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Observations and modeling of the seismic rupture development based on the analysis of Source Time Functions

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EGU 2020 Session SM 2.1

Earthquake Source Processes: Imaging and Numerical Modeling

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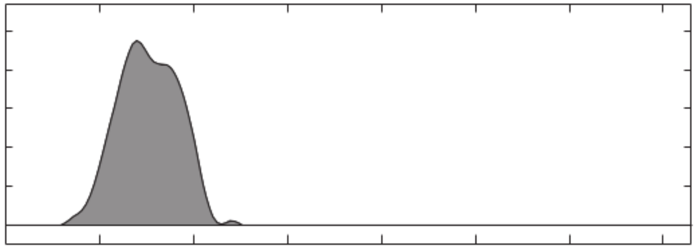
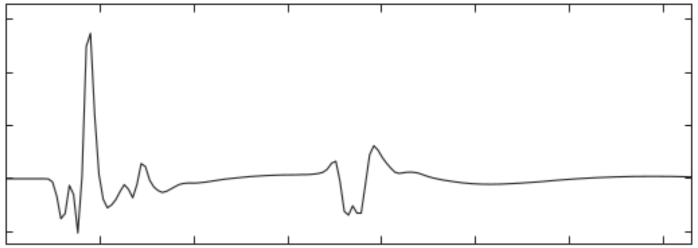
SCARDEC method

Teleseismic displacement is the convolution of the **source term** and the **propagation term**:



Source Time Function (STF)

*



Point-source response

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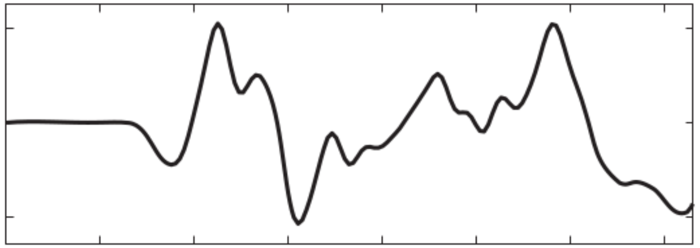
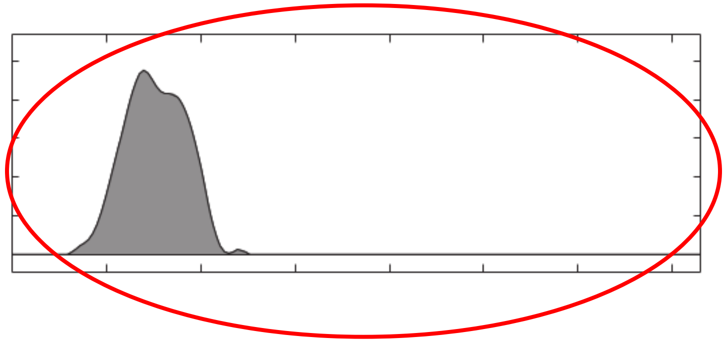


Teleseismic displacement

Systematic deconvolutive approach of body waves (P and SH)
SCARDEC method *(Vallée et al. (2011))*

Extraction focal mechanism, depth, seismic moment and ***STF***



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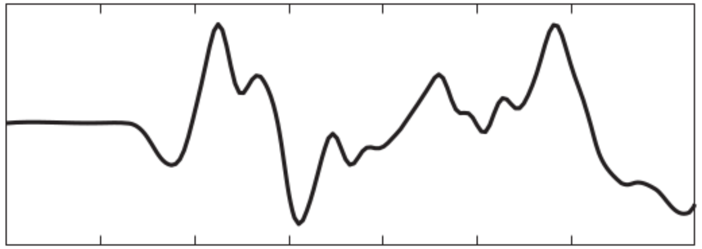
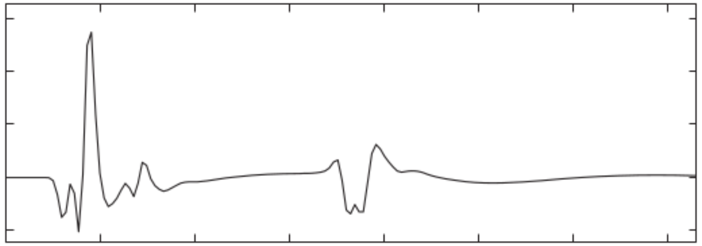


$*^{-1}$



Exhaustive catalog of STFs (~3000 STFs for Mw > 5.8): **SCARDEC database** (*Vallée and Douet (2016)*).

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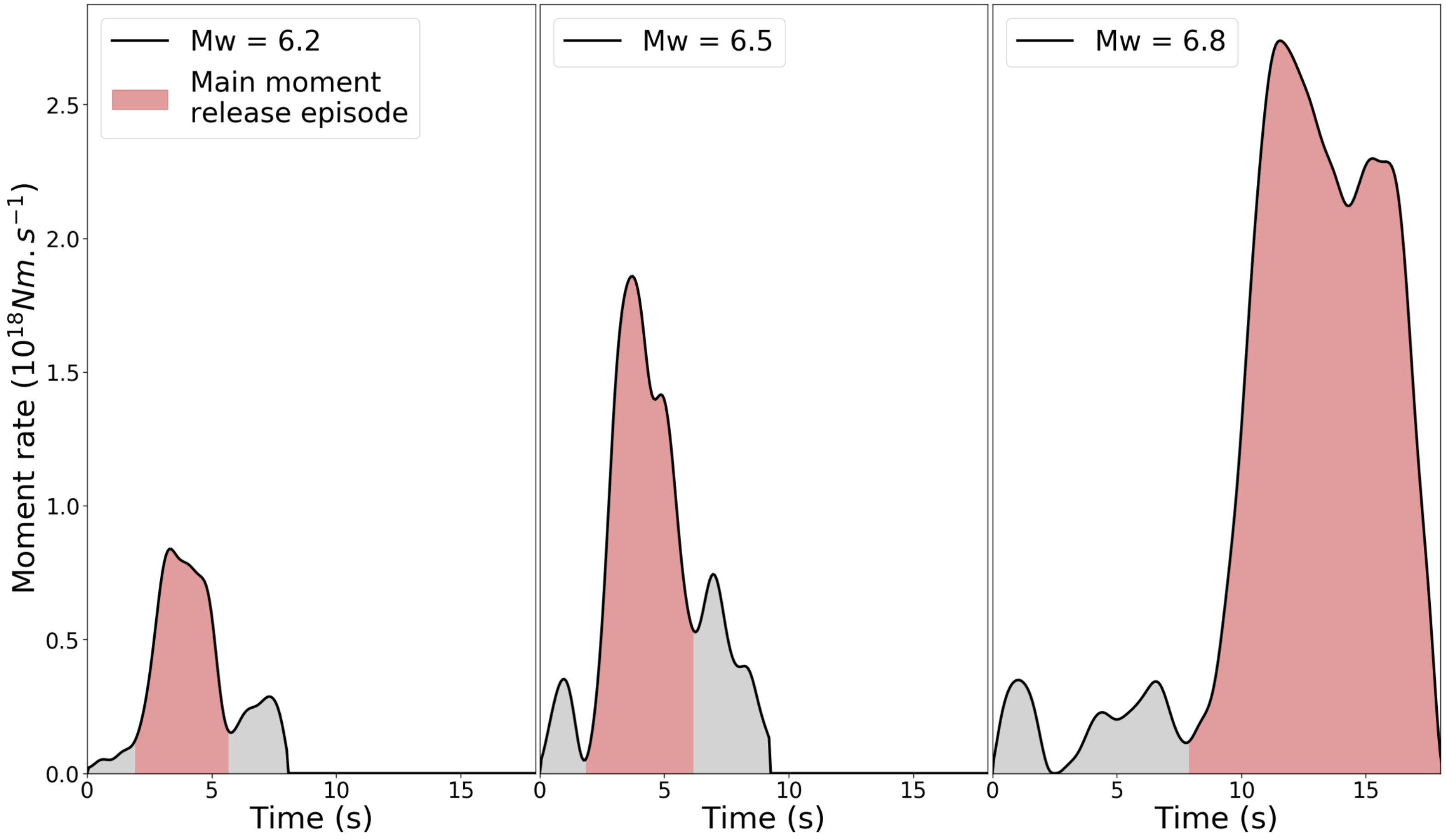
Rupture development

