Earthquake Source Simulations

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A Coupled Numerical Method

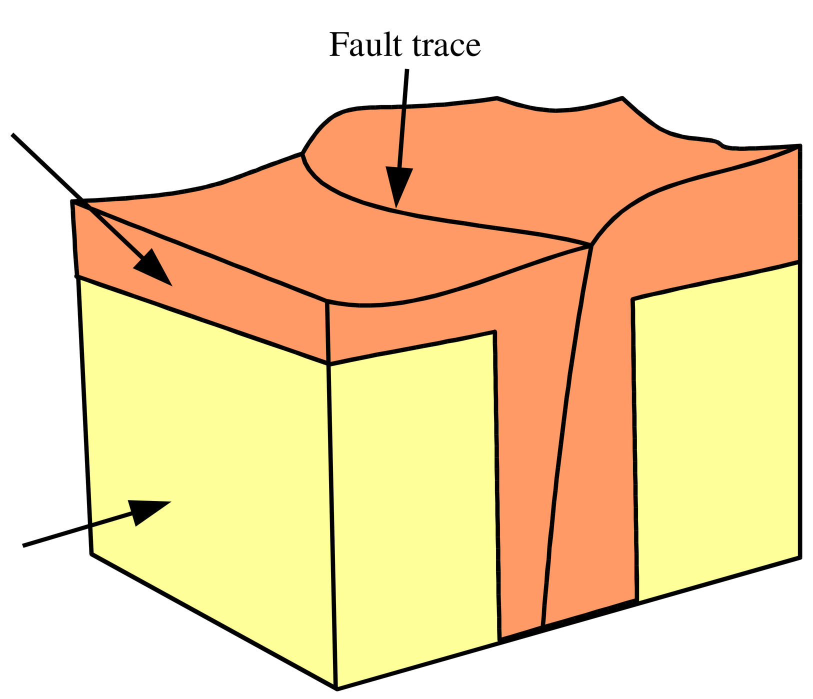
Abstract

We investigate a scheme for interfacing Finite-Difference (FD) and Finite-Element(FE) models in order to simulate dynamic earthquake rupture. The more powerful but slower FE method allows for (1) unusual geometries (e.g. dipping and curved faults), (2) nonlinear physics, and (3) finite displacements. These capabilities are computationally expensive and limit the useful size of the problem that can be solved. Large efficiencies are gained by employing FE only where necessary in the near source region and coupling this with an efficient FD solution for the surrounding medium. Coupling is achieved through setting up and an overlapping buffer zone between the domains modeled by the two methods. The buffer zone is handled numerically as a set of mutual offset boundary conditions. This scheme eliminates the effect of the artificial boundaries at the interface and allows energy to propagate in both directions across the boundary. In general it is necessary to interpolate variables between the meshes and time discretizations used for each model, and this can create artifacts that must be controlled. A modular approach has been used in which either of the two component codes can be substituted with another code. We have successfully demonstrated coupling for a simulation between a second-order FD rupture dynamics code and a fourth-order staggered-grid FD code.

Goal: Single simulation combing different numerical schemes

Rupture Dynamics Model (RDM) performs fault plane and free surface calculations. Handles irregular geometry needed for including realistic topography and dipping faults.

Anelastic Wave Model (AWM) used away from the boundaries were the grid can be made regular. Is much more efficient than the RDM and uses higher order (4th) approximations. Also includes anelastic corrections important for accurate simulation of wave traveling long distances.



Simplify to focus on coupling problem

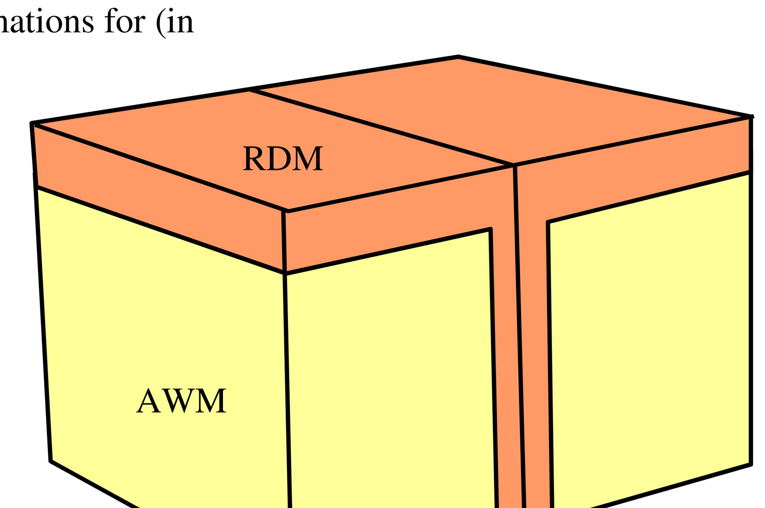
Restricted to rectangular mesh.

