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Search for Generic Rupture Properties Hidden by Earthquakes Diversity : Insights From the SCARDEC Source Time Functions Catalog

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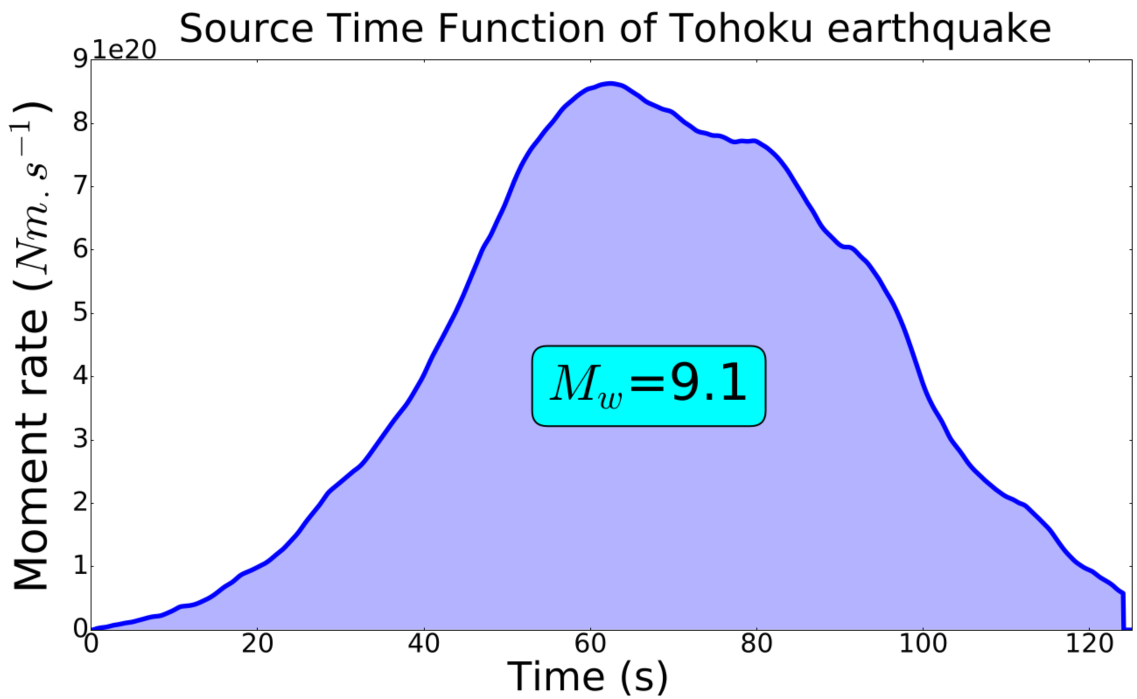
Source Time Functions (STF)

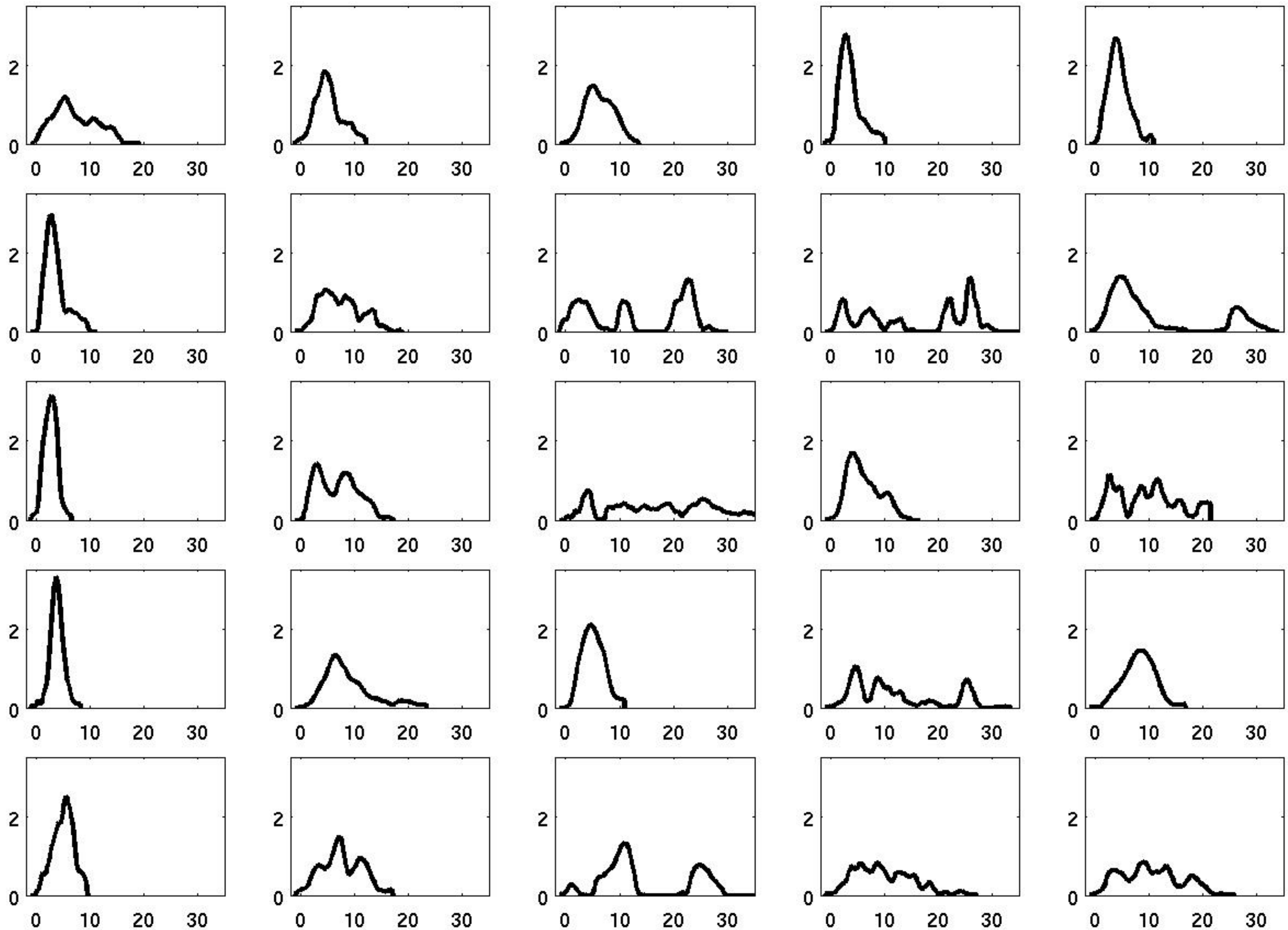
Moment rate $\dot{M}_0(t)$ **released by an earthquake over time.**



