# Dynamic source inversion of the 2014, Mw6 South Napa, California, earthquake

Jan Premus[1], *janpremus@seznam.cz*,
František Gallovič[1], *gallovic@karel.troja.mff.cuni.cz*

1. Faculty of Mathematics and Physics, Charles University, Prague

# Dynamic rupture modelling – the FD3D_TSN code

- Efficient computer code for modelling of the dynamic earthquake source (Premus et al., 2020)

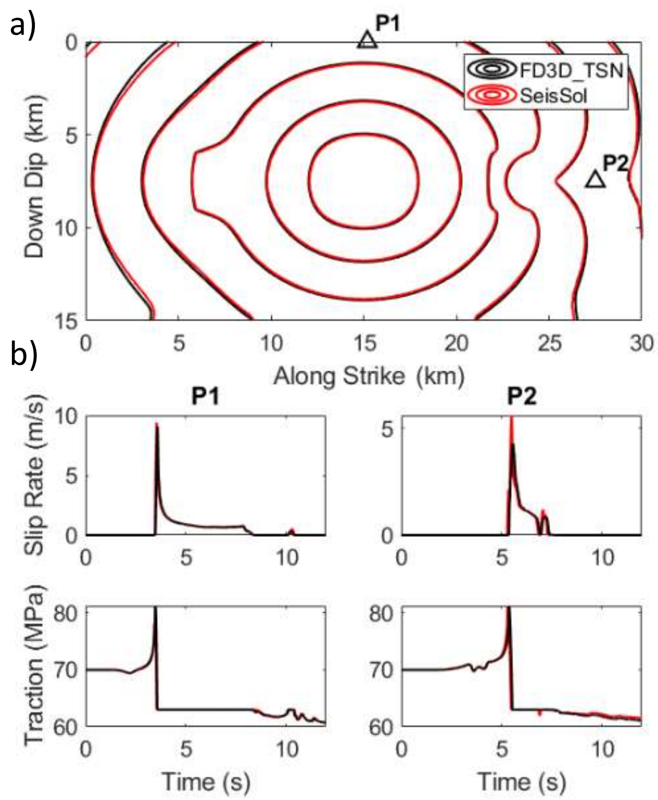
- Freely available at [https://github.com/JanPremus/fd3d_TSN](https://github.com/JanPremus/fd3d_TSN)

- Vertical planar fault with slip-weakening and fast-velocity weakening laws of friction implemented in the fault boundary condition

- Finite difference calculations accelerated using GPU (OpenACC directives)

| **Discrete step (m)** | **Degrees of freedom x time steps (RAM requirement)** | **Single-core wall clock time (s)** | **GPU accelerated wall clock time (s)** |
|---|---|---|---|
| **100** | 54,558,900 x 3000 (210 MB) | 0:3:12 | 0:0:22 |
| **50** | 389,491,200 x 6000 (1490 MB) | 0:39:13 | 0:3:47 |

*USGS/SCEC TPV5 benchmark (Harris et al., 2018) – Table showing performance of single CPU/GPU accelerated versions of the code*
*Comparison of solutions between FD3D_TSN and SeiSol codes: a) Rupture time contour plot b) Slip rate and traction plots in chosen positions (shown in a)) at the fault*



