Reviewer 1 General Comments

The revised manuscript by A. Racoviteanu and co-authors 'Surface composition of debris-covered glaciers across the Himalaya using linear spectral unmixing and Landsat 8 OLI imagery' has improved a lot from its original version and I would like to congratulate the authors for all the work they put in, one can tell that this was no minor undertaking. The resulting manuscript is very nice and interesting to read, and the results come out much stronger than in the previous version. The authors have addressed all my comments, and most importantly the more general ones, in a very rigorous way. I am now convinced of the value and robustness of the method and results that the authors present.
The manuscript has undergone major changes and I still have a number of minor comments/suggestions to improve its readability. Line numbers indicated correspond to the revised manuscript (not the track-changes document):

Thank you very much for another thorough read of the manuscript and for the final comments and suggestions. These are very much appreciated and will improve the manuscript further.

Title
L2: 'and' -> 'applied to' or 'of'
Agreed, we have replaced "and" with "of"

Abstract
L22: 'eastern' -> 'central' according to Fig. 1
Correct. This hadn't been updated. It is corrected now.

L25: Would be nice to specify here the proportion of debris-covered glaciers as it is the focus of the study
True. "glacierized" should be "debris-covered area", as per table 5 – somehow this got changed to glacierized. This was corrected and the number matched as per Table 6. We did not work with full glacierized areas.

L26-27: Numbers do not add up to 100%
Thanks for pointing this out. The number for dark debris got mixed up in the multiple rounds of edits, it was 23.8%, not 12.8% as per Table 6. This has been corrected and they add up to 100.

Introduction
L68: 'been' repeated
Repeated word deleted

L79-85: While this is very interesting, I am not sure that it is very relevant here. I would suggest not mentioning it here but maintaining it in the discussion.
We consider that this frames our study as it points out strengths and weaknesses in current datasets, so we prefer to retain this here.

L83: 'a revised dataset'
"a" added.

L104: These studies are not really 'more recent' but rather just looking at smaller domains with finer resolution
We replaced "more recent" with "other"

L109: Zhang et al., 2021 (**https://doi.org/10.3390/rs13071313**) possibly relevant here.
Thank you. This was added and the phrase was slightly re-written since it only pertained to SAR and OBIA or machine learning. It now reads: "Synthetic Aperture Radar overcomes the limitations of optical remote sensing in areas with frequent cloud cover (i.e., the eastern Himalaya), and has been used to map supraglacial ponds and track their dynamics (e.g. Strozzi et al., 2012; Wangchuk and Bolch, 2020; Zhang et al., 2021)."

L136: 'vegetation the mountain range' - something missing here
"across" was missing. We have added it

Data sources and methods

L166-167: 'selected' repeated twice
Corrected

L191: Figure number missing
Added

L197: suggest specifying 'This RapidEye scene consists of orthorectified…'
Added

L217-218: 'numerical inversion *of* the surface'
Added

L238: suggest specifying 'In this study the outlines in the SDC dataset…'
Added

L244: remove 'see' before Delafontaine et al., 2009
Done

L258: 'therefore' appears twice
Corrected

L272: Sections 2.5.1 is well written and detailed. Very nice to read.
Thank you for this comment!

L317: refer here to section 3.1 for the actual values of these thresholds
Done

L326-327: Unless I am mistaken, no need to spell the acronym of RMSE here (done before)
We had first mentioned it on l 210 but we had not spelled it so we moved it there

L339: 2TP + *FP* + FN
Thank you for spotting this! This was indeed a typo, and has been corrected

L340-342: the difference between recall and precision is not very clear here.
For "recall", we have added ", i.e the percentage of results correctly classified by the algorithm" and it should be clearer now.

L347: specify that this is 6 to 7 glacier *for each site*
Done

L358-360: Very good that you specify this here. In my experience, it is actually quite difficult to fully automate an OBIA approach…
Thank you. Agreed!

L375 topo-climatic
This was corrected

Results
L379: I think here it is still missing that pixels which satisfy 2 different thresholds are categorized as 'unclassified'
This is true, we had described this in detail in the answer to reviewer but not included changes to the revised text. Rather than putting this in the results, we think it fits better in the methods in section 2.5.2 so we added it there: "The thresholds varied by class, because any pixel contains a mixture of materials in various proportions (section 3.1). Pixels which satisfy 2 different thresholds are categorized as 'unclassified'."

L444: Add name of the lakes you refer to in corresponding figure
done

L475: patterns
"n" was added

L484: I would rather suspect (from experience of fieldwork in the region in September/October) that this is due to early snowfalls rather than late ablation season
This is a very good possibility. Since we do not know the exact case we have re-written as: "perhaps due to early snowfalls common in this area at this time of the year."

L487-490: this belongs to the discussion
Shortened and moved to section 4.3

L495-498: discussion
Moved to section 4.5

L509-512: These are interesting results in their own way – would actually be interesting to see. You could consider adding a supplementary figure for this?
We did have a figure showing these results in the previous version of the manuscript. This was removed as per recommendation of both reviewers, and was replaced with the current Fig 11. As such, we do not consider adding this back in.

