Reply Anonymous Referee #3

We are grateful to the reviewer 3 for many valuable comments and suggestions and positive feedback. Below, we report answers to all reviewer comments. The original review text is in black, our reply in green.

General Comments:

The coseismic data from some seismological networks and from SAR Sentinel-1 satellite are analyzed in order to estimate the fault parameters of the 24 January 2020 earth-quake, understand the aftershock distribution, and the future distribution of events on the EAF. The paper is well structured and written. It represents an interesting application of mature software, with some interesting conclusions about the seismic gaps on the EAF fault. But, some conclusions and discussions are not examined with sufficient details, and some sentences are not completely debated. The time correlation among the seismic events can be not studied (only) with an elastic model (Coulomb 3.3), but using also other types of models, for example, visco-elastic, visco-plastic. Some connection between the probable forecast events and the mainshock should be discussed with more detail, especially for the journal where the authors have submitted. The reviewer suggests acceptance after major revision.

We are thankful for the overall appreciation of our research. We have carefully considered all suggestions and discussed them below, providing specific details on how they were accounted to improve our manuscript.

Scientific Comments:

In the Introduction, the authors describe briefly the geodynamic context about the Anatolian plate and the East Anatolian Fault. The slab pull model and mantle flow model are only two of the several models discussed in the literature. For, example, the lateral extrusion of crustal wedges as discussed in Mantovani et al. 2001 (Short and long term deformation patterns in the Aegean-Anatolian systems: insights from space geodetic data (GPS) and Numerical simulation of the observed strain field in the central-eastern Mediterranean region) explain the kinematic of the Anatolian plate using a different point of view. I think, for the sake of completeness it is right to describe briefly and mention the other models of the Mediterranean geodynamic pattern.

Following the reviewer's suggestion, we extended the introduction with respect to the regional geodynamics and included the suggested reference. This surely helps to provide a broader view on the different models proposed in the literature. Our study and results are possibly too specific (i.e targeting a single seismic sequence) to contribute to the discussion on these different hypotheses. We have added the following sentences in the introduction:

"Mantovani et al. (2001) have further hypothesized a role of the post-seismic relaxation induced by seismic activation of the NAF in the current kinematics of the Anatolian block."

The paper represents an interesting application of mature software to analyze and inversion of seismic and SAR/GNSS data. Also, the authors use the Coulomb 3.3 software in order to estimate the coseismic static stress changes. The authors have developed and elastic model in order to estimate the spatial evolution of the Coulomb stress and they have discussed the correlation between the stress pattern and aftershocks distribution. Also, they have suggested that the increased stress in some parts of the EAF can expedite large earthquake activity in this region. I think that this elastic approach is a good model to understand the aftershock distribution, but to study the time distribution of the seismic events in an area it is necessary to use other models, for example, a visco-elastic model where the visco-elastic proprieties of the lower crust can be modeled and reproduce the time evolution of the stress field in the study area. I suggest to the authors introduce in the discussion and/or conclusion paragraph a brief discussion about the problems and limitations of the elastic model when are used in the earthquake correlation time studies.

Thank you for the comment. We agree that the Coulomb stress analysis we perform and discuss has strong limitations, and indeed only discuss it in terms of the spatial distribution of the aftershocks. Using other models, accounting e.g. for viscoelasticity, is beyond the scope of our paper. We accounted for this suggestion by adding new paragraphs in the "Coulomb stress" and "discussion" sections, stating the limitations of the elastic model. Please see the related comments in the technical corrections.

Technical corrections:

Line 44:....it did not host major earthquakes during the last hundred years (Fig. 1): the most recent, large earthquake on the EAF dates to 1971......A more strong earthquake along EAF was 2010.....The 1971 event has occurred only about 50 years ago, and 2010 is only a few 'geological seconds' before now. It is not clear why the authors speak about the last hundred years. I agree with the authors that the large earthquake recurrence time on the

EAF is greater than the NAF, but I suggest to the authors to modify the time span in these sentences in order to have an agreement.

We apologize for the misunderstanding and thanks for pointing out the lack of clarity. We changed “large” to “strong” according to the widely used earthquake classification based on Stein and Wysession (2003).

Class	Magnitude
Great	8 or more
Major	7 - 7.9
Strong	6 - 6.9
Moderate	5 - 5.9
Light	4 - 4.9
Minor	3 -3.9

Stein, S., & Wysession, M. (2003). An introduction to seismology, earthquakes, and earth structure.

