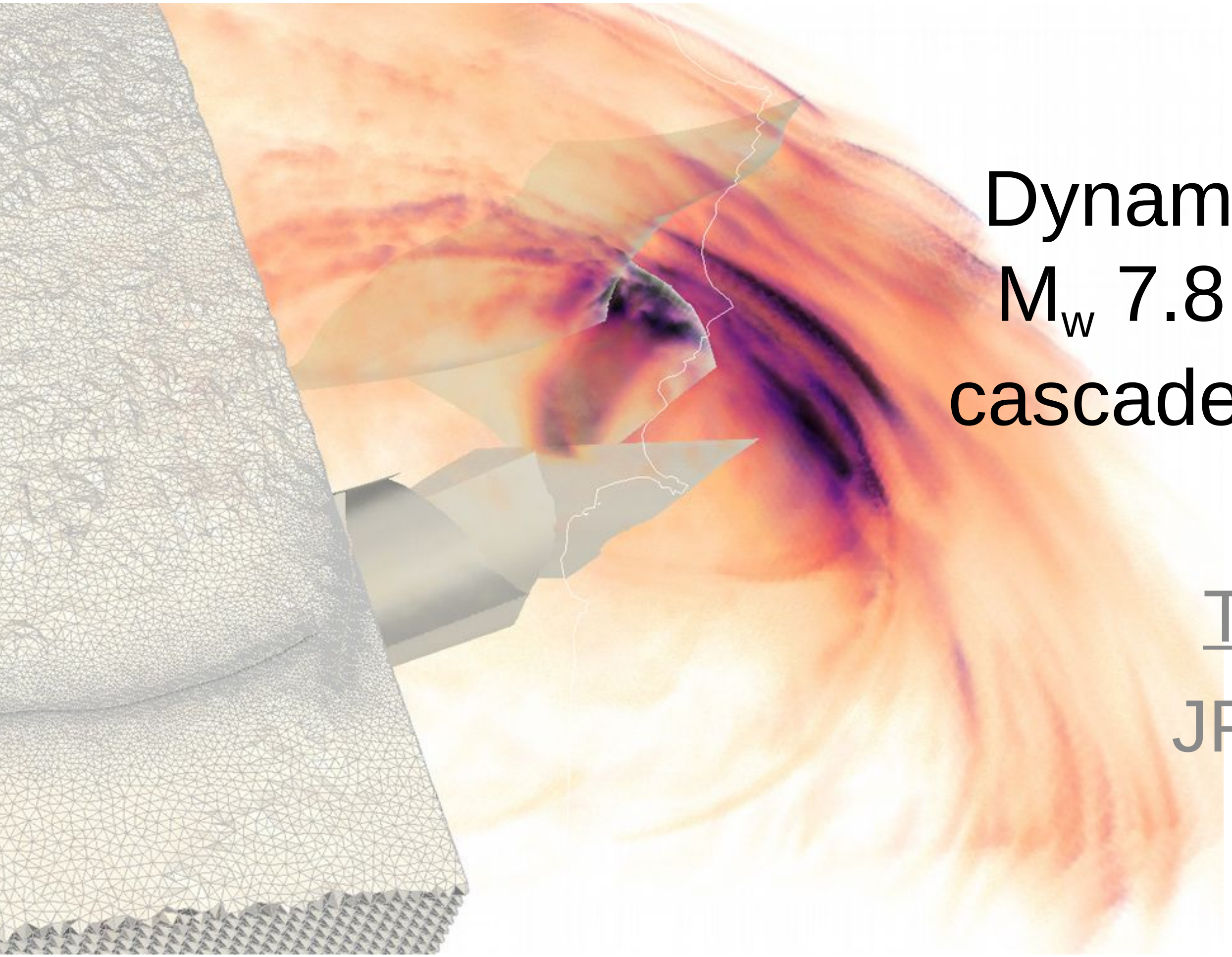
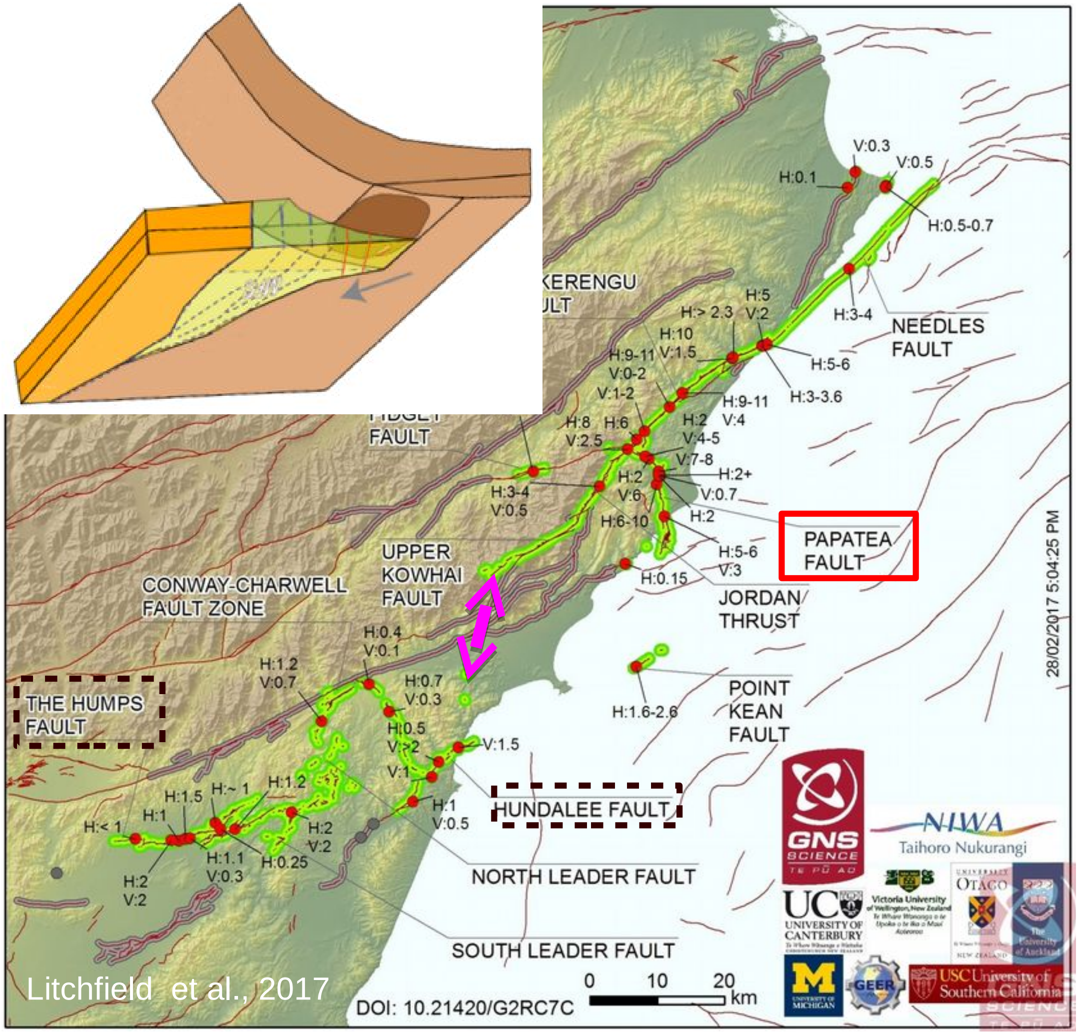


