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Exploring complex normal faulting systems through physics-based dynamic rupture modeling

Cycle Team Meeting

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ANR EQTIME Project

May 9, 2022

Outline

Motivation

Preliminary exploration

Preliminary conclusions & discussion

On going work and to dos!

Motivation

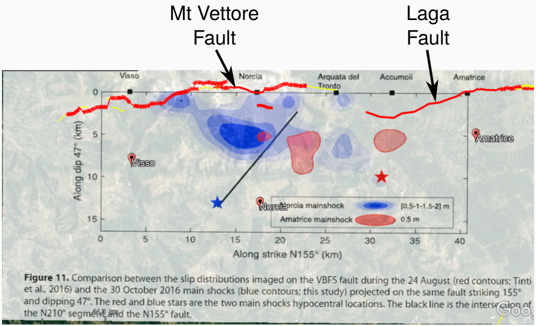
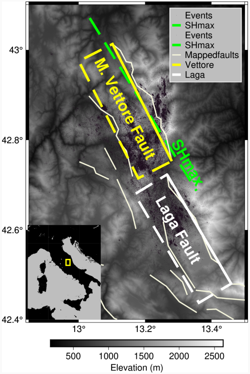
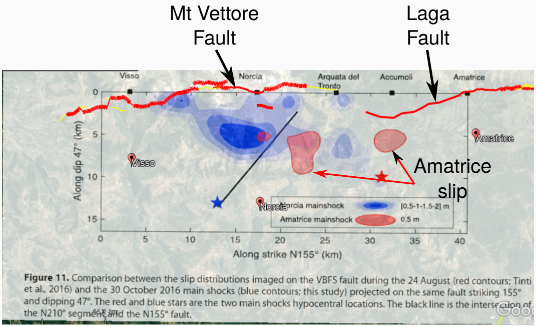
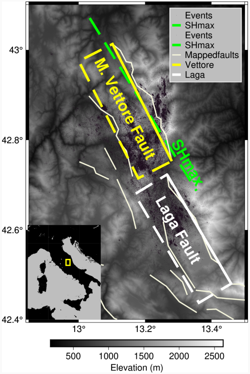


Figure 11. Comparison between the slip distributions imaged on the VBFS fault during the 24 August (red contours; Tinti et al., 2016) and the 30 October 2016 main shocks (blue contours; this study) projected on the same fault striking 155° and dipping 47°. The red and blue stars are the two main shocks hypocentral locations. The black line is the intersection of the N210° segment and the N155° fault.



Modified by O. Scotti from Scognamiglio et al. (2018)





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Seismic Hazard in Central Italy

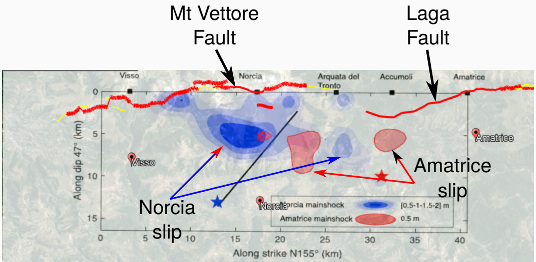
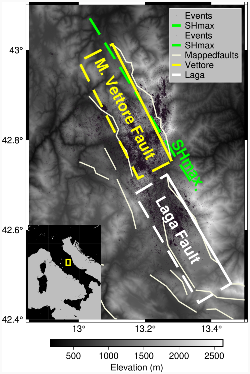


Figure 11. Comparison between the slip distributions imaged on the VBFS fault during the 24 August (red contours; Tinti et al., 2016) and the 30 October 2016 main shocks (blue contours; this study) projected on the same fault striking 155° and dipping 47°. The red and blue stars are the two main shocks hypocentral locations. The black line is the intersection of the N210° segment and the N155° fault.



