What controls slip heterogeneity- prestress, fracture energy, or sliding friction?

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Objectives

- Explore physics of earthquake ruptures using 3-D numerical simulations to understand what controls slip and stress heterogeneity

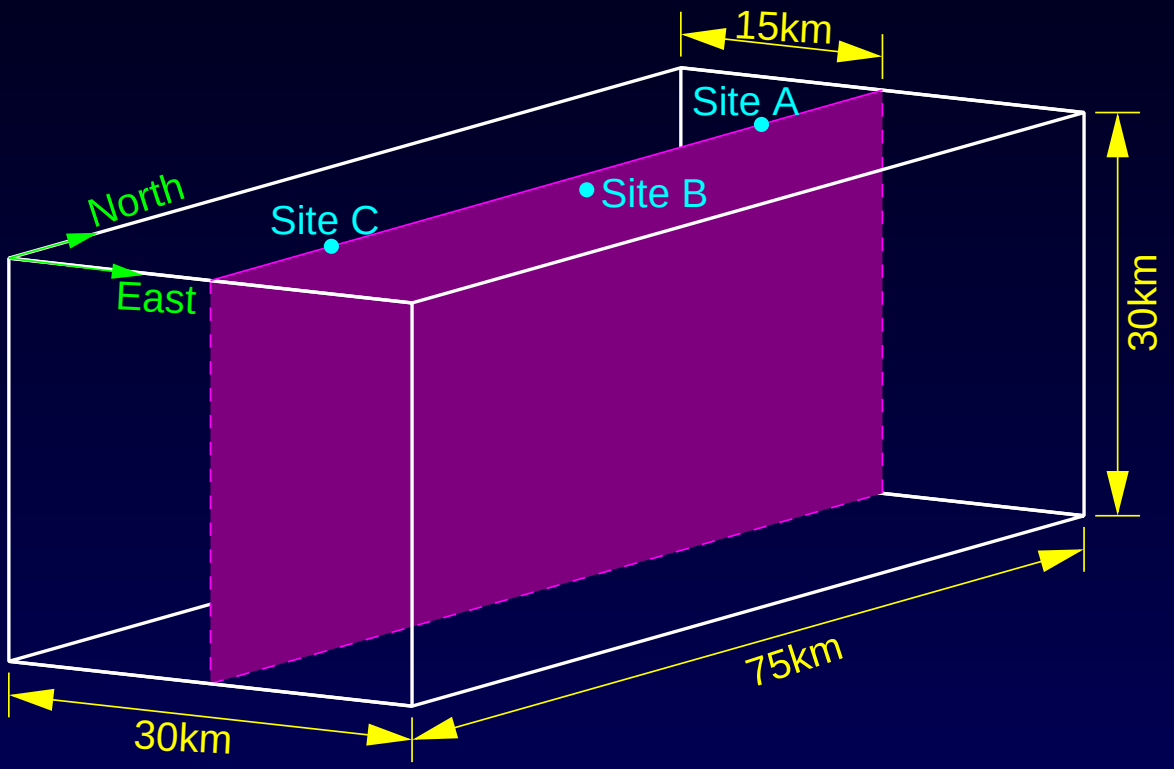
- Seek set of parameters that allows the system to evolve into a stable heterogeneous state
  - Earthquakes occur across wide range of length scales
  - Fault continues to produce earthquakes with heterogeneous slip

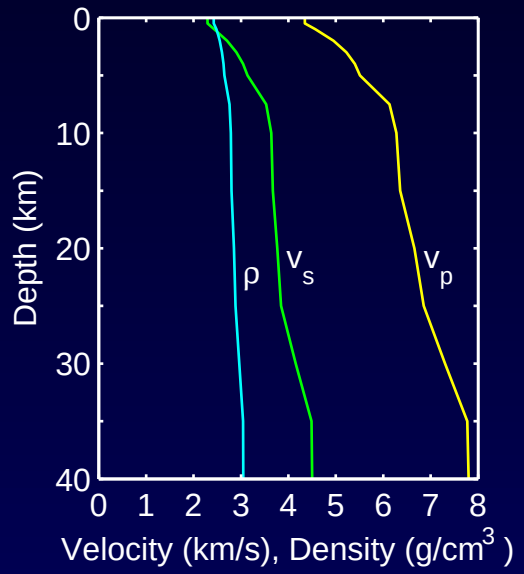
Methodology

- Attempt to produce same rupture behavior with different sets of parameters
  - Prestress
  - Fracture energy
  - Sliding friction
- Want to find sets of parameters that yield stable heterogeneity in stress and slip
  - Compatible with real earthquakes and faults

