Dear Dr. Rachid Omira,

Thank you very much for handling our manuscript. On behalf of my co-authors, I am writing to submit the revised version of our manuscript entitled " Understanding flow characteristics from tsunami deposits at Odaka, Joban coast, using a DNN inverse model" for consideration in Natural Hazards and Earth System Sciences. We are grateful for the opportunity to revise our manuscript and appreciate the insightful comments and suggestions provided by the reviewers.

We have carefully addressed each point raised by the reviewers, and these revisions have significantly enhanced the quality and clarity of our work. Our responses to the reviewers' comments are described below, where each comment is followed by our response and an indication of where the changes have been made in the manuscript.

We are confident that the revised manuscript now meets the high standards of NHESS and provides a valuable contribution to the sciences for natural hazard prevention. The changes implemented not only address the reviewers' concerns but also enrich our study's overall findings and implications.

Thank you for considering our revised manuscript. We look forward to the opportunity to contribute to NHESS and eagerly await your decision.

Sincerely yours,

Hajime NARUSE, Ph.D.

Responses to Reviewer 1:

Interactive comment on "Understanding flow characteristics from tsunami deposits at Odaka, Joban coast, using a DNN inverse model"

We thank the reviewer for the critical assessment of our manuscript and for the numerous comments and suggestions. Please find our responses to each comment below (in bold italics).

1. My main question is related to the assumption of the inverse modeling and interpretation of the results. In this inverse modeling, as explained in the methodology section, flow velocity is assumed to remain constant (in time and space?). If this can be interpreted as averaged velocity over time or space, comparison to the observed values should be made carefully. In particular, I think comparison to observed local maximum velocity is not appropriate.

Iijima et al. (2021) propvided temporal and spatial changes in flow speed estimated based on forward tsunami inundation modeling along a nearby transect in Odaka region. I suggest careful reviewing and comparison of the findings from the paper.

RE: Thank you for your thorough review of our paper. We appreciate your time and valuable feedback. In this response, we aim to address each of your major comments.

Firstly, we would like to address the major comment concerning the flow velocity. We recognize the importance of comparing the maximum velocity reported by Ijima et al. (2021), and a review of their study and a detailed comparison with our results were described in a revised manuscript. The forward model FITTNUSS employed in this study approximates the behavior of tsunami inundation flows by two stages: the stage in which deposition occurs during the flooding current is flowing and the stage in which deposition occurs gradually after the flow has ceased (Naruse and Abe, 2017). The velocity of the actual tsunami inundation flow temporarily varies and is known to be very fast at the beginning but to decay rapidly. From past studies, the velocity in the first stage estimated using the FITTNUSS forward model approximately reproduces the initial rapid inundation velocity of the actual tsunami inundation flow (Naruse and Abe, 2017; Mitra et al., 2020; Mitra et al., 2021). Although the estimates of Iijima et al. (2021) are slightly lower velocities than our reconstructed values, we judge them to be consistent with our results because the high-velocity flow inundated the Sendai Plain. The comparison with their results is described in the text.

Also, It is important to note that our approach, assumptions, and model formulation differ significantly from the study mentioned. Ijima et al. (2021) primarily used the forward model with the assumption of the fault model for producing the initial waveform for their simulation, while the depositional information was not considered in their simulation. In contrast, our study employed an inverse model incorporating tsunami hydrodynamic and sediment transport simulations. The essential difference is that their study estimates the hydrological conditions in the study area based on macroscopic information for the entire Tohoku region. In contrast, our study characterizes tsunamis based on the evidence available in the study area (i.e., tsunami deposits). Based on this difference, our approach complements each other, and we intend to make a detailed comparison of the results of the two studies.

Comments on the manuscript

1. Abstract, P.1, think use of the word 'instability' is not appropriate here. Consider to replace this with another word from the field of geomorphology, which defines undulating surfaces due to man-made features.

