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Natural Hazards and Earth System Sciences Discussions

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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 Dr Mustapha Meghraoui:

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 the organization and

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Discussion paper

the writing of the manuscript. We have addressed each of their concerns as outlined below.

1) General remarks - The main topic of the manuscript (ms) is on the fractal fault distribution and its related seismic activity but this is not clear neither from the title, nor for the abstract and text.
We have rewritten 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".

- This article needs to be restructured in order to clearly put forward the fractal analysis, the authors do not present new fault data and hence, the presented neotectonic and seismotectonic characteristics cannot be considered as the main topic of this article.
We have restructured the paper to provide more clarity and highlighted the fractal analysis for the study of faults.

-The authors mention the existence of 316 fault segments in text and about 22 fault characteristics (in Table 1) of the Morelia Acambay Graben. However, they do not explain how they did select these 22 items among the 316 faults, and which fault segments where used for the fractal analysis. The 316 fault segments deserve to be shown as a supplemental material.
A fault database was constructed on a 15-m DEM and showed in the supplemental material. For the fractal analysis, we have used two data: (a) 316 average magnitudes Mw calculated by the surface rupture length on a 15-m Digital Elevation Model and (b) 22 slip-rates recorded in the literature. This information is reflected in section 3.Materials.

-The seismicity and neotectonic database and related catalogs need to be clearly presented in the form of tables with appropriate legends showing the origin of data. A table of paleoseismic, historical and instrumental earthquakes is needed in this manuscript,

at least for earthquakes with Mw $\geq$ 5.4 (according to their concluding remarks).
We have explained this information in the following sections: 2.1Paleoseismology in the PAFS, and 2.2 Historical and Instrumental Seismicity in the PAFS. The seismic catalog, covering from 1912 to 2018, was obtained from the Seismological Service of Mexico (Servicio Sismológico Nacional, SSN; Fig. 2). The data is available on their web page www.ssn.unam.mx. This catalog only has two events with Mw $\geq$ 5.4 (Acambay and Maravatío earthquakes). We are showed in Fig.1 the seismic events that have affected populations within the PAFS.

-Table 1 needs to include the minimum and maximum, observed and estimated coseismic slip/event for the known faults. Table 1 needs a serious legend.
We have modified Table 1 in the revised version of the manuscript, but we have decided not to include the estimated coseismic slip/event because we focus our work on the temporal analysis of slip rates and on the spatial analysis of fault lengths. Thus, for the temporal analysis of the details of the coseismic slip (timeless term) are beyond the scope of this work. However, we have included, in the subsection 2.2, maximum displacements for three faults with surface rupture (Urbina and Camacho, 1913): the Acambay-Tixmadejé fault (Dmax = 50 cm), the Temascalcingo fault (Dmax = 30 cm) and the Pastores fault (29 $\leq$ Dmax $\leq$ 37 cm; Ortuño et al., 2015).

- An interesting issue is the difference between the fracture density and fracture concentration. This section of the manuscript needs to be developed in order to show the meaning of this difference, explain well the correlation between box dimensions and the effects of the size of fracture concentration. The calculation of the Hurst Exponent H and related strong persistent process, Devil staircase and box dimension should be explained more extensively. These aspects that are fundamental in this manuscript should appear in a separated Methodological section.
This information is reflected in sections 4. Methods for the Study of Faults using Fractal Analysis, 5. Results and 6. Discution.

2)Specific remarks -Title: It has to be reconsidered because as presented, it shows that active faults and paleoseismic analysis are the main topic of the manuscript. I think that the fractal analysis from existing fault data should be clearly announced in this title.

We have restructured the title according to the main topic. 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).

- Abstract: The authors use different magnitude scales (Ms, Mb, Mw). If a seismicity catalogue with homogenized magnitudes exists for Mexico, then the authors should use Mw only in this section.

We have rewritten the Abstract, however, Ms=6.9 and Ms=5.6 was conserved because they are historical earthquakes.

- The Introduction section is not well written, and although it includes several paragraphs as seismotectonic settings, it does not explain the geodynamic context with clear stress and strain distribution. For instance, Figures 1A and B that are redundant they show only the topography and bathymetry. Figure 1C is supposed to show the seismotectonic setting but it looks only like a geographic indication of the Morelia-Acambay Graben. The introduction needs to be better organized to explain the context and main issue, the used general methodology (fractal analysis) and its application elsewhere in comparable seismotectonic domains, previous works emphasizing the main results and finally the main steps adopted in this ms.

