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Occasional but severe: past debris flows and snow avalanches in the Helmos Mts. (Greece) reconstructed from tree-ring records

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The eastern Mediterranean is a hotspot in terms of geomorphic hazards, but the activity of gravitational processes in mountainous areas is largely unexplored. Past and present geomorphic activity is key to predicting future risks with respect to hydroclimatic extremes in a changing environment. We carried out dendrogeomorphic research in the Helmos Mountains (Northern Peloponnese, Greece) to determine the timing, spatial extent, and frequency of debris flows and snow avalanches. Specifically, we sampled 492 increment cores from 123 injured Greek firs (*Abies cephalonica* L.) growing on a debris flow cone and growing along a snow avalanche path. Tree rings were counted and cross-dated with the reference chronology using CooRecorder and CDendro software. The event years were determined based on the location of scars and traumatic resin ducts in the tree rings and by calculating the weighted event-response index (W_{It}). We further analysed the potential preparatory and triggering climate factors responsible for these events using data from nearby meteorological stations and the ERA5 reanalysis. Debris flow activity was reconstructed from 52 trees, providing a 118-year chronology (1904-2021) with 13 event years and only one severe debris flow occurring in the 1970/1971 dormant period (W_{It}=148.0), followed by spatially limited records for the 1986/1987 (W_{It}=3.8) and 1993/1994 (W_{It}=2.5) dormant periods. The return period of the geomorphically effective events was 9.1 years. Similarly, 71 trees allowed the reconstruction of 12 event years in the period 1854-2021 with one major snow avalanche in 1997/1998 (W_{It}=304.5) followed by the 1998/1999 event (W_{It}=6.3). The return period for snow avalanches, including possible events, was 14.0 years. The calculated recurrence intervals of maximum 1-day and 2-day precipitation during a year with severe debris flow (1970/1971) were 1.5-7.6 years and 1.4-13.0 years, respectively. Similarly, other indicators such as maximum monthly precipitation or maximum intensity did not indicate an exceptional rainfall event. We assume a combination of multiple factors including a higher proportion of rainfall at the expense of snow in the winter preceding the event, which allowed saturation of easily erodible moraine deposits in the debris flow source area. In contrast, there are clear climatic indicators of snow avalanche activity in the spring of 1998, when heavy snowfall over three days (62 cm) was followed by rapid snowmelt due to high average temperatures (6-11°C), creating very suitable conditions for snow avalanche activity. We conclude that moderate geomorphic activity that recur on average once every 10-15 years is supplemented by the occasional occurrence of exceptionally large debris flows and snow avalanches depending on the amount and form of winter and spring precipitation.