EGU General Assembly 2020

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

Real-time discrimination of earthquake foreshocks and aftershocks

Laura Gulia[1] & Stefan Wiemer[2]

[1]*ETH, Swiss Seismological Service, Zurich, Switzerland* now at *University of Bologna, Department of Physics and Astronomy, Bologna, Italy*
[2]*ETH, Swiss Seismological Service, Zurich, Switzerland*

EGU General Assembly 2020

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

4 July 2019: M6.4
Ridgecrest, California

24 Aug 2016: M6.2
Amatrice, Italy

15 Apr 2016: M6.5
Kumamoto, Japan

After a moderate/big event, we all wonder

Was this the mainshock or a bigger event has yet to come?

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

So far, Scientists can only give a purely statistical answer, based on compilations of empirical observations: the chance that after a moderate earthquake an even larger event will occur within five days and 10 km is typically 5%.

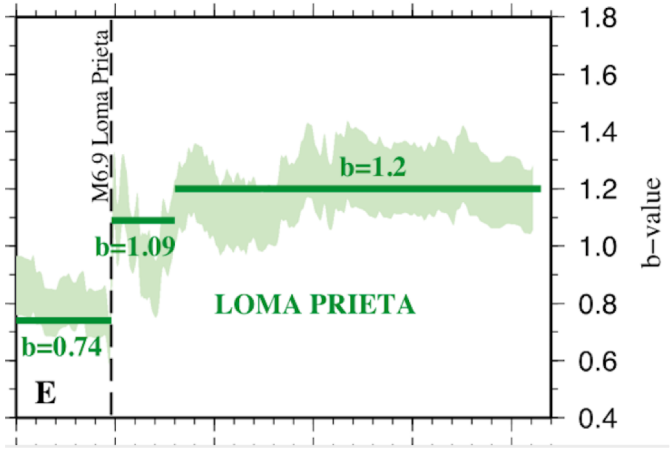
Cosimo, 2020

We propose a simple traffic light classification (**FTLS, Foreshock Traffic Light System**), based on the b-value time-space variations, to assess in real time the level of concern about a subsequent larger event and test it against 58 sequences, achieving a classification accuracy of 95 per cent.

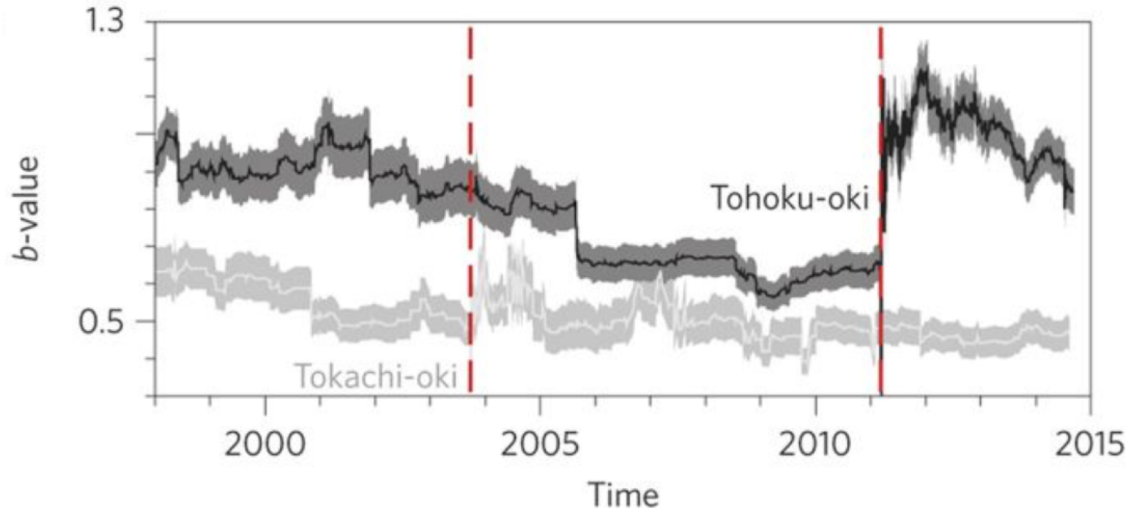
Gulia and Wiemer, 2019, Nature

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

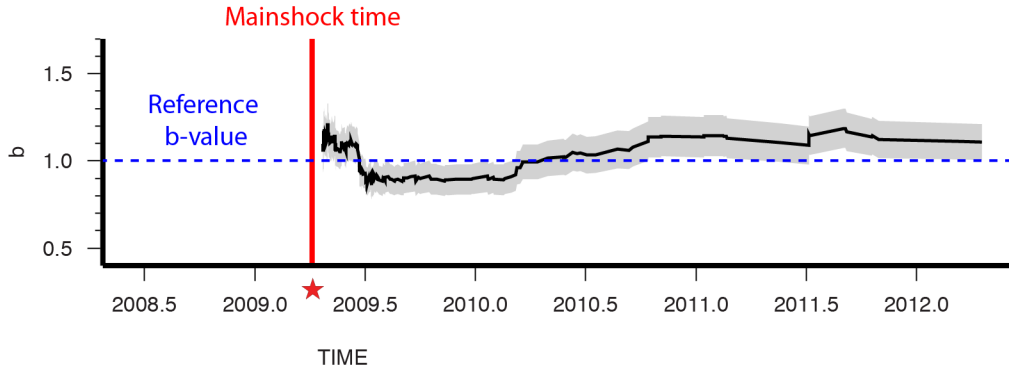
To derive our model, we start from the the b-value correlation with differential stress and some case studies…



Tormann et al, 2012,
Loma Prieta



Tormann et al, 2015,
Tohoku



Gulia et al, 2016,
L'Aquila

EGU General Assembly 2020

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

Individual case studies suggest that after a mainshock, **higher** b-values are observed

Is such increase systematic and common in all the sequences?

We select 58 well-recorded sequences from California, Japan, Italy and Alaska.

To compare them, many problems must be considered:
catalogs incompleteness, uncertainties, data quality, variations, systematic bias…

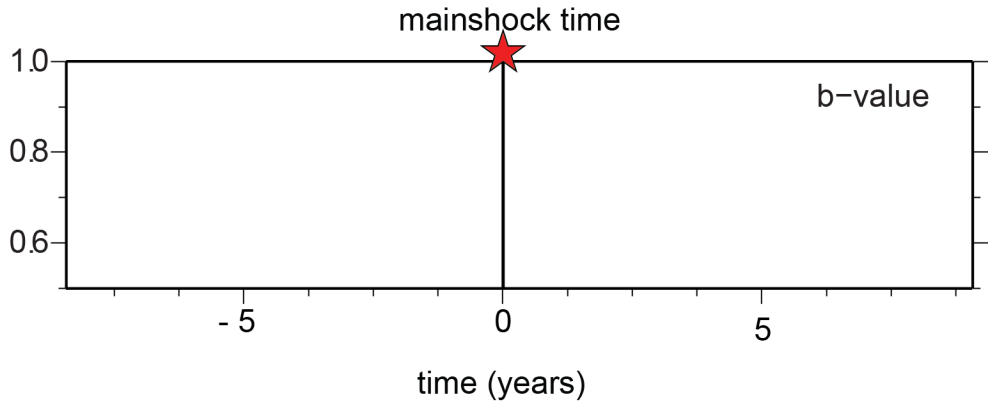
To overcome all such problems, we propose to **stack** the b-value time-series to enhance the signal over the ‘noise’ (variance)

EGU General Assembly 2020

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

We first build the single time-series, splitting the catalog in 2 parts: before and after the mainshock, that becomes the time 0 in the time-b-value plot – *Here an example for Parkfield, 2004, California*