RE: Thank you for the suggestion. We have rephrased the sentence as "Despite having a few topographical anthropogenic undulations that caused the flow height to fluctuate greatly, the

reconstructed maximum flow depth and flow velocity were reasonable and close to the values reported in the field observations".

2. Introduction, P.1**,** Introduction section is not well organized. For details, see the specific comments.

RE: Thank you for identifying this. We have structured and formatted the Introduction section in accordance with the reviewer's feedback.

3. Introduction, P.1, The paper Tanigawa et al. (2014) did not deal with flow reconstruction.

RE: Thank you for the comment. To eliminate any potential confusion, we have omitted the citation.

4. Introduction, P.1, This sentence seems to be out of the context of the previous sentence. The paper Sugawara et al. (2012) did not deal with the numerical modeling of sediment transport.

RE1: The sentence has been removed from the section to improve the clarity of the context.

5. Introduction, P.2, Better to add the author's thoughts whether this flow reconstruction was successful.

RE: P.2, Line 25, We have rephrased the sentence as follows, "Furthermore, in Rikuzentakata City, the flow velocity of the 2011 Tohoku-oki tsunami was estimated to be larger than 2.4–2.7 m/s, based on the flow reconstruction by Naruse et al. (2012). This reconstruction was achieved by considering the critical velocity required for bedload motion specifically related to the largest grain-size category found within the deposits."

6. Introduction, P.2, Fukushima' is too broad to specify where the higher flow velocity was estimated.

RE: Thank you for suggesting this. We have replaced the word with Minamisoma.

Line 30. Indicate the place name and distance from the study area. Is it shown in Fig. 1?

It was measured at the mouth of the Kido River, which is 34 km south of the study site. We added description about this location. Also, all the locations described in the text were shown in Figure 1.

8. Introduction, P.2, It is difficult to understand why collapse of buildings infer higher flow velocity.

RE: P.2, Line 38, We have added a bit of that methodology in the text. "When the overtopping flow was generated from the elevated seawall crown, it led to a substantial increase in velocity (exceeding 11 m/s based on the principles of the Bernoulli theorem) as it encountered the formerly dry soil surface behind the seawall. This sudden surge in velocity was a direct consequence of the flow cascading over the seawall and impacting the ground."

9. Introduction, P.2, It is not clear what is the mode of tsunami inundation flow and why the mode is important in the context of this paragraph. I guess knowing the mode (whether the flow is supercritical or subcritical) is important in terms of engineering, such as designing coastal dikes.

RE: P.2, Line 41, The sentence has been rephrased "Therefore, it is conjectured that the coastal areas of the Fukushima region experienced supercritical, high-velocity inundation flows. However, due to the Fukushima Daiichi Nuclear Power Plant disaster (Mori et al., 2011; Mimura et al., 2011), the specific mode of tsunami inundation flows in that region has not been extensively investigated."

10. Introduction, P.2, This phrase appears in the following sentence. Consider to delete.

RE: Thank you for identifying this. We have deleted the sentence.

11. Topographic Setting and Tsunami Characteristics in Study Area, P.3, 25 km north of Fukushima Prefecture is Miyagi Prefecture. Locate the study area correctly.

RE: Thank you for the suggestion. P. 3, Line 87, We have rephrased the sentence as follows "which is located 25 km north of the Fukushima nuclear power plant."

12. Topographic Setting and Tsunami Characteristics in Study Area, P.3, tsunami flow velocity, heights with increasing distance from shoreline

RE: Thank you for your comment. We have added "tsunami flow velocity" and "heights with increasing distance from shoreline "with the respective sentences.

13. Topographic Setting and Tsunami Characteristics in Study Area, P.3, Move this to the caption of Fig. 2.

RE: Thank you for your comment. We have moved this to the caption of Fig 2.

14. Topographic Setting and Tsunami Characteristics in Study Area, P.3, This is not relevant to this paragraph. Consider to move other section or remove.

Elevation retrieved from Google Earth is not much precise comparing the GSI's 5m DEM. The elevation of the 5m DEM should be validated through field survey.

