Towards 3-D seismic structure of the crust and upper mantle beneath Southeast Asia from adjoint waveform tomography

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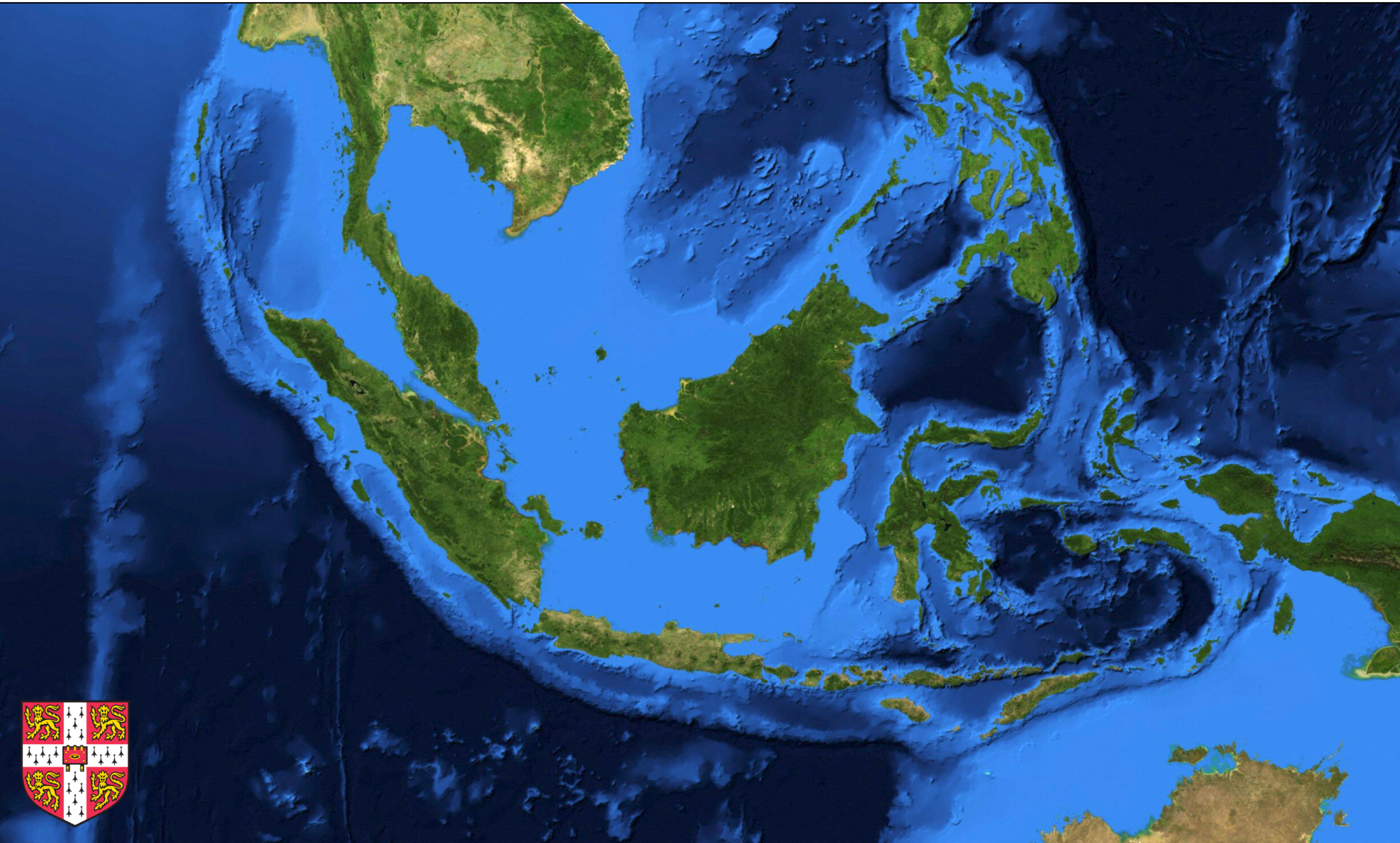


Motivation

- The aim of this project is to obtain a **3-D seismic structural model of the crust and upper mantle** beneath Southeast Asia.

- Southeast Asia is one of the **most complex tectonic regions on Earth** and known to be vulnerable to natural hazards as evidenced by frequent large earthquakes and volcanic eruptions (e.g. Sumatra earthquake in 2004, Krakatoa eruption in 2018).

