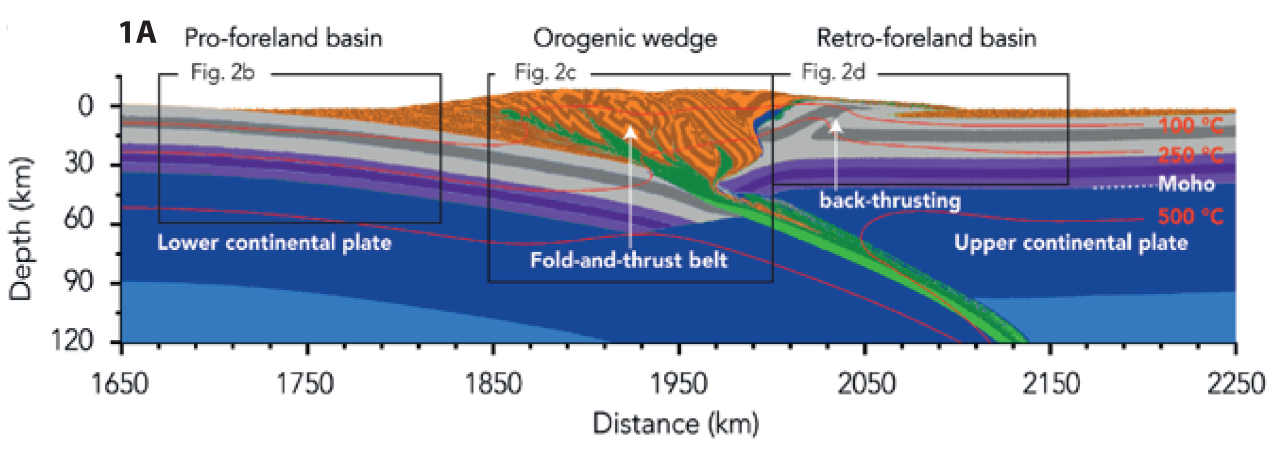
Role of thermo-mechanical processes in seismicity: overview of STM modeling

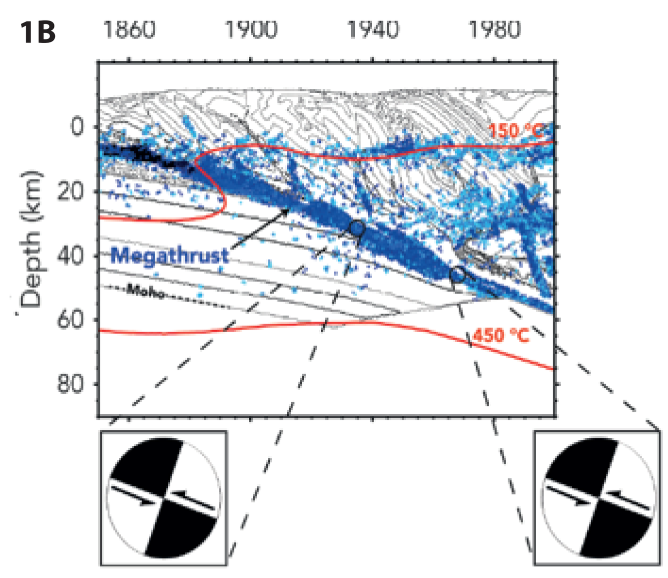
Ylona van Dinther*(1,2) in collaboration with Taras Gerya (2) and students at ETH Zurich:
PhD students: Luca Dal Zilio, Robert Herrendoerfer, Iris van Zelst, Simon Preuss, Casper Pranger, Sylvia Brizzi,
and MSc students: Mario D'Acquisto and Lukas Preiswerk.
(1) Earth Sciences, Utrecht University (NL), (2) Geophysics, ETH Zurich (CH). *Contact: y.vandinther@uu.nl

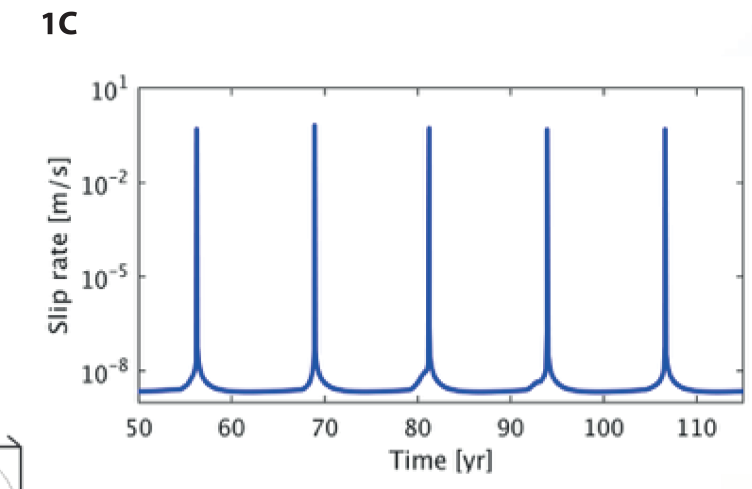
Utrecht University · ETH zürich · STM group

