Dear Matthias Schlögl,

Thank you very much for your thorough assessment of our manuscript and for the constructive feedback provided by both reviewers. We appreciate the time and effort invested in evaluating our work and are grateful for the positive assessment regarding the relevance of the study for NHESS.

We agree with the main points raised by the reviewers and editor and have substantially revised the manuscript accordingly. In particular, we refined the aims and motivation of the study to more clearly emphasize the methodological contribution of automated dock-based UAV systems for geohazard monitoring in alpine terrain. We also expanded the discussion of limitations, remaining technical challenges, operational constraints, and the current level of automation within the presented workflows.

Following the recommendations of Reviewer 2 and the editor, we revised the terminology throughout the manuscript to ensure a clearer and more consistent distinction between “autonomous” and “automated” UAV operations. We also revised the manuscript title to better reflect the methodological innovation and broader applicability of the approach across multiple geohazard types rather than focusing primarily on the individual case-study sites.

In addition, we will upload the code and supplementary data to the data repository DataverseNO. A reserved DOI has already been obtained and is included in the revised manuscript. Below we have included the point-by-point response to the reviewers comments, including all relevant changes made in the manuscript.

We believe that these revisions have significantly improved the clarity, transparency, and overall quality of the manuscript, and we thank the editor and reviewers again for their valuable input.

With best regards,

Alexander Maschler and co-authors

Authors response Ref.1

We sincerely thank the anonymous Referee 1 for the constructive comments on the manuscript. We greatly appreciate the time and effort invested in the review process, as well as the helpful suggestions provided. We agree that the suggested revisions will improve the quality and clarity of our work. We believe that a revised version of the manuscript will adequately address the points raised.

In the following, all reviewer comments are reproduced and addressed. Our responses are provided in blue for clarity. Edits and changes made to the manuscript are given in orange.

RC1: 'Comment on egusphere-2025-6432', Anonymous Referee #1, 06 Jan 2026

Feedback Ref. 1

Summary and overall assessment

The paper presents the first systematic field evaluation of dock-based UAV systems for geohazard monitoring across three alpine environments and introduces an automated end-to-end workflow for displacement and change detection. The topic is timely and important; however, several sections remain too general, and the case-study specific results and methodological details need expansion to demonstrate what was concretely achieved and learned at each site. Here are the major comments. Further comments are in the pdf.

Clarify what dock-based UAVs enabled beyond multitemporal UAV campaigns. The Paper should explicitly state how **the dock-based approach changed feasibility, frequency, reliability, and safety compared** to conventional campaign-based UAV surveys, and tie this to site-specific outcomes. Add for each site, a brief paragraph that contrasts "what would have been possible with manual UAV campaigns" vs. "what the dock enabled". The advantages and limitations of the method should be discussed.

Thank you for the suggestion. In response, we have revised the manuscript to provide a more detailed and structured comparison between dock-based UAV systems and conventional campaign-based surveys (line 445-475). Specifically, we now elaborate on how dock-based approaches enhance operational feasibility, increase temporal resolution, improve data reliability, and reduce field-related safety risks, and we mention the specific aspects at each study site.

The discussion section has been expanded to more thoroughly assess both the advantages and limitations of dock-based systems (line 445-518). We now more clearly delineate the contexts in which such systems offer distinct benefits, particularly in hazardous or inaccessible terrain and where high-frequency observations are required, while also acknowledging scenarios in which conventional multi-temporal UAV surveys remain sufficient, for example at easily accessible sites with lower temporal monitoring demands.

In addition, we have incorporated a dedicated discussion on infrastructure requirements (line 475-495). The revised manuscript now explicitly states that dock-based UAV systems depend on a stable power supply and high-bandwidth internet connectivity for reliable operation. We further note that while solar-powered setups and satellite-based internet can enable deployment in remote areas, implementation remains challenging in high-latitude environments or regions lacking the necessary supporting infrastructure.

