

Dear anonymous reviewer,

we thank you for the very positive and encouraging assessment of our study, as well as for the constructive comments that helped us improve the manuscript. We addressed all suggestions in detail. We clarified the TLS LoD calculation and error sources and provided additional context on the application and limitations of RAMMS::DEBRISFLOW for dry granular flows. We also refined the discussion of model calibration, revised the description of the retaining wall, and added missing methodological details (e.g., vibration monitoring duration). Furthermore, we rewrote the introduction, corrected terminology and figure references, ensured consistent use of abbreviations and BCE notation, and implemented all line-by-line corrections and clarifications suggested.

Overall, these revisions have strengthened the methodological transparency, contextual background, and clarity of the manuscript. We sincerely thank the reviewer for their helpful and constructive feedback.

Sincerely,

Benjamin Jacobs (corresponding author on behalf of all co-authors)

Dear Authors and Editors,

this manuscript presents the application of established mountainous geomorphology methods (Terrestrial Laser Scanning (TLS), InSAR, RAMMS modelling and vibration analyses) to assess rockfall and granular flow activity at the Temple of Hatshepsut in Luxor, Egypt. TLS, InSAR and vibration analyses identify hotspots of geomorphic activity at the cliffs next to the temple, while the modelling approaches aim to predict possible future events and their impacts on the temple and its visitors.

The study is clearly written, well structured, and uses methods well suited for such an application. Its novel adaptation of geomorphological approaches to an archaeological setting is particularly commendable, offering possible opportunities for interdisciplinary research between geomorphology, archaeology and geology. I therefore recommend this manuscript for publication in ESurf.

Prior to publication, however, some points should be considered.

Main points:

- The uncertainty/error estimation of the TLS point clouds is not entirely clear. While the registration errors for both point clouds are provided and a LoD of 0.03 m is stated, it is not explained how this LoD was calculated. Is it based on a 95% confidence interval? Was it calculated based on stable areas only? Please clarify. Additionally, could you elaborate on why the M3C2 algorithm was chosen over a basic DoD approach?

Thanks for your comment. In conjunction with the second review, we edited section 5.1.

The LoD is the instrumental error, controlled by the error propagation from raw data quality and registration process. This includes the scanner's target accuracy (5 mm @ 100 m range), precision (3 mm @ 100 m range), laser beam divergence (0.35 mrad) and

atmospheric correction (RIEGL, 2014). In our analysis the LoD is produced as significant change calculated by the M3C2 algorithm (Lague et al., 2013), and also corresponds to the 95th percentile of model distances (similar to Abellán et al. (2011)).

We did not consider a DoD approach in this study. While it can be very intuitive and straightforward in some applications, it reduces the data analysis to a 2.5D problem (which actually is its charm in some cases). In the case of Deir El-Bahari, however, this approach would lead to reducing the 90° steep cliff to a few pixels (projection in Z-direction) or reduce the topographic complexity and introducing large sources of error by projecting the “cirque-like” shape of the terrain to any flat plane, e. g. parallel to the Z-direction to account for the cliff. *M3C2 is a well-established method for straightforward 3D change detection. It compares raw 3D point clouds and avoids gridding artifacts, interpolation errors and loss of detail in rough or vertical terrain (added in 172 ff).* Therefore, we chose this method.

- As noted in your discussion, RAMMS::DEBRISFLOW was developed for debris flows with significant water content. To me, it is unclear whether this is the first study to apply the model to dry granular flows. If so, the statement that is “[...] a simple and geomorphologically accurate simulation tool for dry flows (granular flows)” (lines 448-449) appears overstated, given that the validation is based only on a single photograph from 1892. I recommend addressing this limitation in more detail and discussing the restricted validation options in greater depth. If there are previous studies using the model in a similar way, please cite them.

Thanks for bringing this up. In conjunction with the second review, we changed parts of the methods section (3.3.2) and the discussion (5.3.2) to provide more context on the use of RAMMS::DEBRISFLOW and the parameters used. We elaborated a bit on the trajectory of RAMMS applications in different environments and compare our input parameters (especially Coulomb friction) to other studies and physical concepts.

We also dialled down the aforementioned sentence to “*However, in the case of this study it turned out to be a simple and geomorphologically sound simulation tool for dry flows (granular flow), too.*”

Furthermore, the presented granular flow simulations are only reconstructions of two historical events. Why did you not apply the calibrated model to the rock tower in A 02, for example?