Observation of the **main seismic moment episode**



*SCARDEC catalog = new opportunity to explore **transient source properties.***

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Motivation of the study

- Observe and quantify the rupture development based on the analysis of STFs from the SCARDEC catalog. *Do small and large earthquakes share a unique rupture development? If yes, is it self-similar? (Renou et al. 2019)*

- Benefit from the observations to better constrain dynamic source models. *Do models reproduce the observed rupture development? If not, how can we modify them and what are the implications for the earthquake source physics?*

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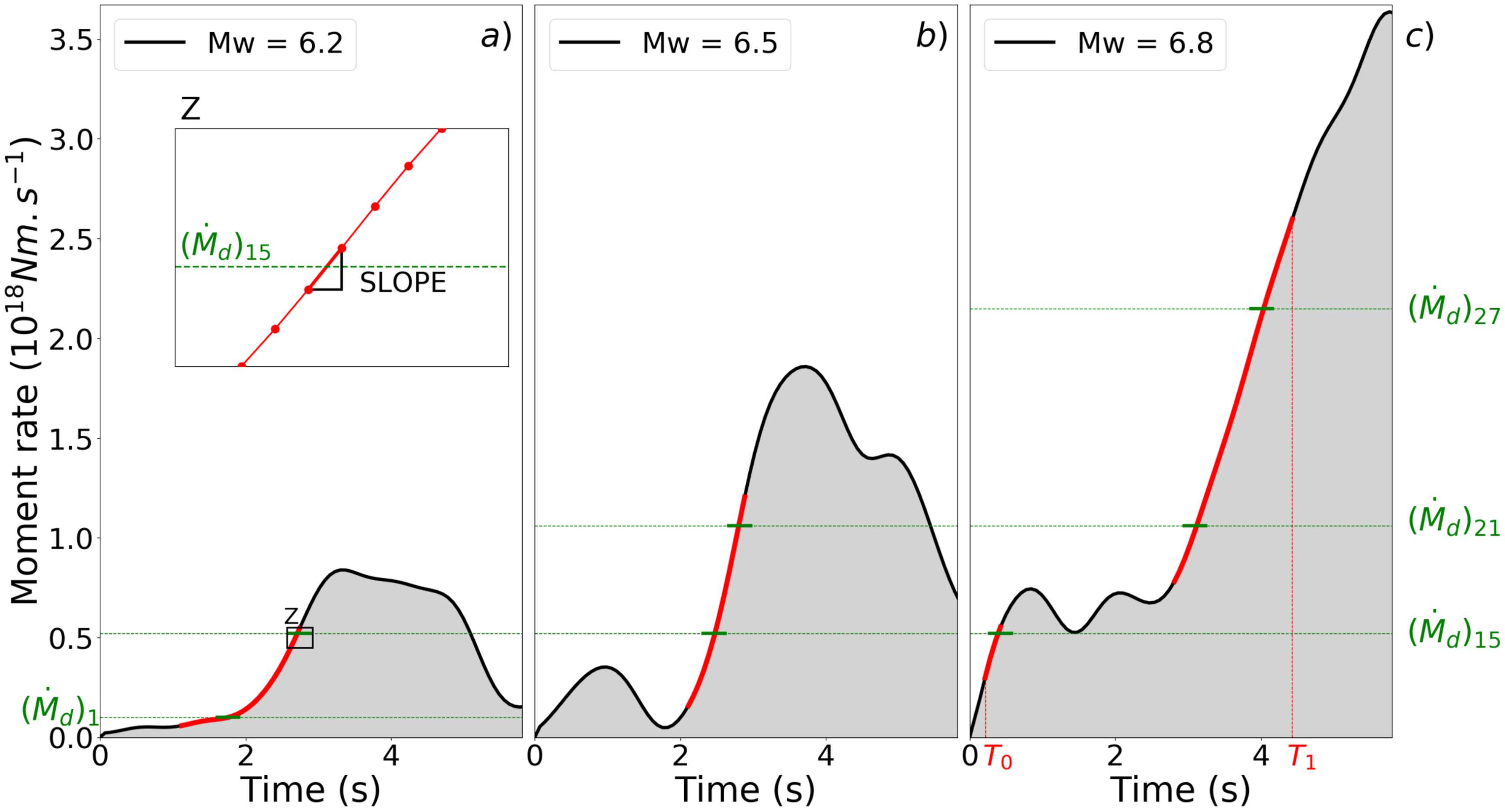
Moment acceleration

Development phase* = *most active part of the rupture (i.e. when STFs grow towards their peak).



Computation of the seismic moment acceleration (slope) at the times when development phases cross **prescribed moment rates**.

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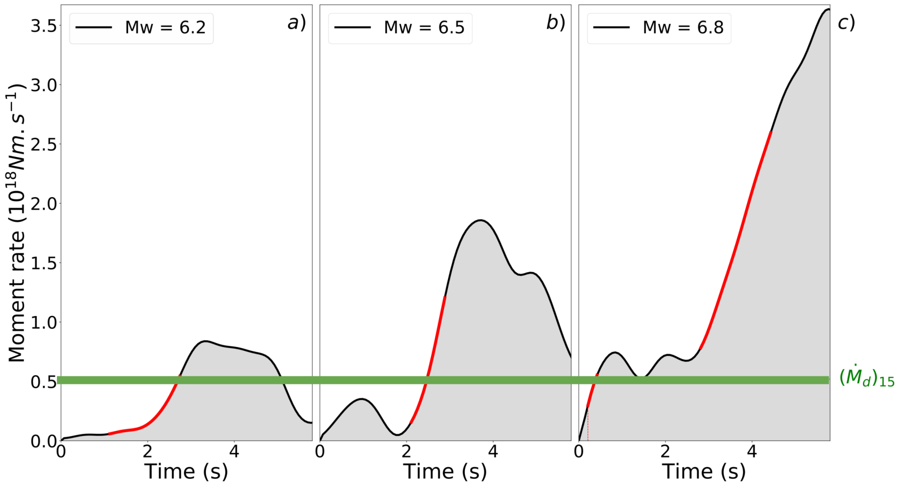
Moment acceleration

