"No Data Left Behind"

Efficient waveform processing for global finite-frequency tomography

Seyed Kasra Hosseini zad[a], Karin Sigloch[a], Simon Stähler[a], Tarje Nissen-Meyer[b], and Heiner Igel[a]
(a) Department of Earth and Environmental Sciences (Geophysics), Ludwig-Maximilians-Universität München, Munich, Germany
(b) Institute of Geophysics, ETH Zurich, Zurich, Switzerland
Email: *hosseini@geophysik.uni-muenchen.de*

1. Motivation

The field of seismic tomography is undergoing a rapid shift towards waveform-based methods that explicitly account for scattered wave energy. Our work addresses the problem of the whole-mantle geometry as sampled by body waves, which has **three key characteristics**:

1. Global tomography implies the largest possible data sets: ideally includes all broadband stations worldwide. Rapid data increase due to new station installations.
2. Body waves have shortest possible wavelengths: they yield maximum image resolution but are very expensive to model computationally.
3. Large-scale mantle structure is well represented by weak perturbations to spherical symmetry. The effects of these lateral variations are approximated well by single scattering (Born approximation).

The **goal** is to build a processing chain that:

- Automates waveform retrieval, management, and processing as far as possible.
- Seamlessly integrates the retrieval and processing of the corresponding synthetic waveforms from a forward wavefield library.
- Extracts finite-frequency observables and assembles the corresponding sensitivity kernels.

Main programming tool: Python

Python as an open source interpreter language with its unique characteristics, such as efficient high level data structures, object oriented programming capability, direct access to external shared C/C++, Java and FORTRAN libraries, large collection of open source modules, is the main programming tool for NDLB algorithm.

What is ObsPy?

ObsPy is an open-source project developed at LMU Munich. It provides a framework for processing seismological data, aiming at rapid application development. [*http://obspy.org/*]

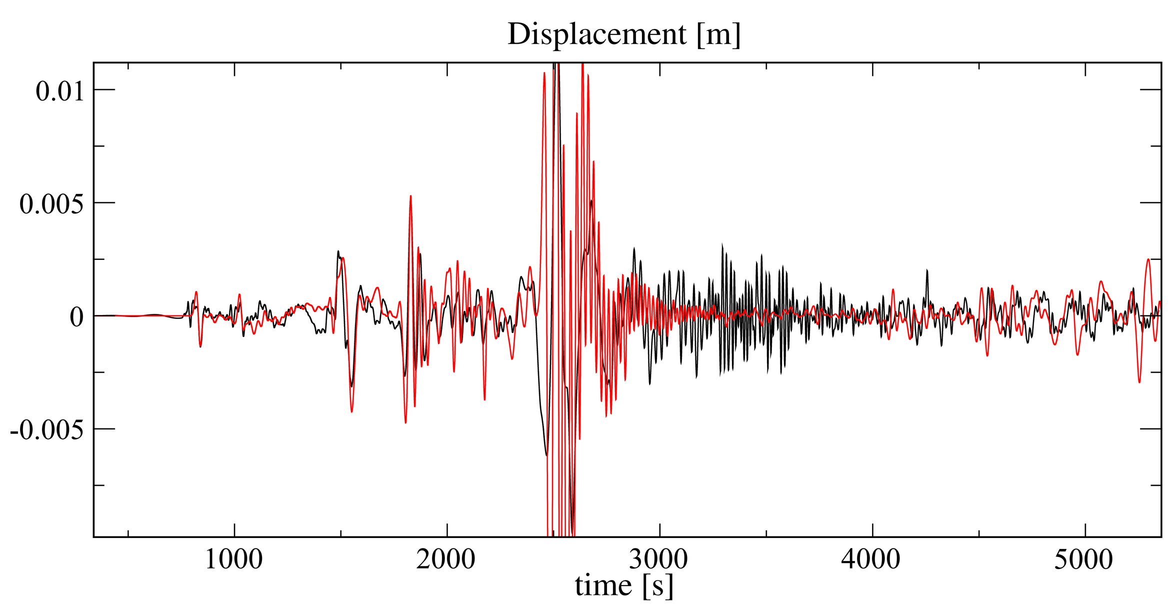
2. Raw Count, Deconvolution and Comparison with Synthetics

