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The Cryosphere Discussions

Interactive comment on "Permafrost distribution in the European Alps: calculation and evaluation of an index map and summary statistics" *by* L. Boeckli et al.

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We thank reviewer #1 for his valuable comments, which helped us to improve the manuscript. The referee comments ('RC') are extracted and answered by the authors ('AC') below.

General comments

RC: . . . For evaluating this study, I had to read the B1-paper, and it is clear that this study is an application of the B1-concept to the Alps. And I wondered, why these two papers were not combined, as the second would nicely underpin the validity of the first.

. . . However, it is difficult to follow this study without reading B1 first.

AC: We agree with reviewer #1 that it is necessary to read the first article to fully understand the statistical methods used. However, we believe that is reasonable to separate the two articles because they address different scientific questions and the combination of both would be much too long. Article 1 describes a generic approach to model permafrost distribution in large mountain area using statistical methods. The focus lies on the establishment of a general modelling framework and the calibration of a model shown as an example for the Alps. This can however be applied to any mountain region. Article 2 focuses on the application of the model to an entire mountain region, which involves additional scientific efforts: a) extrapolation of APMOD to other surface types than used for model calibration, b) establishment of a suitable legend and an interpretation key, c) evaluation of a grid-based prediction with point observations, and d) calculation of Alpine-wide summary statistics describing permafrost distribution. Further, readers not interested in statistical modelling but in permafrost mapping and related summary statistics (or vice versa) may profit from the two articles individually.

RC: The paper is lengthy, and much of the APMOD description in METHODS can be omitted, or partly moved to the DISCUSSION.

AC: We shortened the manuscript and tried to avoid repetition from article 1 as far as possible. We deleted subsection 3.1 from the original manuscript.

RC: Further, the validation to observations not used in the APMOD scheme is ok, but I would like to see how the model performs in relation to the already published modelling approaches, e.g. for the Corvatsch area where much information is available.

AC: We agree with reviewer #1 that a comparison to established modelling approaches would be interesting. However, to assess the performance of APIM the comparison to

TCD
6, C822–C833, 2012

a higher quality data set would be required and this is not available for the Alps.

Nevertheless, we have made a visual comparison of APIM and the permafrost map by the Swiss federal office for the environment (BAFU, 2005) for a test region (including Corvatsch). The gain from such a figure is small, because the different classification schemes (discrete versus continuous classification) do not allow a direct comparison. For a sound comparison of these two maps transfer methods linking these two maps need to be established. To include this in our paper, it would require more information regarding background and methods of the map to compare, and showing and discussing the result of the comparison. Since this would further lengthen the paper we decided to not include it.

RC: I think the paper would improve with a defined RESULT chapter.

AC: We merged the three sections 'Interpretation key for the permafrost index', 'Evaluation of the permafrost index map' and 'Calculation of summary statistics' into section named 'Results'. The section titles from the original manuscript were kept as subsection titles.

RC: I would suggest to provide an alpine-wide map showing that your approach is unifying, or a couple of higher-resolution examples from different regions in the Alps, maybe both regions containing validation and regions which are not that much investigated.

AC: We added a new figure showing APIM on an Alpine-wide scale (Fig. 1, below). We did not add further maps on a better spatial resolution because the map user can download the GoogleEarth overlay, which is provided as a web link.

Detailed comments and suggestions:

RC: p. 850, abstract: Delete last sentence, put in ACKNOWLEDGEMENT

TCD
6, C822–C833, 2012

AC: Done.

Introduction

RC: Is not very good and 'jumpy'. Give first a background for the study, and then Objectives and Aims or Hypothesis, and how you address these with your approach. P. 852, l. 1 ff. can be moved into the discussion, or use parts early in the Introduction. Last paragraph of Introduction should be part of the Discussion. What is the advantage of your study in relation to the cited studies?

AC: We restructured the section as suggested by reviewer #1 and added a clearer statement about the advantage of our study in relation to existing ones by adding: '[...] which often is not declared or described in detail in previous work'. The last paragraph of the 'Introduction' was deleted and the statement regarding models developed for other mountain regions is mentioned earlier in the revised manuscript.

