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Variability of the annual cycle of streamflow records throughout Central Europe

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The annual cycle is the strongest signal observed in many geophysical records.
However, many time series analysis studies regard annual aggregates or monthly values separately, while ignoring the presence of the annual cycle. Further, climatological studies recently report changes in the timing of the seasons, such as advanced seasonal timing of surface temperature, earlier snow melt and earlier onset of the phenological spring season. For water resources management there is the question how basin water budgets are responding to these changes in the annual cycle of temperature. This leads to the critical question of seasonal water availability and subsequently regards the vulnerability of current water supply systems. On the other hand, periodic properties of streamflow records, being integrative in space and time, may also tell us something about changes on larger scales.

In this study, changes of the annual cycle of hydrological variables are analysed for over 150 streamflow records (available from the Global River Data Centre) distributed within major river basins of Central Europe (Danube, Rhine, Elbe, Oder and Weser) over the period 1930-2009. Thereby simple and yet robust methods have been applied to estimate changes of the annual cycle via harmonic function approximation. It is demonstrated that the annual signal, described by phase and amplitude, is robust in terms of very different hydrological regimes and also to human alterations of river flow. Further, the link to seasonal changes in temperature is investigated using gridded data (E-OBS) derived from the European Climate Assessment Dataset.

It has been found that the annual phase of streamflow, representing the timing of the hydrological regime, is subject to considerable year-to-year variability. Anomalies in the phase do show surprising spatial coherence within similar hydro-climatic conditions and are transported along the main river. A circular correlation analysis between the phase of temperature and corresponding streamflow allowed to quantify some effects of climatic changes on streamflow. Again regional differences have been found. Positive and significant circular correlations are found for most rivers in the middle and lower Rhine River, the Upper Danube River, the Elbe and Weser basins. All these basins appeared to originate in low mountains ranges, with winter and spring flows being controlled by snow accumulation and snow melt. On the other hand, rivers originating in high mountainous regions, such as the Upper Rhine do not seem to be controlled by annual temperature timing. Common temporal trend patterns in the annual timing of runoff have only been found for river basins originating in low mountain ranges. During 1960 to 1970 a period of late streamflow timing has been detected followed by a decline in timing corresponding to a trend in temperature towards earlier timing.
Finally, this study confirms findings of spatial coherence of streamflow properties being linked to (i) basin characteristics and (ii) large scale climatic patterns. It also identifies river basins, which are likely to be effected by changes in seasonality of temperature in the future.