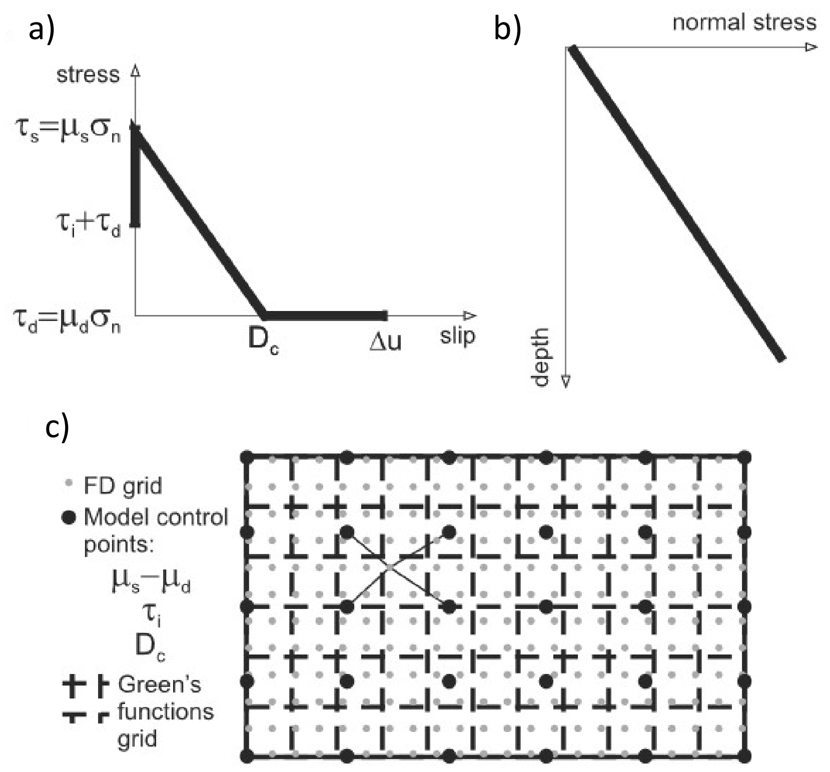
# Dynamic inversion

- Bayesian dynamic inversion suite fd3d_tsn_pt (Gallovič et al., 2019) https://github.com/fgallovic/fd3d_tsn_pt with FD3D_TSN as a forward solver

- We perform inversion of strong ground motions (usual frequency range 0.05 – 0.5 Hz), using random walk on dynamic model space

- Apriori constraints on dynamic parameters, size of the nucleation zone and maximum overstress

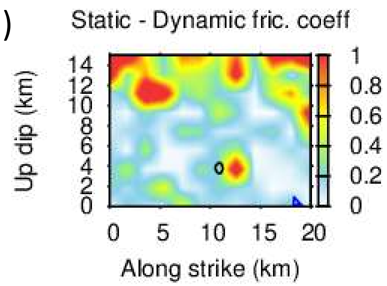
- Synthetic seismograms calculated using precalculated (AXITRA code, Bouchon, 1981) Green's functions




*Parametrization of the rupture model: a) Schematic of the slip-weakening friction law and its parameters, b) Normal stress depth profile c) Illustration of three grids considered in the calculations – i) Finite difference grid ii) model parameter grid (coarsest) iii) Green's functions grid. When changing between grids, values are either spatially averaged (coarser -> denser), or bilinearly interpolated (denser -> coarser) (Adopted from Gallovič et al., 2019)*

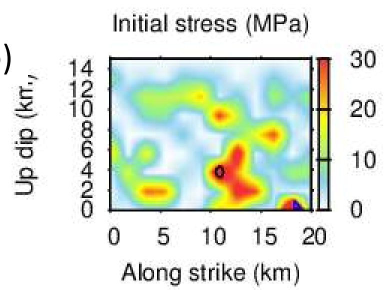
# 2014, South Napa earthquake – best dynamic model

a)



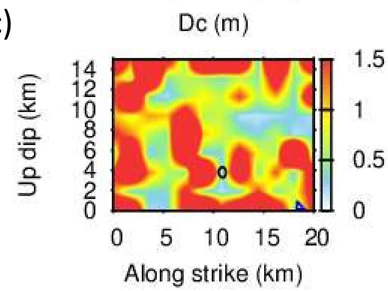

- We performed a dynamic inversion of the 2014, South Napa earthquake.
- Tests with east/west dipping fault geometries (Pollitz et al., 2019) did not show any relevant difference (east-dipping is used here).

b)

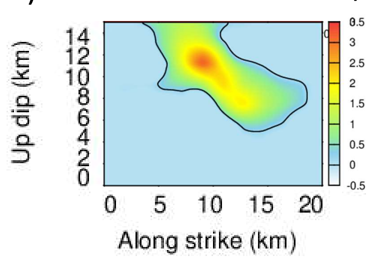



*Spatial distribution of dynamic parameters: a) Static - Synamic friction. b) Prestress. c) Slip weakening distance Dc. d) Final slip e) Moment rate function f) Snapshots of the slip rate and the wavefield.*

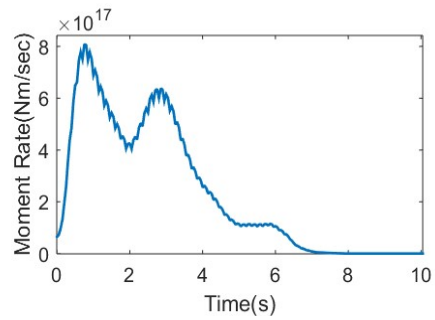
c)