Chapter 2: Methods

RC: Paragraph 2.1.: This is a discussion of APMOD, move to discussion or delete

AC: The overview description of APMOD in the section methods is important, because the whole manuscript is based on this methodology and we see no reason to move this paragraph towards the discussion. Further, the information given in section 2.1 is essential for readers that do not want to read article 1. The second paragraph of section 2.1 is also important because we argue for an index-based modelling approach instead of using probabilities. This strongly affects the following sections of the manuscript, especially the results presented. To underline the importance of this subsection, we changed it to an own section in the revised manuscript.

RC: Paragraph 2.2.: Also much Discussion, only say what you have done and discuss

TCD
6, C822–C833, 2012

later.

AC: In the revised manuscript, the paragraph 2.2 is merged into section 3.3 (see below). Further, most of the text from the paragraph 2.2 was moved to the section discussion to better separate methods and discussions.

Chapter 3: Data

RC: Most of the Data chapter are METHODS, where you want to show how you translate the APMOD outcome into the permafrost index. I would strongly suggest that you make on 'DATA and METHODS' chapter, explicitly showing how you translate from APMOD to APIM. Give a flow chart if you want, this is often beneficial for other readers to understand your thinking here. Move the 'Validation' from 2.2. to the end here or as an own part in 6.

AC: We merged these two sections to one main section 'Data and Methods' and the subsection 'Evaluation' is moved to the end. As mentioned above, the subsection 2.1 is changed to an own section in the revised manuscript.

RC: Paragraph. 3.1.: What is from the B1 paper and what from this study, if from B1, remove.

AC: We deleted this paragraph as suggested by both reviewers and only refer to Boeckli et al. (2012) in the revised manuscript.

RC: p. 857 l. 2: 'In agreement with ...', this sounds like a total different paper, but it is your work. Again, what is this study and what B1?

AC: We added the following sentence to make this clearer: 'To be consistent and applying the rock model to the same surface-cover domain as it was calibrated for, we use the same definition of steep bedrock as in Boeckli et al. (2012):'

TCD
6, C822–C833, 2012

RC: Paragraph. 3.3. I had difficulties to understand this section in terms of how you justify your weighting here. Try to make it a bit clearer, I understand that this is an important part, and therefore it should be easy to understand.

AC: This paragraph is merged in the revised manuscript with paragraph 2.2 from the original manuscript. To address the comment of reviewer #1 we added the following sentences: 'This is necessary because some observation points are not suitable for model evaluation and needed to be excluded beforehand (Sect. 6.2). However, the weighting scheme applied to derive PF_{loc} is based on subjective thresholds.'

Chapter 4: Estimation of offset terms

RC: p. 859, l. 15 ff. Remove the whole first paragraph, we do not need a summary of the following section.

AC: Done.

RC: p. 860, l. 1 ff: Same as 'evaluation', I do not really follow the argumentation. Maybe it is more pedagogic if you start with the equation, and then explain why and what the different components are.

AC: To make this paragraph clearer to the reader, we tried to earlier state that we need to include an temperature offset here by adding the following sentence: '[...] To address this, a temperature offset term is included in the rock model that is based on literature: [...]'.

RC: p. 860, l. 12: What is 'optimistic' here? And what is then 'Pessimistic'?

AC: In the manuscript the expression 'optimistic estimate' is explained in the following

brackets explaining the meaning of optimistic in this respect ('biased towards an overestimation'). We believe that this explanation is sufficient.

RC: p. 861, 1st paragr. This is a Discussion again, move.

AC: This information is needed here because it establishes the chosen offset values. Moving it to the 'Discussion' would bother the reader to jump forwards and backwards in the manuscript.

Chapter 5: Interpretation key for the permafrost index

RC: Remove the whole paragraph and the figure in the appendix. This is an own story, and would be a nice contribution to e.g. the Journal of Maps. Public authorities normally do not read scientific journals, so I guess if you want them to use your maps, you must make a report and guidance how to use your map, and there you can write these things.

AC: We think this section (including the appendix) should not be removed because it concerns an essential part of the production of a map: Typically discrete permafrost occurrence classes (e.g. sporadic permafrost) or pure probabilities (e.g. Lewkowicz and Ednie, 2004) were used for similar maps. Here, we developed a flexible legend that allows together with the interpretation key to further interpret and refine the shown index color in APIM by the map user. This strategy is an important part of the result and could also be set up for other maps.

We strongly believe that this information needs to be addressed in a journal such as The Cryosphere because a) map-based output products are a common way to visualize permafrost distribution and their development should not only be discussed by the geo-visualization community but also the permafrost, b) the reduction of scientific results to a product that is understandable and useful for public authorities is

not trivial and requires discussion and reviewing by permafrost experts.

