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## Seasonal origin of water in a high-elevation grassland: insights from a modelling approach using a snow isotope model and HYDRUS-1D

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Soil and xylem water samples are increasingly collected for isotope analysis to study the movement of water within the soil-plant-atmosphere continuum in alpine ecosystems. However, the low sampling frequency, mainly due to severe winter weather conditions and impervious topography, remains a significant obstacle for building a comprehensive, data-driven understanding of hydrological processes in high-elevation environments.

This study focuses on integrating a newly proposed snow isotope model with HYDRUS-1D to simulate the movement of water and isotopes through the soil-plant-atmosphere continuum in a mountain grassland at 2550 m a.s.l. in the Aosta Valley, northwest Italy. While uncertainties remain regarding the timing and distribution of infiltration during snowmelt and variations in snow isotopic composition, the combined modeling approach successfully reproduces patterns of soil moisture, evapotranspiration, and isotope behavior at the site.

A key finding is the seasonal origin of water: winter-derived water (i.e., snowmelt) primarily contributes to groundwater recharge through soil percolation, while summer-derived water (i.e., rainfall) dominates plants transpiration. Evidence supporting this seasonal pattern comes also from observed isotope dynamics in both the monitored spring water and xylem water. Notably, during the 2022 drought, the ecosystem relied more heavily on winter-origin water to support evapotranspiration, providing a glimpse into how such systems might adapt to future conditions with higher temperatures and reduced snowfall.

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