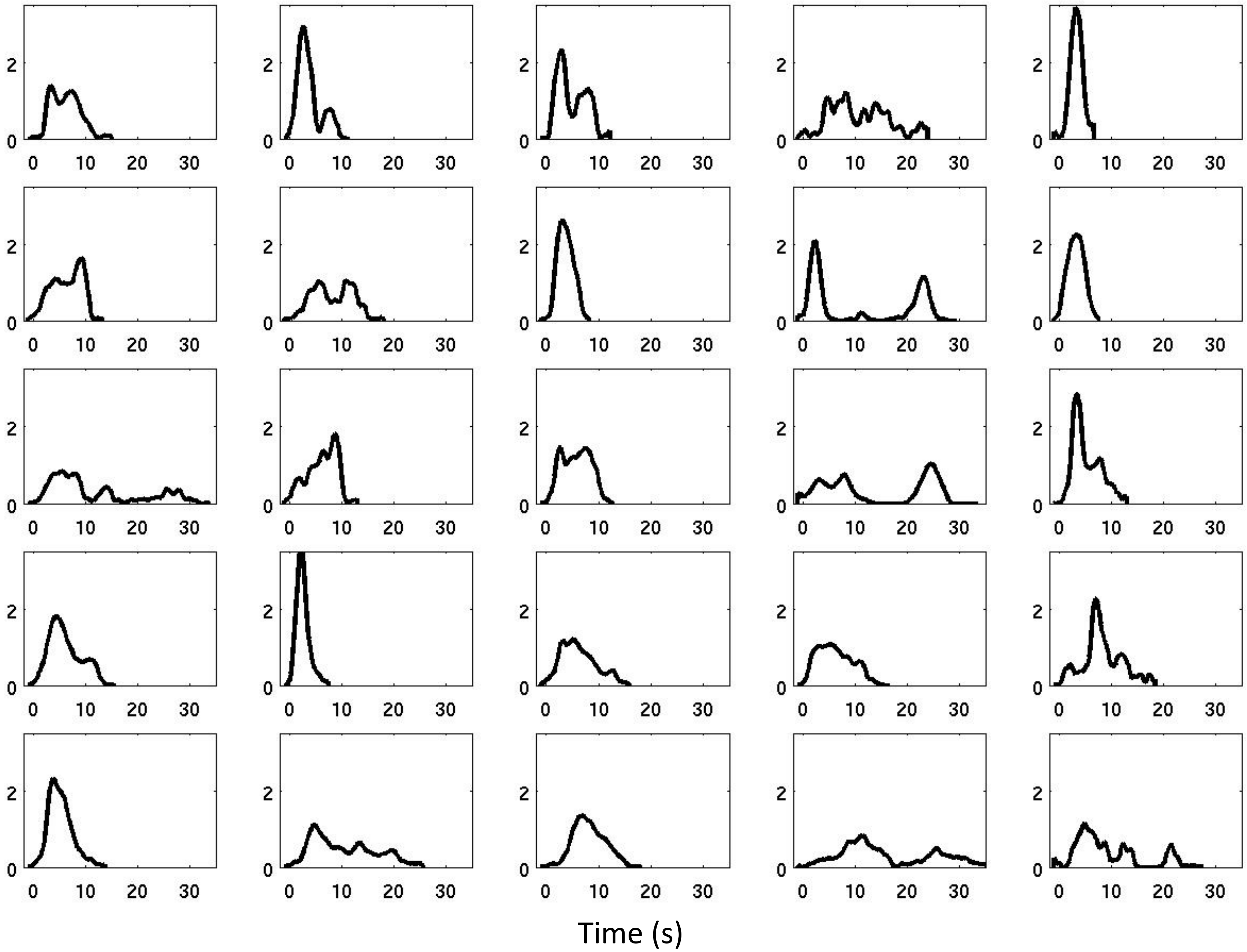
SCARDEC method (Vallée et al., 2011; Vallée and Douet, 2016) provides access to **thousands of these STFs**, freely available on the website

