Response to comments by the reviewers and editor

We appreciate the comments and suggestions from the editor and reviewers, which have allowed us to greatly improve our manuscript. All comments have been addressed. In what follows we give response to the individual points raised.

Reply to the comments of the Anonymous Referee #1.

The following response format will be used:

- Question/Comment (from the reviewer)
- Answer (reply from the authors)
- Changes (new/modified text added to the manuscript)

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Question / comment

“My major concern is the degree of uncertainties introduced by the initial choice of parameters, the fault parameters and whether this range of parameters holds to different tectonic settings. Fault length and width calculations are not trivial. I am not sure about the simplicity of the model, it seems to be dependent on studies for fault dimensions and for the model to be used it for another region, if my understanding is correct, the whole procedure (including the sensitivity analysis etc) has to be repeated.”

Answer:

TREMOL is based on the Fiber Bundle model which is a stochastic cellular automata type model. Our goal is to investigate the basic rules of the FBM, adding some extra assumptions to simulate the rupture of asperities of different scenarios. It is clear that uncertainties play an important role.
All initial parameters depend on the dimensionality of the model (e.g. 2D or 3D), and the tectonic setting itself. Although the stochastic nature of TREMOL does not allow direct relations between known physical values and the parameters of the model, the stochastic approach may enable new insight into earthquake physics, and the stress transfer process during earthquakes.

In the case of π_{Bkg}, the range of values come from the results found in Monterrubio-Velasco (2013), Moreno et al. (2001), Monterrubio-Velasco et al. (2017). In these works, π_{Bkg} was the only parameter required to define the global load transfer-value. Based on π_{Bkg} we investigate π_{asp} and γ_{asp} in the work reported in the present paper.

In the case of fault dimensions, TREMOL requires the length and width of the effective rupture area, and the length and width of the asperity area as input parameters to initialize the model. In order to test the code using finite-fault source models, we used the source parameters derived by Rodríguez-Pérez et al. (2018) for the Mexican subduction zone.

If a user wants to test TREMOL v0.1 for another tectonic region, it is not necessary to perform a sensitivity analysis for each new project. In fact, part of the objectives of the present and previous works, was to carry out sensitivity analyses in order to identify values that can be applied to new models. However, it is a indeed true that TREMOL requires some geometric data such as the length and width of a fault (with the inherent uncertainties), otherwise we would not be able to characterize the seismic source of a particular zone, or seismic series. Such data can be obtained either from specific studies that have determined the dimensions of the faults or, alternatively, from the available relationships between the area and the magnitude of an earthquake. In the latter case, the inferred data will be the magnitude, and then the probable dimensions are computed using the relationships mentioned. Additionally, it is convenient to mention that, albeit TREMOL can model the behavior of a major fault, it is also capable of modelling seismicity at regions with no prescribed fault systems or at areas between faults. Compared to other methodologies, TREMOL requires few data to study, and model complex rupture scenarios.

A sensitivity analysis might be performed to test the range of variations according to uncertainties in the input (geometric and tectonic) parameters, but for our purpose it was considered unnecessary since we were interested in the range of variations of the model parameters. TREMOL v0.1 is rather inexpensive in computing power, hence a parametric analysis similar to that used in this paper can be obtained in a few days using a personal computer (approximately two minutes per realization, including postprocessing and graphs generation). Future work will include a parallel version to reduce the computational time.

Question / comment

"In page 5 line 5 instead of the parenthesis could you give some examples? "

Answer/Changes:

- other parameters (load-transfer value π, strength value γ, initial load values σ, and load threshold σ_{th}).

Question / comment

"In page 5 line 26 why uniform?"

Answer:

