Interactive comment on "Evaluating post-glacial bedrock erosion and surface exposure duration by coupling in-situ OSL and ^{10}Be dating" by Benjamin Lehmann et al.

Answers to Anonymous Referee #1
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Lehmann et al. present a novel way of constraining bedrock erosion rates by combining luminescence rock surface exposure dating (using the IR50 signal of feldspar) with cosmogenic radionuclide dating (^{10}Be from quartz dissolution). They go through an intensive modelling effort and exploit the different but complementary spatial sensitivities that differ by an order of magnitude. In a given rock surface the buildup of ^{10}Be is occurring in the top ca. 1-2 m, while the bleaching of the IR50 signal affects the topmost millimeters to centimeters only, making the luminescence rock surface exposure dating approach particularly sensitive to surface erosion.

The strength of this paper lies in the fact that Lehmann et al. recognize and systematically exploit these methodological differences. It thus represents an important contribution to the growing number of OSL rock surface dating studies and clearly shows (i) the limitation of the luminescence rock surface approach as a tool for purely obtaining exposure histories, particularly for older rock surfaces or environments with intensive surface erosion, (ii) opens up a way to check for the importance of erosion on a given rock surface and (iii) allows obtaining information on surface erosion. Lehmann et al. show that their erosion rates from post LGM glacially polished rock surfaces obtained via their modelling and experimental data are sensible. Indeed, over millennial timescales such data are hardly obtainable via other techniques. This approach might also provide independent constraints for correcting terrestrial cosmogenic radionuclide ages. A note of caution: only two samples are included in the current study, and a more extensive dataset (both CRN and luminescence data) will be required to test the robustness of the modelling framework of Lehmann et al.

The main shortfall of the current version of the manuscript is the way the complex and interwoven modelling steps are presented. While many sections of the manuscript are clear and concise some other parts are hard to follow and, in my opinion, too brief, hence unclear and also sometimes inconsistent, particularly section 3.1. and the immediately following section 3.4 (sections 3.2 and 3.3 are missing or sections are mislabeled). Figures 6 and 7 could also be improved and linked with the text more intimately, thus improving the clarity of the presentation and comprehensibility of the modelling framework. I detail my main concerns in the following and append a list of smaller hiccups at the end.

Main issues – description and comprehensibility modelling steps and modelling framework (section 3):

We are grateful for this very constructive review provided by Anonymous Referee #1. The presentation and the comprehensibility of the modelling steps (section 3) have significantly improved. We thank the reviewer to point out the numbering problem, which has been fixed in the new version of the manuscript. Please find in the following the answer and comment on the reviewer feedbacks. Comments of the reviewer are underling and our answers are in bolt.

p. 12, section 3: it would be helpful to define / explain the essence of the terms "forward model" and "inverse model" (e.g forward in time?) and the workflow in general terms before diving into details. This will help removing abstractness from your explanations.

We added the following note at the beginning of the Section 3, page 12: "In this section, we generate a series of forward and inverse models. The forward model calculates a luminescence signal and a ^{10}Be concentration from synthetic erosion and exposure histories. The goal of the inverse model is to constrain the model parameters (i.e., erosion and exposure histories) using the data (i.e., IRSL signal and ^{10}Be concentration). To validate the inversion procedure, we use the forward model to create synthetic data which we then recover using the inverse model."

p. 13, section 3.1: please be more specific: first sentence "… a series of synthetic luminescence profiles were generated…" – refer to Figure and profiles (green dots, red lines, dotted lines, black lines?)

The sentence: "The first experiment assumes a constant erosion rate over the TCN exposure age $t_S = t_0$" was changed to "For this scenario, erosion rates are assumed to be constant over the TCN exposure age $t_S = t_0$.". We also specifically refer to "dashed lines in Figs. 7a-d".

What exactly is "a single experiment" – the generation of one synthetic luminescence profile? A set of modelling steps that result in Fig. 7a-d, respectively?
In the third scenario, another set of synthetic luminescence profiles were again generated using Eq. (1) in a forward model, but the erosion rate was allowed to vary with time (green dots in Figs. 7a-d). We have rephrased this statement accordingly.

How do your "experiments" differ from a "model" in line 21?
Those are the same experiments. The sentence was changed to "We report the four model outputs calculated using t_S between 1 and 100 a, and erosion rates $\dot{\varepsilon}$ between 10^{-2} and 1 mm a^{-1} (green dots respectively in Figs. 7a-d)."

