We are grateful for the constructive and detailed comments of both reviewers. In accordance with their helpful and insightful recommendations, we will substantially revise the original manuscript to clarify the results and significance of this research.
Below, we provide our preliminary responses to each of the reviewers' comments. The comments of the reviewers are shown in italics and different colors (i.e., those of Reviewer 1 and 2 are brown and blue, respectively), while our responses are provided in black text.

Reviewer 1 COMMENTS AND AUTHOR RESPONSE

R1 General comment 1:
The authors investigate how the grain-size distribution of debris flows affects the fan-forming processes. For this, flume tests have been conducted to compare the debris-flow fan morphology under varying sediment source grain-size distributions. The obtained results associated with the debris-flow runout and space-time variations in the fan morphology provide important insights into how the grain-size distribution affects the fan formative processes. The topic is interesting, investigation is novel, and is within the scope of esurf. However, the ms requires a thorough revision in concept, mechanics and dynamics. Detailed suggestions and comments are provided below hopping that they will help to improve the quality, consistency and clarity of the revised ms.

Reply to R1 General comment 1: We sincerely appreciate your thorough and helpful review. In accordance with your comments, we will carefully revise the manuscript to clarify our findings and assertions in terms of the mechanics and dynamics.

R1 General comment 2:
Abstract can be improved. E.g., "Grain-size distribution was closely related to spatial diversity in fan morphology and stratigraphy." Should be other way round, "Spatial diversity in fan morphology and stratigraphy were found to be closely related to grain-size distribution."

Reply to R1 General comment 2: We will revise the abstract to improve the quality and clarity in accordance with your helpful guidance.

R1 General comment 3: *Introduction is not that much concerned about the main topic on how the grain-size distribution influences the debris flow fan morphology. So, it needs to be substantially expanded focusing on how the grainsize of the source material affects the deposition and fan formation process including the important and often dominant dynamical processes - the material separation, erosion and run-out dynamics.*

Reply to R1 General comment 3: To highlight our main topic on how the grain-size distribution influences the fan morphology, we will revise the introduction in light of important debris-flow dynamics.

R1 General comment 4: *Often the writing is not explicit, not smooth and difficult to follow. It seems if the ms was made for very short paper, less for a professional journal, requiring clearer and smoother presentation. Particular attention should be given on these issues.*

Reply to R1 General comment 4: We apologize for the confusion. To meet the required clearer and smoother presentation, we will thoroughly revise the manuscript in terms of clarity, overall language, and terminology.

R1 Specific comment 1: *L36-37: "Changes in the physical parameters (e.g., flow rate, duration, and sediment concentration)": The writing must be significantly improved, conceptually: flow rate, duration, and sediment concentration are not the physical parameters, rather they are the dynamical quantities. Physical parameters include densities, viscosities, frictions, slope geometry, curvature, etc.*

Reply to R1 Specific comment 1: We agree with this comment and will revise the sentences regarding the physical parameters.

R1 Specific comment 2: *L38-39: "and sediment entrainment rate (Egashira et al., 2001; De Haas and Van Woerkom, 2016)." better change to "and sediment entrainment rate (Egashira et al., 2001; De Haas and Van Woerkom, 2016; Pudasaini and Fischer, 2020: https://doi.org/10.1016/j.ijmultiphaseflow.2020.103416) and separation between the particles and fluid in the mixture (https://doi.org/10.1016/j.ijmultiphaseflow.2020.103292)."*

Reply to R1 Specific comment 2: We will revise the sentence in accordance with your comment. Moreover, we will add new results regarding the phase separation between the particles (solid) and fluid (please see **Reply to R1 Specific comment 14**).

R1 Specific comment 3: *L39-40: "and depending on the topographic complexity, could produce varying functional changes in subsequent debris flows.": not clear how topography produces functional changes and which? "functional and structural changes" what are the functional and structural changes? General readers may not be able to follow the text.*

Reply to R1 Specific comment 3: By avoiding the use of vague terms, such as functional and structural changes, we will revise the introduction section thoroughly.

R1 Specific comment 4: *L50: "A straight flume (8 m long and 0.1 m wide, with a uniform 15° bed slope": This is not true, and the text around must be improved appropriately, consistent with the* *corresponding figure.*

Reply to R1 Specific comment 4: We will revise the related sentences and figure to explain them correctly.

R1 Specific comment 5: *L50-67: "erodible bed conditions": Here comes the great thing! I see two major aspects in this ms. First, as the authors say, the effect of particle size in the erodible bed and how it will affect the deposition fan. I understand this differently than the author, it is not the particle size in initial debris mass (initially water is released) that will influence the deposition fan, but it is how the particle size of the erodible bed that affects the deposition fan when that bed substrate is eroded and entrained by the water flood released from upstream, consequently forming a debris mixture that ultimately flows down and deposits in the gentle open flat slope forming debris fan. The text does not mention this. Second, probably even more important, is the fact that the flood erodes and entrains the granular bed converting it in to the debris flow. So, the physical process of erosion, entrainment and the associated mobility must be described. This could however be done with respect to the mechanical erosion rate models and the mechanical model for the mass flow mobility with erosion (Pudasaini and Krautblatter, 2021: https://www.nature.com/articles/s41467-021-26959-5). I would focus on these governing aspects of experiments.*
Writing style needs to be made more appropriate with better physical understanding. "The supplied water generated a granular flow that imitated a single debris-flow surge and then entrained the erodible bed to the deposition area" This is difficult to follow, probably not representing reality. Does the water flow first generate the granular front by entraining the granular bed? I guess, as the water front impacts the granular bed it will erode and entrain the grain, mixing will take place resulting in the subsequent debris flow. Not that the way the authors explained. Moreover, you mixed up erosion and entrainment, which are clearly two different mechanical processes as proven by the reference mentioned above. So, the process of erosion and entrainment should be carefully investigated/discussed.

