EGUSPHERE-2025-4872 | Brief communication | Answer of Reviews

Old Title: Brief Communication: First field observations of basal slip velocities in natural debris flows

New Title: Brief Communication: In-Situ Measurements of Basal Sliding in Natural Debris Flows

We thank all reviewers for their constructive comments, in response to which we revised the complete manuscript, including the methodological approach. In the revised version, all returned correlation estimates are used irrespective of the correlation coefficient. To assess the tendency of basal slip, results from all considered electrode combinations within the range of -10 m s^{-1} to $+10$ m s^{-1} were subjected to a running median with a window of 5 seconds, yielding a smoothed estimate of the velocity distribution over time. Since the median incorporates both positive and negative values, it serves as an indicator of basal slip, and a positive skew in the estimated velocities is visually identifiable during parts of the flow, suggesting a tendential presence of basal sliding.

A preliminary analysis with coarse temporal resolution indicates the presence of basal velocities, which we provisionally interpret as slip velocities throughout the first event and during surge phases in the second. In both events, these estimates were consistently lower than independently measured surface velocities obtained with a pulse-Doppler radar, lending plausibility to this initial interpretation. Although the results are limited to fixed-bed conditions and two events, and further refinement of the analysis methodology as well as a validation of the sensor detection depth remain necessary, we believe these findings offer a first direct field-based insight into basal slip conditions in natural debris flows.

Please find the detailed point-by-point response to the reviews including a list of all relevant changes made in the manuscript. Note: Review answers are displayed in red and italics. The line numbers refer to the original manuscript.

(1) Comments and replies on reviewer 1:

Reliable measurement of basal velocity is rather difficult. This is partly due to the destructiveness of debris flows. Another obvious reason is how to define the boundary layer of debris flow, and how to detect the field of variables within this layer, without probing out of the boundary layer (as discussed in this communication). This manuscript is therefore a welcome trial on this topic. Please see my detailed comments below.

General comments

1. **Be cautious to use the expression "first time". As far as I know, the Japanese researchers have adopted load-cell pair to measure the basal velocity of bedload (not yet debris flow).**

Goto, K., Itoh, T., Nagayama, T., Utsunomiya, R., Tsutsumi, D., & Mizuyama, T. (2016). Development and installation of bedload monitoring systems with submerged load cells. Journal of Mountain Science, 13(2), 369-376.

Thank you very much for your valuable comments. We would like to clarify that the article you mentioned focuses on bedload measurements in rivers, whereas our study investigates debris flows, which involve different flow dynamics and measurement challenges. To our knowledge, our measurements represent the first attempt to directly measure the slip velocity of natural debris flows in the field. The only other site with similar instrumentation is Illgraben Creek, where a comparable paired sensor system has recently been installed in collaboration with our institute. Nevertheless, we acknowledge the concerns given the preliminary nature of the slip velocity results and will therefore change the title to 'In-Situ Measurements of Basal Sliding in Natural Debris Flows'.

2. **The measured debris flow is natural, but the artificial channel bed (fixed bed) with electrodes cannot reflect the natural erodible bed. Through visualization in flume experiments, it has long been revealed that the velocity gradually decrease into the erodible bed (Amanini et al. 2005 JFM). Also, this might not be applicable to the erosion deposition roll waves (eg. in Illgraben Schöffl et al. 2023 JGR, Jiangjia Ravine Chen et al. 2024 WRR), where subsequent surge erodes the deposition of previous surge. A comprehensive discussion is needed.**

Thank you for this thoughtful and detailed comment. You raise very important points regarding the limitations of our measurement setup that we will address more comprehensively in our revision.

You are absolutely correct that the rigid bedrock channel at Gadria does not replicate natural erodible bed conditions. As demonstrated by Amanini et al. (2005) and others, velocity profiles in debris flows over erodible beds show gradual velocity decrease with depth due to bed particle interaction and potential erosion. Our fixed-bed setup cannot *capture these dynamics, which is indeed an important limitation of our field measurements.*

Furthermore, we acknowledge your point regarding erosion-deposition processes and roll waves, as documented at sites like Illgraben (Schöffl et al., 2023) and Jiangjia Ravine (Chen et al., 2024). The complex interactions between subsequent surges, where later surges erode deposits from earlier ones, represent flow conditions that differ significantly from our Lattenbach creek site. We will expand our discussion section to clearly outline these limitations and specify that our slip velocity measurements are representative of debris flows traveling over rigid substrates. We will also discuss how flow dynamics and basal boundary conditions may differ in settings with erodible beds and active erosion-deposition processes and cite the relevant literature you've mentioned.