To be clear within the manuscript, we have added a new sentence for a definition: ... *“it did not host major earthquakes during the last hundred years (Fig. 1): the most recent, strong earthquakes on the EAF date to 1971 (Mw 6.7 Bingöl earthquake, Duman and Emre,2013) and 2010 Mw 6.1 Kovancilar earthquake.”*

Line 55: I think it is not completely correct to mention a paper only submitted.
Bletery, Q., Cavalie, O., Nocquet, J-M., and Ragon, T.: Distribution of interseismic coupling along the North and East Anatolian Faults inferred from InSAR and GPS data, Geophys.Res.Lett.Earth and Space Science Open Archive,https://www.essoar.org/doi/10.1002/essoar.10502450.1, submitted, 2020.

The Bletary et al. (2020) study is published now in the Geophysical Research Letters. We have edited the reference list as below:

Bletery, Q., Cavalié, O., Nocquet, J. M., & Ragon, T. (2020). Distribution of interseismic coupling along the North and East Anatolian Faults inferred from InSAR and GPS data. Geophysical Research Letters, 47, e2020GL087775. https://doi.org/10.1029/2020GL087775

Line 69. Same consideration about a submitted paper. I think the mentioned results can be not reported.

Please see the previous comment.

Line 76: I suggest to the authors to use the same decimal digits about the Elazig-Sivrice earthquake (6.8) unless they have estimated the magnitude with associated uncertainty on the second decimal digit.

Thank you for pointing out the indeed too high precision we gave, also in your next comment.

Line 116: Unfortunately, I am a physics, and if I write 6.77±0.1 I do not pass the first exam of the Laboratory. I suggest to the authors to write 6.8±0.1 and change in the text substituting 6.8 at 6.77. In Table 1, about this study are reported two 6.7 values, perhaps these values are 6.8.

We fully agree, and we changed all numbers accordingly (e.g. 6.8±0.1), as suggested (also in the title). We fixed the wrong number in table 1.

Line 158: Most of the foreshocks including two Mw~5 are located very close to the mainshock nucleation point, suggesting that they could have played a role in the main-shock preparation. This is a 'strong' sentence with support of only two references, but it can have important fallout, why the authors believe these earthquakes could have a role in the mainshock preparation, these events have anticipated or delayed the main-shock?

"Thank you for pointing out this. We agree that only the vicinity of these earlier earthquakes to the nucleation point of the mainshock strictly does not suffice to suggest that they influenced the mainshock. More investigations would be needed to gain more indications for or against this hypothesis, which are beyond the scope of the study. We removed this sentence."

Line 187: Why do you use these values for Young, shear, and Poisson modulus?

Poisson's ratio (PR) changes between -1 to 0.5; 0.25 is typically used in the laboratory tests and most crustal rocks have Poisson's ratio between 0.25 and 0.3. For Young's modulus (E), 8×10^4 MPa is typically used for rocks that are located in this range of depths. So based on the G = E/[2(1+PR)] relation, the shear modulus (G) is equal to 3.2×10^4 MPa.

Line188: I suggest to the authors to discuss briefly why they have chosen the middle value of the apparent coefficient of friction.

We have added these sentences to the “Coulomb failure stress change analysis” section:

“Choosing an appropriate value for the coefficient of fault friction is difficult. Based on laboratory experiments on the frictional slip within rocks, the apparent coefficient of friction has high values such as 0.5-0.8 (e.g. Byerlee and Brace, 1968). On the other hand, increased pore fluid pressure due to injected fluid decreases the coefficient of friction. A high coefficient of friction (~0.8) is usually assumed for continental thrust faults, while for young and normal faults it may be higher. Low friction has been found to fit best for creeping faults, and very low friction (<0.2) for major transforms, such as the San Andreas (Harris and Simpson, 1998; Parsons et al., 1999; Toda and Stein, 2002). For strike-slip on unknown faults intermediate friction values of 0.4 are usually assumed (King et al. 1994; Parsons et al., 1999) and we follow these examples.”

Byerlee, J. D., & Brace, W. F. (1968). Stick slip, stable sliding, and earthquakes—effect of rock type, pressure, strain rate, and stiffness. Journal of Geophysical Research, 73(18), 6031-6037.