Reply to R1 Specific comment 4: We sincerely appreciate this important comment. We have read the new paper (Pudasaini and Krautblatter, 2021) and interpreted your concern as explained below:
1. Pudasaini and Krautblatter (2021) derived a new theoretical framework called the three-E (erosion-entrainment-energy) mechanical concepts.
2. They defined two velocities: Erosion velocity is the velocity that bed substrate is fed by the debris flow (i.e., the velocity vector intersects the flow line) and Entrainment velocity is the velocity that debris flow transports (entrains) the eroded bed materials. These velocities are basically different.
3. Erosion velocity contributes to the momentum transfer in the debris flow, whereas Entrainment velocity contributes to changes in the inertia of the debris flow. Thus, depending on the relationship between Erosion velocity and Entrainment velocity, the mobility of the debris flow can change.

4. Because in our experiments there is the possibility that these velocities were different between mono-granular material runs and multi-granular material runs, you have wondered that the debris-flow mobility was also different between mono-granular and multi-granular flows.

First, we agree that this new framework can be the key to theoretically unraveling the sediment erosion and deposition processes of debris flows. There is the possibility that our experiments are not adequate for direct assessing debris-flow dynamics based on the proposed 3E concepts. Both beds in the flume and the deposition area (connected plane) gradually change their morphology (slope), meaning that we could not trace the boundary between the flow bottom and bed surface easily, and preventing the measurement of erosion rate. Because of this limitation, most previous studies relied on the measurement of changes in the sediment concentration of debris flows rather than the erosion rate (e.g., Lanzoni et al., 2017). Indeed, even Pudasaini and Krautblatter (2021) have recognized the difficulty of the demonstration of their 3E model using existing flume test and field data. Anyway, while considering the limitations of our experimental setup, we will improve the introduction and discussion sections of the revised manuscript in light of this important framework.

The use of “entrainment” was intended to avoid confusion of the mixing between the erosion of fluvial sediment and erosion of bedrock (like incision). The erosion velocity is carefully defined by Pudasaini and Krautblatter (2021), but we were afraid that most readers recall “bedrock erosion” rather than debris-flow erosion processes. In the revised manuscript, we will adequate terms properly. For example, we will revise the sentences regarding the generation of debris flow as follows.

Revision: *By suddenly supplying water from the upper end of the flume, we generated a granular-water mixture flow that imitated debris flow similar to Lanzoni et al. (2017). We could not control erodible bed saturation completely because bed materials included voids. Saturated bed conditions were approximated by carefully supplying clear water across the entire erodible bed using watering cans just before we started the water supply from the upper end of the flume. Following this operation, a steady flow of clear water (the fluid density is ~1,000 kg/m^3) was supplied at a rate of 0.003 m^3/s for 60 s from the upper end of the flume. The supplied water plunged over the erodible bed and flowed downstream, generating a runoff front over the loose sediment particles. The runoff front scoured the sediment particles of the erodible bed and entrained the eroded particles, dispersing the entrained particles throughout the flow depth, and eventually transforming to a granular-water mixture flow that imitated a single debris-flow surge in the flume (Lanzoni et al., 2017).*

R1 Specific comment 5: *"the fan morphology gradually formed in accordance with the runout and inundation of the released granular flow": This is rather the fan of the granular-water mixture debris flow. For a granular fan, you must only have the dry material without water, for which the fan will be substantially different than what it is now. Two types of granular flow, namely mono-granular and multi-granular, were used to determine the impact of grain-size distribution within a debris flow on the fan-forming processes.": This is not right. You have two types of granular materials in the erodible bed, resulting in two types of debris flows, one consisting of water and mono-granular material, another composed of water and multi-granular [this term needs to be defined carefully, as mono-granular and multi-granular are not the usual terms, usual terms are the mono-dispersed and poly-dispersed, with respect to grain size, etc.].*

Reply to R1 Specific comment 5: We sincerely appreciate this comment and will revise the related sentences to avoid this confusion as follows.

Revision: *The generated granular-water mixture flow reached the deposition area and caused its runout and inundation. The slope of the deposition area decreased from 12° to 3° at a rate of 3° per meter (Fig. 1a, b), and so the fan morphology gradually formed in accordance with the runout and inundation of the granular-water mixture flow.*

Additionally, in the earlier part of the revised manuscript, we will define the mono-granular and multi-granular flows, respectively.

Revision: *In this study, we intended to generate and compare the granular-water mixture flows that are of similar flow states but with different grain-size distributions, to focus on the effects of debris-flow grain-size distribution on the debris-flow fan during the debris-flow runout and inundation processes. To accomplish this, two types of sediment particles were used to generate two types of the granular-water mixture flows: mono-granular particles that sediment particles are quasi-mono-dispersed sediment particles consisting of 2.02–3.24 mm (the average grain size, D_{50}, is 2.6 mm) and multi-granular particles that are poly-dispersed sediment particles consisting of 0.6–7.5 mm (Table 1). The density and the internal friction angle of both particles are 2,640 kg/m^3 and 34.0°, respectively. Hereafter, the granular-water mixture flows that are generated by the mono-granular particles and the multi-granular particles are referred to as the mono-granular flow and the multi-granular flow, respectively. We carried out four experimental test runs for the mono-granular flow and multi-granular flows, respectively.*

R1 Specific comment 6: *Not enough information on the material and channel are provided, e.g., the basal and internal friction angles of the granular material, viscosity of water, their densities, and so on. This information is crucial in understanding erosion-entrainment and mobility, the mixing and separation between particles and fluids, and the transport/deposition of debris mixture.*

Reply to R1 Specific comment 6: We agree with this comment and will add this information in the revised manuscript (please see **Reply to R1 Specific comment 4** and **Reply to R1 Specific comment 5**).