RE: We have addressed your comment by removing the part regarding confirmation from Google Earth. Initially, this was included solely for supplementary verification of the elevation.

15. Topographic Setting and Tsunami Characteristics in Study Area, P.4, Naruse and Abe (2017).

RE: Thank you for identifying the error in citation style. We have corrected this in our revised manuscript.

16. Figure 2, P.5, Location of the transect or data source should be declared.

The inundation heights were measured in the regions from Obama to Idagawa, Fukushima Prefecture (Sato et al, 2014). (b) The transect was in Miyagino-ku, Sendai Plain (Naruse and Abe 2017).

17. Need to explain why these values for the grain size classes have been chosen. Based on grain-size data?

RE: The grain size distributions obtained from measurements, ranging from 0-3 phi, were subsequently categorized into four distinct grain size classes. To facilitate comparison, the phi classes were converted to micrometers. We have added the respective phi scale values in our revised manuscript. The calculations are provided in the Zenodo as "GS_calculations"
The revised paragraph on P.6, Line 126," The measured grain size distributions, spanning from 0 to 3 phi, were divided into six distinct grain size categories. To enable easier comparisons, these phi classes were converted into micrometers. In this study, the grain size distribution was discretized into six specific classes, each characterized by representative diameters of 841, 595, 420, 297, 210, and 149 µm. The corresponding phi scale values for these diameters are 0.25, 0.75, 1.25, 1.75, 2.25, and 2.75, respectively."

18. Results, Grain-size and thickness of tsunami deposits. P. 8, Since the data used for the modeling have not been published elsewhere, consider to add details, such as field and sample photographs and description of their characteristics, a table that compiles site coordinates, elevation, deposit thickness, grain-size metric as supplementary materials.

RE: Thank you for your comment. The revised manuscript now includes field photographs, columnar sections, and descriptions in the supplementary information. Figure 6 displays the deposit thickness and mean grain size distribution. For additional calculations and detailed grain size distribution data, please refer to the Zenodo repository (https://doi.org/10.5281/zenodo.4764153) where the file "GS_calculation.xlsx" can be found. The map includes elevation and coordinates.

19. Discussion, P.11, Iijima et al. (2021, Sed Geo 423, 105978, https://doi.org/10.1016/j.sedgeo.2021.105978)
Reconstructed tsunami flow characteristics along a transect in Odaka region (approx. 1km south of author's survey line), based on thickness and grain size data of tsunami deposit and numerical simulation of the tsunami. According to the results, changes in the tsunami flow speed can be related to artificial topography, such as elevated road. They provided time series of flow speed and profile of maximum flow speed along the transect. In addition, they suggested changes in the type of depositional processes and hence sedimentary structure and grain size variation of the deposits due to temporal and spatial variation of flow speeds. Such findings should be thoroughly reviewed and incorporated in the discussion section.

RE: Thank you for your comment. We tried to find conformable results. Despite of having dike and different topographic settings, the flow velocity has been reported extremely high compared with Sendai plain and the flow condition is supercritical considering the flow depth and maximum flow velocity values reported in the paper.

A new paragraph added on P.15

"As a study of an area adjacent to this study area, our results are comparable with those estimated by Iijima et al. (2021). The forward model employed in this study approximates the behavior of tsunami inundation flows by two stages: the stage in which deposition occurs during the flooding current is flowing and the stage in which deposition occurs gradually after the flow has ceased \citep{naruse2017inverse}. The velocity of the actual tsunami inundation flow temporarily varies and is known to be very fast at the beginning but to decay rapidly. From past studies, the velocity in the first stage estimated in this study approximately reproduces the initial rapid inundation velocity of the actual tsunami inundation flow (Naruse and Abe, 2017; Mitra et al., 2020; Mitra et al., 2021). Iijima et al. (2021) performed numerical simulations for an area approximately 1 km south of this study area and estimated that the inundation flow velocity in the coastal area (0.1 km from the levee) was 8.1 m/s in maximum. In addition, their calculations estimated a flow behavior in which the flooded flow rapidly decelerates inland (4.0 m/s) and then accelerates again to 8.3 m/s. Although these velocity values are relatively smaller than those estimated as the first-stage velocity in this study, their results also support our assumption that the flow in this area was faster than the tsunami inundation flow measured in the Sendai Plain. The large spatial variation in velocity in their reconstructions is probably due to the presence of artificial structures (roads) in the study area. While the flow slowed down significantly when overcoming the unevenness, the study area is a flat area with fields (\ref{fig:1}), so it is predicted that the inundation flow did not slow down and was inundated at high speed.

