We are grateful for the suggestions of the reviewer and his detailed annotations in the PDF. We will revise the manuscript carefully including the annotations given in the PDF. In the following we give detailed answers (in blue) to the comments.

This is a unique and well organized study of avalanche dynamics, which uses in-flow particle sensors, FMCW radar, and avalanche dynamics simulation. The approach is novel and provides new insight into parameterization of avalanche flow models. This is a fundamental contribution to this field, and should be published after minor revisions. I have some main points to consider below, and have attached an annotated PDF with detailed suggestions.

Thank you very much for your positive and constructive feedback on our manuscript. We are pleased that you consider this work a fundamental contribution to the field of avalanche dynamics and appreciate the novelty of combining in-flow particle sensors (AvaNodes), FMCW radar, and simulation for improved model parameterization.

Following your suggestions, we have carefully addressed all comments and will revise the manuscript accordingly. In particular, we will make the following key changes:

- Deliver an improved description of sensor accuracy, including the radar setup, resolution, and positioning in the methods section.
- Add more detail about the avalanche event itself, including a clearer definition of the avalanche characteristics.
- Clarify issues regarding fracture depth variation, uncertainty estimates, and the combination of measurement results to provide a more comprehensive understanding of the data interpretation.

We hope that these revisions will addres all concerns and improve the clarity and scientific value of the manuscript. We look forward to the continued review process.

Sincerely,
Michael Neuhauser

1) Sensor details. Some additional details are needed about the sensors - where is the radar located? What frequency range and range resolution? How accurate do you expect the avalanche front observations to be? This is important to help the reader interpret the results.

A1) We will revise section 2.1 with more information about the measurement systems and rewrite Line [90-95] to:

The FMCW radar system (mGEODAR) was positioned at Seegrube at 1900 m.a.s.l., approximately 700 m away from the release area on the north-facing slope of the Seilbahnrinne, providing a clear line of sight to the main avalanche path up to the avalanche dam, beyond which the radar view becomes obstructed. The radar operates with a range resolution of 0.375 m per bin and a sampling frequency of 50 Hz, enabling the precise tracking of the avalanche front over time. Based on prior evaluations and controlled experiments, the expected positional uncertainty of the radar-tracked avalanche front is estimated to be approximately ±1–2 m, which corresponds to around five radar range bins. This provides reliable observations for tracking the avalanche front's evolution, especially in the middle section of the path where radar line of sight aligns well with the flow direction. In comparison, the AvaNodes (C07, C09, and C10) record GNSS-based three-dimensional positions at 10 Hz, with a manufacturer-specified horizontal position accuracy of ±2.5 m and a

Doppler-based velocity accuracy of ±0.05 m/s along each axis. While the radar offers high temporal and spatial resolution of the avalanche front, the AvaNodes provide complementary data on particle-level dynamics, particularly in the tail of the avalanche. The combination of both systems offers a more comprehensive view of avalanche dynamics, allowing the study of differing flow regimes along the avalanche body.

2) How big are the AvaNodes? This isn't currently included. How does the size and density compare to estimates of the snow particles in the avalanche? Why were the two different densities chosen? How were the density/size of the actual particles estimated?

A2) We will add a more detailed explanation on the size of the AvaNodes and why we came up with these densities. The used densities are inherent to the prototype design, with efforts focused on minimizing weight while accommodating necessary hardware, power source and casing constraints. A density of 415 kg/m³ represents the lowest achievable value within the current design limitations. With the gained experience and further advancements in using these sensors in avalanche experiments, it is now possible to produce a wider range of densities and likely reduce the minimum density of the AvaNodes.

We will add a paragraph to make this clear, at Line [84]:

While snow particles in avalanches tend to have a density between 100 and 400 kg/m³ during the movement and 250 to 400 kg/m³ in the deposition (Dent et al., 1998), it was the goal to achieve similar densities for the AvaNodes. However, due to design constraints, the minimum achievable density was 415kg/m³.

The AvaNodes are cubelike bodies with an outer length of 16 cm, which is comparable to the typical size of snow granules found in the deposition zone (Bartelt and McArdell, 2009). The inclusion of a higher-density node (688 kg/m³) was intended to introduce variation, facilitating the investigation of potential differences in the behaviour of varying densities during flow and transport.