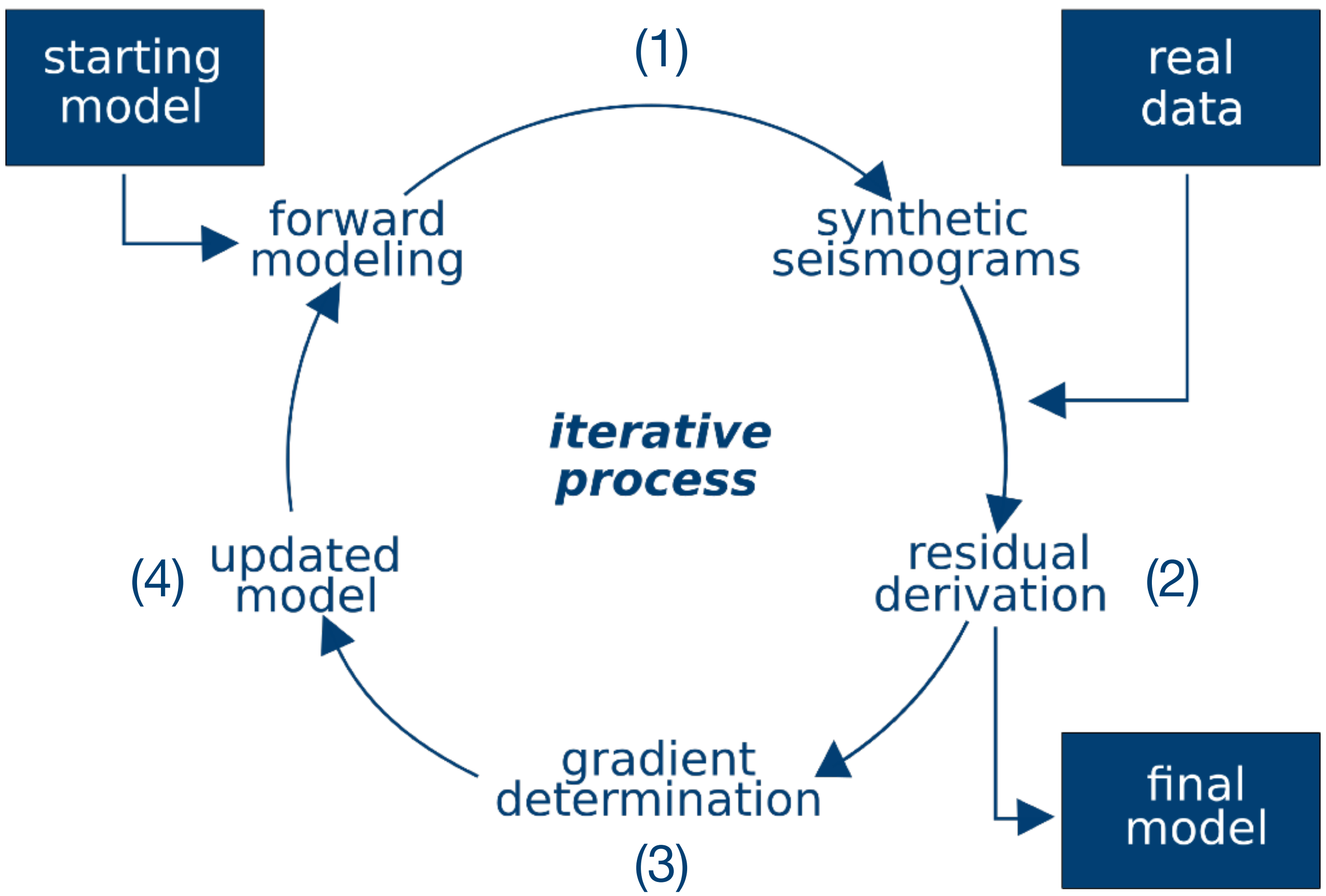
- **Adjoint waveform tomography** is especially suitable for imaging such complex regions since it can account for the effects of anisotropy, anelasticity, wavefront healing, interference and (de)focusing that can hamper other seismological methods.

Mt Kinabalu, Malaysia

Adjoint waveform tomography

Adjoint waveform tomography is an **inverse problem** where an initial model is updated based on the difference between synthetics and observed waveforms.

(1) Synthetic seismograms are computed by **simulating the 3D wavefield**, thereby taking into account both body and surface waves.
(2) Synthetic and observed waveforms are compared using a **suitable misfit measure.**
(3) Sensitivity kernels (and thus the gradient) are computed using adjoint techniques.
(4) The current model is updated using a **gradient-based optimisation scheme** (e.g. L-BFGS).



Data availability

- There are **few public stations** available within the area, mainly targeting hazardous regions.
- However, our recently deployed networks of broadband seismometers on **Borneo and Sulawesi** promise a significant improvement in data coverage, thereby providing new opportunities to untangle the region's complexity.
- The current **event catalogue contains 188 events (M4.5 - 7.7)** which occurred between January 2014 and March 2020 and are distributed spatially as uniformly as possible.

