Reply to Anonymous Referee 3, (NHESS)

Interactive comment on "Reconstruction of flow conditions from 2004 Indian Ocean tsunami deposits at the Phra Thong island using a deep neural network inverse model" by Rimali Mitra et al.,

We thank the reviewer for the insightful assessment of our manuscript and for the numerous comments and suggestions. We have provided answers to your questions as listed below (in bold italics).

Major comments:

Q1: One of the major concerns is the technical problems on writing. Sentences in the body text are often complicated and difficult to understand the author's intent. A complete English proofreading by professional services or native speakers is needed. Section 3.2.1, which explains the sedimentary data from the Phra Thong island, must be placed before the description of the inversion results. In addition, earlier papers sometimes were inappropriately cited, and the order of some figures (and insets) are not consistent with the structure of the paper. Therefore, comprehensive reorganization and correction are required to improve the readability of the paper.

RE: Thank you for the suggestion. This is to inform the reviewer that we have done the English proof reading by professional editing service for journals. However, we agree that we must recheck the overall arrangements, citations, order of figures and sentence constructions. We will recheck all of these and will move 3.2.1 section before the inversion results in our revised manuscript.

Q2: Another concern is that whether the model assumption is valid for the study area. For example, both the transect of the tsunami deposit sites and the reference line (Figure 6) is oblique to the coastline, meanwhile the model assumes that the coordinate x for the forward simulation is perpendicular to the shoreline (equation 2). I'm curious that how likely the direction of tsunami inundation was consistent with these lines. Satellite imageries show that the geometry and directions of the sandy ridges are quite complex, implying the tsunami inundation might have been affected the local topography. Fujino et al. (2010) mentioned that the measurement of the flow direction was not many and in fact only single measurement was made near the coastline of the transect. There may be an uncertainty in the tsunami inundation direction (and probably the sediment source). If this is the case, additional computation of the forward and DLNN model using reference line with different directions are needed.

RE: Thank you for the comment. The transect was considered along the flow direction the flow direction and because of the complicated local topography the perfectly perpendicular locations were not possible to collect. In the previous paper Mitra et al., 2020 it was presented that the DNN inverse model works well perpendicular to the shoreline and Sendai plain was one of the most well-preserved tsunami deposits from 2011 Tohoku-oki tsunami. Moreover, practically in recent or ancient tsunami deposits, it is often difficult to obtain samples from perfectly shore perpendicular transects due to anthropogenic disturbances or complicated topography. Comparison between the model estimates and the observed flow depths represents that even if

we are unable to obtain completely shore-perpendicular transect, the DNN model still predicts reasonable and realistic flow conditions.

Q3 With regard to Section 4.3, I think the flow speed comparison is problematic, since the model assumes a constant flow speed over the inversion region and it is not clear whether it represents either an average, maximum or something else. This also applies to the measured flow speeds. Unless the attributes of the measured flow speeds (i.e. average, maximum or other) are specified, the measured values cannot be compared with inversion results. The comparison to the inversion results of the TsuSedMod also needs a careful discussion, since the TsuSedMod employs different model assumptions and formulations. It is not clear how the comparison of the two different inversion results are justified.

RE: The flow velocity in this model has been considered as constant, and this reconstructed velocity should be compared with the spatially averaged velocity of the field observation. In Mitra et al. (2020), the result of velocity reconstruction was compared with the field measurements that varied in space. As a result, the estimated value matched the spatial average of the measurements.

Our reconstructed values are the only estimates available for this region, and we do not consider that these existing velocity values validate our model because of the different regions where the measurements were taken. In addition, it is true that we do not know the timing of the velocity values that we referred in this paper. Nevertheless, we believe that referring to estimates of velocities in surrounding areas may be useful in interpreting whether the velocity of the tsunami inundation flow in this region was unique.

Q3: The idea of coupling DLNN with other tsunami hydrodynamic model, such as the well validated TUNAMI-N2, is very interesting. Although it must be computationally expensive, the DLNN inversion can include much more physically plausible hydrodynamic models to improve the model performance. I suggest to expand on this aspect, such as outlining a road map and future challenges.