We have rewritten the Introduction and remade Figure 1. The seismotectonic settings paragraphs are moved to the appropriate section.

- (Neotectonic and seismotectonic settings?) Since the Morelia-Acambay Graben has a rich database, a specific section in neotectonics and seismotectonics would therefore be needed after the introduction. In this case, the authors should organize their text and avoid a mix of data. This section needs to present: 1) the seismicity (histor-

ical and instrumental) with emphasis on major events and their characteristics, 2) the geodetic results (GPS, conventional), focal mechanism solutions and fault kinematics for the stress and strain distribution, and 3) the paleoseismic data and results including the estimated slip rates with the corresponding time window and related uncertainties. This section has not to be long but it has to focus on major results showing the related references and how completed is the database (reference to tables in supplementary material is recommendable).
We have divided in three subsections: 2.1 Paleoseismicity in the PAFS; 2.2 Historical and Instrumental Seismicity in the PAF; and 2.3 GPS Measurements.

- Line 20 – 21: Please note that historical earthquakes needs to indicated with their intensities (or inferred magnitudes), their severity (number of victims whenever possible).
We have explained this information in the subsection 2.2 Historical and Instrumental Seismicity in the PAFS.

-Line 22: ".. set of earthquakes . . ." of what magnitudes?
We have added the magnitudes (2.5 < Mw < 3.0) in the Introduction.

-Line 26-27: These lines are concluding remarks and should be moved at the end of ms.
We have moved these lines at the end of the manuscript (5.Results; 6.Discution; and 7.Conclusions).

-Line 40: Instead of cortical, the term "crustal" is usually used in active tectonics.
We have changed the term crustal in the Introduction.

-Line 46: "The kinematics of them . . ." change in Their kinematics . . . This sentence mentions details on the neotectonic episodes and a reference is needed here. **We have changed the sentence in the section 2.Tectonic Setting of the PAFS.**

-Line 49: normal- right? change in Oblique fault with right-lateral normal component.
We have changed the sentence in the section 2.Tectonic Setting of the PAFS.

-Line 55: The 8.2 km depth of the Maravatio earthquake needs uncertainties. The sentence should be rewritten "Subsequently, another earthquake in 1979 with a magnitude Mb = 5.3 and a depth of 8.2 km (Astiz-Delgado, 1980), caused major damage in Maravatío."

We have changed the sentence in the subsection 2.2Historical and Instrumental Seismicity in the PAFS.

-Line 59: "is very probable that this sequence of earthquakes is related to the La Paloma fault of 13 km of length . . .". How did you infer this? If this is obtained from the two local stations then the "probable" should turn into "possible". Please explain. Line 59-60: ". . . active from the Holocene" does not mean much. I would suggest considered active because it affects Holocene deposits.

It is "possible" that these earthquakes are related with the La Paloma fault because the focal mechanism is in correspondence to the fault geometry (normal fault with left-lateral component). Moreover, this fault is considered active, because it affects Holocene deposits. This information is reflected in subsection 2.2 Historical and Instrumental Seismicity in the PAFS.

-Line 63: remove seismic risk and put seismic hazard instead.

We have changed the term in the subsection 2.1 Paleoseismicity in the PAFS.

-Lines 65 to 84: In all these paragraphs, slip rates need to be explained (from which field trenches and markers, e.g., lateral or vertical offset of streams, ...) and measurements span which timeframe.

We have rewritten this paragraph in the subsection 3.3 Slip Rates and their Cumulative Distribution.

-Line 81: What is the mechanism of the dozen faults?

The focal mechanism corresponds to normal faulting with left-lateral components in the state of Michoacán. The three focal mechanism solutions along the PAFS reported in the literature are shown in Fig. 2. This information is reflected

in subsection 2.1 in the revised version of the manuscript.

Are they in table 1?
No, we just settled the values of the slip-rates recorded in the literature, because they are the scope of this work. The focal mechanisms in the PAFS are showed in Figure 2 in the revised manuscript and in Fig.2 in the actual response.

-Line 90: Active faults are ...
Revised.

-Line 92: "... speeds of approximately ..."; fault speed is not used in active tectonics. Slip rate is more appropriate. Please apply correction throughout the text.
Revised.

-Line 91: The title is inappropriate in this ms. You are only extracting the data from previous works and not mapping and describing the faults of the Morelia-Acambay Graben.
The title has been changed. In this work we have mapped 316 fault dimensions (Length and scarp) on a 15 meter Digital Elevation Model, using imagery provided by the Instituto Nacional de Estadística y Geografía (INEGI, acronym in Spanish). Additionally, we are suggesting fault names based on the names of the nearest towns, in order to homogenize nomenclature for researchers interested in correcting or completing the existing database.

