Review of Nico Mölg et al. "The role of debris cover in the evolution of Zmuttgletscher, Switzerland, since the end of the Little Ice Age"

GENERAL COMMENTS

The study by Mölg et al presents a comprehensive analysis of the evolution of the (debris-covered) Zmuttgletscher in the Swiss Alps. Using digitized topographical maps, and orthoimages and surface models that were created from airborne and spaceborne imagery, the authors reconstruct the elevation and surface velocity of the glacier. They additionally present length change measurements, debris thickness measurements, ablation measurements (both under debris and backwasting of ice cliffs), semi-automatic ice cliff classification, radar interferometry, and more. This allows them to study the long-term evolution of the glacier, i.e. from the Little Ice Age to present, in quite impressive detail.

The main findings of the manuscript are that the mass losses and dynamics/velocity of the glacier have mainly been governed by climatic changes that occurred over the study period. It is argued that the expanding supraglacial debris layer and its insulating effects did not play a major role in this. On the other hand, the supraglacial debris is suggested to have had an important control of the glacier area, length and surface gradient, since its presence flattens the mass balance gradient at lower elevations and considerably limits melt near the terminus. There are not many studies that present (long-term) observations of debris-covered glaciers, and the results presented here are therefore a great addition and complementary to the work that has been performed on this subject by others.

Although the messages of the manuscript are surely of interest to the debris-cover and general glacio communities, I'm afraid can't help feeling a bit confused. There are so many methods used, angles approached, and arguments made, that one as reader gets (seriously) lost at times. There is a lot of content that, although generally relevant to the subject, is in my opinion too much to include in this paper. Some of it would be suited for a review paper on the state of Swiss glaciers. On the other hand, some of the methods are presented rather summarily, and are therefore not quite reproducible. Probably a result of having to include so much.

Consequently, I think the paper should be cut down and reworked considerably, with a narrower focus on the intended message. I think it will help if a clearer focus on the implication of the debris and its evolution would be pursued, and the elaborate comparisons of Zmutt with other glaciers would be remove/reduced. I my opinion there definitely even enough material to split this into two distinct stories.

There are many sentences that are very long and have multiple subordinate clauses and multiple types of punctuation. I know this is quite common in German, but I think for readability it would be beneficial to try revisit those and split/clean them up. Grammar and spelling wise there were also some minor issues here and there. Please check the text carefully, and, if possible, have a native speaker look at it once.

The same goes for the figures. I believe that twenty display items in the main text and another 15 in the supplementary is a bit overkill. And this does not even include the inset tables and or graphs in some of the figures. Introducing several new figures in the discussion is also odd and is maybe a bit of a giveaway of the amount of information that is beyond the scope of the paper. I think some figures can be discarded, combined, or at the very least be moved to the supplementary. In short, again, my advice would be to remember the focus of the paper and tailor your figures to that.

The above makes me sound slightly negative, perhaps, but this is not my intention. There is an impressive amount of work put into this paper, which is evident from all the methods, angles and interpretations. It would be a pity if that would obscured by the length and (apparent) complexity of the paper, which would likely lead to an undervaluation of the work. I therefore suggest major revisions that really focus on clearing up the message. Don’t be afraid to kill some darlings.

Of course I would be happy to have another look at the improved manuscript.

SPECIFIC COMMENTS

P1L1
The title is a tad misleading, maybe. Yes, debris cover is incorporated in the analysis and a major component, but the main message is the evolution of the glacier. The results even show that the overall mass evolution of the glacier is not strongly affected by debris? I'm thinking something in the line of "Post-LIA evolution of Zmuttgletscher and its debris cover".

P1L6
Often → generally
Flat. Debris-covered glaciers are generally not flat. They are hummocky due to the spatially variable melt rates induced by the debris. I think you mean gently-sloped or of low gradient.

P1L7
Today → at present

P1L11
Increased from approx. 13% to more than 32%? Provide specific numbers.

P1L15
Maybe provide numbers for the area and cliff changes.
~2005; ~1.5 → Again be specific with you numbers.

P1L20
Why not just call it introduction?

P1L25
Similar rates of thinning at the same elevation bands. Volume changes would imply mass balance but these are largely unknown from these studies. Also no reference to the (more recent) elevation difference paper here [*Brun et al.*, 2017]?

P1L26-29
There is some debate the last years about the importance of supraglacial ponds, ice cliffs and glacier dynamics/emergence. I think there are a number of recent papers that could be added here that touch upon this topic, e.g. [*Pellicciotti et al.*, 2015; *Vincent et al.*, 2016; *Brun et al.*, 2018; *Miles et al.*, 2018].