RDM: 2nd order FD approximations for a viscoelastic solid. Slip-weakening boundary condition for the fault.

AMM: 4th order staggered grid approximations for (in this case) linear elastic solid.

Computational cycle:

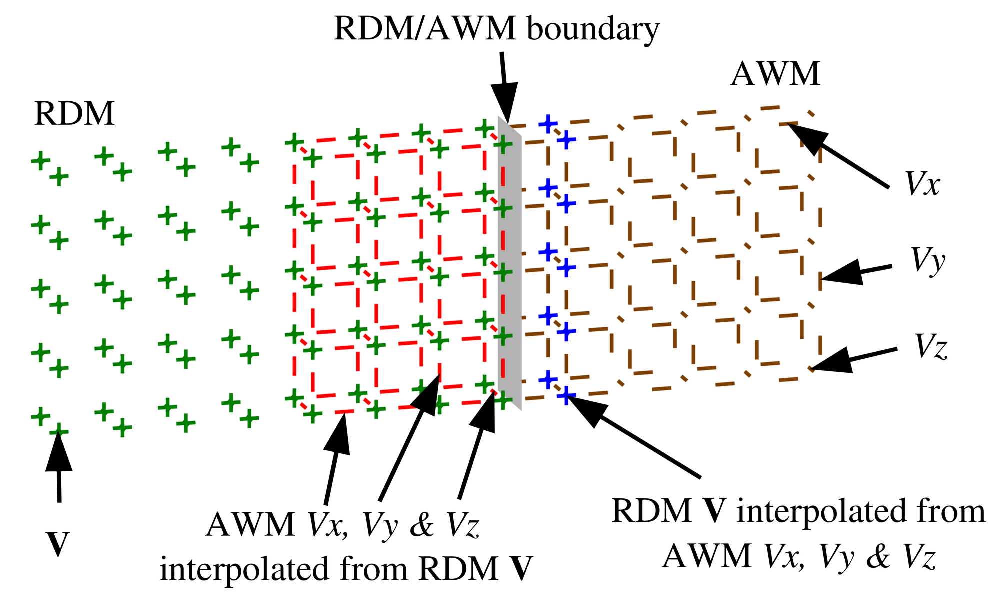
1. Update velocity
   $\partial \mathbf{v}/\partial t = \nabla \cdot \mathbf{T}/\rho$
2. Update stress
   $\partial \mathbf{T}/\partial t = c:(\nabla \mathbf{v} + (\nabla \mathbf{v})^T)/2$
3. Exchange velocity variables at the RDM/AWM boundary