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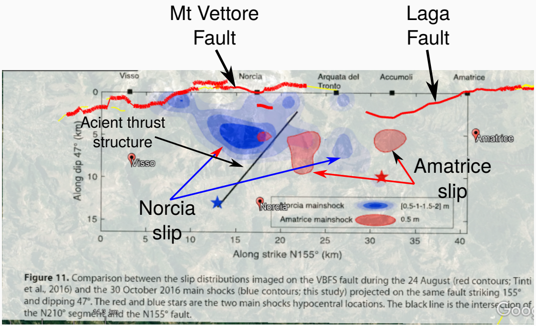

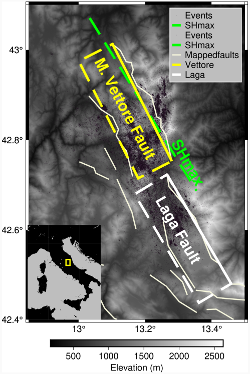

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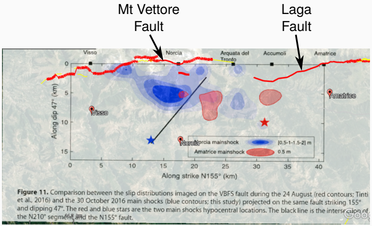
Rupture jump across step-overs



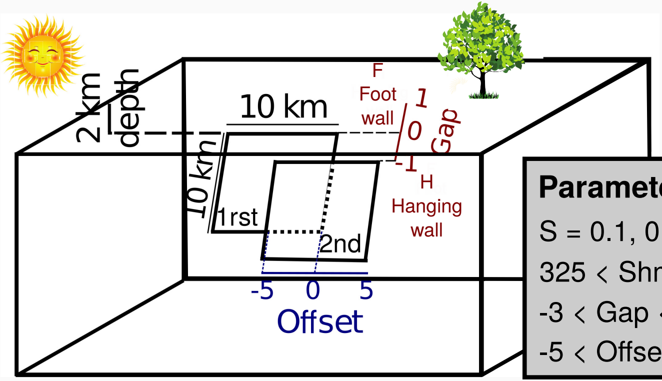
- Potential larger magnitudes?
- Conditions promoting this?
  - Geometry
  - Stress conditions
- To enhance SHA!

Investigate the physical conditons promoting rupture jumps across step overs regarding normal fault systems

Previous studies focused on strike-slip fault systems: Galis et al. (2015); Hu et al. (2016); Bai and Ampuero (2017); Li and Liu (2020); Oglesby (2008), and more ...

Preliminary exploration

Preliminary exploration: Geometry and settings



Parameters:

S = 0.1, 0.2, 0.3, ...

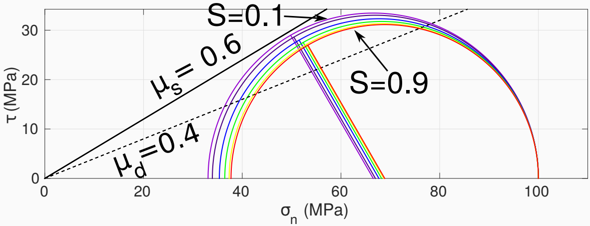
325 < Shmax < 350

-3 < Gap < 3 km

-5 < Offset < 5 km

(www.seissol.org; e.g., Wollherr et al., 2018; Ulrich et al., 2019)

Preliminary exploration: Stress conditions



Stress-Strength dimensionless ratio

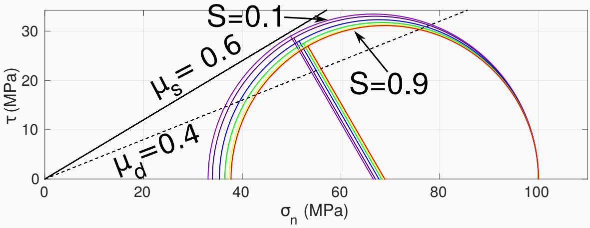
$$S = \frac{\tau_p - \tau_0}{\tau_0 - \tau_r}$$

Stress & medium conditions

- Stress levels explored

  $S = 0.1,\ 0.2,\ 0.4,\ 0.6,\ 0.8,\ 0.9$

Preliminary exploration: Stress conditions



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  μ_s=0.6, μ_d=0.4, d_c=0.15 m

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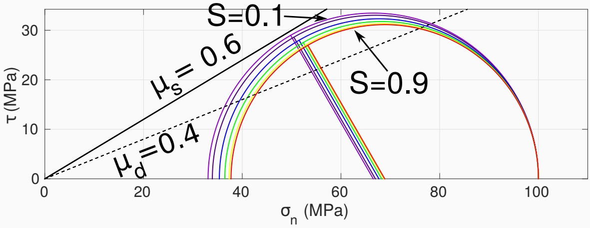