Synthetic wave fields are crucial to solve the inverse problem for two reasons:

1. to be compared to observed seismograms when deriving scalar observables (e.g. travel times) and/or computing the misfit function.
2. to compute sensitivity kernels.

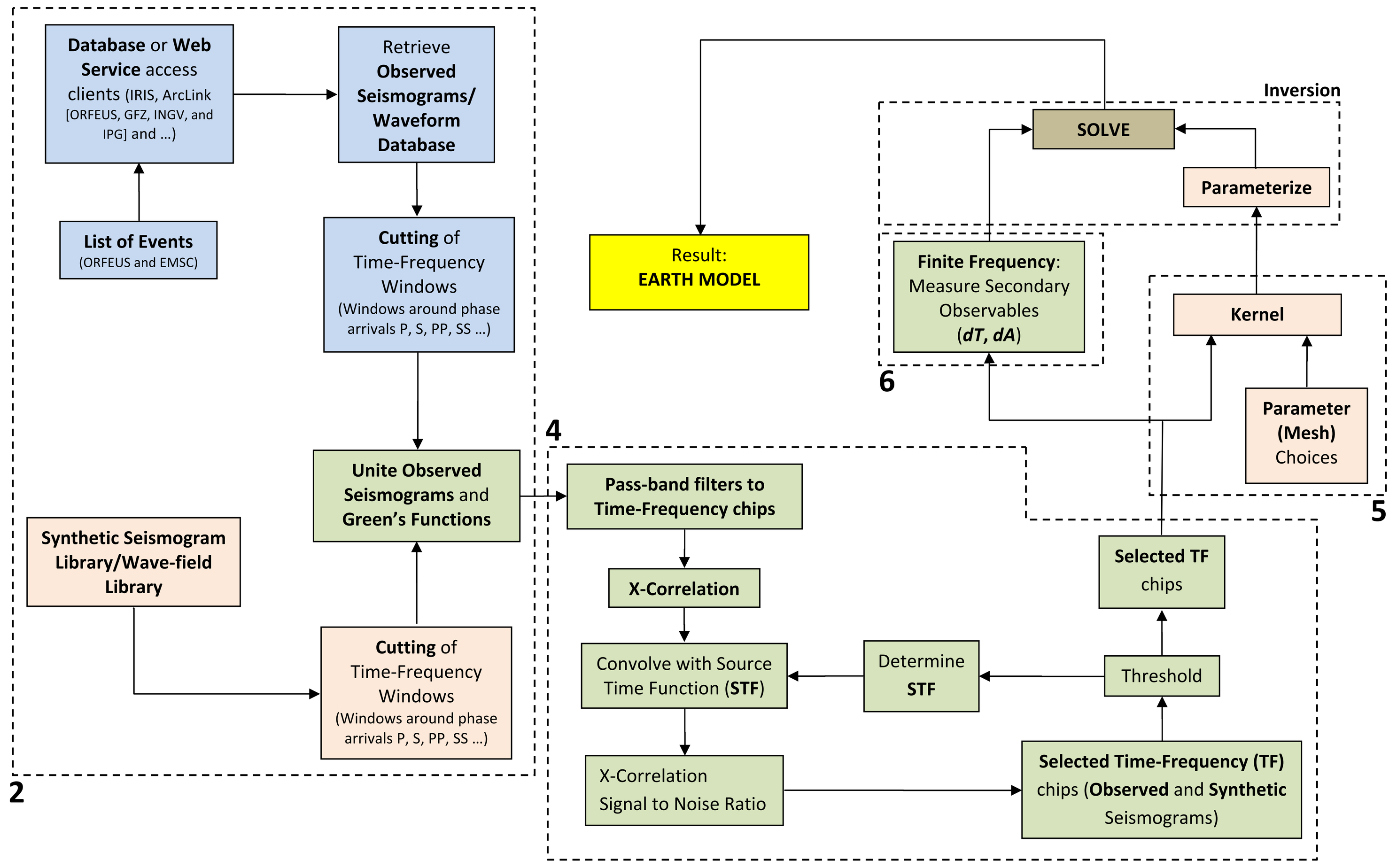
We use the axisymmetric SEM code by Nissen-Meyer et al. (2007). Its computational efficiency allows us to compute seismograms and kernels up to the highest relevant body-wave frequencies. Moreover, **any** fraction of a seismogram in **time** and **frequency** domains is accessible. The former is not feasible with ray theory, and the latter not with 3D numerical wave propagation.