For the source definition and events selection Gulia et al., 2018, GRL




AGU100 ADVANCING EARTH AND SPACE SCIENCE

Check for updates

Geophysical Research Letters

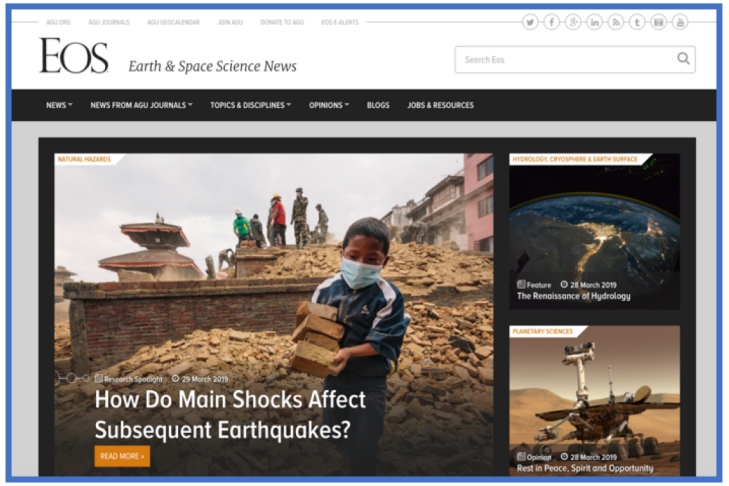
RESEARCH LETTER
10.1029/2018GL080619

Key Points:
- We develop a stacking approach to *b* value time series centered on the mainshock time in order to extract the generic behavior

The Effect of a Mainshock on the Size Distribution of the Aftershocks

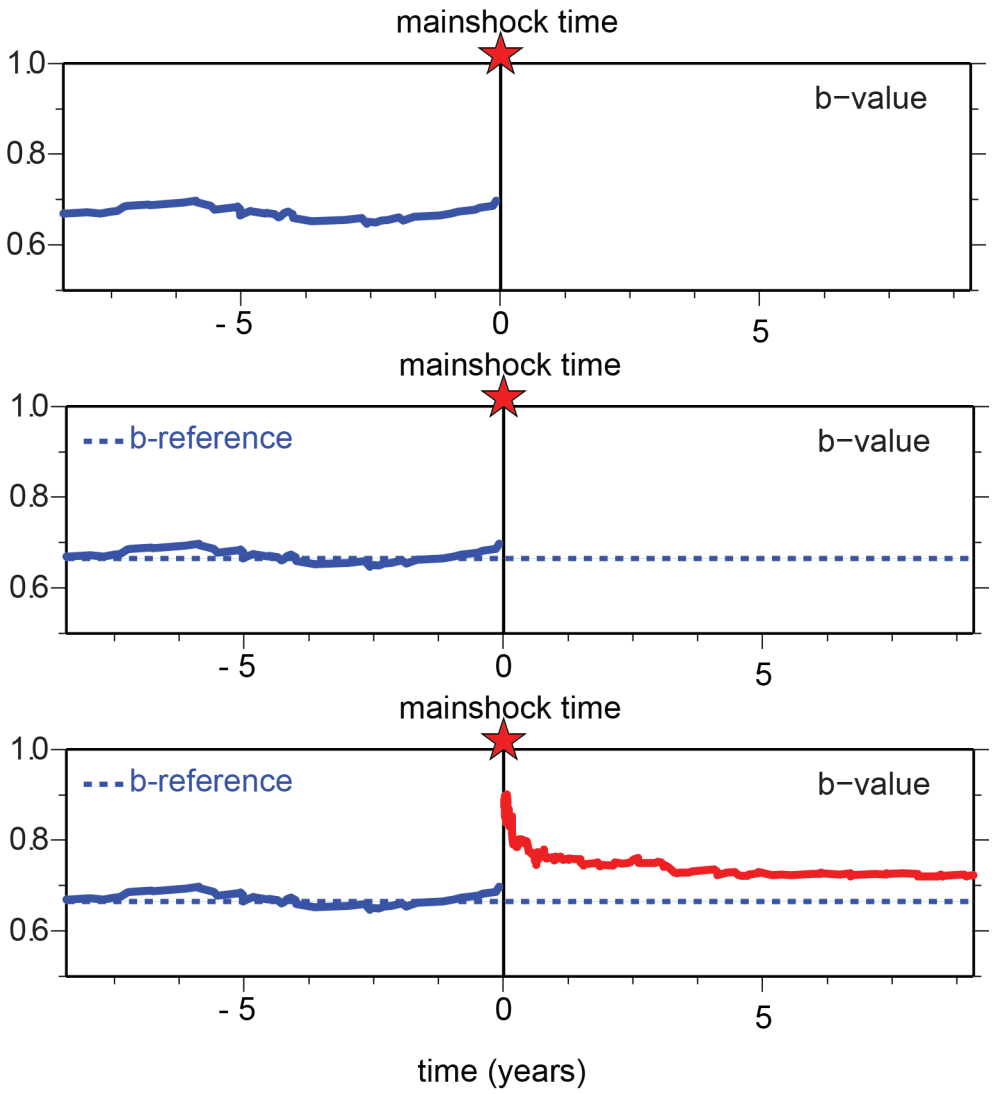
L. Gulia[1], A. P. Rinaldi[1], T. Tormann[1], G. Vannucci[2], B. Enescu[3], and S. Wiemer[1]

[1]Swiss Seismological Service, ETH, Zurich, Switzerland, [2]Istituto Nazionale di Geofisica e Vulcanologia, Bologna, Italy, [3]Department of Geophysics, Kyoto University, Kyoto, Japan


EOS Earth & Space Science News

How Do Main Shocks Affect Subsequent Earthquakes?

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service



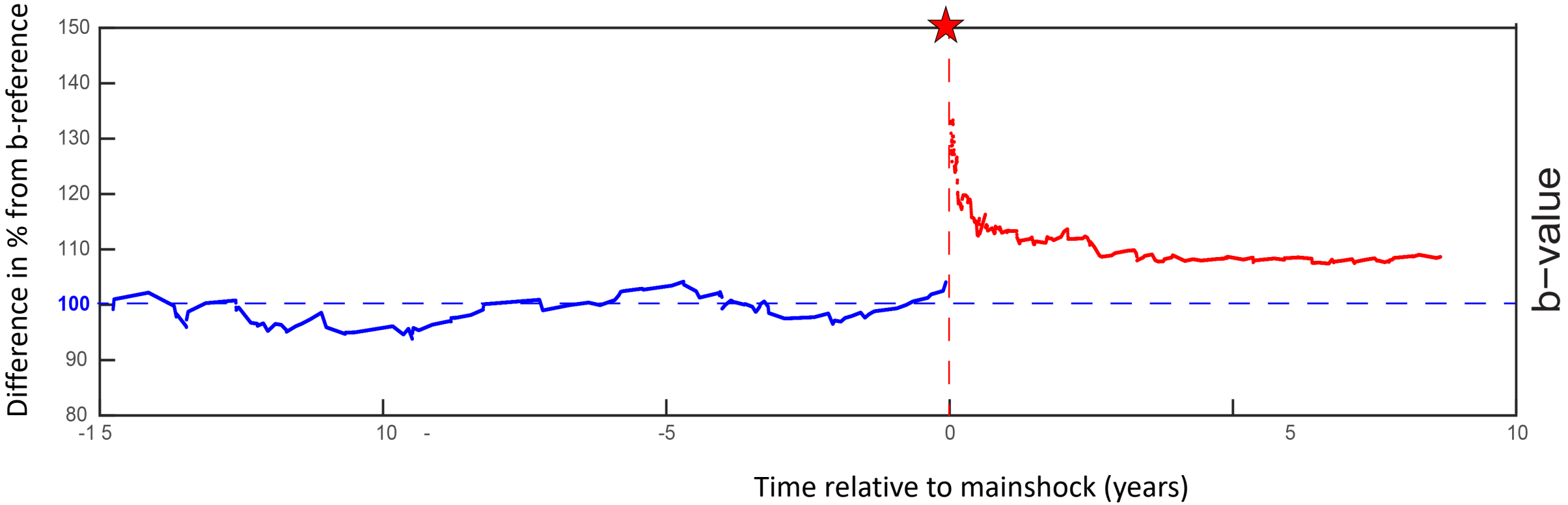
Then, in a moving window approach, we calculated the b-value moving event by event, stopping at the last event preceding the mainshock.

The median of all these estimation is the reference b-value for the sequence

As for the first part of the catalog, we calculated the b-value moving event by event, for the events following the mainshock.