Define a **clear research question per case** study with geohazard focus

We agree with this valuable suggestion revised the manuscript to include clearly defined, research questions for each case study. We have now included a clear central research question (line 116) and specific research questions to each study site (line 118-124).
These questions are designed to better link the methodological approach to the specific hazard processes and monitoring objectives at each site. The overall research question is to evaluate to what extent automated UAV monitoring can improve monitoring of geohazards. The three case study sites show very different settings, process characteristics and spatial extents, expected surface changes and deformation rates: 1) For the study site Supphellebreen: How can high-frequency, automated UAV monitoring capture short-term glacier dynamics in a steep and inaccessible icefall and what temporal and spatial resolution is required to capture these dynamics? 2) For the study site Skjøld: How can automated UAV systems be used for analysing complex slope instabilities with low displacement rates and what are the implications for long term deployment? 3) For Blatten: What are the possibilities and limitations of the dock-based UAV system to monitor the temporal evolution of secondary hazards in restricted post-disaster zones, and what lessons can we learn from the deployment in Blatten?

Expand the Methods section that the reader can follow the result chapter. Describe the workflow steps in more detail and explain the differences between multi-temporal UAVs. Specify **which datasets/timings** were compared. E.g. whether successive pairs (A–B, B–C, C–D) are processed, or whether all time points are referenced to a baseline (e.g., A–B, A–C, A–D), and why (e.g., to maximize sensitivity to acceleration vs. minimize decorrelation). This is important to understand the results.

Thank you for this comment. We expanded the methods sections 3.2 and 3.3 and explained several points such as power consumption (line 216-217), acquisition time (line 219), flight altitude and mission management (line 223-228), Gaussian splatting (line 248-250), 3D reconstruction (line 250-255) in more detail and also specify how datasets are processed (as successive pairs & against baseline) (line 258-260).

Accuracy assessment: Whether a detailed accuracy assessment is necessary depends on the research question. When analysing small deformations close to the detection threshold, such as those at the Skjold rock slope, it is crucial to understand the limitations of dock-based UAVs. A level of detection is necessary for all study sites (even for every data pair) when analysing displacements. Consideration of accuracy is important for the applicability of dock-based UAVs for continuous deformation monitoring.

We thank the referee for this helpful comment. We agree that the extent of the accuracy assessment depends on the specific research question. The primary aim of this study is to demonstrate the overall applicability of dock-based UAV monitoring systems and to present a transferable workflow for assessing displacement rates in challenging and inaccessible

terrain. Within this scope, the accuracy assessment is intended as a representative example of how a level of detection (LoD) can be quantified in inaccessible terrain following established practices in UAV-based monitoring studies (e.g., Chudley et al., 2019).
In the revised manuscript, we made the following changes: 1) Site-Specific LoD: We provide individual LoD values for every study site to improve result interpretability, also included in the figures 5,6,7; 2) In table 3, we also summarize the mean, minimum, and maximum LoD values across the datasets. We expanded the result section for the accuracy assessment (line 341-359). This highlights the system's capability to detect centimetre-level displacements. 3) Expanded discussion: We include a more robust discussion regarding the limitations of this approach when monitoring slow-moving mass movements. (line 401-409). A more detailed investigation into the underlying processes at Skjøld and Supphellebreen is planned for a follow-up study. We also add that refining positioning and further lowering LoD thresholds remains a key direction for future research, as this was not the main aim for our study.

The **result section should focus on the differences between multi-temporal UAV and dock-based UAV and** its significance to geo-hazard monitoring.

Within the scope of our manuscript, we find it logical to focus on the results from our surveys in the results section, which are the base for a detailed discussion about the differences between multi-temporal UAV and dock-based UAV. However, at the end of each result sub-section we added a little section about how the automated approach has given improved results in comparison to conventional campaign-based UAV surveys. In addition, we expanded our discussion section, discussing conventional campaign-based UAV surveys versus automated dock-based systems and the advantages, limitations and remaining challenges (line 454-515).

Add a subsection with **advantages and limitations**.

