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Reply on RC1

May Laor and Zohar Gvirtzman

Author comment on "Classifying marine faults for hazard assessment offshore Israel: a new approach based on fault size and vertical displacement" by May Laor and Zohar Gvirtzman, Nat. Hazards Earth Syst. Sci. Discuss.,
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We appreciate the positive evaluation of our paper and would like to thank Reviewer #1 for his helpful and comprehensive suggestions.

Below are our point-by-point responses:

General Comments

RC: Fault hazard: The problematics of fault hazards should be explained already in the introduction so as to allow the reader a better background and understanding along the text and before arriving to section 5.4 and Figure 13. Please resolve this general term into its specific aspects: surface rupture, coseismic deformation and ground acceleration. Hidden/blind faults may produce coseismic deformation without surface break.

AC: We think you are right. We will add a sentence in the introduction section, which explains what are the hazards posed by faults and emphasizes that this study focuses on surface rupture.

RC: Fault maps: Several fault maps have already been published in the past and besides citing them it is important to discuss, at least qualitatively, how the newly presented map relates to them. Furthermore, past researchers proposed hypotheses about specific faults, such as the one along the Israeli coastline, the Pelusium line (Neev et al., 1973), transversal faults bordering the Palmahim disturbance (Garfunkel and Almagor, 1979), fault offshore the Carmel Coastal Plain (Kafri and Folkman, 1981), etc. I think it is

important to place the present work and discuss its role among and along the history of research, at least in a quantitative manner.

AC: Thank you for this important comment. Though this requires expansion of the geological background, we are willing to add a paragraph before section 2.2 that adds information from previous studies as follows:

In general, the Levant continental margin is considered tectonically-passive for more than 150 my since its formation in the early Mesozoic (Garfunkel, 1988). Nonetheless, Neev et al. (1973) raised the possibility that an active fault runs along the continental margin from offshore Lebanon to Sinai and named this fault "The Pelusium line". This suggestion, which may have had a significant effect on seismic hazard estimations in Israel, produced a hot debate. Garfunkel et al. (1984) argued that all faults displacing the Plio-Quaternary section offshore Israel are related to salt tectonics and cannot produce significant earthquakes. Later on, aided by newer seismic material, Gvirtzman et al., (2008) and Gvirtzman and Steinberg (2012) showed that a series of deep seated faults were indeed active along the Pelusium line (continental margin fault zone) during the Oligocene and Early Miocene, when the Levant passive margin was reactivated alongside the Red Sea opening. Luckily, however, these faults stopped operating and are not active today. In contrast, north of the area studied here, deep-seated faults are operating alongside thin-skinned faults. The Carmel fault, located north of the area studied here, is an active branch of the Dead Sea Transform (Karfi and Folkman, 1981); and active thrusting occurs offshore Lebanon (Elias et al., 2007).

RC: Seismicity: Studying active faults, there is a need to refer to the ongoing seismicity in the region (e.g. Katz and Hamiel, 2018) by discussing the finding of the present work in relation with the location, depth, magnitudes and mechanism of the continental slope seismicity, at least qualitatively.

AC: Recently, Katz and Hamiel, (2018) showed that relocation of earthquakes offshore Israel indicates $M_w < 4$ hypocenters at a depth of ~ 18 km along the continental margin fault zone mapped by Gvirtzman and Steinberg (2012). This finding is enigmatic, because these Miocene faults are covered by a few km of undisplaced rocks (Gvirtzman and Steinberg, 2012). One possibility to reconcile the two observations is that relocation offshore is uncertain and these small earthquakes may occur on shallow, salt-tectonics, faults rather than at depth of 18 km. Alternatively, maybe the Miocene faults that apparently stopped moving are still producing earthquakes. An active example may be the Suez Rift, which also (almost) stopped operating after the Miocene, but is still producing earthquakes.

