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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Active Faults sources of the Morelia-Acambay Fault System, Mexico based on Paleoseismology and the estimation of magnitude M_w from fault dimensions" *by* Avith Mendoza-Ponce et al.

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Dear Professor Aksoy:

We are pleased to resubmit for publication the revised version of MS No.: nhess-2018-63 "Active Faults sources of the Morelia-Acambay Fault System, Mexico based on Paleoseismology and the estimation of magnitude Mw from fault dimensions" We appreciated your constructive criticisms.

REFEREE COMMENTS: The most substantial revision concerns with the need of sig-

nificant improvements on the presentation and structure of the work; more information methodology, the approach and the significance of the results. We have addressed each of your concerns as outlined below.

1) General Organization: -The figures lack significantly of useful information that are necessary to comprehend the study area. Many cities, locations, fault names mentioned in the text are not available in maps and figures, making it difficult for the reader to orient him/herself spatially.
We have restructured Figure 1, 2 and 3.

- Although the authors provide some theoretical information on the statistical calculations the connection and relation to the seismic hazard evaluation is poorly given, the geological significance for each input and output are not provided and discussed in the manuscript sufficiently.
We have restructured the paper to provide more clarity and highlighted the fractal analysis for the study of faults.

-The aim of the study is confusing because throughout the text authors describe several different purposes: 1-prepare an intrinsic definition for active faults (abstract) 2-estimation of possible maximum earthquake magnitudes (abstract) 3-understand the seismic activity from Patzcuaro to Acambay sector (introduction) 4-define the intracontinental structures that are susceptible to generate moderate and strong seismic events (line 85). Aside the quantitative results, the study addresses only the first two purposes clearly. Maximum earthquake magnitudes are calculated via fault length measurements and a comprehensive definition is given for active faults. Based on the Hurst Exponent it is concluded that the fault system is active, however the possibility of an inactive fault system is not discussed within the manuscript.
We have rewritten the aims of the study. The goals have been mentioned in the introduction and they are: (1) the estimation of the maximum possible earthquake magnitudes by three empirical relations; (2) the definition of a microregionalization of the PAFS using the Hurst exponent based on Mw magnitudes;

and (3) the validation of our proposed definition of Active Fault sources for the PAFS by fractal analysis and semivariograms. Consequently, we are proposing the investigation of the dynamics of the Pátzcuaro-Acambay area, in order to improve territory planning and reduce seismic hazard.

-The authors illustrate (Fig 3) that these relationships give different magnitude estimations for the same fault section but do not discuss how they interpret this difference. No reasoning is provided why authors prefer to take into account the Wesnousky (2008) relationship.
The analysis of the three empirical relations results of active faults was summarized as follows: (1) The model proposed by Anderson et al. (1996) always yields lower results than the other relationships; however, (2) the highest magnitudes are obtained with the relationship of Wesnousky (2008); (3) the average magnitudes are obtained by means of Wells and Coppersmith (1994) relationship. We have observed that all three relationships work for the PAFS. However, in this paper, we reported the maximum and minimum earthquake magnitudes estimated by Wells and Coppersmith (1994), because this method is best suited for areas with crustal thickness > 15 km and avoids overestimating the magnitudes (see Fig.3 in the revised version of the manuscript).

-The analysis assumes that each fault section has the potential to rupture the entire crust individually; (at all scales like 3-5 km). Why is 3 km the minimum preferred fault length that is included into the dataset? Can these faults also create surface ruptures?
A key step in this study was to delimit the minimum fault length. For this purpose, we made a test to find the fractal capacity dimension Db for our database which contains 316 average Mw magnitudes calculated from the surface rupture length by the use of three different empiric relationships. We also calculate the Db for the same database but including faults less than 3 km (a total of 628 faults). The results were: Db (316)= 1.33, Db (628)= 1.77.
Based on the results of Nieto-Samaniego et al. (2005), they proved that box di-

mension is in inverse relation with fracture concentration. Moreover, Poulimenos (2000), Cowie et al. (1995), Ackermann et al. (2001) have also shown that the total fracture length is directly proportional to the amount of deformation, i.e., large fractures can accommodate more deformation than small ones. Consequently, we have inferred that the low value of the fractal dimension Db (316)= 1.33 corresponds to greater amounts of large fault lengths: it is well-known that large fractures can accommodate more deformation. Thus, we are interested in the minimum earthquake magnitudes Mw $\geq$ 5.5 (or SRL=3km) for improving the vulnerability studies, because is acutely necessary in the central portion of Mexico.