R1 Specific comment 7: *Another principle concern is the representative grainsize, the two granular materials, mono-dispersed and poly-dispersed are represented by the same average grain size (D50). This does not help to physically clearly study the erosion-entrainment, transport and deposition fans, except that you can say – we observe this and that for the mono-dispersed and poly-dispersed erodible bed. But, we don't know how small and big particles in the mixture influence the erosion, mixing or separation, dynamics and deposition processes. Moreover, different grains might need to be represented by different rheological equations. These are crucial aspects the authors should discuss. Otherwise the results can not be understood mechanically and dynamically clearly, and these data cannot that easily be used in model validation and parameter calibration.*

Reply to R1 Specific comment 7: We agree with this comment. By referring to new results how differences in the grain-size distribution lead to variation in the phase separation and symmetry of the fan morphology, we will improve the discussion section in light of known dynamics with respect to sediment erosion/deposition, flow runout, and the phase separation (**Reply to R1 Specific comment 14** and **Reply to R2 Comment 25**).

R1 Specific comment 8: *L69-70: "sediment was released to the deposition area". A bit strange writing. First, it is not sediment, it is the debris material. Second, it is not released to the deposition area, it is the transported material in the deposition area. So, the dynamical perspectives are weak.*

Reply to R1 Specific comment 8: We will revise the sentence in accordance with your comment (please see **Reply to R1 Specific comment 5**).

R1 Specific comment 9: *L70-73: "The flow depth of a generated granular flow cannot be measured in the flume because the thickness of the erodible bed decreases sequentially in response to the sediment entrainment. Therefore, the displacement of the flow surface at three positions in the flume (upper, middle, and lower, Fig. 1a) was measured to account for this shortcoming, using ultrasonic displacement meters":*
I agree with the first sentence, it is a really complex process, however, there are some literature in

this direction with some success (Lanzoni et al., 2017: https://doi.org/10.1002/2016JF004046). The authors should put some efforts to review relevant literature. The bed erosion process is an under-investigated process, and I respect any attempt in this direction. The second sentence is not the solution to the first, because, the measured flow depth cannot be split into the material from the flow and from the bed. Thus, it cannot be straightforward connected to the erosion depth. Furthermore, the involved energy associated with erosion is the dominant factor to decisively defining the dynamics, runout and the associated impact forces of the erosive mass flows. This needs to be discussed with respect to the references mentioned above.

Reply to R1 Specific comment 9: We agree with your statement about the erosion/entrainment processes and the necessity of the descriptions based on relevant literature. As Pudasaini and Krautblatter (2021) proposed, erosion and entrainment potentially influence the debris-flow dynamics and runout through the different involved energy (different contributions of momentum conservation). Because we could not directly measure erosion and entrainment velocity from experimental data, the explicit application of the 3E concepts proposed by Pudasaini and Krautblatter (2021) is difficult. Thus, while referring to the literature effectively, we will consider such aspects in the discussion section of the revised manuscript. Additionally, we will revise the sentences regarding the flow depth measurements to improve clarity as follows.

Revision: *We measured the flow depths of the generated debris flows in the flume and investigated the runout and fan-forming processes at the deposition area. By comparing the changes in the flow depth between the mono-granular flows and the multi-granular flows, we assessed whether it has been deemed that the multi-granular flows exhibited the analogous hydrograph and velocity, compared with those of the mono-granular flows. Note that, we could not directly measure the flow depths of the generated debris flows because the thickness of the erodible bed decreases sequentially in response to the sediment erosion and entrainment. The continuous sediment erosion and entrainment hampered to estimate of the boundary between the flowing bottom and the bed surface (e.g., Lanzoni et al., 2017), which hampers a quantitative measurement of the flow depth of the debris flow. Instead of the flow depth, we measured the changes in the displacement of the flow surface by three ultrasonic displacement meters (Omron, E4PA) at a sampling rate of 50 Hz. Each ultrasonic displacement meter was installed at the three positions in the flume, respectively (Fig. 1a). Hereafter, the positions are referred to as upper, middle, and lower measurement positions, respectively, from the upstream to downstream of the flume. Because the initial depth of the erodible bed was adjusted as 0.2 m, the flow depths of the debris flow were interpreted based on the measured displacement subtracted from this initial bed depth. Based on differences in the timing that the debris-flow front reached the lower position, we compared the flow rate in the flume among test runs.*

R1 Specific comment 10: *I stop suggesting and commenting on the mechanical and dynamical* *aspects of the ms, and hope that the authors will improve the text while revising it.*

Reply to R1 Specific comment 10: We sincerely appreciate your constructive suggestions again. In accordance with your comments, we will carefully revise the manuscript to strengthen aspects in relation to debris-flow mechanics.

R1 Specific comment 11: *Fig. 2: Figures are difficult to follow. It should be self-explanatory. For example, Run 1-4, are they repeated exps.?*

Reply to R1 Specific comment 11: "Run" indicates each experimental test run. We will revise the sentences in the method section to convey the results smoothly (please see **Reply to R1 Specific comment 5**).

R1 Specific comment 12: *L98-99: "The thickness of the erodible bed decreased monotonically with time, probably because the entrainment rate was the same in all the test runs, irrespective of the grain-size distribution of the granular flows": This cannot be true, could only be a speculation. Because, as proved in the above-mentioned references, erosion rate is a complex phenomenon, and changes with the dynamic load applied by the flow and resisted by the bed. This needs to be discussed.*

Reply to R1 Specific comment 12: As we responded above, we will carefully describe and discuss the aspects regarding erosion/entrainment rate (please see **Reply to R1 Specific comment 4** and **Reply to R1 Specific comment 9**).

R1 Specific comment 13: *L100-102: "Overall, the results from the flume experiment showed that the difference in the grain-size distribution did not lead to substantial changes in the hydrograph and arrival time of the granular flows.": I can't fully agree with this. E.g., if you take the mean of four runs in C and F and plot them in one figure, you will see discernible difference.*

Reply to R1 Specific comment 13: We agree that the previous statement was a strong tone and will carefully explain the differences and similarities between mono-granular and multi-granular flows.