Harris, R. A., & Simpson, R. W. (1998). Suppression of large earthquakes by stress shadows: A comparison of Coulomb and rate-and-state failure. Journal of Geophysical Research: Solid Earth, 103(B10), 24439-24451.

Toda, S., & Stein, R. S. (2002). Response of the San Andreas fault to the 1983 Coalinga-Nuñez earthquakes: An application of interaction-based probabilities for Parkfield. Journal of Geophysical Research: Solid Earth, 107(B6), ESE-6.

Parsons, T., Stein, R. S., Simpson, R. W., and Reasenberg, P. A.: Stress sensitivity of fault seismicity: A comparison between limited-offset oblique and major strike-slip faults. Journal of Geophysical Research: Solid Earth, 104 (B9), 20183-20202, 1999.

King, G. C., Stein, R. S., and Lin, J.: Static stress changes and the triggering of earthquakes. Bulletin of the Seismological Society of America, 84(3), 935-953, 1994.

Line 192: In the caption of Figure S6 change Figure 3 with Figure 4 (I think).

Fixed.

Line 218: These loaded stresses can expedite future large earthquakes on either one of these segments..... I think that the Coulomb stress has been estimated on the fault plane of the previous earthquake or .... I suggest to the authors to explain in more detail these concepts.

We consider both segments in NE and SW ends of the ruptured plane as a receiver fault. Both segments are loaded by positive Coulomb stress change. Both parts experienced strong earthquakes in historical times (former Fig. 1).

We have decided to remove this sentence due to the limitation of the Coulomb stress modelling.

"These loaded stresses can expedite future large earthquakes on either one of these segments"

Line 227: I suggest to the authors to indicate the Figure where the aftershocks cloud north of the EAF can be seen. I think it is the cloud at the NE near the lake.

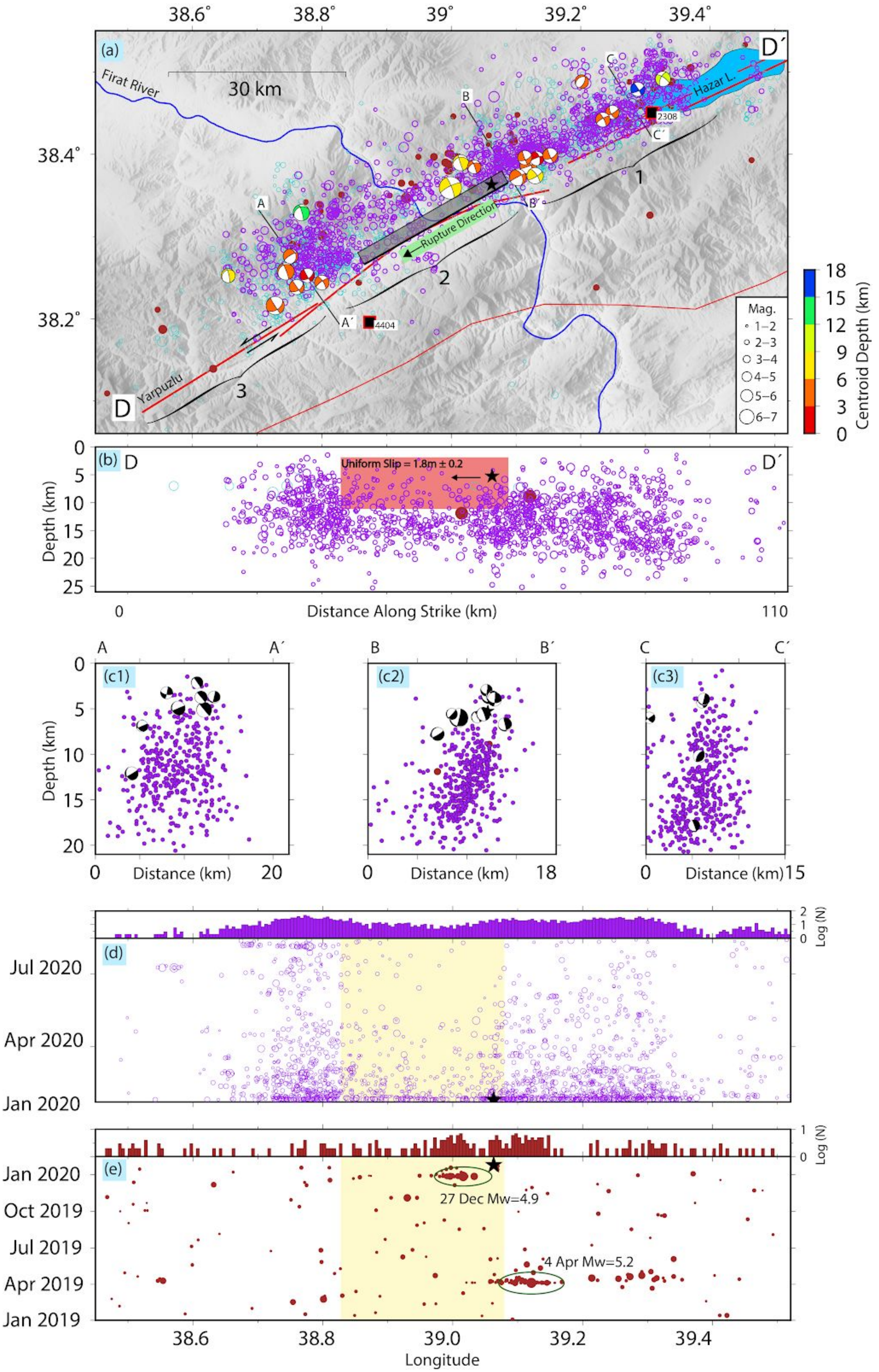
Figure 3 already shows this. We now have plotted this figure with increasing the thickness of EAF in the map and some other changes including the update of the later aftershocks (see the next comment). We also have referred to figure 3 explicitly in the text:

