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The rapid glacial-proglacial landscape modification at Pasterze Glacier in a one-year period as revealed by multiple aerial flight and field campaigns

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The Pasterze Glacier is an approx. 16 km² large and rapidly receding glacier in the Austrian Alps. The aim of this study was to detect and quantify the rapid landscape modification of its glacial-proglacial transition zone between September 2018 and September 2019. The study is primarily based on the analysis of aerial imagery of five different acquisition dates, two in 2018 (11 September and 15 November) and three in 2019 (17 June, 13 and 21 September). The platforms used for data acquisition comprised unmanned and manned aircrafts that led to ground sampling distances (GSDs) of the aerial imagery of approx. 10 cm. These data were photogrammetrically processed to orthophotos and digital elevation models (DEMs), which are the main input for the subsequent analysis. The flight campaigns were complemented mainly with geodetic measurements for ground-truthing purposes, water level measurements and field observations in order to facilitate a better geomorphological and glaciological interpretation.

Thickness changes and horizontal displacement of the Pasterze Glacier tongue and its adjacent proglacial transition zone were detected applying DEM differencing and normalized cross-calculation (orthophotos). These analyses also included a quality assessment, which allowed to discriminate changes from unchanged subareas. By visual interpretation of the orthophotos and our in-situ measurements, we detected substantial geomorphic changes, the further evolution of the proglacial lake's extent and water level changes.

Results show that the thickness of the investigated subarea at the glacier tongue (0.2 km²) decreased up to approx. 18 m from June 2019 to September 2019 with a mean ice thickness decrease of approx. 4.2 m. In contrast, a subarea of the studied proglacial area (0.14 km²) remained rather unchanged (mean thickness decrease of only 0.7 m). Taking into account the comparison of DEM elevation values with geodetically and thus independent elevation measurements, the vertical quality of the DEMs is described by a standard deviation of 0.14-0.16 m and a mean of 0.07 m. The Root Mean Square Errors of the GCPs are 0.08-0.13 m in planimetry and 0.10-0.16 m in heights.

Comparing the orthophotos of June 2019 and September 2019 shows a distinct expansion of the glacier lake towards the eastern part of the debris-covered glacier tongue by several meters in one

summer only. The lake level shows a clear diurnal cycle of typically around 20 cm during sunny days (high irradiation) and changes in the order of half a meter over the entire summer season. Water temperatures of the lake follow a clear diurnal cycle, too with typical values between 1°C and 3°C.

We conclude that the Pasterze Glacier tongue and its adjacent proglacial area changed rapidly in terms of glacier surfaces modification and in terms of proglacial changes on an annual (September 2018 to September 2019) and sub-annual (June to September 2019) time-scale.