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Long-term catchment memory: The underrated thermodynamic dimension

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Long-term memory in hydrological systems is usually ascribed to extensive catchment water storage that builds up in wet periods and empties in dry periods. Besides, additional memory effects can result from plants responding to changing boundary conditions, from swelling or shrinking of clayey soils, etc. However, another fundamental effect is widely ignored. The second law of thermodynamics is often understood as an argument that the effects of external disturbances of natural systems fade off in the long term, resulting in basically stationary systems. However, this falls short of the mark and ignores that the damping of external triggers depends on the frequency of the signal: High frequency signals are much more damped during propagation through the same medium compared to low-frequency signals. This holds for electro-magnetic waves as well as for pressure waves. For example, low-frequency ground-penetrating radar exhibits larger penetration depth compared to higher frequencies, although at the cost of spatial resolution. Music is not only less loud but sounds more muffled on the other side of a concrete wall due to the overproportional loss of higher frequencies. The same holds, e.g., for time series of soil matrix potential or groundwater head that are nothing but irregular pressure waves. Consequently, the high frequency part of the signal of infiltrating rain or snowmelt is much more efficiently attenuated in the vadose zone, resulting in increasingly more smooth time series at greater depth. The low-frequency part of the signal is attenuated as well, but to a lesser degree. Thus, in the long-term only low-frequency signals remain, in some cases exhibiting period lengths of decades and more, which are often mistaken as trends, without any corresponding low-frequency input signal. As much of the catchment hydrology research has been done in small catchments and for shallow groundwater systems, and mostly based on short time series, these effects have been widely and systematically underrated so far. However, at larger spatial and temporal scales they become more evident and need more attention. Often power spectrum analysis is used to assess these effects. Another and even more efficient approach especially for complex systems is provided by principal component analysis of sets of hydrological time series. Some examples will be shown from a lowland region in Northeast Germany with extensive groundwater storage.