Dynamic viability of the 2016 M_w 7.8 Kaikōura earthquake cascade on weak crustal faults

T Ulrich, AA Gabriel,
JP Ampuero and W Xu

Most complex rupture process observed to date?



Litchfield et al., 2017

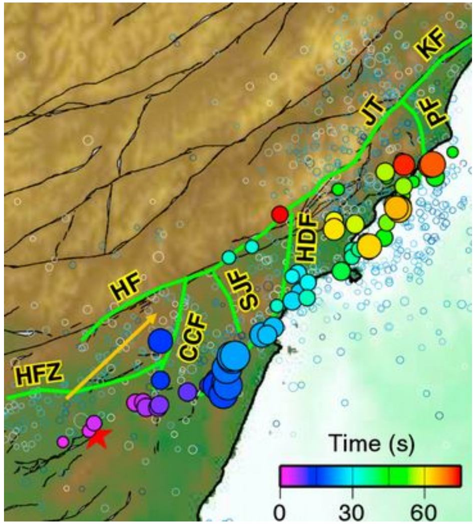
- Highly segmented rupture combining strike-slip and thrusting
- Unknown and not well known structures

Many open questions

- Large gap between rupture trace (~15km)
- Apparent rupture velocity unusually slow (~2 km/s)
- moment release rate sequence
- Role of subduction interface in rupture sequence: one-time link? Overall driving? No rupture?
- Cause of tsunami
- Non-rupture of Hope fault

Characterizing rupture kinematics

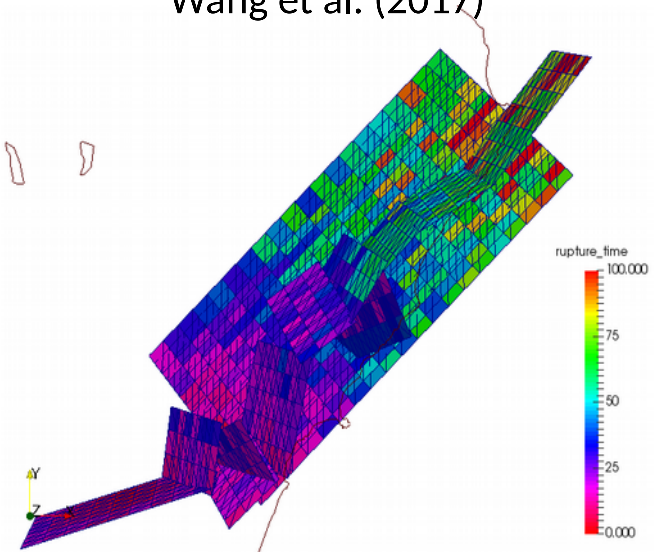
Xu et al. (2018)



Back projection

- Insight on event main features
- Lack of accuracy for details

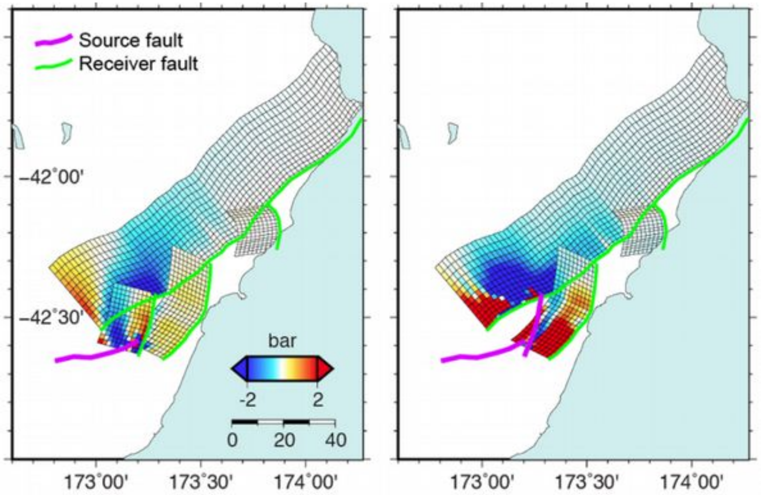
Wang et al. (2017)



Kinematic models

- High dependence on geometry assumptions
- Non-uniqueness
- Not necessarily fully realistic

Xu et al. (2018)

