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Geoscientific
Model Development
Discussions

Interactive comment on "The role of asperities in seismicity frequency-magnitude relations using the TREMOL v0.1.0. The case of the Guerrero-Oaxaca subduction zone, México" *by* Marisol Monterrubio-Velasco et al.

Marisol Monterrubio-Velasco et al.

marisol.monterrubio@bsc.es

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Dear reviewer,

First of all, thanks a lot for your valuable time and comments that help us to improve the manuscript. We have considerably revised the paper following your recommendations. In the next pages, we answer all your questions. We have adopted the following format in our answers:

Question/comment from the reviewer (in bold) Lines in the manuscript where the an-

swer is addressed (–>) Answers or replies from the authors (no special format) New paragraphs added to the manuscript (in italic font)

We are at your disposal to provide any further information you may request, and well satisfied after adding to our manuscript all the new plots, figures, and bibliography files, that are detailed in this reply.

Kind regards, Marisol Monterrubio-Velasco and coauthors.

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1. The magnitude shall not only depend on the ruptured area but also depends on the stress drop or the final slip.

1a) In the current version, the effects of the aspect ratio on the final slip and magnitude are ignored somehow.

→ line 197 - 199

TREMOL is capable of estimating the rupture areas assigning physical units to the numerical domain. In this paper, we do not consider slip to compute the magnitude distributions. On the other hand, TREMOL is not able to model the stress drop since the tectonic load is simulated using dimensionless units. We estimate a mean load drop, not related to any physical unit.

1b) In addition, in Section 6, the number of cells in the computational domain might affect the seismicity frequency-magnitude curve, which was fixed.

→ lines 348 - 354

In order to answer this question, we carried out new simulations where we increase the area of the computational domain. In Fig. A1, we include magnitude histograms for three different Ra values to show the behavior of the frequency-magnitude as a function on area domain size. Based on our conclusions, we added the next explanatory paragraph,

“We observe two main effects of the size variation of the computational domain on the frequency-magnitude curves: 1. The observed minimum magnitude. In our experiments, the effective source area (Table 1) remains constant, thus a finer mesh can support smaller ruptures, and therefore, TREMOL generates lower magnitude events. 2. The total number of triggered events, which is strongly dependent on the minimum magnitude observed in experiments. However, large-magnitude behaviors are not affected by the increase or decrease of the computational mesh. In Fig. A1, we observe an example of frequency-magnitude distribution as function on the mesh size and the aspect-ratio, Ra”

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2. In another paper of theirs, which introduces the code TREMOL, I find they considered the stress drop of each broken patch. Combining the rupture area and the stress drop, they can uniquely determine the magnitude of each earthquake, such as using the inversion of Okada’s matrices. This is important because, given the same rupture area and stress drop, the magnitude of earthquakes also depends on the aspect ratio [Leonard, 2010; Hanks and Bakun, 2002]. So, I suggest the authors estimate the magnitude based on the numerical methods, rather than the empirical magnitude-area relations (equations 2-5).

→ lines 186 - 195

In order to compare the magnitude-area relations to other magnitude estimations, we use the magnitude-moment equation provided in Leonard (2010). We also include a new figure (Fig. 3) to show the spatial distribution of the stress drop database that we used to compute a mean and median stress drop value. And also we add a magnitude-stress drop plot to show the non correlation between this parameters

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3. Line 170: They consider each SA region as independent for an individual TREMOL simulation. But these four regions can affect each other by the static stress perturbation, such as the Coulomb stress.

→ lines 234 - 237

We agree with the referee. Each SA region is modeled as independent and individual sources, and we are not considering any interaction between them. However, future TREMOL versions pretend to introduce the interaction between different asperities regions. In our model, the Coulomb stress change is simulated by the load transfer between the ruptured cells to its neighbors.