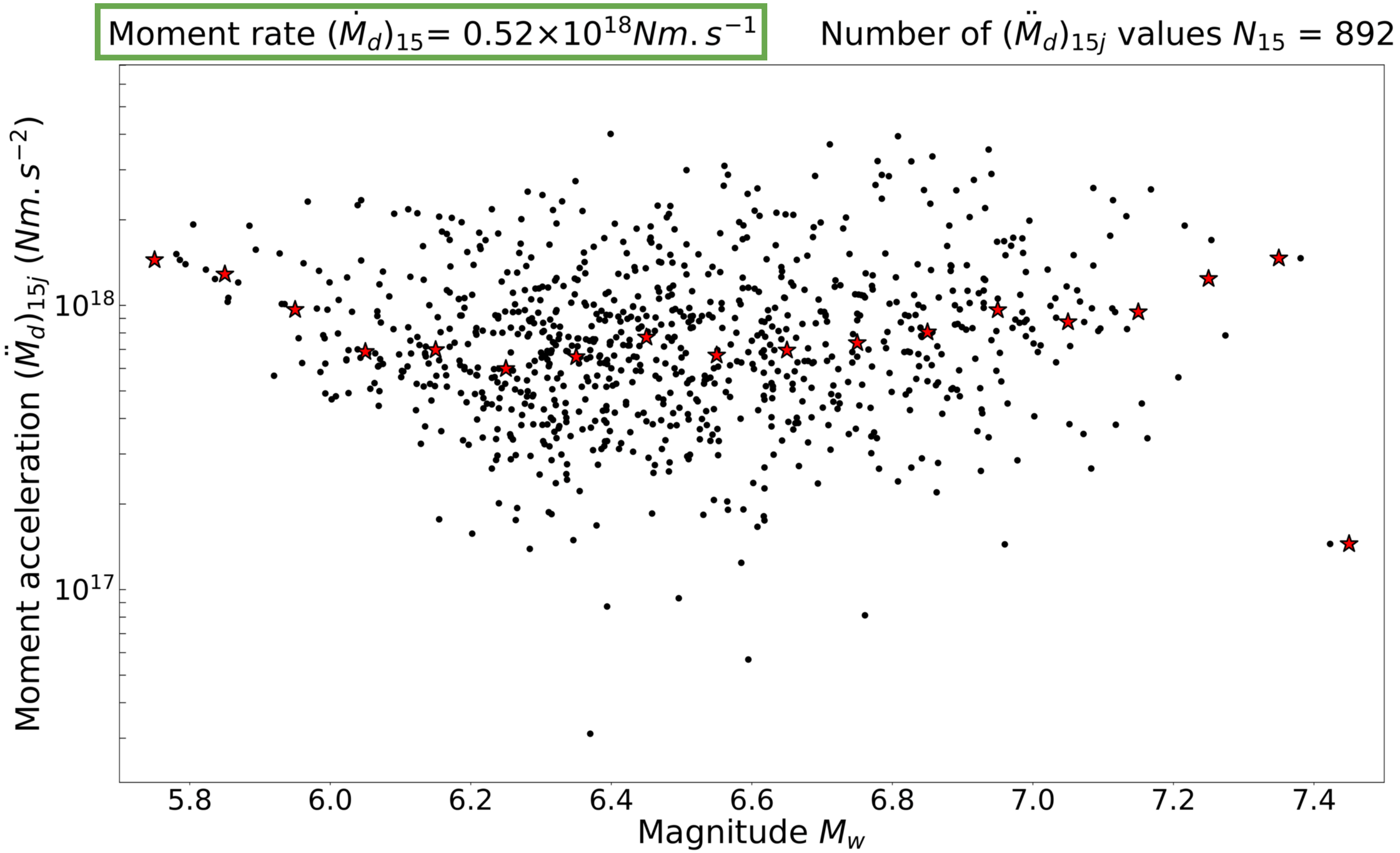
Main benefits of the method:

1 - observe how rupture develops independently of when the main rupture develops.

2 - avoid the hypocentral time information which can be uncertain.

Magnitude-independent signal





Magnitude independency:

1 - favors a **unique shape** for the development phase of all earthquakes.

2 - allows to use slopes for all moment rates to quantify a **generic behavior of the rupture development**.

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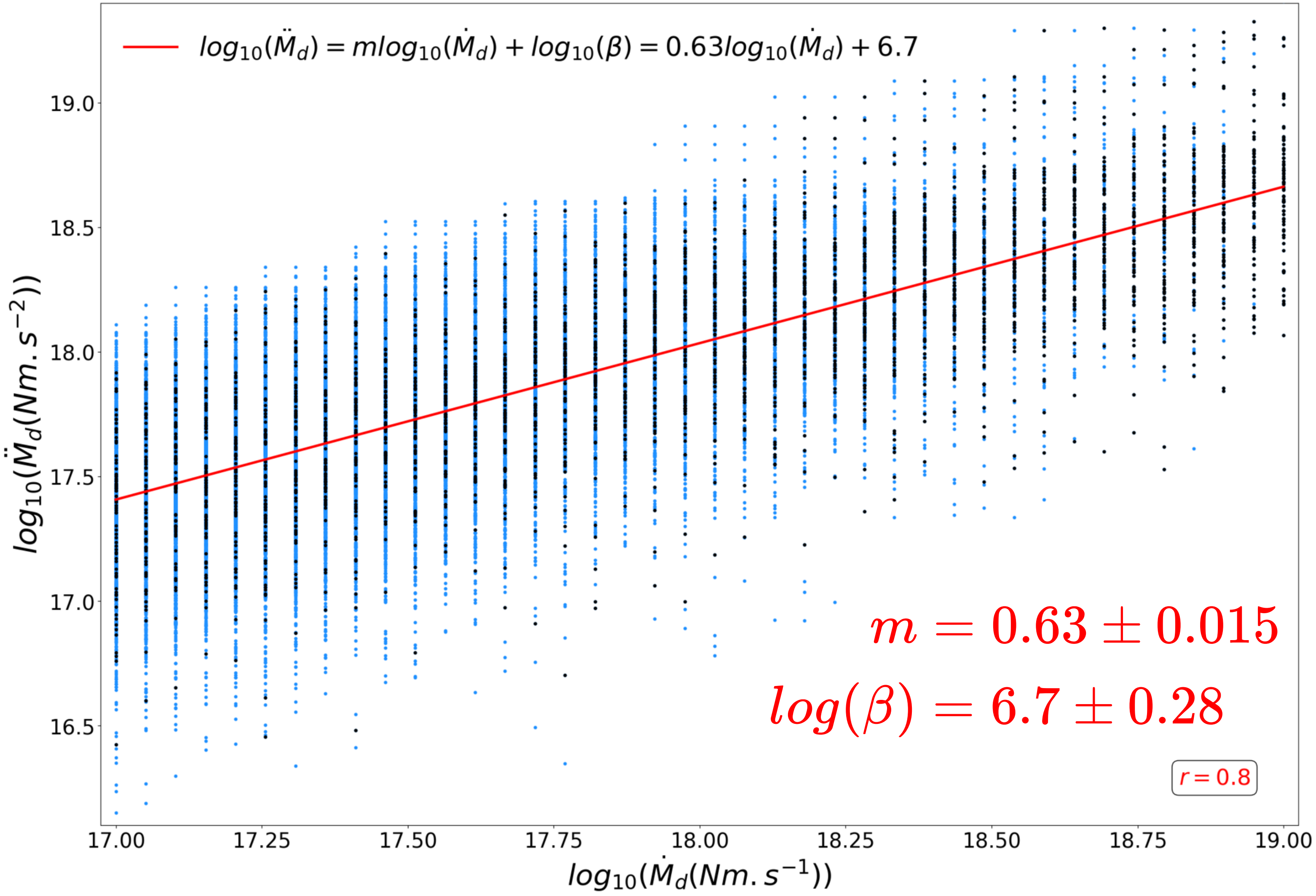
Evidence of a linear increase in log-log scale