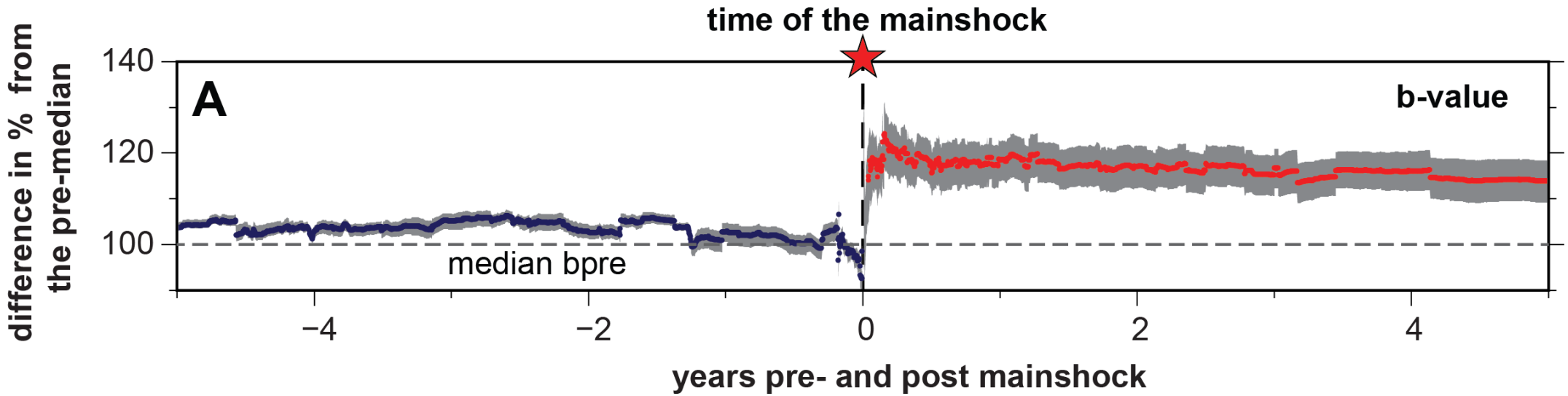
Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

Finally, we plot the difference in percentage with respect to the reference b-value
The use of such values instead of the absolute ones, allows us to compare/stack different sequences



Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

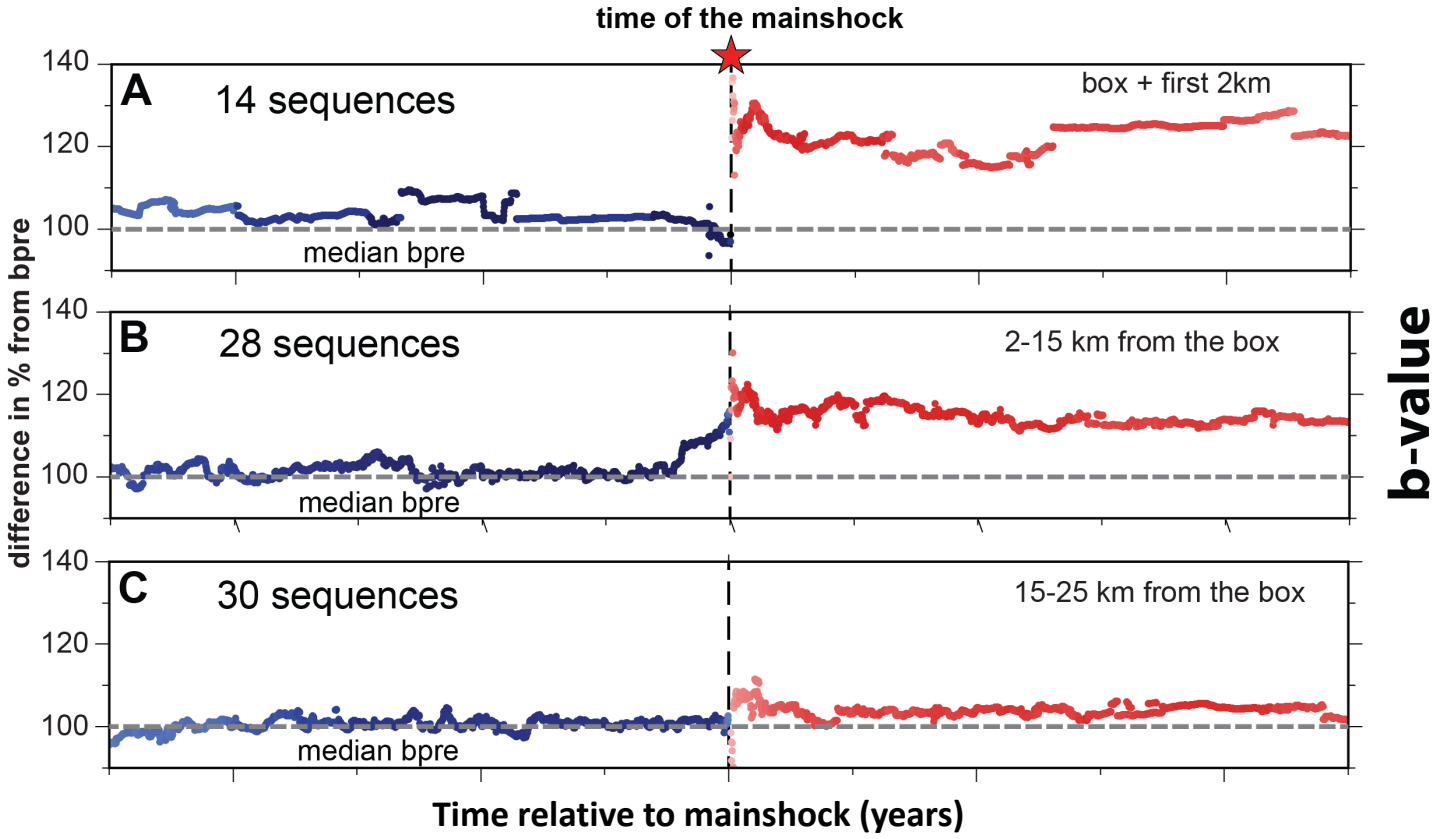
Stack of the 31 sequences from California, Japan, Italy and Alaska

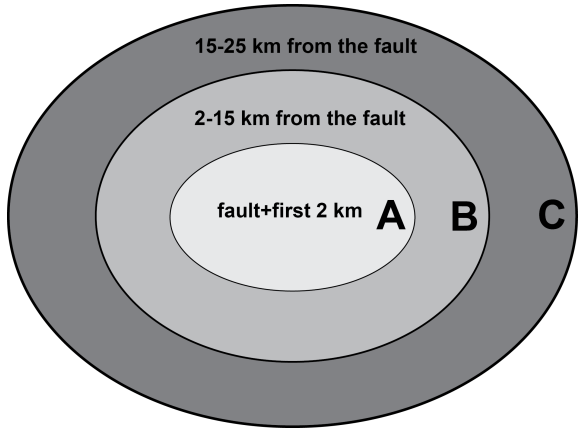


The b-value near the fault plane increases between 10 and 30%

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

By stacking three different and independent sampling volumes around the mainshock fault volume we show that the b-value increase is a function of the distance.



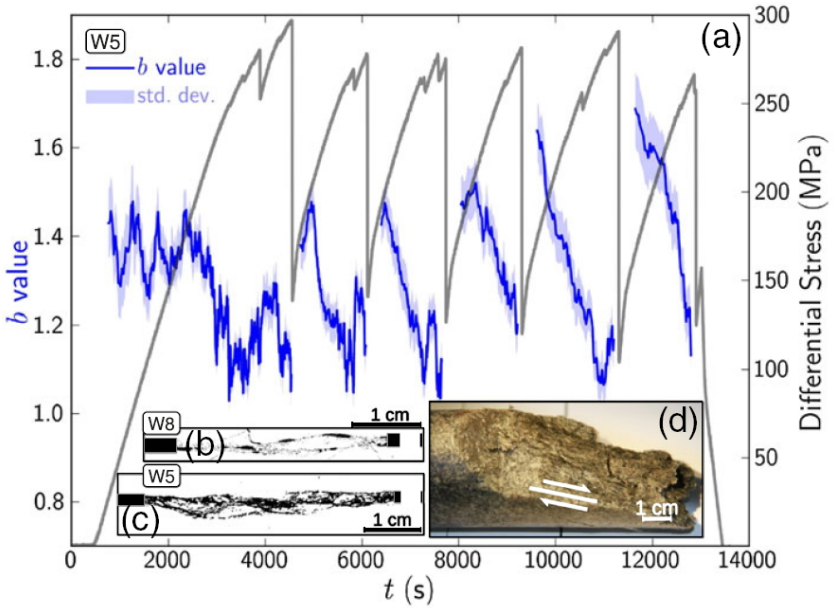


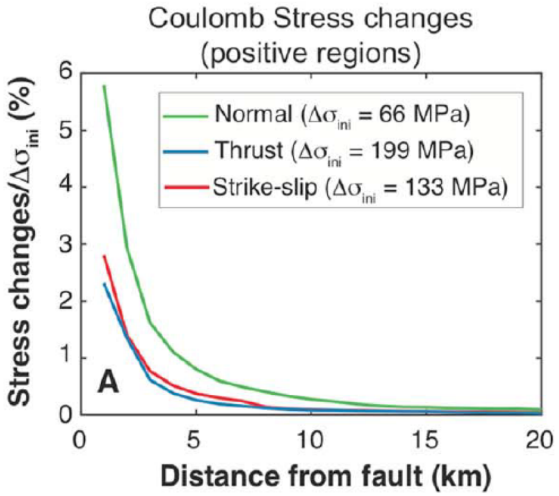
Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