"The location of almost all aftershocks north of the fault trace confirms the fault plane dip towards NNW (Fig. 5)."

See the next comment for the updated former figure 3 (Fig. 5 in the new version).

Line 255: I suggest to the authors to report the three sectors discussed in Figure 3 in order to help the reader.

Thank you for the suggestion. We have shown the 3 sectors in the updated Figure.
Moreover, we updated the aftershocks catalog (Last accessed 15 August 2020) and we calculated the focal mechanism of 4 more events with a magnitude larger than 4.3 which occurred between 31 March and 15 August 2020. All now include in former figure 3.



38.6°
38.8°
39°
39.2°
39.4°
38.4°
38.2°
(a)
Firat River
30 km
Hazar L.
Rupture Direction
Yarpuzlu
D
D´
A
A´
B
B´
C
C´
1
2
3
2308
4404
Mag.
1–2
2–3
3–4
4–5
5–6
6–7
Centroid Depth (km)
18
15
12
9
6
3
0
(b)
Uniform Slip = 1.8m ± 0.2
Depth (km)
Distance Along Strike (km)
0
110
(c1)
(c2)
(c3)
Distance (km)
(d)
Log (N)
Jul 2020
Apr 2020
Jan 2020
(e)
27 Dec Mw=4.9
4 Apr Mw=5.2
Oct 2019
Jul 2019
Apr 2019
Jan 2019
38.6
38.8
39.0
39.2
39.4
Longitude

Former Fig. 3 (Fig. 5 In the new version). Spatiotemporal evolution of the 2020 Mw 6.8 Elazığ-Sivrice earthquake sequence (black stars always denote the mainshock, purple and cyan circles show aftershocks and filled brown circles show foreshocks). a) Spatial distribution of seismicity at the Pütürge segment, located between the Hazar Lake and the Yarpuzlu bend, showing the path of Firat River (blue line). Red lines show main faults (after Basili et al., 2013). Circles represent the epicentral locations of fore- and aftershocks (purple circles show 18 days of relocated aftershocks from Melgar et al., 2020 and cyan circles show AFAD catalog Ml 1+ and azimuthal gap less than 120°, last accessed 15 August 2020). The grey filled box shows the surface projection of the modeled source, with the thick-lined edge marking the upper fault edge. Focal mechanisms of the mainshock, 2 foreshocks and 19 aftershocks (focal spheres, color scale according to centroid depths) shown based on our moment tensor inversion. Black squares denote locations of the closest strong motion stations with their code. b) Depth cross-section along the profile DD' of relocated aftershocks (after Melgar et al., 2020) and events larger than Ml 4 (cyan) from AFAD catalog. The light pink rectangle shows the main rupture area and the dark vector shows the direction of the main rupture propagation, as resolved in this study. (c1-3) Depth cross-sections along profiles AA', BB' and CC', respectively (dip and width of all cross-sections are 90° and 20 km, respectively), showing the focal mechanisms of largest events (cross section projection). d) Temporal evolution of the aftershocks (Ml 1+ and azimuthal gap < 120°) versus longitude; the upper histogram shows the longitude versus the number of events N. The light yellow patch covers the longitudes ruptured in the Elazığ-Sivrice based on our finite-source modelling. e) Temporal evolution of the foreshocks (same style as panel d).