http://scardec.projects.sismo.ipgp.fr/

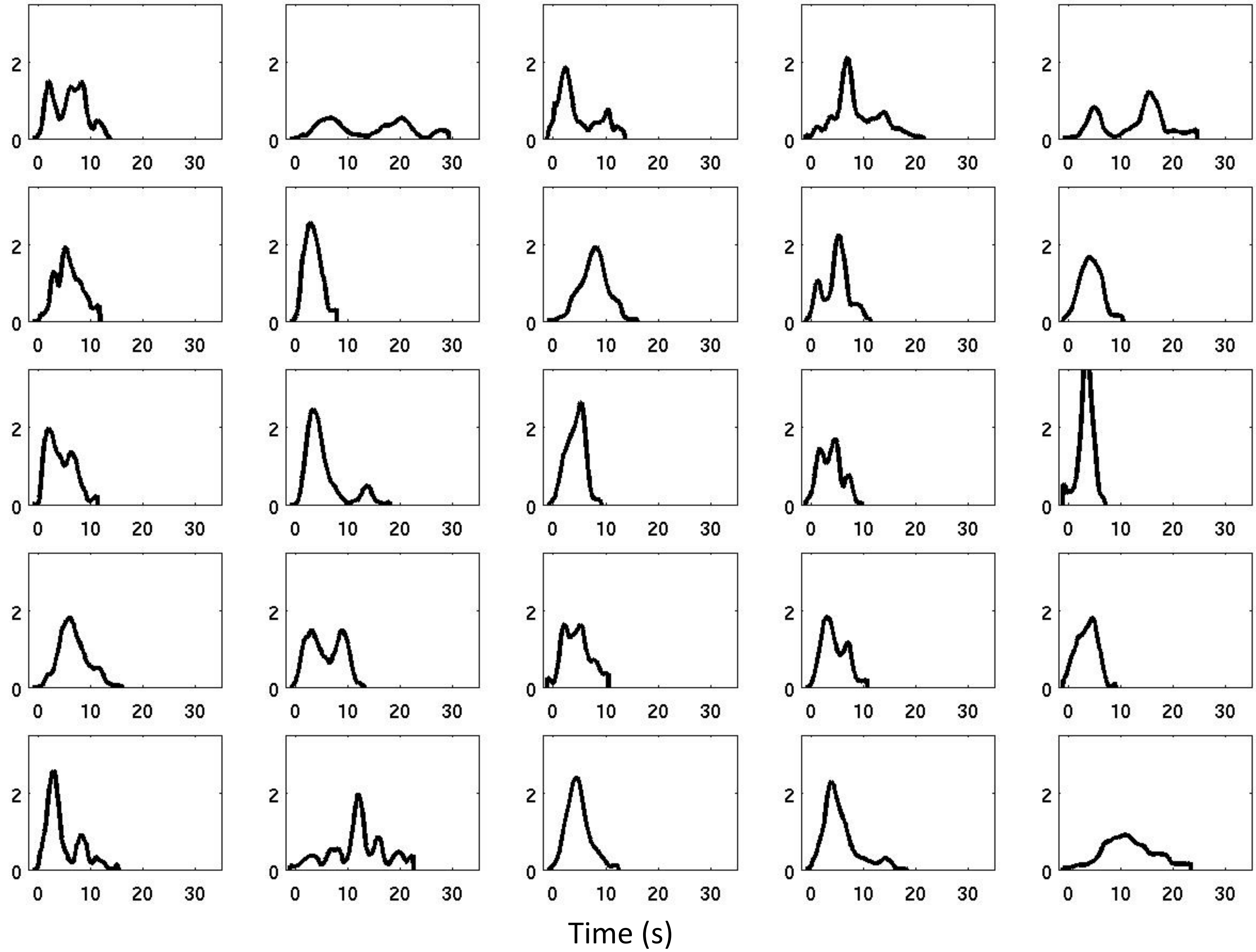
Illustration : STFs for shallow (<50km) Mw= 6.6 earthquakes (vertical scale in 10^{18} Nm/s)



Time (s)