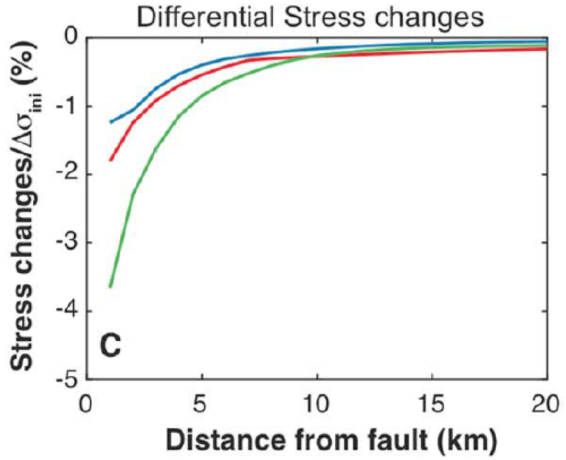
The aftershock b-value increase is in agreement with:

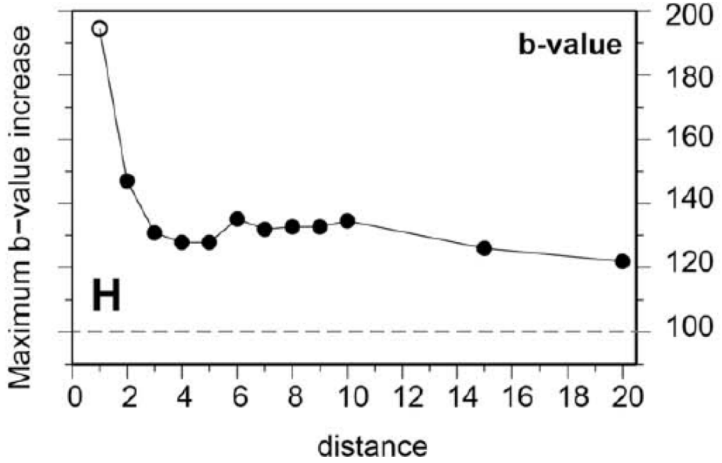
- Laboratory specimens (inverse correlation between b-value and differential stress)
- Insights from Coulomb-based modeling: Only near the fault, faulting style dependent and magnitude dependent.

Goebel et al., 2013, GRL







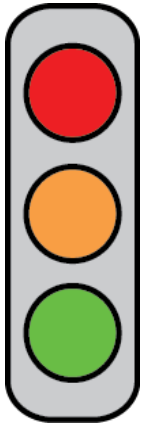


For further details see Gulia et al., 2018, GRL

EGU General Assembly 2020

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

The *Foreshock Traffic Light Model*



We propose that **sequences diverting from the generically observed increased b-value** after a mainshock are ones where a subsequent **larger event** is more likely to occur.

Therefore, real-time monitoring of b-value in aftershock sequences can be used as a currently unique tool for real-time discrimination between foreshocks and aftershocks

No. 7777 10 October 2019

ARTICLE

https://doi.org/10.1038/s41586-019-1606-4

Real-time discrimination of earthquake foreshocks and aftershocks

Laura Gulia[1]* & Stefan Wiemer[1]

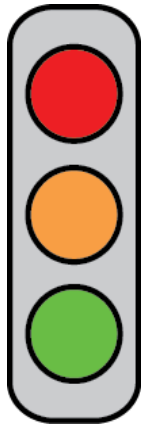
Immediately after a large earthquake, the main question asked by the public and decision-makers is whether it was the mainshock or a foreshock to an even stronger event yet to come. So far, scientists can only offer empirical evidence from statistical compilations of past sequences, arguing that normally the aftershock sequence will decay gradually whereas the occurrence of a forthcoming larger event has a probability of a few per cent. Here we analyse the average size distribution of aftershocks of the recent Amatrice–Norcia and Kumamoto earthquake sequences, and we suggest that in many cases it may be possible to discriminate whether an ongoing sequence represents a decaying aftershock sequence or foreshocks to an upcoming large event. We propose a simple traffic light classification to assess in real time the level of concern about a subsequent larger event and test it against 58 sequences, achieving a classification accuracy of 95 per cent.

Gulia and Wiemer, 2019, Nature

EGU General Assembly 2020

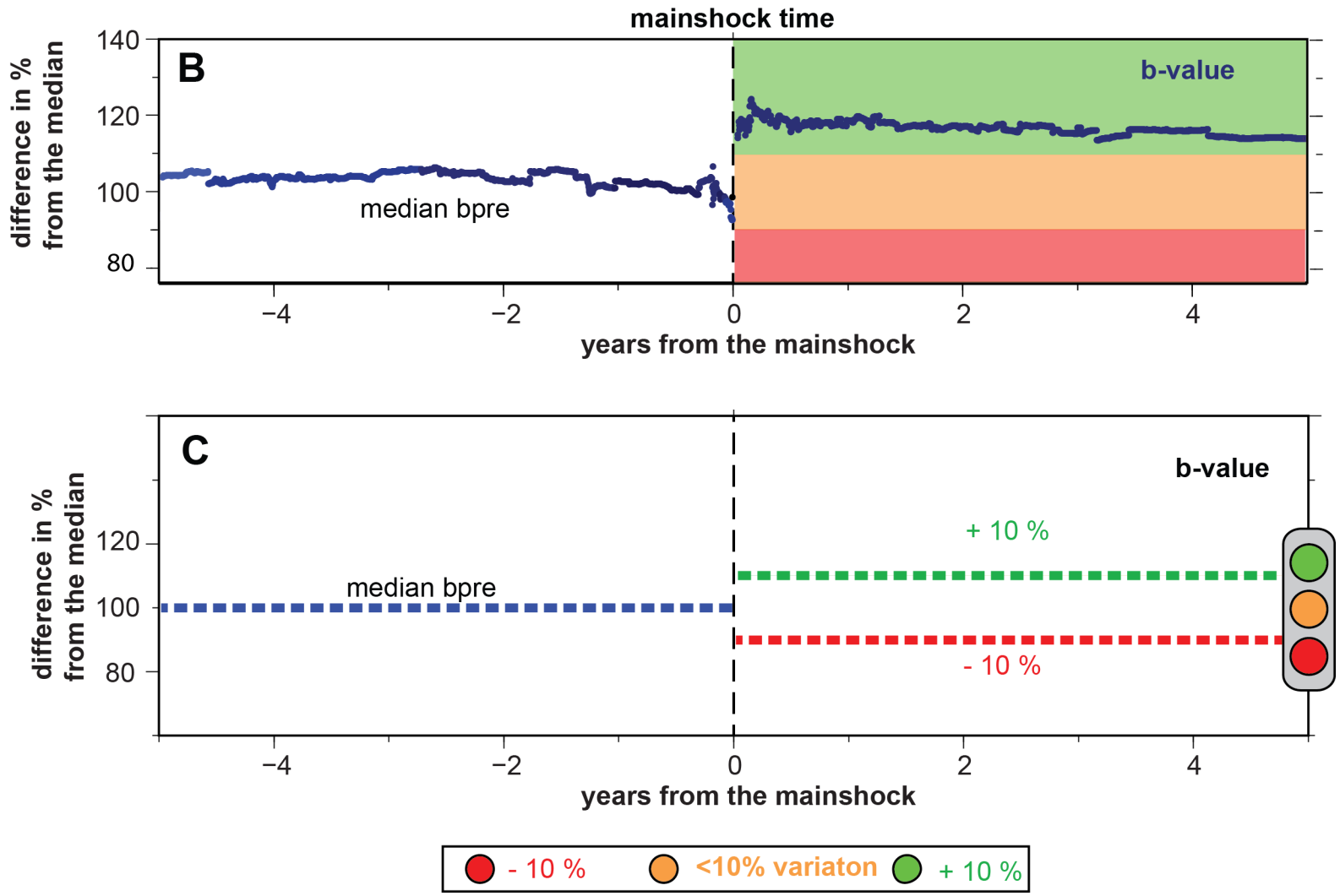
Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