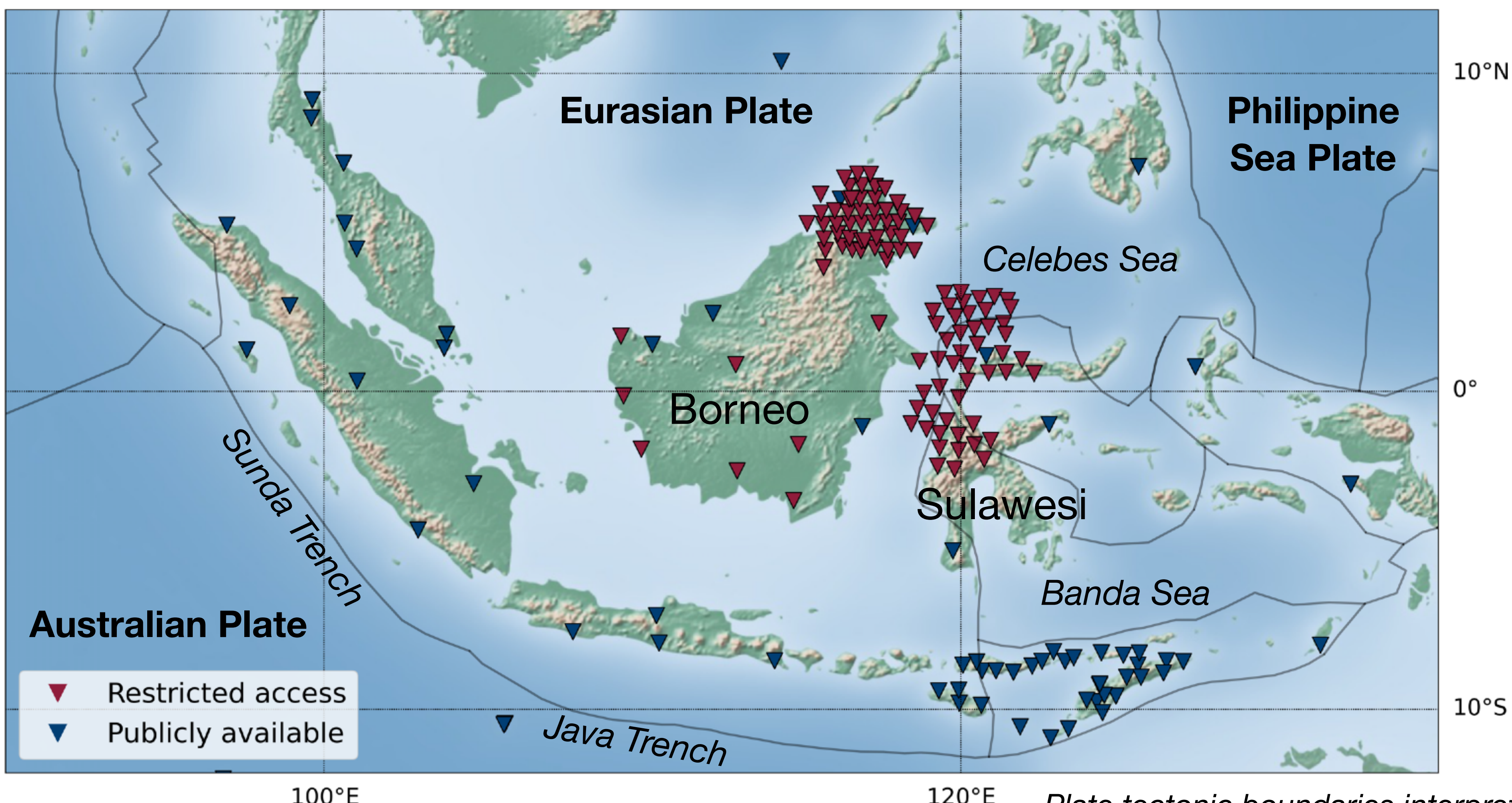


Plate tectonic boundaries interpreted by Bird (2003)