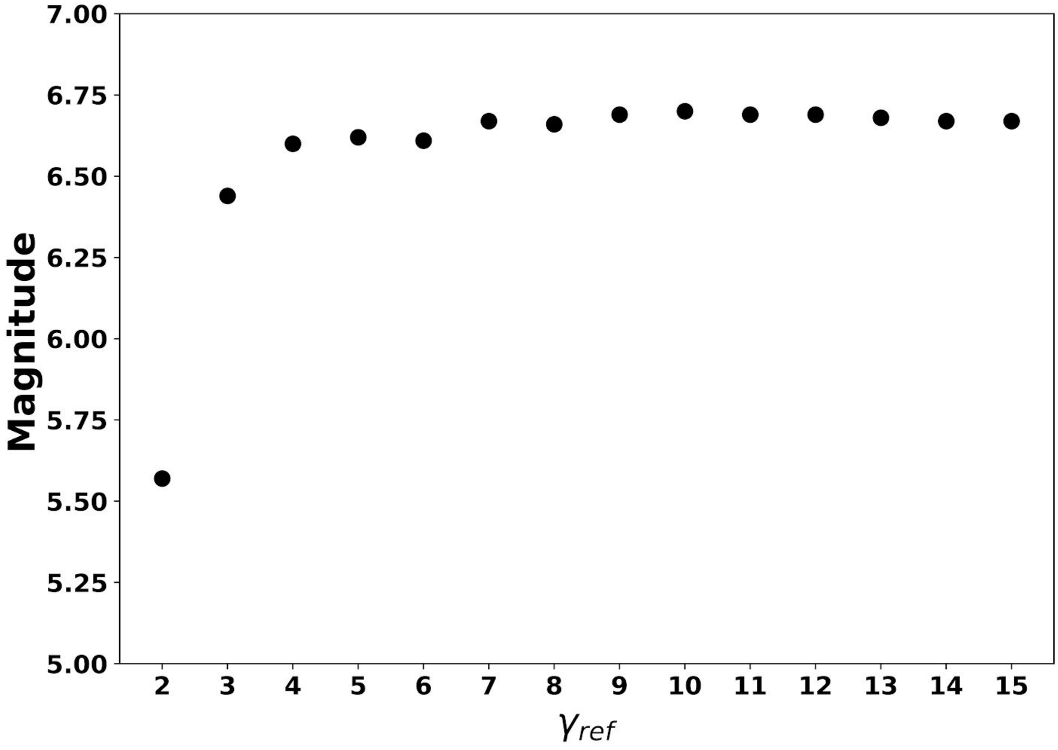
The uniform distribution is used because it is a simple random distribution that assigns initial load values in a heterogeneous manner. Being uniform, all values have equal probabilities of being assigned but that does not mean that all values are equal. This assumption allows simulating the unknown initial load (or stress) field. Moreover, an important reason for selecting this distribution is because of the results of tests comparing observed seismicity with the synthetic catalogs resulted. In Monterrubio-Velasco et al. (2017) a Gaussian distribution was tested to assign the initial load values. The results were unsuccessful because the observations and the synthetic catalogs were completely different. Moreover, the number of free parameters increases the number of degrees of freedom to choose the best range of distribution variables.

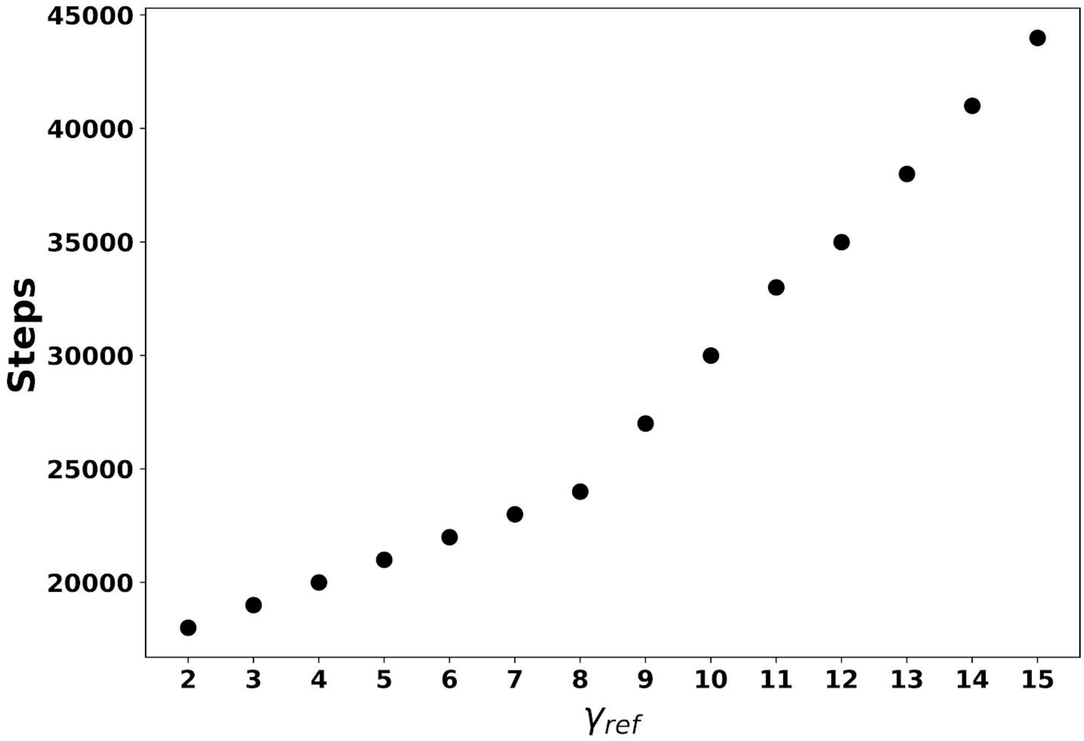
Question / comment

"In page 6 line , how do you assign γ_{ref} ? Would different values give you significantly different results in your final output?"