Some specific comments

3. **Line 36-39. Not sure how these field and experimental measurements support the occurrence of basal slip. Please elaborate**

Text of line 36- 39: „In natural debris flows, the occurrence of basal slip conditions has not yet been directly confirmed; however, there is strong evidence supporting the existence of sliding at the base, based on investigations of erosion and deposition processes (Berger et al., 2011; Roelofs et al., 2022) as well as measurements of surface velocities (Aaron et al., 2023) or vertical velocity distributions (Nagl et al., 2020). This study introduces a novel technique to measure basal sliding and reports of the first results."

Understanding slip velocity at the interface between the debris flow and the bed is fundamental for predicting both flow dynamics and erosional processes. Berger et al. (2011) documented rapid channel bed erosion at Illgraben within 20 seconds of flow arrival, indicating strong basal interaction with the channel bed due to high shear stress conditions. Roelofs et al. (2022) identified two primary mechanisms driving debris flow erosion: basal shear forces from sliding of the flow along the bed, and impact forces from particle collisions. The basal shear force mechanism is fundamentally controlled by slip velocity, the differential velocity between the debris flow and the stationary bed, which determines the magnitude of shear stress exerted on the bed surface. Aaron et al. (2023) inferred the vertical velocity profile by tracking different objects in a debris flow, including rolling boulders, floating boulders, and woody debris. The relative velocities of these objects provided information about the velocity profile, as each object type samples the flow at different depths. Nagl et al. (2020) measured vertical velocity profiles and basal shear and normal stresses in natural debris flows at Gadria creek and observed highest values occurring at the flow front. Since basal shear stress is fundamentally linked to slip velocity in debris flow models, whether rheological, frictional, or based on other constitutive relations, quantifying slip velocity is essential for providing boundary condition information to predictive models. While previous studies have measured the *consequences of basal interaction (e.g., erosion and shear stress) or inferred velocity profiles from surface or internal flow observations, direct field measurements of slip velocity, as presented in this study, offer unique insights into the fundamental mechanics that govern debris flow–bed interaction.*

4. **Line 73-74. I am quite interested in the basal velocity of steady roll waves. With the surge front running on previous deposition, I guess a clear basal slip velocity does not exist?**

Line 73-74: "Within the surge, several roll waves occurred. Toward the end, the flow behavior becomes more turbulent and gradually transitions into a debris flood."

The first debris-flow event occurred only a few days after maintenance work at the monitoring station, so the deposits are relatively small in depth, at least in the area of the monitoring setup. The slip-velocity sensors were not covered by debris deposits from the beginning (see video footage). For this reason, we already see slip-velocity estimates upon the arrival of the front of the surge. Note that the front is not necessarily classically granular but rather represents an abrupt transition from debris flood to debris-flow behavior.

Following refinement of our analysis methodology, we preliminary conclude that significant slip occurs only during debris-flow fronts. While we can cross-correlate velocity estimates also during more viscous regimes of the debris flows (e.g., during surges with roll waves), the slip velocity fluctuates around zero on average in these sections. Nevertheless, the question about the occurrence of slip velocities during roll waves is of course very interesting and will certainly be revisited and examined in more detail in future studies.

5. Line. 123-125This is also a problem for the load cell-based measurement. The measured stress is actually a stress averaged through a certain thickness. But the first thing should be how to define a basal layer?

We thank the reviewer for this insightful comment, which addresses a fundamental aspect of basal measurements in debris flows. We assume that the measured slip occurs within the sensing volume near the sensor array and the force plate. A rough estimate of the penetration depth can be approximated by the distance between the anode and cathode electrodes. Our measurements therefore capture the velocity within this near-bed layer rather than at a mathematically precise interface. Importantly, the fact that our sensors detected movement indicates that the material in direct contact with the force plate was mobilized. Even if only a thin layer of material covered the sensors, this layer was actively flowing rather than remaining stationary. This demonstrates that the complete material above the sensors was activated during debris flow passage, meaning we are measuring true basal slip velocity rather than internal deformation within a static deposited layer. Nevertheless, further investigation is needed to precisely characterize the sensor's penetration depth and spatial resolution.

(2) Comments and replies on reviewer 2:

Review: "First field observations of basal slip velocities in natural debris flows"

General Assessment

The study presents interesting initial field observations of basal slip velocities in debris flows, addressing an important question in debris flow rheology. The authors demonstrate that basal slip occurs continuously and is not limited to specific phases, which challenge established no-slip assumptions.