Model Geometry

Planar, vertical strike-slip fault in layered half-space

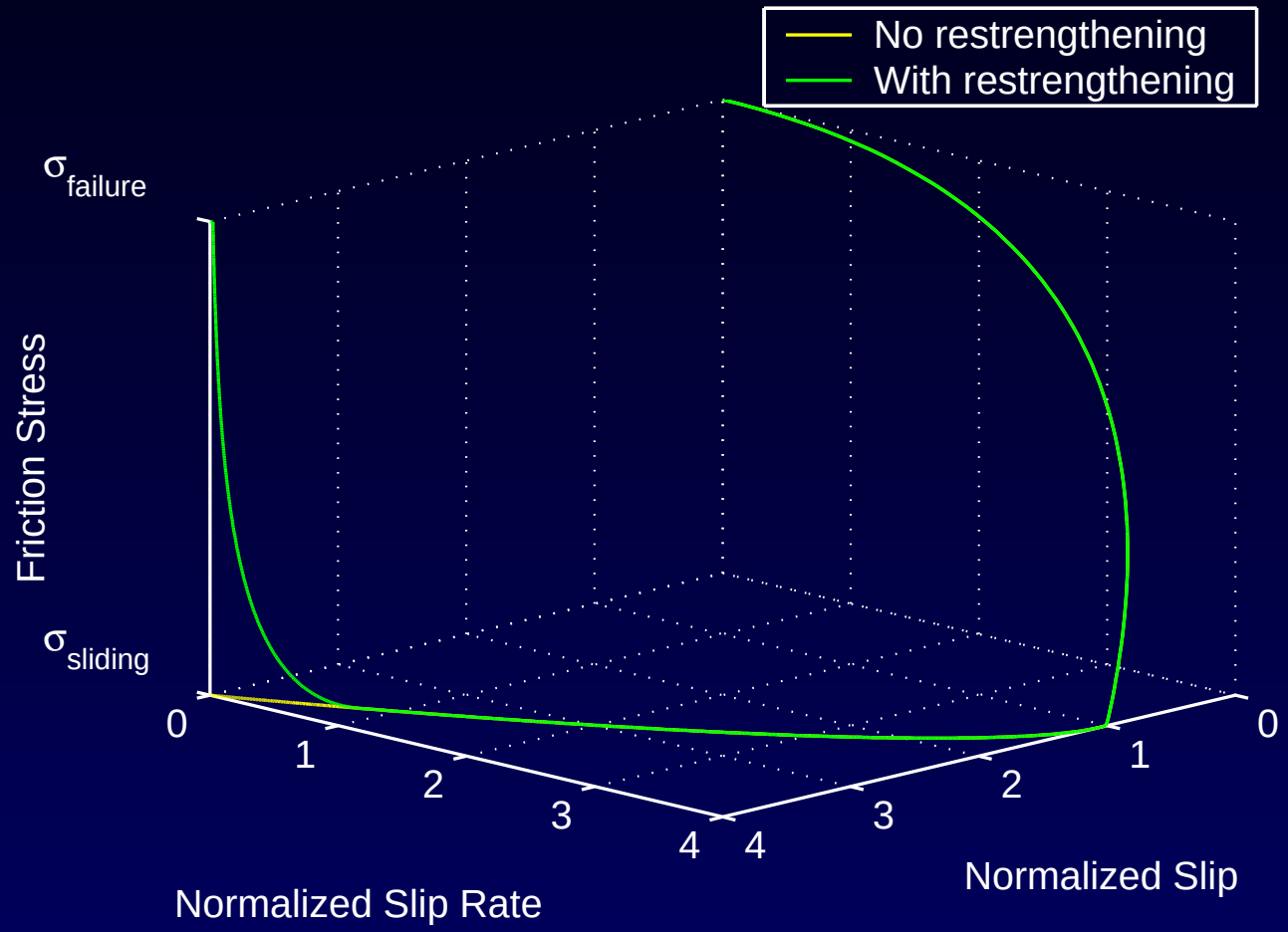




Friction Model

Slip- and rate-weakening friction with better numerical stability

Add state variable to slip-weakening friction model to control rate dependence



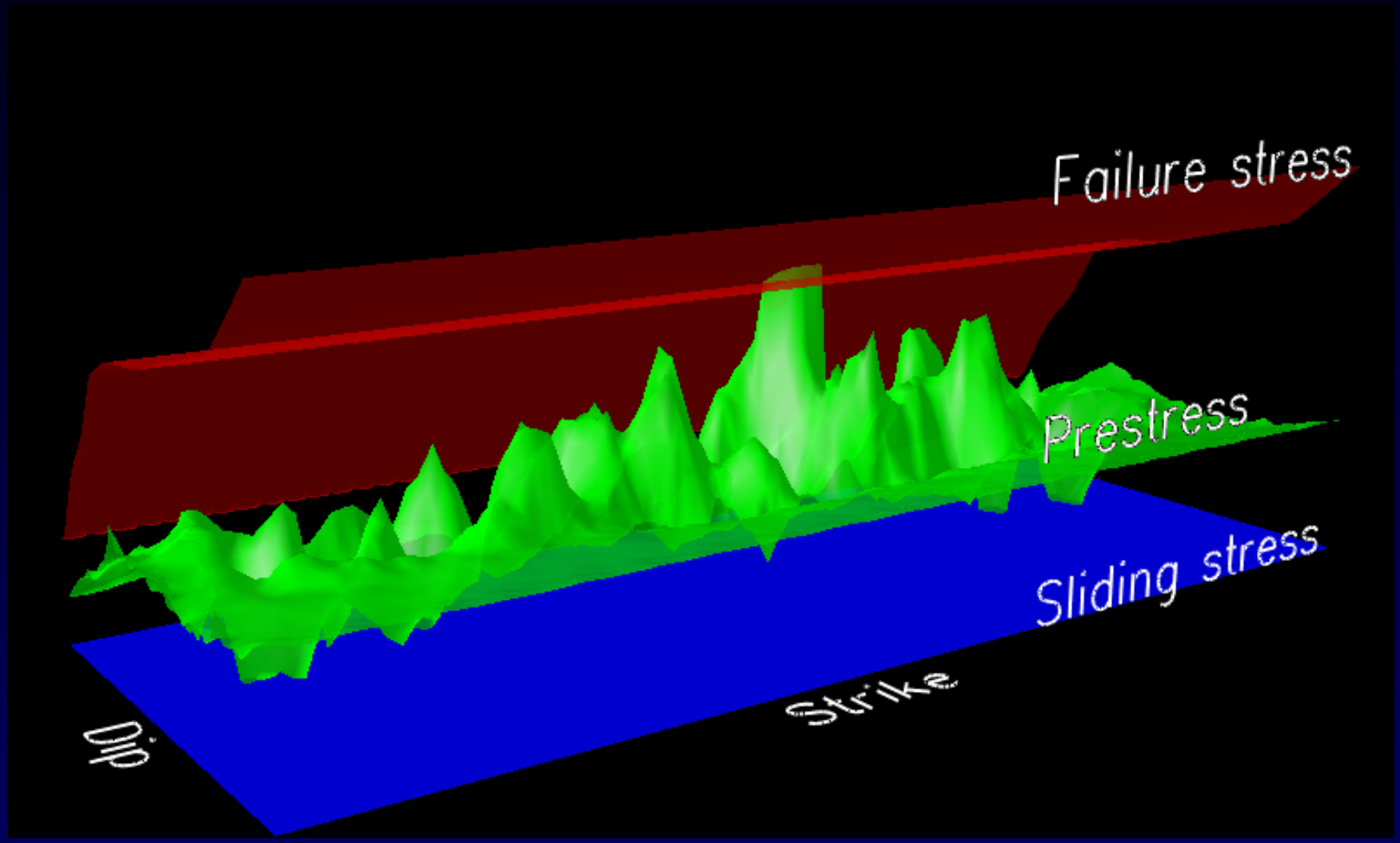
Scenarios

Similar ruptures with different spatial variations in σ_0, $\sigma_{sliding}$, and E_G

- 9 different combinations of spatially homogeneous and heterogeneous
  - Prestress
  - Fracture energy
  - Sliding friction
- 3 levels of shear-restrengthening in friction model
  - No restrengthening (conventional slip-weakening)
  - Restrengthening after sliding stops (slip-weakening with healing)
  - Restrengthening when slip rate is low (slip- and rate-weakening)
- 27 total simulations