“Is worth mentioning that TREMOL 0.1.0 does not model the simultaneous interaction among the four sources, i.e., the Coulomb stress changes from one source to the next are not considered. However, the objective of this exercise is to aggregate the curve as an example of the aggregated seismicity without considering the interaction between sources. Future TREMOL generalizations would include such interactions.”

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4. In addition, each asperity may have different earthquake cycles due to various loading condition and their TREMOL implementation does not allow simulating a full earthquake cycle

→ lines 137-139

We already addressed this point in the revised manuscript.

“The current TREMOL implementation does not allow simulating a full earthquake cycle, because most of the tectonic load is spent during the whole process of the mainshock rupture and foreshocks, and no extra load is added during the simulation”

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5. It might be tricky to simply combine all SA curves into one synthetic aggregated curve. At lease, the authors shall discuss the possible effects of this procedure in the manuscript.

As we mention above we are not considering the interaction between sources in this model version. However, in future versions we will incorporate this observed feature. In lines 234 - 237 we include a discussion on that.

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6. Fig. 12 is very interesting but hard to understand.

→ lines 362 - 375

We add a paragraph including a possible explanation related to what we observe in the numerical results and the real seismicity behavior. Moreover, we add references of other previous works to support our conclusions of the results found in this figure, them included in the Introduction section. Moreover, we move some introductory phrases of Section 6 to the introduction to improve the reading. We also include a new figure (Fig. 1) to graphically illustrate the results analysis.

“The behavior of the synthetic seismicity displayed in Fig.11 is very interesting and shows a possible relation of the area size and shape in the transition between a GR distribution-type behavior and a characteristic-type. In the numerical experiments, we observe that narrow synthetic faults (large Ra values, Figs. 11 and A1) produce large earthquakes and few low-magnitude events. The extreme behavior is observed for Ra=2.4 where low-magnitude events disappear, and only one maximum magnitude event is generated. A possible explanation of this behavior could be related to the physical process observed in real scenarios, as analyzed by previous works (see Introduction references). For example, the conclusions in Wesnousky et al., (1983) offer an explanation for the observed numerical results because, in our model, the characteristic event is closely related to the fault length. Moreover, Sibson (1989) proposed that

the seismogenic structures relate to the characteristic earthquakes. In TREMOL, the seismogenic structures are defined by the computational domain including its boundary conditions. The model boundaries are absorbent, i.e., the cells at the border dissipate a fraction of its load and no ruptures occur outside the edges. Therefore, TREMOL considers an inner seismogenic domain and an aseismic contour. As Ra increases, the width of the seismogenic zone decreases and the fault rupture grows in length Leonard (2010). Moreover, as Ra increases, the quantity of load that dissipates through the boundary increases because a larger number of cells lay in the frontier (Fig. A2). Consequently, the quantity of energy inside the seismogenic zone is lower as Ra increases, and the system is only able to generate few but large earthquakes related to the asperity area.” ____ 7. Do these two models have the same effective width?

line 349

No, the models have the same effective area but the width and length is modified following Eq. (8)

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8. Why does the narrow fault tend to produce larger earthquakes?

We include a possible explanation in lines 362 - 375.

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9. Based on the fracture mechanics theory, wider faults (larger leastic energy release) are more likely to propagate larger earthquakes. More explanations for this figure are needed.

We include a possible explanation in lines 362 - 375.

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10. Line 275 – “In that sense, we could conclude that the maximum magnitude is

related to the total rupture area and not to its aspect ratio or shape". This is not correct if the aspect ratio is large. Magnitude depends on the final slip. Given the same stress drop, the final slip depends on the shorter dimension of the rupture areas if the aspect ratios are high. From the observations, the scaling relation between magnitude and rupture area is different for aspect ratio =1 and >1 (See the difference between the L-model and W-model [Hanks and Bakun, 2002]).

→ line 376 - 380

Our explanation was not complete, we clarified the comments including a sentence in the manuscript.