R1 Specific comment 14: *L113: Grain size separation is one aspect, but separation between particles and fluid (as seen in the experimental results) is another, even more complex mechanical phenomenon in debris flow. However, the authors did not discuss anything on it.*

Reply to R1 Specific comment 14: We sincerely appreciate this important suggestion and agree that the separation between particles (sediment) and fluid is certainly one of the important aspects. As the preliminary analysis, we measured time-series changes in runout distances of the fronts of generated debris flows with a temporal resolution of 0.1 s, using the captured video and the grid lines at the deposition area (**Figure R1**). We found the different trend with respect to the separation between the solid (sediment particles) and fluid phases: the phase separation of the multi-granular flows occurred in the earlier stage of runout processes compared with those of the mono-granular flows. We will assess and discuss these results in the revised manuscript.

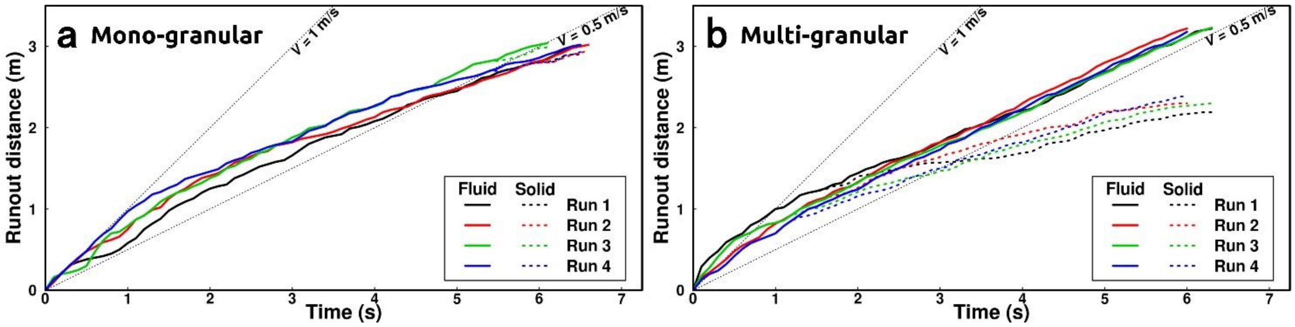

Figure R1: Time series changes in the runout distances of the flow fronts. (a) mono-granular flows. (b) multi-granular flows.

R1 Specific comment 15: *L123: "avulsed obviously": it is better also to put orthophoto to clearly see avulsion. The quality of Fig. 5-8 should be improved, with filters, or whatever means such that we can clearly see avulsion. The problem I have seen is that avulsion cannot be predicted, or was not possible with the present setup. We should understand why this is happening. This needs to be discussed, because, one of the main aims of experiments should be to generate reproducible results.*

Reply to R1 Specific comment 15: We apologize for the confusion. While effectively using metrics regarding the fan shape, we will improve the explanation how the avulsion occurred in response to the fan development (please see **Reply to R2 Comment 25**).

R1 Specific comment 16: *L142-144: "Some equations that describe debris flows assume that multi-granular debris flows can be approximated to mono-granular debris flows with the same average grain-size (e.g., Egashira et al., 1997; Takahashi, 2007).": This is not the state-of-the art. The multi-mechanical, multi-phase mass flow model by Pudasaini and Mergili (2019: https://doi.org/10.1029/2019JF005204) has proven the necessity of simulating debris flows as mixture of different materials, that has been used in accurately simulating complex multi-phase natural events (Mergili et al., 2020: https://doi.org/10.5194/nhess-20-505-2020; Shugar et al., 2021: DOI: 10.1126/science.abh4455). The ms should be up dated with relevant, recent literature.*

Reply to R1 Specific comment 16: We apologize for the confusion. In the revised manuscript, while referring to the suggested multi-phase model, we will revise the related sentences to improve clarity.

R1 Specific comment 17: *L144-145: "However, the mono-granular and multi-granular flows with the same average grain-size produced fans with different morphologies": This is probably the most important aspect of this ms, and I like it. However, it has not yet been clearly discussed for why this is so. The authors should put some energy to explore why it is happening, that will lift the importance of this paper to a higher level.*

Reply to R1 Specific comment 17: We agree with these comments and will emphasize the explanation of why the differences in the fan morphology arose in the revised discussion section, by referring to new results (please see **Reply to R1 Specific comment 14** and **Reply to R2 Comment 25**).

R1 Specific comment 18: *L146-147: "which indicates that existing models that assume a mono-granular approximation may provide ambiguous simulations of the debris-flow deposition and inundation ranges.": This proves the need of multi-phase mass flow models (mentioned above) in properly simulating debris flows. This should be discussed.*

Reply to R1 Specific comment 18: We sincerely appreciate this important comment and agree with the importance of how relatively small particles behave like fluid or solid and change the stress structure of debris flows. As you mentioned, natural debris flows obviously contain such small particles, which may be responsible for further variations in the fan morphology. We will revise the discussion section considering this aspect.

R1 Specific comment 19: *Discussion and Conclusion, References:*
Needs re-working, including the above suggestions. E.g., multi-phase flow simulations, erosion-entrainment and mobility, separating particles and fluid, and so on. Important point why the flow with the poly-dispersed erodible bed has shorter travel distance and run-out reveals that more energy has been consumed for this than the bed with mono-dispersed particles. This exclusively depends on the erosion velocity controlling the mobility of the mass flow, this fact has been proven by the mechanical model for the mobility of erosive mass flows by Pudasaini and Krautblatter (2021). The discussion and conclusion should give proper space for these important mechanical and dynamical aspects also observed in this ms.

Reply to R1 Specific comment 19: We sincerely appreciate this important comment and will discuss this aspect referring to new results (please see **Reply to R1 Specific comment 14**).

R1 Technical comment 1: *L22: "sinks", the meaning was not that clear, better would be "deposits"?*

Reply to R1 Technical comment 1: By avoiding the use of vague terms, we will improve the clarity of the introduction section thoroughly.

R1 Technical comment 2: *L29: Please check English.*

Reply to R1 Technical comment 2: We will revise it adequately.