Thanks for the comment, very good point. At this point of the project, we focussed on historic events and their benefit for calibrating models, that can and will be used in case larger instabilities become imminent in the future, hence the term “areas of increased monitoring demand” in Figure 3c. However, public availability of such models needs to be carefully considered is subject to approval by the Egyptian Ministry of Antiquities.

- The manuscript briefly mentions the retention wall at the temple only twice. From my point of view, the existence of this wall means that the rockfall problem has already been recognised and countermeasures have been taken. As this is directly related to the study, I would like to suggest that you provide some more detail about the retention wall. For example, when was it built? Does it serve its purpose based on the rockfall model?

Thanks for your comment. The retaining wall is indeed somewhat helpful regarding possible rockfall hazards but was not necessarily meant for this. We edited parts of the discussion (section 5.3.1) to address this: *This becomes especially obvious in the case*

of the effect of the retaining wall behind the Temple of Hatshepsut. Originally built in 1968 to stabilize the soft Esna Shale formation immediately above the festival courtyard and the entrance to the Amun shrine (Lipinska, 1977), the retaining wall serves as a natural rockfall collector for smaller and intensely fragmented rockfalls.

We also unified the term “retaining” wall throughout the manuscript, as this is the correct technical term. Before “retaining wall” and “retention wall” were both used.

Minor points:

- I would like to suggest going through the manuscript again in detail and checking the sentence structure and consistency (e.g. figure numbers). Below, I have listed a few of such points that caught my attention.
- Please double check all abbreviations in the manuscript. These should be defined when first mentioned, but not again in subsequent references.
- In accordance with the ESurf guidelines, please use the neutral BCE (before the common era) instead of BC (and avoid a mixture of both).

Thanks, we changed this and hope we caught all Abbreviations and Figure references.

Lines 31-32: Double use of the word “worldwide”

Line 32: “[...] has been emphasized in many publications [...]” – please name some.

Line 40: Use BCE instead of BC

Line 44: A word is missing here

Line 45: It is the Valley of the Kings, not the Valley of Kings

Line 50-53: It is not clear whether this “benchmark field study” is the present study or another one. Please clarify

Line 86: Please define LiDAR

All the above: Thanks, we rewrote most of the introduction and included your remarks where applicable.

Line 90: Typo: It is the Deir El-Bahari Valley

Thanks, changed.

Line 115: A word is missing here, please refine

Thanks, changed “hanging” to “overlying”.

Line 125: “to” is missing here

Thanks, changed.

Line 136: The brackets of this in-text citation are incorrect

Thanks, changed.

Line 150: Maybe even mark the rock tower in figure 1 for better visualization

Thanks, changed.

Line 162: Please define MSA as Multi Station Adjustment

Thanks, changed.

Line 201: “A02” should be “A03”

Thanks, changed.

Lines 201-202: The block sizes seem to be quite random at this point in the manuscript. Please consider referring to S1 here

Thanks, we added an extra sentence on this: *Here, 0.01 m^3 corresponds to the five distinct rockfalls in our 1 one-year TLS data, and 25 m^3 to the largest single rockfall reported for the last century (Abdallah and Helal, 1990) as well as larger distinct blocks in the cliff (S1, S2).*

Lines 206-208: Why did you not just analyse the block sizes and shapes behind the retention wall?

Thanks for your question. The block sizes above the retention wall are limited to very small sizes. To account for varying magnitudes of single rockfalls in our simulations, we expanded the range of block sizes. As volumes of up to 25 m^3 are reported in the literature (Abdallah and Helal, 1990) as well as visible as distinct blocks in the cliff (S2) – even in our AOIs – we found this approach appropriate.

Section 3.4: Information on the time / duration of data acquisition is lacking

Thanks, we added: *We used a Trillium Compact 120 s seismometer on March 6th, 2023 (09:37 to 23:43) with a sampling rate of 200 Hz.*

Line 243: HVSr was already defined

Line 244: SSR was already defined

Line 247: SSI was already defined

All above: Thanks, changed

Line 264: What does “significantly” mean here? Is it based on a statistical parameter?

Thanks, yes, we added: *For better visual accessibility, we subsampled the change detection to a point spacing of 0.25 m and 100 significantly changed points (from M3C2 analysis) in a radius of 1 m.*

Line 270: How was the total rockfall volume calculated? With or without the LoD?