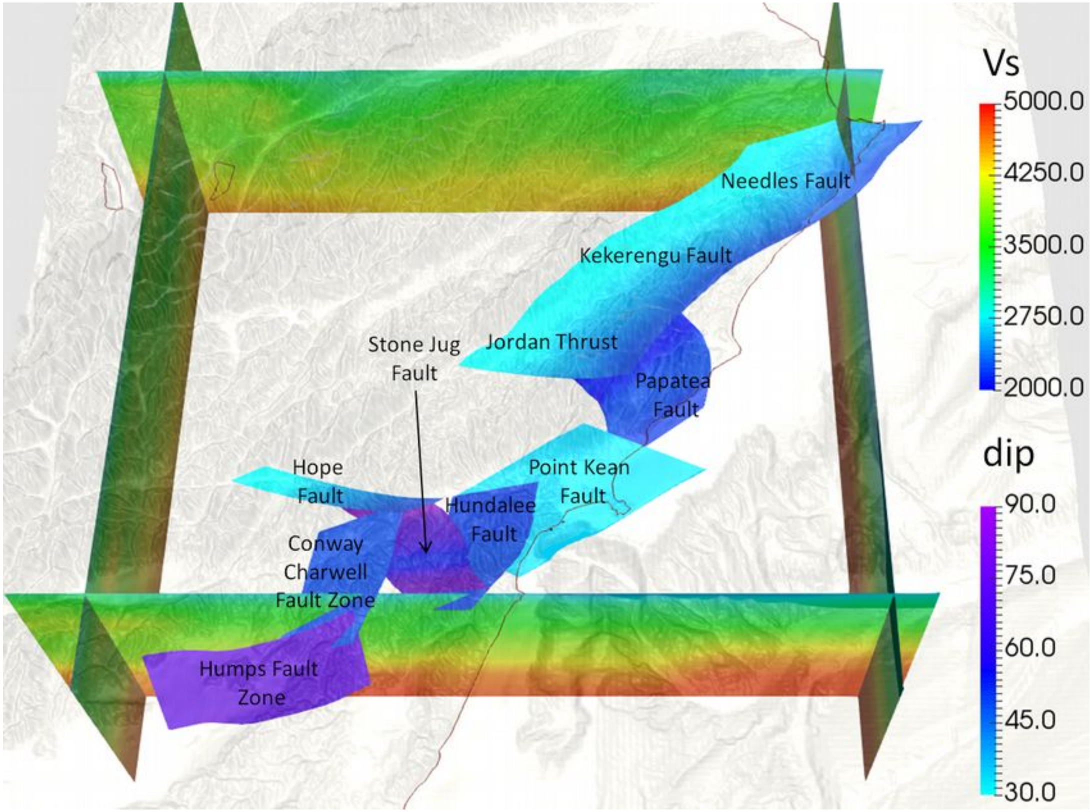


Sequential Coulomb failure analyses

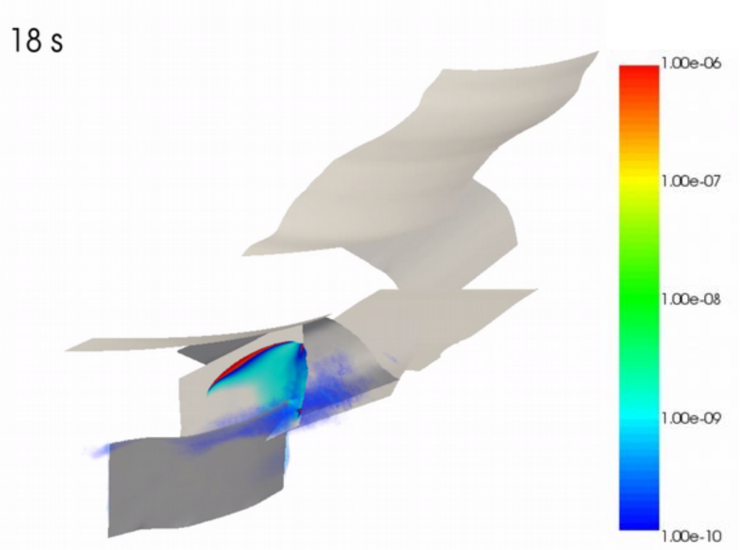
- Sequentially looking at **Coulomb failure stress changes** using static source model
- Questionable results as dynamic stress >> static stress

=> Dynamic rupture simulations to constraining the competing views

Dynamic rupture modeling brought to a new degree of realism



- Highly segmented fault geometry adapted from Xu et al. (2018)
- 3D subsurface model
- High-resolution topography and bathymetry
- Fast-velocity weakening Rate and State friction law
- Off fault-plasticity



Reducing the non-uniqueness in dynamic modeling

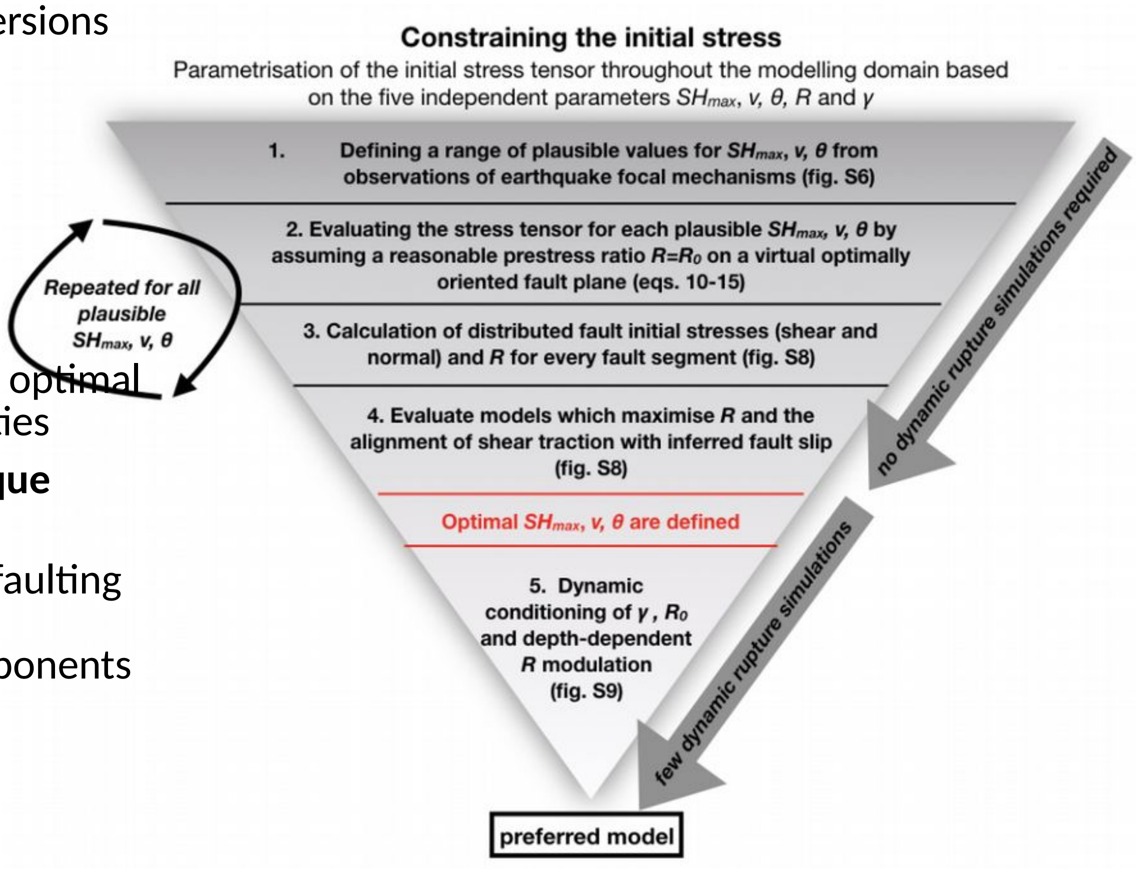
- Regional stress estimates from moment tensor inversions featuring significant uncertainty
- We search for a smoothly varying regional stress parametrized by:
  - 3 angles (principal stress orientations)
  - 2 additional values (amount of deviatoric stress)