Renou et al. (2019)

$$\ddot{M}_d = \text{Moment acceleration}$$
$$\dot{M}_d = \text{Moment rate}$$

- Power-law equation: $\ddot{M}_d = \beta(\dot{M}_d)^m$
- The expression for the time evolution of the development phase is :

$$\dot{M}_d(t) = (\beta(1-m))^{\frac{1}{1-m}} \times t^{\frac{1}{1-m}}$$

$$\dot{M}_d(t) = \alpha_d \times t^{n_d} = 10^{16.9 \pm 0.1} \times t^{2.7 \pm 0.11}$$

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The development phase does not follow the steady self-similar growth

- **Self-similar circular crack** with **constant stress drop** and **rupture velocity** (*Kostrov (1964)*) is governed by:

$$\dot{M}(t) \propto V_r^3 \Delta\sigma t^2$$

Analytical models

- Here we have:

$$\dot{M}_d(t) = \alpha_d \times t^{n_d} = 10^{16.9 \pm 0.1} \times t^{2.7 \pm 0.11}$$

Observations from STFs

Can this transitory trend be retrieved in **dynamic source models**?
(collaboration with *Hideo Aochi*)

→ Required to generate source variability and complete description of an earthquake.

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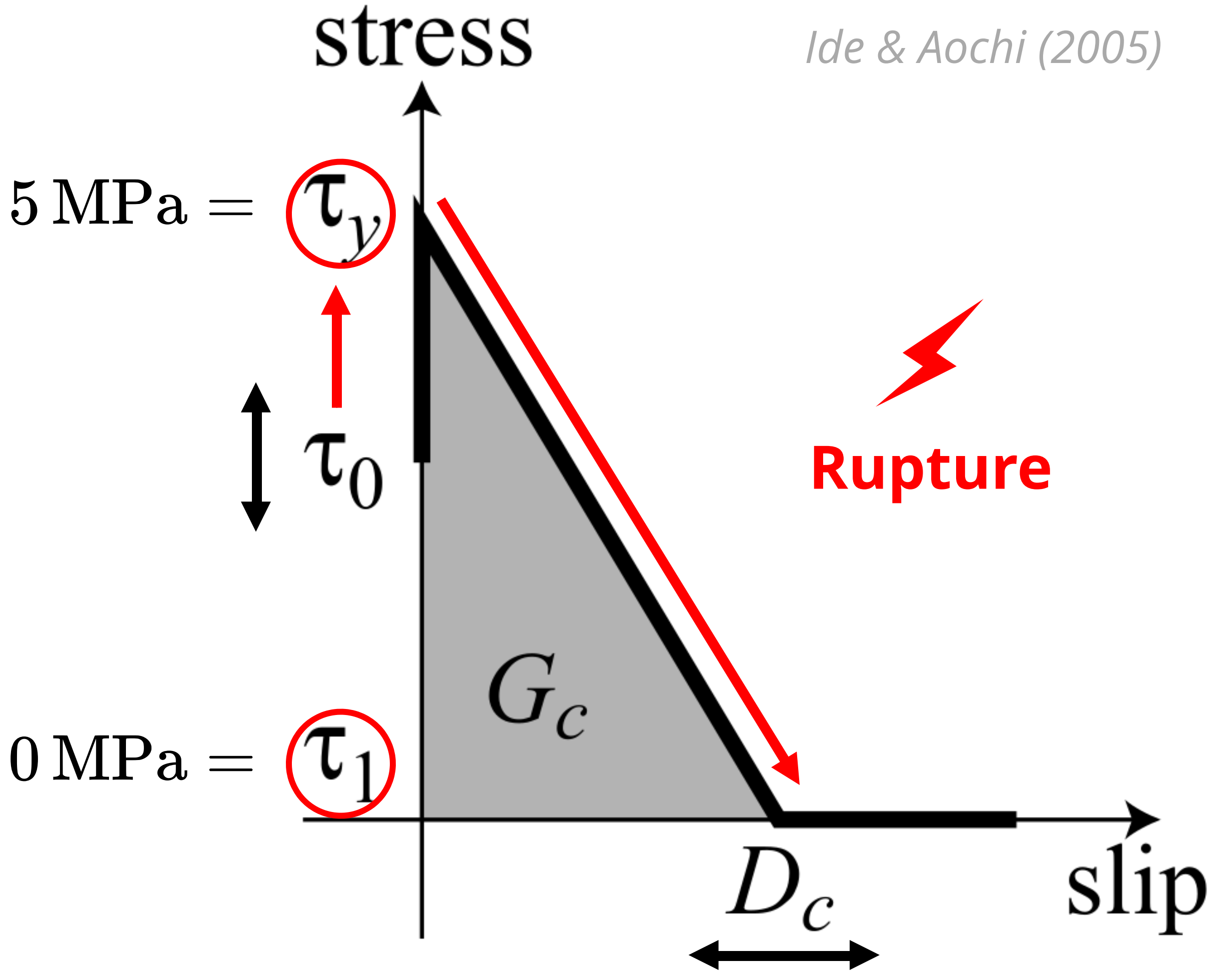
Dynamic rupture of an earthquake

*Slip is produced as a result of the **stress conditions** on the fault and the **strength of the material**.*



How to reproduce the rupture complexity and perturb the moment rate evolution?

Possible origins of the rupture complexity:

- heterogeneity in **initial stress** τ_0
- heterogeneity in **friction parameter** D_c