3) Some discussion of the avalanche type (dry vs wet) and the flow regime that the sensors and simualtions are representing is needed at the beginning of the paper, as the methods are introduced.

Based on meteorological records and observations from the deployment team, the avalanche can be classified as a dry, dense flow avalanche.

We will expand paragraph Line 75 -80 with more information about the avalanche event:

The data sets used in this article originate from an avalanche experiment (number #20220025) that was performed on the 22 of February 2022, at the test site Nordkette, Seilbahnrinne, in Austria. The avalanche was released during avalanche control work after a new snow precipitation event of around 40 cm new snow at Seegrube. Some parts of the avalanche reached the catching dam at 1800 m asl resulting in a maximum altitude difference ΔZ of 400 m and a projected travel length Δs_xy of 690 m along the main flow direction. More details to this avalanche event is found in (Neuhauser et. al, 2023).

According to the international avalanche classification (avalanche atlas (UNESCO, 1981)), the observed avalanche classifies as A2B1C1D2E2F4G1H1J4, corresponding to: slab avalanches (A2), with a sliding surface within the snow cover (B1) and dry snow (C1) in the zone of origin, channelled avalanches (D2), dominated by the dense, flowing part (E2) in the zone of transition and mostly fine (F4), dry (G1), clean (H1) deposits in the zone of deposition with intentional human release (J4) within avalanche control work.

4) How was the accumulation in the starting zone estimated? How about the fracture depth? It is stated that an interval board was used and estimates included an assessment of wind redistribution. How was the wind redistribution component estimated? Was the release volume varied in the simulations? Seems like this would be a sensitive parameter, similar to the friction and other parameters investigated. Some discussion is warranted here.

A4. Thank you for your interest. The release area and release thickness were estimated as fixed input parameters for the simulations. These values were derived by combining manual field observations, including measurements from an interval board located near the release area, with meteorological data from a nearby automatic weather station. Although we acknowledge the potential sensitivity of the release volume, in this study we focused on varying the friction parameters while keeping the release volume constant. We agree that a more detailed sensitivity analysis of the release volume would be a valuable addition for future work.

5) An overall summary of the uncertainties in all the estimates used for the assessment would be helpful - for example, what is the uncertainty in the vertical velocity? The avalanche front position?

A5. Thank you for the suggestion. We agree that a summary of uncertainties is important for the interpretation of our results. The uncertainties of the measurement systems used in this study have been addressed in our first paper (Neuhauser et al., 2023). The AvaNode GNSS modules typically exhibit an uncertainty in vertical velocity of approximately ±0.05 m/s, depending on satellite availability. For radar-based front tracking, the positional uncertainty is estimated at around 1–2 meters, which corresponds to approximately 4–5 radar range bins. We will include a summary of these uncertainties in the revised manuscript for clarity.

Please see also A1 where we show the planned update for Section 3.1, so that more information about the used measurements techniques is available.

6) Why was only C10 focused on in the analysis in terms of the error assessment? Was it possible to find a set of parameters for all 3 AvaNodes that gave a low error? I realize this might not be possible when including the avalanche front position, but what about just for all 3 AvaNodes?

A6) We tried to point that out in the Discussion section. Line 295-300 and with Figure 4,5 and 6.

In general, it is possible to determine a parameter set for the three AvaNodes as well as for the avalanche front. The challenge is to combine the different measurements. One approach is to take the mean values of all measurements. Alternatively, a weighting scheme could be applied. For example, assigning less weight to C07 due to its density, which does not represent typical snow granules in this avalanche, and assign a higher weight to the avalanche front, as it provides critical impact pressures.

We aimed to highlight that a wide range of parameter sets can reproduce the movement of both the avalanche front and the AvaNodes with low errors, as shown in Figures 4 to 6.

However, the methodology for optimally combining these parameters is such a complex topic that should be the focus of a separate study.

We will change the paragraph Lines [298-301] to:

Interestingly, the optimization results revealed that different observational datasets, such as the AvaNode velocities and radar front positions, lead to distinct yet relatively narrow bands of well-performing parameter combinations. As an outlook, a promising strategy would be to combine these complementary observational constraints in a weighted manner, depending on the specific modelling objective. Such a targeted combination could enable the identification of parameter sets that simultaneously provide good agreement with both particle and front observations, thereby improving the robustness and general applicability of simulation results.

Overall this is an excellent paper!

Thank you for this very encouraging statement.