  → We developed a **systematic approach** to aim for optimal stress parameters within their identified uncertainties

  → To be consistent with observations requires **unique conditions**

In particular, we find that cascading strike and thrust faulting is enhanced by a high stress ratio

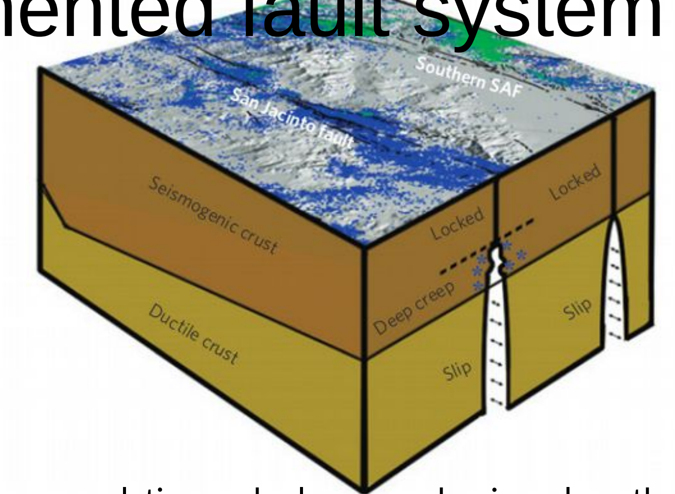
$\nu = (s_2 - s_3)/(s_1 - s_3)$, With $s_1 > s_2 > s_3$ the principal stress components



Cascading rupture on a highly segmented fault system

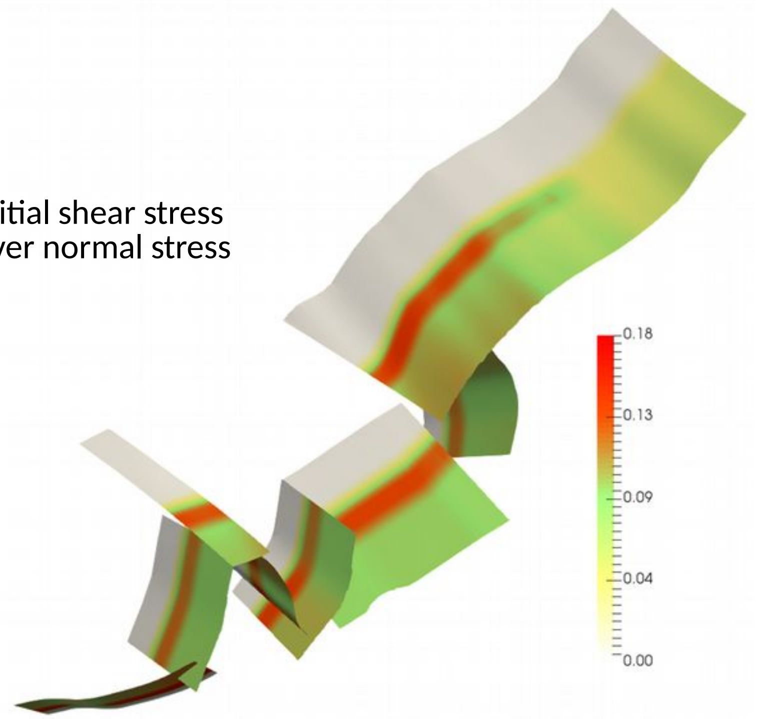
How to achieve such challenging rupture

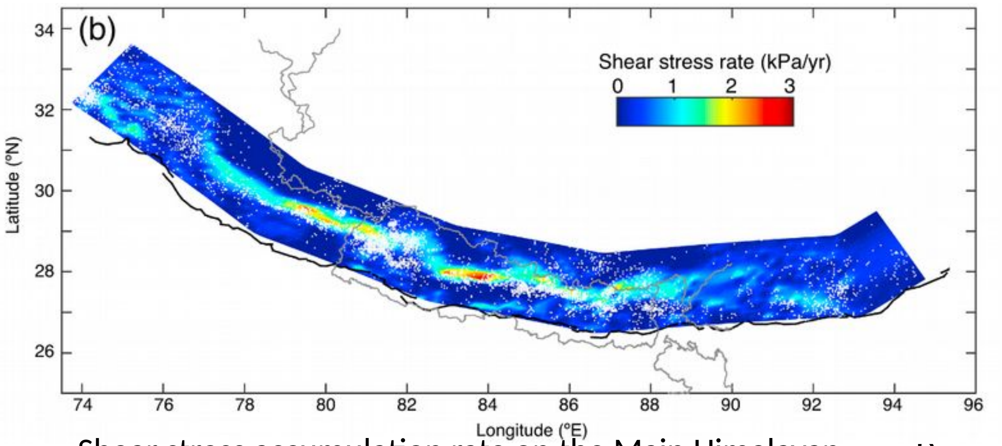
- Prestress very close to critical? (unlikely)
- Our assumption: combining **weakly loaded fault** and **deep stress concentration** induced by (interseismic) deep creep → restores dynamic triggering potential.



Strain accumulation and release mechanism along the southern SAFS, Wdowinski (2009)

