Efficient Finite Difference Code for Dynamic Source Inversions

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Outline

We introduce fast finite difference code FD3D_TSN for simulations of dynamic earthquake rupture propagation based on FD3D code by Madariaga et al. [1998].
Tests using USGS/SCEC benchmarks TPV5 and TPV104 [Harris et al., 2018] are performed and accuracy assessed by comparison of the results with FaultMod code by Barall [2009].
As an example application, we show the result of the dynamic inversion of the 2014 Mw6.0 South Napa, California, earthquake and compare it with model from the kinematic inversion by Gallovic [2016].

Code description

- 3D staggered grid finite difference method [Madariaga et al., 1998]
- Traction at split node implementation of the fault boundary condition [Dalguer and Day, 2007]
- Two friction laws implemented: slip weakening, and fast velocity weakening rate and state [Rojas et al., 2009]
- Vertical fault only
- Utilizing antisymmetry of shear components of velocity and stress across the fault - FD calculations in half of the domain
- Stress imaging implementation of the free surface
- Perfectly matched layers absorbing boundary condition
- Parallelization for GPU using OpenACC directives

TPV5 benchmark

- Vertical strike slip fault
- Slip-weakening friction law
- Homogeneous distribution of material and dynamic parameters with the exception of three prestress heterogeneities
- Parts of the fault rupturing at supershear speed
- Nucleation at the central heterogeneity

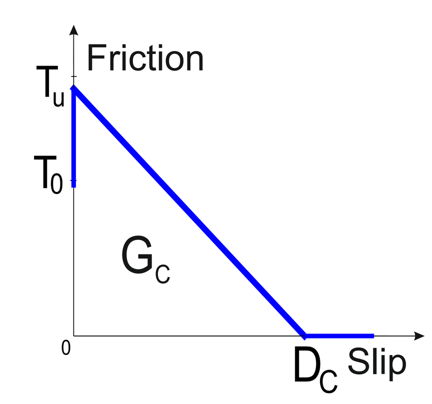

Figure 1: The linear slip-weakening friction law

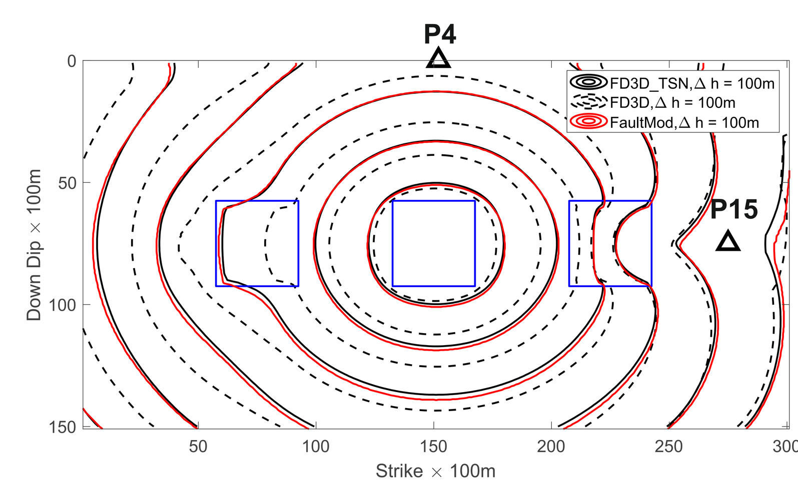

Figure 2: Rupture time contour plot for the TPV5 benchmark. Blue squares denote positions of the predefined stress heterogeneities. Results of FD3D_TSN (black line) and FaultMod (red line) are practically identical, while FD3D (dashed line) shows significantly lower rupture speed.

