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Implication of multi drought definitions to identify streamflow drought across Europe

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Several approaches to identify hydrological drought exist, which result in differences in drought frequency, timing, duration, and deficit volume (drought characteristics) using the same hydrometeorological data as input. This has created confusion within the hydro-meteorological community, as well as in operational water management services on the difference in drought characteristics obtained with the different approaches. The aim of this study, therefore, is to provide a comprehensive overview of the differences of hydrological drought, i.e. streamflow drought, using different identification approaches for the pan-European river network (>10,000 river grid cells). Time series of daily streamflow data were obtained from the LISFLOOD hydrological model forced with gridded meteorological observations from 1990 to 2018. Streamflow droughts were detected using the daily and monthly Variable Threshold methods (VTD and VTM), daily and monthly Fixed Threshold methods (FTD and FTM), and the Standardized Streamflow Index with 1-month accumulation period (SSI-1). For the threshold methods the Q80 (flow that is equaled or exceeded 80 percent of the time) is applied, whereas for the SSI a threshold of about -1 is used. We applied a centered 30-day moving average (30DMA) smoothing technique to the daily flow data to reduce the number of minor droughts. This is the first study that compares all these drought identification approaches in such a systematic way at this large scale. Our results (pan-European maps, tables) clearly show that characteristics of streamflow droughts derived with different approaches deviate, partly associated with different climate regions across Europe. The daily threshold methods (VTD and FTD) identify twice as much drought events than the monthly threshold methods (VTM and FTM) due to the daily resolution and minor droughts, even with smoothing. Average duration of FT droughts is longer than VT droughts. In addition, FT droughts have higher drought deficit volumes than VT droughts (~ 30-60%, dependent on climate region), whereas using monthly data (VTM and FTM) result in higher deficits (~10-60%) than daily data (VTD and FTD). In northern and central European regions (Köppen- Geiger Dfb, Dfc and ET climates), the variable threshold methods (VTD and VTM) generally detect drought earlier (March-July) than the fixed thresholds (FTD and FTM) (July-October). In the western European regions and the Mediterranean differences in timing among identification approaches are not so clear. The characteristics of SSI-1 drought, in general, are close to what is being identified with the VTM approach. Differences in drought characteristics highlight the importance of whether end-users should take seasonality into account or not (VT and SSI-1 versus FT) and consider temporal variability (daily versus monthly). Certainly, there is no unique hydrological drought definition that

fits all purposes; hence we suggest that users should clearly agree among themselves upon a sharp definition on which type of streamflow drought is required to be identified for a specific application.