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Interactive comment on "Thermal characteristics of permafrost in the steep alpine rock walls of the Aiguille du Midi (Mont Blanc Massif, 3842 m a.s.l.)" *by* F. Magnin et al.

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Author's response to reviewers' reports

Paper title: Thermal characteristics of permafrost in the steep alpine rock walls of the Aiguille du Midi (Mont Blanc Massif, 3842 m a.s.l.) Authors: F. Magnin, P. Deline, L. Ravanel, J. Noetzli, P. Pogliotti

Dear Handling Editor: Dr. Tingjun Zhang, dear reviewers: Dr. Andreas Hasler and anonymous,

All the authors deeply thank you for having thoroughly read our submitted paper, and for the encouraging comments and relevant remarks that you provided.

All these remarks and suggestions have been considered to produce the revised version of our paper and we think that the manuscript has been significantly improved. We hope that it now satisfies the standards for a publication in The Cryosphere.

Hereafter you will find the detailed answers to your comments, with comments from referees, authors' response and changes in the manuscript (written in red). These changes have been reported in a supplementary revised manuscript in which they are highlighted in yellow. We replied to every comment and question, but some of them do not have any sense any more in the revised version. The text has been subject to major revisions:

1. The abstract now states major observations that confirm previous studies and extent existing knowledge. 2. The introduction is widened with background components, with the scientific goals, previously placed in the site description (former sect. 2.2), and with specific research questions. 3. The site description section is restricted to a single section (former sub-sect. 2.2. moved in the introduction of the revised version), but is widened with complementary measurements not used in this study (formerly in method sect. 3.2). 4. In the method sections, titles are adapted; sub-section 3.2 is reduced and only presents complementary measurements used in this study. Table 1 now contains information on the snow thickness at the logger locations. 5. The design of Table 2 is modified (coloured) to improve visibility. 6. In section 5 (rock surface temperature) and section 6 (borehole records), the data description is now separated from its interpretation. In section 5, sub-sections 5.1 and 5.2 are merged in a single sub-section (5.1. Surface Offset patterns). Section 5.3 becomes sub-section 5.2, and 5.3 is built with the discussion lines of the section 5 from the submitted version.

In section 6, sub-section 6.3 is totally rewritten with the discussion lines of the sub-sections 6.1 and 6.2 of the submitted version. Figure 8 and the related discussion of the previous sub-section (6.3. Heat flux end bedrock structure) is removed, but is summarized as an outlook in the new perspective section. Table 3 is completed with air temperature data. 7. The section 7 (conclusions) is reworked in accordance with the re-organisation of the introduction and discussion. 8. An additional section, (8. Further developments), outlines our research perspectives with the presented dataset.

These modifications, aim at satisfying the requirements expressed by reviewers, and we hope that they will allow the paper to be accepted for publication.

Best regards.

Dr. Florence Magnin, on behalf of all the authors.

Response to anonymous Reviewer #1

Reviewer #1: The subject matter is appropriate for the Cryosphere and should be of great interest to other permafrost scientists and the alpine geohazards scientific community in general. The presented data and interpretation of results is sound and are clearly presented. The paper is very well written and figures are of high quality and fully understandable. However, I have some general comments, questions and suggestions for improvements (see below) the authors should consider in a revised version of the paper. In my opinion, the paper is acceptable for publication with minor revisions. Authors reply: Thank you very much for these encouraging comments. We addressed all your comments hereafter, and together with the answers to Reviewer #2, A. Hasler, we hope that the revised version will satisfy The Cryosphere standards.

Reviewer #1, General comment #1: The paper is dominated by presentations of new data and interpretation of results from steep alpine rock walls. I miss some more discussion on how your results may contribute to better understand permafrost-related hazards in general, and the thermo-hydromechanical processes involved. Are e.g.

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some of your results related to the effects of variations in snow cover and bedrock structure important? You conclude that "the thermal features of BH_N show that the fracture has a greater impact than snow insulation on the permafrost thermal regime, whereas it seems that snow insulation has probably more influence on the active layer pattern". This is in my opinion very interesting results and could be further discussed in the light of present knowledge. Authors' reply: This study is based on a limited number of data and only aims at presenting the AdM data set. The authors didn't expand the discussion on the contribution of this study to the global understanding of permafrost-related hazards to avoid straightforward generalization. However, we draw some research perspectives in a new section, 8. Further developments, to meet this requirement and the following comments: e.g. "...Specific investigations addressing the snow control effect may be required to better understand the impact of thick snow accumulations and summer snow falls on ALT and permafrost changes which may contribute in the knowledge development on rock fall activities. The detailed analysis of the pictures showing the evolution of the south and northeast faces, of the snow probes and boreholes records at the AdM, will support this project..." Also, following recommendations from Reviewer #2, we separated the results description and discussion which allowed to more precisely discuss our results in the light of the present knowledge (see sections 5.3 and 6.3). Reviewer #1, General comment #2: In the introduction the authors state: "The last few decades have seen an increase in rockfall activity from steep, high-altitude rock walls in the Mont Blanc Massif (Western European Alps)...". Do you have any ideas or strategies on how your monitoring program could be used or expanded to better understand the increased rockfall activity in this area? Authors' reply: Our monitoring program has been designed to collect various kinds of data, and for model development and validation. A statistical model of permafrost distribution has been implemented on a high resolution DEM of the Mont Blanc massif (submitted to Géomorphologie), and has been validated with 8 electrical resistivity tomography (ERT) measurements on 6 different sites in sensitive permafrost areas (submitted to Journal of Geophysical research: Earth Surface). This model will allow characteriz-