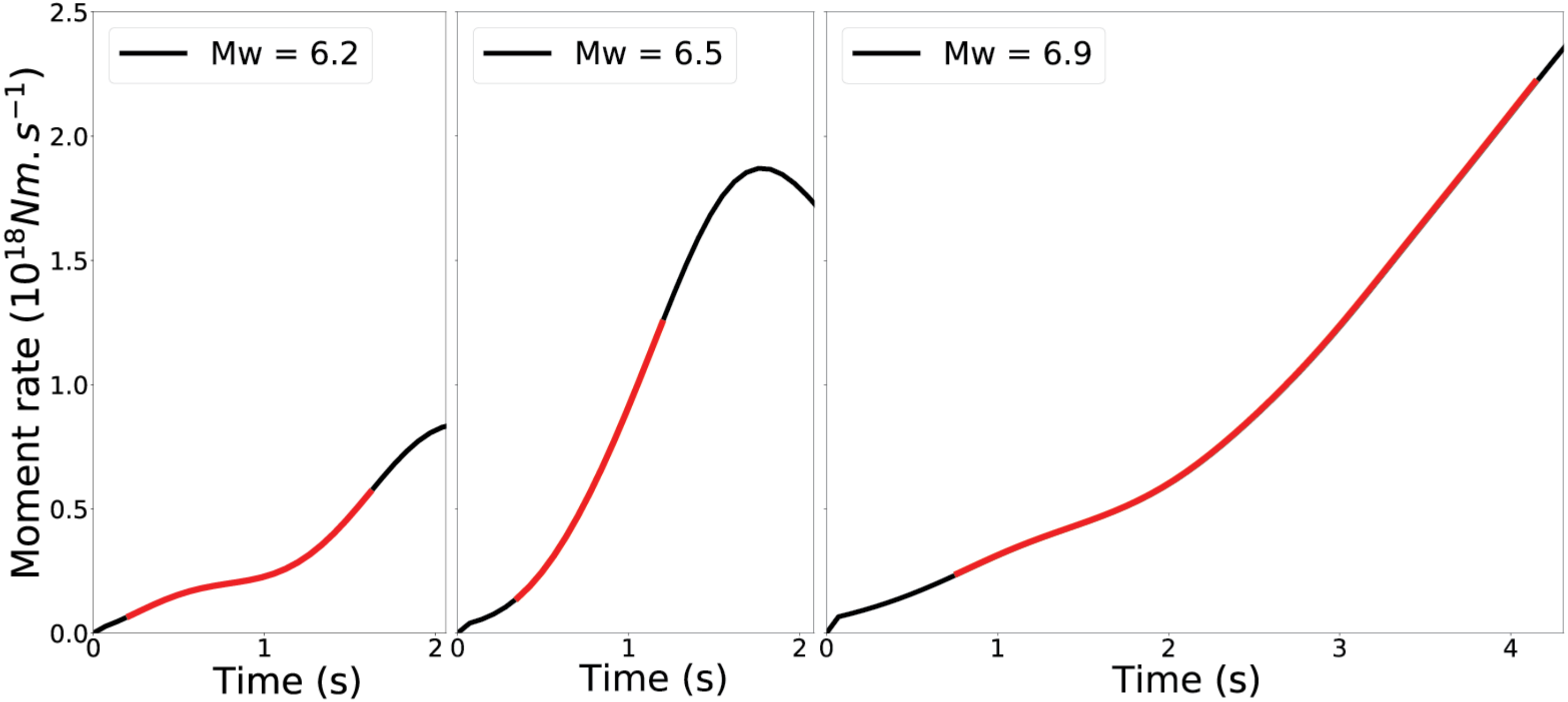
0
2
0
10
20
30
Time (s)


Time (s)

STF diversity is obvious :

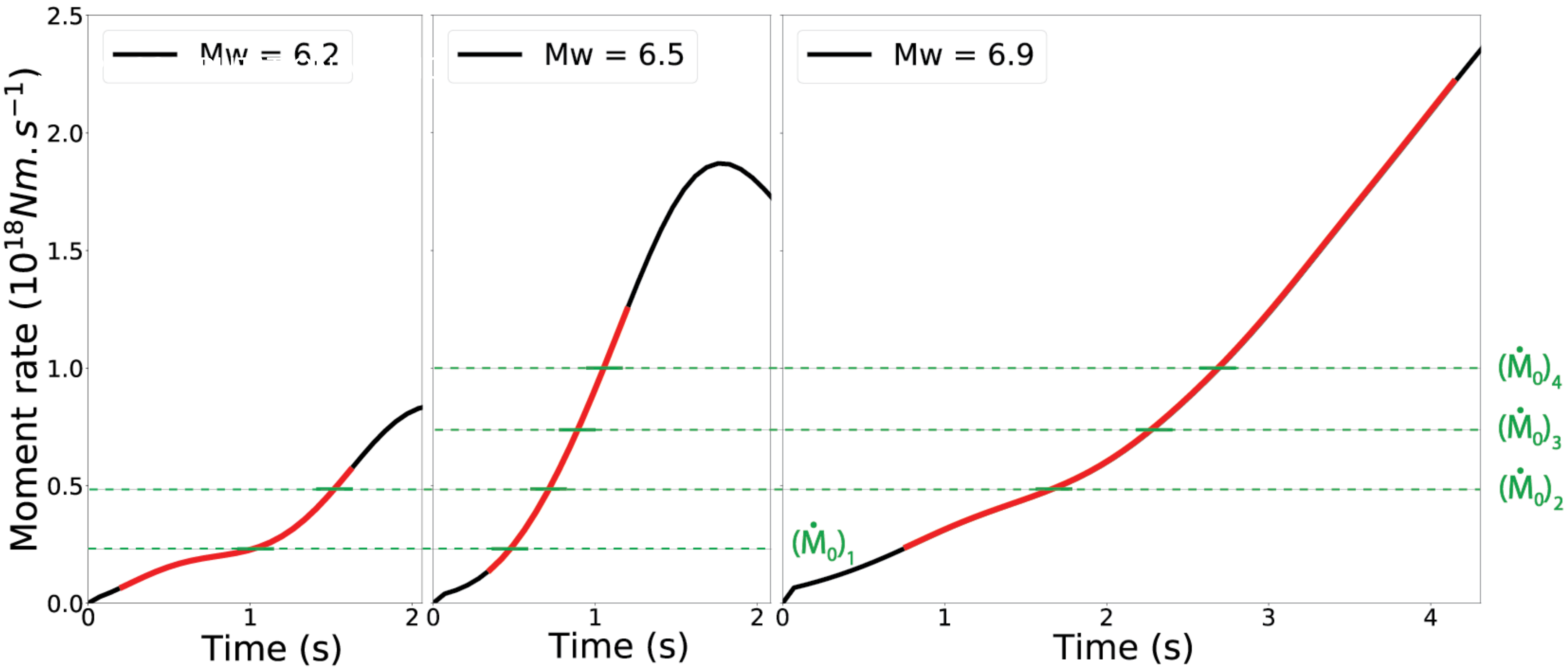
- **source duration and peak amplitude**
- **number of peaks (complexity)**