P1L37
Wouldn't call this 'as a result'.
These glaciers also often have a long flat (low-gradient!) tongue because the insulating surface debris layer just allows them to extend into the lower, warmer valleys.

P2L1-6
Long. Rephrase.

P2L7-12
Same here. Basically two paragraphs of one sentence each. Also these long itemizations could use some inline numbering.

P2L22
I think the importance part can be skipped, not quite relevant here and statement has an endless list of footnotes.

P2L36
Are the latlon for the peaks relevant? The only important one, for the glacier, is missing.

P2L40
Only originates from the rock walls? What about the other possible sources, see e.g. [*Evatt et al.*, 2015]?

P3L9-10
"at near-by almost"???

Can similar values really be assumed. We often considerably different behaviour of glaciers in a valley due to differences in microtopography etc.

P3
I think that there is some irrelevant information provided in the study area section. Keep it clean and simple.

P4L9
plane → airplane

P5 section 3.1
Because the results depend strongly on the DTMs I think this section is a bit short. There are all kinds of caveats and things that can go wrong with DTM generation (especially working without fiducials and markings in Agisoft). A bit more detail on the exact procedures followed would be welcome.

P5L25
The DTM was produced FROM the tri-stereo image using photogrammetry, I'd guess.

P6L8
manually digitizing / manual digitization

P6L15
I think calling this ice fall is quite confusing terminology. Maybe ice deposits?

P6L17

…allowed correct interpretation of…

P6L29-30
Isn't this just normal error propagation? If it is not, why did you choose to

P6L32
which → that

P7L5
Undertook → performed
for setting → to put

P7L6
…two metre long PVF stakes…

P7L12
information → data

P7L12-14
When and how often were these measurements performed. Need more details.

P8L1-6
Have you not considered the object-based ice cliff mapping I've done before [*Kraaijenbrink et al.*, 2016]?

P8L17-18
I do not understand what you mean here. How can one assume a plane due to curvature? Or is the plane curved to mimic the laterally slightly convex glacier surface? But then it is not a plane, right?

P8L32
I'm not sure if "stand" is the right word here

P8L36-40
It is completely unclear to me when each specific method was used and for what reasons.

P9L2-3
Just a complicated way to say area-weighted?

P9L10-11
I do not understand why this was done. Now you're assuming a single elevation for the entire period for specific parts of the glacier? Wouldn't it be better to leave it as no data and perform weighted statistics appropriately?

P9L22
impact on surface → impact surface

P9L23
So there is a class for 5 cm debris and for debris thicker than 15 cm. What about the rest? That is, between 5 and 15? Or do you mean just two classes, thin and thick, <15 and >15?

P24-P26
So now there is suddenly a lot of debris thickness data. I don't understand this? How were the maps produced? Were there that many pits dug for all these time steps? If so, that's quite impressive.

P9L35
Correlation quality ('strength')? I'd just use 'correlation'. Correlation itself implies a quality/strength of fit.

P10L8
Why *smaller or equal* than 0.03, and not just a uncertainty value?

P10L8
There should be no space between the first number and the plusminus symbol.
You use m/yr semi-consistently throughout the manuscript. Preferebly use scientific notation and in glaciology it is somehow common to use pro annum instead of per year: 12.1 m/yr → 12.1 m a^{-1}. Change this throughout.

P10L14
slowed down → decelerated

P10 Fig3
Figure 3 is a bit confusing with all the length changes and additional table. What is the point here. Maybe combine figure 3 and 4, and skip the display of the other glaciers? Just mentioning in text that they are quite similar around Switzerland would suffice, I think.

P10L27
…resulting in 33% debris cover at present.

P11 Fig5
The different periods are a bit difficult to read with the current colour scheme. This could be improved by mapping it over a wider range of luminosities, i.e. from lighter yellows to darker reds.

P11L16-17
I'm not a geomorphologist, but is superficial the right terminology?
"in the metre scale" sounds strange

P12 Fig7 panel b
No error bars on these points?
The melt rate below the debris surface depends both on elevation (i.e. temperature + radiation) and on debris thickness. To have an accurate curve the melt rates have to be normalized by the clean ice melt rate at the same elevation. Does *normalized* in this figure mean that you had a stake at the same elevation on a clean part of ice, representatively close to the debris stake, that was used to normalize each point? If so, did you clear the glacier of debris or did you find a naturally clear spot? Could there then have been errors in the clean ice ablation measurements by radiation emitted or reflected by nearby debris; an energy balance component that would not exist on a completely debris-free glacier?