Major Concerns

Method Not Applied for the First Time

The authors present the method as a "novel monitoring system" (lines 15-16), but obscure the fact that **the same measurement method was already applied in 2020 by Nagl et al. at the Gadria station, Italy** (lines 53-54, line 138). The method was originally developed for laboratory experiments (Kaitna et al., 2014) and then transferred to the field. The present study thus **does not represent a methodological innovation, but rather an application at another location**. This should be clearly stated in the abstract and introduction. The actual contribution lies in the analysis of two new events, not in the development of the method.

Critical Limitation Due to Artificial Channel

A fundamental problem of the study is the **heavily modified measurement environment**. The sensors are installed in an artificial, concrete-reinforced channel supported by a series of check dams (lines 48-51). The authors themselves mention that the sensors are located "directly above a check dam" (lines 132-133), which could influence acceleration effects.

It is extremely difficult to infer natural basal friction conditions from measurements in such an artificial channel, because:

- The roughness of the concrete channel bed is fundamentally different from natural substrates
- Hydraulic jumps and turbulence at check dams drastically alter flow dynamics
- The geometric constraint of the channel suppresses natural lateral dynamics
- Erosion and deposition processes that dominate basal interaction in natural channels are largely eliminated

The authors do not discuss this limitation with sufficient critical depth.

Urgent Need for Further Investigation

The study is based on only **two events at a single, heavily modified location**. For robust conclusions, the method urgently requires:

a) Investigations at different locations:

- The authors mention a planned comparative study at Illgraben, Switzerland (lines 153-154), but without these data, the results remain site-specific
- Ideally, measurements should be conducted in **natural, undisturbed channels** to test transferability

b) Different configurations:

- The study shows clear differences between sensor pairs (lines 99-106), indicating methodological uncertainties
- The penetration depth of the sensors is completely unclear (lines 123-126), which massively complicates interpretation

c) Different debris flow characteristics:

- Different **material compositions**: The two events already show different behaviors (granular vs. viscous-turbulent)
- Various **volumes**: Both events are relatively short (25-35 minutes) – larger, longer events might behave differently
- Different **velocities**: The v_slip/v_surf ratio varies between 0.3 and 0.5 – a systematic analysis across a broader velocity spectrum is missing

Supplementary Materials Not Accessible

A significant issue is that **the supplementary materials, including the webcam videos of both events (mentioned in line 70), are currently not accessible**. The authors reference the supplementary material multiple times (lines 70, 157, 159, 161) with a Zenodo DOI (https://doi.org/10.5281/zenodo.17249344), but this material cannot be reviewed. These videos and data would be essential for:

- Verifying the qualitative descriptions of flow behavior (lines 71-79)
- Understanding the visual differences between granular and viscous phases
- Assessing the plausibility of the measured slip velocities
- Evaluating the flow conditions in the artificial channel

The manuscript cannot be fully evaluated without access to these crucial materials. The authors should ensure the supplementary materials are publicly accessible before publication.

Additional Methodological Concerns

1. **Uncertain detection depth**: The authors acknowledge that the sensors may not measure basal velocity but rather the velocity of the lowermost layers (lines 123-126). Without knowledge of this depth, the "basal slip velocities" in the title may be misleading.
   We thank the reviewer for these comments regarding the measurement methodology. It is important to emphasize that the measuring processes directly at the channel of torrential channels is inherently challenging. We assume that the detection radius of the electrode pairs corresponds to their horizontal spacing and planned laboratory experiments will allow us to examine this assumption in more detail. As already noted in our response to Reviewer 1, our measurements therefore capture the velocity within the near-bed layer rather at a mathematically precise interface between channel ground and passing debris. In the course of a revised analysis methodology, we have concluded that we can derive clearly positive velocity estimates during the fronts of debris-flow surges, which preliminary indicates clear slip conditions in this front regimes. During the more viscous parts of the events, the correlation results fluctuate relatively uniform around 0. From this, we can infer that while movement occurs down to the sensors, no actual slip occurs in these flow regimes. However, we are still uncertain about what exactly happens at the basal layer in these regimes. For this reason, laboratory experiments are planned, including investigation of the immersion depth of the sensors into the passing debris. It should be noted that during flow regimes without debris-flow behavior (e.g., fluvial bedload transport), no slip velocity estimates can be correlated, which already indicates that different interactions between the passing debris and the channel ground occur during debris flows.
2. **Low correlation rate**: Only 12-18% of possible correlations are valid (lines 94-98), indicating substantial data gaps.
   We thank the reviewer for this comment regarding a low correlation rate. The high-frequency conductivity measurements from the electrode pairs (sampling rate: 2.4 kHz) exhibit strong fluctuations and respond rapidly to short-term changes in the composition of the passing debris (e.g., solid-fluid ratio, passage of large boulders, etc.). Our processing strategy is likewise designed to obtain a high temporal resolution for the velocity derivation, using a floating window length of 1.0 s. In a revised analysis approach, we have omitted additional limitations and allowed all values between -10 and +10 m/s regardless of the correlation coefficient (ACF). This results in 50-60% valid velocity estimates, enabling more robust median values to be calculated.