But can we examine how the rupture develops when breaking the main patch(es) of the fault ?



This information can be quantified by a **slope measurement** of the red part of the STF, that we refer to as the **development phase** : the rising part of the STF between 7% and 70% of the peak moment rate

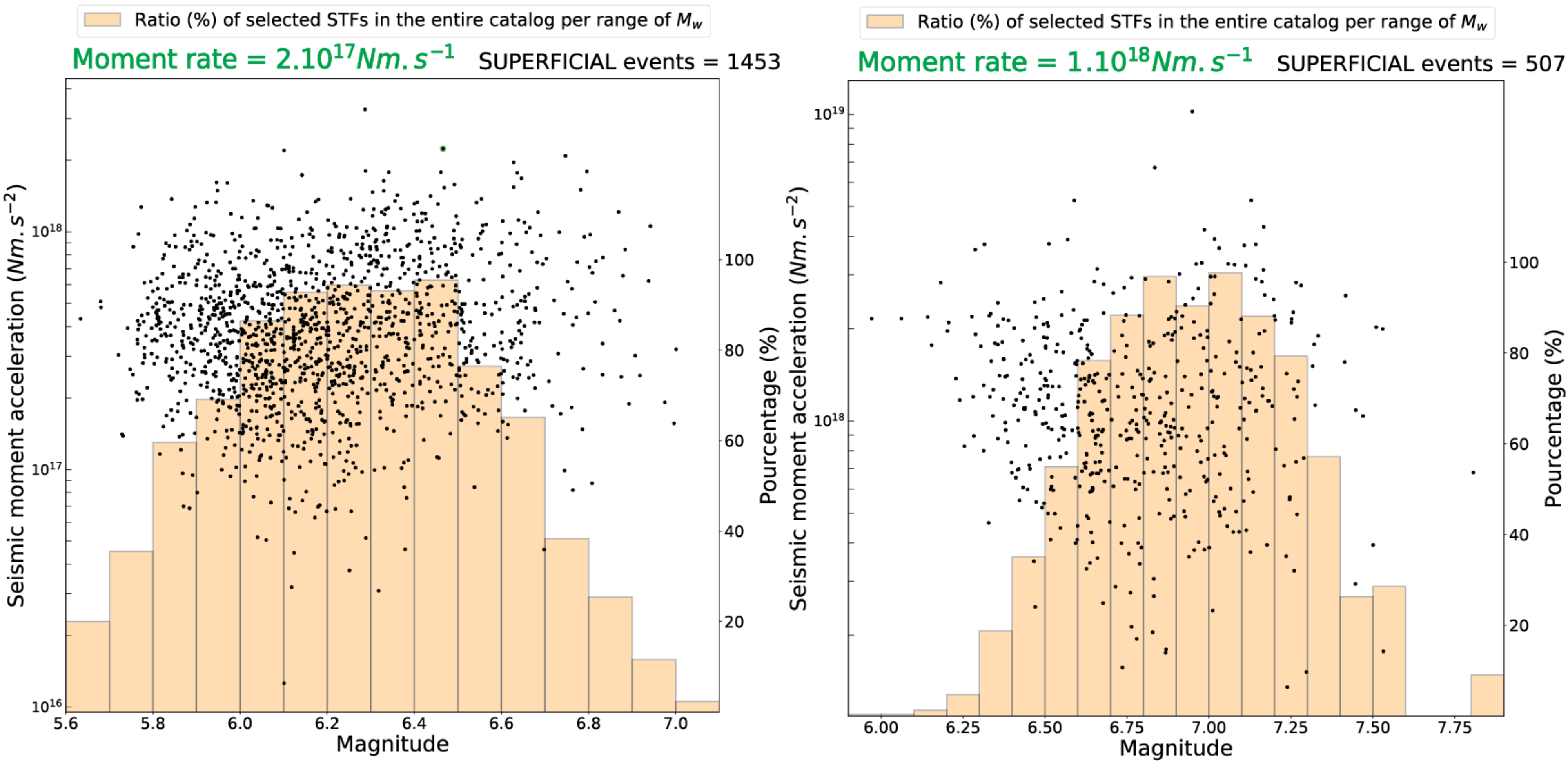
Computation of the seismic moment acceleration (slope) at prescribed moment rates if their values are within the development phase