R1 Technical comment 3: *L85: "SfM-MVS": is its meaning clear?*

Reply to R1 Technical comment 3: By referring adequate literature, we will revise this sentence.

R1 Technical comment 4: *L97-98: "while, apart from run 1, those of the multi-granular flows were around ~0.03 m": Not true. Please check all the technical details carefully.*

Reply to R1 Technical comment 4: We will carefully revise it to improve clarity.

Reviewer 2 COMMENTS AND AUTHOR RESPONSE

R2 Overall comment: *In this manuscript the authors used a flume to analyse how the grain size distribution of a debris flow may impact the morphology of the resulting fan. The authors ran 2 sets of experiment runs in their flume, all parameters inside the experiments were kept constant except the grainsize distribution. One set of experiment runs used monogranular sediment while the other used multigranular. Both sets had the same average grain size so the authors could identify the impact of variations in grain size on the debris flow fan. They quantified these changes by measuring the surge height in the flume, the speed of the surge within the deposition area, the runout distance and a DEM of the final debris flow. The authors discovered that multigranular debris flows were more likely to produce alluviations in the debris flow resulting in asymmetrical fans. They postulate that these alluviations are the result of grain size segregation occurring within the flow where coarse sediment is forced to the front of the flow where it can produce an obstacle for any following surges.*

I think this study is an interesting addition to the literature on debris flows. The experiments seem well thought-out and the results aim to fill a clear knowledge gap. However, there are several areas where I feel the manuscript needs to be improved before it is ready for publication. The manuscript is very short and as a result I feel that significant detail is missing, particularly from the description of the experiment design, results and discussion. I also found the figures poorly cited and discussed throughout. I have provided more specific comments below for the authors to read through. I hope the authors find my comments useful and I look forward to seeing the revised manuscript.

Reply to R2 Overall comment: We sincerely appreciate your insightful review and constructive suggestions. In accordance with your comments, we will thoroughly revise the manuscript to improve clarity and the level of detail in all sections. My response to each of your specific comments is provided below.

R2 Comment 1: *Introduction: The introduction is too short and vague to be of use to the reader. Despite the research statement at the end of the section it is not completely clear how the authors see the study contributing to the literature. It is also not obvious from these paragraphs why the authors have chosen to focus on grain size distribution for this study rather than many of the other controlling factors highlighted here. Finally, this section would be greatly improved if there was better separation between discussing debris flow physics from debris flow fans. Currently it is very confusing whether the authors are referring to how a certain parameter might affect a debris flow or how it may affect the autogenic fan forming processes or the links between the two.*

Reply to R2 Comment 1: We agree with this comment and will revise the introduction section by separating descriptions with respect to debris-flow physics and debris-flow fans.

R2 Comment 2: *Lines 25 – 26: What specific climate and sediment dynamics information can be identified from debris flow fans? And how is it derived? How is the form (which is what is investigated here) important?*

Reply to R2 Comment 2: By avoiding the use of vague terms, we will improve the clarity of the introduction section thoroughly.

R2 Comment 3: *Lines 26 – 29: If debris flow fans are primarily formed by autogenic processes how can information on any external forcing be derived from them?*

Reply to R2 Comment 3: By avoiding the use of "autogenic", we will explain how fan-forming processes are driven in the revised introduction section.

R2 Comment 4: *Lines 31-33: Shifting the focus of the paragraph from a geological perspective of fans to one about hazard is confusing to the reader particularly as neither focus is well covered.*

Reply to R2 Comment 4: We agree with this comment. We will explain those aspects with regard to debris-flow hazards and records of sediment regimes as general importance to study debris-flow fans in the first paragraph of the introduction, rather than the explanation in detail.

R2 Comment 5: *Lines 34-36: It would be useful to the reader if the authors would elaborate on how* *these physical factors affect morphology and stratigraphy of the fans.*

Reply to R2 Comment 5: We agree and will carefully explain on linkages between debris-flow physical factors and influences on morphology and stratigraphy of the fans.

R2 Comment 6: *Lines 36 – 38: From this section the reader cannot tell how these changes will affect the debris flows. The authors do not define the property that is changing carefully nor do they describe the impact of these changes on debris flow behaviour. Without this information the readers can not make the link between debris flows and the resulting fan.*

Reply to R2 Comment 6: To taking account this comment and **R2 Comment 4**, while avoiding the use of vague terms, such as functional and structural changes, we will revise the introduction section thoroughly.

R2 Comment 7: *Lines 44 – 48: This is a good succinct research statement however it is completely disconnected from the preceding 2 paragraphs. It does not mention why the authors have chosen to focus on grain size distributions nor how they expect them to change the debris flow fan.*

Reply to R2 Comment 7: To convey our intention and why we designed the experiments that control only differences in grain-size distribution, we will thoroughly revise the introduction section.

R2 Comment 8: *Methods: The experiment design is reasonably well explained, however I struggled to understand what exactly was being measured. The authors have gone to great lengths to capture the vast amounts of data generated by the experiments; however, they do not discuss why they collected these particular datasets or what they plan to do with them. A better motivating statement within the introduction will help to improve this section.*

Reply to R2 Comment 8: We agree and will provide adequate context at the end of the introduction section to smoothly connect to the methods section. Also, we will carefully describe why we measured both flow depth in the channel and changes in the fan morphology to convey our intention that examines whether debris-flow surges with different grain-size distributions can provide different fan morphology even their flow states are similar.