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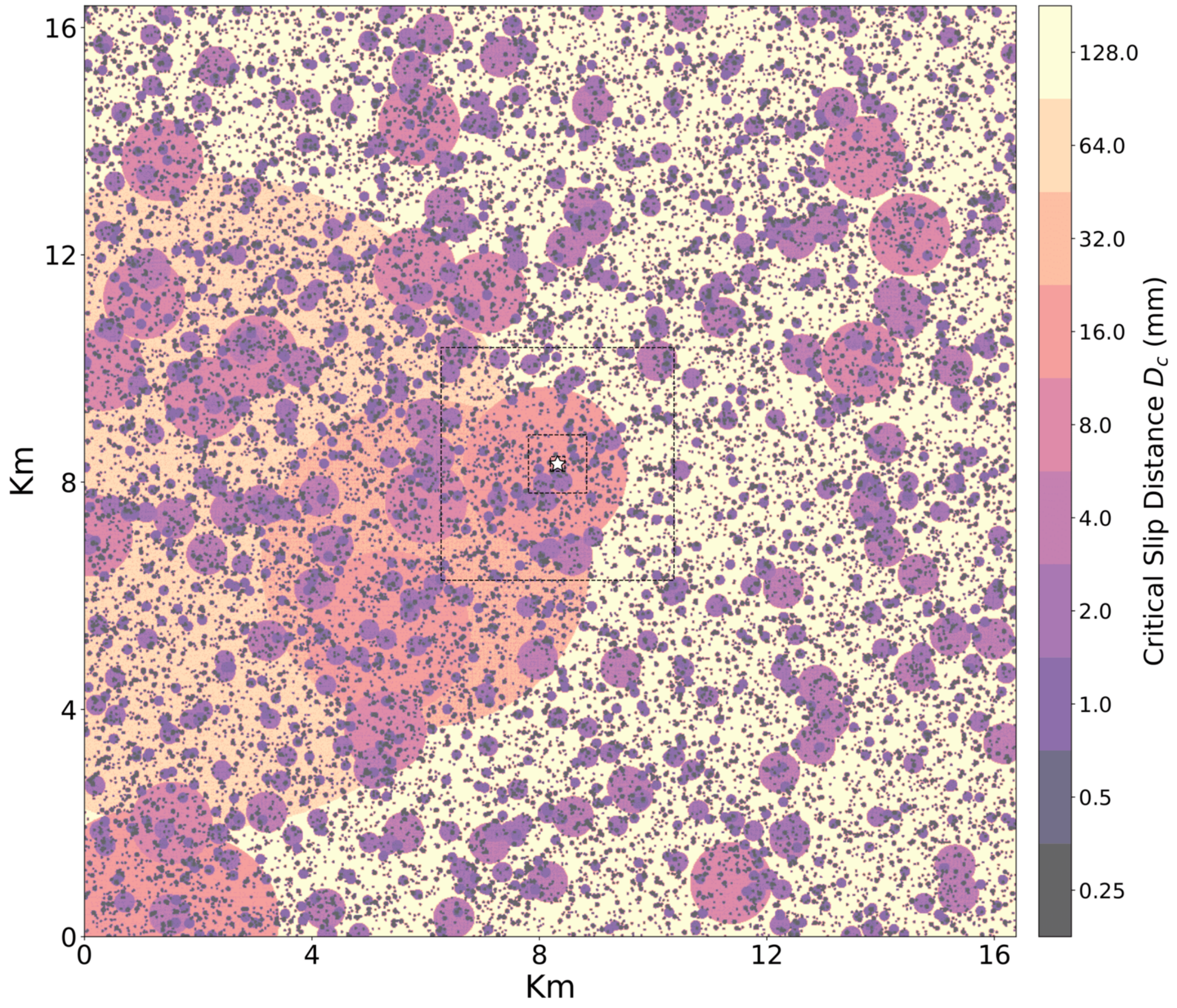
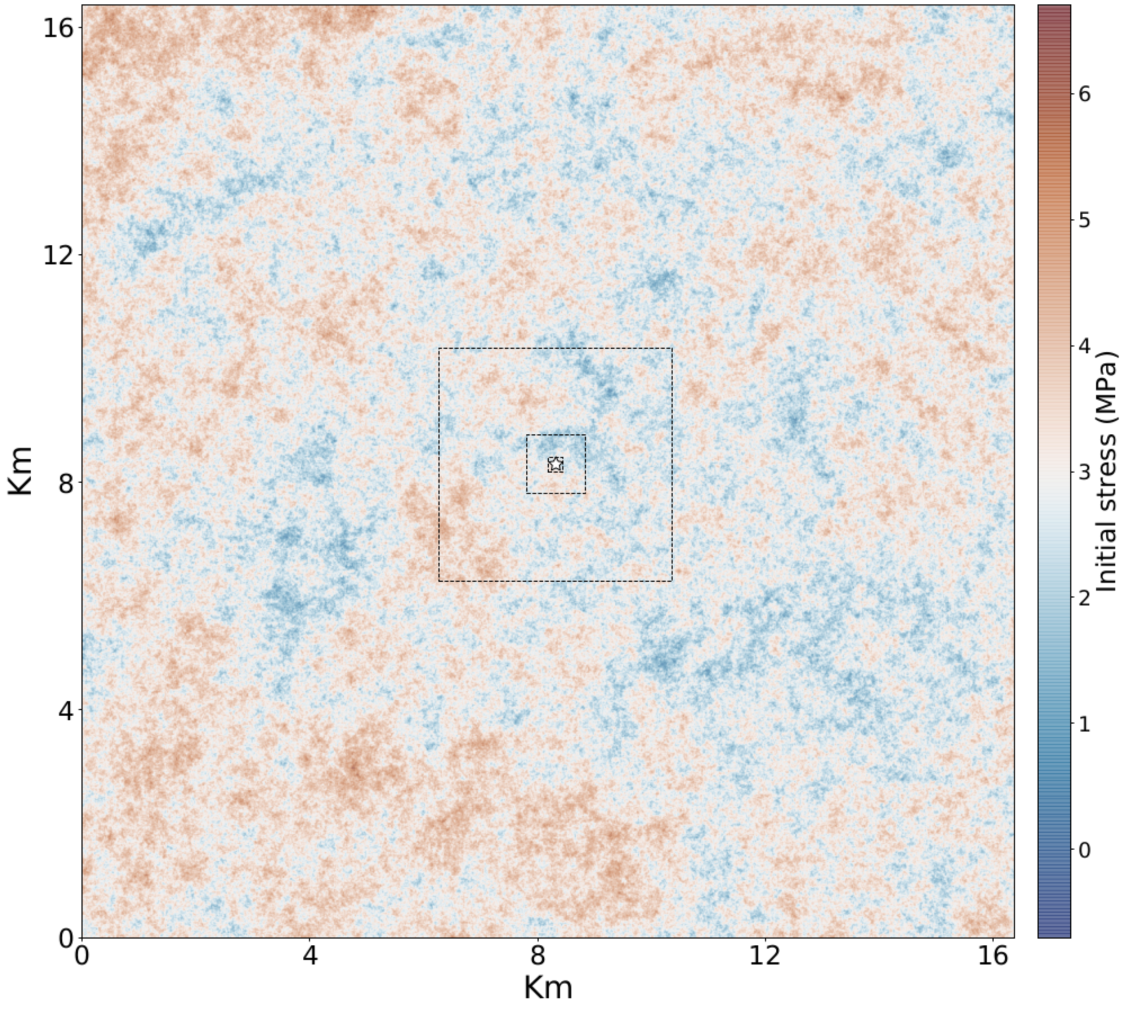
Heterogeneities in initial stress and fracture energy



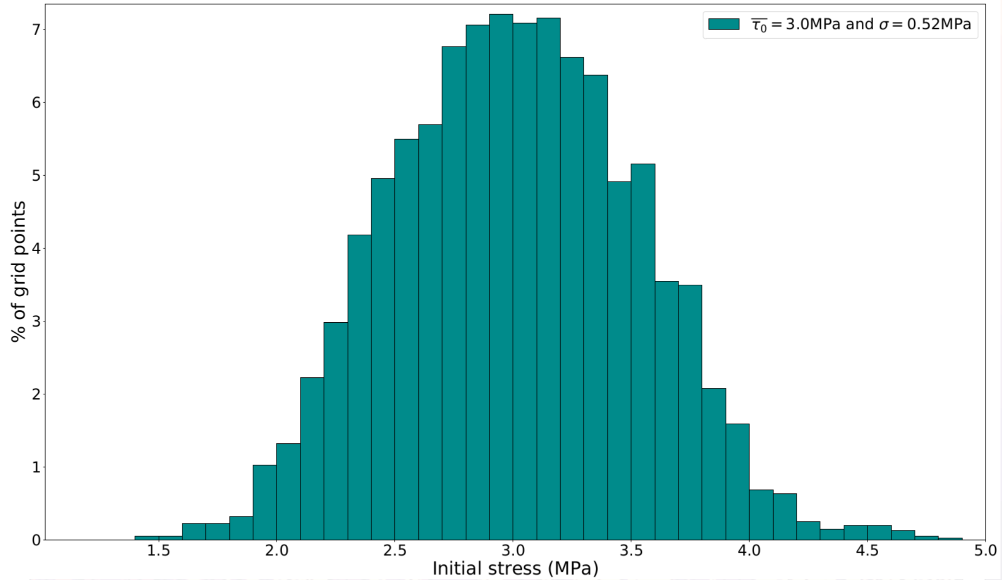


$\boldsymbol{D_c}$: fractal distribution of circular patches (*Ide and Aochi (2005)*).

