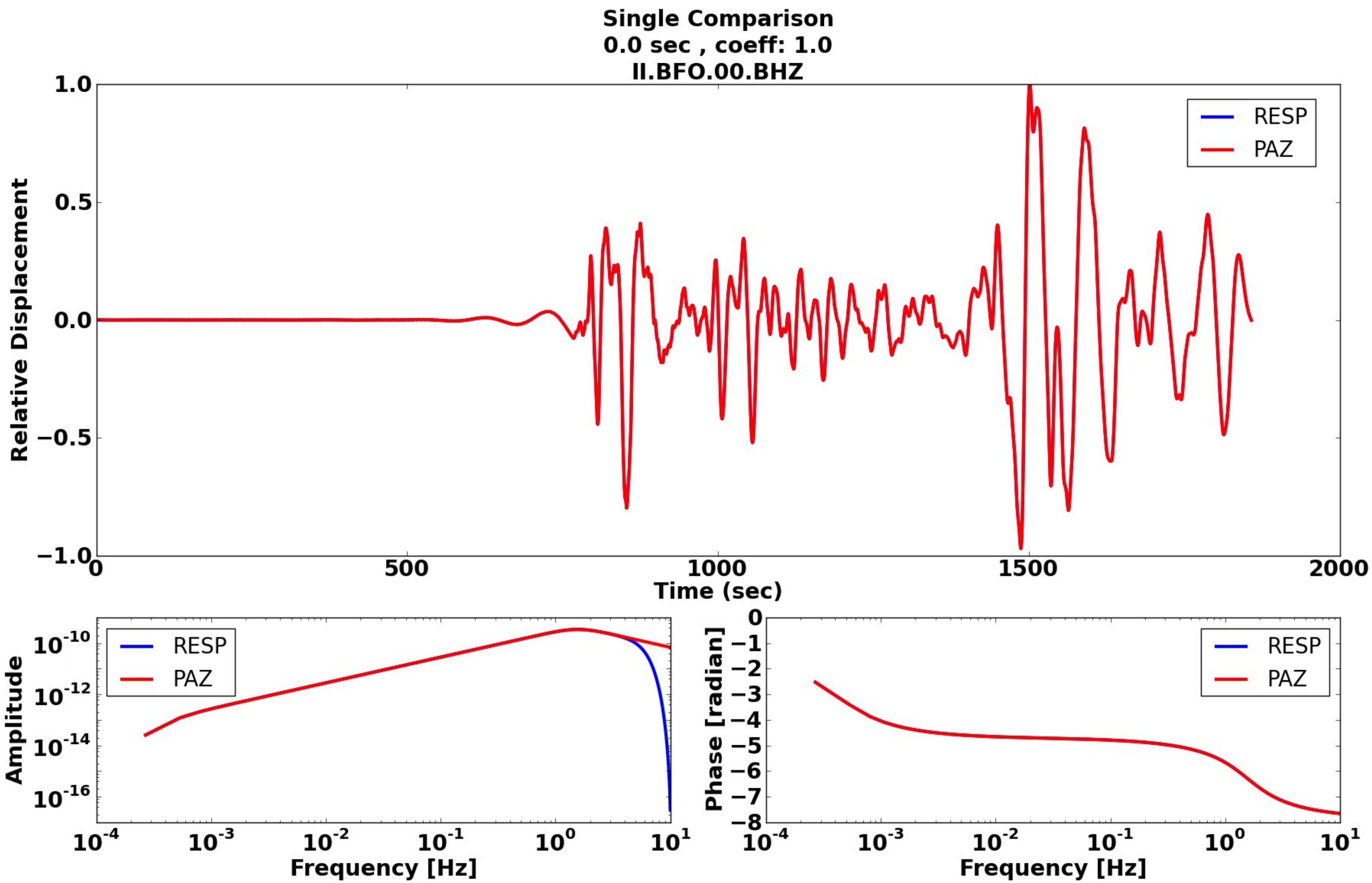
Serial = 0.3 MB/sec – Parallel (4P) = 0.8 MB/sec – Parallel (10P) = 2.0 MB/sec

ObsPyDMT performance (processing)