- Computation for the whole SCARDEC catalog, leading to **hundreds of slopes for each moment rate**

- **No time information used:**
  - **Insensitive to the exact hypocentral time**
  - **Insensitive to the time where the earthquake "really" starts**

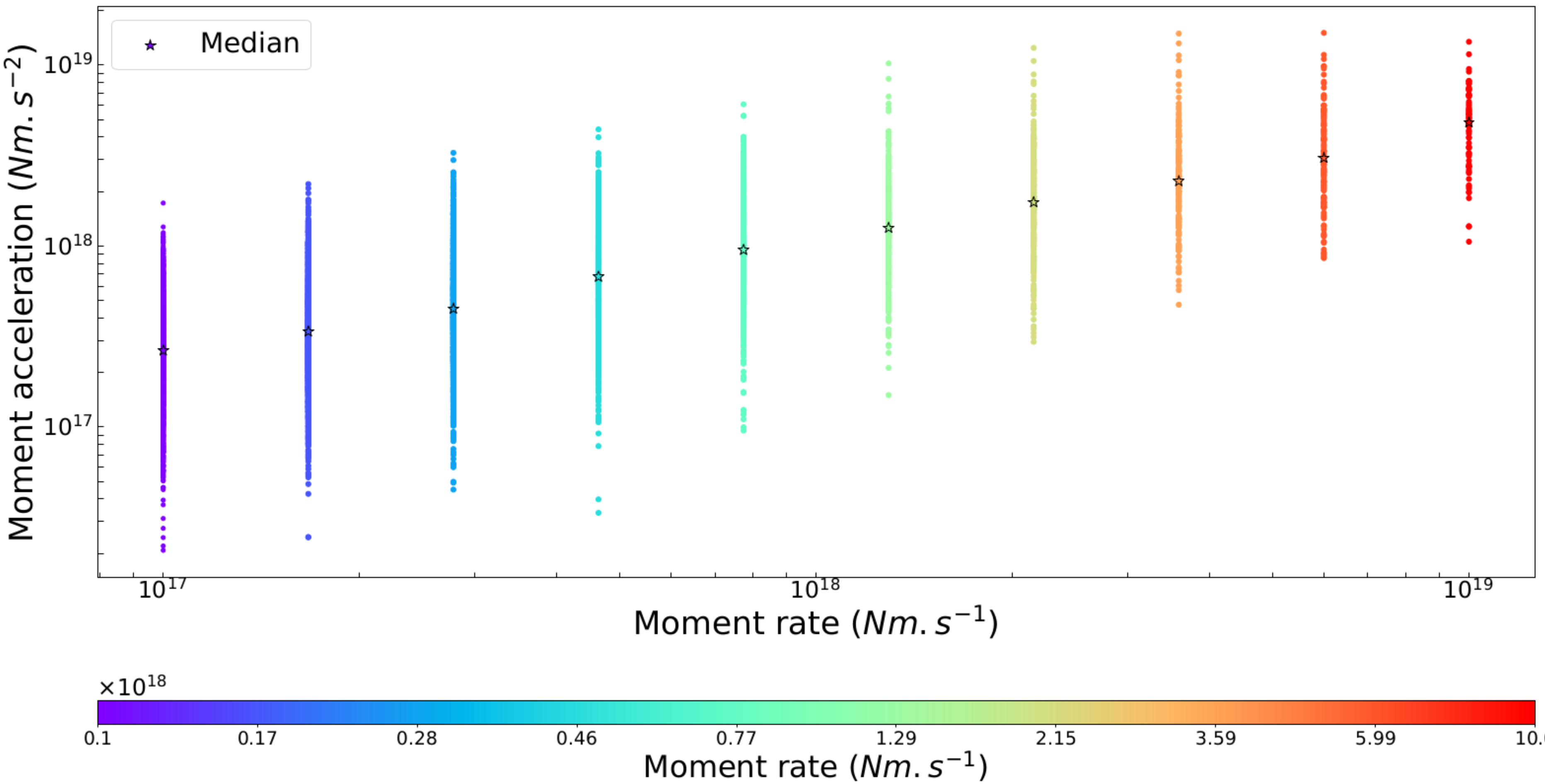
Can we see a trend in the slope values as a function of the final magnitude? Do the larger magnitude events accelerate faster or slower?



Significant variability, but no visible dependency of the slope with magnitude, whatever the prescribed moment rate….