"In our results, we observed that the maximum magnitude is approximately 7.4, independently on the aspect-ratio. Nevertheless, as is seen in Fig. 2 the frequency-magnitude curve is clearly dependent on the aspect-ratio. Therefore, we pointed out that the maximum magnitude remains constant for all Ra variations (Fig. 11 in the manuscript). In that sense, we observed that the maximum magnitude is related to the asperity area and not to the aspect-ratio of the computational domain. As seen in our simulations the lack of low-magnitude events strongly depends on the aspect-ratio."

Please also note the supplement to this comment:
https://gmd.copernicus.org/preprints/gmd-2020-115/gmd-2020-115-AC1-supplement.pdf

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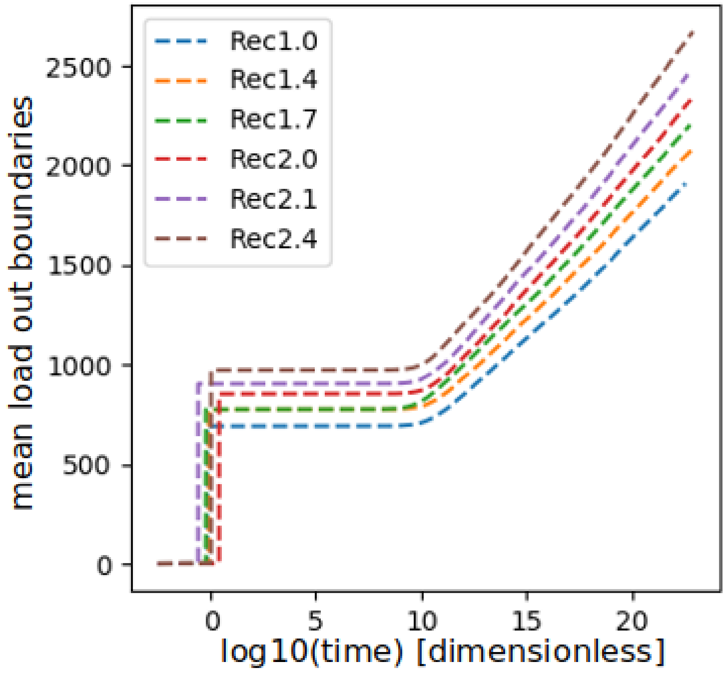
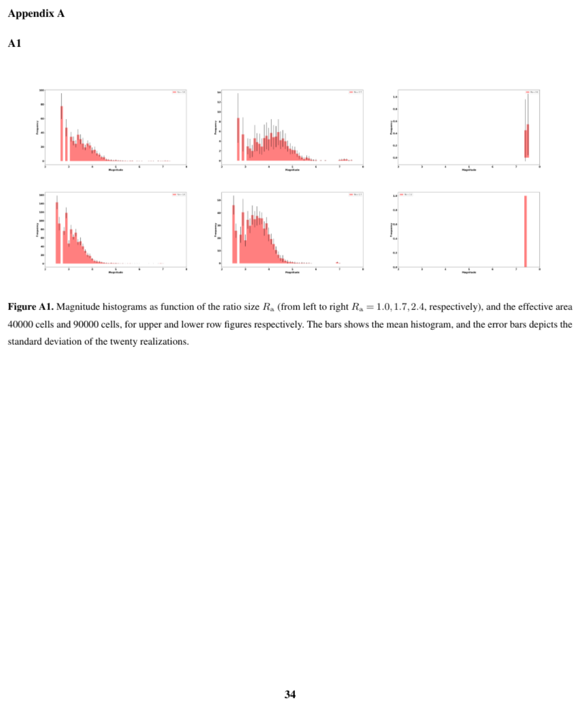


Fig. 1.



Appendix A

A1

Figure A1. Magnitude histograms as function of the ratio size R_a (from left to right $R_\mathrm{a} = 1.0, 1.7, 2.4$, respectively), and the effective area 40000 cells and 90000 cells, for upper and lower row figures respectively. The bars shows the mean histogram, and the error bars depicts the standard deviation of the twenty realizations.

Fig. 2.