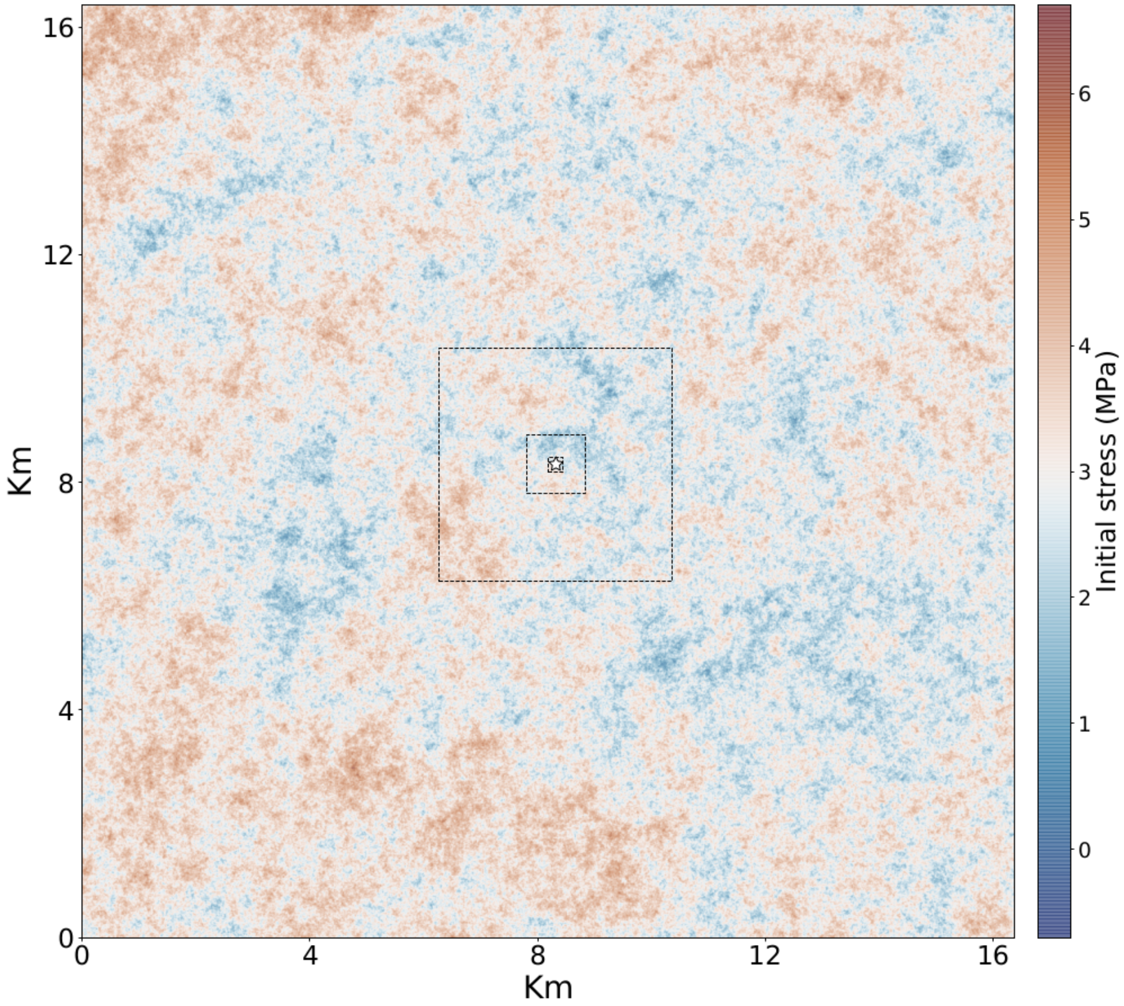
$\boldsymbol{\tau_0}$: spectral description with power law decay at high wave numbers (*Ripperger et al. (2007)*).

Heterogeneities in initial stress and fracture energy

Same heterogeneous map of initial stress
for 10 heterogeneous maps of D_c



$$\overline{\tau_0} = 3\,\mathrm{MPa} \qquad \Delta\tau_0 = 0.52\,\mathrm{MPa}$$



Mutli-scaling dynamic rupture based on a ***renormalization technique*** *(Aochi and Ide (2004)).*

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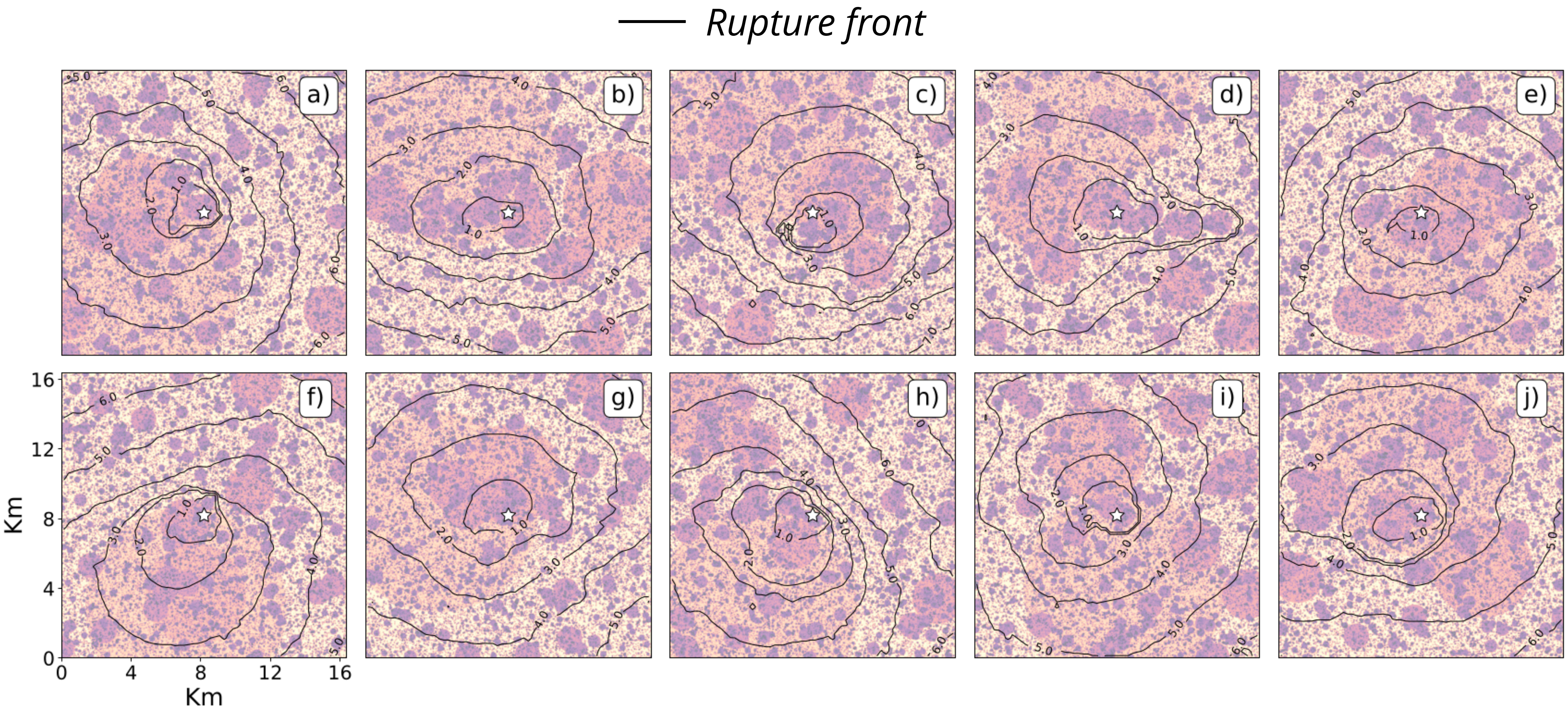
Realistic rupture scenarios



