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Decadal to seasonal evolution of small debris-covered glaciers in permafrost environments in relation to their internal structure and climatic factors

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Debris-covered zones are extending on numerous glacier systems in mountainous regions. This situation results from an increase in debris supply and from a decrease of sediment evacuation capacity in glacier systems in the negative mass balance context. The progressive covering of ice mass affects particularly small cirque glacier systems (<0.5 km2) present in alpine permafrost environments. Indeed, in comparison with other glaciers, these systems have several characteristics (thin ice body, polythermal regime, a high debris content and glacier-permafrost interactions) that limit glacial dynamic and related sediment evacuation.

Associating massive glacier ice, ice-debris mixtures and deglaciated debris under permafrost conditions, these systems are experiencing specific and complex response to climate forcing. However, despite their important role on alpine water and sediment flux systems and because they are situated at the frontier between glacial and periglacial researches, the characterisation of these systems and of their current evolution remains a challenging task. Specific needs concern especially the precise knowledge of their composition, the detection and the quantification of ongoing processes and the recognition of the main factors controlling the evolution of the different system components.

Exploring and synthetizing the results of a multi-site (Rognes, Tsarmine, Entre la Reille), multi-temporal (from seasons to decades) and multi-method (ERT, GPR, dGPS, Lidar, photogrammetry, thermal monitoring, etc.) research led in the NW European Alps between 2011 and 2015, this contribution tries to enlighten and explain the different situations encountered in these complex systems. Three main zones, with specific behaviours can be distinguished according to the internal structure:
- The larger zone corresponds to the strictly glacial zone. In comparison with the other zones, the responses to climate signal are rapid, illustrating the local high sensitivity to climatic and hydrologic forcing. In consequence, intense (dcm to m) ice melt, basal sliding and internal deformation occur, especially during the melt season. However, the increase of the debris-cover thickness and content toward the glacier margins reduces the current dynamics. Modifying the glacier driving stress and inverting the ablation gradient, it leads to a differential evolution between the rapidly melting top and central zones and the margins, progressively decoupled from climate signal.
- In some marginal zones, where cold glacier ice, debris and pre-existent frozen sediment bodies (i.e. rockglaciers) can be associated in a slowly creeping ice-debris mixture. The very low surface lowering measured illustrates the weakness of local ice melt. Climate signal is largely attenuated and delayed in these zones where the complex responses are essentially experienced by weak variations of internal deformation rates.
- Finally, deglaciated debris are almost inactive. The weak detected movements are mainly related to superficial postglacial rebalancing and localised mass wasting during the melt season.