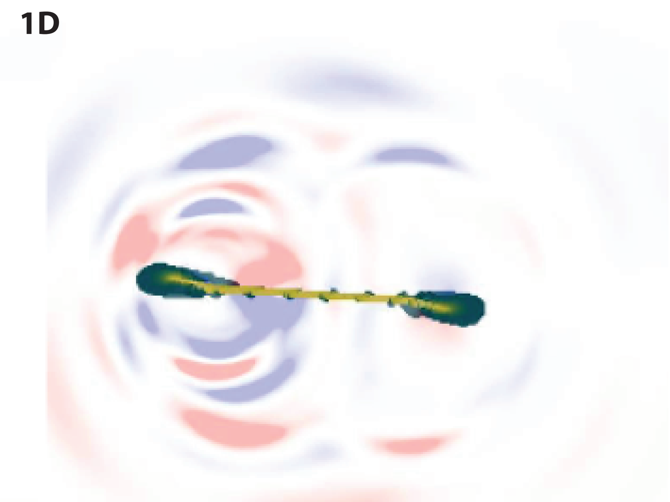
Bridging time scales from tectonics to dynamic earthquake rupture

A summary of what **seimo-thermo-mechanicanical models (STM)** can do:









Tectonics
- Thermo-mechanical evolution of convergent margins
- For millions years and over 100-1000's km's
- Static friction
- Δt = 1000 years

Earthquake-like events on various faults:
- Rate-dependent friction
- Inertia added
- Δt = 1-5 years

Rate-and-state dependent friction
- invariant reformulation w. $\tau_{II} = \sigma_{\text{yield}}$
- From periodic earthquake cycles to slow and aseismic slip
- Δt = milliseconds - years

Dynamic earthquake rupture
- Seismic wave propagation
- Fault evolution
- Δt = milliseconds

All done using same code based on
- 2D finite-differences on fully staggered grid w. marker-in-cell technique
- to solve conservation of mass, momentum and heat
- using a visco-elasto-plastic rheology and laboratory-based parameters for different lithologies
- with some hydro- (e.g., slab dehydration and fluid flow) and chemical components (e.g., serpentinization, melting)

- resolve interseismic, coseismic and postseismic phase
- resolve nucleation size and cohesive zone
- accurate and convergent solution on predefined fault

- grid size convergence through W=Wm*log(1+K(V0/Vp))

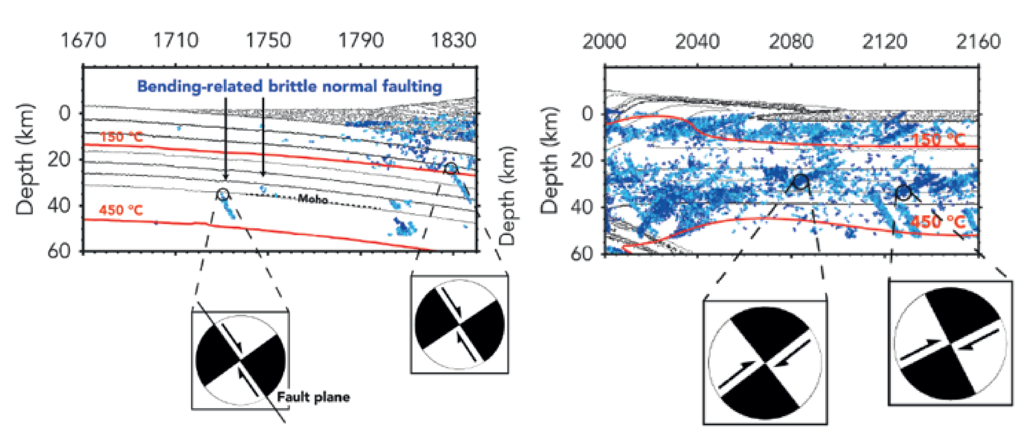
See: Gerya & Yuen, PEPI, 2007; van Dinther et al., JGR, 2013a,b; GRL 2014; Dal Zilio et al., EPSL, 2018; Herrendoerfer et al., JGR, 2018; Preuss et al., EarthArXiV, 2019; in prep.