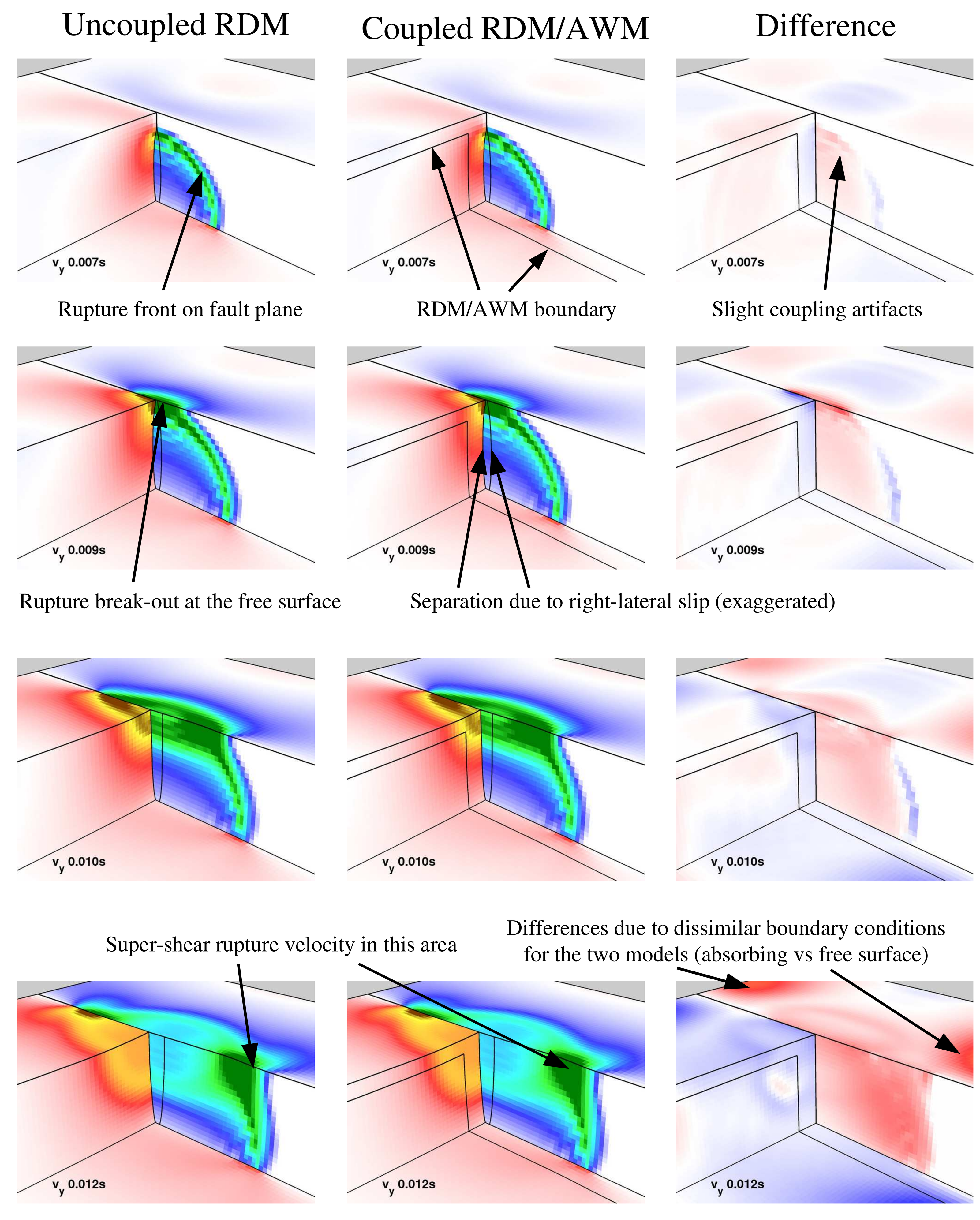
Computation notes:
1. Boundary conditions not shown.
2. For viscoelastic RDM, stress calculations also include an acceleration gradient term

Coupling Scheme: Interpolate and exchange velocity field variables at the boundary

Schematic diagram showing the velocity locations on a 12x5x2 subsection of the grid in the coupling region. The RDM uses 2nd order approximations and the AWM uses 4th order approximations on a staggered grid (velocity components *Vx, Vy & Vz* are not colocated). After each time integration step the coupled **V** nodes in the RDM (blue) are interpolated from the AWM and the coupled *Vx, Vy & Vz* nodes in the AWM (red) are interpolated from the RDM. MPI communications is used to transfer the variables between the codes.



Comparison of Numerical Results for Uncoupled RDM vs Coupled RDM/AWM



Data Management for Large Simulations

To be useful earthquake source models must capture a large range of length and time scales. The large volume of data that these types of simulations generate presents challenges for storage, analysis and visualization. Often much of the data is simply discarded and never looked at. High performance data management systems (or digital libraries) such as the SCSC Storage Resource Broker can help solve this problem. We show here results from a rupture dynamics model (RDM) designed to test these capabilities for use in the SCEC Community Modeling Environment (SCEC/CME). In addition to storage, SRB also manages descriptive metadata for model documentation.