We agree with referee 1 & 2 and added a subsection focusing on advantages and limitations, including a comparison between conventional campaign-based UAV surveys and automated dock-based systems (line 455ff), practical and infrastructural challenges (lines 482ff) and regulatory frameworks and operational constraints (lines 500ff).

We also addressed the specific comments from referee 1 in the pdf within the revised manuscript.

Accuracy Assessment Comments REF 1

The accuracy assessment of displacements and change detection is essential to understand the the advantages and limitations of the method. The method's main advantage is that data can be acquired at short intervals. The level of detection is important here, as it helps to determine the most suitable data acquisition interval. This level of detection must be determined for each study site.

We included the accuracy assessment for the 3 studysites and provide LoD values. See above.

Fig 5. I would suggest reducing the stretching of the colour map to highlight the differences in velocity. The legend fonts should be larger

We adjusted the stretching of the colormap and made the legend and the fonts larger to ensure better readability.

Fig. 8 Increase Fontsize how can the displacement be negative? Do you define a reference direction? This should be mentioned in the method section

We increased the font size of the figure and clarified the definition of displacement direction line 355-350) in the method section (positive displacement corresponds to downslope displacement and negative displacement corresponds to erosion).

Authors response Ref.2

We sincerely thank Alexander Raphael Groos for this thorough assessment of our manuscript. We appreciate the positive evaluation of the relevance of the work. We thank the reviewer for the constructive suggestions for improvement, particularly regarding the need to more clearly define the aims of the study, emphasize the added value and limitations of the approach, and strengthen the broader conclusions across the case studies. We appreciate the complementary perspective to Referee 1 and the detailed feedback provided and agree that the feedback will improve the manuscript.

In the following, all reviewer comments are reproduced and addressed. Our responses are provided in blue for clarity. Edits and changes made to the manuscript are given in orange.

RC2: 'Comment on egusphere-2025-6432', Alexander Raphael Groos, 16 Feb 2026

This is a review of the manuscript by Maschler et al., entitled "Automated UAV systems for geohazard monitoring: case studies from the Supphellebreen icefall (Norway), the Skjøld instability (Norway), and the Blatten landslide (Switzerland)", submitted for publication in NHESS. The authors present the application of a commercial dock-based Unoccupied Aircraft System (UAS), together with a new integrated data processing pipeline, for persistent geohazard monitoring in mountainous terrain, in the context of three different case studies. Once installed, state-of-the-art dock-based UASs facilitate quasi-autonomous photogrammetric surveys (and other types of measurements) on demand or at regular intervals, even beyond visual line of sight. Hence, they have great potential to complement ground-based and spaceborne systems for geohazard monitoring and risk assessment, especially in complex alpine terrain. Dock-based UASs might be of particular interest in cases where, for example, the study area is difficult to access, located within a risk zone, or beyond visual line of sight, and where frequent measurements or long-term monitoring are necessary. However, dock-based UASs come with certain practical limitations, as they are relatively costly (compared to conventional campaign-based UAV surveys), require a stable power supply, and must conform to regulatory and legislative frameworks, which may prevent timely installation and operation. The manuscript is easy to read and fits the scope of NHESS. I acknowledge the effort the authors put into the setup of the dock-based system, the data collection, and the development of the data processing pipeline. However, I fully agree with the other reviewer that a major revision is necessary to specify the aim of the study, emphasise the added value and limitations of the presented monitoring approach, and outline which broader conclusions can be drawn from the three different case studies.

I have attempted to complement Reviewer 1's report, though some overlap is inevitable given the shared main concerns.

General comments

1. **Specify the main aim of the study** (see also Review 1) in the abstract and in the last paragraph of the introduction. Briefly discuss the benefits and limitations of different geohazard monitoring techniques (e.g. ground-based, spaceborne, airborne, conventional campaign-based UAV surveys) in the introduction, and emphasise in which cases a dock-based UAS might be a game changer (e.g. financially, technically, practically, research-wise) and in which situations multi-temporal UAV surveys would simply do the job. The study of Walter et al. (2022) provides a nice example of a dock-based UAS for repeated catchment-wide mapping of sediment dynamics and the monitoring of a debris flow torrent in alpine terrain. You cite their paper, but you could outline in more detail how your monitoring approach adds and relates to their and other studies.