RE: Thank you for the suggestion. We agree that our proposal might be computationally expensive. In our revised manuscript we will add some more outlining about the possible combination with TUNAMI-N2 and the possible challenges.

<u>Minor comments:</u>

1. ***Abstract:*** I suggest to use 'distance' rather than 'length'.

   RE: Thank you for your suggestion. We decided to change the 'length' to 'distance' all over the document.

2. P-1, Line 22, Out of context?
   RE: Thank you for the comment. We have removed the sentence at line 22 considering the sentence as out of context.

3. P-2, Line 25, I can understand what the authors intended to say, but the wording is unusual. Consider to revise, line 28, I understnad what the authors intended to say, but the structure of the sentence is not easy to follow. Consider to revise, line 31, I understnad what the authors intended to say, but the structure of the sentence is not easy to follow. Consider to revise.

   RE: Thank you for the suggestion. We hope to revise the whole paragraph in our revised manuscript.

4. P-2, Line 25, lower?

   RE: In the sentence we tried to explain that the tsunami preparedness was not appropriate because of higher tsunami return period that resulted into extensive damages.

5. P-2, Line 36, The sentence is incomplete.

   RE: Thank you for identifying this. We considered revising the sentence as "Meanwhile, other flow parameters, such as flow velocity and depth, remain largely unknown".

6. P-2, Line 40, I understnad what the authors intended to say, but the structure of the sentence is not easy to follow. Consider to revise.

   RE: Thank you. We have considered revising the sentence.

7. P-2, Line 57, It seems some of the papers are not cited appropriately. For example, this paper is a report of forward tsunami propagation and inundation modeling. Check all other citations carefully whether they are used appropriately.

   RE: Thank for the comment. We will recheck the citations and we revise the sentence as follows:

   To reconstruct quantitative values of tsunami characteristics from the deposits, various numerical forward and inverse models which incorporate sediment dynamics, and transport and depositional equations have been established.

8. P-3, Line 60, The structure is not easy to follow. Compare the estimated and observed values for the inundation distance and flow speed and depth.

   RE: We agree with the reviewer. We added few more sentences to compare the estimated and observed values. These sentences are added
   Line 60 "The DNN inverse model predicted the tsunami flow conditions. The reconstructed inundation length was 4,045m which is close to the original maximum inundation length of approximately 4,020 m, values of run-up flow velocity were 5.4 m/s which was close to the spatial average of the measurements which ranged from 1.9 to 6.9 m/s, and the estimations

of the inundation depth was 4.11 m which was also within the range of the in-situ measured values from Sendai plain."

9. P-3, Line 65, The sentence is complicated. Consider to revise.

RE: Thank you for the comment. In response to your comment we will revise the text as follows: Line 65, "The Phra Thong island is one of the locations where the tsunami deposits were preserved without a great amount of topographic irregularities with almost no anthropogenic disturbances."

10. P-3, Line 67, This sentence must be divided into two sentences.

RE: Thank you for the comment. In response to your comment we will revise the text as follows: Line 66, The coastlines of Phra Thong island were severely eroded and retreated by the 2004 tsunami. However, the presence of widespread mangrove forests with other waterborne plant debris helped in the identifications of the extent and direction of the flow.

11. P-3, Line 75, Difficult to understand how the flow conditions can be used to estimate sediment characteristics.

RE: Thank you for the comment. . We will add the following paragraph to modify the text,

P.3, Line 73, Here, we conduct an DNN inverse analysis of the tsunami deposits measured at Phra Thong island and reconstruct the flow conditions such as the maximum inundation length, flow velocity, maximum flow depth and sediment concentrations of five grain-size classes. The inverse model was based on the forward model, which was proposed by Naruse and Abe, (2017). The forward model calculations were iterated at random initial flow conditions to produce artificial training data sets that represent depositional characteristics such as the spatial distribution of thickness and grain-size composition. Using the artificial training datasets, the DNN was then trained to establish a relation between the depositional characteristics and the and the flow conditions. The post-trained DNN model was ready to predict flow conditions from the tsunami deposits after the performance of the trained DNN was verified using test data sets. The 1-D cubic interpolation was applied to the field data sets of Phra Thong island to fit the dataset in to model grids. Finally, this DNN inverse model was applied to the field data sets from the Phra Thong island, Thailand to reconstruct the flow conditions of 2004 Indian Ocean tsunami. We also used the reconstructed flow conditions to estimate the spatial distribution of the volume per unit area and grain-size composition from Phra Thong island and compare the distribution with the measured data. Our inverse model was already validated to be effective for 2011 Tohoku-oki tsunami deposits distributed in Sendai Plain. In case of Phra Thong island, we validated the results by the field measurements of the tsunami flow depth. Also, the estimated thickness and grain size distribution of tsunami deposits were compared with the actual measurements. Our inverse analysis results could be used for designing future tsunami hazard assessments and disaster mitigation strategies in Thailand.

