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Discussions

Interactive comment on "Tectonic Origin Tsunami Scenario Database for the Marmara Region" *by* Ceren Ozer Sozdinler et al.

Ceren Ozer Sozdinler et al.

cerenozr@cc.kagawa-u.ac.jp

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This paper by Ozer Sozdinler et al. presents a very interesting study of tsunami hazard around the Marmara Sea (Turkey) where many vulnerable coastal facilities are exposed to possible impacts, following submarine earthquakes. It is an important contribution to improve the mitigation of tsunami hazard in the area. The paper is worth being published after a revision is done to better discuss the hypotheses, and the results and their limitations.

We thank referee for his/her comments and contributions in improving our manuscript. Below are our answers to each comment. Due to the fact that the manuscript has been subject to a major revision in the real sense, we would like to ask the reviewer to have

a fresh reading of the revised manuscript which probable is more mature in terms of addressing the limitations and uncertainties in the study.

As stated on p.2, the objectives are twofold, first to check whether tectonic scenarios alone can explain historical scenarios, and second to bring some practical results directly applicable in the frame of the operations of the Tsunami Warning System. While the first aspect is partly discussed in the conclusion, the second issue is less addressed in the final comments. If and how the scenario database should integrate operational processes could also be more detailed, as well as (in a few words) the system proposed by Necmogliu. If this paper presents the first scenario database, how the current operational procedures work without focal mechanism available? This could be a bit described.

Details of the proposed local/near-field tsunami early warning is provided in Necmioglu, 2016 (1). Reference to the tsunami early warning in this study has been removed since the scenario database produced, or all relevant studies so far conducted, indicate the very-limited use of earthquake generated tsunami scenarios for real-time early warning scenarios. The conclusion section has been revised to address the limitations of the methodology used, addition of new credible worst-case scenarios based on Bulut et al. (2019) (2), addition of a discussion on slip deficit based on selected previous studies.

(1) Necmioglu, O.: Design and challenges for a tsunami early warning system in the Marmara Sea, Earth, Planets and Space, 68:13, doi: 10.1186/s40623-016-0388-2, 2016.

(2) Bulut, F., AktuÄ§, B., YaltÄśrak, C., DoÄ§ru, A. and Özener, H. (2019), Magnitudes of future large earthquakes near Istanbul quanti ed from 1500 years of historical earthquakes, present-day microseismicity and GPS slip rates, Tectonophysics 764 (2019) 77–87

More fundamentally, this paper provides a deterministic approach, very valuable to estimate maximum impacts. While the probabilistic approaches are nowadays more and more common practice, it should be recalled in the introductory part how each approach provides different indicators. This is first addressed only on p.12, while it could be evoked before. Especially when the scenarios SN are built, it is not very clear how the combinations are done. It is stated "in an arbitrary manner without prior assumption" (p.3), but a fully deterministic way would be to have the maximum worst case slips assigned to each unit fault (or a maximum magnitude in the area, which is not discussed). A probabilistic method would systematically explore any slip possibility or any magnitude possible. So finally the method used seems to be in-between. Could the authors comment more on these issues about the methodology used, and about the slip values assigned? How the maximum magnitude can be defined in the area? How a fully aleatory exploration of slip distribution would provide different results? And also, how robust is the coastal amplification computation, using a bathymetric grid which does not seem to be highly resolved?

The scenarios used in this study are considered to be to credible worst-case scenarios, where especially Mw values are derived from Wells&Coppersmith (1994), which indicates a maximum of Mw 7.4 in the Marmara Sea, taking into account the total length of the rupture and thickness of the seismogenic layer. Based on the reviewer comments received, authors decided to also include a set of example worst case scenarios, as proposes by a recent study, namely Bulut et al., 2019 (1), including the 1509 earthquake associated with a Mw 7.5. The following section has been added to the manuscript:

"It is arguable that the maximum earthquake scenarios with Mw 7.4 obtained by Wells and Coppersmith (1994) in this study may not represent all possible significant earthquakes in the region. In their recent publication, Murru et al. (2016) combined a total of 10 different Mw = 7.0 to Mw = 8.0 multi-segment ruptures with the other regional faults at rates that balance the overall moment accumulation and they found an aggregated 30-year Poisson probability of M > 7.3 earthquakes at Istanbul of 35%, which increases to 47% if time dependence and stress transfer are considered. They indicated that

considering the stress transfer effect from the Izmit earthquake in the calculations, the combined probability to have an event with M $\geq$ 7.0 up to M8.0 at Istanbul city becomes 47%. Bulut et al. (2019) reported that the present-day slip deficits reach up to 1.7 m beneath the Western (TekirdaÄ§ Basin) segment, and 4.0 m and 5.4 m beneath the Central (Central High and Kumburgaz Basin) and Eastern (ÇÄśnarcÄśk Basin) segments, respectively. These segments most recently ruptured in August 1766, May 1766 and October 1509 and currently have a potential to generate Mw 7.2, Mw 7.4 and Mw 7.5, earthquakes respectively. Although contiguous ruptures have not occurred historically, ruptures of contiguous segments could occur as a Mw 7.5 earthquake in the west, or a Mw 7.6 earthquake in the east or as a single through-going Mw 7.7 rupture. In consequence of these evaluations, alongside 30 earthquake scenarios, we also performed tsunami simulations for three historical big earthquakes, Mw 7.5 1509, Mw 7.3 May 1766 and Mw 7.4 August 1766 earthquakes, as complement worst-case scenarios proposed by Bulut et al (2019). Associated slip values for these earthquakes have been derived from Hanks and Kanamori (1979), considering the fault length (L), fault width (W), Mw (Bulut et al., 2019) and rigidity modulus (3.25x1011 dyn/cm2), as shown in Table 2. It's noteworthy, however, that the empirical relationships proposed by Wells and Coppersmith (1994) results with lower Mw and associated slip values for these earthquakes (shown as WC94 in Table 2). The reason for that is mainly due to the fact that Mw values proposed by Bulut et al. (2019) are based on a mean slip deficit rate of 9.9 mm/year derived from a summation of the seismic moment released by historical earthquakes for a period of 1500 years."

References to Leonard (2010) have been removed, since it was used only for comparison purposes with respect to Wells and Coppersmith (1994). The manuscript has been updated accordingly. Tables are updated. A new table explaining the use of formula provided in Wells and Coppersmith (1994) has been added. Standard errors defined by Wells and Coppersmith (1994) have been also considered in the Mw calculations to determine Mw(min) and Mw(max) values. Corresponding Moment values have been calculated from the Mw= 2/3 logM0 $-$10.7 (Hanks and Kanamori, 1979). Corresponding displacement has been obtained from M=μAD, where A is the rupture area, D is the displacement in m and μ is the rigidity modulus taken as 3.25x1011 dyn/cm2. The total earthquake moment for each scenario is derived from the summation of the moments associated to the individual segments considered to be ruptured in a given scenario All these explanations have been added to the manuscript. Authors tried to address the slip heterogeneity in a rather simplistic way, where slip values on each segment within a given scenario is not static, thus corresponding to a variable slip distribution along the whole rupture area. This does not capture the true effect of the slip heterogeneity in tsunami modeling, but should be acceptable given the limitations of the deterministic methodology used in this study.

The argument related to the probabilistic approach was a misunderstanding due to the poor language used in the initial submission. The manuscript has been updated accordingly. With respect to the landslide generated tsunamis as the key element of tsunami hazard in Marmara, the manuscript has been improved based on Latcharote et al, 2016 (3).

Finally the results are difficult to read, even though it is practical to have the series of scenarios in supplementary material. Some key scenarios could be displayed to partly illustrate the results. And also it would be very interesting to identify which scenario contributes to which maximum coastal impact (a kind of de-aggregation).

Table 3 (corresponds to Table 4 in previous manuscript) and also Table 4 in updated manuscript provides the most affected coastal areas with corresponding scenarios. We intended to design the Supplementary Material as a handout for tsunami database in Marmara Sea. Therefore, we only provide integrated results in the main text and give the details of each scenario in Supplementary Material. We have also analyzed 3 historical earthquakes as complement worst case scenarios and provided their results separately both in Supplementary Material and in the manuscript.