It should be noted, however, that their perspective on the research approach differs from that of this study because Iijima et al. (2021) performed tsunami inundation calculations using a forward model according to an existing fault model. Although they conducted a field survey of the sediments, they did not estimate the flow conditions from the sediments by inverse analysis. Even if the fault model is correct, tsunami inundation predictions by forward modeling are not always accurate due to local topography and model assumptions. This study provides new information on the behavior of tsunami inundation flows to the Joban Coast area from a new perspective of tsunami deposit inversion.

20. Discussion, P.11, Sato et al. (2014) showed a clearer relationship between ground elevation and tsunami watermark elevation (Fig. 9 in their paper). Their scatter plot of shore-normal distance and watermark elevation (Fig. 10 in their paper) also indicates a clearer landward-decreasing trend. Consider to develop such a diagram for the verification. Authors may be able to convert the flow depth to water level by adding ground elevation at the data point.

RE: Thank you for your suggestion. In light of your comment, we have included an additional figure in the revised manuscript to complement Figure 9. This new figure, which is based on Figure 10 from Sato et al. (2014), provides further support and enhances the findings presented in our study.

21. Figure 9, P.14, Provide references for the data.

Re: We have added the reference, Naruse and Abe, 2017 in our revised manuscript.

22. In this inverse modeling, as explained in the methodology section, flow velocity is assumed to remain constant (in time and space?). If this can be interpreted as averaged velocity over time or space, comparison to the observed values should be made carefully. In particular, I think comparison to observed maximum velocity is not appropriate.

We acknowledge the range of reported values (10-17 m/s) from the surrounding regions. As described above, the FITTNUSS forward model approximates the tsunami flow behavior into two stages, and the reconstructed flow velocity roughly corresponds to the initial fast inundation flow. Considering this information, we have concluded that our simulated flow velocity of 12.1±0.4 m/s falls within the reported range of values from the area.

23. Influence of inundation by Froude supercritical flows, P.14, I think careful interpretation will be required for the Froude number derived from the presented inverse modeling. Does the supercritical condition happen throughout the transect?

RE: Yes, predominantly supercritical condition prevails along the entire transect. This represents an averaged-out scenario.

24. Influence of inundation by Froude supercritical flows, P.15, This sentence is out of context.
Thank you for your suggestion.
RE: We have removed the sentence in our revised manuscript.

25. Influence of inundation by Froude supercritical flows, P.15, Based on video analysis and numerical modeling, Hayashi and Koshimura (2013) demonstrated that Froude number of the tsunami inundation flow on Sendai Plain was greater than 1.0 at 1.4-1.6 km from the shoreline.

RE: Thanks for raising the important point. Hayashi and Koshimura (2013) reported a Fr-supercritical inundation flow in the Sendai Plain, but they assumed a water depth of only 1 or 2 m when calculating the Fr number. This is because they only discussed the Fr number at the inundating frontal part of the flow. On the other hand, when the depth of the main part of the inundating flow is considered, the tsunami inundation occurred in the Fr-subcritical condition in the Sendai Plain. In contrast, we estimate that the central part of the flow was Fr-supercritical on the Joban coast, which is very different from the situation in Sendai Plain. In this regard, we have added the following text to the discussion section.