12. P-4, Line 102, Expression for the rate of total sedimentation is missing.

RE: Thank you for identifying this. The typing error will be corrected in the revised manuscript.

13. P-4, Line 104, Consider to explain how likely the assumptions are valid for this case.

RE: Thank you for your comment. The explanation is as follows:

"The velocity of the run-up flow of the tsunami, U is assumed as uniform and steady, but the inundation depth varies in time and space. Hence, this model simplification is called the quasi-steady flow assumption (Naruse and Abe, 2017)."

14. P-4, Line 113, Elaborate how the grain-size classes were determined. Measurement of tsunami deposit? Complete descriptions for the data (number of data points and their locations, thickness, grain-size distribution and other sedimentological features) are needed..

RE: Thank for the suggestion. We will add a new figure on the thickness and grain size distribution and also move the study area section before the methodology section.

15. P-5, Line 119, Figure 1a must be placed at first. Consider to exchange the position of Figure 1a and 1b, and swap the names. Or just revise the structure of this section

RE: Thank you for the suggestion. We will do the necessary changes in the revised manuscript.

16. P-5, Line 120, measured (or observed)

RE: Thank you for the comment. These are all measured deposit. We will replace the word "natural" with "measured".

17. P-5, Line 132, Complete descriptions are needed for the basis for selection of the range of the input values. The description may include appropriate reference to field observations or experimental data.

RE: Thank you for the comment. We will include the necessary references for the selection of the range of input values.

18. P-5, Line 146, The sentence is complicated. Consider to revise.

RE: Thank you for the comment. In order to apply the inverse model to the to the measured values of field dataset from Phra Thong island in 1-D vectors, the collected data points must be fit into that fixed coordinate system of the model.

19. P-7, Line 165, Difficult to understand what 'epochs' indicates. Iterations?

RE: Thank you for your comment. The number of epochs indicates the number of times that a full data set has passed the optimization calculation. The specific number of epochs was determined based on the rates of the progress of the training. We can modify the text as follows:

"The training process proceeded with a certain number of epochs that indicates the iterations of the optimization calculation by the full dataset."

20. P-8, Line 173, Why the flow depth was biased?

RE: Thank you for the comment. In our consideration, the bias is caused by the internal algorithm and neural network structure, but we hope the biasness will be sorted if we improve the neural network structure in future. In future studies, the algorithm of the neural network structure can be improved to eliminate or reduce the bias of the parameter. We can add this clarification in our revised manuscript.

21. P-8, Line 178, This section must be moved to somewhere in the section 2. Not in the result section. Readers may want to see whether model assumptions for the sediment source is valid in this island. Were the tsunami deposit along the transect totally brought from the sea?

RE: Thank you for your suggestion. We decided to move the section before methodology.

22. P-8, Line 180, Swap Figures 5 and 6. Figure 5 must be appeared first in the text. Give name of insets (a, b and c) for current Figure 6 for the convenience of readers.

RE: Thank you for the comment. We will revise the positions and labelling of the figures.

23. P-8, Line 191, However, the reference line seems not to be perpendicular to the coastline, according to Figure 6. Explanations are needed regarding the compatibility to the model assumption (i.e. inversion transect must be perpendicular to the coastline).

RE: We are assuming that this comment is the same comment or related to Q2. Please refer to the reply of Q2.

24. P-8, Line 192, The sentence is complicated. Consider to revise, Line 204, The sentence is complicated. Consider to revise.