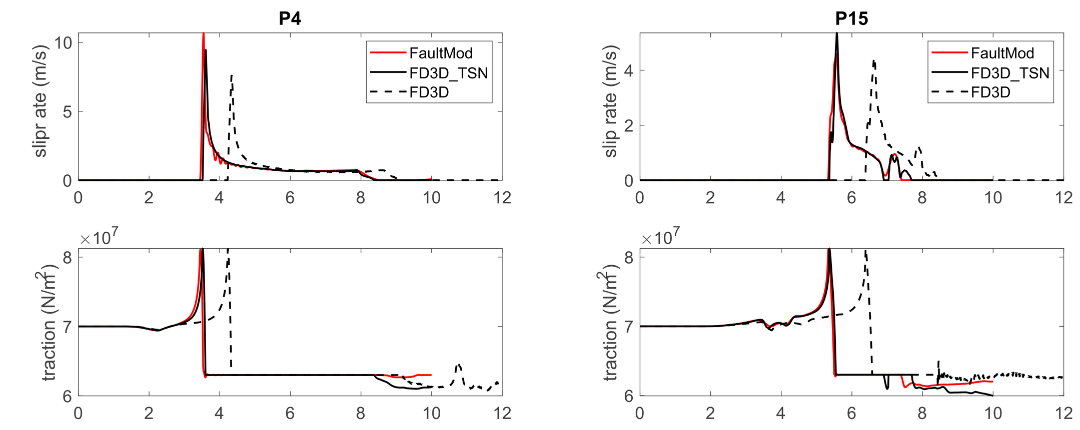

Figure 3: Slip rates and tractions on the fault in positions denoted by triangles in Fig 2.

TPV104 benchmark

- Vertical strike slip fault
- Fast velocity weakening friction law
- Velocity weakening fault surrounded by velocity strenghtening layer
- All initial parameters homogenous in the velocity weakening area.
- Nucleation by imposing a time dependent perturbation in traction in the centre of the fault.

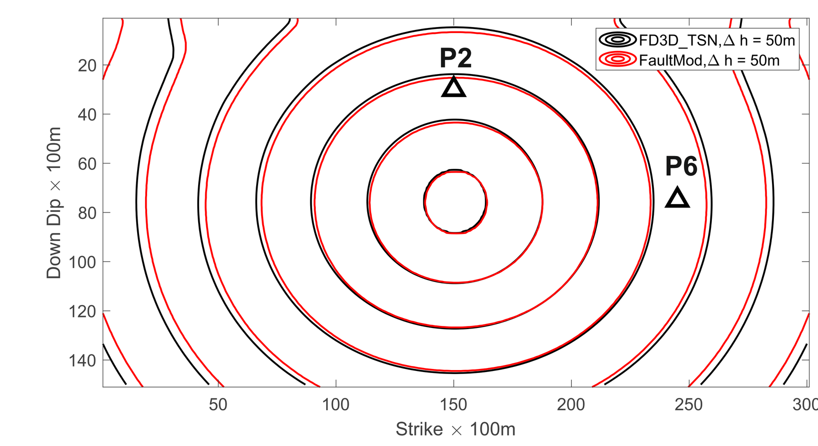

Figure 4:Rupture time contour plot for the TPV104 benchmark.

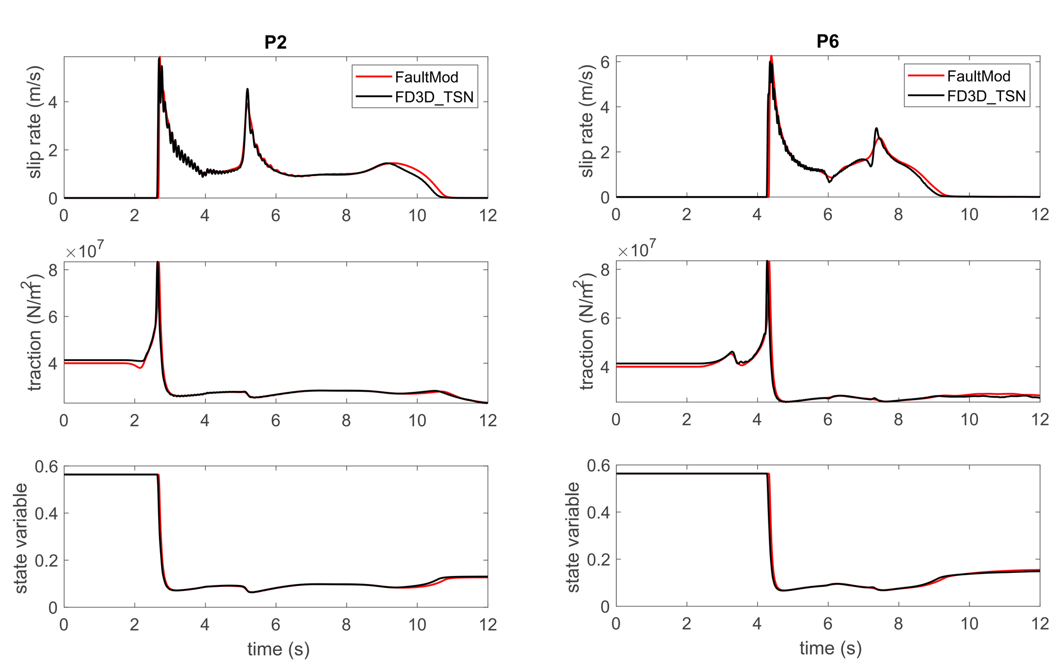

Figure 5: Slip rates, tractions and state variable on the fault in positions denoted by triangles in Fig 4.