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  $$\mu_s \xrightarrow[t \to 1]{} \mu_d$$
  at a 4×4 km^2 patch

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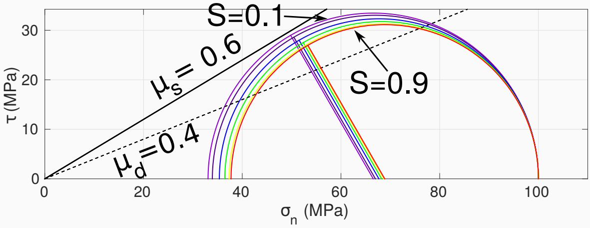

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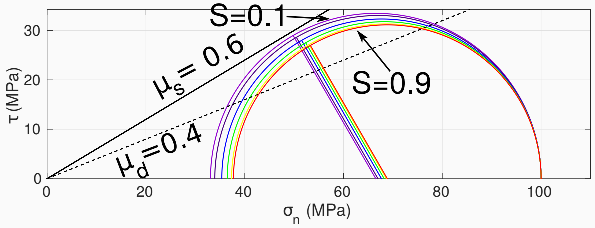
- σ_{zz} is fixed to 100 MPa (∼3.6 km depth)

Preliminary exploration: Stress conditions



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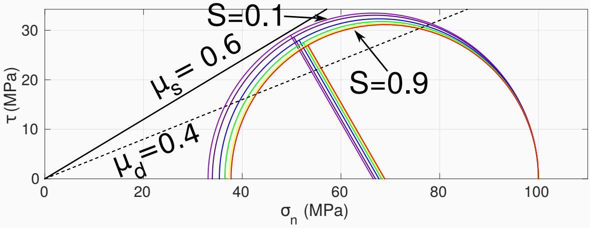
- σ_{zz} is fixed to 100 MPa ($\sim$3.6 km depth)
- Homogeneous half-space
  V_p=6.3, V_s=3.6 km/s, ρ=2800 kg/m^3

Preliminary exploration: Stress conditions



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- σ_{zz} is fixed to 100 MPa ($\sim$3.6 km depth)
- Homogeneous half-space
  V_p=6.3, V_s=3.6 km/s, ρ=2800 kg/m^3
- Faults share same stress level

Inspired by Aochi (2018)

For these cases: Gap $= 1$ km, Offset $= 1$ km

Only 1 fault segment breaks

S: 0.6

Preliminary exploration: 3 different cases

For these cases: Gap = 1 km, Offset = 1 km

Only 1 fault segment breaks

S: 0.6

Rupture is arrested after jumping

S: 0.4

Preliminary exploration: 3 different cases

For these cases: Gap = 1 km, Offset = 1 km

Only 1 fault segment breaks

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Rupture is arrested after jumping

S: 0.4

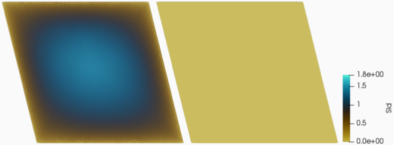
Both segments break

S: 0.2

Preliminary exploration: 3 different cases

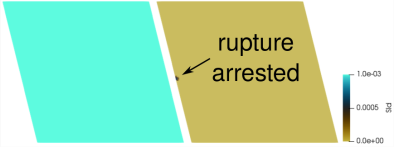
For these cases: Gap = 1 km, Offset = 1 km