Chapter 6: Evaluation of the permafrost index map

RC: This is a validation. DELETE the first sentence! DELETE the last paragraph of the chapter or move this to an earlier place. The AUROC presentation is nice, but as mentioned above, how is the performance in relation to earlier models? Consider at least an inter-comparison, this is often valuable as the earlier published models serve as a sort of state of the art, and you want to improve that. I understand that your approach is based on a much better data basis; however, often this does not necessarily mean that the model performs better.

AC: As suggested by reviewer #1 the first sentence was deleted and the last paragraph was moved to the new subsection 'Evaluation' in the new section 'Data and Methods' in the revised manuscript. As stated earlier, it is challenging to make a sound qualitative or quantitative comparison APIM with existing products. Further we believe that gain of such a comparison is small because existing map-based products are based on much less calibration data and none of them is validated properly with measurements.

Chapter 7: Calculation of summary statistics

RC: This is a RESULT, move.

AC: This section was changed to a subsection in the section 'Results'.

Chapter 8: Discussion

RC: I would suggest a restructuring of the discussion. I have suggested that many earlier paragraphs should be moved into the discussion, and at present there seems to be some redundancies. In the discussion you should discuss first the uncertainties and model advantages (in relation to older approaches) and limitations, then the obtained

TCD
6, C822–C833, 2012

permafrost distribution for the Alps and finally some sentences about what your new findings mean for mountain permafrost science and possible practical applications such as planning etc. This is a suggestion, at present the discussion could be improved, and there is no scientific discussion in relation to comparable approaches elsewhere.

AC: To address the critique that there is no scientific discussion in relation to comparable approaches we added the following sentences at the beginning of Sect. 6: 'APIM is based on a larger calibration data set in comparison with comparable map-based products. Further, existing permafrost distribution models are calibrated for a specific spatial domain or surface type (e.g. using basal temperature of snow (BTS, Haeberli 1973) measurements in gentle terrain) but later applied to a whole mountain range. This spatial extrapolation that is required for every spatially distributed permafrost model is done in a transparent manner in this work by introducing temperature offsets (Sect .4).'

Chapter 9: Conclusion

RC: p. 867, l. 22: 'A high index value ...': You never showed that high APIM means 'permafrost in very cold condition' What is 'Very cold'? Then you should show a scatter of e.g. borehole temperatures against APIM-values.

AC: As mentioned in the manuscript, a high APIM value points to permafrost in nearly all conditions and a low APIM value to permafrost only in very cold conditions. The intention behind the formulation of these terms was to keep the interpretation of the legend flexible and to communicate the uncertainties that come together with APIM. 'Very cold' in this sense mean a topographical situation that is favorable for permafrost presence (i.e. occurrence of coarse blocks, large fractured rock and/or location at foot of a talus slope). To make this clearer to the reader we changed the term 'very cold conditions' to 'very favorable conditions' and included the following sentence in the revised manuscript: 'The term 'very favorable conditions' refers to a situation

TCD
6, C822–C833, 2012

(topography and ground characteristics) that locally modifies favorably conditions for permafrost presence.' We did not include a scatter of borehole temperatures to APIM values in our manuscript because a) the amount of borehole temperatures are not sufficient, b) the mean annual ground surface temperature that are included in the database are based on different measurement depth and observation periods and c) sub-grid variability makes it hard to compare measurements taken from point location to the gridded prediction of APIM.

RC: Bullet point 3: 1-6%? This is a large range, what is 'relative area of permafrost occurrence'? In relation to country? Or in relation to the APIM?

AC: In line with the discussion, in the revised version the relative area of permafrost in the Alps is concluded to be 3%. Further we clarified what is meant with relative area in the revised manuscript: '[...]The relative area of permafrost occurrence in relation to the total area of the Alps is estimated to be 3% when considering an index ≤ 0.5*.'*

And: Nobody expects to calculate 'Exact' extents, or nobody can. You can remove that sentence. Remove the last sentence, too (l. 15 ff.).

AC: These two sentences were removed in the revised manuscript.

Chapter 10: Data availability

RC: Delete or remove to Acknowledgement. In 30 years your paper will still be available and citable; will the exact link for data download also survive 30 years at your Department? Therefore it is maybe better to have this type of info other places than in the main paper text.