Revision in the end of the introduction section: *The primary objective of this study was to assess how the grain-size distribution influences the fan morphology, especially during the debris-flow runout and inundation. To archive this, we carried out reduced-scale flume tests to compare the fan morphology that was formed by the single debris-flow surge with the different grain-size distribution but with similar flow characteristics. Using the photogrammetry and video-image analysis, we* *investigate how the difference in the grain-size distribution serves to variations in the runout characteristics and fan morphology. The intention underlying this comparison was to interpret the differences in the fan morphology in terms of known debris-flow mechanics. The final goal was to elucidate whether the difference in the grain-size distribution of the debris flow can change the fan morphology by solely influencing during the runout process without the difference of the debris-flow magnitude in the channel.*

Revision in the method section: *We measured the flow depths of the generated debris flows in the flume and investigated the runout and fan-forming processes at the deposition area. By comparing the changes in the flow depth between the mono-granular flows and the multi-granular flows, we assessed whether it has been deemed that the multi-granular flows exhibited the analogous hydrograph and velocity, compared with those of the mono-granular flows. Note that, we could not directly measure the flow depths of the generated debris flows because the thickness of the erodible bed decreases sequentially in response to the sediment erosion and entrainment. The continuous sediment erosion and entrainment hampered to estimate of the boundary between the flowing bottom and the bed surface (e.g., Lanzoni et al., 2017), which hampers a quantitative measurement of the flow depth of the debris flow. Instead of the flow depth, we measured the changes in the displacement of the flow surface by three ultrasonic displacement meters (Omron, E4PA) at a sampling rate of 50 Hz. Each ultrasonic displacement meter was installed at the three positions in the flume, respectively (Figure 1a). Hereafter, the positions are referred to as upper, middle, and lower measurement positions, respectively, from the upstream to downstream of the flume. Because the initial depth of the erodible bed was adjusted as 0.2 m, the flow depths of the debris flow were interpreted based on the measured displacement subtracted from this initial bed depth. Based on differences in the timing that the debris-flow front reached the lower position, we compared the flow rate in the flume among test runs.*
The measurements of the runout and fan-forming processes relied on image analyses. To observe the runout and fan-forming processes, four digital cameras were installed above the deposition area (Fig. 1a) similar to Tsunetaka et al. (2019). One of these cameras (PENTAX, K-3ii) recorded a video of the fan-forming processes at a frame rate of 60 fps. The images extracted from the recorded video were used to analyze the debris-flow runout distance and velocity as well as the changes in the flow direction during the inundation at the deposition area. The other three of these cameras (Nikon, D5100) were automatically synchronized using the external shutter (Canon, TC-80N3) and captured images at 1-s intervals. These sets of three synchronized images were processed to generate topographic data of the formed fan morphology using a photogrammetry method. Below, we explain the detail of each image-based analysis.

R2 Comment 9: *Lines 50-60: The authors have not explained how the debris flow surge is generated. The paragraph could be separated to first describe how and where the surge is generated before* *discussing the depositional area.*

Reply to R2 Comment 9: While referring to the adequate literature and considering given comments, we will carefully explain how we generated debris-flow surges (please see **Reply to R1 Specific comment 4**).

R2 Comment 10: *Lines 61-67: How fans are produced in this study? Is the fan a result of a single surge triggered by the outlet of water? Or the result of multiple surges? Is the erodible layer rebuilt between surges? What is going to be measured as a result of these experiments?*

Reply to R2 Comment 10: We focused on the debris-flow fan that is formed by a single debris-flow surge. Each experimental result (each run) indicates the data of the fan formed by a single surge rather than multiple surges. We will explain why we designed such setup and condition by descriptions regarding our intention (please see **Reply to R1 Specific comment 5**).

R2 Comment 11: *Lines 69-74: Why is flow displacement being measured? Why is the flow height of the surge important to the authors?*

Reply to R2 Comment 11: We intended to clarify differences and similarities between the mono-granular and multi-granular flows in the flume using measurements of flow heights. We will carefully explain our intention and how the measured depth helps our interpretations (please see **Reply to R1 Specific comment 9** and **Reply to R2 Comment 8**).

R2 Comment 12: *Lines 79-80: What is being measured and how?*

Reply to R2 Comment 12: To check the accuracy of the SfM photogrammetry, we compared the deposition depths of the experimental debris-flow fan that were directly measured after each experiment run using a ruler. We will explain it in detail in the revised manuscript as follows.

Revision: *To assess the accuracy of DEMs, deposit depths of the debris-flow fan were directly measured at the intersections of the grid lines using a ruler after each experimental run, and compared the measurements with the deposition depths extracted from the generated DEM. The measured elevations corresponded to the DEM-extracted elevations, thereby indicating that the DEMs approximated well to the fan morphology (Fig. S1).*

R2 Comment 13: *Line 86: It is not clear what is meant by "the SfM-MVS photogrammetry could not measure locations where granular flows descended". Does this mean that the photogrammetry cannot measure the flow when it is moving?*

Reply to R2 Comment 13: Yes, the moving flow provided complex surface undulations and different brightness in captured images, which resulted in unmeasurable zones of the photogrammetry results. We will clarify this point in the revised manuscript as follows.

Revision: *During the inundation of sediment at the deposition area, the SfM-MVS photogrammetry could not measure locations where granular flows descended (i.e., moving zone), which resulted in holes of DEMs due to lacking topographic data.*

R2 Comment 14: *Results: The results section also suffers from the same problems as the previous sections. What is being measured and compared between the different runs is not specifically stated and as a result it is hard to understand some of the findings of the manuscript. Many of the result figures are poorly explained and some are cited out of order or not cited at all.*

Reply to R2 Comment 14: We agree with this comment and will revise the results section by referring to figures adequately.

R2 Comment 15: *Line 95: What is the lower portion of the flume? How is this defined?*

Reply to R2 Comment 15: The lower position should be stated as the lower measurement position of the ultrasonic sensor. We will revise the related sentences to define it (please see **Reply to R1 Specific comment 9** and **Reply to R2 Comment 8**).

R2 Comment 16: *Line 96: Same with arrival point and upper position.*

Reply to R2 Comment 16: Similarly, we should define the upper position indicates as the upper measurement position of the ultrasonic sensor. We will revise the related sentences to define it (please see **Reply to R1 Specific comment 9** and **Reply to R2 Comment 8**).

R2 Comment 17: *Line 97: What is a run? This refers back to the earlier point that it is not clear whether the experiment is single or multiple surges.*

Reply to R2 Comment 17: A run indicates an independent experimental test run. We will define it in the revised manuscript (please see **Reply to R1 Specific comment 5** and **Reply to R1 Specific comment 11**).