The example below shows the comparison of an observed and a SEM synthetic seismogram up to 50sec dominant period, for the recent large Tohoku-oki earthquake (station BFO, vertical component):



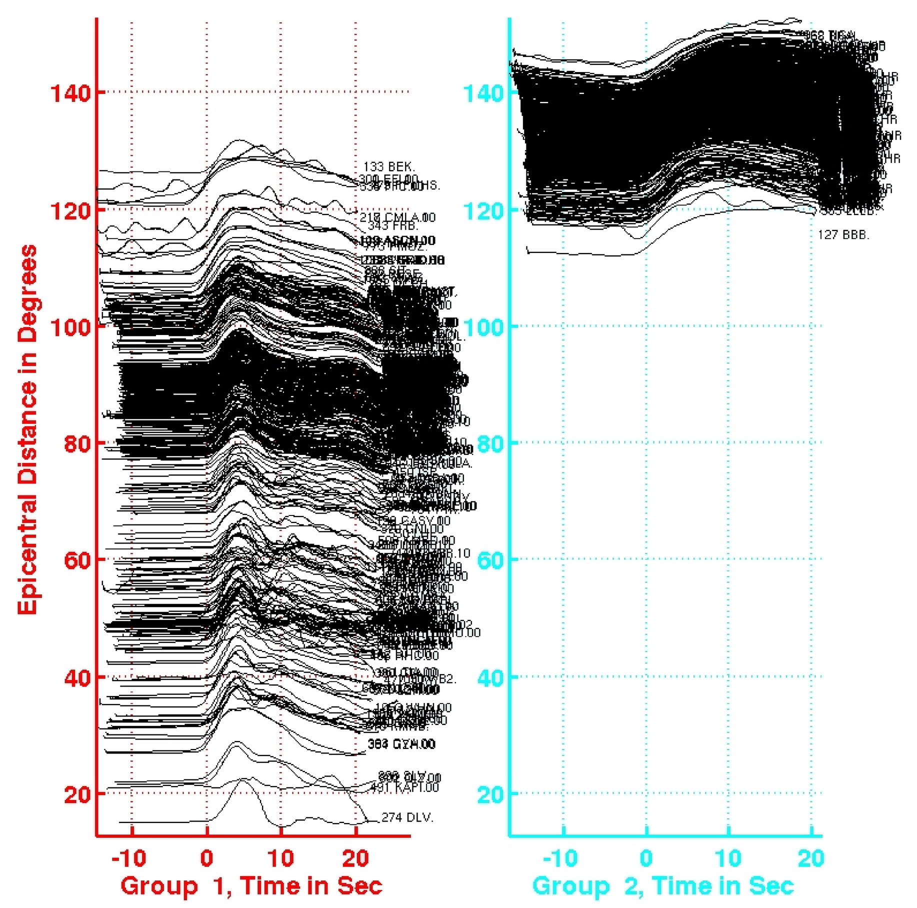
Event: 2011/03/11 05:46:23Z NEAR EAST COAST OF HONSHU, JAPAN
Mag: 9.0, Lat: 38.30, Lon: 142.50, Depth: 21.90

