Review of *'An empirically-derived hydraulic head model controlling water storage and outflow over a decade in degraded permafrost rock slopes (Zugspitze, D/A)'* for **ESurf** by Scandroglio et al.

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1. Overview and suggestion

The paper constrains the contribution of snow melt relative to precipitation events for feeding a fracture aquifer that can be monitored thanks to a unique set-up, which measures discharge at two fracture outputs in a tunnel located under the Zugspitze, the highest peak in Germany. With the measurements, they quantify the groundwater storage in the fracture network. Additionally, they propose an empirical model based on the Darcy's equation for constraining the hydraulic head above the tunnel.

The paper is highly relevant: Mountain groundwater is a current hot topic in Hydrological studies and ground observations are needed to calibrate larger scale models and understand how much water mountains can store, a crucial question for mitigating freshwater resources. Unfortunately, mountain groundwater observations are rather scarce: This study fills this observational gap in a unique high mountain environment. However, in its current form, the paper is not clear about its aim and findings. Not that there are none but rather because of the writing and presentation. I have doubts that the paper was extensively checked and reviewed by the co-authors before submitting. Additionally, I have one question for the authors: Is it a hydrology paper or a geomorphology one ? I struggle to understand why it was addressed to Earth Surface Dynamics and not HESS. In brief: The science is good but the presentation makes it challenging to digest.

Nevertheless, because the results are highly relevant for the mountain groundwater community and re-analysis is not necessary, I would still recommend **a major revision** for this paper.

2. General Comments

A. The title is misleading to me: there is at the moment a high emphasis on the empirical model where most of the paper is about reporting (very interesting) field observations. The model just serves as an interpretation and a starting point for the discussion in my opinion. Also why being so specific ? The 'permafrost slopes' are barely addressed and I don't feel this is the object of the study. Something like **In-situ observations of the dynamics of an alpine mountainous fractured aquifer** would be more general and accurate (just an example). Sorry to be annoying but this is for your readership and it is important ! Also: What is D/A ? (Yes I know it's Deutschland/Austria but it may not connect with everybody) .

B. The structure of the paper is not clear and makes the reading difficult. The authors introduce a lengthy method section, explaining also their model at the same time. Then, they proceed to show the results section, in which they

show the model results at the end of the section. I would advise to make a separate section regarding the model so that you have: Methods → Results (This is what informs and motivates the model you build here and the point of the paper !) → Empirical Model → Discussion. This would be straying a bit from the usual paper structure but you would gain clarity.

C. I cannot find anywhere a clear key message for the study. What's your new finding (Snowmelt vs Rain), a quantitative estimate (what is the storage in the fracture, or a relevant timescale ?) etc… Make it clear in your conclusion and at the end of the intro. I think it would be worth emphasizing how much relative storage is actually entering the fracture. It is great to have such a measure at a 50m depth.

D. The knowledge gap is not well defined in the intro as well. Are you talking about the water budget in the mountains ? Landsliding ? I struggle to see the typical introduction architecture**:** *Motivation -> Knowledge Gap -> The solution you bring and the question you want to address (not the current 4 listed!) -> A brief overview of the findings.*

E. I would keep the statement about slope stability in the discussion and remove it from the introduction for instance. Make it a full hydrological paper and commit to the choice. Some of the cited literature does not advance the paper.

F. The paper is full of words, abbreviations and phrasing that lengthens or distract from the reading in my opinion. For example at the start of the discussion where the sentence gives twice the same info: *'Differently from previous studies, here, for the first time'.*
The paper could benefit from a trim of at least one third of the current version: some sentences are too long and unclear and some paragraphs do not add to the context of the study. I started to note all grammar and organisational mistakes (not reported in this review !) but I stopped as it is not the job of the reviewer and is very time-demanding. I suggest checking throughout before sending it again to reviewers.

3. Specific comments

Abstract:
I would clean the abstract. Examples:
1→ you start with a permafrost sentence… The paper is not about permafrost induced slope instability. It's about the water budget… Find another opening.
6→ data set of meteorological data → meteorological data. Check throughout.
10→ 'We developed', who is we ? Did you develop a recession curve ? Not the right verb. Check throughout.
15 → 'Here, we show' sounds like the start of a method, So that would be higher before summing up your results. This cuts the flow of the abstract.

Intro:

The third paragraph arrives out of the blue after the first two on hydrology. Does this paragraph contribute to your paper ?

Line 55 to 60 → Would fit better in the discussion part of the paper.

Study Site description and characterisation:

Line 106 → How do your results compare to the gravimetric measurements if you mention it ?

Line 117 → 'The mapping agrees only partially'. If you write it, I just want to ask why ?

Methods and Data:

Line 121 → This pre method paragraph could be in the intro.

Line 140 → I think it is a lot of abbreviation to grasp. Also → Why calling your precipitation PSUM and not P ?

Line 174 → Title is unclear. What about Modelling of … fluid flow etc..

Line 156 → 'are united' → 'are combined' check throughout (line 160 also)

Line 180 → I am not sure we need this info.

Line 177 → 'a likelihood' → this word is statistically connotated. Are you sure this is the one you want ?

- I found that the part on the recession is too long (from 188 to 195).
- Introduce your variable after the equations, and make the equation part of your sentences
- The time dependency '(t)' is often omitted in almost all equations, please add it or say that you don't mark it for brevity.

Line 211 → 'would also strongly influence the flow behaviour…'

How can you make this statement at this point of the paper ? We haven't yet seen your data.

Line 215 → I would have this part in a separate modelling section as stated above.

Lines 234 → 'yq' typo ?

A note on the model: Would it be possible to list all the assumptions you are making ? For instance, Lateral flow in the fracture network is not consider for your Darcy Head where you assume a main conduit ?

Results and data interpretation:

Line 261 → 'earlier than the model' → Which model ?

Line 308 → When you use 'bigger' to describe a variable, I think it would me more correct to say 'larger'. Check throughout.

Part 5.4 → There's a lot of text and data from the recession analysis. Yet, no recession curves are shown in the main text. I think you should show it.

Line 355 → Why thes values for L ? After all, you have 50m of rocks above the tunnel ?

Figure 1: The little table is confusing: It looks like the measurements are about the loggers and not the fractures.

Figure 2: It’s a nice figure but Would it be possible to have fewer abbreviations ? As it is, you need to do mental gymnastics to recall all the abbreviations.

Figure 3: Nice figure but it looks the water is in the void of the fracture. It would be nice to indicate, you consider the fracture to have finer materials in which the water circulates. Also what you call ‘baseflow’ → It doesn't seem to correspond to the classic hydrological definition. Could you define what you consider baseflow in the paper ?

Figure 7: Would you consider having somewhere a plot of the Precipitation vs the Flow of the fracture ? That would show the transient storage in the fracture in a nice concise way.