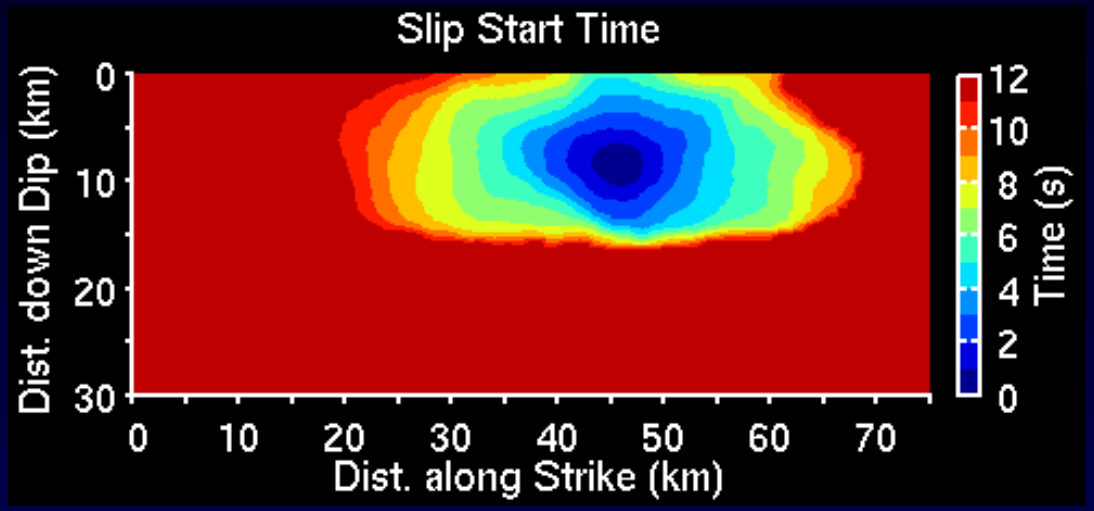
Scenario I: Heterogeneous Prestress

Heterogeneous dynamic stress drop



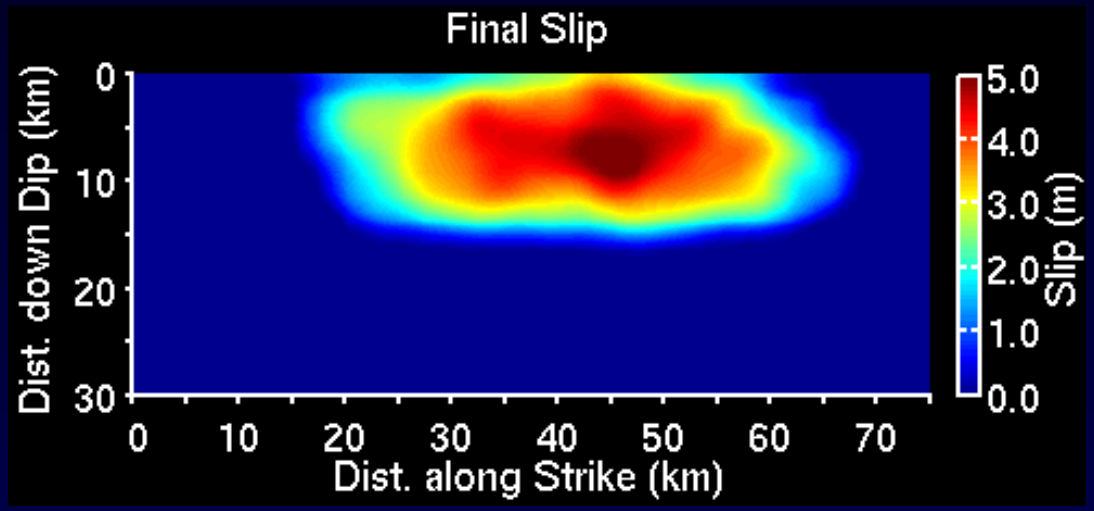
Scenario I: Rupture Propagation

Bilateral rupture controlled by heterogeneity in prestress



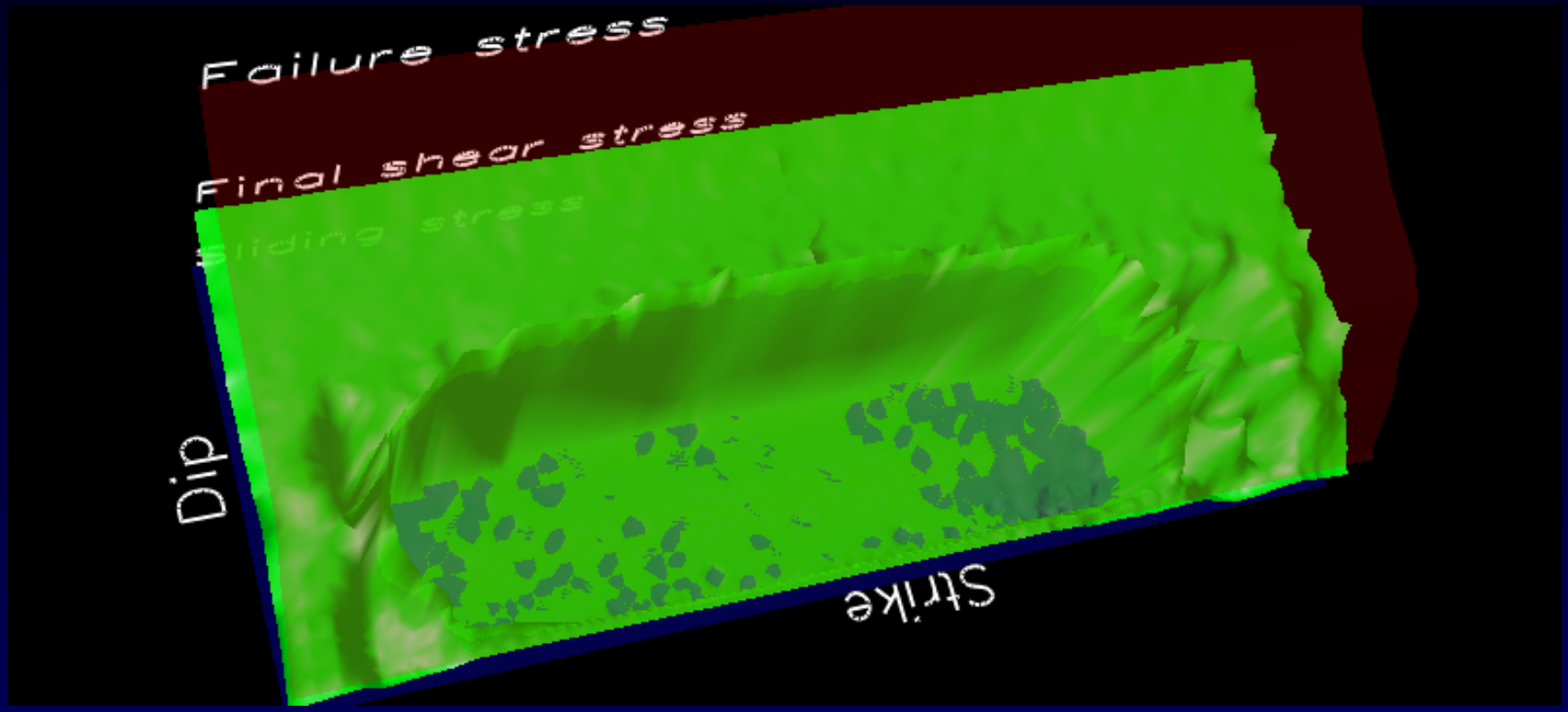