We define 3 levels of alert:



RED: the big event was not the mainshock and a bigger event will occur;
ORANGE: undefined, keep monitoring the b-value;
GREEN: the big event was the mainshock: the sequence will decay normally

Gulia and Wiemer, 2019, Nature



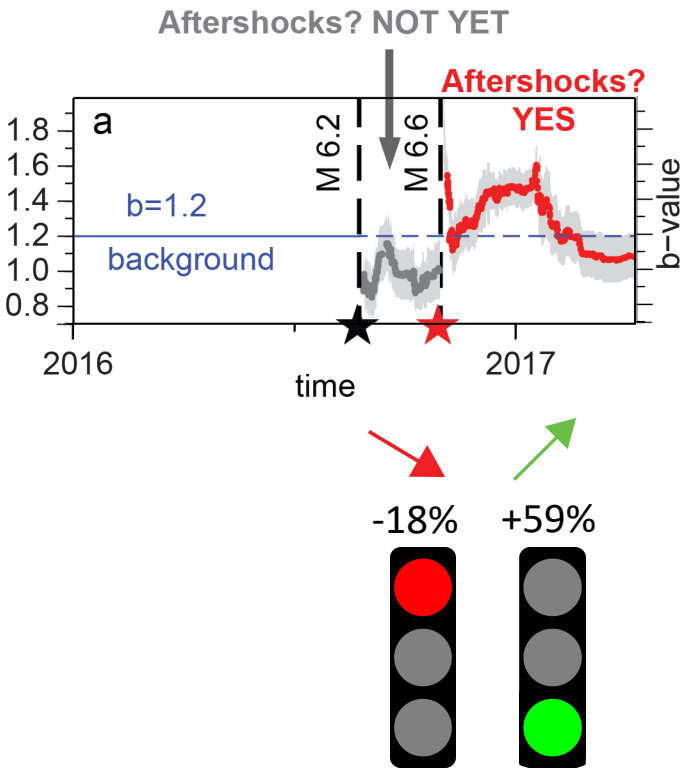
Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

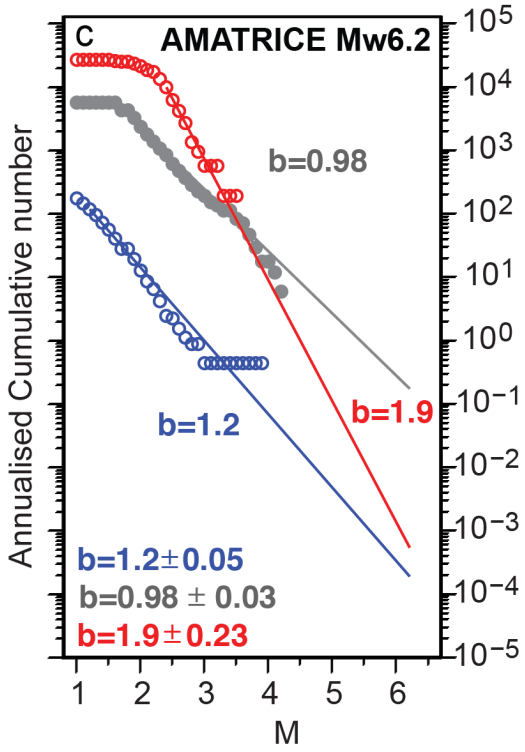
We test the model on 2 well-recorded sequences – Kumamoto, Japan, and Amatrice-Norcia, Italy, both in 2016 - where a M>6 has been followed by a bigger event