Line 264 and ...: I can in agreement with the authors about the increasing of the stress on some fault segments due to the study earthquake. The problem could be represented that the elastic model adopted to give the 'instantaneous' stress increasing, as briefly discussed for the authors to provide the energy for the aftershocks. The possibility of a stress transfer could be investigated with viscoelastic or similar models where it is possible to model the distribution of the stress/strain in the time. But another approach could require a lot of time, therefore I suggest to authors to discuss briefly the different approaches between elastic and viscoelastic (for example) models and the kind of results that they can obtain.

We have added the following two paragraphs to the "Coulomb failure stress change analysis" sections:

"In the last decades, many studies confirmed the role of earthquake interactions by reshaping the state of stress on nearby faults (Stein et al., 1992; Hainzl et al., 2010). The most notable mechanisms for explaining stress interaction between earthquakes are (Freed, 2006): (1) static stress transfer, due to permanent deformation in the vicinity of an earthquake's rupture surface (e.g. King et al., 1994; Steacy et al., 2005; Stein, 1999), (2) dynamic stress changes, due to the passage of seismic waves (e.g. Kilb et al., 2000; Felzer et al., 2006), (3) viscoelastic relaxation, and poroelastic rebound (e.g. Freed et al., 2001), (4) release of fluids during and after faulting, and fluid pore diffusion (e.g. Sibson et al., 1975; Sibson, 1981; Hickman et al., 1995). Among these, especially static stress transfer is widely accepted to play a key role (e.g., Stein et al., 1992; King et al., 1994; Harris et al., 1995; Yadav et al., 2012; Mitsakaki et al., 2013)."

And:

"In this study we use the software Coulomb 3.3 (Lin and Stein, 2004; Toda et al., 2005) to calculate the coseismic static stress changes. A uniform elastic half-space following Okada (1992) is assumed. The Coulomb Failure Stress Changes (ΔCFS) are commonly used as a scalar indicator of the stress change. The change in CFS depends on shear stress change $\Delta\tau$, normal stress change $\Delta\sigma$, and the apparent coefficient of the fault friction on the receiver fault μ', which includes the unknown hydrostatic pore pressure change (King et al., 1994).

$$\Delta CFS = \Delta\tau + \mu'\Delta\sigma \qquad (1)$$

The large uncertainties are associated with the Coulomb failure stress change calculation, which are mainly due to non-unique slip inversions (Hainzl et al., 2009, Woessner et al., 2012), secondary stress triggering (Helmstetter et al., 2005), and poor knowledge about assumed receiver faults (Sharma et al., 2020). Here the uncertainties of the slip inversion are neglected in the calculation of ΔCFS. Another limitation of the coseismic ΔCFS model is that only elastic responses to fault slip are considered, and thus viscous effects in the triggering process remain unaccounted for (Freed and Lin, 2001; Freed, 2005). In the future it would be useful to calculate postseismic stress changes from viscoelastic stress relaxation by considering plastic models for the Earth. Nevertheless, first order effects of static stress changes are well represented with our simple approach."

Steacy, S., Gomberg, J., & Cocco, M. (2005). Introduction to special section: Stress transfer, earthquake triggering, and time‐dependent seismic hazard. Journal of Geophysical Research: Solid Earth, 110(B5).

Kilb, D., Gomberg, J., & Bodin, P. (2000). Triggering of earthquake aftershocks by dynamic stresses. Nature, 408(6812), 570-574.

Felzer, K. R., & Brodsky, E. E. (2006). Decay of aftershock density with distance indicates triggering by dynamic stress. Nature, 441(7094), 735-738.

Freed, A. M., & Lin, J. (2001). Delayed triggering of the 1999 Hector Mine earthquake by viscoelastic stress transfer. Nature, 411(6834), 180-183.