L512-515: discussion

We moved it to 4.1, it fits well there (also merged with the comment below)
"At the mountain range scale, the distribution of supraglacial features may be governed by more complex factors which include geomorphologic, glaciologic and climatic patterns. The topo-climatic conditions for the occurrence of supraglacial ponds on the surface of debris-covered glaciers have been addressed in a small number of studies (e.g. Sakai, 2012; Sakai and Fujita, 2010). While we could hypothesize that both ponds and vegetation tend to develop on stagnant, low angle (< 2°) areas of the debris-covered tongues (Sakai and Fujita, 2010; Reynolds, 2000; Quincey et al., 2007) and at lower elevations, which would favour increased temperature and therefore increase surface melt, we found that trends were not statistically significant on a glacier-by-glacier basis."

L519, 525: Show this exponential decay in the corresponding figure along with its coefficients
done

L520-521: Discussion
Re-phrased and moved to the paragraph above in section 4.1 (see text pertaining to comment on l 512 – 515)

L523-524: 'slope gradient' is wrong here, it should be slope as the gradient of the slope is actually the second derivative of the topography. There are several occurrences of this in the text, make sure to correct all of them.
Corrected

L530: specify '*glacier* aspect'. Remove 'slope'.
Done

L532-536: this is mostly discussion
Moved to section 4.2 ***Spatial and spectral limitations of the Landsat data***

Discussion L539: A lot of this paragraph, as well as figure 13 should appear in the results. This will need to be reformulated.

We have added a new section to the results, 3.7 Supraglacial pond and vegetation distribution over the large domain where we present only trends in the pond and vegetation distribution over the mountain range (Fig 13 a,b) and introduce Fig 13. The introduction of the discussion section was re-worked to only discuss the controls. This should read better.

L554: I do not understand this as eastern Tibet is actually in the south of the range, especially when considering a 1x1° grid
We removed this because it was mentioned several times in the uncertainties

L594-595: These trends appear to be very small and I am wondering if they are really relevant…
We agree, but we prefer to present them and we have added that:
"However, we note that trends in glacier velocities noted here are very small and may not be conclusive*".*

L603-604: No need for such a justification, suggest removing this whole sentence.
Done

L615-620: This makes sense but am not sure it is appropriate here. It reads more like a 'response to reviewers'. Suggest removing to stay concise.
***Remove**d*

L630: 'Landsat' repeated.
Repetition removed

L639: '*square* meters'
Added

L663: 'we are aware …' comes back several times in your discussion and I personally do not like it. I would suggest remaining objective and removing it.
We have removed the two instances in which this appeared

L668: Here you mention that your approach can help track the changes in lake turbidity. I would also insist on the fact that it can help track the changes in pond area, which is also a great outcome.
Moved to the end of that paragraph and rephrased to read: "Since lake turbidity is temporally highly variable and since our current dataset is a snapshot of pond density, it cannot be used to infer any variability in sediment concentration, but it provided the basis for tracking changes in glacier area, which has further applications.

L696: '*square* meters'
Done

L696: some of these ice sails are actually probably large enough to encompass several Landsat pixels and could explain some of the bare ice patches.
We cannot prove this, but we now express it as a possibility only

L728: Suggest simplifying title to 'Wider applicability of the method'.
Agreed and have simplified it

L729: 'demonstrated'
Changed

L736: can -> could
Changed

L736: remove 'we acknowledge that'
Removed

Tables
Table1: add 'Band 1' for the Landsat 8 OLI bands

We are not sure what is meant here "add Band1"
Each Landsat band is preceded by Band 1, 2 etc

Figures

Figure 1: What are the plain lines? Add reference for these regional/climatic outlines
It was a bug in Arc in the way - this is now fixed. Reference was added, as well as labels for the regions

Figure 2: Turquoise over red is difficult to see and could be a problem for color-blind readers. Nice that you shoed the ground truth points. I was wondering if there would be a way to show the different classes? It would be interesting to have a zoomed-in view of one of the glaciers to show these different classes.

Thanks for pointing this out. We have changed the colours to green and yellow.
With regards to the classes: Since the classes are defined as pure SINGLE pixels, it would not be an interesting figure, i.e. just showing some coloured pixels zoomed in. Therefore we feel it would clutter Fig 2 without adding any important information.

Figure 6: It is hard to distinguish the LMM ponds from the OBIA ponds. Suggest taking different colors

We have tried all the possible colours and completely re-done the figure, and unfortunately could not find a better way to display unless we zoom in, which is not possible while retaining the overview of the spatial extent. In this case, this seems to be the best we can do, and the figure has much improved from the last version. The LMM and the OBIA match pretty well, and this is the key point here. Left unchanged.

