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Clustering patterns of volume change to classify glacier states and fates

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Historically unprecedented glacier retreat rates are observed in mountain ranges all over the world. These high recession rates are expected to continue during the next decades. There is currently a window of opportunity to learn from the first vanishing Alpine glaciers and develop monitoring strategies to track the pace and extent of a deglaciation phase.

Austria has a long history of in-situ mass balance monitoring at select glaciers, as well as a rich data basis of regional glacier inventories and multi-temporal digital terrain models from aerial surveys. As such, monitoring programs are in an ideal position to track the ongoing, rapid changes and place them in a historical context. With increasing rates of change it becomes all the more important to leverage the specific advantages of different data sets and combine them for a complete picture of regional changes and local processes.

To this end, we compare long time series of annual mass balance data measured in-situ via the direct glaciological method at select monitoring sites in western Austria with results derived from remote sensing based digital terrain models. We use the latter to extract histograms of surface elevation change at hundreds of individual glaciers, over multiple time periods. This allows us to quantify the variability of surface elevation change and how it has changed in the past decades, and provides a basis for discussions of regional representativity of in-situ monitoring sites.

Additionally, we use a self-organizing maps algorithm to cluster the individual “profiles” of surface elevation change into groups. This helps to visualize recurring patterns of change in specific geographic regions or elevation zones while preserving the characteristics of different, individual glaciers and their response to climatic forcing, and gives us a sense of the state of disequilibrium of certain mountain ranges.

All available data indicates that recent years have been characterized by large area and volume losses, strongly negative mass balance values, and disintegration especially of low-lying glacier

tongues. Firn cover has been strongly depleted so that some glaciers effectively no longer have accumulation zones. Variability of surface elevation change has generally increased at lower elevations and remained mostly constant at higher elevations, but this varies significantly between individual glaciers. The long-term in-situ monitoring sites skew to very large glaciers compared to the regional average. Larger glaciers, including most of the monitoring sites, tend to exhibit a strong elevation gradient of surface change, with large losses at low elevations. Small glaciers typically have a less pronounced gradient, if any, and especially very small glaciers at lower elevations have significantly less negative elevation change values as large glaciers, in the same elevation zone. When clustering individual glaciers into types, we find a clear shift to surface change distribution curves that suggest processes of disintegration. This tendency is strongest in the most recent time period. At current rates of mass loss, glaciers are projected to retreat entirely to above 2800m in the Ötztal and Stubai ranges by 2050.