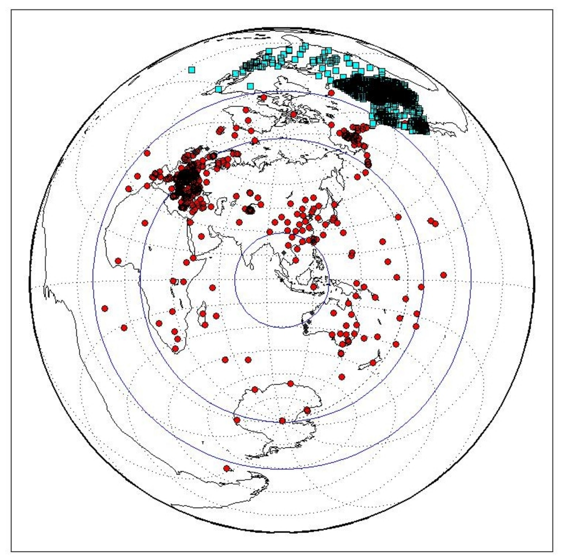
3. NDLB Schematic Algorithm

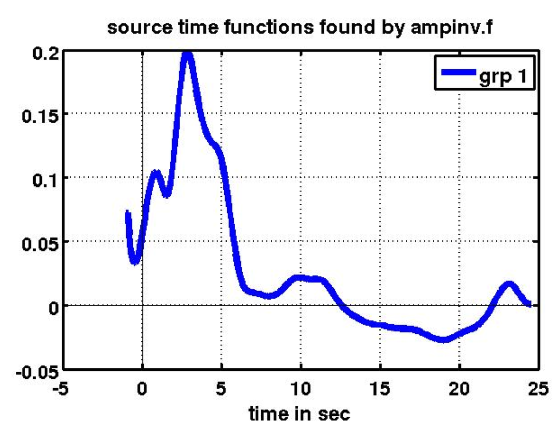


4. Quality control and deconvolution of the source time function

Broadband recordings of P and Pdiff waves. This SOUTHERN SUMATRA earthquake (mb=7.5, depth 81 km) generated a large number of core-grazing wave paths and therefore samples the deepest part of the mantle.