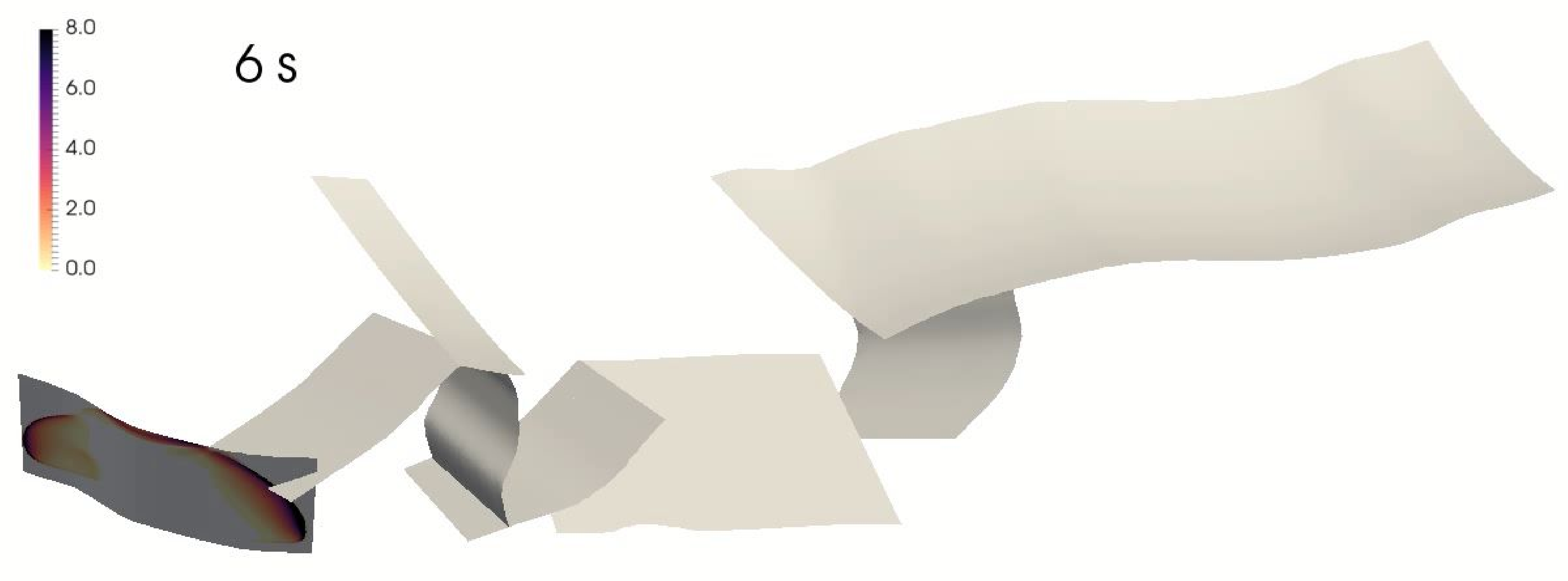
initial shear stress
over normal stress





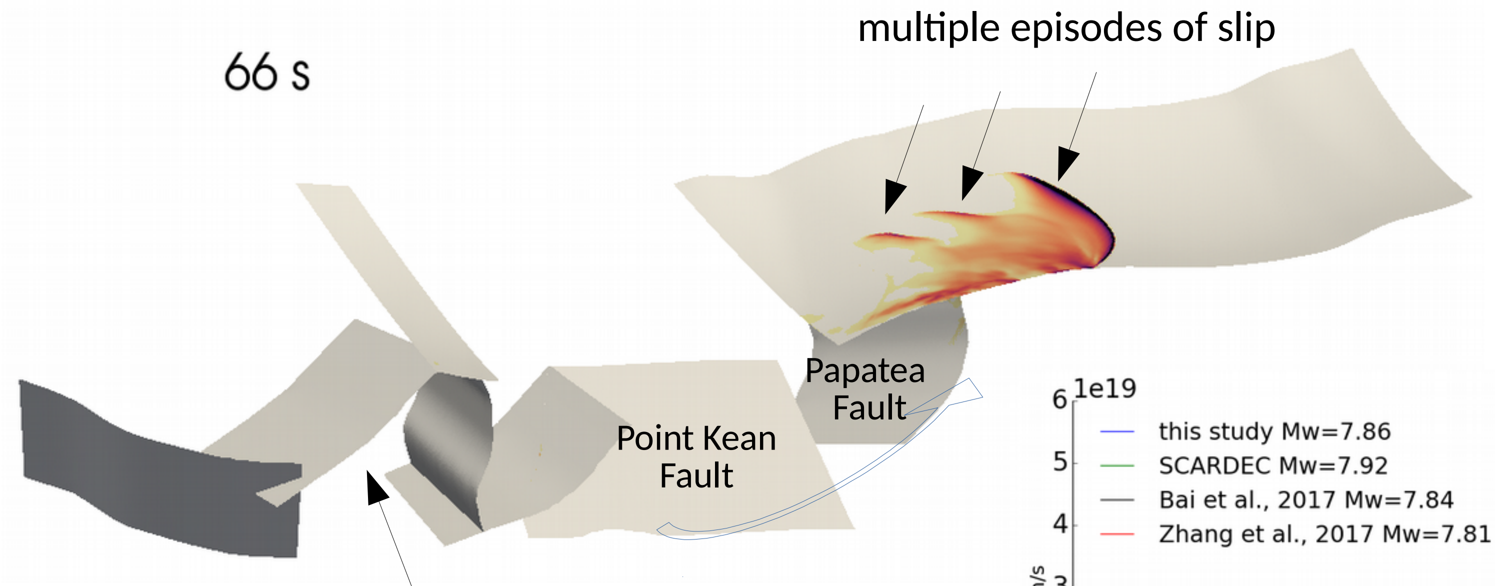
Shear stress accumulation rate on the Main Himalayan Thrust, Stevens and Avouac (2016)