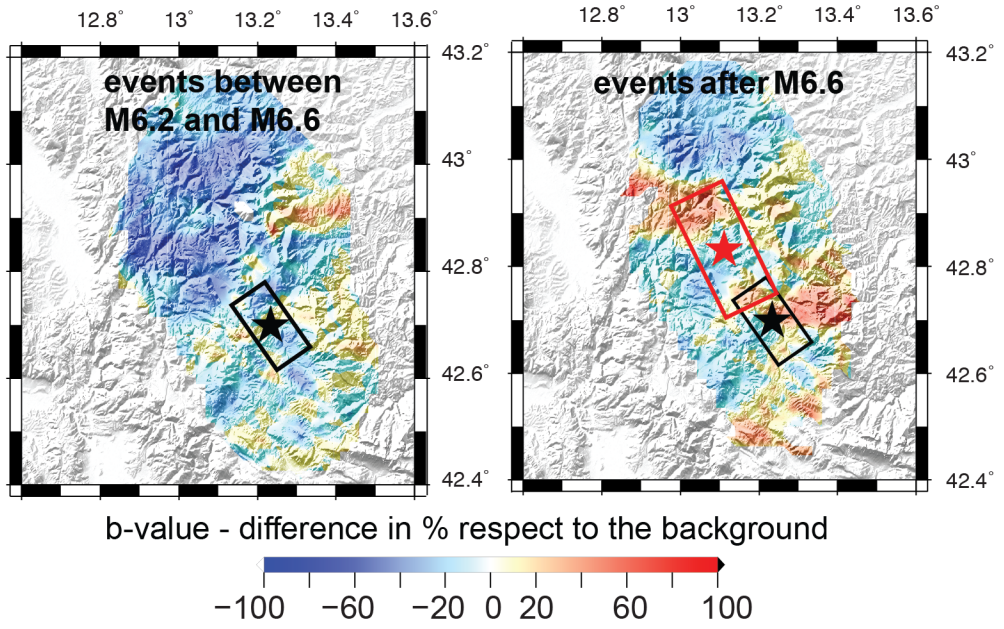
EGU General Assembly 2020

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

Amatrice, 24 August 2016, M6.2

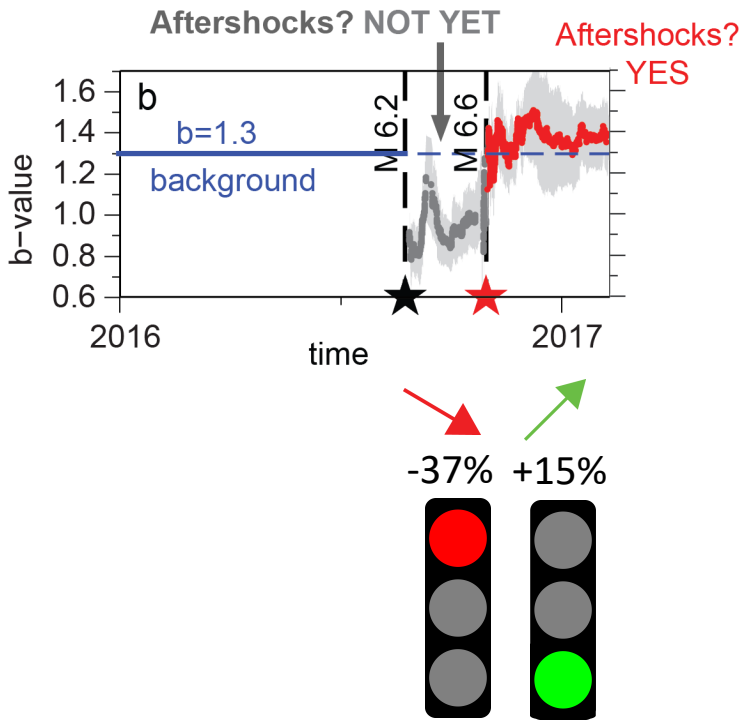


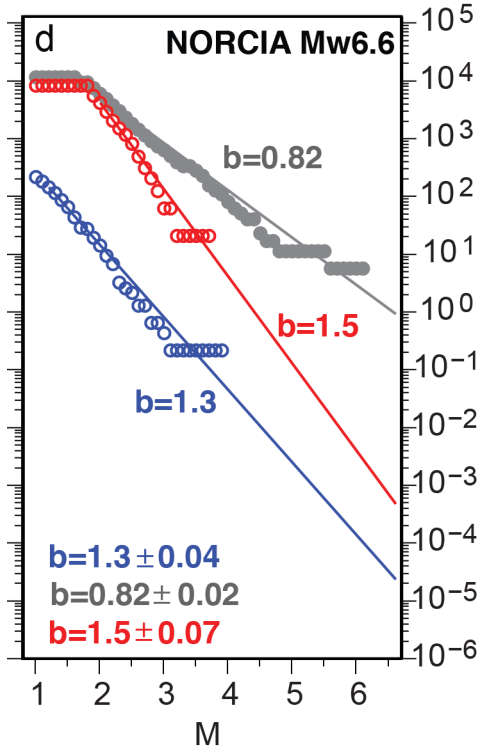




Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

Norcia, 30 October 2016, M6.6

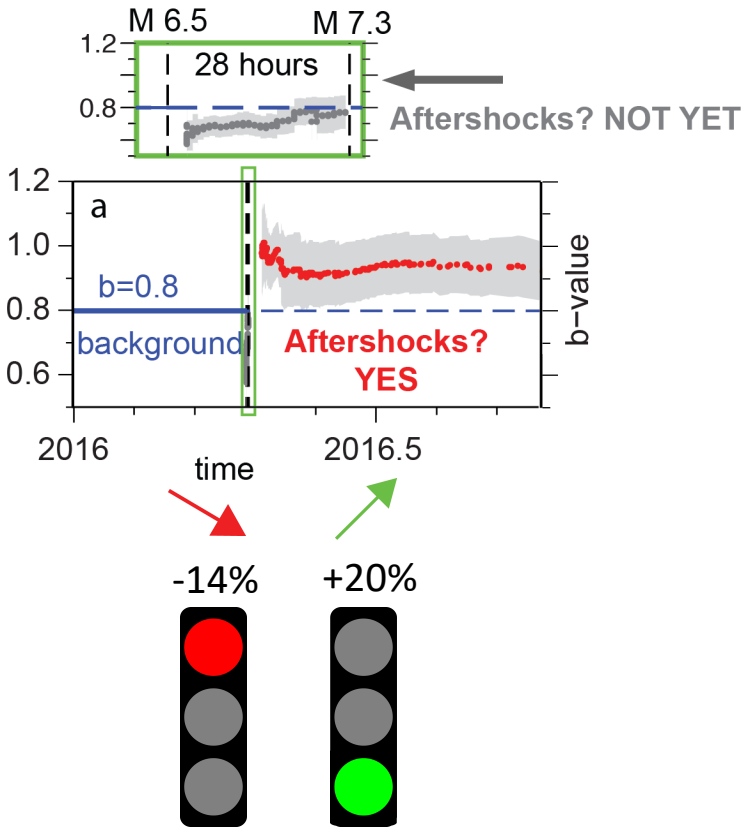


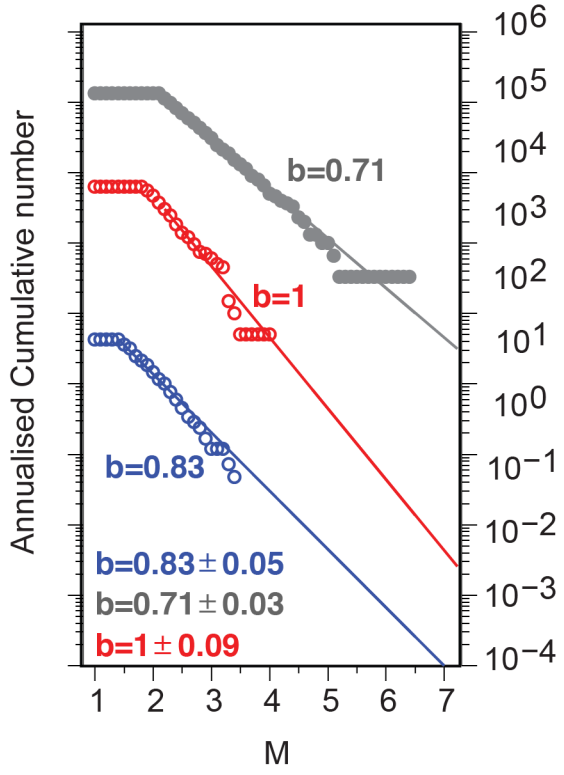


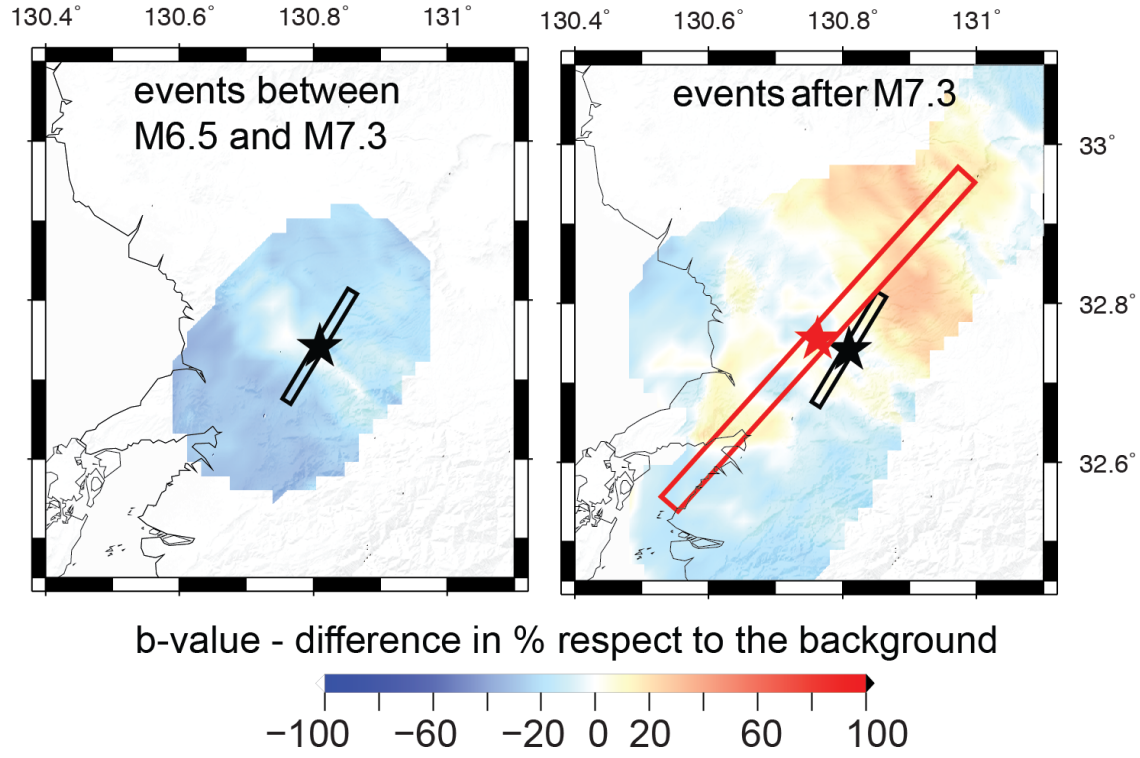
EGU General Assembly 2020

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

Kumamoto, 14 April 2016, M6.5

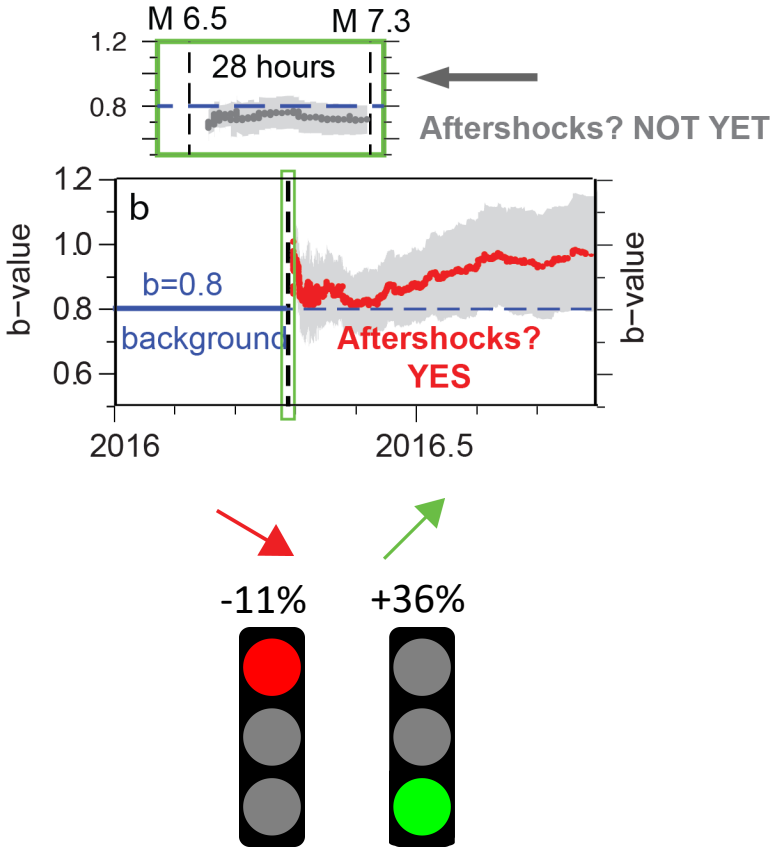


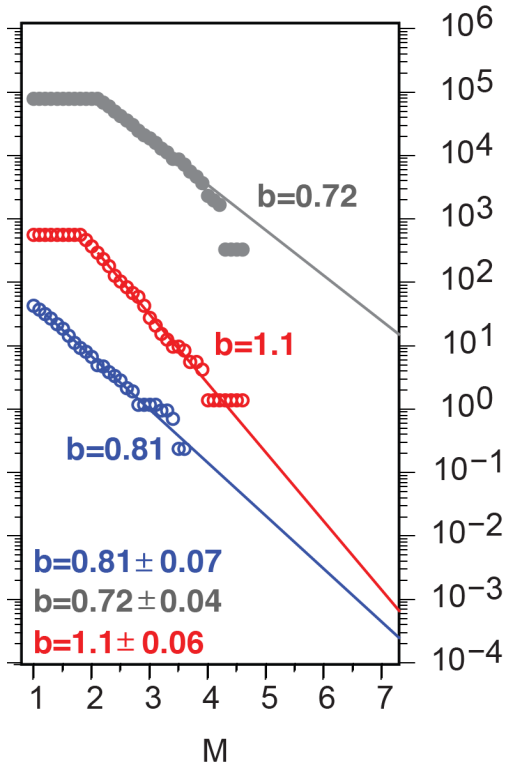




Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

Kumamoto, 16 April 2016, M7.3