Only 1 fault segment breaks



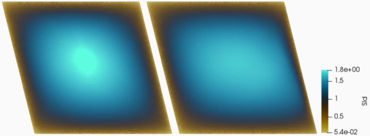
S: **0.6**

Rupture is arrested after jumping



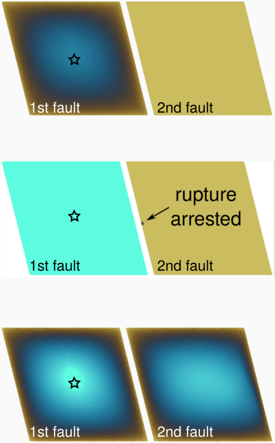
S: **0.4**

Both segments break



S: **0.2**

Preliminary exploration: 3 different cases



○ Only 1st fault breaks

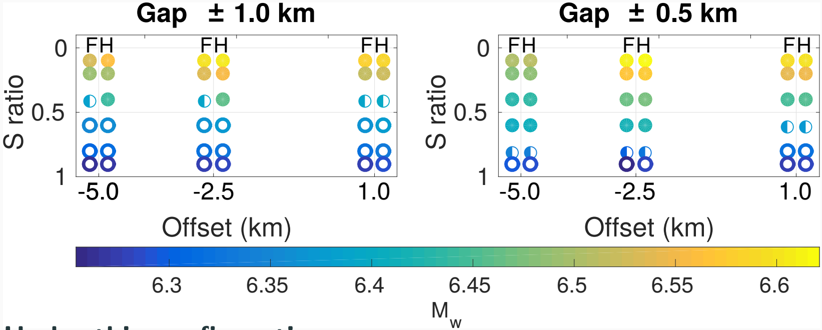
◐ Rupture arrested on the 2nd fault

● Both faults break

3 Different cases

Preliminary exploration: Results from simulations

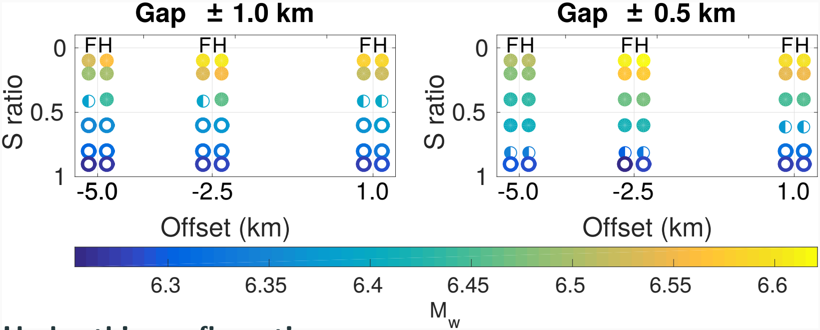
72 simulations: [4] Gap values × [3] Offset values × [6] Stress levels



Under this configuration:

Preliminary exploration: Results from simulations

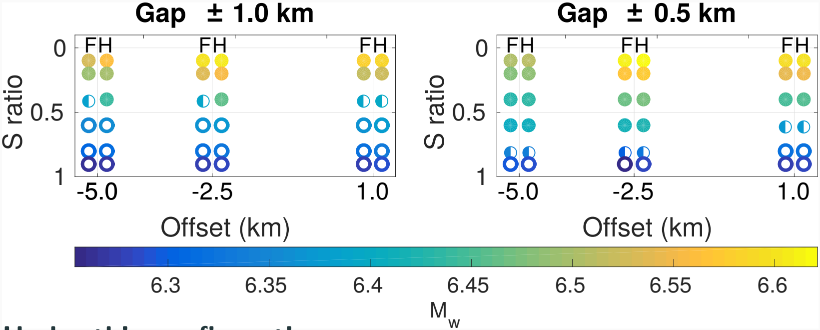
72 simulations: [4] Gap values × [3] Offset values × [6] Stress levels



Under this configuration:

S depends only on the stress level and not on μ_s or μ_d.

72 simulations: [4] Gap values × [3] Offset values × [6] Stress levels



Under this configuration:

S depends only on the stress level and not on μ_s or μ_d.

Rupture is arrested mainly due to the pre-stress level of faults.

Preliminary exploration: Results from simulations

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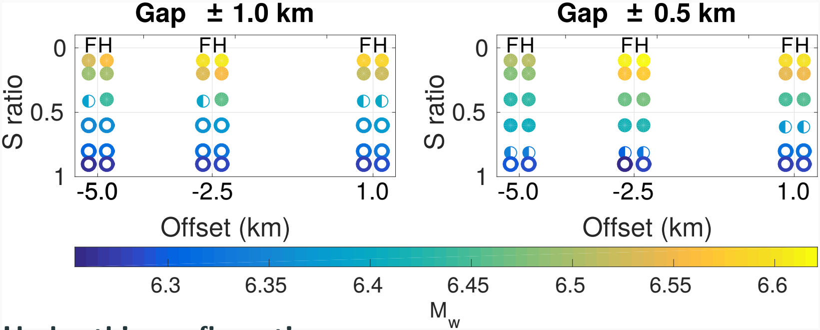

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Beyond > 1 km offset jumps might be expected only at low S-ratio levels.