R2 Comment 18: *Line 101: Unclear how the arrival time is measured.*

Reply to R2 Comment 18: We measured the time from the timing that the flow front started its runout at the deposition area to the timing that the flow front stopped as the arrival time. We will add new results with respect to the arrival time in the revised manuscript with an explanation of how we measured them (please see **Reply to R1 Specific comment 14**).

R2 Comment 19: *Lines 103-106: This should be in the discussion or introduction rather than in the results*

Reply to R2 Comment 19: We agree and will discuss this aspect regarding flow state and similarity low in the discussions section.

R2 Comment 20: *Lines 110 – 113: It is unclear which panel is figure 3 is being referred to. Panel 3c is also not cited at all in this section.*

Reply to R2 Comment 20: We apologize for the confusion and will revise the related sentences to clarify the referred figure.

R2 Comment 21: *Figures S2 and S3 seem important to the overall narrative of the manuscript and therefore the authors should consider including them as part of the main text.*

Reply to R2 Comment 21: We appreciate this suggestion and will include Figures S2 and S3 in the revised main text.

R2 Comment 22: *Lines 119-121: State how the locations of the lobes differ, are they closer to the flume exit? Does the slope differ between the 2 locations?*

Reply to R2 Comment 22: We agree that a detailed explanation is necessary here. Because the generated DEMs 10-seconds after the start of the runout could not measure the lobe surface due to the lack of data, we cannot mention differences in the slope accurately. Given this, as you mentioned, we will explain the difference based on the distance between the lobes to the flume outlet.

R2 Comment 23: *Line 124: Why is the series of events being described in terms of time? Time is not likely to be a controlling factor in how the debris flow behaves. The slope over which it is traveling is much more likely to be the control (along with the grain size distribution).*

Reply to R2 Comment 23: We sincerely appreciate this important comment and agree that the slope is one of the factors that directly controls how the debris flow behaves. In this study, we focused on how a single surge (i.e., a continuous flow) forms the debris-flow fan in accordance with the sediment deposition and inundation, which is the difference of our study compared with previous related studies that focus on whether the differences of characteristics among surges influence on the fan morphology. These previous studies allowed to measure the slope by measuring the topography of lobes before and after supplying each surge. In contrast, because in this study the surge continuously moves until the end of an experimental run, we could not measure the changes in the surface slope of the fan during the fan-forming phase. This is an inevitable limitation arising from the difference in the study target. Given this, while highlighting the difference in the target of our study, we will explain time-series changes in the fan-forming processes by referring to new results with respect to the symmetry of the fan (please see **Reply to R2 Comment 25**).

R2 Comment 24: *Figures 5 – 9 are very poorly explained and hard to interpret. This is not helped by there being no explanation of what is meant by "Run" in the experiment.*

Reply to R2 Comment 24: We apologize for the confusion and will revise the related sentences to clarify what run indicates here (a run indicates an independent experimental case, also please see **Reply to R2 Comment 10 and 17**).

R2 Comment 25: *Lines 217-129: A numerical metric would help to compare the shape of the mono vs multigranular flows. Perhaps the angle of deviation from directly straight or a ratio of the left vs right side length?*

Reply to R2 Comment 25: We sincerely appreciate this important comment and agree that a numerical metric can help the comparison of topography between the mono- and multi-granular flows. Considering the simplicity of the definition, we will add the latter metric of the ratio of the length.
To investigate differences in the fan shape between the mono-granular and multi-granular flows, we proposed an index that focuses on the symmetry of the fan shape. The proposed symmetric index (SI) is defined as
SI = LR/LL –(1)
where LR and RR are the length of the fan from the midline to the edge of the left and right bank side of the fan, respectively. When the fan width is close to symmetry, a SI value is approximately one. We calculated values of SI indices from the width of the fan at cross-sections per 0.2 m from the outlet of the flume, using orthophotos and DEMs 10, 20, 30, 40, 50 seconds after the start of the flow runout (**Figure R2**).
Time-series changes in the SR indices demonstrate the linkage between the sifting of the direction of the flow runout and fan development processes. The differences in the SI values among test runs became notable with the increase in the distance from the flume outlet in the measurements after 20 s, 40 s, and 50 s from the start of the flow runout (**Figure R2 c–d and g–j**). This increase in the asymmetry of the fan morphology corresponded to the timing of shifting the flow direction (i.e.,

avulsion process). Moreover, the range in the SI values among test runs widened in the multi-granular flows compared with that of the mono-granular flows (e.g., **Figure R2 g–h**). Therefore, the wide-ranged grain-size distribution within the debris flows could result in diverse deposition and inundation patterns when the avulsion occurred. We will improve the clarity of the results and discussion sections in the revised manuscript while explaining these new results in detail.