RC: Seismogenic zone: The PGA map of the Israeli Building Code 413 is based on seismogenic zones defined by Shamir et al. (2001). How does the presented hazard map

(e.g. Figure 13) relates to these zones? Should the continental slope be added as a new seismicogenic zone to the database of the Israeli PGA map?

AC: This question should be considered by scientists that will produce the next PGA map. Obviously, they will need to address the question of the potential magnitude. The question regarding the seismicity of the continental margin fault zone (or Pelusium line) is out of the scope of our study. The question regarding the potential magnitude of salt-related faults deserves more study and we intend to dig into it in the near future.

RC: Landslides: Same idea as above.

AC: Thank you for this comment. We thought and debated this a lot and finally decided that we prefer not to get into the marine landslides subject because this paper focuses on faults hazard. Nonetheless, we do cite Katz et al., (2015), in this context.

Specific comments

Highlights

RC: I suggest rephrasing the highlights to better speak in favor of the importance, finding and potential application of this work. For example, the first highlight (Mapping "active faults"...) is a general notion not specific to this study; the fourth highlight (Large faults scarps...) seems to have already been attributed to Elfassi et al. (2019a) in lines 142-144?

AC: Thank you. After correcting the text, we will reconsider the phrasing of the highlights.

Abstract

RC: You propose a new innovative approach and exemplify it on the specific case study of the Israeli continental slope. Why not wrapping up the abstract by proposing its implication and application to elsewhere similar marine environments, marine building codes, hazard assessment for submarine infrastructure facilities, etc?

AC: We will add a sentence that clarifies the advantage of this map for early master planning and infrastructure route selection.

RC: Line 21: Please explain in short, what do you mean by 'active faults': are they capable of surface rupture, coseismic surface deformation, ground acceleration, and within a given time frame? See also the relevant comment above.

AC: Very important. Thank you we will explain that.

RC: Line 28-29 (and 64-65): You write about three hazard levels but mention only two? What would be the role of the middle category?

AC: We will also write about the intermediate hazard level. Noteworthy, the question regarding how to use our new map by regulators and planners is not in our yard. We define three hazard levels and regulatory agencies will decide how to use this maps. They may demand that infrastructure will not cross red faults; they may decide that red faults requires site specific surveys; or many other possibilities of usage.

Introduction

RC: Lines 45-46: Some of the works mentioned in the introduction did dealt with active faults (e.g. Armijo et al., 2005); also, there is very interesting work of Elias et al. (2007) regarding active historical seismogenic fault offshore Lebanon, I think it should be mentioned as well.

AC: Thank you. We will recheck the reference list.

RC: The Dor and Palmahim disturbances play major role in this study. There is a need to give some background about them.

AC: Our map relies on two criteria- (1) vertical offset, and (2) fault plane area/fault length in map view, regardless of the tectonic mechanism of Dor and Palmahim disturbances. We prefer not to extant the geological background beyond what we wrote, and in particular that the second referee requested to shorten the background chapter.

RC: Section 1.2 deals with the goal and the methodology of this work. Consider rephrasing the headline to 'Goal and methodology'?

AC: Thank you, we will change it.

Chapter 2. Scientific background

RC: Lines 144-147: I think this hypothesis needs to be verified by magnitude estimation. For example, as a thumb rule, $M \sim 6$ crustal earthquakes are considered the minimum for generating surface rupture. What would be the estimated magnitude of the high (red) hazard class of faults for generating surface rupture - you have length, depth, area, and can assume vertical offset, say 1 meter?

AC: This is a very good point and we thought about it a lot.

Observations:

- 1. Surface rupture indicates $M \sim 6$.**
- 2. Faults plane area indicates $M < 5$ (figure 12)**
- 3. The Israeli earthquakes catalog consists of $2 < M < 4$ (Katz and Hamiel, 2015).**

=>Apparently, these thin-skinned salt-related faults do not follow the common rules of thumb.

We are considering adding a paragraph on this topic in the discussion chapter, but not expanding on this complicated question that requires further deep research.