3. **Methodological artifacts**: The higher velocities of the central sensor pair (larger spacing) suggest systematic errors that are not yet understood (lines 99-106, 127-133).

The slightly higher velocities between electrodes ED2 and ED3 can be attributed to the larger horizontal spacing of these two electrode pairs. As mentioned in the manuscript, the cross-correlation analysis is subject to a lower-bound velocity that depends primarily on the electrode spacing and the chosen length of the floating analysis window. This lower-bound velocity cannot be undershot within the cross-correlation-based velocity derivation. Since we assume low basal velocity values, we have extended the maximum permissible lag within the cross-correlation from half the window length to the entire window length, thereby reducing the cutoff velocity by a factor of two. For future, more detailed investigations of slip-velocity-based analyses, this factor will of course taken into account, and the window length will be adjusted accordingly.

Positive Aspects

- The study provides valuable field data on a difficult-to-access research question
- The continuous presence of basal slip is an interesting finding
- The discussion of limitations (Section 4) is partially transparent
- The planned laboratory investigations of penetration depth are sensible

Recommendations

1. **Revise title and abstract**: Remove "First" and clarify that this represents further applications of an existing method

We thank the reviewer for (1) pointing out an unclear formulation that might lead to misunderstanding, (2) for suggesting being more moderate with drawing conclusions from this preliminary analysis.

We agree that the method of cross-correlating conductivity signals is not new as it was introduced for the lab by Kaitna et al. (2014) and applied by Nagl et al. (2020) to the field. Note that the idea of deriving velocities from signal cross-correlation has also been applied before in studies e.g. on granular material (e.g., Ahn et al., 1991; Boateng and Barr, 1997)*) and snow avalaches* (e.g., Schaefer et al., 2010; Sovilla et al., 2014; Tiefenbacher and Kern, 2004).

The novelty of our contribution is that we first time apply an established technique to measure basal slip in natural debris flows and present first estimates of a process (=basal slip) that has been observed in the lab (e.g., Sanvitale and Bowman, 2010; Taylor-Noonan et al., 2022) *and addressed in models (e.g., Bartelt et al., 2017). Considering the major challenges involved in field monitoring of such destructive processes and the challenge in designing a respective setup, we are heavily excited and aim to share this with the scientific community via a Brief Communication. This is in accordance with the scope of this manuscript type offered by NHESS as stated on the journal homepage:* “Brief communications are timely, peer-reviewed, and short (2–4 journal pages). These may be used to (a) report new developments, significant advances, and novel aspects of experimental and theoretical methods and techniques which are relevant for scientific investigations within the journal scope *[…]"*.

We agree with modifying the title and the abstract, but respectfully note, that the word "first" in the original manuscript related to the process rather than to the technique.

The new title is:
"In-Situ Measurements of Basal Sliding in Natural Debris Flows"

The new abstract:
"The propagation of debris flows is expected to be controlled not only by the internal deformation of the material but also by basal sliding of sediment along the channel. In-situ measurements of basal slip velocities in field-scale debris flows are currently missing. This study introduces a novel monitoring setup that has been designed to directly measure basal slip velocities using paired conductivity sensors. Preliminary results of two events that were recorded at the Lattenbach catchment (Tyrol, Austria) in June 2025, are associated with a high degree of uncertainty, however, results indicate the presence of basal sliding especially at the front of natural debris flows. Independently measured surface velocities were consistently larger that estimated basal slip. These preliminary findings support theoretical approaches that represent the granular nature of such flows. Future research will focus on refining the derivation methodology, the temporal resolution of the results, the detection depth of the sensors, analysing additional events, and conducting comparative studies across different catchments to further understand the role of basal slip in debris flows."