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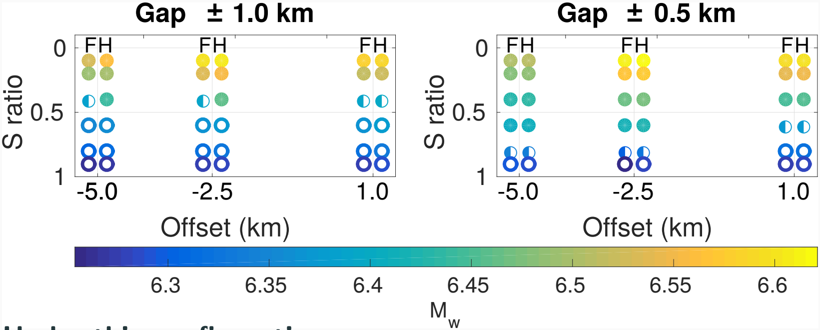

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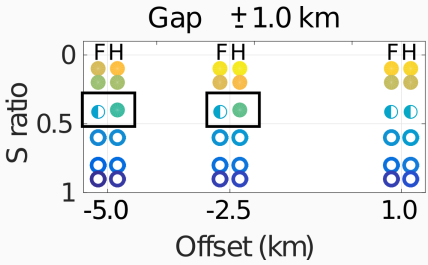
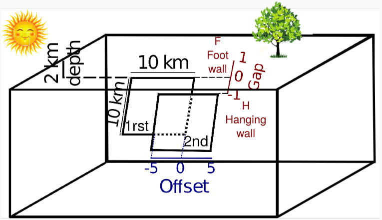
Stress shadow and **hanging/foot wall asymmetry** are observed.

Preliminary conclusions & discussion

Hanging/foot wall behavioral asymmetry



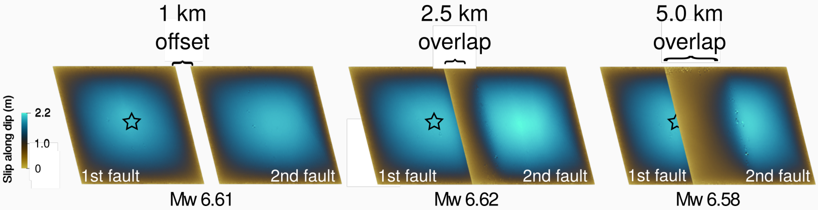


Triggering potential:

When the 2nd fault is located on the hanging wall (with respect to the 1st fault) the dynamically triggered rupture is more likely to be self-sustainable (break away).

Stress shadow: Slip VS Fault Proximity

For these cases: Gap $= 0.5$ km, $S = 0.1$



Slip VS Fault Proximity:

The final slip distribution (estimated energy) increases/decreases according to the distance between faults.

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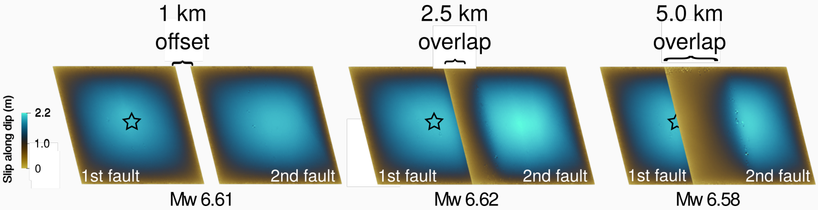

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The final slip distribution (estimated energy) increases/decreases according to the distance between faults.

Large overlap $\rightarrow$ Fault proximity $\rightarrow$ high triggering effect

but,

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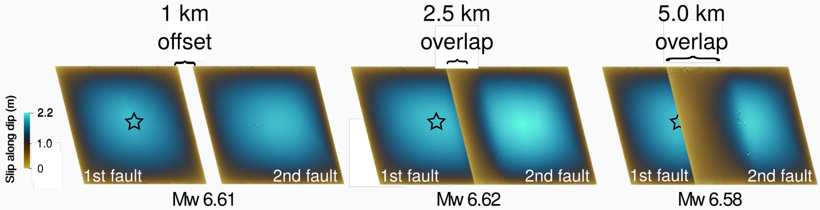


Slip VS Fault Proximity:

The final slip distribution (estimated energy) increases/decreases according to the distance between faults.