The dynamic rupture model

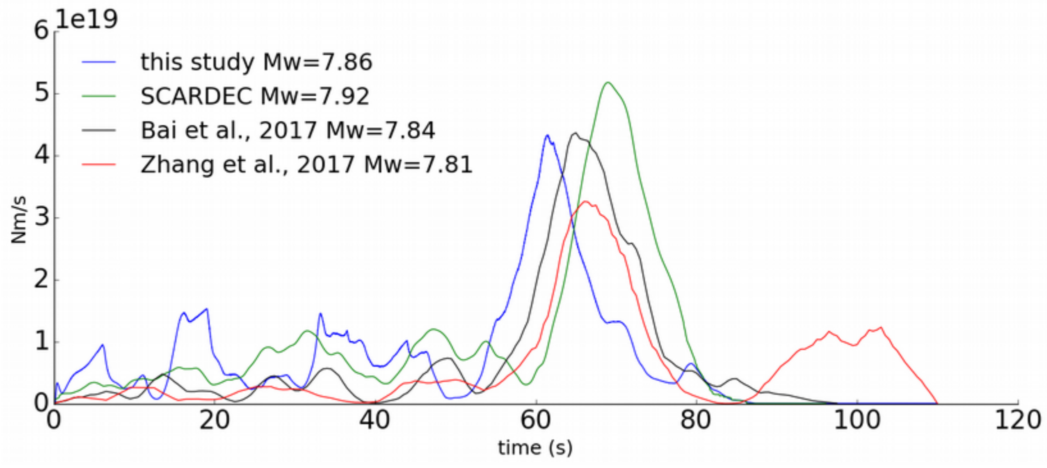


The dynamic rupture model

multiple episodes of slip

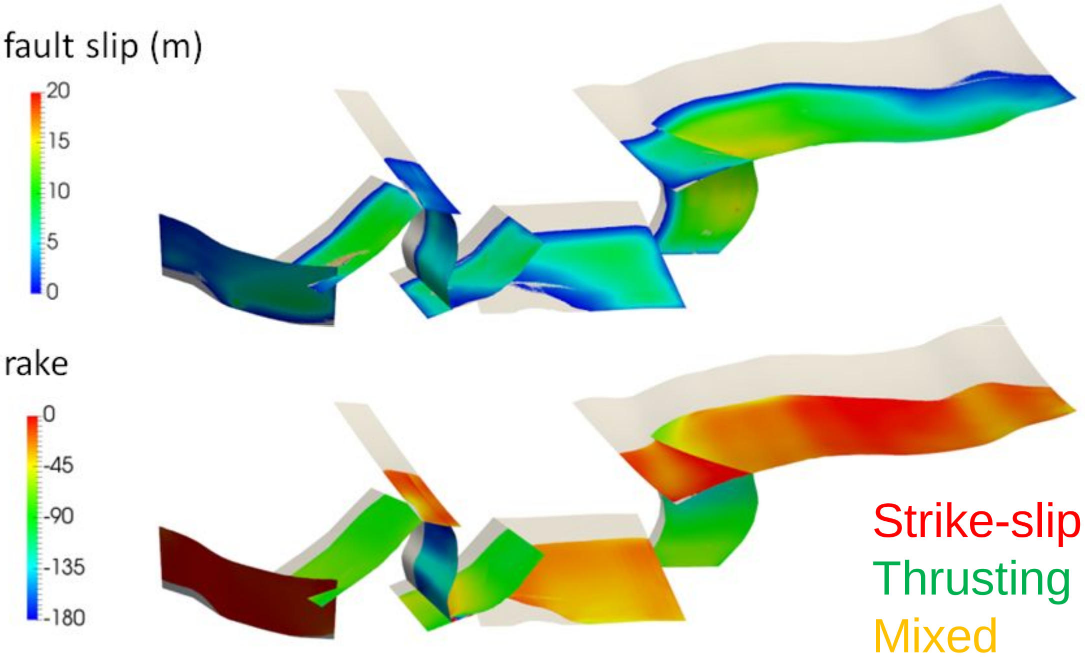


slow apparent rupture velocity from zigzagging rupture path
(average rupture speed 2.9 km/s)

