From glacier retreat to proglacial dynamics:

a multi-scale, multi-method perspective since the Little Ice Age

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Glacial and proglacial environments are rapidly changing in response to climate warming, resulting in glaciers fragmentation, rapid proglacial geomorphological change, and increased hazard potential. We investigate these processes in a glacierized catchment at the head of the Valtournenche Valley (western Italian Alps). To assess glacial and proglacial changes across multiple temporal and spatial scales, we integrated historical imagery, orthophotos, repeated Unmanned Aerial Vehicle (UAV) surveys, and field observations. Historical aerial images and orthophotos were used to repeatedly map geomorphological features as they evolved and to quantify glacier retreat and fragmentation since the Little Ice Age (LIA). The two glaciers in the study area have lost half of their surface area since 1820, and around 2005 the upper and lower sectors completely disconnected, leading to increased retreat from an average of 4.3 m/year (1956-2005) to 13.0 m/year (2005-2024). This highlights the strong influence of glacier fragmentation on the acceleration of glacier shrinkage, a process relevant to other alpine glacierized settings. Without any connection with the upper part, the ice front is becoming increasingly steeper and more concave, meaning that there is no longer any downstream ice movement, i.e. a dead-ice body. Annual-scale changes (from 29/08/2024 to 05/08/2025) of the dead-ice body and adjacent proglacial plain were analysed using two high-resolution (0.05 m) UAV-derived DEMs; after error assessment, surface and volume changes were quantified. The geomorphological features that exhibited the greatest losses in volume and surface elevation were the dead-ice body (-5,18 x 10^4 m^3, -0,6 m) and its ice cliff (-5,67 x 10^4 m^3, -1,9 m). It was also detected a proglacial plain volume change of +2,19 x 10^3 m^3 (or +0,05m of surface elevation), due to the reworking and deposition of the debris from the dead-ice body. The availability of loose material, transported downstream by these sediment fluxes, increases the likelihood of potentially dangerous mass-transport events. Overall, these results provide new insights into the integrated evolution of an alpine glacial–proglacial landsystem, linking glacier fragmentation, stagnation, melt and associated sediment reworking to rapid downstream geomorphological changes.