Scenario I: Final Slip

Spatially heterogeneous slip



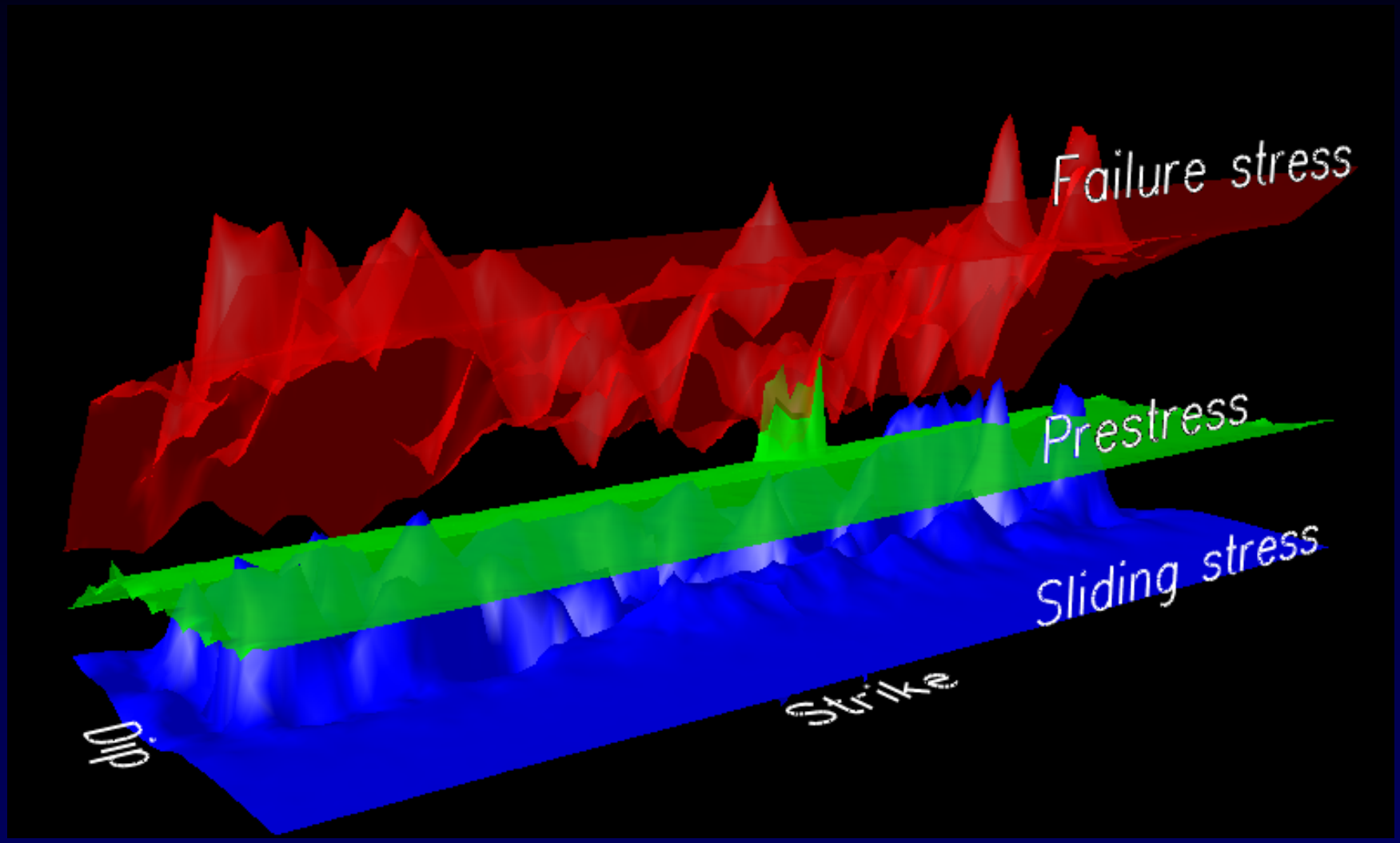
Scenario I: Final Shear Stress

Rupture removed stress field heterogeneity



Scenario II: Heterogeneous Sliding Friction

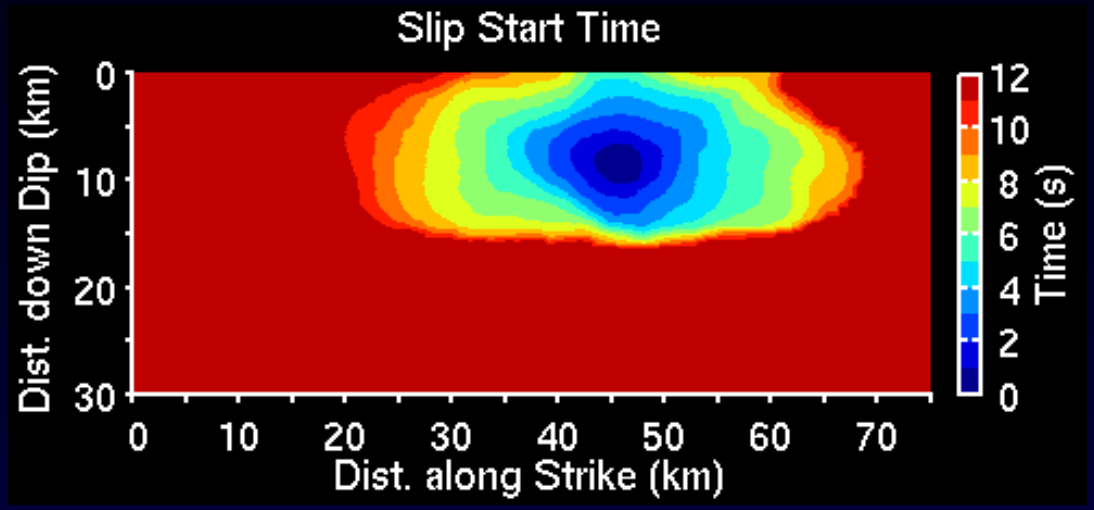
Same dynamic stress drop as scenario I