2. **Make supplementary materials accessible**: Ensure all referenced videos, data, and code are publicly available for review

Supplementary materials are now accessible.

Emphasize limitations more clearly:

- Artificial channel as a fundamental constraint

We agree that an artificial channel is a constraint. However, considering the challenges faced in debris flow field monitoring, we raise the question of the technical feasibility of installing such a setup in a non-artificial channel section. Consider also that many monitoring stations are located in or in the vicinity of an artificial channel section (cf. review by Hürlimann et al., 2019. One could argue that the fixed concrete bed is representative of (a) natural bedrock channels *and (b) the numerous Alpine torrents that have been stabilized with check dams and concrete protection structures. However, we think that besides the discussion of the general representativeness of an artificial channel, our measurement efforts contribute to a fundamental understanding of the flow behavior of sediment fluid mixtures such as debris flows.*

We changed the text to: (Line 42-47): "This system is installed between two force plates within a channel section, which is reinforced by a series of check dams with a fixed concrete bed preventing erosion. While this fixed bed condition does not represent natural channels with mobile sediment beds, it is representative of bedrock channels and alpine torrents that have been stabilized with check dams and concrete armouring for hazard mitigation (cf. Hürlimann et al., 2019). The fixed boundary condition prevents bed erosion, allowing direct measurement of slip velocities over a non-erodible surface, which is relevant for a fundamental understanding of the flow-behaviour of debris flows."

- Difficult transferability to natural conditions

Please also see answer to the earlier question "Difficult transferability to natural conditions". We adress this concern by modifying text in the manuscript.

- Preliminary character of the results

We changed the wording to "first results or initial results".

- **Prioritize method validation**: The planned laboratory tests and Illgraben study should be completed before drawing far-reaching rheological conclusions

We agree that we should avoid drawing far-reaching rheological conclusions in this Brief Communication paper. Hence, we rewrite line 22-32: " In often used shallow water models, the flow resistance may be represented by rheological models that consider debris flows as a homogenous viscous fluid (e.g., Kamali Zarch et al., 2025), and by that simplify the representation of the complex processes governing the flow behaviour, including the assumption of a non-slip condition at the boundary. On the other side, models that represent the granular nature of debris flows include basal sliding at the flow-bed interface ((e.g., Pitman and Le, 2005; Pudasaini and Mergili, 2019). In natural debris flows, the presence of basal slip has not yet been directly confirmed in natural debris flows; however, there is indication supporting the existence of a sliding part of a debris flow at the base, based on investigations of erosion of bedrock (Hsu et al., 2008) and loose sediment (Berger et al., 2011; Roelofs et al., 2022) as well as measurements of surface velocities (Aaron et al., 2023) or vertical velocity distributions (Nagl et al., 2020). "

And for line 119-131: " Basal sliding occurs in many, gravity-driven eomorphological mass flows, such as in snow avalanches (e.g., Kern et al., 2009), rock avalanches (e.g., Pudasaini and Mergili, 2024) or temperate glaciers (e.g., Bierman and Montgomery, 2020). Based on two natural debris-flow events, we demonstrate that a segmentally assessment of slip velocities is feasible and that basal sliding can occur in natural debris-flows over non-erodible (fixed) channel beds. The debris-flow fronts in both events are clearly captured and there is indication of basal sliding, potentially due to their coarser, more granular sediment composition, as already demonstrated in laboratory studies by Sanvitale and Bowman, 2017. Significant slip velocities are *observed predominantly at the fronts of debris-flow surges, while the waning phase of surges and the more viscous flow regimes exhibit non-detectable conditions. The exact detection depth of the conductivity sensor pairs, i.e., the influence of the shear rate along the boundary layer, is not yet known. As a first approximation, this detection depth corresponds roughly to the spacing between the sensor pairs, although the conductivity of a debris-flow mixture is primarily governed by its composition and, above all, by its fluid content. At lower fluid contents (e.g., at debris-flow fronts or in very granular debris flows), we expect a reduced conductivity and, accordingly, a shallower detection depth."*

- **Specify outlook more concretely**: Explicitly state that measurements in undisturbed, natural channels and for various debris flow types are necessary

Thank you for the comments we changed the conclusion.

Conclusion

The study is an interesting **exploratory contribution**, but is severely constrained by the **artificial measurement site, limited data basis (two events), methodological uncertainties, and currently inaccessible supplementary materials**. The method urgently requires further validation at different locations, ideally in natural channels, and for different material compositions, volumes, and velocities before the results can be considered representative of "natural debris flows."