"Hayashi and Koshimura (2013) measured the velocity of the 2011 Tohoku-oki tsunami in the Sendai Plain from the video records and reported that the 2011 Tohoku-oki tsunami was a supercritical flow in the area close to the coast. However, when they calculated the Froude number, the flow thickness was set to only 1 m or 2 m because they were interested in the behavior of the frontal part of the inundation flow. Nevertheless, the Froude number of the tsunami inundation flow exceeded unity in the Sendai plain only up to 1200 m from the shoreline. Considering that the central part of the flow reached a depth of 3--4 m, the Froude number is half of the value for the 1 m depth setting, indicating that the tsunami inundation flow was Fr-subcritical in most of the area in the Sendai Plain (Hayashi and Koshimura, 2013)."

26. Influence of inundation by Froude supercritical flows, P.16, Readers may not able to understand the bathymetric differences between Odaka and Sendai. Consider to provide an additional figure that compare the bathymetries.

RE: Thank you for the suggestion. In response to your comment, we have provided the bathymetric information in Figure 1A.

Responses to Reviewer 2:

Interactive comment on "Understanding flow characteristics from tsunami deposits at Odaka, Joban coast, using a DNN inverse model"

We thank the reviewer for the critical assessment of our manuscript and for the numerous comments and suggestions. Please find our responses to each comment below (in bold italics). Please note that we have addressed all typographical errors and minor revisions, as highlighted by the reviewer in the manuscript. However, we have exclusively addressed the major comments and questions posed by the reviewer.

Major comments:

1. P.2, "References needed. I don't think it is that much less than other areas. Please see the Study site section in Iijima et al. (2021, Sedimentary Geology)."

TODO: EDIT THIS PARAGRAPH.

RE: P. Line 48. Thank you for the comment. We have rephrased the paragraph as "However, the study of tsunami deposits around Minami-Soma has been limited due to the area being restricted until June 2012, primarily due to concerns regarding nuclear radiation exposure (Sato et al., 2014). We thank the reviewers for their important remarks. We closely examined Iijima et al. (2021), who surveyed adjacent areas, and fully discussed in the discussion section the implications of their findings for our study (Lines X-X). We also discussed the differences in perspective between their study and ours (Lines X-X).

2. P.3, "I think these citations are not needed here. It could be taken as if authors used their samples."

RE: P.3, Line 88, We have retained only the work by Koff et al., 2012, since their paper provides the distance information. The other citations have been excluded according to the suggestion.

3. P.3 "Please put the official name first (The 2011 Tohoku Earthquake Tsunami Joint Survey (TTJS) Group). I think "TTJS Group" would be an appropriate abbreviation. Please check the web page."

RE: P.5, Line 96, Thank you for the suggestion. We have revised the abbreviation to 'TTJS' and also added the official name.

4. P.4, "Did Sato et al. (2014) sample anything? I understand from the text that Sato et al. (2014) and TETJSG measured the tsunami height. Please clarify in the caption and legend. Also, it would be good to put the measured values in the map. This is more important than the sampling point number."

RE: Thank you for your comment. The authors' perspective is that displaying all measured values on the map could potentially make it appear cluttered. The primary purpose of this map is to illustrate the locations rather than to convey quantitative measurements. Additionally, it's worth noting that the corrections of measured values were executed differently across various survey groups. For instance, the values were extracted from the

KML file obtained from the TTJS website. Sato et al. (2014) did not take samples as the reviewer pointed out, so we revised the legend of this figure. We have removed the labels related to sample numbers, taking your suggestion into consideration.

5. P.11, Figure 6b, "Why is there a range in sorting?"

RE: Thank you for your comment. Sorting is represented by the standard deviation, indicating that we have taken into account the dispersion around the value.

6. P.16. "Is a gentle slope unsuitable for this model? I don't think it was mentioned in the text."

RE: Thank you for bringing this to our attention. The authors have considered removing the phrase 'gentle slope.'