We agree with the comments and defined the main aim of this study more clearly and will make efforts to better position it within the broader context of geohazard monitoring approaches. In the revised manuscript, we will clarify the primary aim both in the abstract and in the final paragraph of the introduction. This allows us to more clearly position dock-based UAS within the existing methodological landscape. We further emphasize the specific situations in which dock-based UAV systems provide clear advantages, such as in hazardous or inaccessible terrain, under the need for high temporal resolution. At the same time, we acknowledge scenarios where conventional multi-temporal UAV surveys may be sufficient and more cost-effective.

We clarify the main study aim (line 16-17) and more explicitly stated and differentiated how our study relates to and extends previous work such as Walter et al. (2022). In particular, we emphasise that our contribution goes beyond repeated elevation change mapping by demonstrating a broader applicability across different geohazard contexts, including glaciers, complex slope instabilities, and post-disaster landscapes, with a stronger focus on the derivation and analysis of surface displacements (line 70-81). We discuss the capabilities of both the conventional and dock-based approach under 5.2.1 Conventional campaign-based UAV surveys versus automated dock-based systems and 5.2.2 Practical and infrastructure requirements.

2. The **motivation for the selection of the three** specific study sites is vague. What were the criteria for the selection? The apparent link between the case studies is the different geohazards (glacier lake outburst flood, rockfall, ice-rock-debris avalanche), but a bit more context on the magnitude and impact of previous glacier lake outburst floods at Supphellebreen and the rockfall activity at Skjøld would be helpful to understand how critical continuous monitoring at these sites is. Moreover, please also be more specific about how the frequent UAV surveys aided "ongoing hazard assessment and response efforts" in Blatten. It seems that operational monitoring with the dock-based UAS was not possible in

Norway because of aviation safety regulations. Did you try to obtain permission for operational use, or was the test setup planned as such right from the beginning (see general comments below)? Please clearly state the aim and purpose of each case study and explain how they complement each other and contribute to the overall aim of the manuscript.

We thank the reviewer for this helpful comment. We clarified the motivation and selection criteria for the three study sites and more clearly state the central research question and specific research questions of each case study in the section 2 Test sites & Data (line 115-123). We clarified the regulatory constraints while keeping this discussion concise, as these aspects are site- and country-specific and not the main focus of this study. As noted in the methodology, for the setup in Norway all flights were conducted under supervision by a pilot and observer on site (line 213). We also explain how the three case studies complement each other and contribute to the overall aim of the paper (line 100-110). We added more context about the previous GLOFs (line 140-146) and the instability Skjøld (155-162).

3. Since this manuscript may become a basic reference for future studies dealing with autonomous UAV surveys in complex terrain, careful use of terminology is essential. I am wondering why the authors refrained from using or discussing the adjective **"autonomous"** and instead use the description "automated UAV systems" when referring to their dock-based UAS. An "automated UAV system", as stated in the title, could be any (off-the-shelf or customised) UAV that follows a pre-determined flight route and is only controlled by a pilot in the case of unforeseen events. However, from my point of view, the manuscript focuses on something different: the application of an autonomous UAS in alpine terrain, although full operation might not (yet) be possible in all cases due to regulatory and legal frameworks. Careful differentiation between automated, automatic, and autonomous UAVs is important, as different operational restrictions may apply (see e.g. https://www.easa.europa.eu/en/faq/116449). In this context, I would appreciate it if the authors could provide additional information on how much human intervention was necessary during the surveys and subsequent data processing. For example, was a remote pilot in a control room mandatory for continuous flight monitoring at Blatten? Was the data processing initiated automatically after upload from the dock, or was this done manually?