Freed, A. M. (2005). Earthquakes triggering by static, dynamic, and postseismic stress transfer. Annu. Rev. Earth Planet. Sci., 33, 335-367.

Sibson, R. H. (1981). Fluid flow accompanying faulting: field evidence and models. Earthquake prediction: an international review, 4, 593-603.

Sibson, R. H., Moore, J. M. M., & Rankin, A. H. (1975). Seismic pumping—a hydrothermal fluid transport mechanism. Journal of the Geological Society, 131(6), 653-659.

Hickman, S., Sibson, R., & Bruhn, R. (1995). Introduction to special section: Mechanical involvement of fluids in faulting. Journal of Geophysical Research: Solid Earth, 100(B7), 12831-12840.

Yadav, R. B. S., Gahalaut, V. K., Chopra, S., & Shan, B. (2012). Tectonic implications and seismicity triggering during the 2008 Baluchistan, Pakistan earthquake sequence. Journal of Asian Earth Sciences, 45, 167-178.

Mitsakaki, C., Rondoyanni, T., Anastasiou, D., Papazissi, K., Marinou, A., & Sakellariou, M. (2013). Static stress changes and fault interactions in Lefkada Island, Western Greece. Journal of Geodynamics, 67, 53-61.

Pollitz, F. F., & Sacks, I. S. (2002). Stress triggering of the 1999 Hector Mine earthquake by transient deformation following the 1992 Landers earthquake. Bulletin of the Seismological Society of America, 92(4), 1487-1496.

Hainzl, S., Enescu, B., Cocco, M., Woessner, J., Catalli, F., Wang, R., and Roth, F. (2009), Aftershock modeling based on uncertain stress calculations, J. Geophys. Res., 114, B05309, doi:10.1029/2008JB006011.

Helmstetter, A., Y. Y. Kagan, and D. D. Jackson (2005), Importance of small earthquakes for stress transfers and earthquake triggering, J. Geophys. Res., 110, B05S08, doi:10.1029/2004JB003286.

Sharma, S., Hainzl, S., Zöller, G., and Holschneider, M.: Is Coulomb stress the best choice for aftershock forecasting?. Journal of Geophysical Research: Solid Earth, 125, e2020JB019553. https://doi.org/10.1029/2020JB019553, 2020.

Line 264 .... It is not clear in the text which scenario the authors believe it is more realistic (1, 2, or 4). Please clarify this point.

We assume the reviewer refers to line 246. Thanks for pointing out the lack of clarity. As we have mentioned in line 244 of the submitted manuscript: Both scenarios, 1 and 2 are plausible and not in contradiction with the data. We have also added a new paragraph about the segmentation in the discussion section.

“The near-field data, in particular InSAR data which is more sensitive to rupture segmentation of shallow earthquakes (Steinberg et al., 2020), do not indicate a strong rupture segmentation and the modeled synthetic data fit well enough to the observation without doubling the degree of freedom by allowing for two segments instead of one. With more free parameters the fit to the modeled data is quite naturally increasing, but if the increase in data fit is significant enough would need an extra analysis, e.g. based on informational criteria by Steinberg et al., (2020).”

Steinberg, A., Sudhaus, H., Heimann, S., Krüger, F.: Sensitivity of InSAR and teleseismic observations to earthquake rupture segmentation, Geophysical Journal International, ggaa351, https://doi.org/10.1093/gji/ggaa351, 2020.

Line 284: Local seismicity clusters, appearing months prior to the Elazig-Sivrice earthquake occurrence, probably track the slip instability onset. Probably I am in agreement with the authors, but they could briefly explain why these events have increased the stress on the Elazig-Sivrice fault. There is also a possibility that they have decreased the stress on the fault.

We discuss these seismicity clusters months prior to the Elazig-Sivrice earthquake. But as the previous comment also refers to this issue, we removed the part of the discussion about the slip instability onset and the role in the mainshock preparation. More investigations would be needed to gain more indications for or against this hypothesis, which are beyond the scope of the study.

Line 525 Caption Figure 1: lost references about the kinematic pattern shown in the left up corner of the figure.

Fixed.

Line 675: lost reference about the active faults (Basili et al. 2013).

Fixed.

Best regards,
Mohammadreza Jamalreyhani
(on behalf of all co-authors)