AC: This is indeed a critical point and we therefore decided to use Pangaea

TCD
6, C822–C833, 2012

(www.pangaea.de), an Open Access library aimed at archiving data, to guarantee the long-term availability of our data. By this, the data can be identified using a Digital Object Identifier (DOI). Accordingly, the beginning of section 10 was rewritten: 'The APIM is freely available for download at: http://doi.pangaea.de/10.1594/PANGAEA.784450 in georeferenced png format. Additionally, the interpretation key (Fig. A1) and the surface-cover map (cf. Fig. 6) that defines the used vegetation mask as well as the distinction of debris cover and bedrock based on slope angle are available. Alternatively, all data is available as a kmz overlay for Google Earth and as a Web Mapping Service for use in a GIS environment (accessible at: http://www.geo.uzh.ch/microsite/cryodata/PF_map_explanation.html).'

References: BAFU: Hinweiskarte der potentiellen Permafrostverbreitung in der Schweiz, Bundesamt für Umwelt (BAFU)/Swiss Federal Office for the Environment, 2005.

Keller, F.: Automated mapping of mountain permafrost using the program PERMAKART within the geographical information system ARC/INFO, Permafrost and Periglacial Processes, 3, 133–138, doi:10.1002/ppp.3430030210, 1992.

Lewkowicz, A. G. and Ednie, M.: Probability mapping of mountain permafrost using the BTS method, Wolf Creek, Yukon Territory, Canada, Permafrost and Periglacial Processes, 15, 67–80, doi:10.1002/ppp.480, 2004.

Interactive comment on The Cryosphere Discuss., 6, 849, 2012.

TCD
6, C822–C833, 2012

Interactive Comment

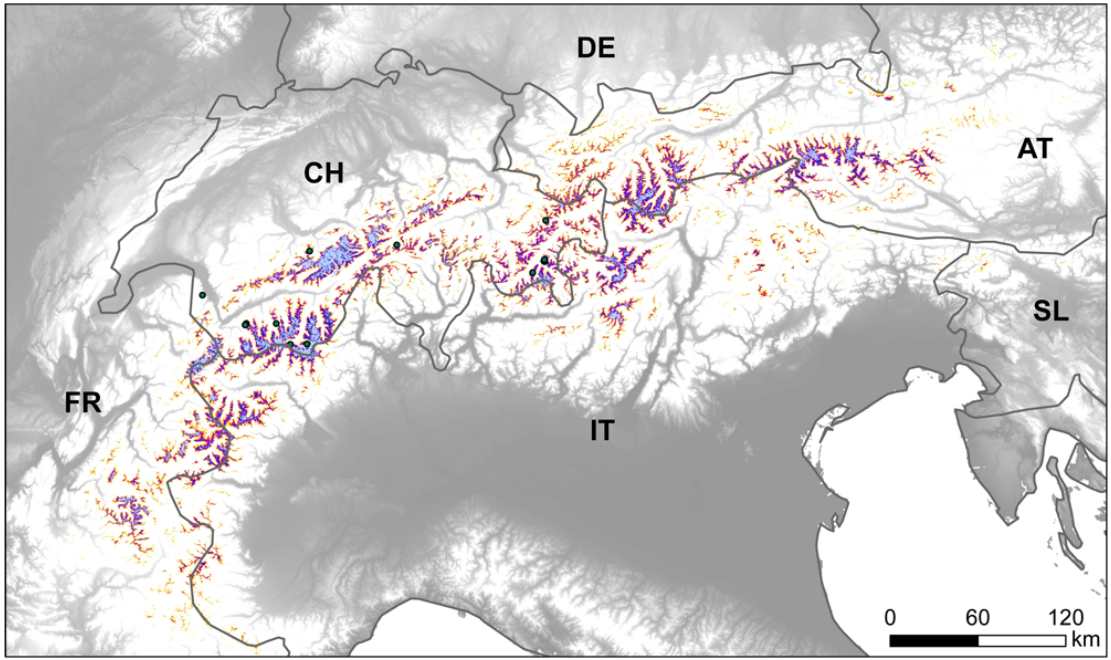

Fig. 1. Alpine Permafrost Index Map (APIM) shown for the European Alps (AT: Austria, CH: Switzerland, DE: Germany, FR: France, IT: Italy, SL: Slovenia). The map should be interpreted together with the legend

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