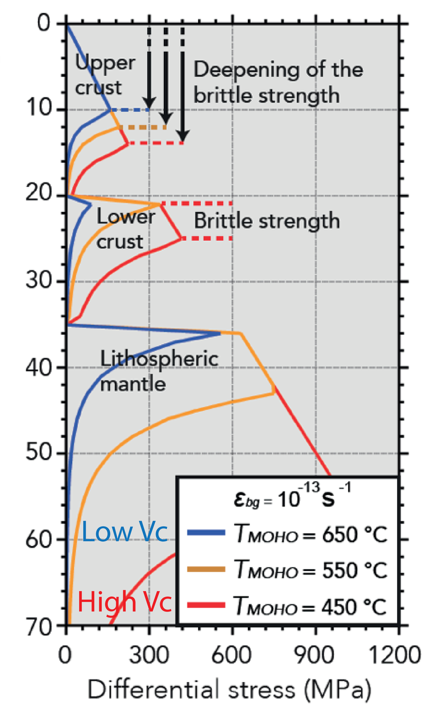
How thermal coupling increases Mmax and b-value

>> Convergence rate not only increases seismic rate, but also maximum magnitude and proportion of large events (b)

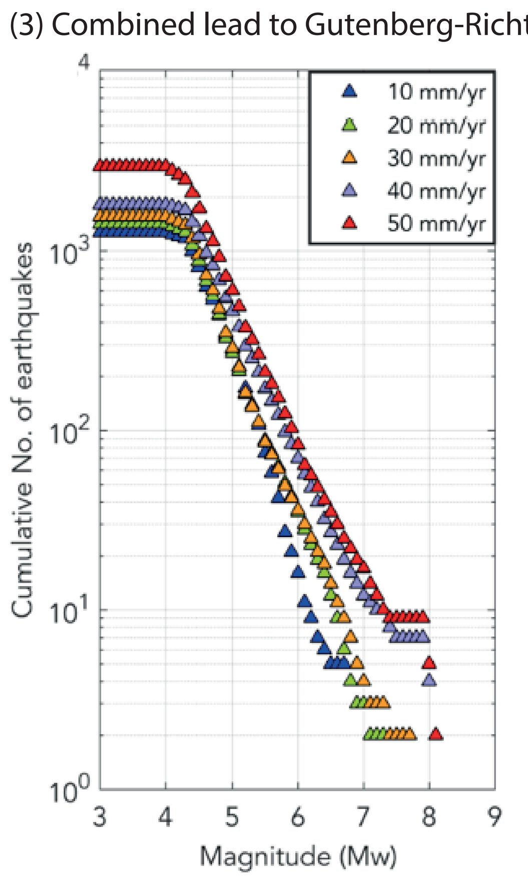
(1) 10 million years of thermo-mechanical evolution of continent-continent collision leads to setup in Fig. 1A

(2) Spontaneous ruptures of various sizes and types are generated (see also Fig. 1B)





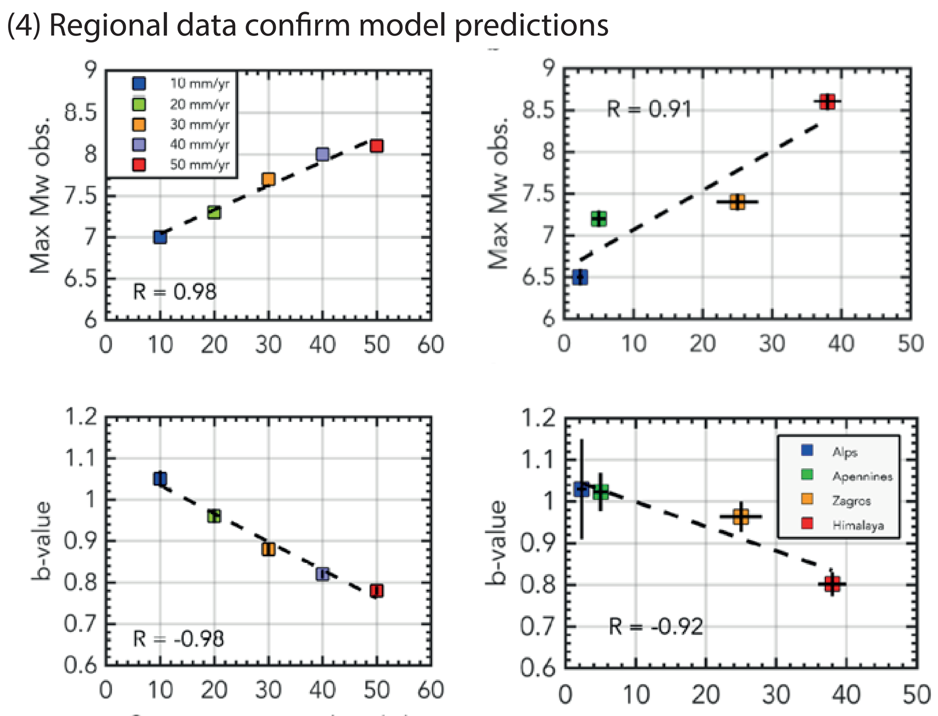
(3) Combined lead to Gutenberg-Richter law