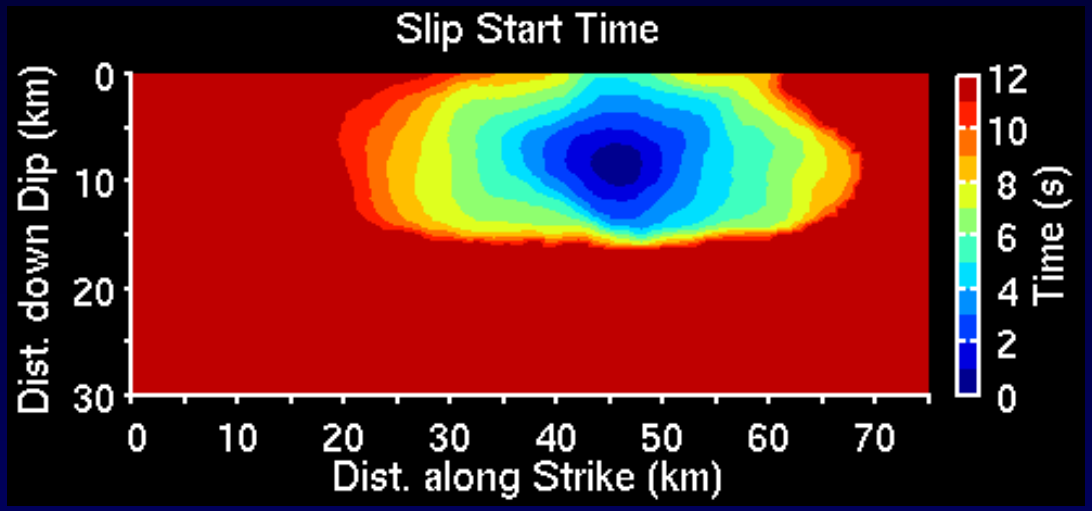
Scenario II: Rupture Propagation

Identical rupture propagation

Scenario II



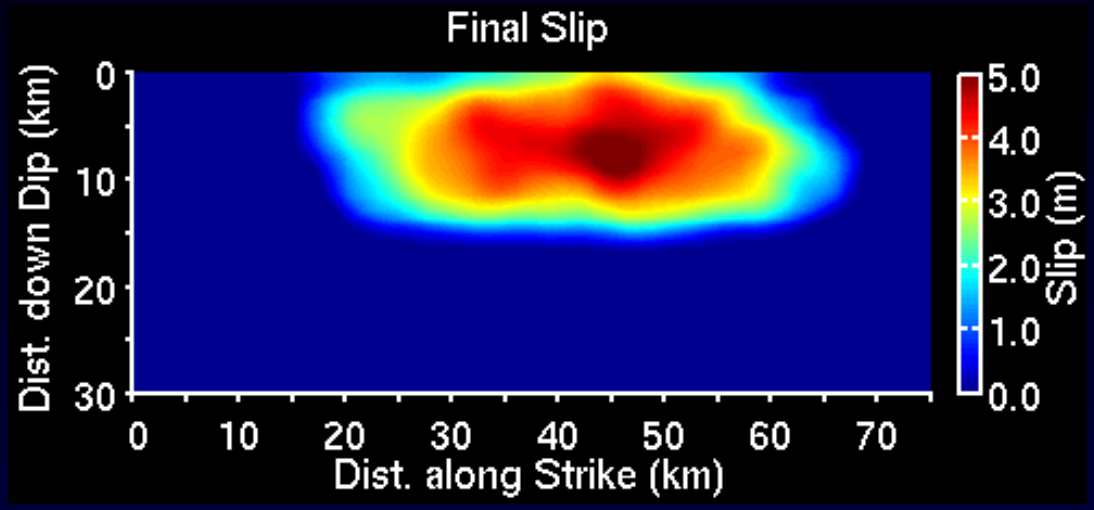
Scenario I



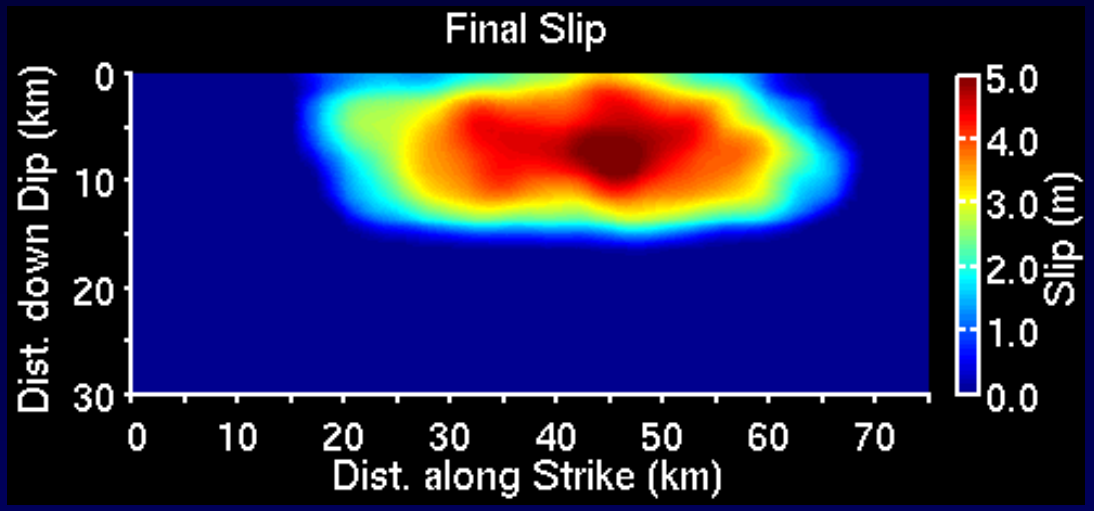
Scenario II: Final Slip

Identical slip distribution

Scenario II

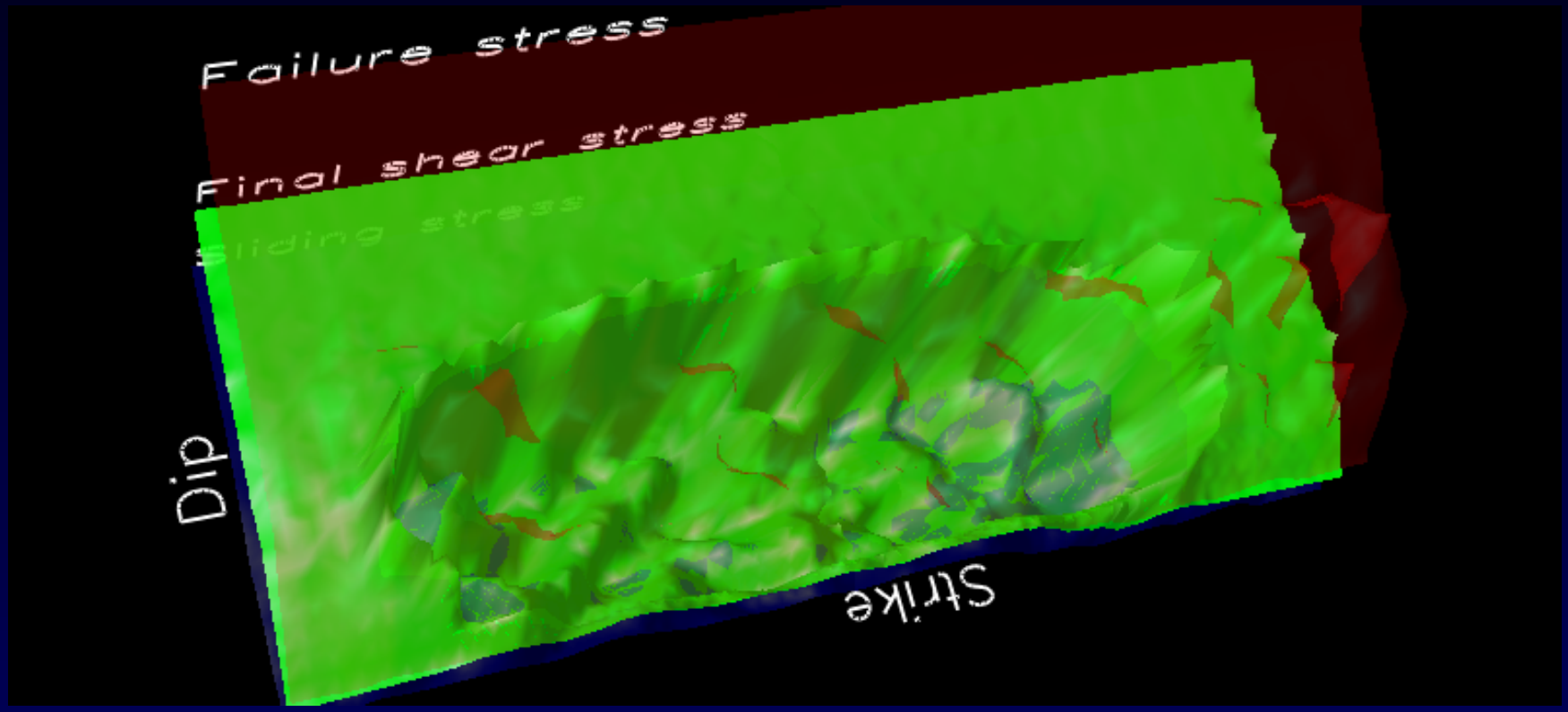