- Complex rupture surface expansion with global **subshear rupture velocities**.
- Clear **preferential direction of propagation** as a result of random patches distribution.

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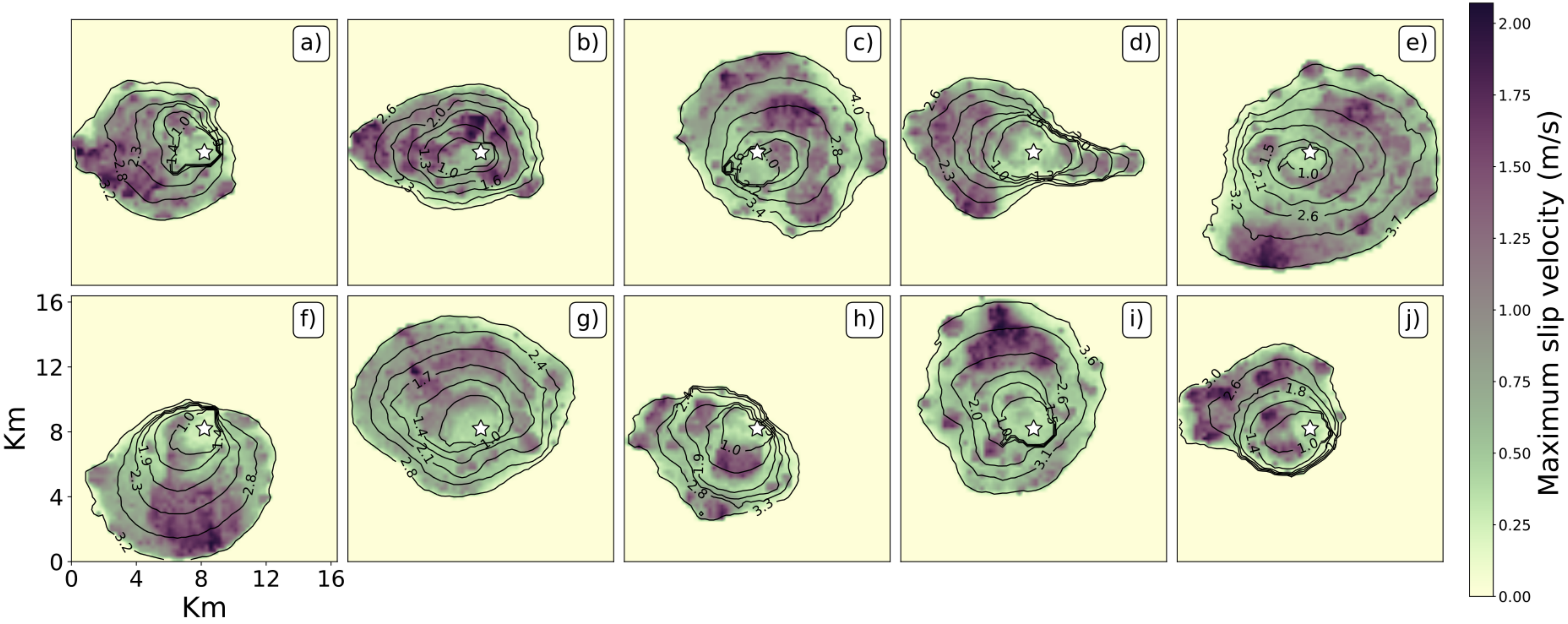
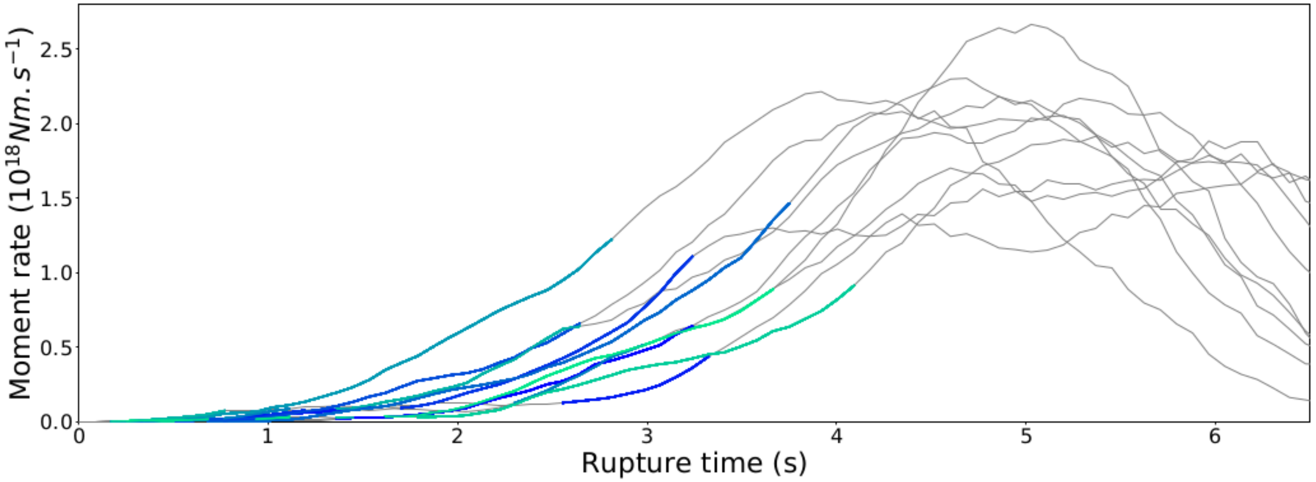
Combined effect of heterogeneous fracture energy and initial stress