See: Dal Zilio et al., EPSL, 2018

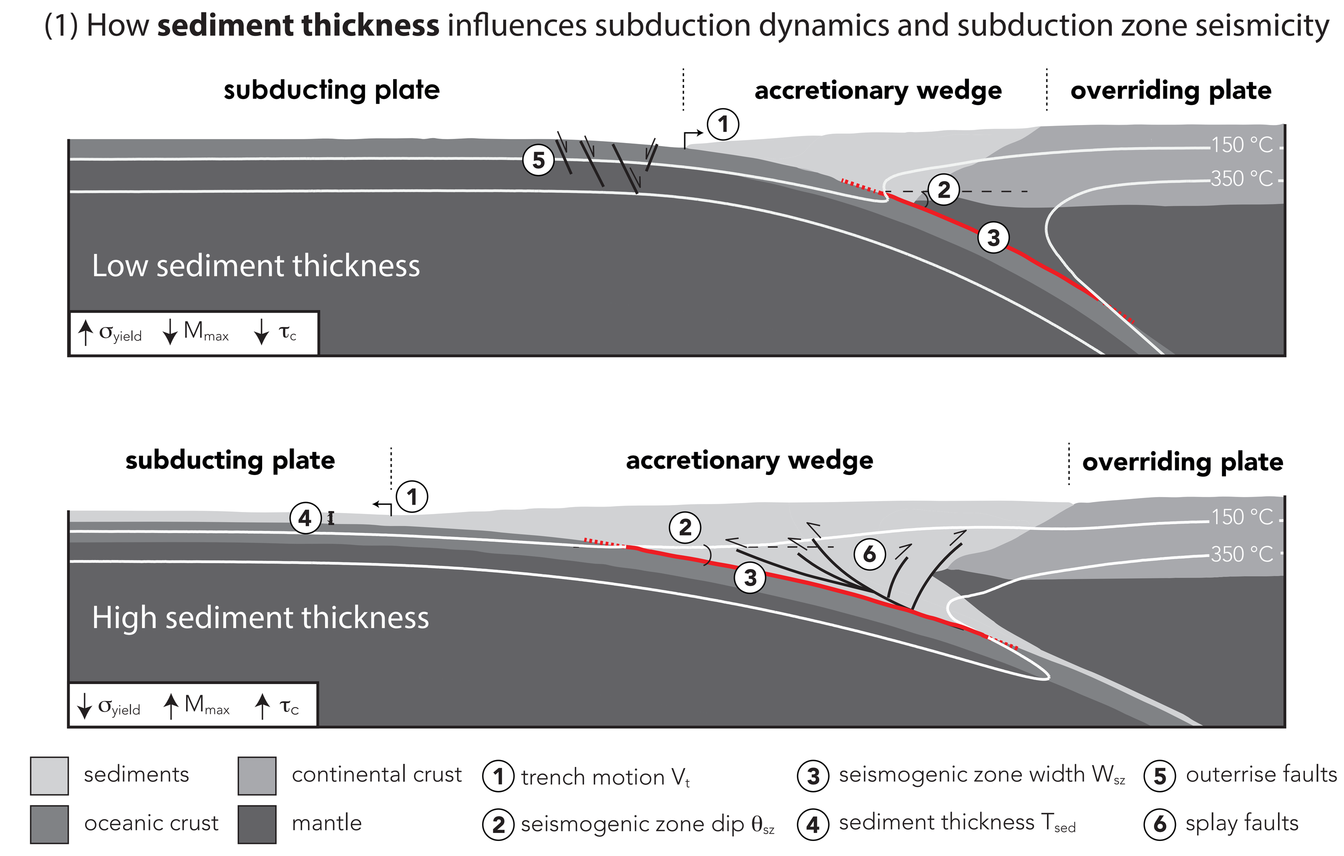
(5) Mechanism:
- Faster penetration of cooler temperatures to larger depths
- Larger brittle portion leads to larger and relative more larger events