-Furthermore, this analysis needs to consider the spatial distribution and interaction of the faults. An earthquake may rupture several adjacent fault segments; which would necessarily imply a larger earthquake magnitude. Authors need to consider multi-segment ruptures according to fault segmentation patterns and spatial distribution of the faults. Therefore, I consider that the estimation of maximum magnitude needs a revision. Since fault length is a critical parameter in their analysis the mapping procedure should be clearly explained. The authors apply most likely remote-sensing techniques but the mapping approach and the "type and quality" of base-maps is poorly given ("imagery" + 15x15 m DEM). The "morphological" criteria used to classify the faults as "active" should be given definitely.
Notwithstanding the importance of this kind of study, the linkage mechanism is beyond the scope of this work, due that we need to know the maximum possible length for each fault, and for this purpose we need a DEM with more resolution. Based on the Db and Hw results, we can neatly determine the lower limit (3 km) of fault lengths for the PAFS, but we cannot establish a definite upper limit due the faults hidden under Holocene deposits, not identifiable on a 15-meter Digital Elevation. We nevertheless estimated an upper limit of fault lengths (38 km) as a first approximation.

-A complex definition for active faults is provided in the manuscript: "an active fault, is defined here as a plane that ground-rupturing with speeds of approximately 0.001 mm/year, with seismic activity associated, at least, in the last 10,000 years and is oriented in favour of the current stress field. The active fault planes must be related to earthquakes of magnitude Mw $\geq$ 5.4 or capable of generating rupture lengths greater than or equal to 3 km." Authors need to show that all 316 faults fulfil that definition (for example, have all faults a minimum of 0.001 mm/yr slip-rate? Which studies provide this information?

This is the first study that works with a set of slip rate estimations in the system. We support our results based on the fractal analysis for this slip-rates: Figure 4 shows that Db = 1.86 is related to a lower concentration of low slip rates in the PAFS, suggesting that larger faults accommodate the strain more efficiently; and with a strong persistence (Hw = 0.949), i.e. the periodicities of slip rates are close in time (process with memory). Moreover, active faults are optimally oriented to the current stress field, in terms of variogram analysis, an anisotropic direction was identified in ENE direction (80°, Fig.5), as well as the active fault planes are related to earthquakes with a minimum magnitude of Mw $\geq$ 5.5, or capable of generating rupture lengths greater than or equal to 3 km. Thus, we can prove, in terms of fractal analysis, that the 316 faults studied for the PAFS are seismically active.

- What type of information provides the CeMIEGeo database on faults?

The CeMIEGeo provides fault length information around the Cuitzeo Lake.

-The seismicity of the study area is concentrated to the eastern part (Figure 2). Leaving many earthquakes in the West with no earthquakes at all. How are faults satisfying the Mw $\geq$ 5.4 criteria?

We have restructured the Seismotectonic Setting and added the following subsections: 2.1Paleoseismicity in the PAFS; 2.2Historical and Instrumental Seismicity in the PAFS and 2.3GPS measurements. Here, we set out that The Pátzcuaro-Acambay Fault System can be divided into three zones with differ-

ent geological and geophysical settings, and in the Results and Discussion we present the Hurst analysis. The results in the spatial domain strongly suggest that the PAFS is classified in three different zones (western PAFS, central PAFS and eastern PAFS) in terms of their roughness (Hw = 0.7, Hw = 0.5, and Hw = 0.8 respectively; Fig. 3), with their corresponding magnitudes (5.5 $\leq$ Mw $\leq$ 6.9; 5.5 $\leq$ Mw $\leq$ 6.7; 5.5 $\leq$ Mw $\leq$ 7.0). As we can see in the historical seismicity, paleoseismology studies and the spatial distribution of faults in the western zone, the faults are capable to generate earthquakes with magnitudes 5.5 $\leq$ Mw $\leq$ 6.9. Thus, we strongly believe that the area must continue to be monitoring in order to reduce seismic hazard in central Mexico.

-The entire dataset should be available for download so the results can be reproduced and tested.

The datasets generated during the current study are available from the corresponding author on reasonable request. The seismic catalog, covering from 1912 to 2018, was obtained from the Seismological Service of Mexico (Servicio Sismológico Nacional, SSN) and it is available on the web page www.ssn.unam.mx.

-The text provides a theoretical but limited description of the Hurst Exponent analysis. The method tests the tendency of a time-series (here the various slip-rates given in Table 1). However, the slip-rates are controlled by the spatial distribution of the stress field and therefore have a local significance. The authors need to explain why this approach based on time-series is applicable on a dataset that has a spatial significance. In addition, more information is necessary on how slip-rates have been exactly used in the calculations.

We have rewritten this section and added extra subsections for more clarity: 4.1Self-similar Behavior in Earth Science, 4.2The Hurst Exponent, 4.3Wavelet Variance Analysis, 4.4Box Dimension, 4.5Variograms, 4.6Intensity Scale (ESI 07), and 4.7Active Fault Definition.

-Uncertainties and error ranges are not discussed in the manuscript. What are the error ranges for the fault length and slip-rates? How do they affect the results? This questions should be addressed within the text.

The assumed error for the morphometric parameters measured was not relevant for our analysis because the lowest fault length (3000 m) is lesser than the map resolution (15 m). However, we estimate the following range 0.0002 < error <0.007 km. This information is reflected in subsection 3.1Mapping the Pátzcuaro-Acambay Fault System in the revised version of the manuscript. As we can see in table 1, not all the slip-rates errors are reported by previous authors, and they are in the range of 0.02mm/yr.