Some remarks in detail: p.2, l.16 and l.20: what does “TR” mean? (in NTWC-TR and

TSP-TR)

TR is the abbreviation for “TURKEY”. We revised as National Tsunami Warning Center of Turkey (NTWC-TR), and Tsunami Service Provider of Turkey (TSP-TR).

p.2, l.22: it is very affirmative to propose that a comprehensive set of scenarios is defined, while their choice seems questionable (see below). It could be rephrased.

The sections related to the methodology have been improved. The random character of the assigned slip values remains still questionable, yet still acceptable within deterministic approach, and additional credible worst-case scenarios from the literature (2) has been added. Please note that, based on comments received from 4 reviewers, the manuscript has been modified considerably and authors tried to address all comments in a holistic way, which necessitate a “fresh” reading of the manuscript.

p.2, l.25: the fact that the methodology is essentially deterministic could be already mentioned here.

The paragraph starting with “The geometry of the possible tsunamigenic faults in the Marmara Sea. . .” has been updated as “In this deterministic study, the geometry of the possible tsunamigenic faults in the Marmara Sea. . .”

p.3, l.7: recent seismotectonic studies propose 4 to 5 m of slip deficit. The scenarios chosen later are far from these slip values (which of course can be only partly accommodated during earthquakes). But it deserves a discussion at least in the choice of the scenarios.

We added additional credible worst-case scenarios as provided in Bulut et al (2019) corresponding to these higher slip deficits.

p.3, l.12: the reference should be (Le Pichon, 2014) and not (Pichon, 2014).

Corrected.

p.3, l.26 to 31: this is a weak part of the paper, since the definition of the scenarios SN is much too short. Is the “arbitrary manner” chosen to be representative of a certain magnitude level, or a level of heterogeneity, or? When long ruptures are studied (ex SN05), how is the highest place of slip chosen? By the way it could be also informative to have the average slip given in Table 2. Globally the 30 scenarios are an excerpt of possible scenarios but it is not proven that they are fully representative of the possible earthquakes.

Slip values in each segment for a given scenario has been assigned randomly. This also applies for the segment with highest slip. References to Leonard (2010) have been removed, since it was used only for comparison purposes with respect to Wells and Coppersmith (1994). The manuscript has been updated accordingly. Tables are updated and moved to Supplementary Material. A new table explaining the use of formula provided in Wells and Coppersmith (1994) has been added. Standard errors defined by Wells and Coppersmith (1994) have been also considered in the Mw calculations to determine Mw(min) and Mw(max) values. Corresponding Moment values have been calculated from the Mw= 2/3 logM0 -10.7 (Hanks and Kanamori, 1979). Corresponding displacement has been obtained from M=μAD, where A is the rupture area, D is the displacement in m and μ is the rigidity modulus taken as 3.25x1011 dyn/cm2. The total earthquake moment for each scenario is derived from the summation of the moments associated to the individual segments considered to be ruptured in a given scenario. All these explanations have been added to the manuscript. Authors tried to address the slip heterogeneity in a rather simplistic way, where slip values on each segment within a given scenario is not static, thus corresponding to a variable slip distribution along the whole rupture area. The segment with highest slip has been chosen randomly. This does not capture the true effect of the slip heterogeneity in tsunami modeling, but should be acceptable given the limitations of the deterministic methodology used in this study. This deterministic study cannot capture slip heterogeneity and calculated tsunami heights could vary regionally/locally, depending on the position of the high slip on the rupture plane. This is a limitation of the methodology used in this study and authors tried to address this by adding additional credible worst-case

scenarios as provided in Bulut et al (2019).

p.4, figure 1: the slip is uniform for each segment, but varies from one segment to another; it could be mentioned in the caption (and refer to Table 1 to have the values). Corresponding explanation has been added to the figure caption: “Segments correspond to a rectangular area with an associated uniform slip, i.e. the slip is uniform for each segment, but varies from one segment to another. The main characteristics of the plotted fault segments are summarized, and corresponding slip values are given in Table S.1 in the Supplement Material.”

p.4, l.12 to 15: the 90 m grid seems very well resolved for offshore areas, while the increased resolution near the coastal zones is not specified. Does the fact that coastal structures are added imply that additional refined bathymetry is added? Is there any run-up calculation on the topography?