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(3) Comments and replies on reviewer 3:

The basal boundary dynamics; particularly, the basal velocity; of the particle-fluid mixture debris flows is one of the fundamental mechanisms controlling the motion, run-out and deposition morphology, and the devastating impact forces of such flows. These are mechanically/dynamically known, as their importance. However, the measurements of the basal velocity of such flows is rare, or as claimed by the authors, non-existing for the field debris flows. The authors mention that, this study introduces a novel technique to measure basal sliding velocity and report some first results, based on two recent natural debris flows in Austria. I appreciate the authors efforts in obtaining the basal velocity, for different types of mixtures and different parts of the flow body. These results already provide some important basic information as one would anticipate. However, in parts, the writing appears to be odd. It contains invalid, inaccurate statements and claims. It is not clear how the basal velocity was obtained, and are these for the particle, fluid or for the mixture? Please make it clear. Flow dynamical and bed morphological conditions should be mentioned before explaining the velocity results. The main velocity results are a bit difficult to perceive: how these results can be physically explained with respect to the velocity of surface and the flow depth changes as they do not directly match to each other? In general, I would suggest to properly re-formulate the ms. Please see the attached file for detailed suggestions for improvements.

Many thanks to the reviewer for the comment. Measuring basal slip velocities in natural, field-scale debris flows indeed provides new insights into their complex flow behavior, especially regarding the interaction between the mixture and the channel bed. At the onset, we would like to politely emphasize once again that this manuscript is a "Brief Communication", intended only to offer a concise glimpse into new methodologies and findings. Below, we would like to address the review's comments within the manuscript:

Line 1: Indicating the article type ("Brief Communication") is mandatory.

Line 13-21: We adapted the abstract based on the comments.

Line 25-27: We will consider this literature comment.

Line 32: We added references according to the suggestions.

Line 37: This sentence is related to measurements and not to model assumptions.

Line 54-57: We revised the sentence for clarity.

Line 57-58: As the sensor system has only recently been installed and no comparable measurements are available, it is not yet fully clear which particles the measured velocities refer to. Based on experience with a similar system used to derive vertical velocity profiles at Gadria creek, the measurements are assumed to most likely represent *the velocity of the solid phase. Laboratory experiments within a follow-up project are planned to address this question in more detail.*

Line 60: The theoretically maximum achievable velocity can be derived as follows:

$$v_{max} = \Delta s \times f_s$$

where: Δs [m] is the spatial offset between the sensors of each sensor pair and f_s [s^{-1}] is the measurement frequency (fixed to 2,400 Hz).

Given the fixed properties we can derive the following (theoretically) maximal achievable velocities:

$v_{max\_ED1\_ED2}$ = 144.0 ms^{-1} (with Δs_{ED1_ED2} = 0.06 m)

$v_{max\_ED2\_ED3}$ = 184.8 ms^{-1} (with Δs_{ED2_ED3} = 0.077 m)

$v_{max\_ED3\_ED4}$ = 144.0 ms^{-1} (with Δs_{ED3_ED4} = 0.06 m)

In the course of revising our analytical methodology, we have decided to include negative estimates in our analysis. We have modified the evaluation logic as follows: All correlation estimates between -10 and +10 m/s are now accepted, regardless of the correlation coefficient. We have updated the methodology section of the manuscript accordingly.

Line 69: Material composition of the debris flows is qualitatively assessed via the video recordings. Unfortunately, there was no opportunity to collect material samples of the debris-flow deposits. Sampling is planned for future events. The video recordings reveal a highly variable mixture composition during the events, as mentioned in the manuscript. The morphology of the channel was briefly described in the Method section. As the force plates are located directly upstream of a check dam, the slope in the immediate vicinity of the conductivity measurements remains very small, if it is not completely horizontal.

Line 82: This is referenced to the event of 15 June.

Line 85-90: We revised the paragraph for clarity.

Line 90 and Line 114: The v_{slip}/v_{surf} ratios refer to the median values of all slip velocity estimates over the entire to the median of the surface velocity values during the entire events. Due to the revision, we modified the text and excluded the specification of event-based v_{slip}/v_{surf} ratios. We focus on a flow-segment-based specification of vslip/vsurf ratios (e.g., within debris-flow front sections).

Line 112-113: We rephrased the sentence for greater clarity.

Line 144-145: We deleted the sentence.