EDIT: I see now in the text there was one reference stake at 2600. I'm then not quite sure whether the conclusion made are sound.

P12L16-17
Could perturbation of the debris layer during drilling of the stakes have caused a difference in the debris matrix that could have affected the melt rates?

P12 section 4.3
I am a bit confused by the mixed terminology between exposed ice and ice cliffs. At first I thought that with exposed ice, bedsides ice cliffs also patches with very thin or absent debris were meant. However, in this section and also further in the manuscript, it seems like exposed ice and ice cliffs are used interchangeably. Please make this clearer and be consistent with your terminology. If you just mean ice cliffs, I would suggest sticking to that term, since this is most commonly used in literature.

P12L23
,but the → ,and

P13L1
The promille is a bit confusing and unnecessary here, I think. Just stick to 0.5% and 1.8% in this sentence.

P13L10
This also depend on variable rates of ice emergence, which should theoretically be taken into account if an analysis on a subset of a geodetic dataset is performed, also see [*Brun et al.*, 2018]. Ideally, to really look at the effect of ice cliffs and their relative melt, there should be some correction for the downglacier displacement of the ice and cliff.

P13L26
balances → stable

P13 section 4.4
Uncertainty ranges should be included in the numbers that are provided in this section.

P14L7
Pushed down sounds odd. "Travelled downglacier with the flowing ice"?
…at a higher rate…, is it relevant if the rate is higher? They are 'pushed' irrespective of the velocity (expect for completely stable ice).

P15 Fig9
Color of the class -0.5–0.5 should be white, in my opinion.

P16L6
"at 50 cm resolution"

P16L11
remove 'due to higher temperatures'

P16L14
"There is no clear hint" does not sound very scientific.

P16 Fig10
Instead of plotting glacier section number on the x axis it would be more informative to use the mean elevation of a section instead. In that case, you may also consider switching the axes to get an dh/dt gradient kind of plot, similar to figure 17.
What does the 'relation' show in the subtable? A regression through sections? Should ideally be filtered for significance. Consider skipping the table entirely.

P16L29
This is not based on your data, right? Provide inline reference.

P18L4
Unclear, please rephrase.

P18 section 5.1
Could use some subsubheadings

P19L9
These uncertainties are a bit unclear to me. A range from *about* 1 meter to 2 meter. Also, when you convert that to m a^{-1}, doesn't that depend on the variable time span between each observation pair?

P19L19-20
Bit irrelevant background info

P19L27-30
I agree. I think it is not fair to compare 1.5-day measurements to those over much longer time spans. There will be quite some intraannual, intraseasonal and probably diurnal variability in velocity. This should clearly be acknowledged prior to the discussion.

P19L42
Don't miss [*Kraaijenbrink et al.*, 2016] here :-)

P20L8
I don't think the discussed P and T encompass "*all* glacier-related variables".

P20 Fig 14
Not a big fan of introducing new figures, data and analyses in the discussion section.
Discussion is to discuss the results already presented.

P20L22
is it a constant increase, or a continuous increase?

P20L28
Exposed-ice? You mean ice cliff? Earlier comment applied to this section as well.

P21L4
Was even moded → has even moved. Same next sentence.

P21L7
Attenuated is not the right word here. Attenuate means *to make something else smaller, thinner, or weaker*.

P21L14
During…decades → Over the last 16 years
I really don't get these ranges that use the tilde symbol. About 0.80 to 0.98 seems rather specific to me. Why is this an estimate?

P21L15
Same for larger than a range. Isn't >1-2 m the same as >2, essentially? Or do you mean something like greater-than above similar or equal to 2 m? (e.g. $\gtrsim$, $\gtrsim$, $\gtrapprox$)?

P21L16-17
"As a result length and area changes have been comparably small given the high mass loss".

P21L26
"surfacing of debris"

P22L17
We always refer to these cavities as *voids*, as per i.a. [*Benn et al.*, 2012]

P24L26
"A sample" is not very specific. Also why suddenly this new analysis, which does not really provide any novel insights, at the end of the discussion?

P24L29
Remove "than higher up"

P25 Fig 17
I think you could do without this analysis and this figure. If you decide to keep it, at least indicate the actual elevation instead of class number.

P25L9
Swiss glacier's mass balance → Swiss glaciers

P25L15-17
per year is missing from the units here

P25L23
remove today

P25L32
contributary cause → contributes to

P26L1-…
I found the sudden use of procent points a bit strange in this section. Points are a bit irrelevant as they do not show whether something changed from for example no debris to 30% debris, or from 60% to 90%. Surely the actual increases are presented in the original papers?

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