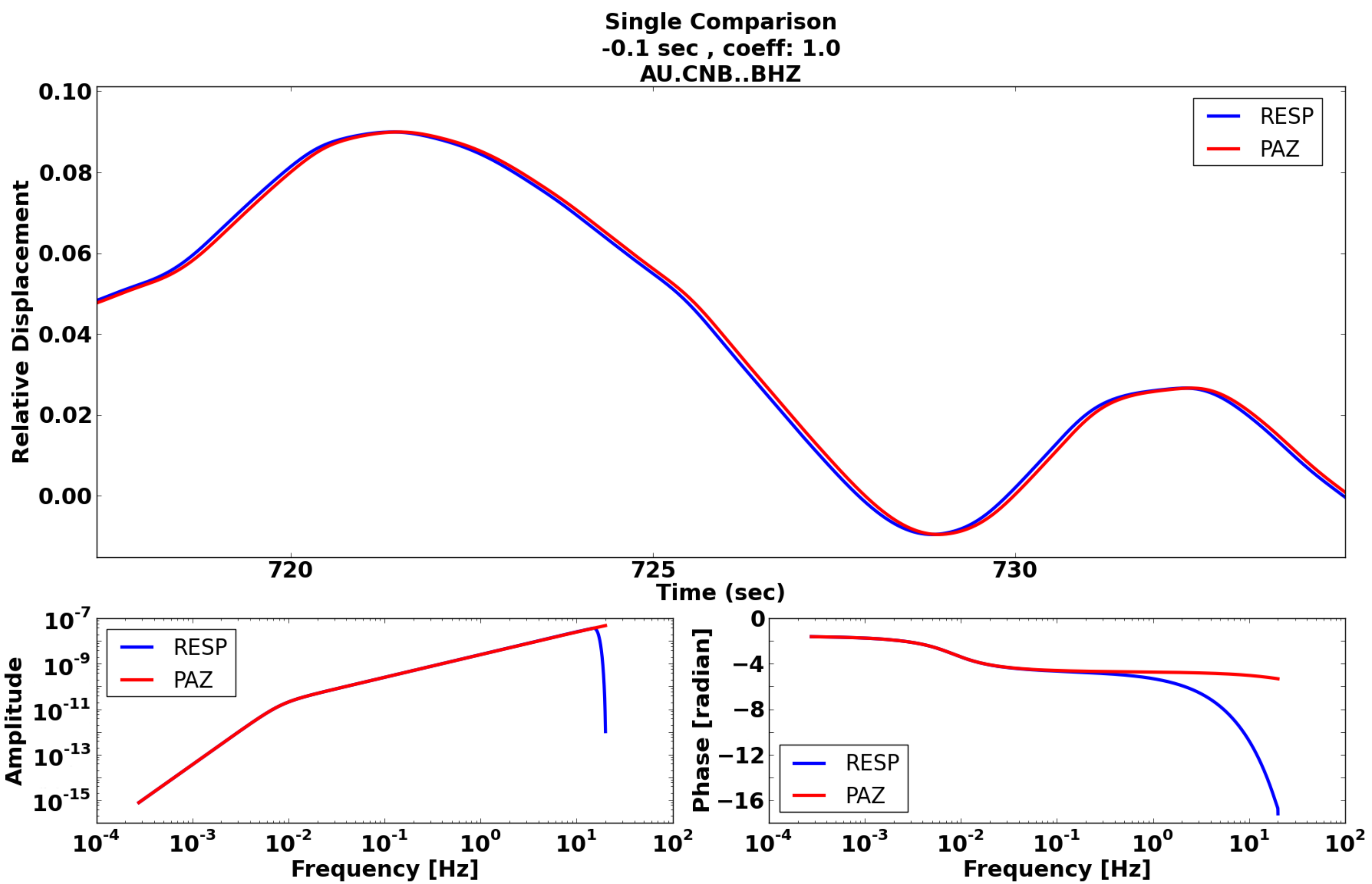


https://github.com/kasra-hosseini/obspyDMT

Instrument correction



Instrument correction

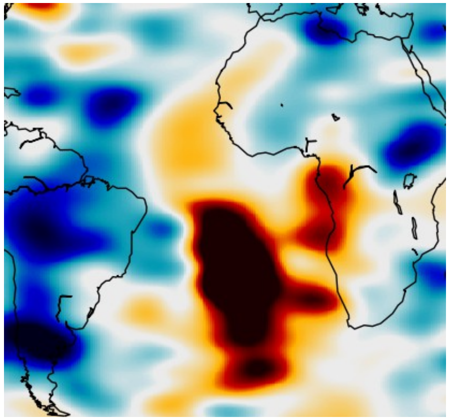


La Reunion?

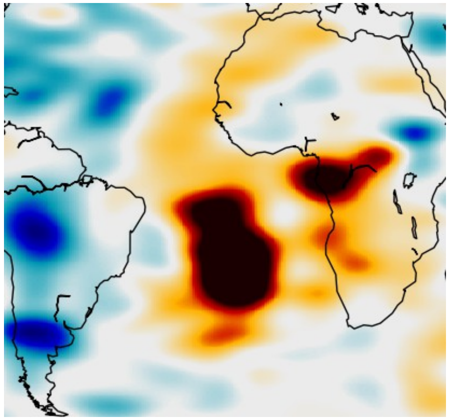
- JUST travel time anomalies projected on CMB without correction (ellipticity, topography and crust)

  ~~tomography model~~
- Poor coverage in some parts of the area
- Other tomography models?
- Combining all the measurements for all the frequencies with correct sensitivity kernels?

30sec



15sec



2.7sec