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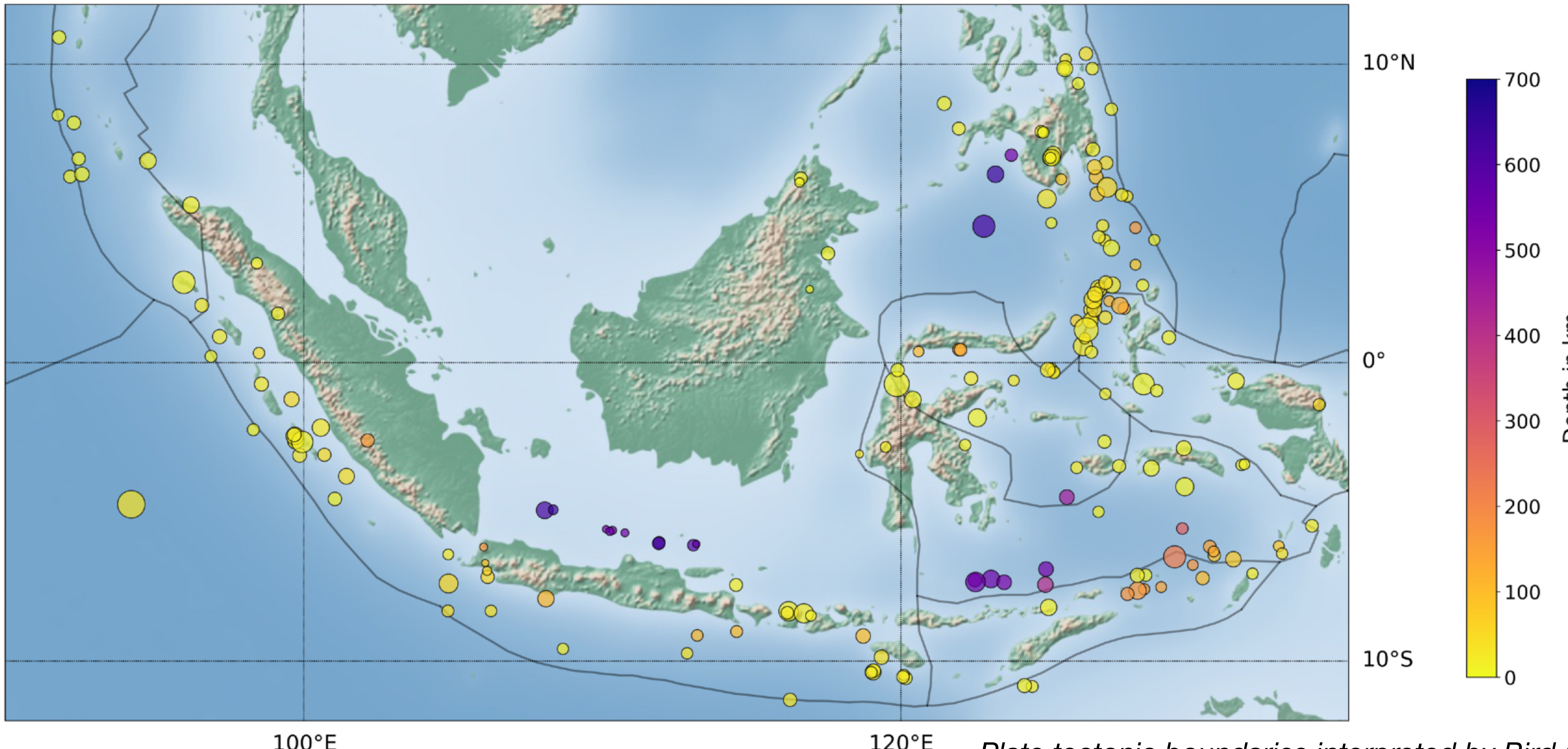
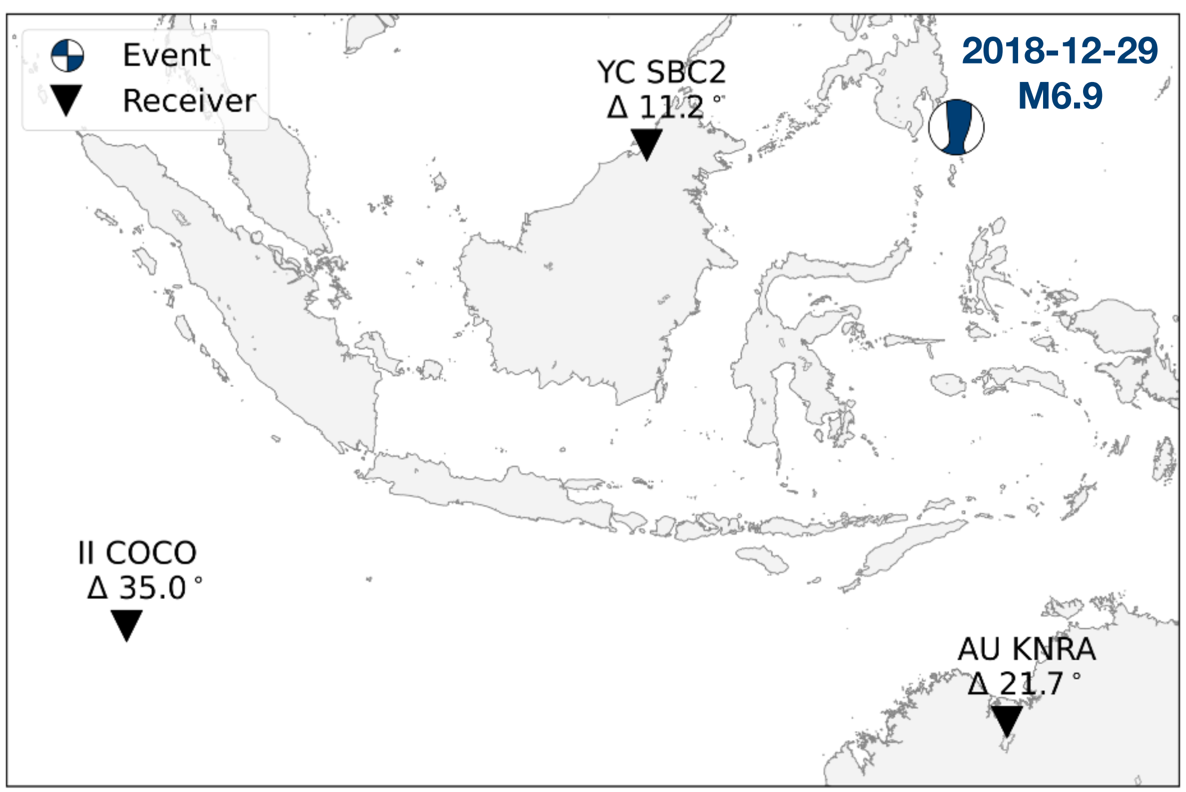