Would it be better to talk about scenarios?
For clarity "experiment" was change for "scenario".

These terms as well as the subsequent modelling steps and model setup are not always well defined yet. You go on in line 16: "In the first experiment… (→ results in dashed line in Fig. 7a-d)" … and in line 17: "In the second experiment …" but what does this now result in? the green dots, the red curves in Fig. 7a-d?
The mention "(green dots in Figs. 7a-d)" was added at the end of this sentence.

At the end of this paragraph you introduce the reference luminescence profiles (black lines) → would be helpful to move this upward and mention it together with e.g. constant erosion scenarios (dashed lines) before going into the more complex scenarios where erosion varies through time.
Changed as suggested.

Line 18: tc – is this the corrected TCN age? From Figs. 7a-d (text within figure) it looks like; but from Table 1 not necessarily so!?
tc is indeed the corrected TCN age. We moved t_0 and t_C from the "Both methods" section to the "TCN dating" section of Table 1, and include TCN in front of "exposure age".

You introduce Fig. 7 in section 3.1 first; then you hop to Fig. 6 (that is unmentioned in the text up to this point) – this out of sequence move is a bit confusing.
We added a mention of Figure 6 in the paragraph 3.1. This sentence was added in this paragraph: "Figure 6 illustrates the schematic representation of four different erosion scenarios through time (Figs. 6a and 6b) and their resulting luminescence signal (Fig. 6c)."

You have to elaborate on the concept of varying the erosion rate through time and on Fig. 6. The time axis in this figure needs to be read from right to left (because it is a forward model!?).
Figure 6 was flipped to have the exposure event on the left and so the time going from left to right. The purpose of this figure was to illustrate the step function used an erosion rate history. We hope that with this updated figure the reader understands more the concept of step function in time.

The rational for using such step functions is not clear (here and in the related explanations on p. 9. L. 15) – what do you actually intend; to simulate climatic transitions e.g. from Pleistocene – Holocene in addition to capturing transient states? Sentence starting in line 18 onward: "Initially between… This is illustrated in Fig. 6" is unclear.
"The assumption made here, is that the evolution of erosion in time can follow a step function. Our objective is to explore the effect of a non-constant erosion rate in time on both the luminescence signal and ^{10}Be concentration. This is the simplest possible time varying erosion rate history. The erosion is initially equal to zero, i.e., between the corrected exposure age tc, and an

onset time of erosion ts, and increase to a fixed rate between ts and today. Note that more sophisticated erosion rate histories could be tested with the same approach, which is beyond the scope of the current study."

Maybe you can improve Figure 6 (make a Fig. 6a and b out of it) and come up with a worked example illustrating how the scenarios in current Fig. 6 translate into a plot like Fig. 7a, b, c or d (which could become Fig. 6b?). In this context: my thinking was that the indicated values in Fig. 7a-d (text within figure) for ts of 1 year and 100 years, respectively, should also be reflected in the tc versus the t0 ages (text within figure). Maybe this could be clarified with a Fig. 6a+b solution too.

Figure 6 was changed and divided in Figure 6a being a flip version was flip to have the exposure event on the left and so the time going from left to right. The purpose of this figure was to conceptualize how the step function is set. We hope that with this new figure the reader understands more the concept of step function in time. Figure 6b illustrates how erosion history can be described by a single dot in a diagram "Erosion rate $\dot{\varepsilon}$" vs "Onset erosion time t_S". Finally, Figure 6c presents the resulting luminescence signal for the different erosion histories. In this way, Figure 6 gives a clear explanation of how experiments were designed and prepares the reader for Fig. 7. "Schematic representation of four different erosion scenarios through time (a) and (b) and their resulting luminescence signal (c). t_0 is the uncorrected ^{10}Be exposure age, t_S the onset times of erosion, t_C the corrected exposure ages, and $\dot{\varepsilon}$ the erosion rate. Note that the luminescence plots in (c) are not model outputs but drawings, with the aim of conceptualizing how the experiments are designed."

p. 14 line 6: it reads like the reference signal (what is the reference signal here? Black line in Fig. 7a-d? pls specify) is at 17 mm depth. But you actually mean that the luminescence depth-profile is brought 7.8 mm closer to the surface relative to its former position, thus lying at 17 mm absolute depth! Pls improve wording. Line 8: depth (instead of deep)

This paragraph was rearranged in the following way:

"By applying a constant erosion rate of 10^{-2} mm a^{-1} to a rock surface exposed since t_0 (16428 ± 589 a), the luminescence signal is brought 7.8 mm closer to the surface (i.e., 17 mm deep from the surface) compared to the reference signal (luminescence signal exposed since t_0 and no affected by erosion; black line in Figs. 7a-d at 24.8 mm deep from the surface). For a constant erosion rate of 1 mm a^{-1}, the luminescence signal is brought 15.4 mm closer to the surface (i.e., 9.4 mm deep from the surface) compared to the reference signal (difference between black lines and dash lines measured at NLS = 0.5 in Figs. 7a-d).

Line 9 onward to rest of this section: pls refer to figures whenever you actually discuss data/scenarios that are visualized in the respective Figures and thus link text and Figures much more closely than is currently the case!

We thank the reviewer to point this lack of clarity, the referring to figures was improved as suggested.

Line 9: "…is applied for a duration of 1a" – unclear: does this mean that (referring to Fig. 6) the erosion only started 1 year (or 100 years in the case of fig. 7b and d) before sampling? i.e. for 16454 yrs no erosion; 1 year erosion of 1mm? – can this be integrated into a worked example (e.g. Fig. 6b, see above?)

The durations of erosion (1 and 100 years) correspond to a duration before sampling. We add the mention "before sampling" after each duration in the text.

Line 9: "…and integrated over its specific corrected exposure age" what exactly do you mean with integrated; with corrected for erosion 10^{-2} = tc max in Fig. 7a? pls specifiy

This sentence was changed for: "and for an exposure time corrected with its specific erosion history tc".

p. 15 line 7: ts times $5x10^{-1}$ a = 182 days but in line 16 the same ts is 110 years!?

The ts values mentioned in line 7 are the values defining the space in which the inversion model will be sampled to reproduce the experimental / synthetic values (i.e., $5x10^{-1}$ a and $3x10^{4}$ a). However, the values mentioned in line 16 are the values defining the space where the ^{10}Be concentration will not be possible to recover due to too strong erosion and described as the "forbidden zone". This space is defined with the following boundary conditions $\dot{\varepsilon}$ = 10 mm a^{-1}, t_S ~110 a and $\dot{\varepsilon} \sim 5 \times 10^{-1}$ mm a^{-1}, t_S = 29210 a.

Line 28: "which should be recovered in the inversion" = green dots in Fig. 7a-d? pls specify
We thank the reviewer to point this lack of clarity, the referring was added as suggested.

p. 16, line 7: "... the would reproduce this specific lum signal (Fig. 7e)" = yellow triangle in Fig? pls specify
We thank the reviewer to point this lack of clarity, the mention: "Normalized likelihood > 0.9: yellow area in Fig. 7e" was added.

Ad Fig. 7 e-h: what is the axis label of the colour bar at the right? What are the units?; green dots hard to see (better white?)
The unit of the colour bar at the right was added "Normalized Likelihood", yellow (value 1) means high probability to have recovered the solution. Green and black dots were changed for green and black strokes and white fills.

Ad Fig. 7a-d: red lines – inferred solutions: are these the fits to the synthetic data? Pls explain in text;
The sentence on page 15, line 30 was improved in this way: "We then select the pairs of $\dot{\varepsilon}$ and t_S leading to the maximum 5% likelihood values which are fitting the synthetic data (the threshold of 5% is arbitrarily chosen), and plot their corresponding luminescence profile values (red lines in Figs. 7a-d)."

Fig. 7d: where is the dashed line – overlapping with red line? pls offset slightly.
Changed as suggested.

p. 18, line 5: by applying a constant erosion rate
Changed as suggested.

Line 8: what do you mean by insets here?; d and c have to be swapped.
The sentence has been changed to "(e), (f), (g) and (h) represents the likelihood distributions inverted from the synthetic luminescence profiles respectively in (a), (b), (c) and (d)."

Minor issues

p. 1 line 14: TCN abbreviation not explained here or in text
Changed "in situ cosmogenic ^{10}Be (TCN)" to "terrestrial cosmogenic nuclide ^{10}Be (TCN)" in both the abstract and the main text.

p. 1, line 33: (Figs 1a and b) to a coarse-grained rough surface (Figs. 1c and 1d).
We thank the reviewer to point this mistake, we changed as suggested.

p. 2 line 2-3: (e.g. deterioration … Breakdown) – is this degree of detail really needed? You do not specify these terms and it thus remains unclear what the differences between these specific processes are… can be simplified.
"(e.g., deterioration, decay, crumbling, decomposition, rotting, disintegration, disaggregation or breakdown)" was deleted for simplicity.