Thanks, we slightly modified this sentence: *For an area of ca. 6,5 ha of exposed rock wall (S6), we calculated a total volume of five distinct rockfalls of $0.589 \pm 0.05\text{ m}^3$ (S1), which translates to a rock wall retreat rate of $\sim 0.009 \pm 0.001\text{ mm/a}$.*

You are absolutely right, that considering the LoD when calculating rockfall volumes is generally relevant. As shown in S1 we went without the use more advanced volume computation (e. g. concave alpha-shape or cut / fill) at this stage of the study, as (i) there are only five distinct rockfalls in our data, (ii) they are very small and (iii) more accurate estimates would not

substantially change the message. Nonetheless, we added the error effect from the LoD (± 0.03 m) to the stated values.

Line 290: I do not understand why table 1 shows that velocities exceeding ± 5 mm/a are significant

Thanks, we slightly modified this sentence: *Based on the statistical characteristics of the dataset, velocities exceeding ± 5 mm/a, approximately corresponding to double the standard deviation, are considered significant (see **Fehler! Verweisquelle konnte nicht gefunden werden.**)*.

Lines 293-295: Based on S8 I assume that these locations represent A02 and A03. If so, please state

Thanks for your suggestion. In fact, this sentence refers to all three parts of the cliff where the InSAR analyses shows activity, that are later defined as AOIs A 01 to A 03. However, this interpretation is done in conjunction with the TLS results (see dedicated section 4.3). In this section only the results from the InSAR analyses are presented and we feel that mentioning the AOIs by name before they are defined in the manuscript may be confusing to the readers.

S8 is restricted to A 02 and A 03, as the InSAR-results are too patchy in A 01 to be considered one possible, mechanically linked area of instability.

Line 301: AOI was already defined

Thanks, we reworked section 3.2. Therefore, this is now the first mention.

Lines 306-309: Here, the locations are called “A 01” etc. But before they are called “A01” etc. Please decide on one spelling

Thanks, we did this for all AOIs and rockfall scenarios. It is now A 01 etc.

Line 317: Figure number is missing

Thanks, changed

Lines 322-324: If the rocks hit the retention wall – is it a “hit” or a “miss”?

Thanks, this would be a “miss” as they do not reach the visitor perimeter (compare Figure 4). The flat top of said retaining wall is regularly cleaned from debris to prevent any built-up of material.

Lines 324-325: Please refine this sentence

Thanks, we wrote: *The number of rocks deposited in the Temple of Hatshepsut visitor area increases with the size of the released blocks, as larger blocks tend to travel farther.*

Line 332: Figure number is incorrect

Thanks, changed

Line 377: Typo: “basis”

Thanks, changed

Lines 382-383: Please refine this sentence

Thanks, we wrote: *Our data show that environmental conditions at Egyptian heritage sites can have a major impact on data quality and thus on the LoD.*

Line 431: Typo: “scarce”

Thanks, changed

Line 441: Type: “it” is missing

Thanks, changed

Lines 452-454: You could discuss using a monoplotted method to better assess information based on a single historical photograph

Thanks, great idea! We thought about this, however, all the “interesting bits” are either obscured by temple debris in the old photo or by the reconstructed temple (= terrain) in the view of the TLS data. Good line of site / perspective and the amount of terrain alteration (i. e. change in surface elevation change between the date of the monoplotted photo and the DSM generation) is crucial for good results. Both of which are problematic in this case.

We also tried terrestrial SfM with several historic images from the ground and even from post WWII aerial shots. However, we did not get anywhere with this since and therefore left it out. As mentioned in the manuscript and the comment above, the entire area of Deir El-Bahari was subject to very intense terrain alterations over decades. The area of the Tutmoses II temple (event A), for example, was used as a sediment dump between ca. 1910 – 1960, and the area of event B was cleared stepwise from ca. 1930 onwards. As Photography was expensive and complicated at the time of the earliest digs, the number of photographs is too limited for SfM convergence.

We added this to the methods section (3.3.2): *To better constrain the volume of the failures we set out to reconstruct the deposition geometry with terrestrial and aerial photogrammetry and monoplotted. However, due to the intense and repeatedly anthropogenic terrain alterations and limited number of usable historic photographs, this approach lead to little to no success.*

Line 494: Use BCE instead of BC

Thanks, changed

I would like to thank the authors for preparing and submitting this research article, and I congratulate them on a well-executed and valuable study.

Thank you very much indeed!