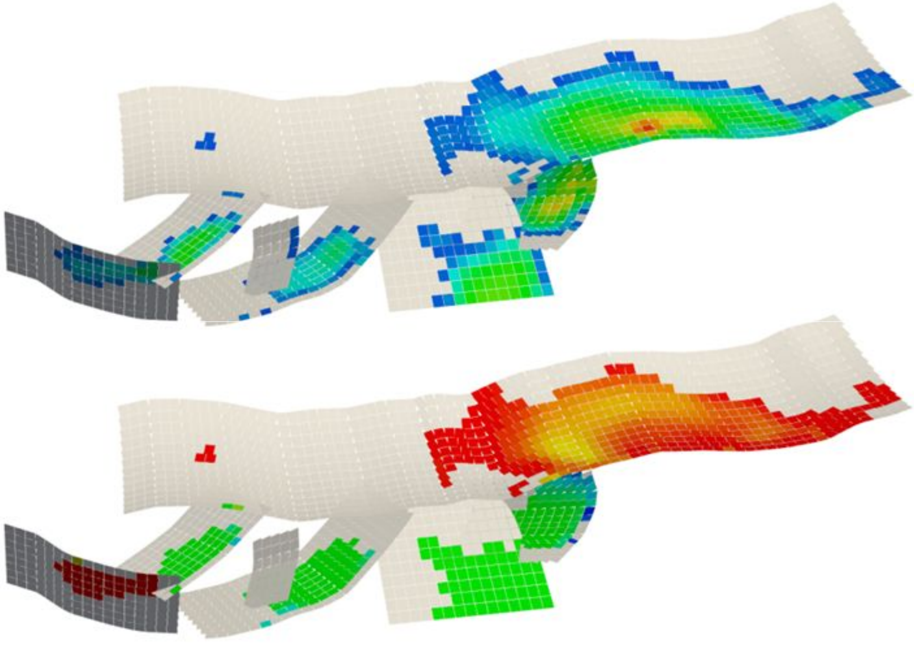


seismic moment release rate

Validation against inversion results



Dynamic rupture model

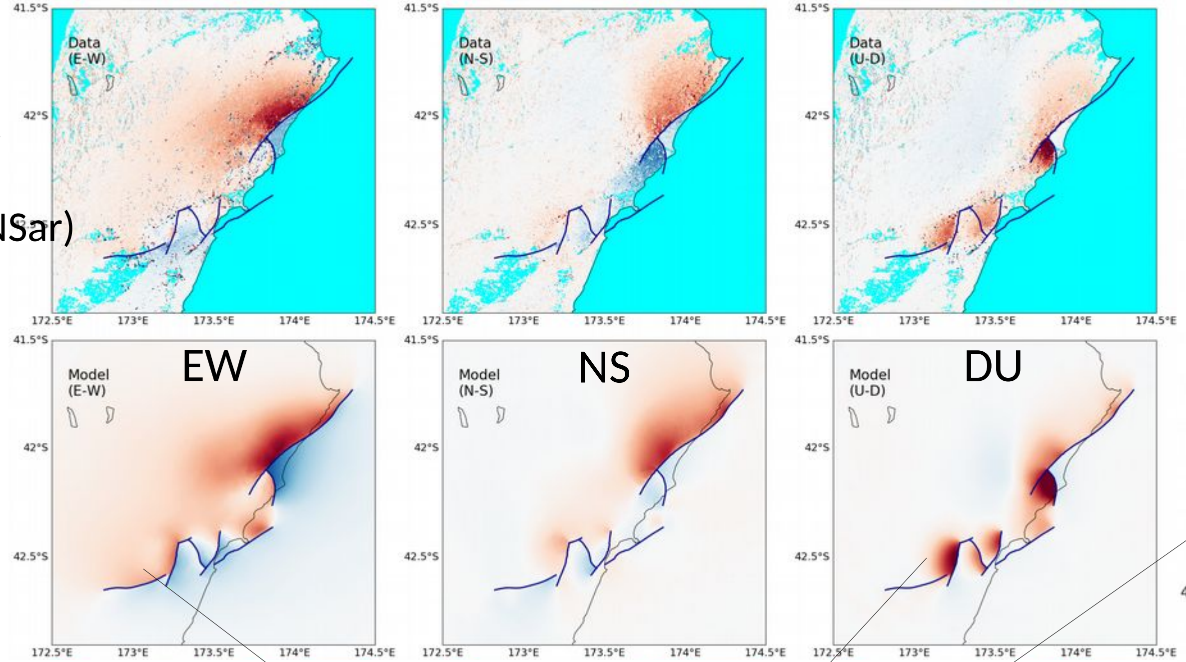


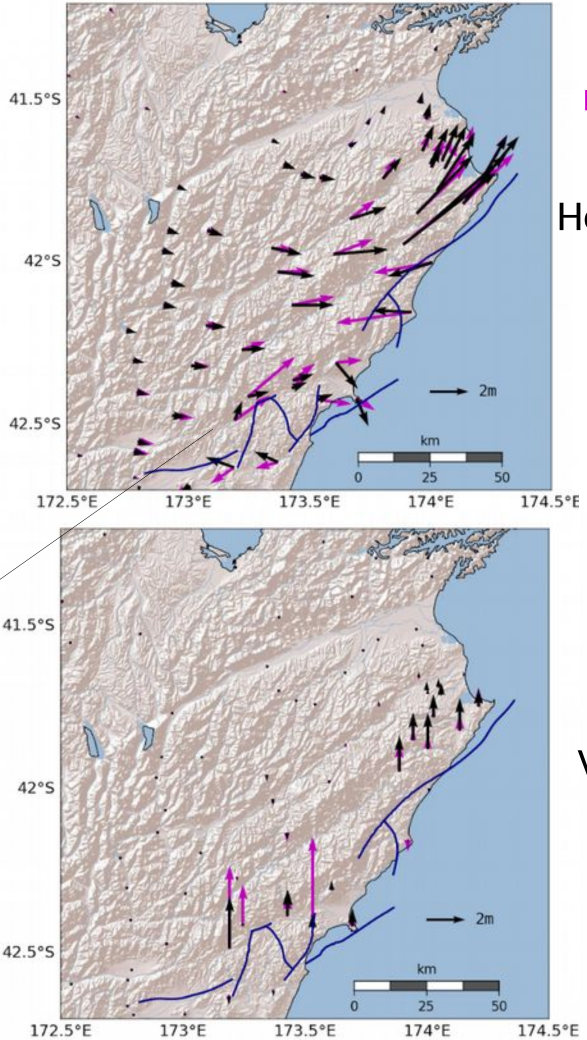
Xu et al. (2018) inversion

Consistency with surface deformations data

Xu et al.
(2018)
(from INSar)

Model



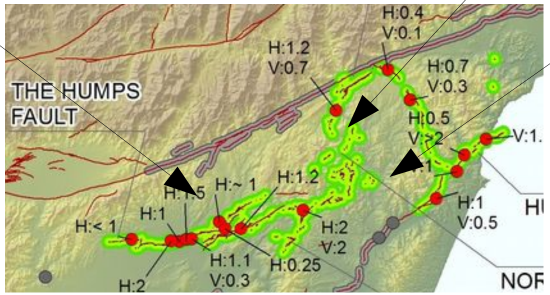


GPS
model

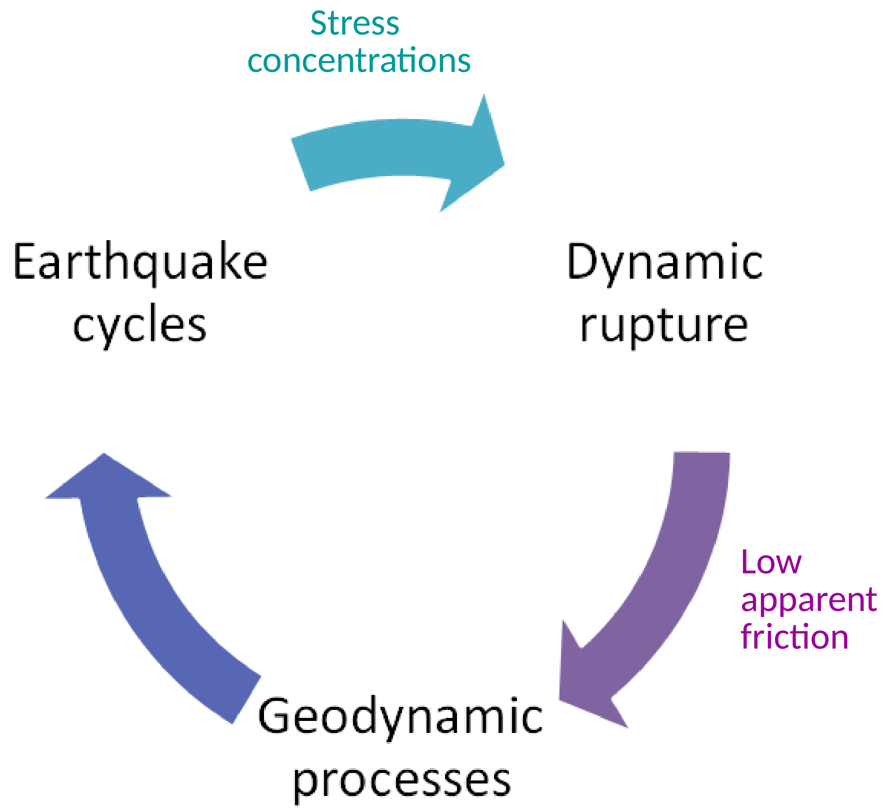
Horizontal

Vertical

Unmodeled
segmentation



Interplay of Processes Across Multiple Time-Scales



- Strong dynamic weakening (μ_d=0.1)
- deep stress concentrations
- elevated fluid pressure (66% of lithostatic)