Thank you for this thoughtful and important comment. We agree that a careful and consistent use of terminology is essential. The choice of the term "automated UAV system" was discussed extensively among the authors and with colleagues in the field. We opted for "automated" rather than "autonomous" because the presented system combines automated and partially autonomous components but does not yet operate as a fully autonomous system. For example, flight execution and the data processing workflow are automated, while higher-level decision-making is made by humans such as flight route AOI selection, remote flight monitoring, etc. The system does not independently interpret results or trigger actions such as warnings or interventions. Parts of the UAVs safety features, such as the return to home and obstacle avoidance can be done by the UAV autonomously.

While previous studies (e.g. Walter et al., 2022) use the term "autonomous," we consider "automated" to be a more precise description of the current level of system capability. To avoid ambiguity, we clarified the distinction between autonomous, automated and semi-automated UAV systems in the introduction to ensure that it is more defined (line 55-67).

4. Since the authors identified current **regulatory frameworks** as one of the main barriers to the (operational) application of autonomous and beyond visual line of sight (BVLOS) flights, the legal requirements and undertaken administrative steps should be briefly discussed for each site and outlined in more detail in the general discussion section.

In response to the reviewer's comment, we have added 5.2.3 Regulatory frameworks and operational constraints to the discussion. We now briefly summaries the key legal requirements and administrative procedures for each study site, including the distinction between VLOS operations in Norway and SORA-based operations in Blatten conducted in coordination with emergency authorities. In addition, the general discussion section has been expanded to more comprehensively address regulatory constraints, including permitting processes, operational limitations, and implications for scalability. This addition aims to highlight the practical relevance of regulatory frameworks, while maintaining a concise presentation given the site-specific and evolving nature of such regulations (line 498-513).

5. The advantages of the presented geohazard monitoring approach are mentioned at several locations in the manuscript, which is fine, but the manuscript would benefit if the **limitations and challenges** were discussed equally thoroughly. The following aspects, for example, would be worth addressing: current regulations and required permits for autonomous and BVLOS flights (potential conflicts with on-demand operations), safety measures, power supply of the dock-based UAS, data transfer, and UAS maintenance, especially in remote mountain areas.

We thank the reviewer for this suggestion. We added a subsection (line 452-515) focusing on advantages and limitations compared to campaign-based UAV surveys in the discussion and added information within each case study results section showing what the automated system enabled compared to conventional surveys. We also address in more detail infrastructure and regulatory needs. We also added a dedicated subsection to the discussion, where we address limitations and challenges, including current regulations and required permits for autonomous and BVLOS flights, potential conflicts with on-demand operations, safety measures, power supply, data transfer, and system maintenance.

6. Always **define acronyms before** using them for the first time (e.g. GNSS, InSAR, RTK, PPK, GCP, NVE, SORA, NTRIP, AOI, FH2), even if they are widely used, and keep their number to a minimum so that non-experts can also follow the manuscript easily.

We kept the number of acronyms to a minimum and defined the remaining ones.

7. Are there any restrictions or why are the **code and data not published** along with the manuscript? That is against common practice. Please have a look at the NHESS Data policy: https://www.natural-hazards-and-earth-system-sciences.net/policies/data_policy.html

We thank the referee for highlighting this important point. We fully agree with the NHESS data policy and the importance of open and reproducible research. The codes will be published under Dataverse NO (https://dataverse.no/ together with data and supplementary information such as animations with the final manuscript.

Specific comments

Line 1-3: I suggest rephrasing the title. Consider including “autonomous” and/or “dock-based” as well as “mountainous/alpine/complex terrain”. It is probably not necessary to mention the three study sites explicitly. In any case, I would replace “landslide” with “rock-ice avalanche”.

Thank you for the suggestion. We changed the title to: Automated dock-based UAV systems for geohazard monitoring in alpine terrain.

Line 15-29: Specify the aim of the study, explain the motivation for selecting the three specific study sites, and briefly discuss both the potential and the limitations of the presented monitoring approach.

We state the aim, motivation for site selection, and briefly outline both benefits and limitations.

Line 35: “develop into multi-hazard cascades” → Please specify what you mean or provide an example.

We use the failure event of the Birchgletscher in Blatten as a concrete example of such a multi-hazard cascade.