We have prepared single study domain in 90m grid size compiling all data listed in this section (30” GEBCO data, ASTER, digitized coastline and coastal defence structures). We didn’t use nested grids in the analyses and didn’t make any inundation analyses. However we used ASTER data in order to force the data compilation process for having more reliable coastline. We updated that section as below.

“Tsunami numerical modelling is performed using 90m grid sized bathymetry - topography data as a single study domain. It was prepared by compiling various data as multi-beam bathymetric measurements, 900m grid sized GEBCO data in the sea as well as 30m grid sized ASTER data on land. Besides, coastline and coastal defence structures i.e. breakwaters, groins and large docks in the ports were also digitized in GIS environment and added to bathymetry - topography data for increasing the resolution and precision in coastal zones. Higher-resolution ASTER data has an important role in data compilation process as it is denser compared with the bathymetry data. In that way, interpolation between less sensitive bathymetry data and much denser topography data provides more reliable coastline in 90m grid sized study domain. The precision in coastline supports the process of selecting synthetic gauge points in shallow zone very close to shoreline, which is described in coming sections below."

p.5, l.6: what is KRDAE

KRDAE is the abbreviation for Turkish name of "Kandilli Observatory and Earthquake Research Institute". We changed it with KOERI; abbreviation of English version.

p.5, l.16 and below: it is probably more convenient to have detailed results in supplementary material, but then it is difficult to follow the text with only synthetic Tables. In addition all the geographical names are not displayed on Figure 3 (and on the latter the names could be emphasized with a larger font size). (see also p.10 below)

We have updated Figure 3 with more visible names of important locations also including locations of historical earthquakes and observed runup values. We agree that following the results from Supplementary Material is not practical compared with having the results in the main manuscript. However, we have many scenarios and it would not be possible to include simulation results in the main text due to document size limit. The results for each scenario are discussed in the caption of each figure including arrival times, most affected locations and water level fluctuations. We intended to design the Supplementary Material as a handout for tsunami database in Marmara Sea. Therefore we only provide integrated results in the main text and give the details of each scenario in Supplementary Material.

p.5, l.19: please insert a space between figure and unit in 25cm (should be 25 cm), and it is to be applied throughout the paper.

Corrected in the whole manuscript.

p.6, Table 1: the signification of SSF, NSSF, etc.. should be made explicit, even if we can guess it is strike-slip, normal, etc.. Explanation added.

p.7, Table 2: please add the unit of displacement (meters?) in the caption. And the number of digits after comma should be unified (by the way a precision of 10 cm is

probably enough, so only one digit)

Tables have been updated/improved. This table was moved to Supplementary Material.

p.8, Figure 3: the names are difficult to read and could be enlarged.

Figure 3 were totally replotted.

p.9, Table 3: the table is difficult to read and does not bring much to the reader. Probably it would be more informative to have at least 1 or 2 scenarios displayed to figure out the source pattern used.

We agree with the referee and moved Table 3 from main manuscript to Supplementary Material.

p.9, l.6 and below: are the maximum amplitudes from crest to trough? Or only 0-tocrest?

Tsunami maximum wave amplitude is used as the vertical distance between peak of tsunami and undisturbed sea level (please refer to UNESCO-IOC Tsunami Glossary 2019).

p.10, l.5 and below: it is difficult to follow the presentation of the results, first because the names are not all easy to find in Figure 3 (maybe they should be recalled on Figure 4?) (is Kadikoy displayed on Figure 3?), and also because the values in the text do not seem to be all consistent with the values seen on the map. For instance values of 2 m (hence in red) mentioned in the text are not striking in the figure 4. Could it be made clearer?

Kadikoy is the name of district including Haydarpasa and Bostanci. We changed the name "Bostanci" with "Bostanci_Kadikoy" in Figure 3. The explanation in this section was totally reviewed.

p.11, Table 5: as said before, the results are difficult to read. But this kind of analysis may be useful for operational aspects. Is it the case? Or is it only some illustration of the results?