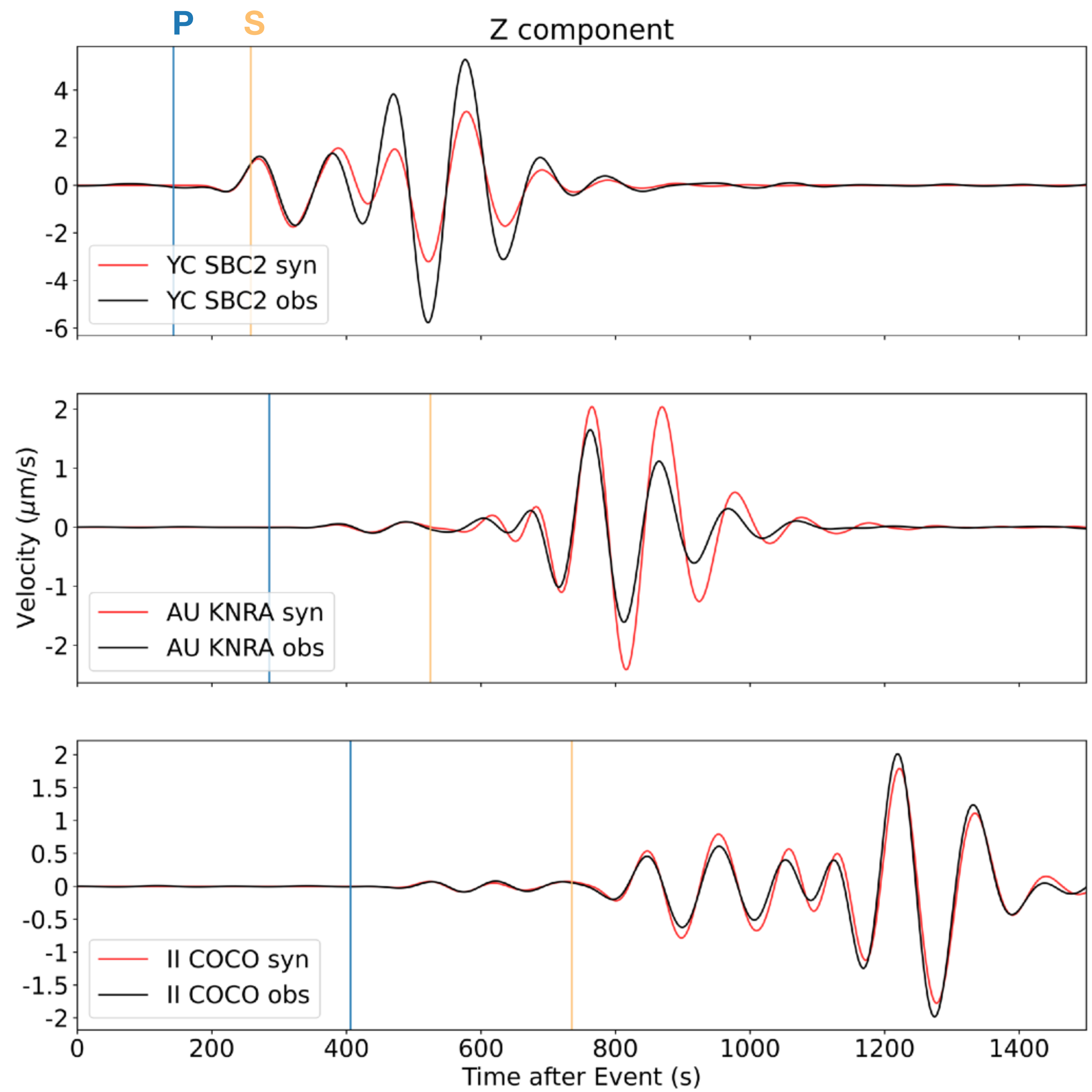
Plate tectonic boundaries interpreted by Bird (2003)