Scenario I



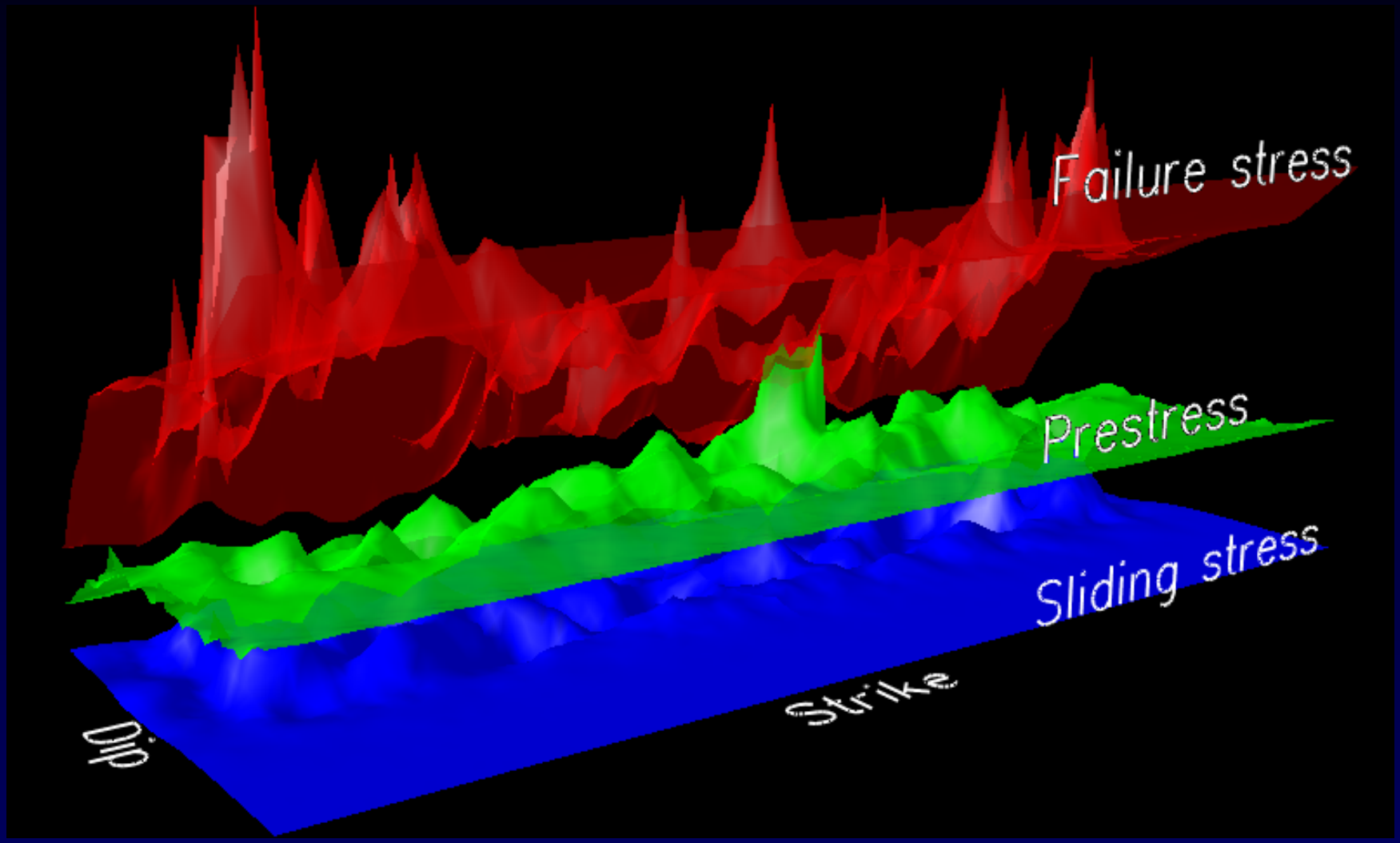
Scenario II: Final Shear Stress

Rupture maintains stress field heterogeneity



Scenario III: Heterogeneous Everything

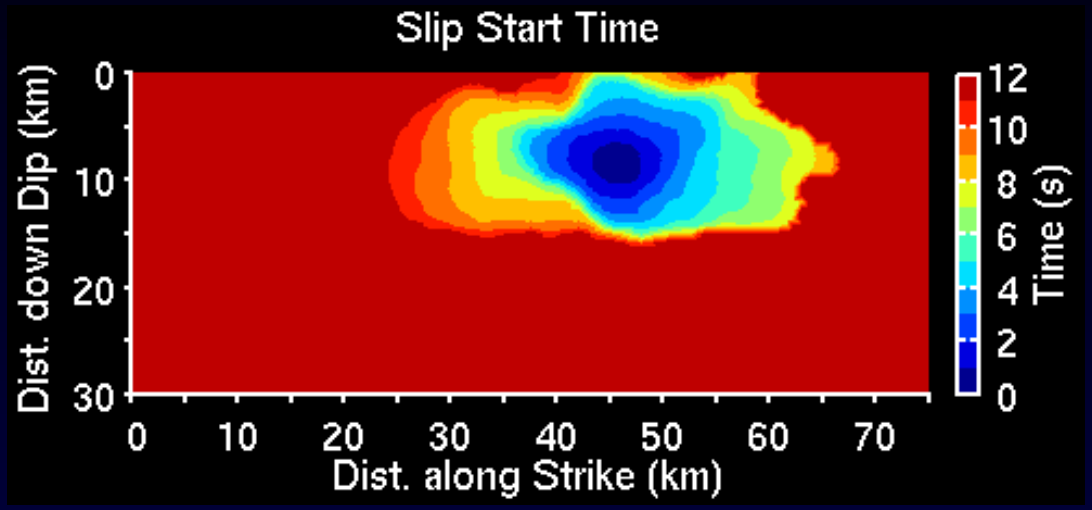
Heterogeneous prestress, fracture energy, and sliding friction