…. But the slope itself is changing (increasing) with the moment rate values

Besides the variability, there is a clear evolution of the mean (or average) acceleration values throughout all the prescribed moment rate values



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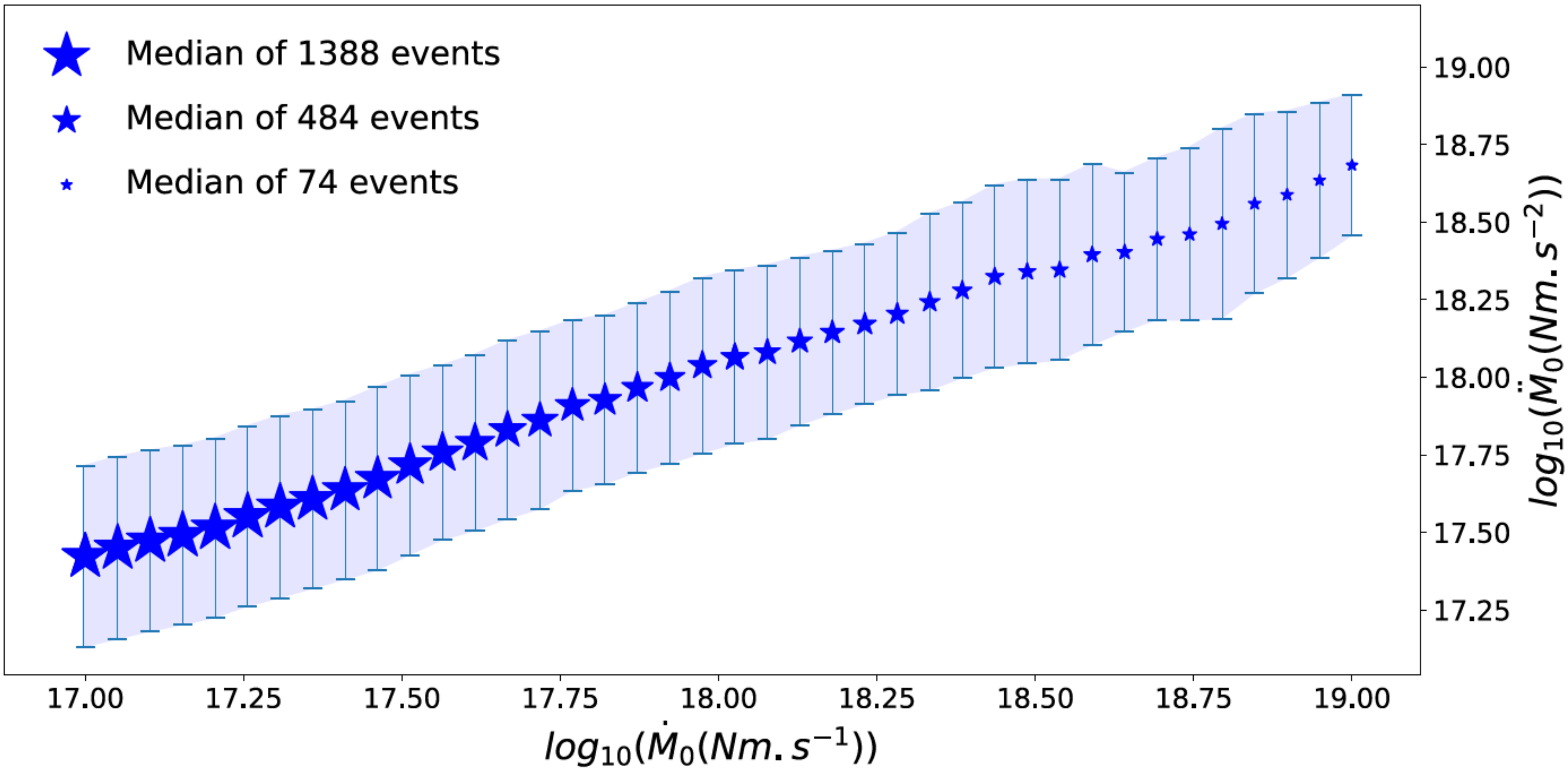
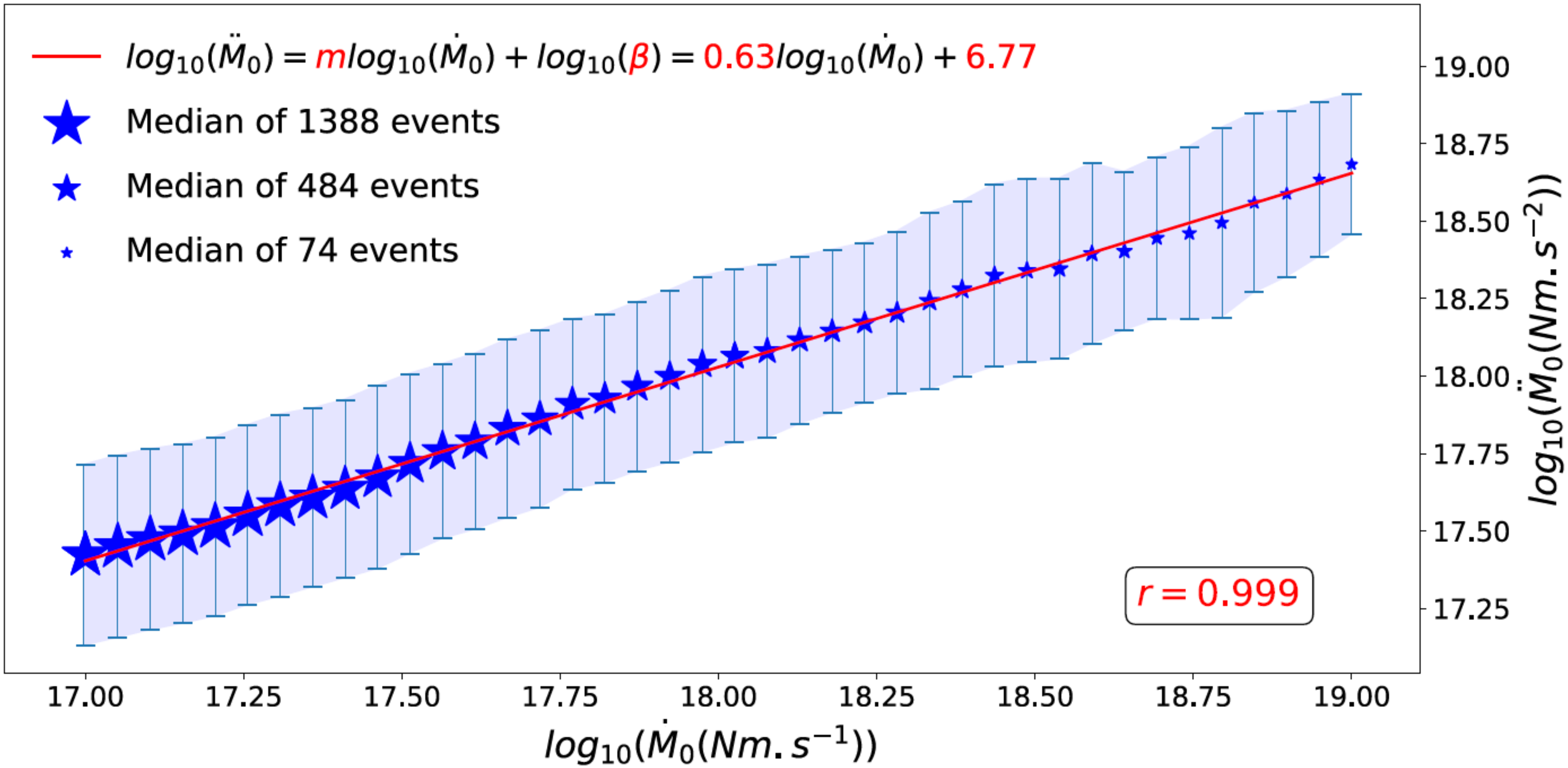