Answer:

The parameter γ_{asp} quantifies the "hardness" of the asperity relative to the background material. The value γ_{ref} = 2 indicates that the strength in the asperity is twice that in the background. The range of γ_{ref} explored (2,5,7,9,11,14) is based on an experimental choose. However, Fig. 12 shows a remarkable result because the mean of the maximum magnitude of an event as a function of γasp does not change much for values $\gamma_{ref} > 3$.
As γ_{asp} increases the simulation requires a larger number of iterations to break a cell in the asperity, thus implying a larger computational cost.
Our election (γ_{ref} = 4) assures a "stable" maximum magnitude in the lowest computational time. To visualize this fact we show the magnitude, the computational time [seconds] and the steps required to activate the whole asperity, for one execution, as function of γ_{ref}.
In this sense, we considered that a value γ_{ref} = 4, is adequate from the computational point of view and to assure the statistically similar values of maximum magnitude although this value increases.

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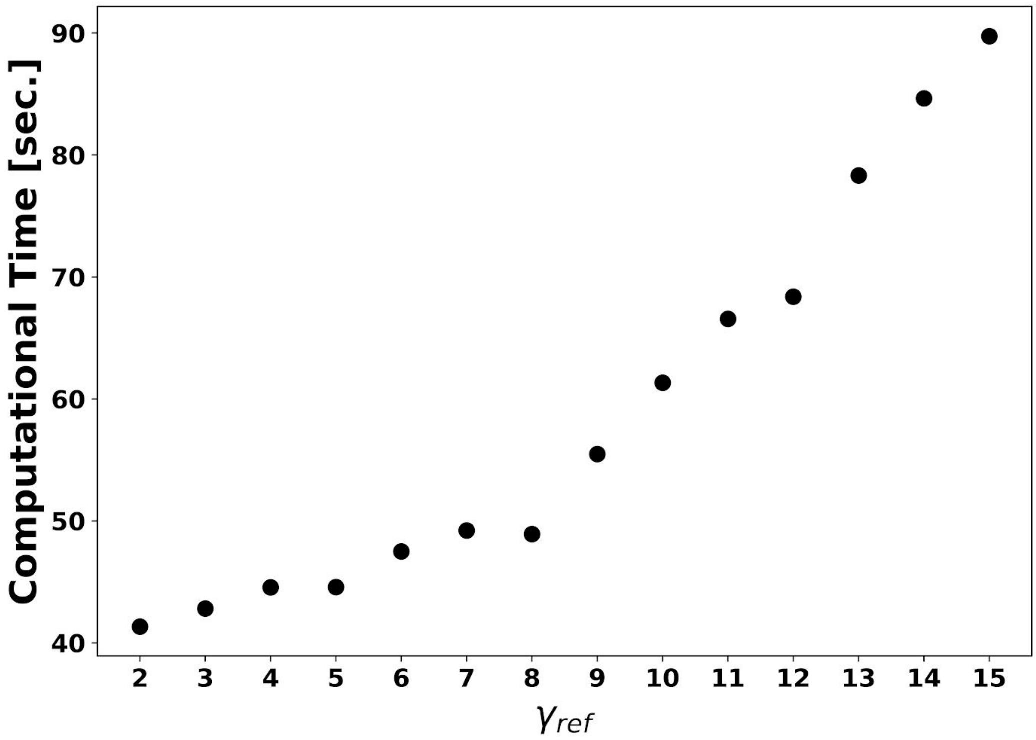
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γ_{ref}

Question / comment

In page 7 Why 0.98 and 0.02? Is there a reference? What criteria are used for this choice?

Answer:

This assumption is in agreement with what is expected for the maximum shear stress directions with respect to the main stress orientation which gives rise to both synthetic and antithetic faulting (e.g. Stein and Wysession, 2008). We could assign a different percentage, but the goal was to assign as much of the load as possible to orthogonal neighbors. Although it is possible to include these values as free parameters, it would require additional degrees of freedom, since in this work it was not the study object we assumed values which way successful results in Monterrubio-Velasco et al. (2017).

Question / comment

Are the range of values found in the sensitivity analysis unique to the examples in Mexico?

Answer:

No, the values of π, γ, and σ are generic for any simulation of similar type of earthquakes. The particular data for the Mexico examples are the effective area size and the asperity area which come from the results of finite-fault models.