Line 10: erosion. Here you actually mean erosion of rock surfaces! Pls specify
"of rock surfaces" was added after "erosion" as suggested.

p. 3 line 15: burying them under sediment. No I think it was the other way round i.e. the sediment that is buried (sealed) due to large boulders (rock fall event) pls check.
This part has been changed to the following: "Some of the paintings were damaged by a rockfall event, and conventional luminescence was applied on a rockfall boulder and buried sediments (Chapot et al., 2012). This provided a minimum age for the event."

p. 3 last sentence: pls specify (cite) already here which papers / equations you are actually gonna review, because you start from established models. In the next and subsequent sentences you talk about the proposed model – here you mean your own; or Sohbati or someone else? …so it is unclear what you are gonna review and how this will link with your own stuff.
We thank the reviewer to point this lack of clarity. As the reviewer mentioned we don't review papers / equations but we start from establishing models. In this sense, the sentence "To achieve this, we first review the theoretical and model approach to simulate the evolution of luminescence signals in rock surfaces" was removed. And the next sentence was modified in this manner: "To achieve this, we developed a new model which depends on the exposure age, the surface erosion, the trapping and detrapping (bleaching) rates and the athermal loss (c.f. Eq. 1, Section 2.1.1)".

p.5 line 12: IRSL – it might be beneficial to briefly explain in the intro already that there are several signal that can be targeted depending on the mineral, rather than just hopping onto IR50 with preparing the reader for it.
Following this suggestion, we added that statement at the end of the introduction (page 3, line 20): "Note that several signals can be targeted in the same rock slice depending on the mineral (e.g., Sohbati et al., 2015; Jenkins et al., 2018). OSL is usually used to analysed the luminescence of quartz (Murray and Wintle, 2000) and IRSL for potassium-rich feldspar signal (both at 50°C and 225°C, Buylart et al., 2009)."

Line 12: Sentence: "Shobati et al., (2011, 2012a,b) introduced … duration". Is this the model you show below (Equation 1)? If yes pls specify (which paper?). In entire paragraph it is not quite clear from where equation 1 is taken from, of if you added some aspect to it!?
Equation 1 is the new model proposed in this actual study: This section was changed to: "Sohbati et al. (2011, 2012a, b) introduced a mathematical model that describes the process of luminescence bleaching with depth in a homogeneous lithology, enabling the quantification of rock surface exposure duration. Here we propose a new model describing the evolution of luminescence in rock surface as a function of different parameters characterizing the probability of charge trapping […] (c.f. Eq.1, Section 2.1.1)."

And what Huntley's contribution to this specific equation exactly is.
Huntley's contribution was mentioned after the parameter r' for recombination center distance. We acknowledged this was not relevant, and thus removed the citation and mentioned it later when we go into details of the fading parameters.

p. 5-6: suggestion: describe equation terms 1-4 first and explain Ou et al. + Sohbati's solution of equation therafter.
Changed as suggested.

p. 6 line 7: these parameters. μ or what?
We thank the reviewer to point this lack of clarity, we changed the sentence for "[…] for a complete description of $\overline{\sigma\varphi}_0$ and μ parameters […]".

p. 7 line 7: what is the fading term her in terms of g-value
The values mentioned in the text correspond to two end-members between g-values ~0%/decade and 10-15%/decade.

p. 9 line 19: NLS. Abbreviation not introduced in main text (only in fig caption)
We checked and NLS is introduced on page7, line 12.

p. 20. Line 18: no figure 8 with IRSL curves in text of supplement!
We thank the reviewer to point this mistake, figures were wrongly labeled. This has been corrected.

p 23. Line 22: show; "… that OSL-exposure can be used to identify multiple burial and erosion events…" – but actually these approaches are not a pure OSL rock surface exposure approach but rather an OSL rock surface burial approach – which is not quite the same.
We thank the reviewer to point this mistake, the studies mentioned in the text are indeed using OSL rock surface dating, which include both exposure and burial. But this is just a word issue, the exposure problem (erosion) is still valid for that approach if one wants to recover exposure durations. The term "OSL-exposure" was changed for "OSL rock surface dating".