(4) Regional data confirm model predictions

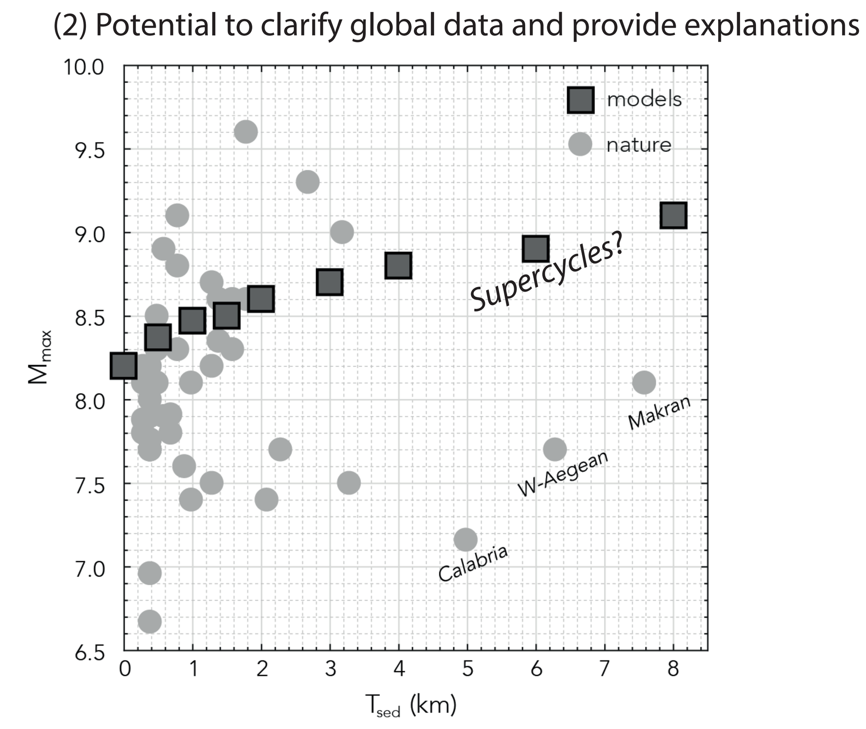


How thermo-mechanical coupling impacts seismicity

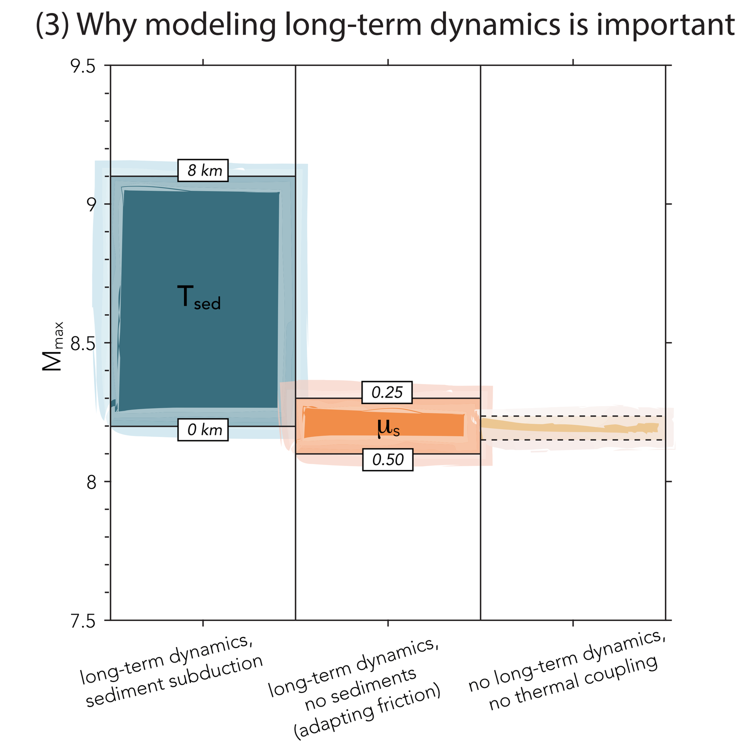
(1) How **sediment thickness** influences subduction dynamics and subduction zone seismicity



(2) Potential to clarify global data and provide explanations



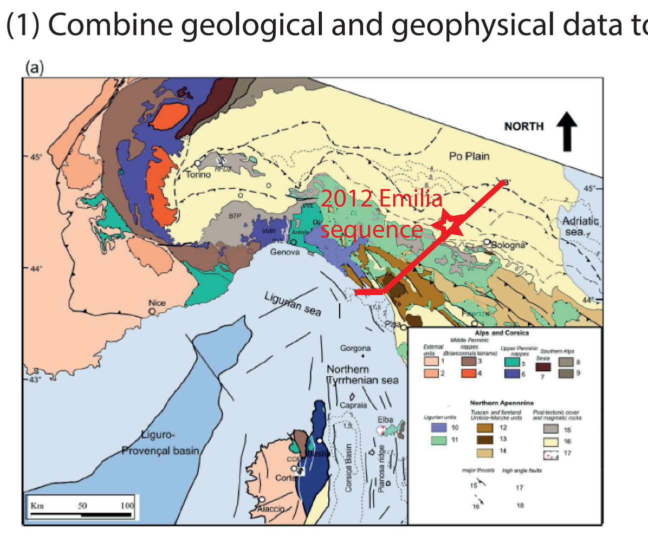
(3) Why modeling long-term dynamics is important

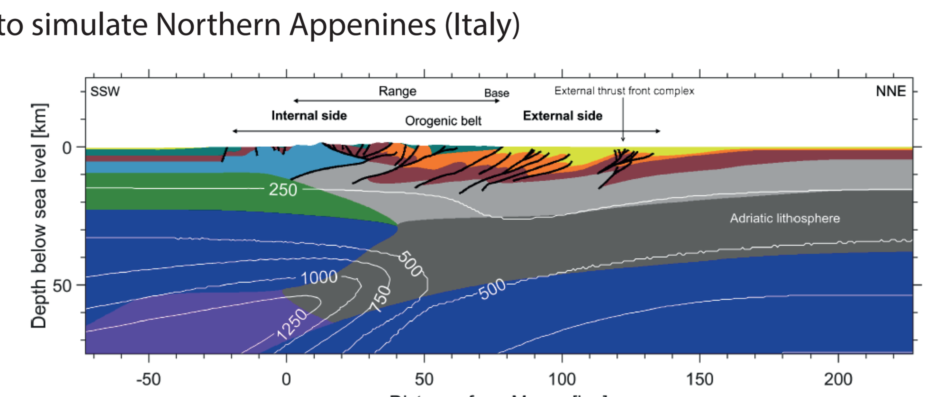


See: Brizzi et al., EPSL, subm.