RC: Lines 157-161: "... it has been suggested that faulting was initiated by basinwards salt flow" - is this explanation relevant also to group II (Figure 9) that is located outside the salt area? Or also to group I of strike slip nature?

AC: Group II isn't related directly to the salt flow. However, we cannot reject the possibility of indirect relationships between Group I and Group II. Regarding group III (strike-slip nature)- we will add a reference describing the ss faults (Ben-Zeev and Gvirtzman, 2020).

RC: Lines 171-174: There is a need to present in short the nature of the 350ky horizon, it is the key for evaluating the recent activity of the study faults. Similarly, describe in short the lithology of units 3 and 4. Is it the contrast between the two that yields the 350 ky horizon? Unit 4 is the lithological environment that hosts the faults system studied in this work.

AC: The 350 ky horizon represents an unconformity, that is usually expressed in the form of a strong seismic reflector. Elfassi et al., 2019 described seismic units according to seismic facies. We do not have information about the lithology of the four seismic units except for the general notation that all units are part of Yafo formation, which consists mainly of clay and some sand. Our faults penetrate all 4 units.

Section 3.2 Bathymetry data and Table 1

RC: What are the uncertainties associated with these grids, mainly in the vertical dimension, which is the key parameter to define the total offset and rate of slip.

AC: We will add this information.

Section 4.4. Fault geometry and location

RC: Lines 328-332: Looks to me also like a set of blocks rotated around horizontal axis?

AC: Yes, but the location of the axis is not clear. We will add this term to the text.

Discussion

RC: Line 380 – The very high sedimentation rate could also be attributed to down slope transport of materials?

AC: Yes. Sedimentation includes all sources of material that are accumulated.

We will clarify this in the text.

5.4. Assessing the hazard of surface rupture

RC: 466-470: Please note that modern approach for surface rupture hazard mitigation is being developed towards Probabilistic Fault Displacement Hazard Analysis (PFDHA), much like PSHA for ground shaking.

AC: Very important comment, we will mention it.

RC: There are a few transversal (striking E-W) faults in the mapped region. They seem to be unique and deserve some attention.

AC: We are not sure about the mechanism of these E-W transversal faults. The N-S transversal faults were mentioned in Ben-Zeev and Gvirtzman, (2020) and a mechanism was proposed. Also, we have a lack of 3D data on this area, compared to the N-S transversal faults area.

Technical comments

RC: Hidden faults: Do you mean blind faults?

AC: It may be the same, but these faults do not exactly meet the dry definition of "blind fault" and because of that we decided to call them "hidden faults".

In the blind fault ideal model, displacement decreases from a maximum located at the center of the fault plane to a tip line of zero displacements. Ideal blind faults grow by radial propagation with no migration of the point of maximum displacement, which is also the nucleation site of the fault (Watterson, 1986; Barnett et al., 1987). With the absence of dated horizons and knowledge about the phase of activity on these faults, it's difficult to differentiate between blind faults and syn-sedimentary faults. We can just say that they are not crossing all the youngest horizons but they do have a genetic relation to faults crossing the seabed.

RC: Lines 243-249: Can you explain the reason for the increase of sedimentation rate from the deep basin towards the off shelf zone? If this area is also subject to slope failure, one would expect increase of sediment accumulation towards the basin?

AC: This reflects the progradation of the shelf by all mechanisms including slope failure. In figure 4c you can see the progradation lineament with very high sedimentation rates along the shelf break.

RC: Line 308-9: Please rephrase.

AC: We rephrased it. Thank you.

RC: Line 310: Should be: "dashed red line in..."?

AC: Yes, definitely. Thank you.

Figures-

AC: We appreciate the comments on the figures and we will fix what is needed.

The responses are available in the attached PDF file.

Please also note the supplement to this comment:

<https://nhess.copernicus.org/preprints/nhess-2021-393/nhess-2021-393-AC1-supplement.pdf>