-Similarly, the fractal analysis lacks of adequate information on the geological significance of the analysis. What is the meaning of a staircase like pattern from a tectonic/geologic perspective?

There is a dependence and causality between the Hurst Exponents, fractal Dimension and the PAFS dynamics, we have developed this topic in the Results and Discussion section of the revised version of the manuscript.

-In line 198 the author states the high value of the fractal dimension "may indicate the possibility" for generation of a major earthquake on the faults of the MAFS; which is a highly ambiguous result. More information is needed on how the method is applied. Which dataset is exactly used? What are the 2D boundaries of the study?

Spatial-temporal methods were applied to the active fault data, and the fractal behavior observed for the entire PAFS allows us to define that the PAFS is seismically active. This is supported by the results of the Hurst analysis for the fault lengths and its corresponding magnitudes Mw (spatial analysis) as well as the slip-rates estimations of earlier studies (time analysis). We have included a better explanation in the section 5. Results in the revised version of the manuscript.

-However, a distinction should be made among faults mapped within this work and obtained from other sources so readers can better evaluate the contribution of this work.

This is the first study that works with a fault population in the PAFS defining a total of 316 active faults with fault dimensions (Length and scarp) on a 15-meter Digital Elevation Model. Moreover, we estimated 316 average Mw magnitudes calculated from the surface rupture length by the use of three different empiric relationships. We perform a major revision in the revised version of the manuscript in order to explain the contribution of our work along the entire document.

-In addition, the mapping approach should be defined precisely in order to evaluate the reliability of the fault map.

The criterion for the tracing of fault segments was the union of small traces to form a larger one, but only if the geomorphological continuity was clear. The lengths of fault trajectories, which is the main object of study, corresponded to the lengths of mountain front sinuosity, and the scarp was measured at the maximum hillslope value for each fault.

We have expected differences in length with both the previous and the most recent works, due to the different resolutions and techniques used in each study. However, we are open to improving the fault traces with better resolutions in future works. This information is reflected in subsection 3.1Mapping the Pátzcuaro-Acambay Fault System.

-The main results of this work are based on a statistical analysis of the fault map and paleoseismic findings. However the results are poorly discussed and their significance in terms of active tectonics is not well addressed.

We have rewritten the Results, Discussion and Conclusion for clarify how this analysis contributes to the seismic hazard assessment.

2) Further remarks on the manuscript

1-Title: The title calls for a manuscript that actually deals with significant amount of paleoseismic field work that permit to determine new seismic sources and their characteristics. However, the work is based on mathematical approaches on previous works.

I suggest to revise the title that is more compatible with the used methodology.
We have changed the title and highlighted the main objective during the text. The current title is "Active Faults Sources for the Pátzcuaro-Acambay Fault System (Mexico): Fractal Analysis of Slip Rates, and Magnitudes Mw Estimated from Fault Length". Traditionally this system has been named as Morelia-Acambay Fault System, in spite of, this extends to the city of Pátzcuaro. Thus, we consider that is more accurate to name it as Pátzcuaro-Acambay Fault System (PAFS).

2- Abstract: 2/3 of the abstract is dedicated to the seismotectonics of the study area. Most of this general information is neither connected to the applied methods nor the results of this work. The abstract may get more informative if more detail is provided on the approach and methodology. Also, the significance of the results is not sufficiently and clearly expressed.
We have restructured the abstract to provide more clarity.

3-Figure 1 and 2 require additional information on location names, major faults systems and information on concerning the seismic activity. 4-Acambay earthquake location and related surface rupture should be given. 5-Add Focal Mechanisms need information for earthquake magnitude and time. 6-Slip-rates should be placed on the fault map. 7- The corresponding seismic activity is not available.
Figure 1 and 2 have been reconstructed.

8-Figure 3: It is unclear what it represents. Is it based on fault central points from A to B? Requires a detailed figure caption.
The profile A-B was about the depth of seismicity and we removed the profile A-B in the Figure 2. We do not present it in the manuscript because this is full of information.

9-The results and discussion section contains theoretical information on the used methods, which should be placed to appropriate section.
We have moved the theoretical information to the methodology section.

10- Figure 4 requires more explanation. Requires labelling and a detailed figure caption.
We remade this figure.

11-In Table 1: The 2 mm/yr slip-rate for the Venta de Bravo fault could not be found in the related citation (Suter et al., 1995).
We have changed the reference by Suter et al., 1992.

12-Table 1 Add error ranges for slip-rates, fault length and scarps.
We have added a few available slip-rate and their uncertainties along the PAFS.

13-Line 173-179 and 184-188: The purpose of these texts within the context of maximum magnitude is not clear.
We have removed these lines and moved to 2.1Paleoseismology in the PAFS (173-179) and to 4.6 Intensity Scale (184-188).

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2018-63/nhess-2018-63-AC3-supplement.pdf

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