Line 37-38: “Monitoring is often the only way to predict hazardous events” → Please modify this statement, as modelling and knowledge from previous events are also important.

We revised this statement and acknowledged modelling and prior knowledge.

Line 43: “To overcome these challenges” → Perhaps rather compare ground-based (stationary) and mobile measurement techniques, as differential GNSS, photogrammetry, LiDAR, etc. can be deployed within both ground-based systems and UAV/airborne systems.

We rephrased this section slightly to make clear that LiDAR can also be deployed on UAV/airborne systems.

Line 47: “Yet, conventional UAV surveys remain largely manual and campaign-based, which is often limiting their frequency” → I disagree. Conventional UAV surveys are usually campaign-based, yes, but not necessarily performed manually. Comprehensive surveys are usually performed using automatic UAVs. Please be careful with the terminology (see general comment).

We refined the wording to more accurately describe automated flight planning in conventional UAV surveys. We used “manual” to refer to the need for on-site deployment of the UAV (e.g. setup, unfolding, battery changes) prior to executing an otherwise automated mission, and we clarify this distinction in the manuscript.

Line 49-50: “as they reduce the need for human intervention” → Please specify what you mean by “human intervention”. On-site visits might be limited to installation and maintenance of the system, but a remote pilot is usually required for flight monitoring and safety reasons.

We specified accordingly that this refers primarily to reduced on-site presence, while remote supervision remains necessary in most cases.

Line 52 & 55: Please be more precise. The paper by Walter et al. (2022) deals with monitoring sediment dynamics in the context of debris flow torrents, so it also has a geohazard focus, similar to this study. “systematic field evaluation of a drone dock-based automated UAV system” → Please clarify what you mean by “systematic evaluation”. Outline how it adds to or relates to the above-mentioned study by Walter et al. (2022).

We specified and differentiate how our study relates to and extends previous work. In particular, we emphasize that our contribution goes beyond repeated elevation change mapping by demonstrating a broader applicability across different geohazard contexts, including glaciers, complex slope instabilities, and post-disaster landscapes, with a stronger focus on the derivation and analysis of surface displacements.

Line 86: “These three locations, chosen for their contrasting mass-movement characteristics and monitoring challenges” → Please state this already in the introduction and explain in what sense the mass-movement characteristics and monitoring challenges differ.

We state this now in both the introduction and in the section test sites and data.

Line 97: You state that no previous studies exist, but below you cite several studies with respect to Supphellebreen. Please clarify.

We clarified and correct this statement that no previous studies exist in context of assessing of the glacier dynamics, and ice velocities.

Line 98: “Temporal (diurnal and seasonal) variations…” → How do you know this? Please provide supporting evidence or a reference.

We now provided supporting references (e.g., Wangensteen et al., 2006; Hart et al., 2025) for this statement. (line 134-136).

Line 103: This information is needed right from the beginning to understand the motivation for selecting this site. What were the characteristics, magnitudes, and impacts of previous GLOFs?

We clarified this and added information respectively (line 138-146).

Line 105: I think the reference “Breien, 2008” is missing in the bibliography. Please check.

Thank you for pointing out, we added (Breien et al., 2008) to the reference list.

Line 120: How do you know this? Can you provide an appropriate reference? A bit more background on the geology would be helpful. How exceptional or critical is this site risk-wise, considering the presumably large number of slope instabilities in Norway?

We provided additional geological context; the site is currently under investigation and not risk classified yet (line 148-151).

Line 131: “that partially impacted local infrastructure” → To what extent? Please be more specific.

We added this information that the ice avalanche in 1993 hit the ski infrastructure. This information was found in a newly added reference (Walliser Bote, 1993).

Line 150: It is unclear at this stage whether you are using a ready-to-operate commercial system or presenting a newly developed dock-based UAS. Clearly state which individual components (hardware and software) were implemented and which were newly developed.

In the method section we state that we use a commercial dock & drone system.

Line 163: Can you provide a rough cost estimate for the dock and UAS?