Figure 12: This figure could be very much improved. It is currently very raw and simplistic. There is space to add additional information. For example, I suggest showing the exponential decay you mention by fitting and exponential to your points. Since we are talking of bins, wouldn't horizontal lines or bars make more sense than points? For c), specify in figure that this is glacier aspect.

It is already specified in the figure caption "aspect over glaciers". We changed to "glacier aspect". We also added the functions (exponential decay for (a) and polynomial for (b).

Figure 13: It is difficult to see any correlation with such plots. It could be worth increasing the size of the dots in a first step. However, if you really want to show a correlation, it would be interesting to do so in an x-y plot.

We have increased the size of the dots. In Figure 13 we aim at summarizing spatial trends, and this is clear in the text and caption. We did not present it as a corelation analysis but rather as support for the discussion of the controls. At the suggestion of both reviewers, we have added a correlation matrix.

Reviewer 2 General Comments

The revised manuscript by Racoviteanu et al. on spectral unmixing of debris-covered glaciers has been considerably reworked and has been much improved with respect to the initial submission. I compliment the authors on their effort.

Comments provided by reviewer #1 and by me have been largely responded to satisfactorily and the manuscript was adapted where necessary. There is better validation now; a weak analysis has been replaced with more convincing approach; the discussion about the advantages and, importantly, the limitations of the approach has become much clearer; and many of the more subjective statements and interpretations were removed.

There a still a few points that I think should be resolved before publication of the manuscript.

Thank you for these comments, and for reviewing the paper once again and providing very useful comments. We have addressed these line-by-line comments as well as the bigger concerns.

L96. I would not say it is freely available, as that is not entirely true.
Planet imagery for free (of course within the area limitation) for academic purposes with an API. We do not wish to go into detail here. We have removed "freely" but this is not correct either.

L196. Fix the underscore in the reference.
This will be done at the very final version of the paper when the references will be converted to plain text as it is related to a glitch in EndNote which we use here to manage the references

L237. Fix the underscore in the reference.
Same as above

L257. LMM is here defined as plural form ('models'). In other places in the manuscript, it is also used as singular. Be consistent. LMMs is preferable when used a plural.
We added "s" where appropriate.

L276-277. Consist in -> consist of
done

L352. Cannot really put my finger on it, but "the Langtang" and "the lahaul spiti" sounds very odd. What about using Khumbu Region, Langtang Region, Lahaul Spiti Region throughout?
Added "region" to the for instances where this was found.

L349. Is HarrisGeospatial really written without a space?
See comment above with regards to l 196. This is fixed when references will be converted to plan text.

L367. “Numerous” is quite understating. “Majority” or even “vast majority”
We have changed to “the vast majority”

L475. Patters -> patterns
Fixed

L540-L592.
I think the approach taken here is very much an improvement over the previous analysis, which I think was not very convincing. However, I do not really understand why it was chosen to do the analysis on a 1x1 degree grid, as this makes the presented analysis still somewhat shallow. The authors state it is to have optimal comparison with other papers (Brun, Shean, Dehecq etc.), but that comparison is not really made in the manuscript. They also indicate that more detailed analyses are necessary to robustly analyze the drivers of debris-covered glacier surface properties. However, since all input data have much finer resolution or are even available at the glacier level, the authors could have presented a more robust and detailed analysis using their data. A more sophisticated approach that looks at individual glaciers seems very much feasible and not much more elaborate than what is currently presented, and could quite easily and logically be combined with the results presented in Figure 11.

In the previous version of the manuscript, we presented a glacier-by-glacier analysis and both reviewers found the results not conclusive because of the glacier-by-glacier variability. Accordingly, we binned our data by (a) elevation and (b) 1x1 grid, with the aim to show the principle large-scale patterns of ponds and vegetation distribution rather than to try to derive causal relationships, as we feel this is too much to cover along with the method description within this paper. The 1x1 grid approach is standard to many HMA-region publications, and our paper fits within this approach to summarize spatial trends. We have added more comparisons with Dehecq, Brun etc.

We still contend that given the complex, time-dependent, covariance of debris-covered glacier surface properties, a deeper analysis seeking causal relationships and drivers of these large-scale patterns should be performed only on a further quality controlled dataset and in conjunction with additional datasets, simulated glacier states and, while undoubtedly interesting, this lies outwith the scope of this paper.

The authors present trends of the different variables with latitude and longitude to evaluate regional patterns. By discussing it in light of these spatial patterns, they infer relations between the variables in a rather unquantified manner. It would be much stronger to directly compare the different variables and quantify whether they actually correlate. This would mean providing the correlations and whether these are actually statistically significant. Clearest would be to include an additional panel to Figure 13 with a correlation or trend matrix for all the presented

variables in Figure 13 (+ latitude + longitude). Also, for the now-included trends with latitude and longitude, it should at least be mentioned whether these trends are significant or not.

We have added a correlation matrix as a separate table (Table 7).

L600 stepper -> steeper
Corrected

L667 ponds -> pond
Corrected

L783 Python-based -> scripted
Changed