RE: Thank you for your comment. We will undertake necessary changes in our revised manuscript.

25. P-10, Line 206, How do we interpret the increasing trend for the maximum flow depth?

RE: Thank you for your comment. Figure 7c shows that the jackknife standard error of maximum flow depth has an increasing trend up to sampling window size 1600 m. After sampling window size 1600 m that it becomes stable. We will add this clarification in our revised manuscript.

26. P-11, Line 212, The sentence is quite complicated and is not easy to follow in terms of English writing. Consider to revise.

RE: Thank you for your comment. We will rewrite the sentence in our revised manuscript.

27. P-11, Line 212, This figure must be appeared after current Figure 7.

RE: Thank you for the suggestion. We will rearrange the figures.

28. P-12, Figure 6, This is not a appropriate caption for this figure.

RE: Thank you for the comment. We will modify the figure caption and labelling.

29. P-14, Line 234, Are there any reason for the biased results for the flow depth?

RE: We assume that this comment is related to comment number 18. Please refer to the comment 18.

30. P-17, Line 264, Is this value incudes the bias of -0.38m?

RE: Thank you for the comment. This value does not contain the additional bias -0.38. We will mention this with the sentence in line 264.

31. P-17, Line 267, Elaborate what is Tsuji and KSCOE- http://www.nda.ac.jp/~fujima/TMD/

RE: Thank you for the comment. To address this point, in the revised version we will add the details of the Tsuji and KSCOE group.

32. P-17, Line 276, Considering the local topographical variations, topographic elevation is needed for other sites to calculate and compare the flow depths.

RE: Thank you for the suggestion. Previously we averaged the elevation of the area. To address this point, we will add the ranges of elevation and the respective flow depths. The revision will be as follows:

P., 17, line 269, The maximum and measured flow heights from Phra Thong island were reported 7.1 m and 5.5 m respectively (http://www.nda.ac.jp/~fujima/TMD/). The corresponding maximum and minimum values of elevation are 3.1 and 1.1 m respectively (Jankaew et al., 2008, 2011; Brill et al., 2012b). Hence, the approximate estimate of measured maximum flow depth is ranged from 2.4 m to 6.0 m. Considering the bias correction of 0.38 m, the reconstructed value of maximum flow depth (4.3 m) falls within the range of measured maximum flow depth values.

33. P-17, Line 283, I think flow speed comparison is problematic, since the model assumes that the flow speed is constant over the inversion region and it is not clear the inversion result represents either an average, maximum or something else. This also applies to the measured flow speeds. Unless the observational condition is specified, the measured values cannot be compared with inversion results. The question is that the attributes of the measured flow speeds (i.e. average, maximum or other).

RE: Thank you for the comment. We assume this comment is related to Q2. Please refer to the reply of Q2.

34. P-17, Line 286, Is this mean the tsunami flow speed was measured using video footages from aircrafts? Rossetto et al. (2007) did not mention about that.

RE: We apologize for mentioning aerial footage. Rossetto et al. (2007) mentioned about the video footage only. We will correct the statement in the revised version.

35. P-18, Line 288, TsuSedMod uses different model assumptions and formulations. It is not clear how the comparison of the two different inversion results are justified.

RE: We agree with the reviewer. We decided to remove the comparison with TsuSedMod.

36. P-18, Line 306, Before mentioning this, outlines of Masaya et al. (2019) must be introduced. It seems that the paper includes not only the tsunami hydrodynamic simulation but also sediment transport simulations.

RE: Thank you for the suggestion. In our revised manuscript, we will add the outlines of the model (Masaya et al., 2019) including hydrodynamics and sediment transport.

37. P-18, Line 311, The idea is very interesting. Although it must be computationally expensive, the DNN inversion can include much more physically plausible hydrodynamic models to improve the performance. Better to expand on this, such as outlining a load map and future challenges.

RE: We thank the reviewer for appreciating the idea. Currently, the model calculation of Masaya et al., 2019 based on the single assumption of measured parameters which are not optimized. Model TUNAMI-N2 could be integrated with the forward model of DNN inverse model but the model needs to be modified for multiple grain size classes with the optimized parameters. We will add these details in our revised manuscript.