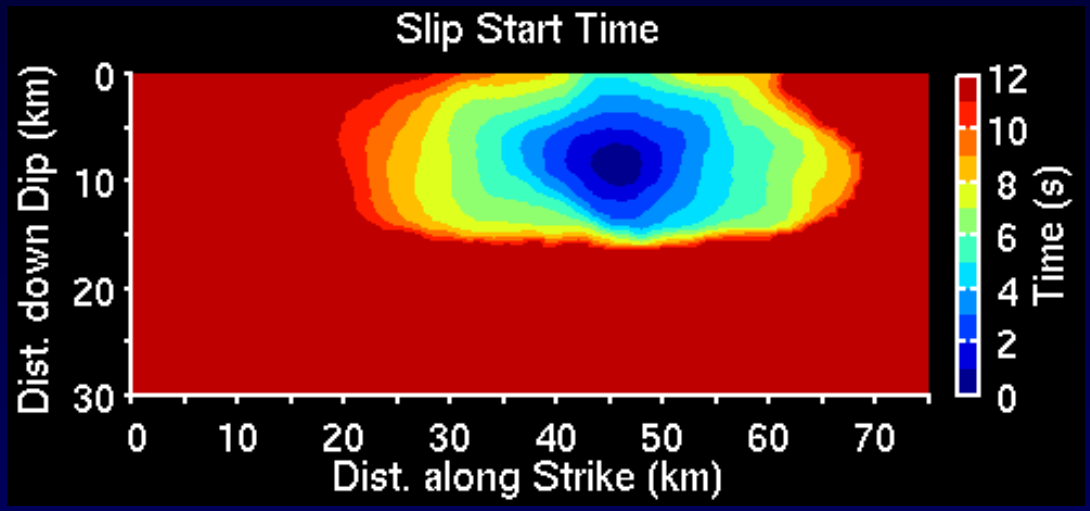
Scenario III: Rupture Propagation

Similar rupture propagation

Scenario III



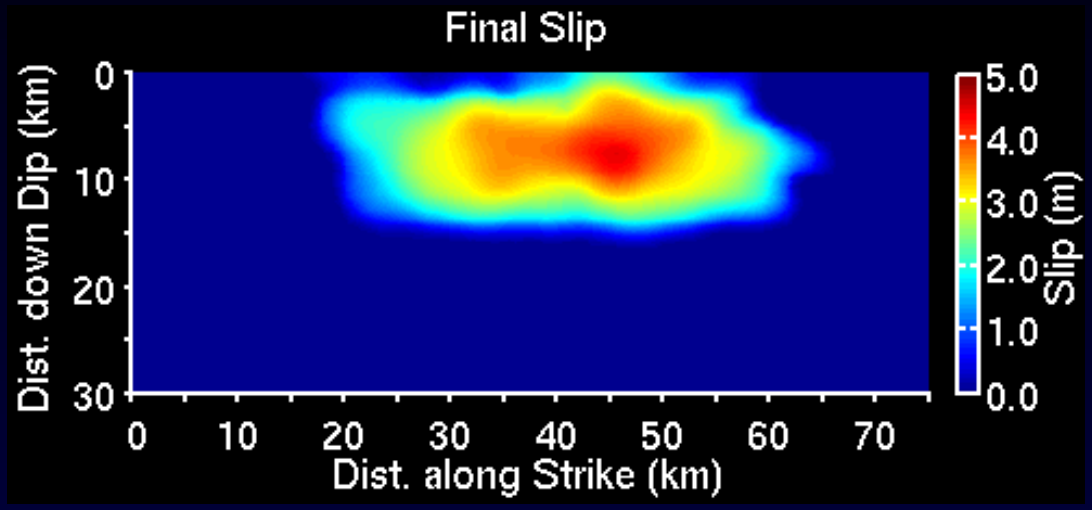
Scenario I



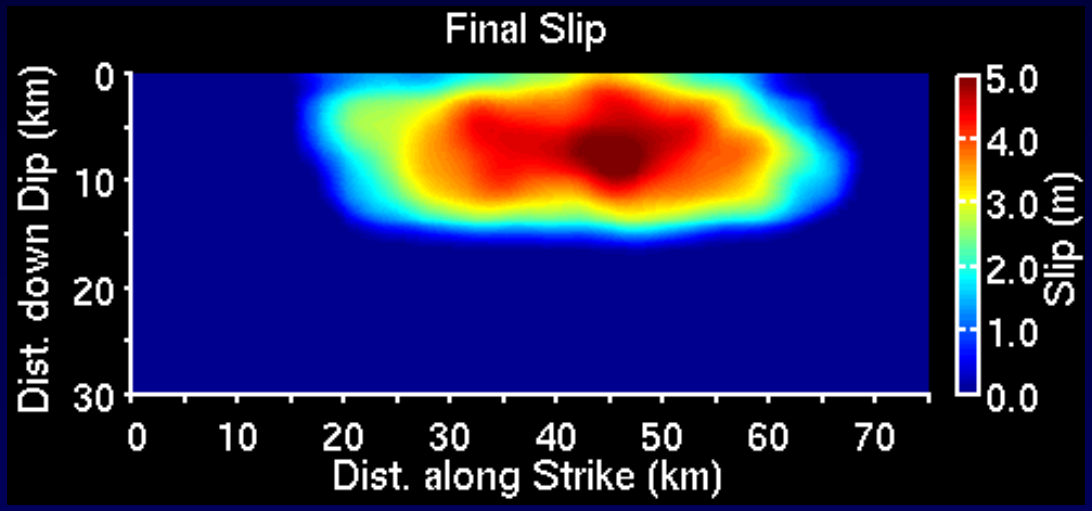
Scenario III: Final Slip

Similar spatial distribution but smaller peak slip

Scenario III

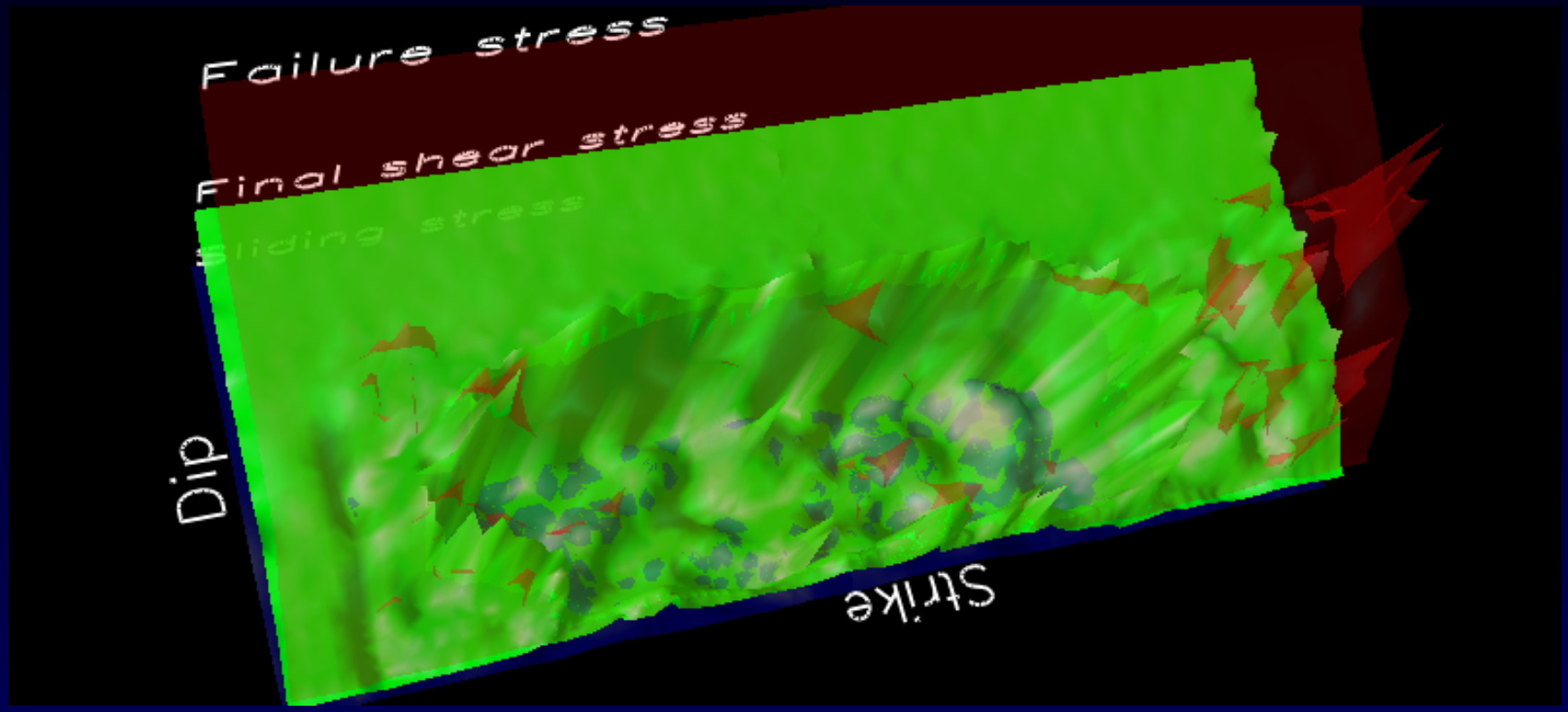


Scenario I



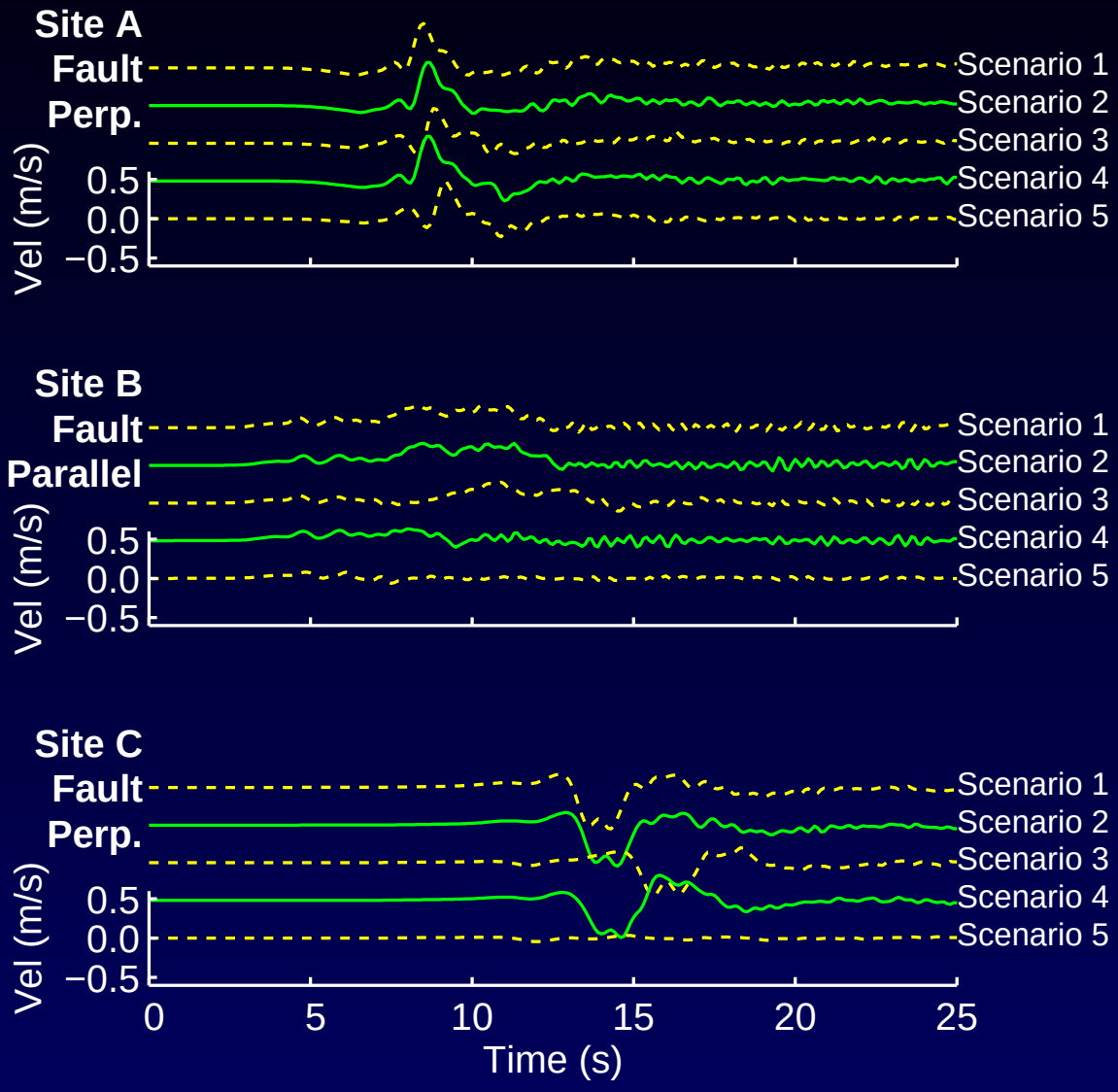
Scenario III: Final Shear Stress

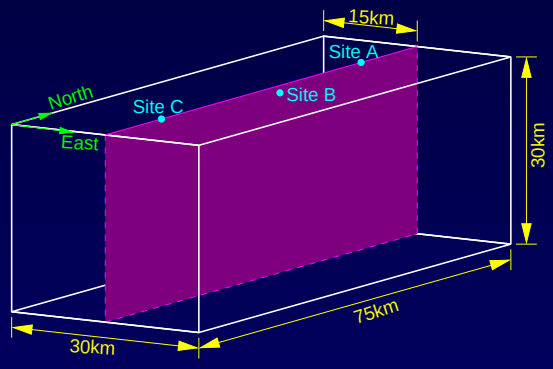
Rupture maintains stress field heterogeneity



Comparison of Ground Motions

Ground motions do not constrain the physics of the rupture process.





Conclusions

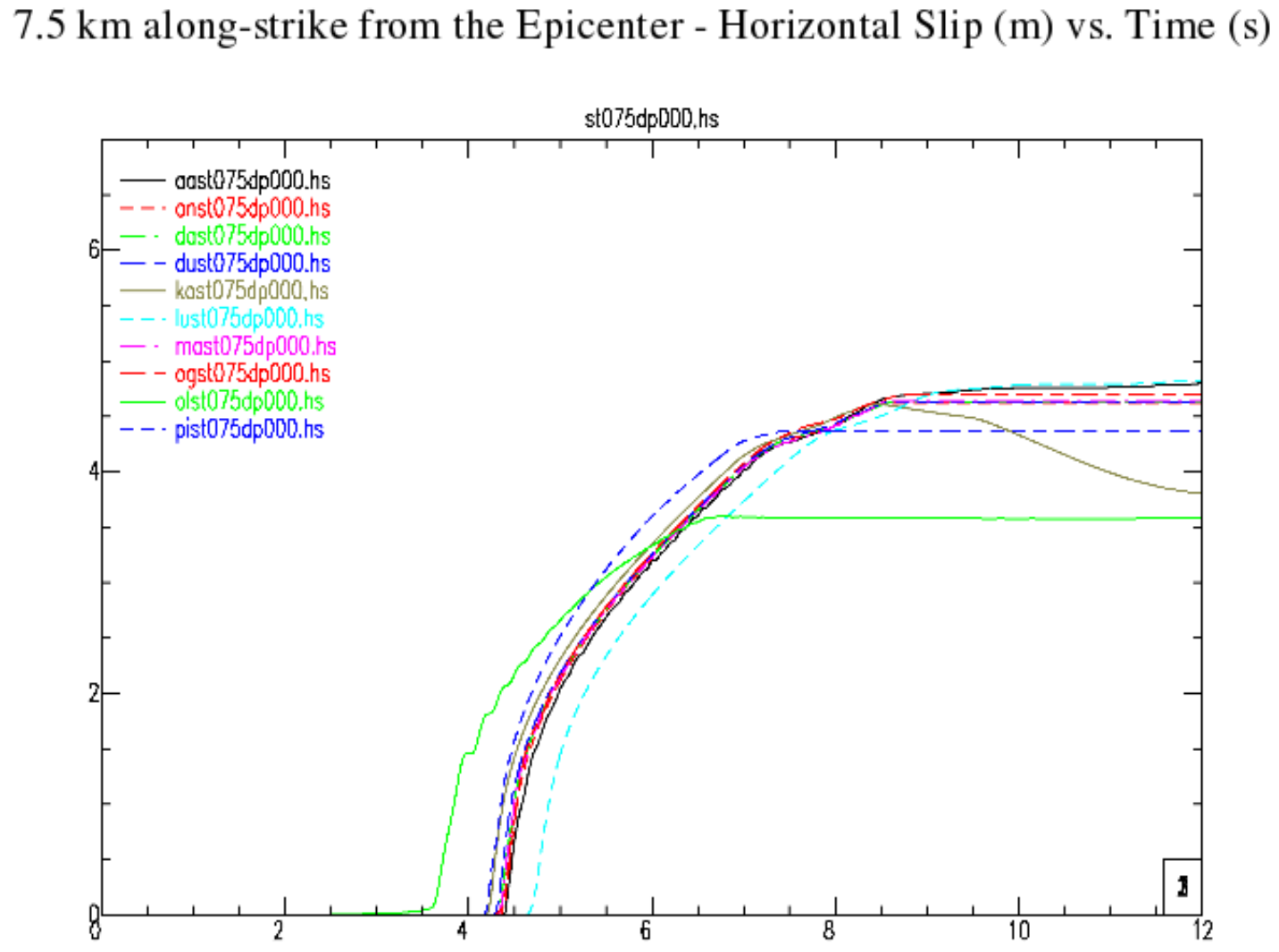
- What controls slip heterogeneity?
  - Prestress? No
  - Fracture energy? No
  - Sliding stress? No
  - Rate restrengthening in friction model? No
  - All of the above? Probably
  - None of the above? Probably
    Nonplanar fault geometry may yield similarly realistic behavior.

- Ground motions cannot constrain the trade-off between variations in prestress, fracture energy, and sliding friction.

- Thin slip zones with low dynamic sliding friction coupled with strong static friction provide a suitable mechanism for slip and stress heterogeneity.

SCEC Earthquake Source Physics Group

Benchmark and validation of spontaneous rupture modeling software



Computational Infrastructure for Geodynamics (CIG)

NSF funding began Sep 1, 2004 ($6.75M over 5 years)

- Create toolbox of modular, extensible open-source geodynamics modeling software
  - Crustal deformation
  - Mantle convection
  - Geodynamo
- Community members
  - 29 U.S. member institutions
  - 4 foreign affiliates (all in Australia)
- Why join?
  - Participate in deciding what software is developed
  - Training in use of software & techniques

`http://www.geodynamics.org`