We provide a cost range compared and compare it to a comparable standalone UAV in the discussion section. However, these values are highly region-specific, subject to change.

Line 164-165: Some information on the power supply and consumption would be helpful.

We added information about the power supply and consumption in the method section. However, more detailed investigations are needed to assess deployment in remote environments, particularly for solar-powered system configurations.

Line 178-180: I assume the flights were conducted autonomously and BVLOS (and above 120 m), so a Specific Operation Risk Assessment (SORA) was necessary (https://www.easa.europa.eu/en/domains/drones-air-mobility/operating-drone/specific-category-civil-drones/specific-operations-risk-assessment-sora). Can you provide information on the legal requirements and how a permit was obtained within such a short time?

Thank you for this important comment. The flights were conducted on behalf of the Regional Command Staff and under subcontract to the Cantonal Police of Valais. As such, the operations fall under the Swiss state aviation framework. This allows certain extensions of the operational conditions defined in the SORA for dock-based operations. We clarified this regulatory context and its implications in the revised manuscript in the discussion section.

Line 201: Is the data processing initiated automatically after upload, or is this done manually? (see general comment)

We clarified which steps are automated and which require manual input in the method section (linie 190-195)

Line 205-206: Could you explain why you use two different photogrammetry software packages (DJI Terra and OpenDroneMap) to create the point clouds, orthophotos, and digital elevation models? I am not familiar with DJI Terra, but in OpenDroneMap there are many processing options. Please specify whether default settings or any specific settings were applied. You refer to the ODM GitHub repository as a reference, so I assume the access date should be 2025 and not 2020. Two other suitable references are Toffanin (2019), a user guide from the core developer, and Groos et al. (2019), the first case study using OpenDroneMap for UAV-based photogrammetry in alpine terrain.

We justified the use of both in the method section added additional references and fixed the reference. (252-254)

Line 238/250: Please describe your observations here and leave the conclusions for the discussion section.

We made sure to separate observations more clearly from interpretation by removing sentences from here and moving to the discussion (line 418-420).

Line 240-248: "Monitoring of the icefall at Supphellebreen" → The accuracy and level of detail of the velocity and surface change products are impressive, but it is unclear how these observations are linked to the UAV-based monitoring and risk assessment of GLOFs at this site, which was reported earlier in the manuscript as a motivation for this study.

Thank you for your comment. We clarified through the specific research questions what our intentions with the Supphellebreen case study were and further expanded the test site description on the occurrence of both the 2004 GLOF and debris flows in the area, including their past impacts (line 117-119; 138-145).

Line 250-260: Given the number of flights at this site (n = 7), what is the added value of the dock-based system here?

The number of flights was reduced after initial results indicated very small displacements (~5 cm over a two-week interval), close to the level of detection. Nevertheless, we believe this test site provides important value, as it represents a different process type, exhibits smaller magnitudes of displacement compared to the other study sites, and highlights specific challenges for unstable slope monitoring. It therefore offers useful insights into current limitations (small displacements and, for our setup with photogrammetric mapping, vegetation) and potential areas for methodological improvement.

Line 264-265: "The automated monitoring campaign following the rock-ice avalanche event at Blatten highlights the possibilities offered by automated UAV systems in post-disaster response" → Please specify this and provide examples.

We provide concrete examples of how UAV data supported response efforts in the result section for Blatten (line 332-336)

Line 267: “could only be visited once” → Once during the entire monitoring period?

Yes, we specified this by adding “could only be visited once during the monitoring period May-November 2025 (table 2 & line 323)

Line 299: “Automated UAV systems offer a paradigm shift in the monitoring of dynamic geohazard environments” → A paradigm shift in what sense? This is a strong statement and should be supported by sufficient evidence and robust arguments.

Thank you for this comment. By paradigm shift, we refer to the transition from the use of UAVs as tools for primarily campaign-based surveys toward the integration of automated, near-continuous monitoring systems. This enables more frequent, repeatable, and time-critical data acquisition, moving UAVs from episodic mapping tools to potentially components of operational monitoring frameworks. We specified this by being more specific about where this could lead and adding more robust arguments in lines (372-380).