- Figure 2 is a bad quality map. Unless a clear srtm background topography can be shown, it should be removed, leaving only the seismicity and tectonic data in the map. The dates and magnitudes of focal mechanisms need to indicate in the map and in a table with their characteristics (in the supplemental material).
The Figure 2 has been reconstructed.

-Line 102: Unless you indicate criteria for selection, the characteristics of the 316 fault segments need to be shown at least in the supplemental material.

We have showed the 316 faults in the supplemental material.

-Lines 105 and 106: Fault length, Fault scarp height (?)
The lengths of fault trajectories are corresponded to the lengths of mountain front sinuosity, and the scarp was measured at the maximum hillslope value for each fault.

-Line 111: Distance between a locality and fault zone. **We have changed the statement in 3.1Mapping the Pátzcuaro-Acambay Fault System.**

-Estimation of Mw magnitudes as shown in Figures 3 a and b needs a reevaluation. Including the uncertainties of fault parameters is critical in the fractal analysis.
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. Figure 3 has been modified in order to show the magnitude variations from east to west (the firmagram plot). Even more, the Hurst exponent values were included for the western, central and eastern sectors of the PAFS, as well as we have printed the most known faults names.

-The section 2.4 on the fractal analysis is devoted almost entirely to the methodological aspect; please indicate it accordingly as for instance "Method of faulting study using fractal analysis". The manuscript is mainly based on this methodology section and it should be presented before the database (seismotectonic) section.
We have rewritten this section and added extra subsections: 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.

-Line 149: In equation (??), please complete.
In the last manuscript was the equation (2). In this new version corresponds to equation (1) in the subsection 4.4 Box Dimension.

-Line 162: . . . as fault planes . . . Also remove speeds, and replace by slip rate.
We have corrected this term.

-Line 164- 165: " . . . earthquakes of magnitude Mw $\geq$ 5.2 or related to rupture lengths greater than or equal to 3 km." Why Mw $\geq$ 5.2 and why lengths $\geq$ 3 km? How about hidden faults below Holocene deposits? As indicated by Langridge et al., (2013) and Sunye-Puchol et al., (2015) some faults can be hidden by young sedimentary deposits. In this case the fault lengths may increase. This issue needs to be discussed.
We have changed the minimum earthquake magnitude Mw $\geq$ 5.5 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 first paragraph of Discution). Finally, supported by Db and Hw, we can neatly determine the lower limit (3 km) of fault lengths for the PAFS. However, 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.

-Line 177-178: The described seismicity, frequency and related b-value which is also a fractal distribution needs to be called earlier along with the fractal analysis in this manuscript. As this work is based on the Magana-Garcia Master thesis, that is not published and difficult to access as a reference, it should be presented with some details in introduction and seismotectonic section (or even in the supplemental material).
The seismic catalog plotted in Fig.2, covering from 1912 to 2018, was obtained from the Seismological Service of Mexico (Servicio Sismológico Nacional, SSN; Fig. 2) and the data is available on their web page: www.ssn.unam.mx. The focal mechanism parameters were reported previously by Astiz-Delgado (1980), Suter et al. (1992; 1995), Langridge et al. (2000), Singh et al. (2012), and Rodríguez-Pascua et al. (2012).

-Line 180: Why this Table 1 is called only in section 3. This reference to the database should be called earlier!!!

We have called Table1 in subsection 3.3 Slip Rates and their Cumulative Distribution.

-Line 184: Please give a reference to the Environmental Seismic Intensity scale (ESI 07) **We have given a reference and described the Scale in section 4.6Intensity Scale (ESI 07).**

-Line 189: Hurst (1951) does not exist on the list of references.
We have added Hurst (1951) in References section.

-Line 191-192: The reference to the Hurst Exponent H and strong persistent process for the slip-rate distribution, along explanations on the Devil staircase should be explained in the methodology section.
We have rewritten the methodology section and added extra subsections (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).

-Line 192-193: "...cycles or periods with different seismic activity ...", you mean variable seismic cycles?
This means that periodicities of earthquakes are different along the PAFS. We have rewritten the subsection 4.2The Hurst Exponent to set out the elements necessary for understanding the results of H: (a) the spatial domain, strongly suggests 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, Hw = 0.8 respectively), showing different dynamics in seismotectonic activity; (b) the time-domain, with a strong persistence Hw = 0.949, suggests that the periodicities of slip rates are close in time (process with memory).