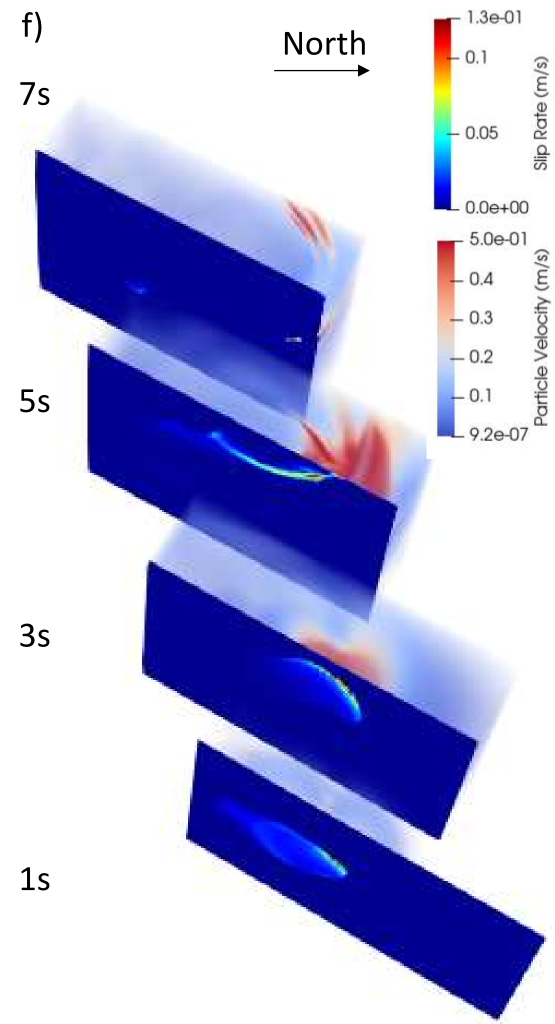

d)




e)



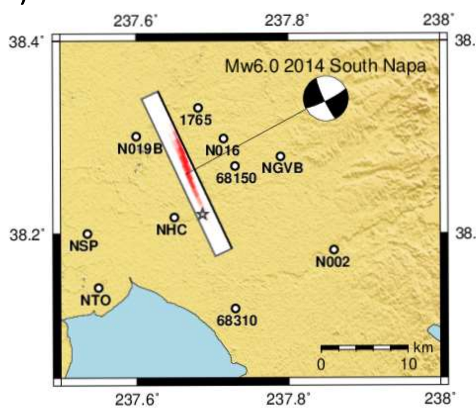

f)



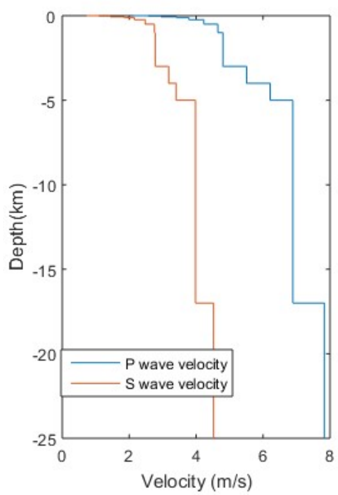
# 2014, South Napa earthquake – seismograms

- For strong ground motions (used for inversion), the variance reduction is 0.49.
- Modelled high frequency seismograms are comparable, some features are missing - shorter length of the synthetic seismogram, high frequency motions smaller on some stations.

a)

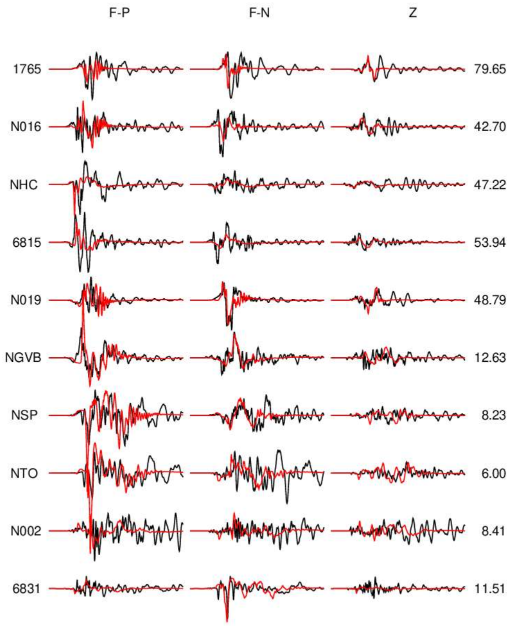



b)




c)


d)

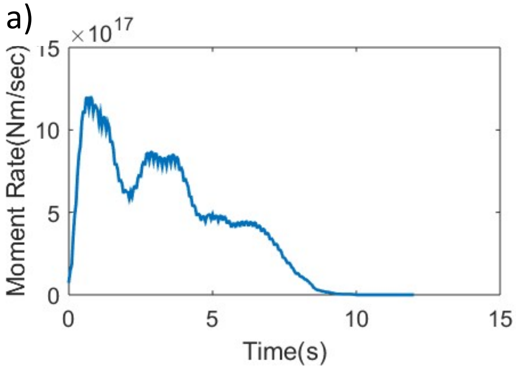



*a) Map showing orientation of fault with final slip, source mechanism, and positions of stations used for the inversion.*
*b) Velocity model. Measured (black) and synthetic (red) seismograms c) up to 0.5 Hz d) up to 5 Hz*