Line 341: “4D datasets offer a robust foundation for training deep learning models” → Please be more specific or provide an example.

We specified this by including example (lines 427-428).

Line 356-358: Is this not a bit too optimistic? During precipitation, strong winds, and ground fog, UAV surveys are usually not feasible or deliver data of reduced quality. Can you quantify the number of days with stratus clouds where the base height is high enough for UAV surveys to be performed safely?

The observation was intended as a general indication rather than a quantified assessment. A detailed quantification would require site-specific analysis of weather data and would be interesting to assess in a future study. At the same time, the UAV system used shows a relatively high tolerance to wind and precipitation, allowing flights close to operational limits. However, under such conditions, data quality may be reduced, which should be systematically assessed in future studies.

Line 357: “low fog” → Do you mean ground fog or stratus clouds (i.e. low-level clouds)?

Low level clouds, we changed this to be more specific (line...).

Line 365: Why a maximum of 120 m above ground level? Do you refer to the maximum flight altitude in the “open” category defined in the EU drone regulation?

The flight height was defined by what was necessary to cover the AOI in reasonable time with the drone chosen, the desired ground sample distance and the regulations.

Line 374: Please provide a rough cost estimate here.

We provided a cost estimate in the discussion section advantages/limitations. However, these values are highly region-specific, subject to change.

Line 394: “failure event” → Consider using “rock-ice avalanche” or “rockfall and glacier collapse”.

We agree that “failure event” is rather unspecific and changed it to rockfall and glacier collapse.

Line 397-398: Have autonomous surveys up to 3000 m a.s.l. been performed? Can you explain what “dynamic mission adjustment” meant in practice? Both information should be included in the methods section.

We added information about these details into the methods section.

Thank you for the comments on the tables and figures. We improved the readability in the revised version, including increasing font sizes and enhancing clarity where necessary. We also took the specific suggestions of referee 1 into account and revised the figures and tables accordingly.

Table 1: Could be moved to the appendix. I think an overview table with key figures regarding the dock and UAV would be more interesting.

Thank you for the suggestion. As suggested, we included key figures of the dock and the UAV in a revised Table 1. We also decided, to incorporate the information of the existing table one (about the camera sensor) in this new revised table 1.

Table 2: Maybe add the maximum distance of the UAV from the dock during the surveys.

We added the distance of the Dock to the AOI to table 2.

Figures 1-3: The overview maps (a) are difficult to interpret. Add contour lines or colour by elevation. Maybe highlight the location of critical infrastructure below the monitored sites.

We added contour lines to the overview maps in Figures 1–3 to improve topographic interpretation. We also included additional annotations for infrastructure below and include the camera locations from which the aerial photographs were acquired.

Figure 5: The labels are difficult to read. Please increase the font size. Add a scale bar and a north arrow (if the map is rotated). Are the white spots in (c) snow patches or data gaps?

We increased the font size, added the north arrow and scale bar. In the captions, we added explanations to the white spots (point cloud data gaps)

Figure 6: Change the unit to cm or mm per day. A scale bar and north arrow are missing. It is difficult to recognise the mentioned features in (e) and (f).

We changed the unit as suggested and added a scale bar and north arrows where missing. We added a better figure description and mention that the white arrows indicate the detachment of the rock falls from the tower.

Technical corrections

None at this stage.

References

Toffanin, P. (2019). OpenDroneMap: The Missing Guide. MasseranoLabs LLC. [https://odmbook.com/]

Groos et al. (2019). The Potential of Low-Cost UAVs and Open-Source Photogrammetry Software for High-Resolution Monitoring of Alpine Glaciers: A Case Study from the Kanderfirn (Swiss Alps), 9(8), 356. https://doi.org/10.3390/geosciences9080356.

Walter et al. (2022). Brief communication: An autonomous UAV for catchment-wide monitoring of a debris flow torrent. NHESS 22, 4011-4018. https://doi.org/10.5194/nhess-22-4011-2022.