Comparison of seismograms

- Realistic synthetics were obtained using **Salvus** (Afanasiev et al., 2019), accounting for anisotropy, attenuation and topography.
- A **multi-scale approach** (Bunks, 1995) is adopted, which mitigates the risk of entrapment in local minima and cycle skips.
- **Delayed observed waveforms agree with an anomalous low-velocity zone** in the upper few hundred kilometres revealed by several global tomographic studies (e.g. Ritsema, van Heijst, and Woodhouse, 1999; Amaru, 2007)

Period range: 100 - 150 s
Velocity model: PREM[1]





[1] Dziewonski and Anderson, 1981

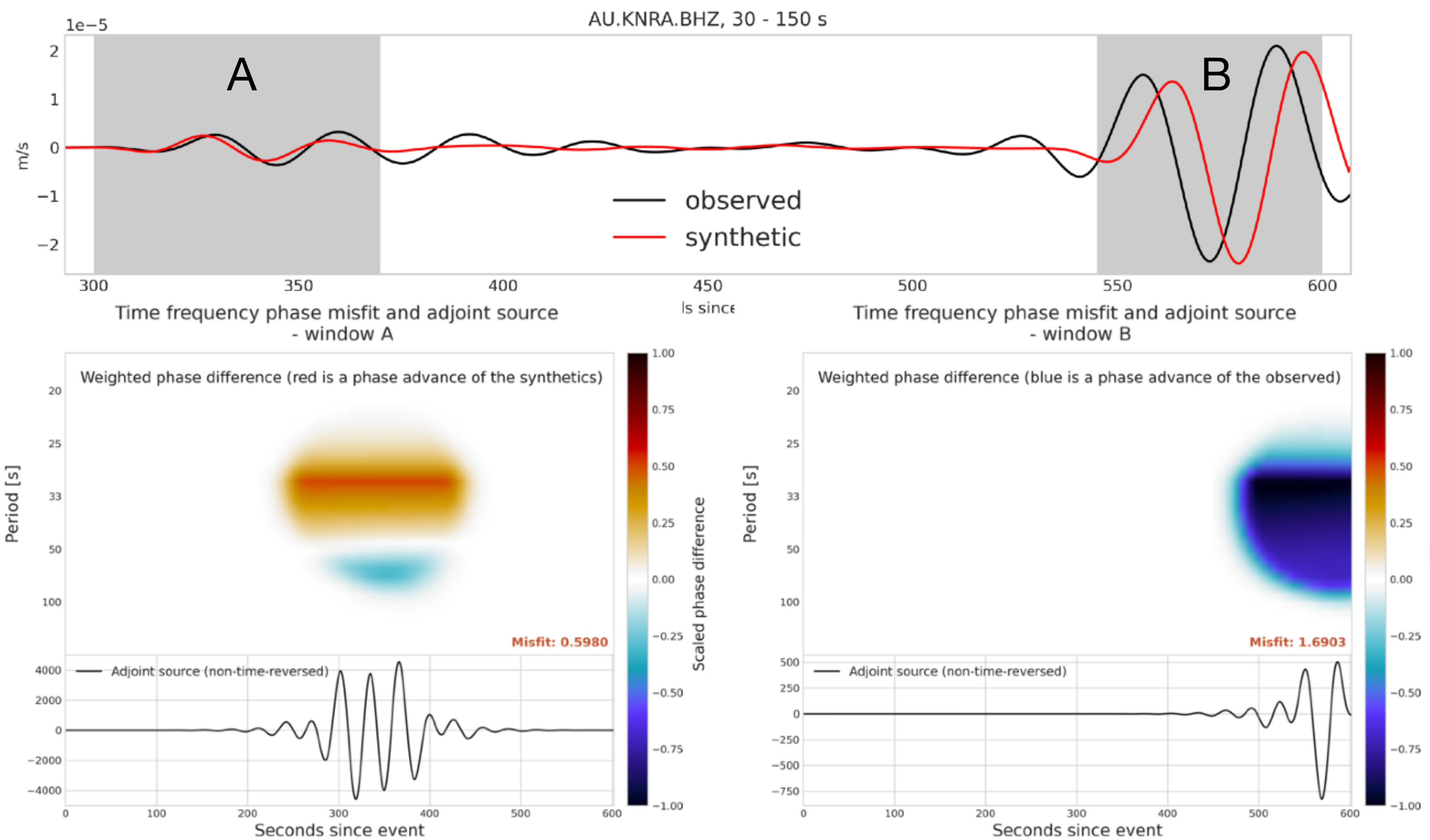
Choice of objective function

- The objective function **defines the measurement(s)** made on a seismogram.