Large overlap $\rightarrow$ Fault proximity $\rightarrow$ high triggering effect

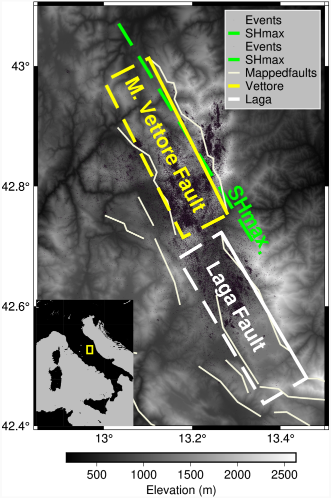
but,

Stress shadow $\rightarrow$ decreases slip distribution on 2nd fault

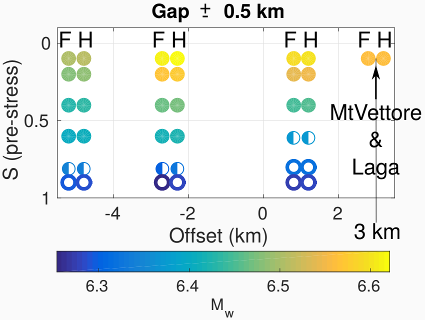
On going work and to dos!

Central Italy complex normal faulting system

Mapped fault traces



Fault2SHA Database (Faure Walker et al., 2021)



Central Italy:

- ☞ Extensional regime
- ☞ Multi-segment normal faulting system
- ☞ Complex fault geometry
- ☞ Seismicity along one or serveral segments
  - 1980 Ms6.9 Irpinia
  - 2016 Amatrice-Visso-Norcia

Things to do

Some steps to follow (little by little):

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- Complexify fault geometry, larger, rougher, ...

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- Complexify fault geometry, larger, rougher, ...
- Account for a stratified embedding medium

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- More realistic stress field: regional, depth-dependent

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Some steps to follow (little by little):

- Complexify fault geometry, larger, rougher, ...
- Account for a stratified embedding medium
- More realistic stress field: regional, depth-dependent
- Include topography

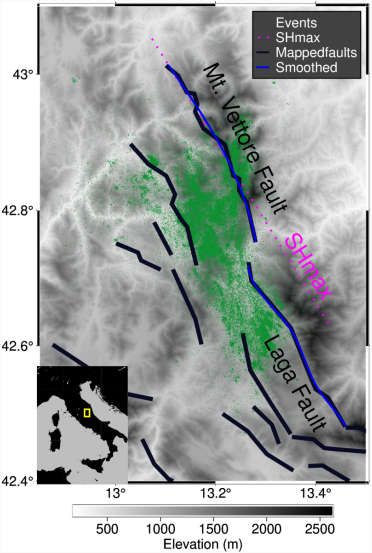
Things to do

Some steps to follow (little by little):

- Complexify fault geometry, larger, rougher, ...
- Account for a stratified embedding medium
- More realistic stress field: regional, depth-dependent
- Include topography

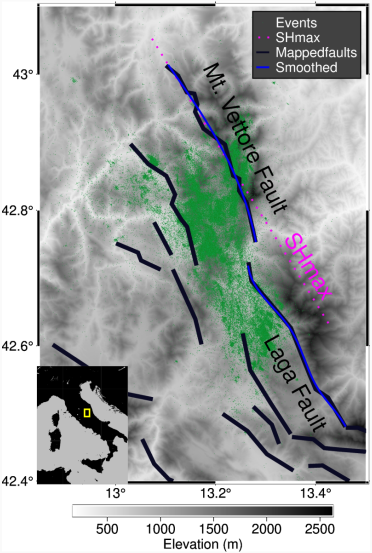
While exploring for the physical properties promoting rupture jumps across step overs

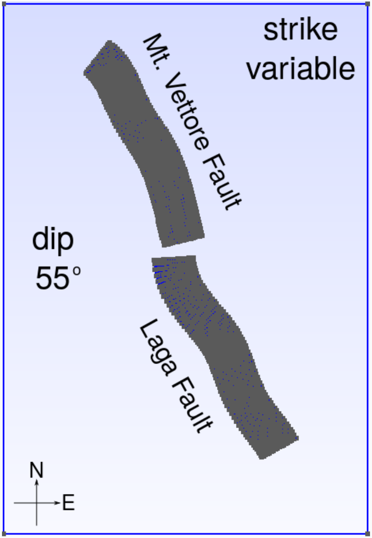
Complexifying the fault geometry



Events from Tan et al. (2021)

