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Dissecting the water tower of Europe: high-resolution ecohydrological modelling of the Alps

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Mountain land surface and ecological processes are intrinsically heterogeneous and difficult to represent in models because the complex terrain creates steep gradients in climate, soil, and land cover. We used the fully distributed, process-based ecohydrological model Tethys-Chloris (T&C) to perform a high spatiotemporal resolution simulation of the European Alps (257,000 km^2). By analyzing hourly simulation results over three years (2000-2003) with a spatial resolution of 250x250 m^2 across the study domain, we quantified: (1) the components of the hydrological budget in different seasons and how streamflow may respond to increasing temperature; (2) the role of vegetation on the Alpine water balance during very warm summers. Uncalibrated ecohydrological simulations were tested in reproducing spatiotemporal patterns of observed snow cover and discharge with very satisfactory results. Due to the challenge of projecting climate change forcing in mountainous areas at such a high resolution, we used a space-for-time substitution to infer how an increase in air temperature could affect the ecohydrological response. The results suggest that total annual runoff over the entire Alpine area is strongly controlled by precipitation and therefore it is resilient to changes in temperature, despite evapotranspiration being energy-limited and temperature-dependent. For instance, a +3°C scenario affects annual runoff similarly to a decrease of only 3% in precipitation. Results are quite different when the focus is on the growing season only, during which evapotranspiration is a significant component of the water budget and an increase in temperature can modify considerably the hydrological response. For instance, evapotranspiration contributed to reduce water yield during the 2003 growing season because vegetation benefited from the unusually warm and sunny conditions in a large part of the Alpine region at high elevations. In summary, model results with high spatiotemporal resolution provided insights into ecohydrological patterns that would not be possible with observations alone and helped to better understand the response of Alpine water resources to climatic changes.