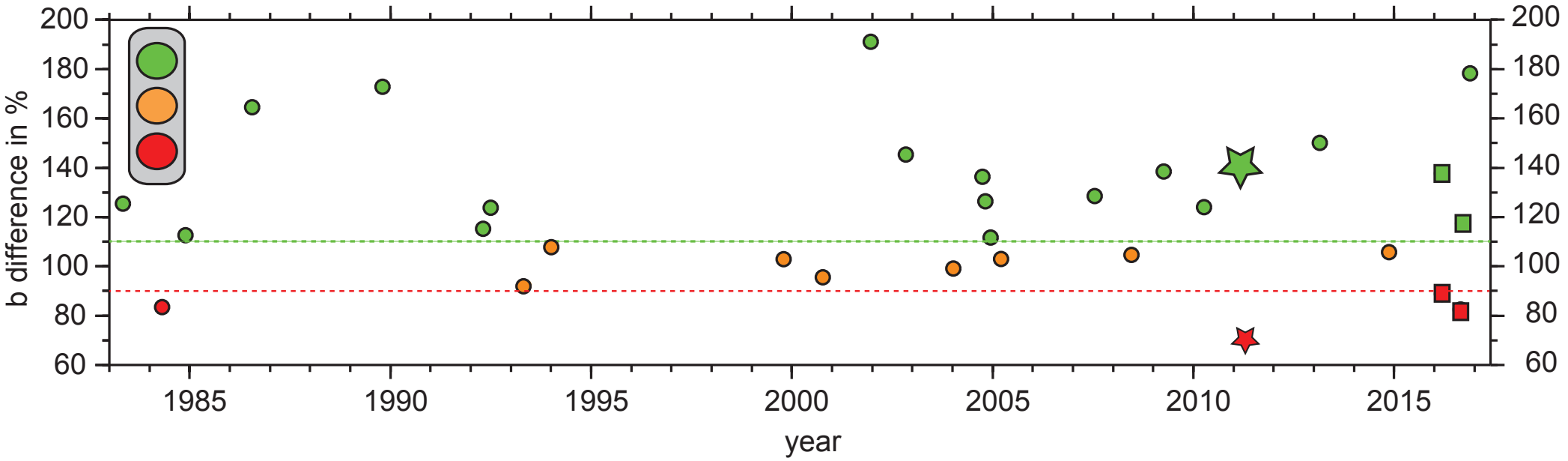


Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

We finally re-analyzed the 58 sequences, obtaining a robust value for 25, in addition to the values obtained for the foreshocks of the Norcia and Kumamoto sequences, resulting in a total of 29 sequences. The red and green stars are the Tohoku M9 in 2011 (green) and its biggest foreshock (red).

Binary classifier:
2 successful alerts (true positives)
1 false alert (false positives)
0 missed events (false negatives)
18 correct negatives (true negative)

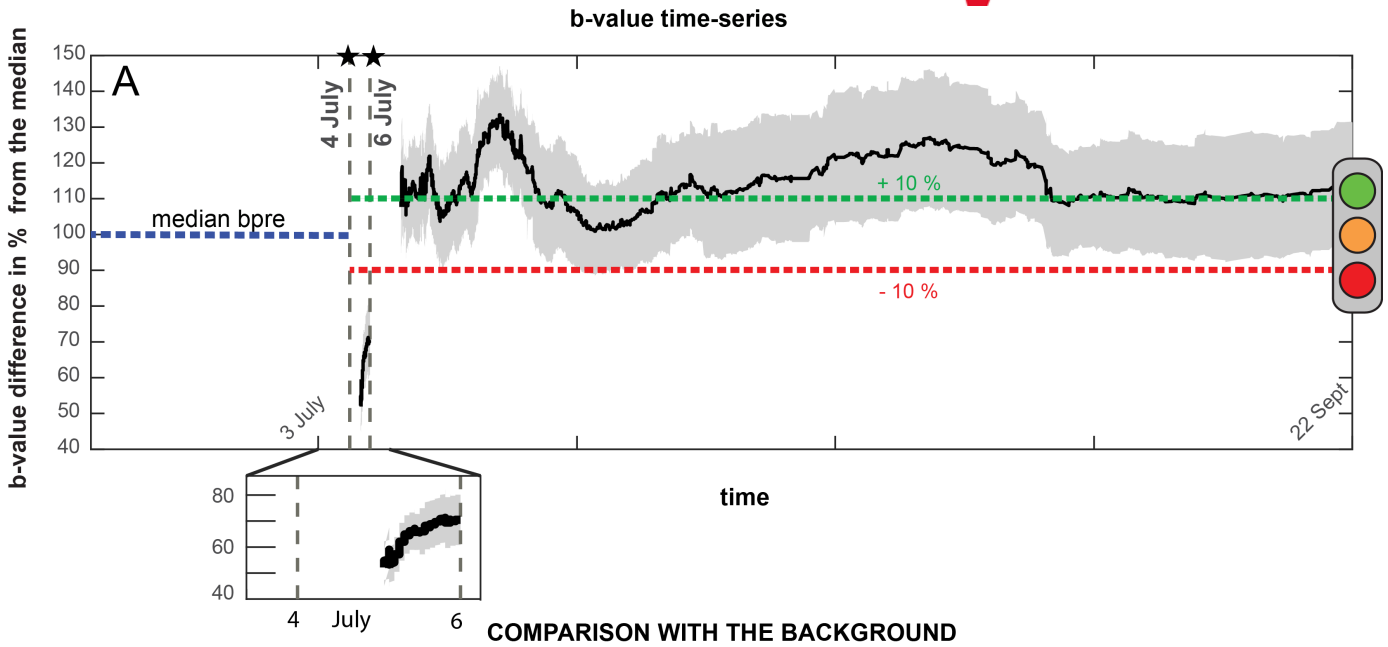
Confusion matrix analysis: accuracy of 0.95.
The random chance of correctly identifying two out of two mainshocks, with only one false alert and no missed events is below 1%.