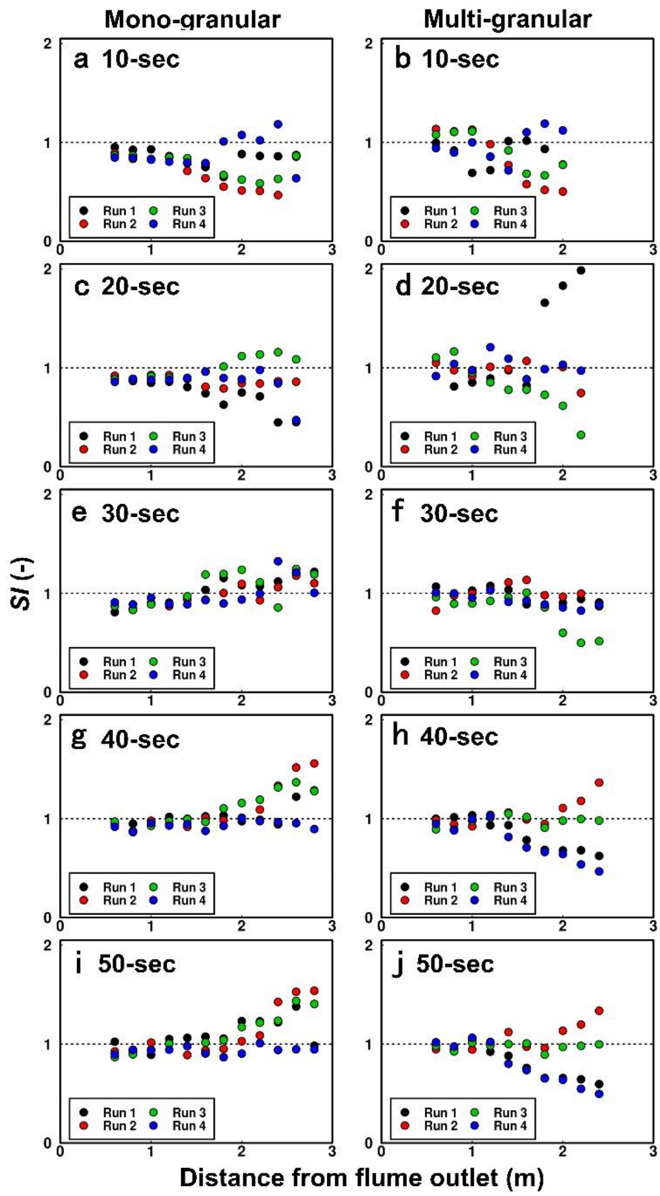

Figure R2: Time series changes in the SI values of the debris-flow fans. (a) mono-granular flows. (b) multi-granular flows. The left and right panels indicate mono-granular flows and multi-granular flows, respectively.

R2 Comment 26: *Line 135: The difference in shape at the 2.2m line could be due to the difference in runout. While in the monogranular flow the authors are measuring the apex of the flow height in the multigranular it after the apex. As the debris flows are producing a fan like shape you would expect the fan to be wider after the apex regardless of the granular structure.*

Reply to R2 Comment 26: The difference in the runout distance is closely linked to the difference in the fan morphology between the mono-granular and multi-granular flows, which is responsible for the difference in the changes in the flow directions during the fan-forming processes. As you mentioned, we also should note the location of the fan apex and Figure 10g–i measured the difference in the shape lower than the fan apex carefully. Considering this, we will revise the third paragraph to clarify how the difference in the runout between mono-granular and multi-granular flows propagates to the differentiation in the fan shape.

R2 Comment 27: *Discussion: The discussion, similarly to the introduction, is lacking in detail and is too vague in some of its points to make an impact on the reader. Currently the discussion spends too much time focusing on areas the authors did not investigate (pore fluid seepage) and not enough time putting their results back into the context of the literature. To help the reader the authors should put their results, which are interesting and novel, front and centre and discuss the processes that they actually recorded before moving on to areas they do not have direct evidence for.*

Reply to R2 Comment 27: We agree that the discussion section too much focuses on the impact of the pore fluid seepage, rather than discussing the obtained results in detail. In the revised manuscript, we will mainly focus on the description of how flows provide the fan with different shapes in accordance with the difference in the grain-size distribution. Then, we will discuss the mechanisms that potentially form different fan shapes (please see **Reply to R1 Specific comment 14** and **Reply to R2 Comment 25**).

R2 Comment 28: *Lines 141 – 142: The term "processes" is too vague and the results do not mention stratigraphy at all so this seems like a strange sentence to start the discussion with.*

Reply to R2 Comment 28: We will revise this sentence to focus on the difference in the fan morphology.

R2 Comment 29: *Lines 142 – 147: This section is poorly linked to the previous opening statement of the discussions.*

Reply to R2 Comment 29: Again, according to this comment and **R2 Comment 28**, we will revise this sentence to focus on the difference in the fan morphology.

R2 Comment 30: *Lines 150 – 151: This would also apply if the flow was monogranular with coarse grains.*

Reply to R2 Comment 30: We agree with this comment. The coarse monogranular grains can increase the flow resistance but also may decrease the entrainment rate in the channel. To control the flow state in the channel between the monogranular and multigranular debris flows, we carefully designed the grain-size distribution of the multi-granular flow. Specifically, we intended to generate the flows with a similar entrainment rate (i.e., flow depth) without the phase shift of relatively small sediment particles. While highlighting our intention of the experimental setup, we will revise the main text.

R2 Comment 31: *Lines 152 – 155: The authors previously mentioned that there was minimal difference between the thicknesses of the mono and multi-granular flows. This idea of the coarser grains forming an obstacle which diverts the tail of the flow should be expanded upon further with more descriptions if the authors believe it to be significant.*

Reply to R2 Comment 31: We agree with this comment. By referring to new results adequately, we will expand the explanation regarding this idea (please see **Reply to R1 Specific comment 14**).

R2 Comment 32: *Lines 158 – 164: It is unclear what the authors are suggesting here. How can there be moisture differences in the bed of the depositional area? The depositional area is the same for all of the test runs? Unless they are discussing deposition on a previously deposited fan? This is very underdeveloped.*

Reply to R2 Comment 32: We agree with this comment. Again, by referring to new results adequately, we will expand the explanation regarding this idea (please see **Reply to R1 Specific comment 14**).

R2 Comment 33: *Lines 165 – 169: This section is a strange ending to the manuscript. It focuses on two areas which the authors did not measure in their study; stratigraphy and moisture content of the fan.*

Reply to R2 Comment 33: We agree with this comment. Based on new results with respect to the phase separation and fan morphology, we will revise the discussion section thoroughly (please see **Reply to R1 Specific comment 14** and **Reply to R2 Comment 25**).

R2 Comment 34: *Conclusions: The conclusions does not contain any references to the discussion and therefore it feels disconnected from the rest of the manuscript.*

Reply to R2 Comment 34: We agree with this comment. Taking account into how the phase separation and fan asymmetry influence fan-forming processes, we will revise the discussion section. By referring to our new findings and assertion in the revised discussion section, we will improve the clarity of the revised conclusion section.