Computation

Rupture Dynamics Model
- 400 x 800 x 800 nodes
- 3000 time steps

Run on SDSC Blue Horizon
- 512 Processor
- 12 hours
- 6000 CPU Hours

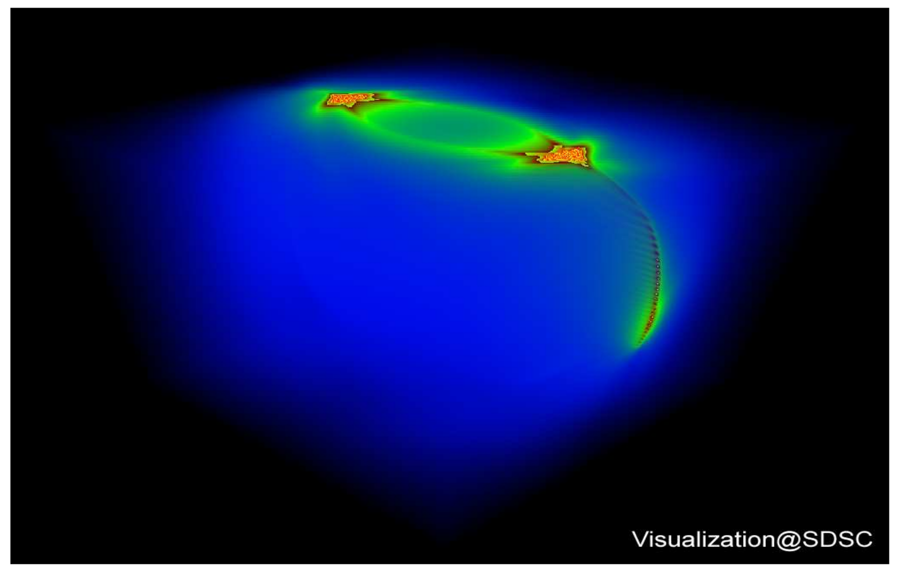
Output written to GPFS parallel file system
- Throughput – 230 Mbytes/s

Output Statistics

Velocity vector field
- 3000 time steps
- 3GB per time step

Stress tensor field
- 300 time steps
- 6GB per time step

10 Terabytes total storage
- 1.8 million files
- Transferred from GPFS to SRB

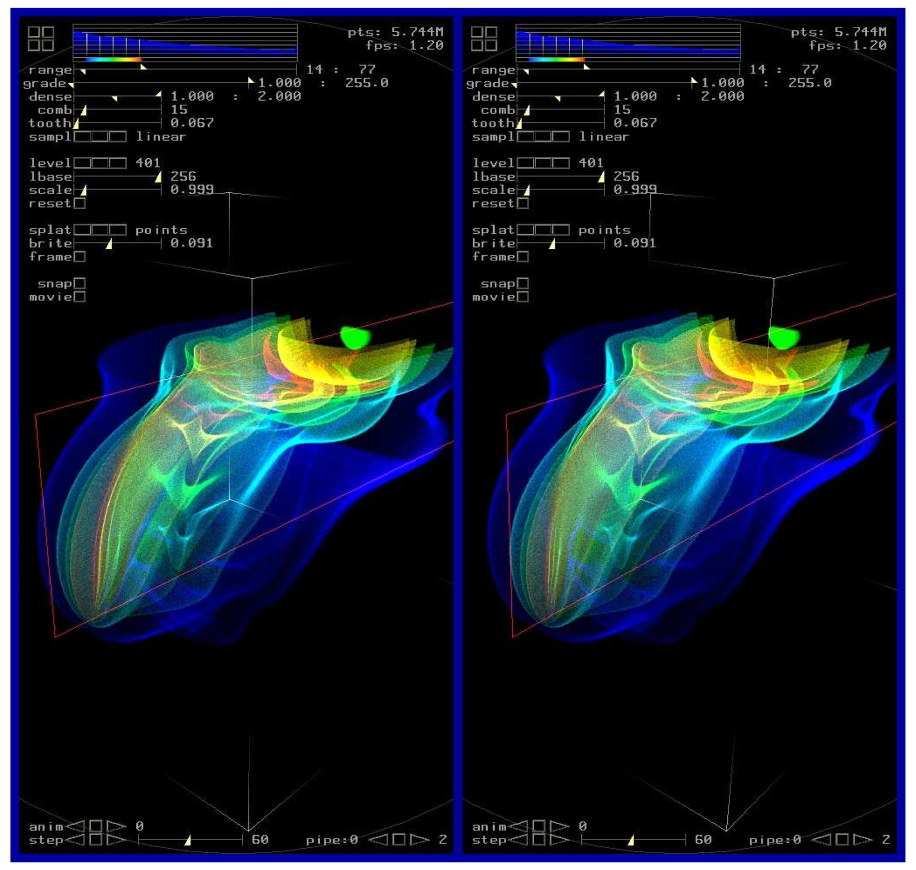


Volume visualization generated by the NPACI Scalable Visualization Toolkit using direct access to SRB. http://vistools.npaci.edu

For more on data management in the SCEC/CME see:

Poster NG11A-0177, SCEC Community Modeling Environment (SCEC/CME) – Data and Metadata Management Issues, Minster, et al

Poster ED32C-1203, Community Digital Library Requirements for the Southern California Earthquake Center Community Modeling Environment (SCEC/CME), Moore, et al



Stereo pair volume visualization of the model generated by the ISI GVU software.

For more information see poster ED32C-1212, Grid-based Visualization Framework, Thiebaux, et al