In log-log scales, the increase is almost linear, meaning that the evolution can be modeled as :

$$\ddot{M}_0 = \beta(\dot{M}_0)^m$$

Numerical values :



$$log(\ddot{M}_0) = m log(\dot{M}_0) + log(\beta) = 0.63 log(\dot{M}_0) + 6.77$$

How to relate these slope observations to the time evolution of the moment rate ?

$$\ddot{M}_0 = \beta(\dot{M}_0)^m$$

$$\int_0^t \frac{\ddot{M}_0(u)}{(\dot{M}_0(u))^m}\,\mathrm{d}u = \int_0^t \beta\,\mathrm{d}u \qquad (\forall t, \dot{M}_0(t) > 0)$$

$$\text{if m} \neq 1, \quad \frac{(\dot{M}_0(t))^{1-m}}{1-m} = \beta t$$

$$\dot{M}_0(t) = (\beta(1-m))^{\frac{1}{1-m}} \times t^{\frac{1}{1-m}}$$

Using values of β and m previously determined:

$$\dot{M}_0(t) = \alpha \times t^n = 8.7 \cdot 10^{17} \times t^{2.67}$$

Sum-up of the observations

- We observe the behavior of the **moment rate acceleration**, at times where the STF is **growing toward its peak** value (**not necessarily close to the hypocentral time**) : **rupture development phase**

- SCARDEC database **does not show any magnitude dependence** of this rupture development phase, favoring a **cascade-type rupture process.**

- The slope is larger and larger when measured at increasing moment rates, meaning that **the rupture development accelerates with time**

- Quantitative analysis highlights that **the moment rate in this rupture development phase grows faster than quadratically with time**.

Discussion

What does the observed rupture development tell us about the rupture process during earthquakes ?

$$\dot{M}_0(t) = \mu \int_S \dot{u}(x,y,t)\,dS$$

➡ In a simple model where rupture process expands bidimensionnally at constant slip rate $\dot{u}$ with constant rupture velocity :

$$\dot{M}_0(t) \sim t^2$$

➡ During rupture development, **the slip rate and/or the rupture velocity should increase** in order to agree with the observations showing moment rate growing faster than quadratically with time

➡ **Such an observation, qualitatively in agreement with dynamic models, provides a strong observational constraint on the rupture process**