-Line 200: This has to be included in the Methodology section.
We have included the fracture concentration in the methodology section.

-Line 221: What us the mathematical behaviour? You mean the mathematical or statistical expression of faulting behaviour?

The distribution for the PAFS displays a fractal behavior, i.e. this fault population presents a self-similar behavior. This means that the log-log plot of frequency versus lengths for the PAFS obeys an inverse power law as you can see in the Fig.3 (distribution on a straight line).

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2018-63/nhess-2018-63-AC2-supplement.pdf

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EQ	DATE	MAGNITUDE	LOCATION AFFECTED	REFERENCE
1	June 19th,1858	M_S = 7.5 – 7.7	Morelia and Pátzcuaro	Figueroa 1987; Garduño-Monroy et al., 1998a; García-Acosta and Suárez, 1996; Singh et al., 1996; García Acosta, 2001; Garduño-Monroy et al., 2011
2	XIXth century	-	Zinapécuaro-Tlalpujahua	Garduño-Monroy et al., 1998b; Garduño-Monroy et al., 2009
3	November 19th, 1912	M_S = 6.9	Acambay	Urbina and Camacho, 1913; Suter et al., 1995b, 1996
4	February 22th,1979	M_s = 5.6	Maravatío	Astiz, 1980, 1986; Garduño-Monroy and Gutierrez-Negrín, 1990

Fig. 1. Seismic events that have affected populations within the PAFS.

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EQ	DATE	MAGNITUDE	FOCAL MECHANISM	REFERENCE
Acambay	November 19th, 1912	M_S = 6.9	strike=102, dip= 70, rake=-90	Singh et al (2011); Astiz-Delgado (1980); Suter et al (1995); Suter et al (1992); Langridge et al (2000); Rodríguez- Pascua et al (2012)
Maravatío	February 22th,1979	M_s = 5.6	strike=280, dip= 66, rake=-48	Astiz-Delgado(1980), Suter et al. (1992)
Morelia	October 17th, 2007	M_w = 2.7	strike=265, dip= 75, rake=-30	Singh et al (2012)

Fig. 2. Focal mechanism solutions in the PAFS.

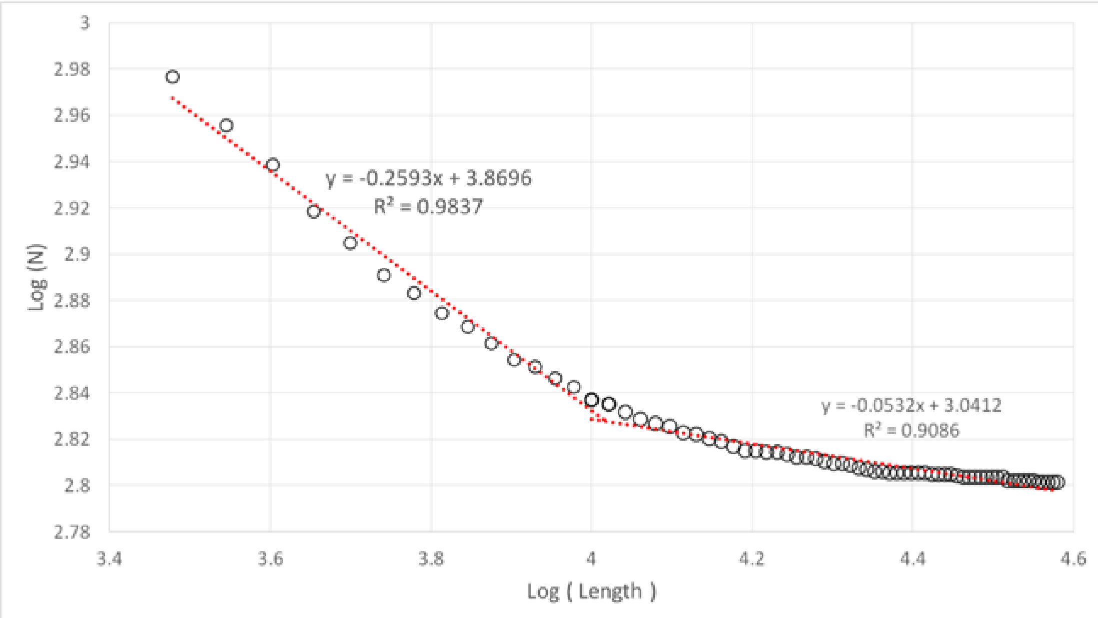

Fig. 3. Log-log plot of frequency versus lengths for the PAFS obeys an inverse power law

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