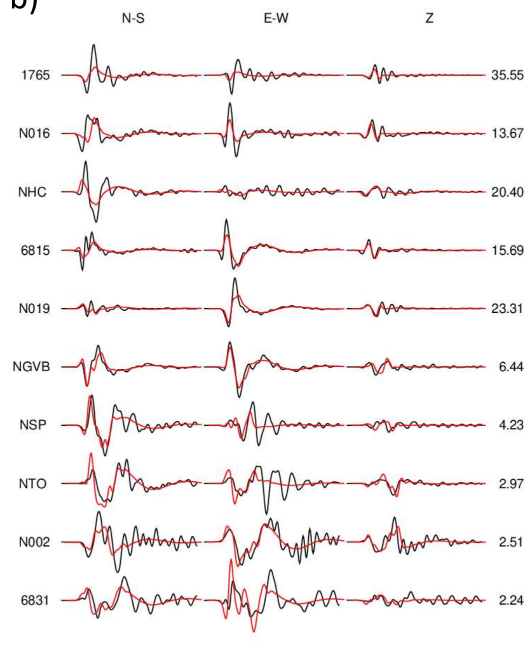
# Outlook – addition of the fault zone

- Fault zone of damaged material is simulated as a decrease in s wave velocity/shear modulus
- Test case – addition of fault zone (width 500m and velocity reduction 30%) into already presented dynamic model
- Low frequency seismograms practically unchanged (variance reduction drop from 0.49 to 0.47)
- High frequency seismograms (station N019) show oscillations due to near surface velocity model
- We notice overall longer duration of both rupture propagation (from 8s to 9s) and seismograms (e.g. station 6831)

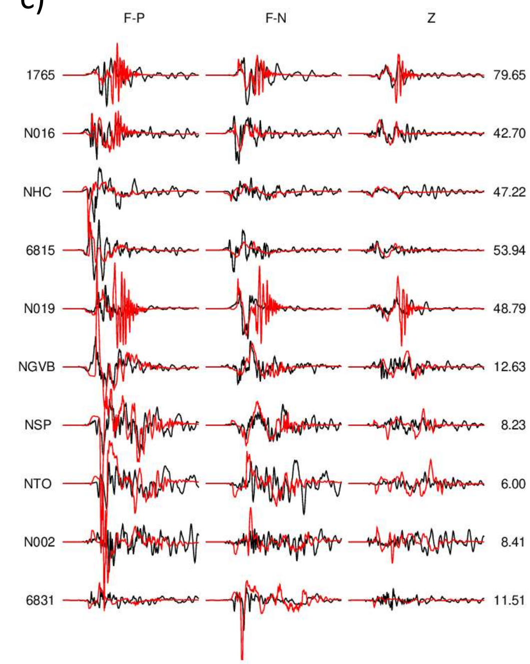
a)




b)




c)




*a) Moment rate function. Measured (black) and synthetic (red) seismograms b) up to 0.5 Hz c) up to 5 Hz*

# Conclusions

- We performed a dynamic inversion of 2014, South Napa earthquake, constraining its dynamic parameters.

- Resulting model was further used to model high frequency ground motions showing good results, but underperforming (lower modelled ground motions) on several stations.

- Addition of a low-velocity fault zone into the dynamic model offers a promise of improving high frequency radiation.

- While an addition of the fault zone did not impact low-frequency seismograms, we are planning to perform a dynamic inversion with a fault zone to further optimize the dynamic model.

# Citations and acknowledgements

We acknowledge financial support through the bilateral project of the CzechScience Foundation and DFG, 1806716J and GA 2465/21,respectively. Jan Premus acknowledges support from Charles University grant SVV 115-09/260447.

**Citations:**

Gallovič, F., Ľ. Valentová, J.-P. Ampuero, and A.-A. Gabriel, Bayesian Dynamic Finite-Fault Inversion: 1. Method and Synthetic Test, *J. Geophys. Res. Solid Earth*, 2019.

Bouchon, M., A simple method to calculate Green's functions for elastic layered media, *Bull. Seismol. Soc. Am.* 71,959–971,1981.

Premus, J., F. Gallovič, L. Hanyk, and A.-A. Gabriel, FD3D_TSN: Fast and simple code for dynamic rupture simulations with GPU acceleration. *Seis. Res. Lett. (Accepted).*

Harris, A. R., K. Bai, and J. P. Ampuero et al., A suite of exercises for verifying dynamic earthquake rupture codes. *Bulletin of the Seismol. Soc. Am*., 2018.

Pollitz, F. F., Murray, J. R., Minson, S. E., Wicks, C. W., Svarc, J. L., and Brooks, B. A., Coseismic slip and early afterslip of the M6.0 24 August 2014 South Napa, California, earthquake. *Journ. of Geophys. Res. : Solid Earth*, 124, 11728–11747, 2019.