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Causes of glacier melt extremes in the Alps since 1949

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Recent record-breaking glacier melt values can be attributed to peculiar extreme events and long-term warming trends that shift averages upwards. Analyzing of one of the world's longest mass-balance series in the framework of extreme value statistics, we show that detrending melt anomalies makes it possible to disentangle these effects, leading to a fairer evaluation of the return period of the melt corresponding to the exceptional 2003 heat wave and, more generally, to characterize extreme melt values by a more realistic bounded behavior. Using surface energy balance simulations, we show that three independent drivers control melt variability: global radiation, latent heat flux and the amount of snow at the beginning of the melting season. Extremes are governed by large deviations in global radiation combined with sensible heat turbulent transfers. Long-term trends are driven by the lengthening of melt duration due to earlier and longer-lasting melting of ice along with melt intensification caused by trends in long-wave irradiance and latent heat flux due to higher air moisture. The processes governing these trends in glacier melt are expected to persist under projected global warming.