Drought duration and spatial dependence increase during propagation

Manuela Irene Brunner\textsuperscript{1,2,3} and Corentin Chartier-Rescan\textsuperscript{1,2,3}

\textsuperscript{1}Institute for Atmospheric and Climate Science, ETH Zurich, Zurich, Switzerland
\textsuperscript{2}WSL Institute for Snow and Avalanche Research SLF, Davos Dorf, Switzerland
\textsuperscript{3}Climate Change, Extremes and Natural Hazards in Alpine Regions Research Center CERC, Davos Dorf, Switzerland

As droughts propagate both in time and space, their impacts increase because of changes in drought properties. Even though drought propagation has two dimensions – a temporal and spatial one – these are mostly studied separately, which neglects that the propagation of droughts through the hydrological cycle may extend from local to spatial characteristics. Therefore, it is yet unknown how the spatial extent and connectedness of droughts change as droughts propagate from the atmosphere to and through the hydrosphere.

In this study, we assess not only how local meteorological droughts propagate through the hydrological cycle to streamflow and groundwater but also how drought spatial extent and connectedness change with drought propagation. To do so, we use a large-sample dataset of 70 catchments in the Central Alps for which both observed streamflow and groundwater data are available.

We show that drought propagation from the atmosphere to the hydrosphere affects both local and spatial drought characteristics and leads to longer, delayed, and fewer droughts with larger spatial extents. 75\% of the precipitation droughts propagate to P-ET or further, 20\% to streamflow, and only 10\% to groundwater. Of the streamflow droughts, 40\% propagate to groundwater but 60\% do not propagate. Drought extent and connectedness increase during drought propagation from precipitation to streamflow thanks to synchronizing effects of the land-surface such as widespread soil moisture deficits but decrease again for groundwater because of sub-surface heterogeneity. These findings have implications for drought prediction and management. They suggest a partial predictability of streamflow and groundwater droughts by atmospheric and hydrological deficits and that large scale streamflow deficits may be partly compensated by groundwater, which shows less frequent and spatially extensive droughts than streamflow.