Complexifying the fault geometry

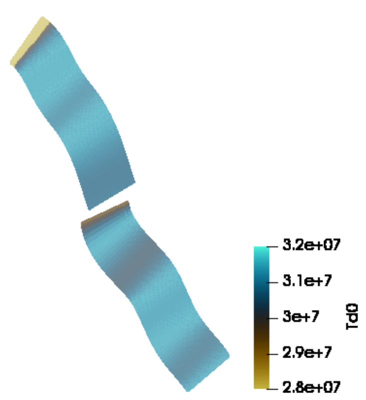




Events from Tan et al. (2021)

Initial exploration with complex geometry

Initial shear stress along dip (Pa)

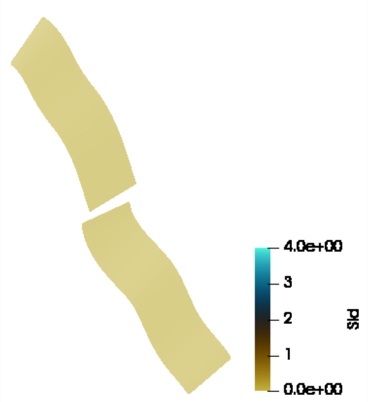


Summary:

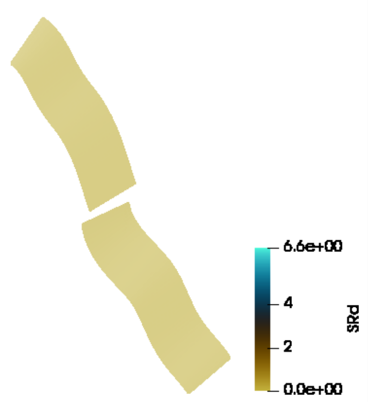
- Stress levels explored $S = 0.1$
- Linear Slip Weakening: μ_s=0.6, μ_d=0.4, d_c=0.15
- Slow rupture initiation $\mu_s \xrightarrow[t \to 1]{} \mu_d$ at 16π km^2 patch
- $\sigma_{zz} = 100$ MPa ($\sim$3.6 km depth)
- Homogeneous half-space V_p=6.3, V_s=3.6 km/s, ρ=2800 kg/m^3
- Stress level affected by geometry

Initial exploration with complex geometry

Cumulative slip along dip (m)



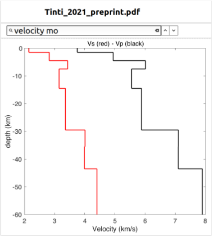
Slip rate along dip (m/s)

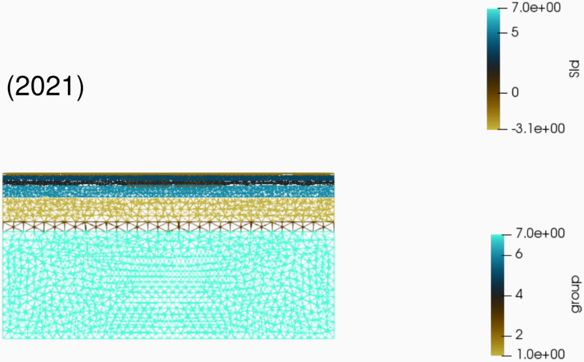


$\sim$20 seconds of rupture

Initial exploration: complex geometry + layered me

From Tinti et al. (2021)





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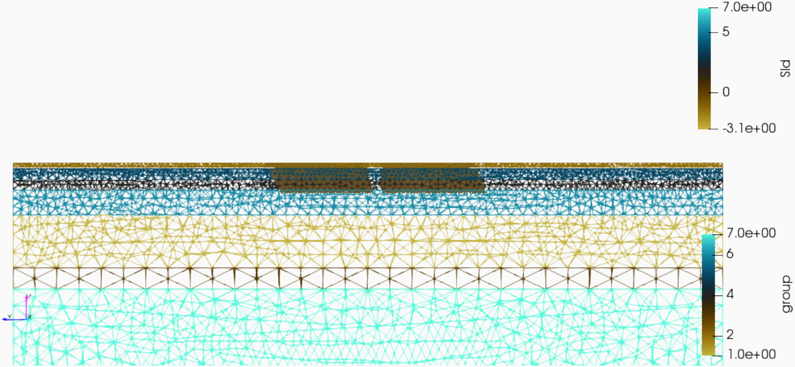