- Finding a suitable objective function remains an active area of research (e.g. Yuan et al., 2020). Most objective functions favour large-amplitude signals, meaning surface waves. Thus, in particular **depth information**, derived mostly from small-amplitude body waves, ends up being lost.

- Sophisticated weighting and window selection algorithms have been introduced to balance amplitude differences (e.g. Krischer et al., 2015), but there is still a **trade-off between including as much signal as possible while avoiding noisy data**.

- Below, we show an example for **frequency-dependent phase misfits** based on the time-frequency transform of both data and synthetics (Fichtner et al., 2008).



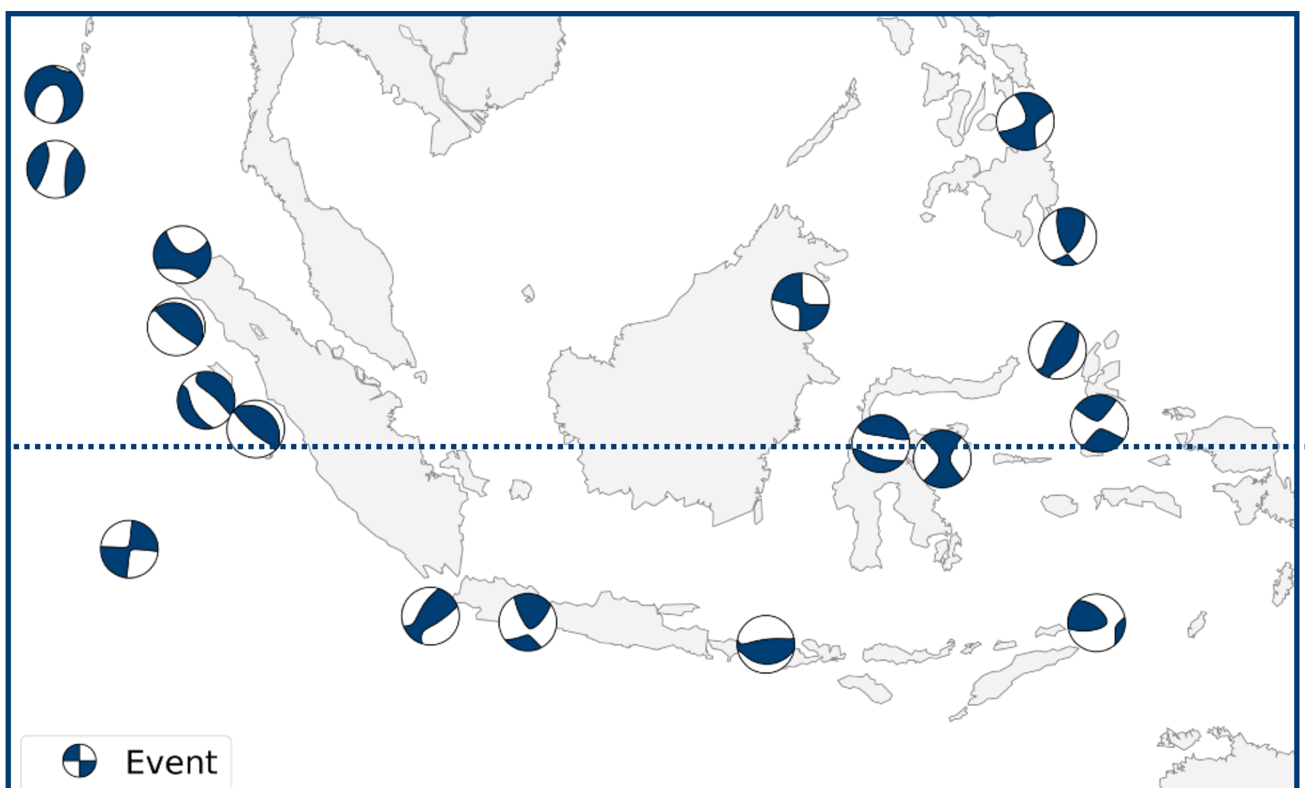
Multi-event kernel

- A smoothed multi-event gradient shows a dominantly positive gradient, which indicates that a **velocity decrease** is required (as expected from delayed observed waveforms).
- Note that source imprints have not yet been removed.