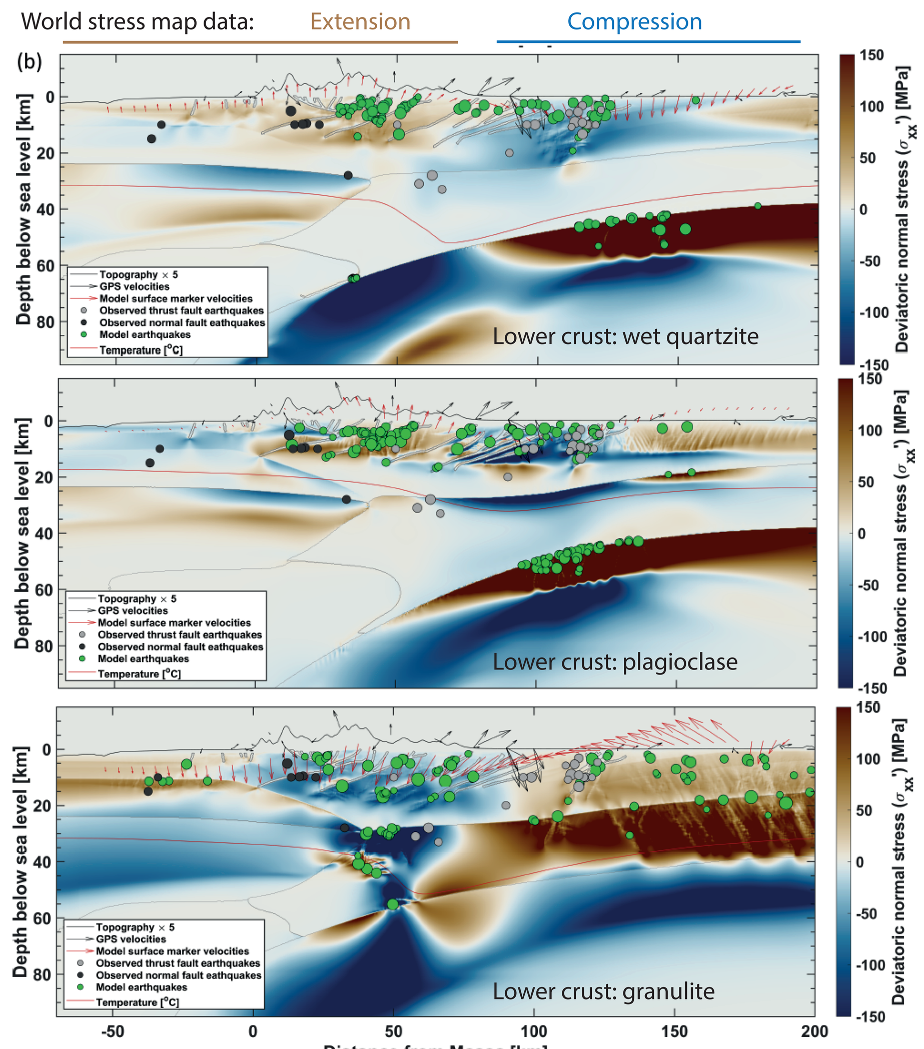
How deep rheology and temperature affects seismicity

(1) Combine geological and geophysical data to simulate Northern Appenines (Italy)