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ing the link between bedrock temperature and failure by determining the temperature at rock fall locations that are documented each year by a network of observers. We also aim to develop 2D to 3D numerical transient models using the statistical model as upper boundary conditions and the ERT results for validation. Such a model has been performed on horizontal cross-sections of the Piton central at the Aiguille du Midi and will be submitted in the coming months. Moreover, the combined analysis of our various data (crack-meters, air and bedrock temperatures for instance) will allow to describe and to better understand the relationship between thermal and mechanical processes. In the revised version, we mentioned these projects in the new section 8.: e.g. "...The here presented data set will be used for statistical and numerical model evaluations designed for mapping the permafrost distribution in the Mont Blanc massif (Magnin et al., 2014) and for predicting the temperature field distribution and evolution over the next century at the AdM (Noetzli et al., 2014b). The statistical model will be used for determining the bedrock temperature and related permafrost thermal regime at the inventoried rock fall locations to analyze the relationship between bedrock temperature and failure..." Reviewer #1, Specific comment P2836, L11-13: Did you do any calculations or have any idea how much the bedrock temperature for the borehole sites is influenced by the galleries (e.g. air circulation) and other installations at AdM, e.g. heating from the restaurant(?) above BH_S? Authors' reply: We didn't perform any calculation but only made an assumption which is that the borehole are not affected by the anthropogenic disturbance as they are located well-below the anthropogenic level (several tens of meters downstream infrastructure). Moreover, unlike the Piton Nord, the Piton Central, where the boreholes are installed, contains little artificially heated areas. We added this precision in the revised version: "The possible disturbances in the Piton Central are assumed to be related to air ventilation and heating from the local workers team rooms especially, but because of the pluri-decametric vertical distance in between the galleries and the boreholes, we assume that these last ones are not affected by the anthropogenic disturbance"

Reviewer #1, Specific comment P2838, L11-13: Did you use this data in the present paper? It was not clear if you used the Météo France data or your local weather data, or did you combine it? Did you compare the Météo France data with your own air temperature data? Did you correct for altitude difference between e.g. the Météo France station and your local sites for calculating the ASO and SSO? At witch height above rock surface was the air temperature measured and did you consider possible errors in your air temperature measurements itself, e.g. the influence of the surface properties on radiative errors (see e.g. Huwald, H., C. W. Higgins, M.-O. Boldi, E. Bou-Zeid, M. Lehning, and M. B. Parlange (2009), Albedo effect on radiative errors in air temperature measurements, Water Resour. Res., 45, W08431, doi:10.1029/2008WR007600.)? All this points may be relevant and important to get the correct air temperature, influencing the ASO and SSO values for your sites. Some more information and critical assessments on these points would be useful. Authors' reply: We only used the Météo France data for two main reasons: they cover a longer time-period and they are not supposed to be influenced by the rock albedo as the weather station is located 3 m above the really top of the Piton Central and is shielded. We corrected the elevation in the Table 1 ("3845 m a.s.l" instead of 3842). We have contacted the Météo France engineer and according to him, the air temperature records maybe slightly warmer than in the free atmosphere during warm days without wind. The air temperature data from the three stations were compared before, and finally weren't presented it in the study. The two weather stations located close the rock surface are clearly influenced by the rock surface albedo as MAAT is +1°C close to the south face than Météo France (2009 that is the only common year of complete records) and is +0.5°C close to the north face than the Météo France records. We didn't include these precisions in the submitted draft to do not confuse the reader with too many information on air temperature, to keep the reader focus on the surface offset concept, and because these air temperature data are short and discontinuous. We didn't correct the elevation in the submitted draft as we assumed that applying a theoretical lapse rate would not be more precise than using the records without corrections. This question also arose from Reviewer #2, and we reprocessed the surface offset data with a lapse rate correction (standard value of

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0.006.m-1) for every sensor. In the revised version we added these preicisions: “We applied a standard lapse rate of 0.006°C.m-1 on air temperature in order to balance the elevation difference between the Météo France station and the sensors”. The general patterns of surface offset distribution, either annual or seasonal, remain unchanged. It just slightly reinforced the colder character of snow covered and south-exposed sensors compared to snow free sensors in the same aspect. 2011 ASO at BH_N is also slightly closer than N1 and N2 values. The interpretation remains unchanged but we corrected the absolute values in the revised version: 9.5°C and 1.5°C (p. 2040, l. 23): “9.3°C” and “1.3°C”; 4.8°C and 10°C (p. 2852 l. 22): “4.1°C” and “9.5°C”. âĂČ

Interactive comment on The Cryosphere Discuss., 8, 2831, 2014.