2014 Mw6.0 South Napa, California Earthquake

- On 24 August 2014, an Mw 6.0 earthquake struck the Napa area in the north San Francisco Bay region.
- The kinematic finite source inversion was done by Gallovic [2016] with variance reduction of the best model of 0.61.
- Our dynamic inversion [Gallovic et al., 2019] finds spatial distributions of prestress and parameters of the slip-weakening friction law - static friction coefficient and characteristic weakening distance *Dc*.The best-fitting model with variance reduction of 0.55 is shown.
- The same set of low frequency (0.05-0.5 Hz) data was used in the kinematic and the dynamic inversions.
- Synthetic seismograms are calculated using AXITRA code [Bouchon,1981].
- Small size of the fault (15x10km) and its geometry (dip 82°) make the earthquake suitable for the dynamic inversion.

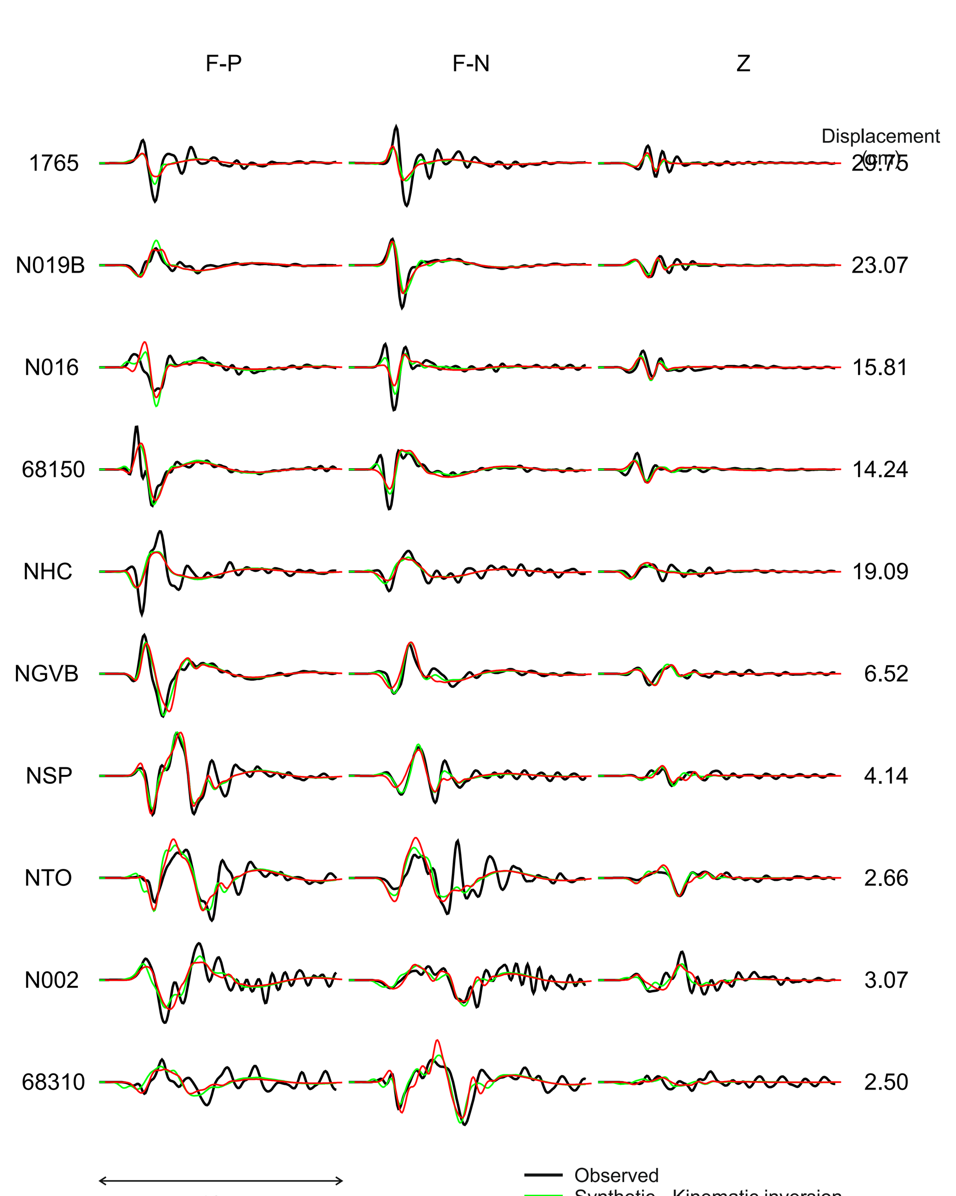

Figure 6: Comparison of observed seismograms (black) with synthetics (green and black for the kinematic and dynamic inversion, respectively).

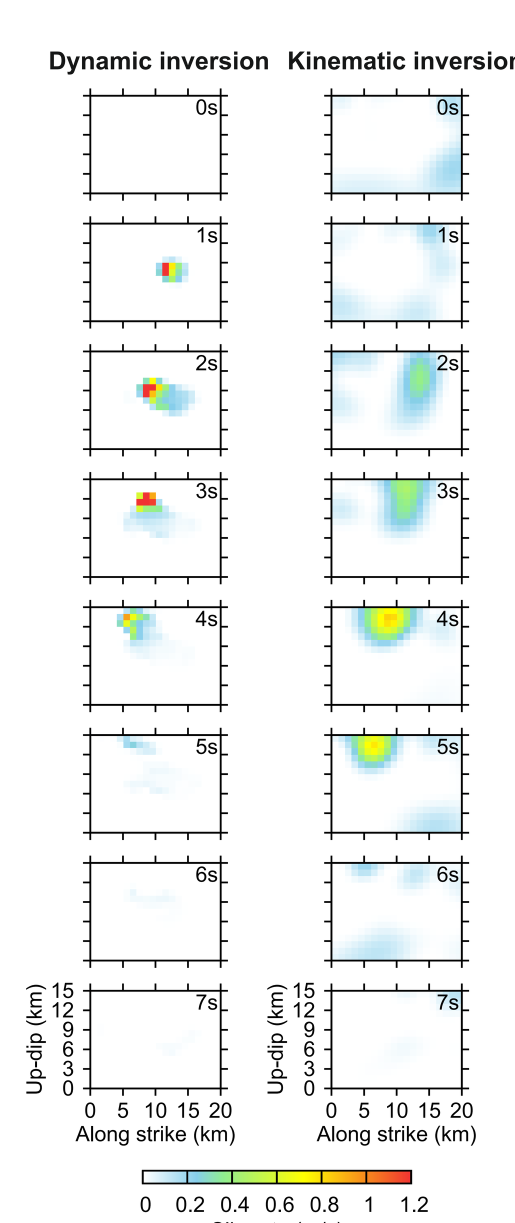

Figure 7: Comparison of the rupture propagation snapshots for the best models from the dynamic (left) and kinematic (right) inversions.

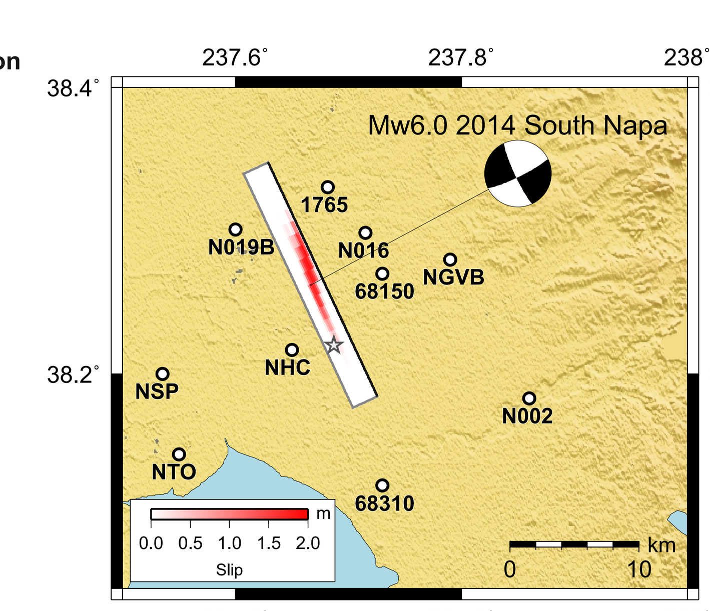

Figure 8: Map of the area showing the position of the finite fault (rectangle) with color-coded slip distribution, NCEDC earthquake mechanism (beachball), USGS epicentre (star) and stations (circles) used for the inversion.