References to the possible operational aspects have been removed from this study, as it becomes apparent from all reviewer comments that it added further confusion to the manuscript. Please refer to the last comment below for further clarifications on this aspect.

p.12, l.1: the deterministic approach is evoked for the first time. It should be put in a broader context earlier in the introduction of the paper. The comparison with the work by Hancilar is not very clear: are the results of the new study well below their 50 yr probability? What would be the difference using different slip distribution along the chosen unit faults of the scenarios?

The section referring to HancÄślar (2012) has been updated, as follows:

"Moreover it should be noted, however, that the maximum wave height calculated in this study is relatively lower in comparison to the available probabilistic studies published so far, such as Hancilar (2012), which provide inundation maps resulting from probabilistic tsunami hazard analysis for a 10% probability of exceedance in 50 yr including the building numbers and types, lifeline systems and demographic data in Istanbul, reaching run-up height of 5-6 m. Hancilar (2012) also highlights that the residential buildings at risk are mainly located in Kadikoy, Tuzla, Bakirkoy and Princes' Islands where our study points out significant wave heights as well."

It's true that this deterministic study is/cannot capture slip heterogeneity and calculated tsunami heights could vary regionally/locally, depending on the position of the high slip on the rupture plane. This is a limitation of the methodology used in this study and authors tried to address this by adding additional credible worst-case scenarios as provided in Bulut et al (2019).

Please note that, based on comments received from 4 reviewers, the manuscript has been modified considerably and may require a fresh reading.

p.12, l.8: the word "comprehensive" is used twice within two lines

We completely revised this section.

p.12, l.13: it as a key message of the paper to show that submarine landslides will add an additional hazard following earthquakes. However the scenarios used do not seem to cover all the extreme possibilities: is it incontestable that no seismic scenario can produce high waves, with a local high slip and accurate model of the coastal amplification?

With respect to the landslide generated tsunamis as the key element of tsunami hazard in Marmara, the manuscript has been improved based on Latcharote et al, 2016 (3). Please also refer to the additional paragraph added to the manuscript, as shown above. It is indeed correct that there is a probability of a seismic scenario producing high waves, with a local high slip and accurate model of the coastal amplification, which can be captured in a probabilistic study, which is outside the scope of this study.

p.12, l18-20: il would be useful to describe a bit more the system introduced as a tsunami warning system in KOERI, with no use of focal mechanism, and how the results of the paper will be practically input in this system.

Details of the proposed local/near-field tsunami early warning is provided in Necmioglu, 2016 (1) and authors would like to avoid repetition in this manuscript. However, reference to the tsunami early-warning in this study has been removed since the scenario database produced, or all relevant studies so far conducted, indicate the very-limited use of earthquake generated tsunami scenarios for real-time early warning scenarios, as far as the upstream component of the tsunami early warning system is considered, for which KOERI is responsible as the National Tsunami Warning Centre. The results of this paper are expected to contribute to further studies on inundation mapping, which then would present added value to the civil protection authority to identify evacuation zones/routes and tsunami assembly areas/safe zones, as elements of downstream component of the tsunami early warning system.

(1) Necmioglu, O.: Design and challenges for a tsunami early warning system in the Marmara Sea, Earth, Planets and Space, 68:13, doi: 10.1186/s40623-016-0388-2, 2016.

(2) Bulut, F., AktuÄ§, B., YaltÄśrak, C., DoÄ§ru, A. and Özener, H. (2019), Magnitudes of future large earthquakes near Istanbul quanti ed from 1500 years of historical earthquakes, present-day microseismicity and GPS slip rates, Tectonophysics 764 (2019) 77–87

(3) Latcharote, P. Suppasri, A., Imamura, F., Aytore, B., and Yalciner, A. C.: Possible worst-case tsunami scenarios around the Marmara Sea from combined earthquake and landslide sources, Pure and Applied Geophysics, 173 (2), 3823-3846, 2016.

Please also note the supplement to this comment:
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2019-186/nhess-2019-186-AC3-supplement.pdf

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Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2019-186, 2019.