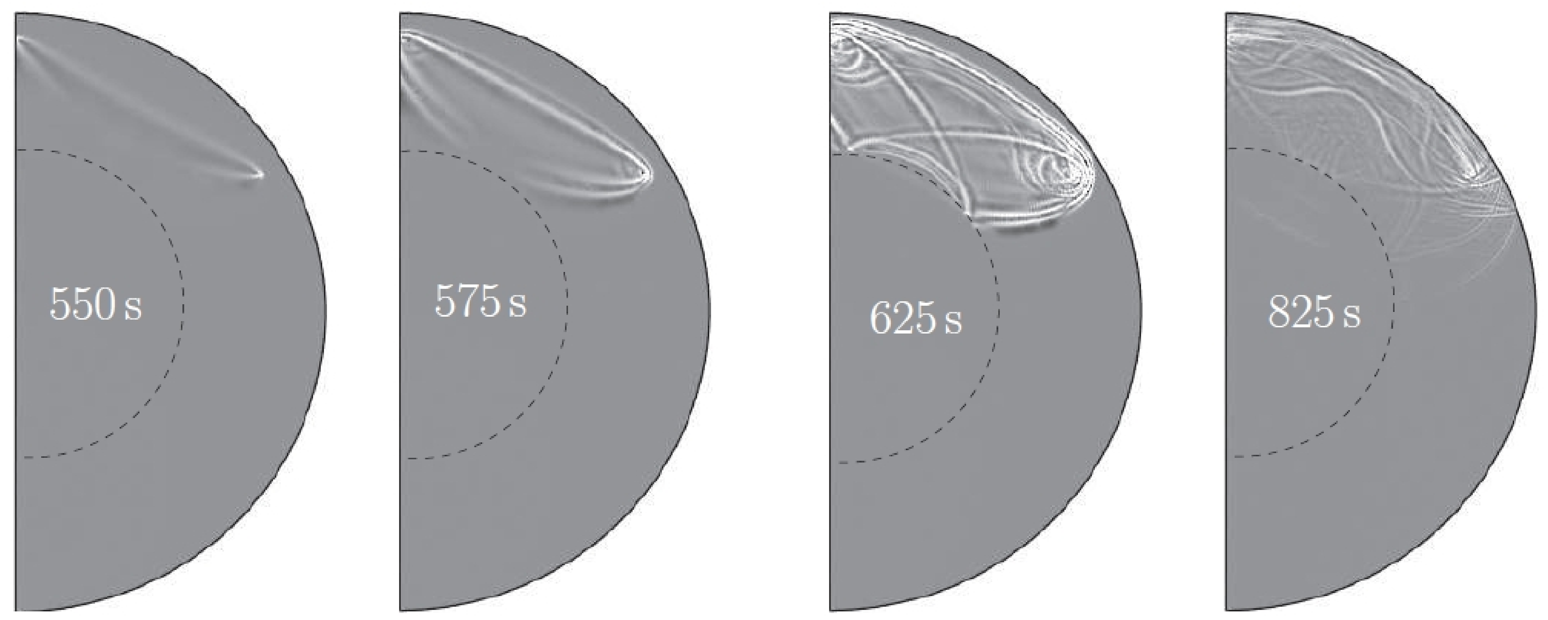






Event: 2009/09/30 10:16:09.249 SOUTHERN SUMATRA, INDONESIA
Mag: 7.5, Lat: -0.72, Lon: 99.87, Depth: 81.00

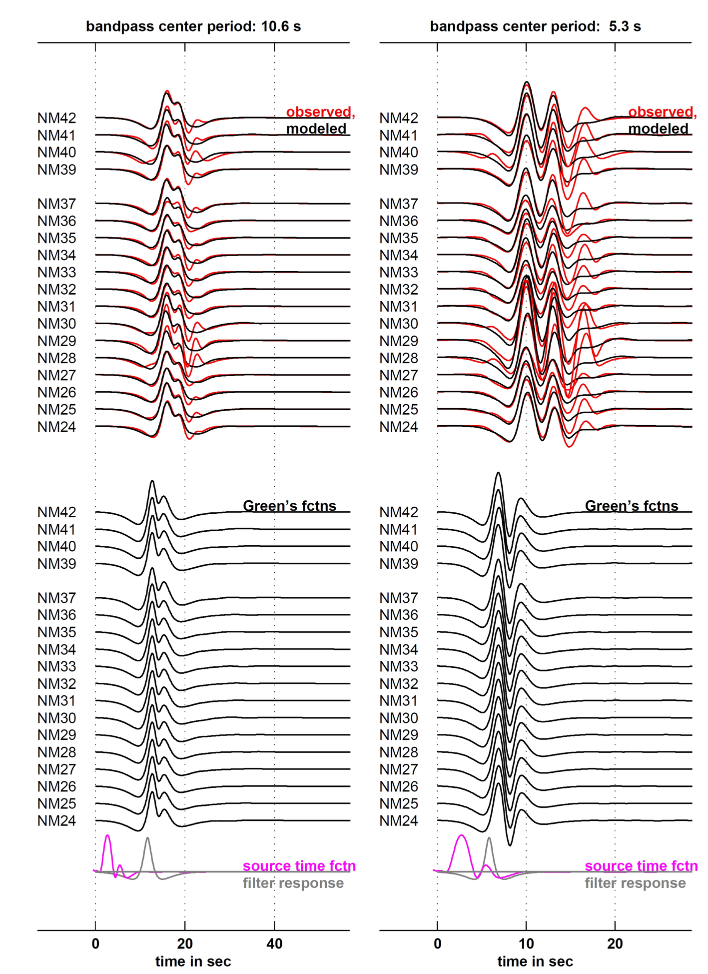
5. Sensitivity kernels from full waveform forward modeling