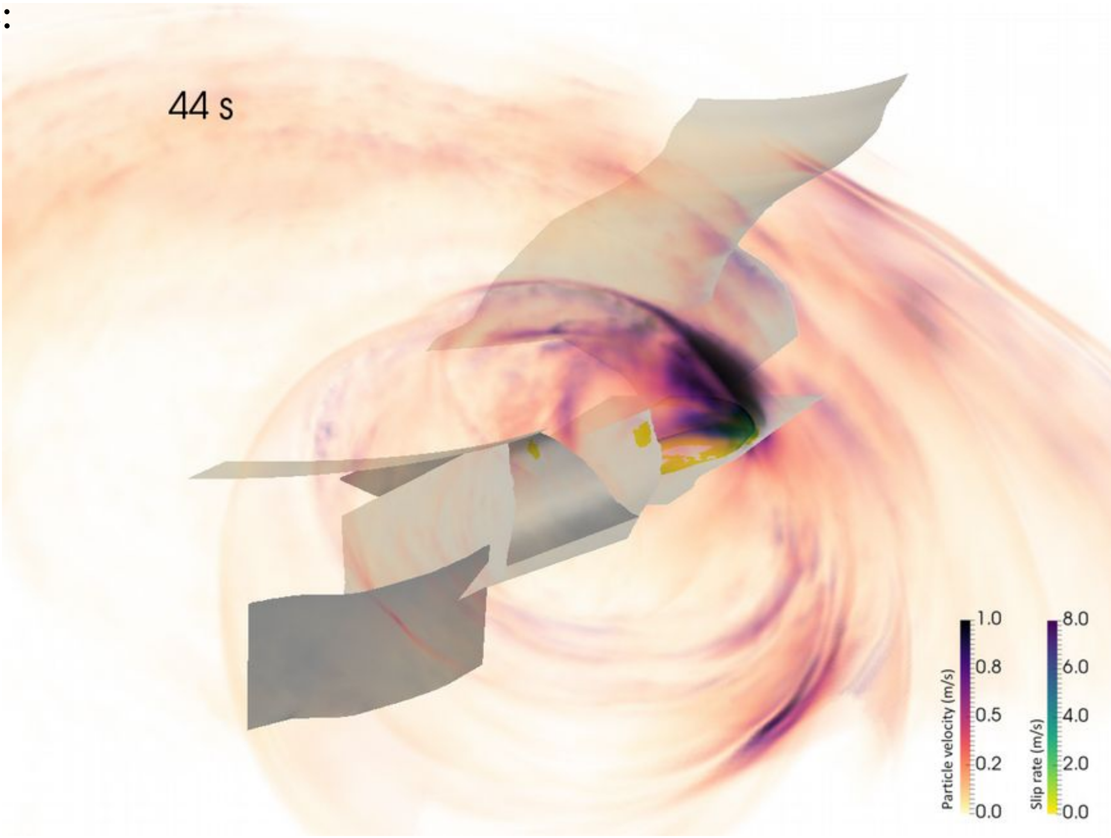
Conclusions

- Physics-based interpretations of puzzling observations: rupture cascade combining strike and thrust faulting, slow rupture, gap in surface rupture, moment rate release sequence

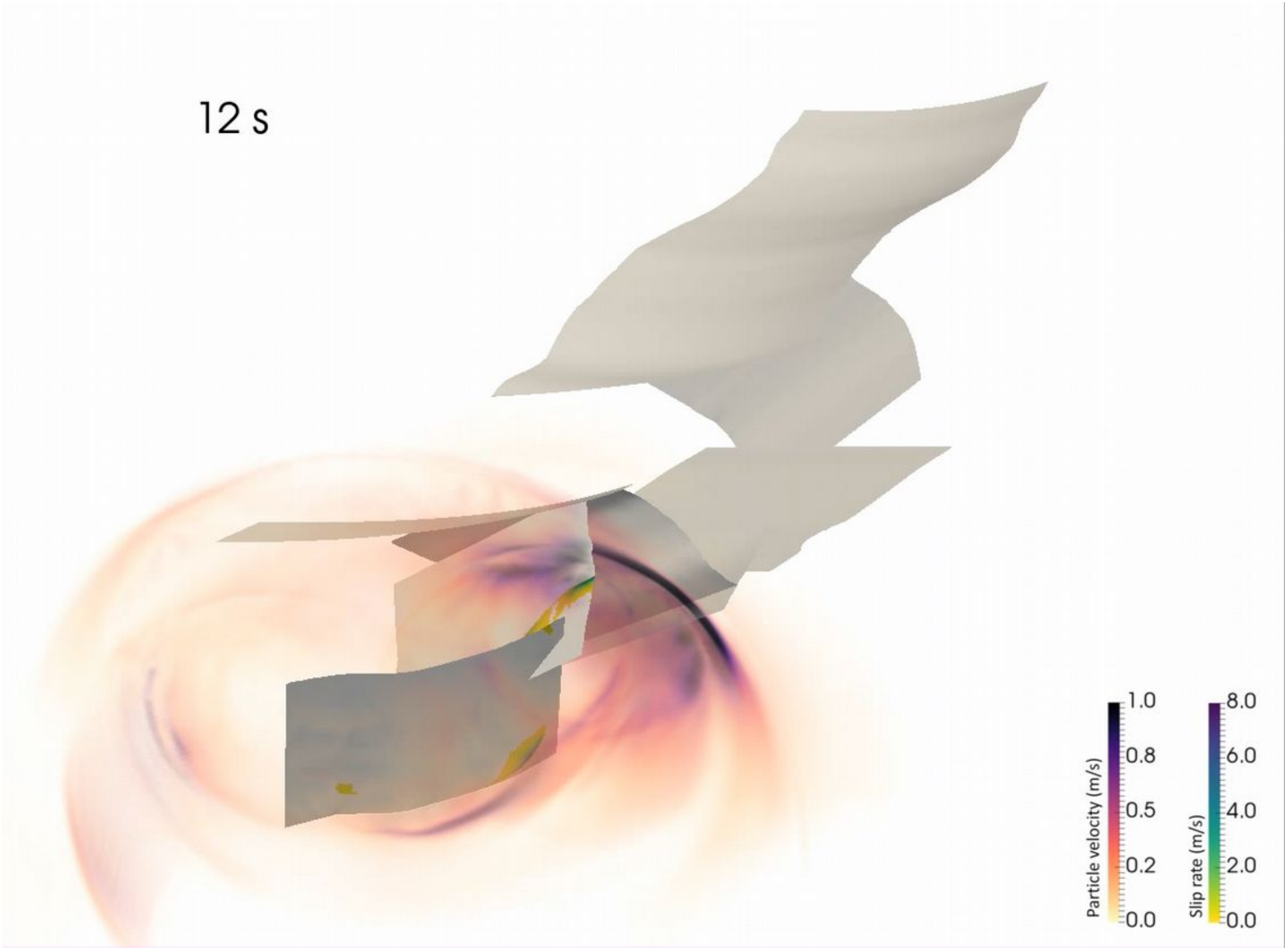
- Slip on the subduction interface not required
- how to integrate it in this framework?
  - below our assumed stress concentration depth
  - not well oriented according to our stress setup
  - far from the crustal faults

    → lower friction? Stress rotation with depth?

- Hazard assessment: better evaluate the possibility of **extreme events**
- State of maturity of dynamic rupture solvers: integrate earthquake physics into **rapid earthquake response**



Thank you!


12 s
Particle velocity (m/s)
1.0
0.8
0.5
0.2
0.0
Slip rate (m/s)
8.0
6.0
4.0
2.0
0.0