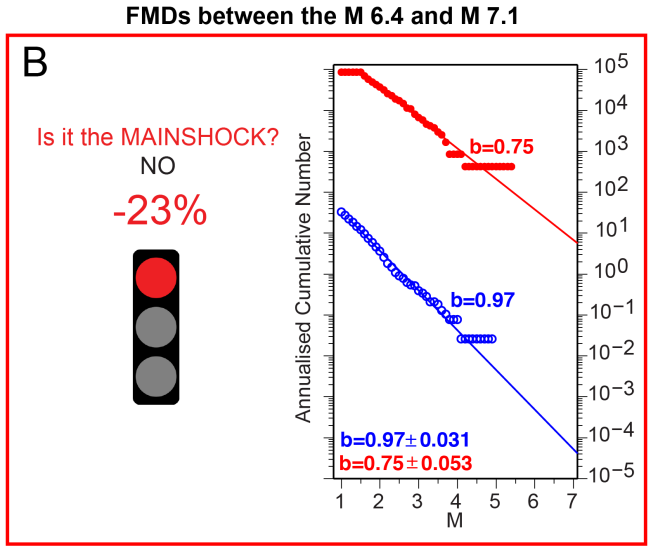


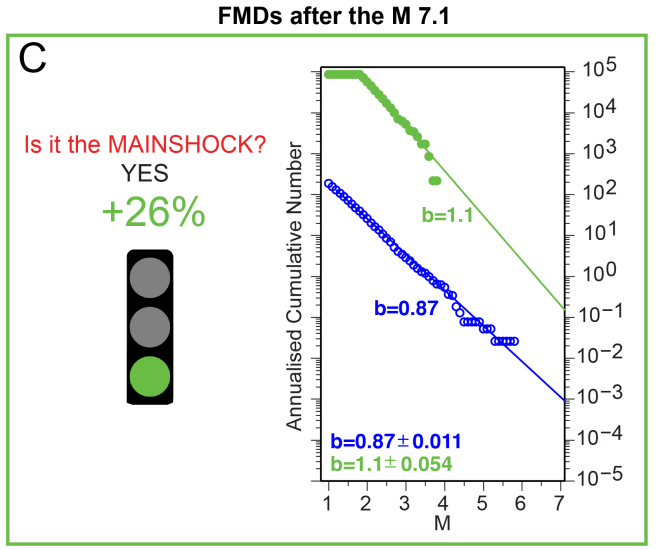
EGU General Assembly 2020

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

The 2019 Ridgecrest, California, sequence
offered us the chance to successfully test the FTLS in **near-real-time** with preliminary data







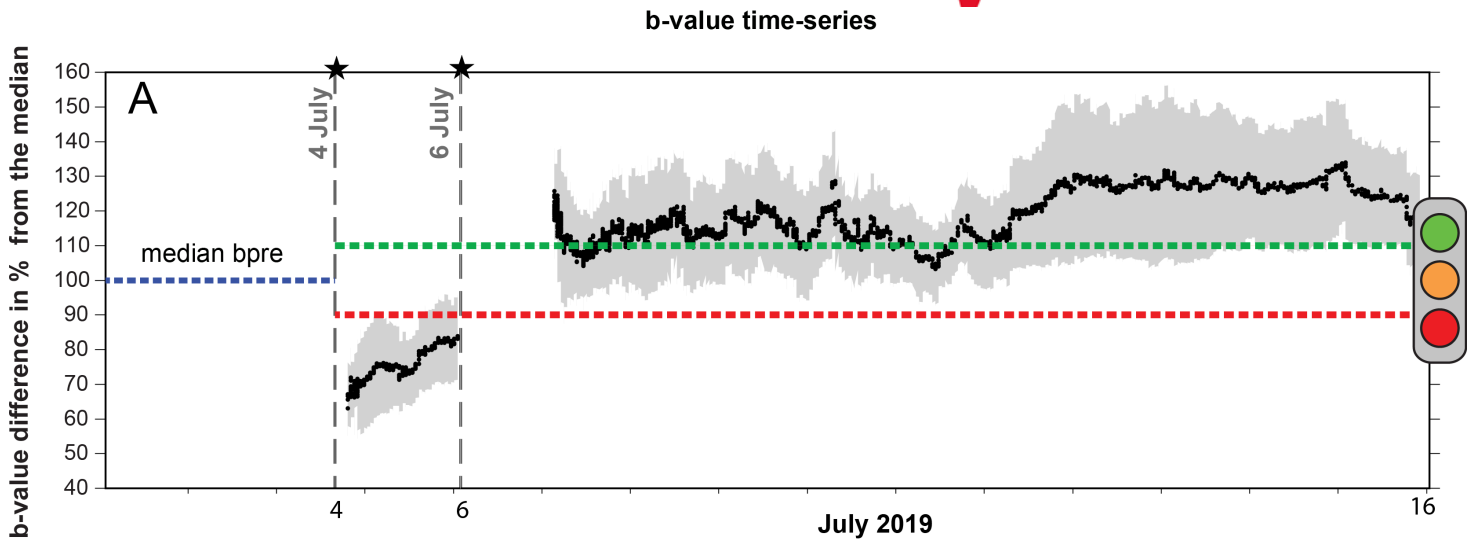
Gulia, Wiemer, Vannucci, *submitted to SRL*

EGU General Assembly 2020

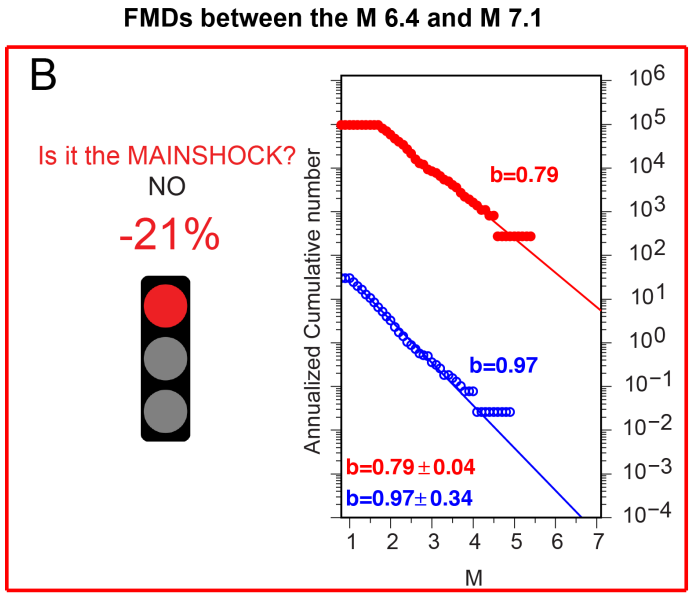
Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

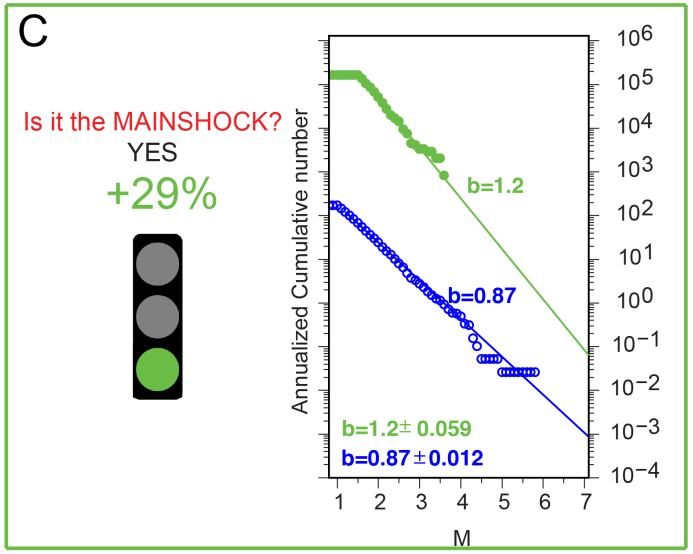
High-definition data recently published by Shelly (2020, SRL) and the revised focal mechanism (GCMT) confirm the results

Gulia, Wiemer, Vannucci, *submitted to SRL*



COMPARISON WITH THE BACKGROUND





Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

Conclusion

We developed a model to discriminate, in real-time, whether a moderate to big event is the mainshock or a bigger event has yet to occur.

In Regions of the World with sufficient network coverage, the Foreshock Traffic Light System (FTLS) can support Civil Protection as well as decision makers providing additional information on an ongoing sequence.