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The Cryosphere Discussions

Interactive comment on "Ground surface temperatures indicate the presence of permafrost in North Africa (Djebel Toubkal, High Atlas, Morocco)" *by* Gonçalo Vieira et al.

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GENERAL COMMENTS

The research article "Ground surface temperatures indicate the presence of permafrost in North Africa (Djebel Toubkal, High Atlas, Morocco)" presents new observations and thoughts on the permafrost occurrence in the High Atlas. Due to the particularly poor data basis concerning permafrost and related phenomena in North Africa, any new measurements and findings on the potential permafrost distribution are of high importance, not only for the research community but also from an environmental and socio-economic perspective.

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The gap in research and the knowledge from previous studies are well described in the introduction and the topic is nicely put into a larger context illustrating the characteristics of arid and semi-arid environments. Moreover, the environmental conditions and the geological setting of the studied region are compared with other high mountain areas. The overall objective, to contribute to the question of permafrost distribution in North Africa, is very ambitious. Probably too ambitious because recent studies and direct observations are missing and the acquired GST time series only cover one year of data for a small number of spots. Although the authors grade their work as an "exploratory step towards an in-depth assessment aiming at the characterization and modelling of permafrost in the High Atlas", the main critique on this article could be: Why didn't the authors wait two years longer to publish their work together with a sound data basis, consisting of at least three years of continuous GST data and e.g. some complementary geophysical investigations?

The general approach combining weather station data series, remote sensing data and a geomorphological interpretation of the landforms is certainly a good starting point to maximise the informative value of the GST data. However, although the authors clearly point out that the few observations must be interpreted very carefully, the measurement setup and some of the results seem somehow on the limit of being scientifically reasonable. Personally, I doubt that only four miniature loggers can provide a meaningful 'altitudinal gradient', and I would avoid making linear regressions (P7_L3 & Fig. 8) out of it nor extrapolate these results to a larger area. On the other hand, the publication can be justified because almost no permafrost observations are available for the High Atlas, and because this paper may motivate the mountain permafrost research community to put particular emphasis on that region. Moreover, the article is a nice complement to other mountain permafrost papers enriching the TC special issue "The evolution of permafrost in mountain regions". Therefore, I recommend this research article to be published with minor corrections. The following comments could help to improve the article, mainly concerning the interpretation of the GST data. Most important, I would like to encourage the authors to keep on measuring and observing the permafrost in the High Atlas!

SPECIFIC COMMENTS

Title: The experience from the European Alps showed that one year of GST measurements does not provide reliable results on the ground thermal regime because of the high inter-annual variability of weather and snow conditions. In this regard, I suggest rethinking the title of the manuscript, e.g. towards a more neutral formulation “New observations indicate the occurrence of permafrost in the High Atlas mountain range (Djebel Toubkal, Morocco)”.

Interpretation of GST data: The interpretation of the GST data as a ‘BTS signal’ is only valid if a thermally insulating snow cover is present for longer than just a few weeks. It seems like logger T3 fulfils this criterion around end of February 2016 (Fig. 10). At T1 and T2, the active layer is likely not in a thermal equilibrium with the permafrost base, these GST records characterise an integral of the recent atmospheric conditions with some modification by a temporarily snow cover. Depending on the terrain roughness and the snow density, about 50-100 cm of snow are required to effectively insulate the ground surface from air temperature variations (e.g. Keller and Gubler (1993); Zhang (2005); Staub and Delaloye (2016)). If there is less snow under winter conditions, the ground is likely colder at its surface than a few meters below. Although the potentially snow-covered period is shorter and snow heights are lower on average in the Toubkal massif than e.g. in the European Alps, the timing and duration of the snow cover probably play a key role for sporadic permafrost occurrence also in the High Atlas – as described by the authors. In comparison to the permafrost areas in the Alps, where the conditions during the winter season are often more important for inter-annual ground temperature variations than the summer warming (cf. PERMOS (2016)), snow disappearance is up to three months earlier in the Toubkal massif (despite of persisting snow patches), even at 3500 m asl. This means that the ground is usually snow free during the entire period of maximal insulation. The local effects of shading could be very important. Probably a GIS-analysis on topo-climatic parameters such as potential

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incoming solar radiation, slope and curvature could help to characterise the acquired GST data and putting it into the spatial context. Moreover, it might be interesting to quantify ground thawing and freezing degree day sums for the summer and winter period.

Measurement setup: A future GST measurement setup around Djebel Toubkal could be installed similarly as described by Gubler et al. (2011) to provide some observational evidence on the GST variability considering different ground materials and topo-climatic situations at least for a few years. I am fully aware of the high financial and logistical effort for such permafrost observations in the remote High Atlas, but I think that such a data basis is required for any further steps towards permafrost mapping and modelling. At best, such spatially distributed GST measurements would be complemented by ERT surveys and geomorphological mapping. Building up a rock glacier and frozen debris lobe inventory

Weather and climate data: The authors characterise that particular year with GST observations in the climatological context by using meteorological data (Sect. 4.1, Figs. 3-5, 11 and 13). This is clearly a challenging task regarding the sparse data available, but the spatial transfer of air temperature data over ~3500 m elevation between Menara at Marrakesh to the Djebel Toubkal mountain is not satisfactory from a scientific point of view. Although the lapse rates provided and calculated seem plausible, these lapse rates likely vary over the season and the weather conditions can be very different in the mountains to what is measured in Marrakesh. The “significant correlation” of monthly air temperature values between Neltner and Sidi Chamarouch (P6_L14 and Fig. 3) is likely a result of the high seasonal temperature amplitudes. However, the comparison to other quantitative and qualitative data sources could be extended. For example, the snow climatology could be analysed over the entire period of available satellite imagery. Also satellite-derived land surface temperature data could enhance the comparison of the period 2015-16 in a larger temporal and spatial context – of course with limitations due to the lack of validation data and the difficulties in mountainous terrain. Maybe even RCM reanalysis data could help to assess the regional climate history.

P7_L20: Clarify that you mean daily maxima in the sentence “A plateau in the maxima. . .”

P7_L23-24: I would not state the relationship between elevation and MAGST of these four locations as “statistically significant” and rather try to quantify the uncertainty of each data point. The uncertainty of MAGST is likely much higher than $\pm$0.4°C/100m. Observations from the Swiss Alps show that elevation can be a poor proxy for MAGST, depending on the terrain and snow characteristics (boulder size, terrain roughness, solar irradiation, exposure to wind, and accumulation of snow by wind or avalanches) and regional weather patterns (e.g. Gubler et al (2011)).

Fig. 5: Clarify, that the dashed line is the extrapolation for the summit of Djebel Toubkal. If possible, add an uncertainty estimate (e.g. using a range of lapse rates).

Fig. 6: Add readable point labels and a legend for the colours.

Fig. 7: What are “daily hourly maxima”?

Fig. 8: See comment above. Maybe add an uncertainty estimate to each point?

Fig. 10: GST data series can be calibrated during the zero curtain period. It is visually not clear, if this calibration was done or if the dashed line is not really at 0°C at some of the time series.

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