Runtimes for TPV5

Discretization	Domain size Spatial nodes × time levels	Single CPU i7-3930K 3.2GHz	GPU GTX Titan
***Δx*=100m**	5280000 × 3750	340 s	37 s
***Δx*=50m**	37705500 × 7500	4868 s	358 s

Table 1: Runtimes of TPV5 dynamic model simulations on CPU and GPU. The finer discretization contains 14.3 times more nodes.

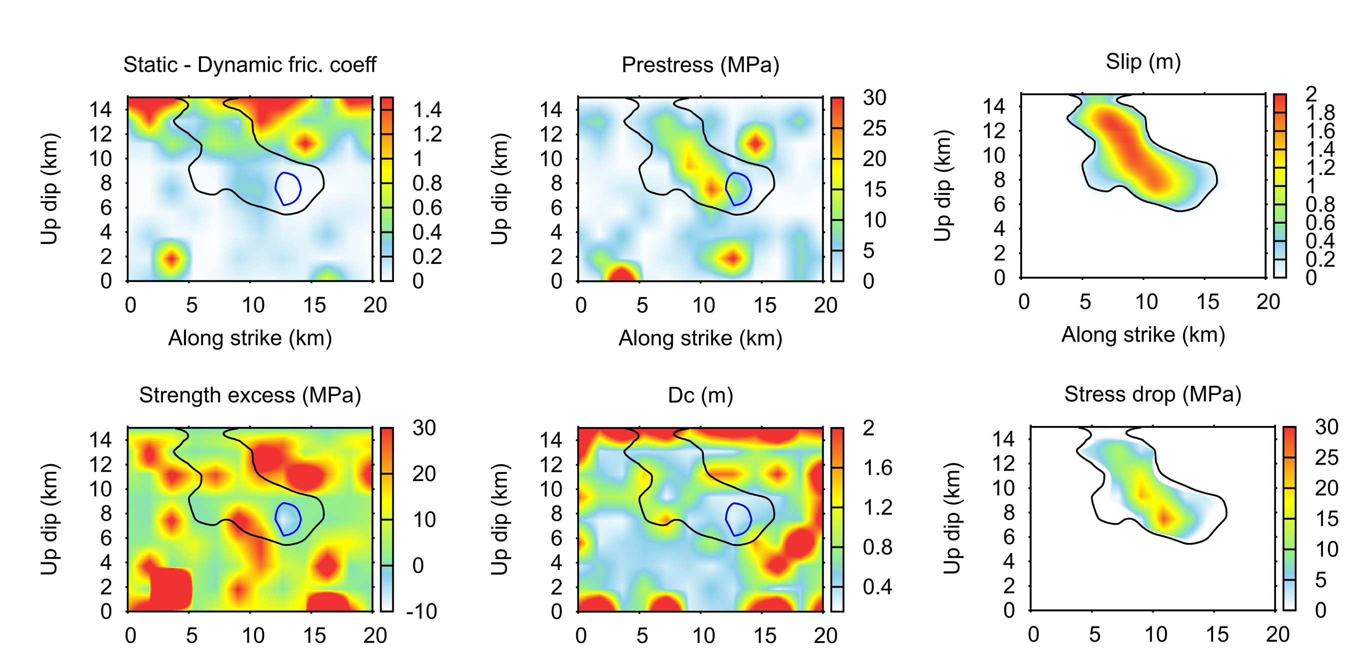

Figure 9: On-fault distribution of dynamic parameters, slip and stress drop for the best model inferred by the dynamic inversion. The black and blue lines outline the slip and nucleation areas, respectively.

Outlooks

- Development of FD code with irregular grid for even better efficiency
- Dynamic inversions using fast velocity weakening friction
- Adding complexity to the model (fault zones)

References

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