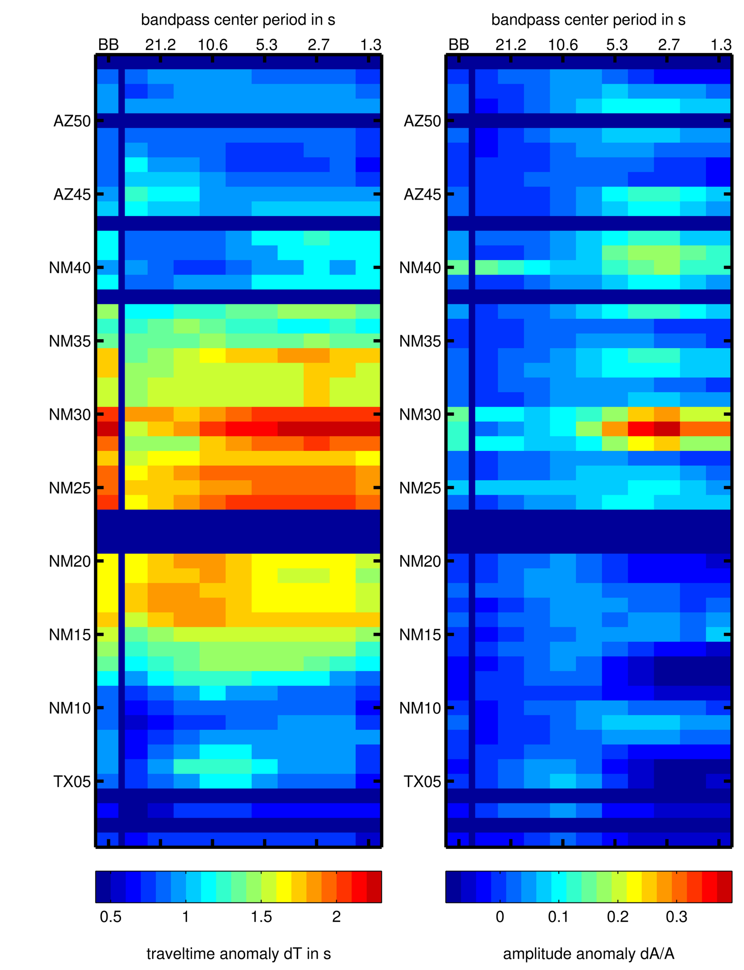
We use full-waveform modeling to compute synthetic seismograms and Born sensitivity kernels. The expensive sensitivity kernels are computed only once, through a spherically symmetric reference model, but to the highest relevant frequencies ($\sim$ 0.5 Hz dominant), using the axisymmetric SEM code by Nissen-Meyer et al. (2007). This code is computationally efficient enough to reach the highest frequency range, for the large number of source-receiver combinations required in global-scale tomography.

Panels show the temporal evolution of the cumulative waveform sensitivity since rupture time, for a wave train comprising phases direct P wave, depth phase pP, core reflection PcP, and first and second surface multiples PP and PPP.

6. Finite-frequency measurements on the bandpass-filtered seismograms



Fits between data and synthetics at dominant period of 10s (left) and 5s (right)



Finite-frequency measurements (travel-time and amplitude anomaly) on the bandpass-filtered data and synthetics

Event: 2000/06/21 00:51:47 ICELAND
Mag: 6.5, Lat: 64.00, Lon: -20.64, Depth: 17.10