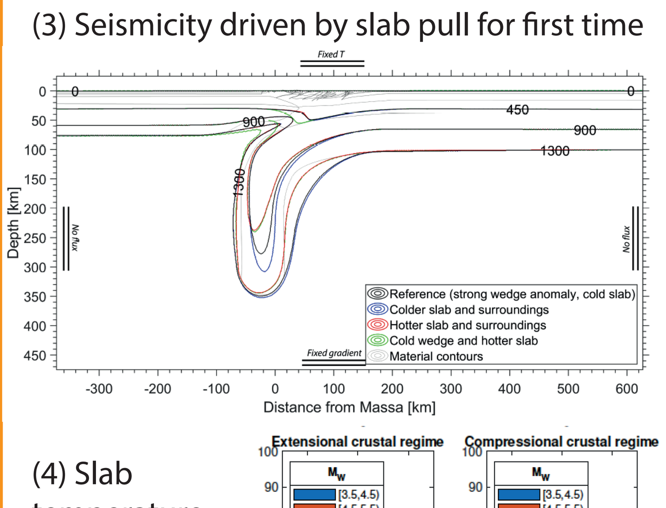


World stress map data: Extension Compression

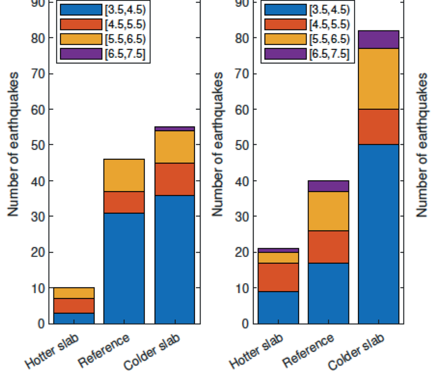


(2) Weak lower crust and hot mantle wedge >> are needed to reproduce stress and seismicity

(3) Seismicity driven by slab pull for first time



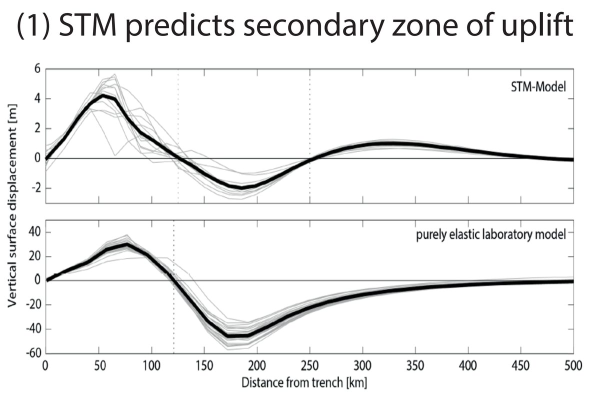
(4) Slab temperature and pull affect seismicity



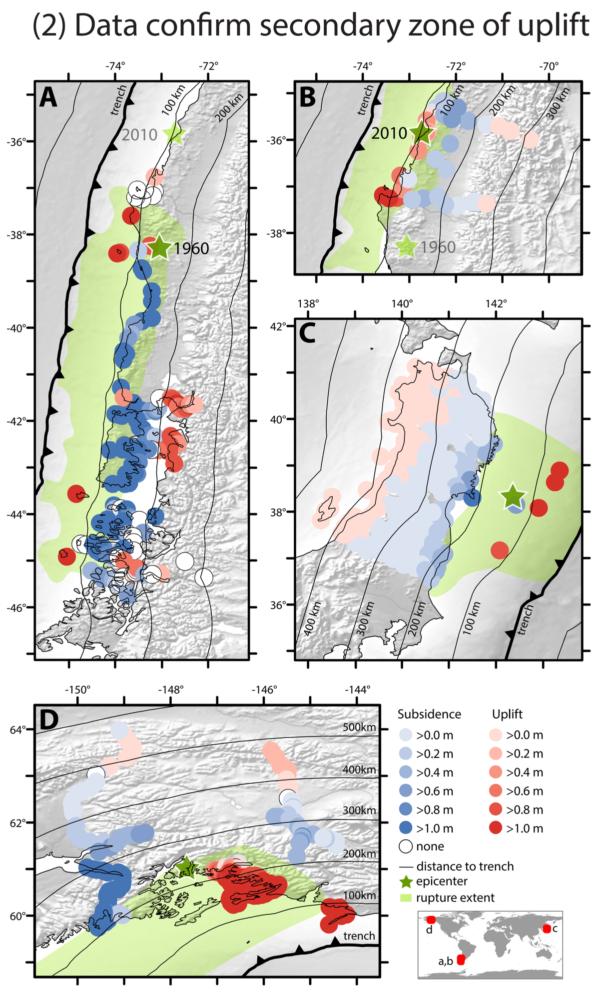
See: D' Acquisto et al., JGR, n. subm.