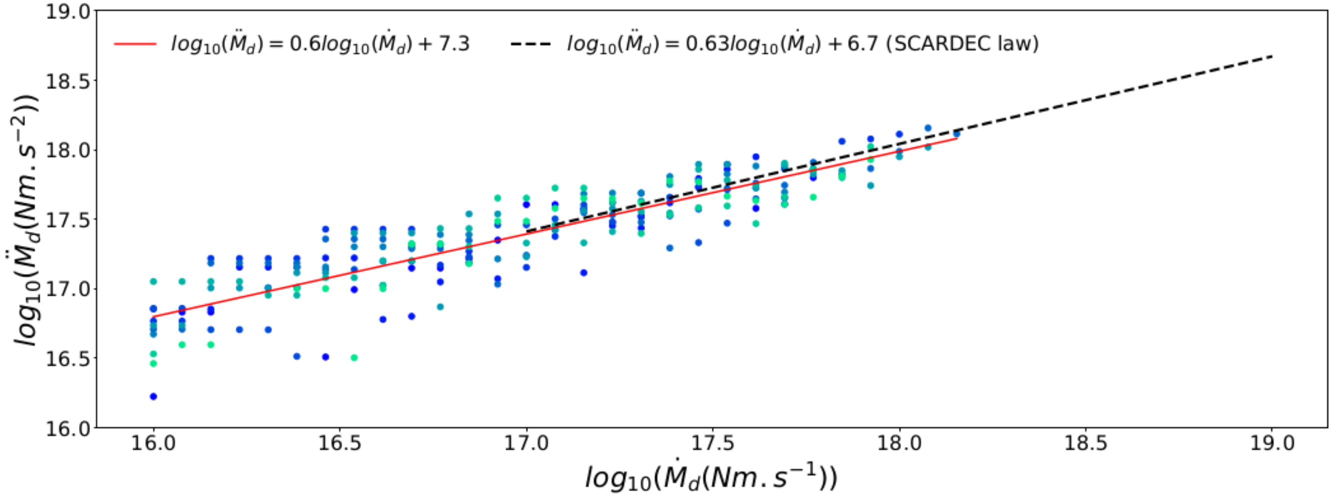
*As moment rate is dependent on **slip velocity** and **surface rupture expansion**, we represent maximum slip and rupture front contours.*



Correlation between slip velocity and rupture velocity

Combined effect of heterogeneous fracture energy and initial stress





Combination of both heterogeneous fracture energy and initial stress shows promising features required to reproduce the observed development phase.

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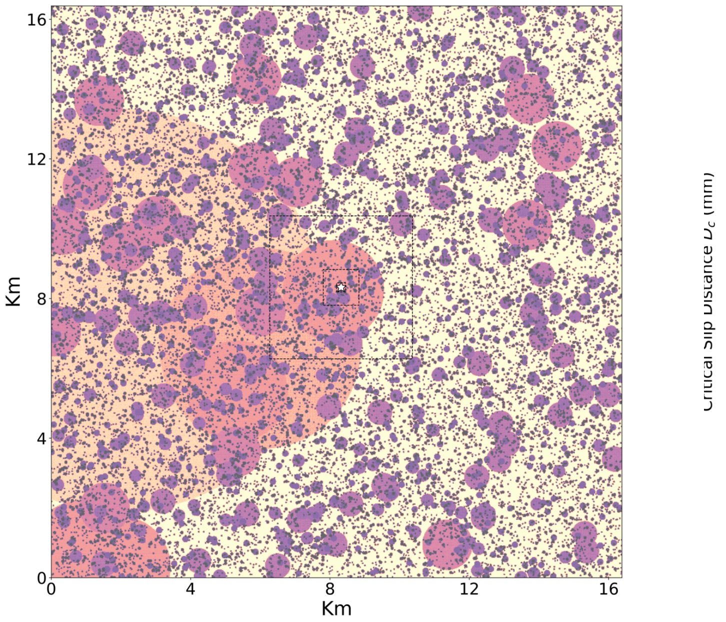
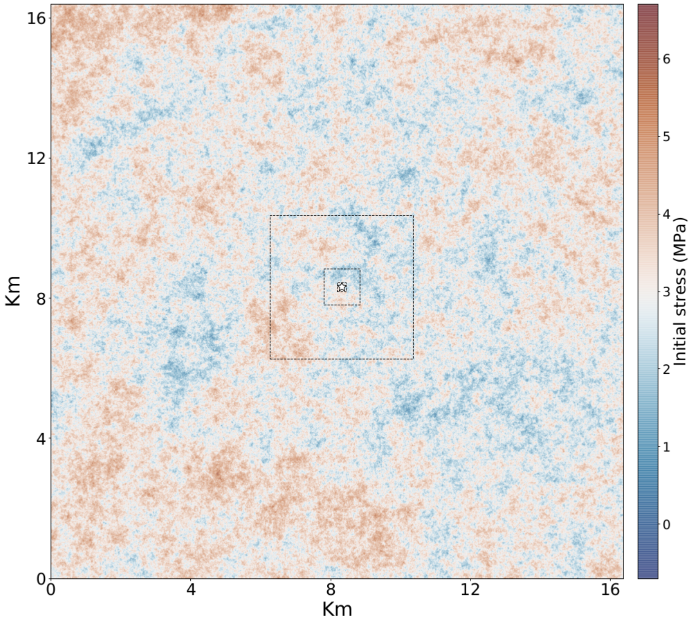
Dynamic constraints

- **Combining dynamic heterogeneities** results in **realistic rupture scenarios**.
- **Correlation between rupture velocity and slip velocity** is well reproduced in our dynamic simulations.
- **Such dynamic constraints** are required to reproduce the **observed STFs.**

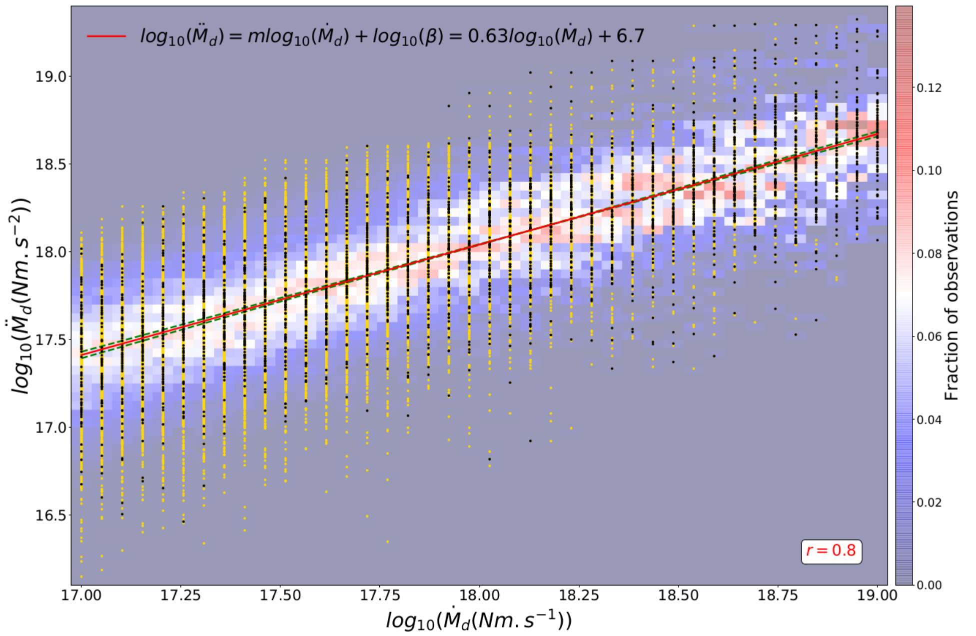


heterogeneous D_c

&



heterogeneous τ_0



SCARDEC observations

Thank you for reading!