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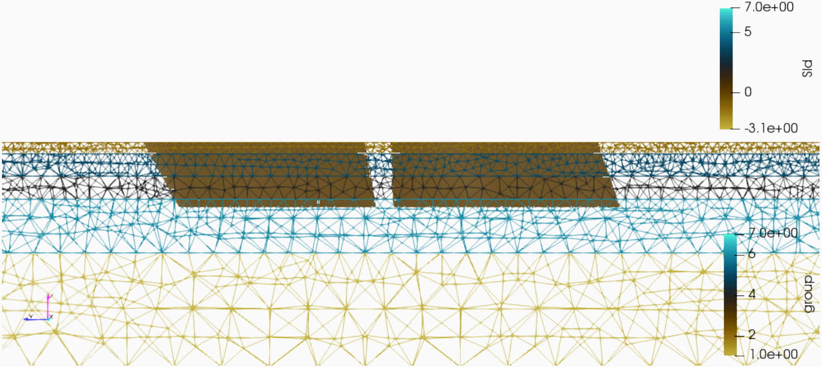

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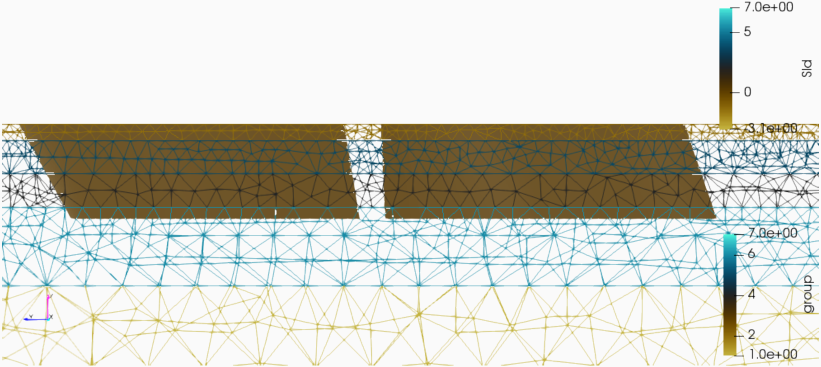
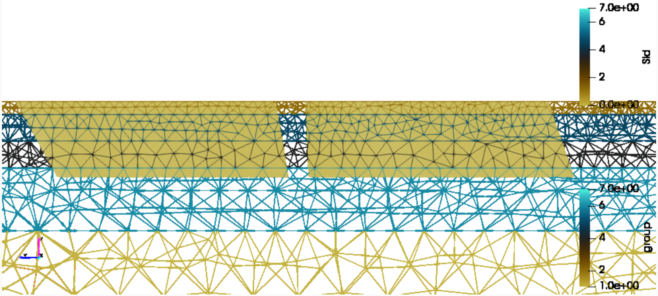


Initial exploration: complex geometry + layered me

Slip rate along dip direction (m/s)

Cumulative slip along dip direction (m)



20 sec. of simulation → velocity model is the only change

Differences compared to other studies:

- We deal with normal faulting systems
- Under our configuration, beyond > 1 km offset jumps might be expected only at low S-ratio levels
- Different ways to initiate the rupture

To dos:

- Improve our mesh ✓
- Account for stratified media ✓
- Explore depth-dependent and heterogeneous stress fields
- Include plasticity, topography, ...

Thanks for listening!

Departure: From April 1 2022 CRCN IRD

- Keep the exploration on this fault system
  Jan. – Apr. : depth-dependent stress+topography+plasticity
    - Interact with the new postdoc (if there is a replacement)
      Apr. – Jun.
- Extend this research to other regions and fault systems
    - Libanon (Dead Sea Fault), Peru ?
      Apr. – Jul.
- Prepare a publication related to this study
  Mar. – . . .
- Prepare a report/tutorial of what I have done
  Mar. – Apr.

References

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