Lithosphere mechanics affects surface displacements

(1) STM predicts secondary zone of uplift

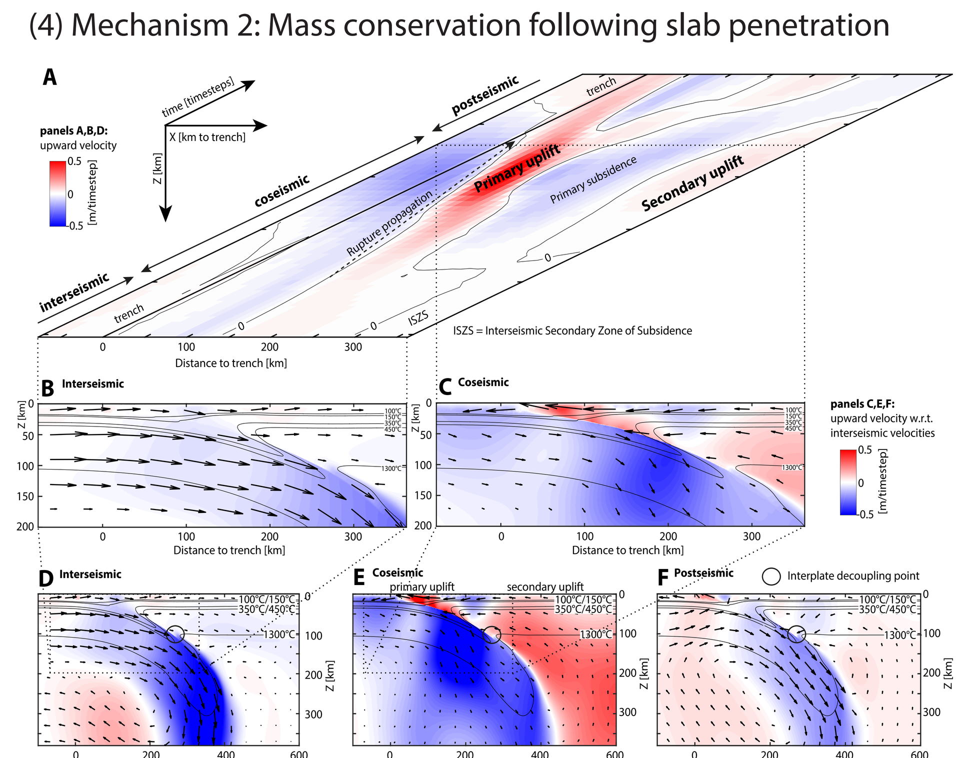


(2) Data confirm secondary zone of uplift

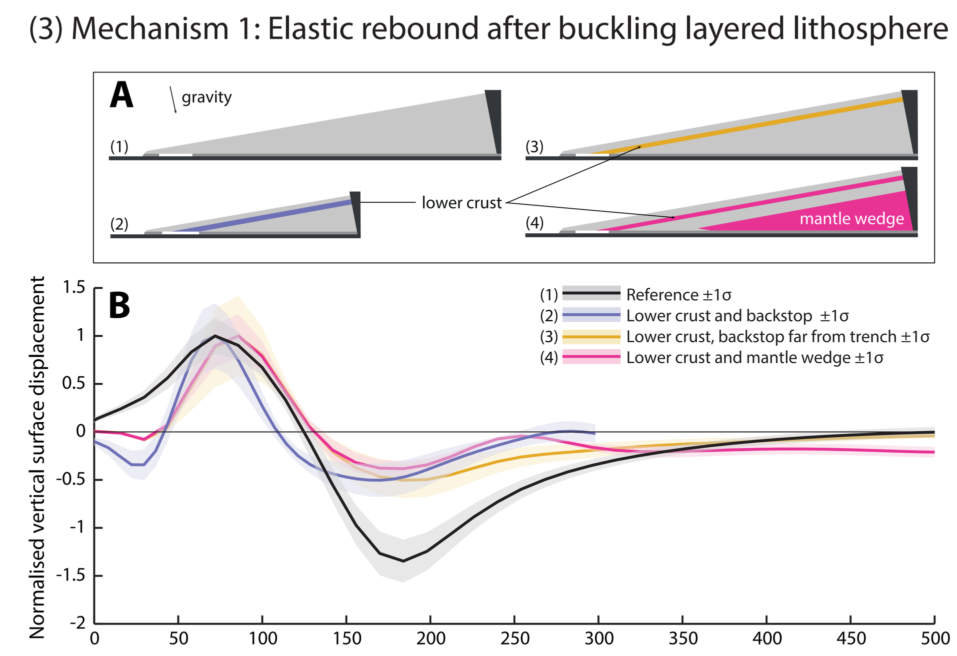


See: van Dinther et al.,PAGeo, 2019

(4) Mechanism 2: Mass conservation following slab penetration

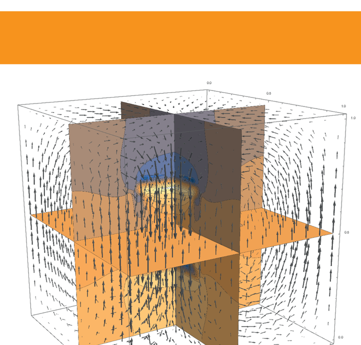


(3) Mechanism 1: Elastic rebound after buckling layered lithosphere



Summary

These examples illustrate how thermo-mechanical coupling, tectonics and rheology affect seismicity.
More work and potential is being demonstrated by STM group at ETHZ/UU.
Coupling with **fluids** is illustrated in the next poster by Petrini et al.
Coupling with **chemisty** is illustrated in the presentation of Gerya et al.
Meanwhile also developments in 3D and HTM coupling are nearing completion >>



<< 3D Long-term deformation

3D Dynamic earthquake rupture >>

Pranger et al., in prep.