Question / comment

It would be interesting to see how your estimations compare with empirical relationships like Wells and Coppersmith (1994)

Answer:

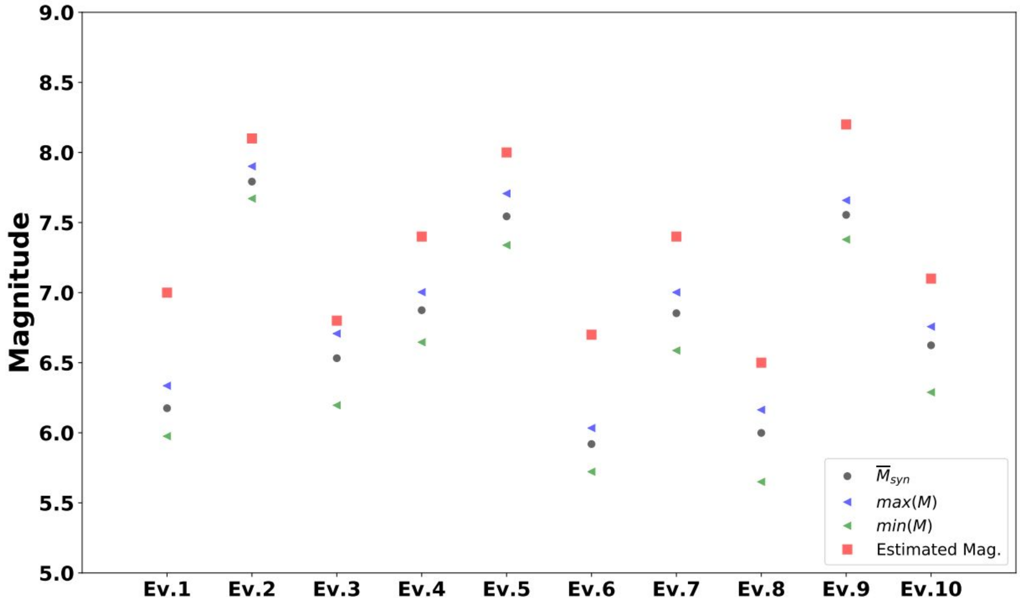
We considered more appropriate to compare the relationships of Strasser et al (2010), and Blaser et al (2010), since both were developed for subduction earthquakes. In the following table, we add the magnitude values using these three relations (Wells and Coppersmith (1994), Strasser et al (2010) and Blaser et al (2010), using as Area the mean value (“Simulated Area [km²]”) reported in the manuscript.

	Real Magnitude	Simulated Area $[km^2]$	Wells and Coppersmith (1994)	Strasser et al., (2010)	Blaser et al., (2010)
Ev.1	7	140.65	6.18	6.26	6.44
Ev.2	8.1	6281.24	7.79	7.65	8.32
Ev.3	6.8	325.30	6.53	6.57	6.85
Ev.4	7.4	727.36	6.87	6.86	7.25
Ev.5	8	3506.22	7.54	7.44	8.03
Ev.6	6.7	77.15	5.92	6.04	6.14
Ev.7	7.4	691.49	6.85	6.84	7.23
Ev.8	6.5	93.00	6.00	6.11	6.24
Ev.9	8.2	3596.07	7.55	7.45	8.04
Ev.10	7.1	403.97	6.62	6.65	6.96

Because the empirical magnitude-area relations can result in different magnitude values (Fig. 14), we decided to compute not only the magnitude but also the area of the maximum simulated earthquake (Fig. 15 and 16). However, if the user wants to use another empirical relation it is possible to add it in the script (TREMOL_singlets/postprocessing/calcuMagniSpaceTimeSinglets.jl).
In the particular case of Wells and Coppersmith (1994) relation is given as,

$$Mw = 4.07+ (0.98 * \log10(A)),$$

We have plotted the mean magnitude, the maximum magnitude and the minimum magnitude considering Wells and Coppersmith (1994) relation and the mean value of the maximum magnitude obtained in TREMOL v0.1.
Comparing this plot with Fig. 14 in the manuscript, the magnitude values obtained by using Wells and Coppersmith (1994), are lower than those computed using Eqs. 7, 8 and 9. It is worth noting that Eqs. 7, 8 and 9 were developed for Mexican subduction earthquakes Rodríguez-Pérez and Ottemöller (2013).



Question / comment

Some typos/syntax errors observed throughout the paper Eg. Page 1 line 15 should be earthquake magnitudes, Long sentence page 2 line 20 to 25 Page 5 line 11 should be: are computed in the. . . Figures are very far from the page they are referenced especially towards the end of the paper eg page 26 There is more than one section named Model validation

Answer

In the revised manuscript typos/syntax errors have been corrected.