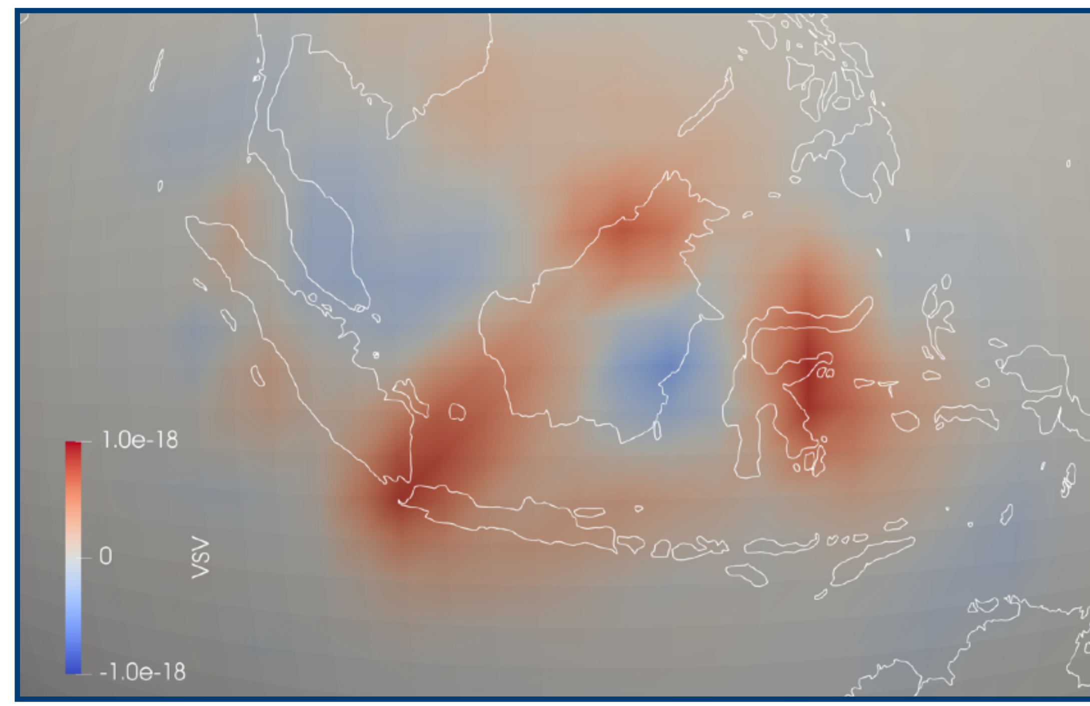
Parameters

18 events (M5.8-7.7)
period range: 100 - 150 s
velocity model: PREM[1]
misfit function: time-frequency misfit (Fichtner et al., 2008)
window picking based on LASIF (Krischer et al., 2015)

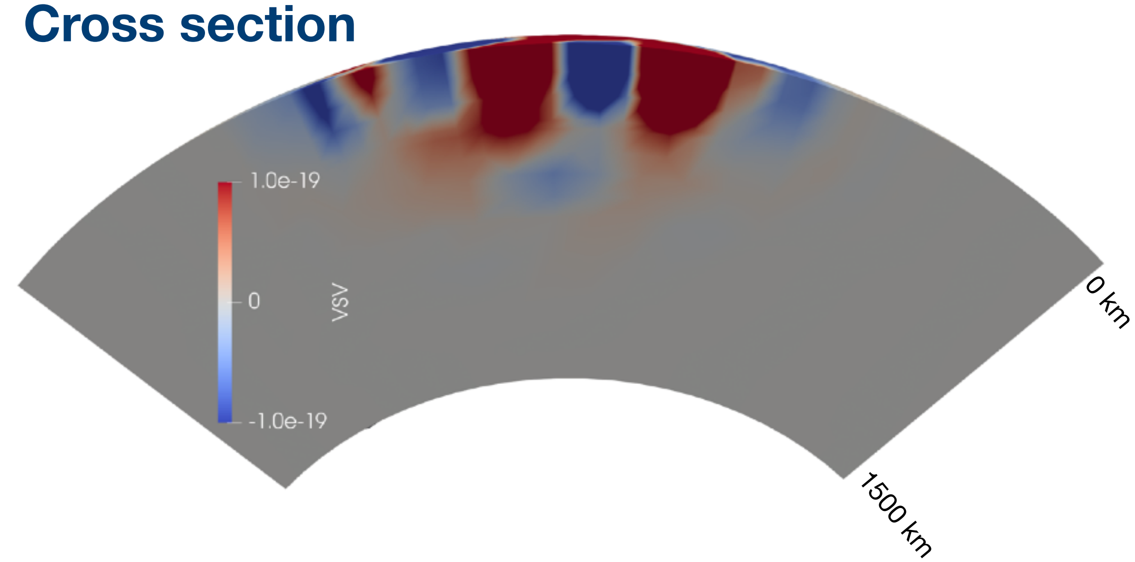
Event locations



Depth slice (100 km)



Cross section



[1] Dziewonski and Anderson, 1981

Next Steps

- Investigate the possibility of enhancing depth sensitivity by optimising the data selection procedure (as suggested by Blom, Gokhberg, and Fichtner, 2020).
- Constrain a large-scale 3-D seismic structural model of the crust and upper mantle beneath Southeast Asia.

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EPSRC bp Schlumberger

Palawan, Philippines

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