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Dynamical clustering: A new approach to make distributed (hydrological) modeling more efficient by dynamically detecting and removing redundant computations

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The structural properties of hydrological systems such as topography, soils or land use often show a considerable degree of spatial variability, and so do the drivers of systems dynamics, such as rainfall. Detailed statements about system states and responses therefore generally require spatially distributed and temporally highly resolved hydrological models. This comes at the price of substantial computational costs. However, even if hydrological sub systems potentially behave very differently, in practice we often find groups of these sub systems that behave similarly, but the number, size and characteristics of these groups varies in time. If we have knowledge of such clustered behavior of sub systems while running a model, we can increase computational efficiency by computing in full detail only a few representatives within each cluster, and assign results to the remaining cluster members. Thus, we avoid costly redundant computations. Unlike other methods designed to dynamically remove computational redundancies, such as adaptive gridding, dynamical clustering does not require spatial proximity of the model elements.

In our contribution, we present and discuss at the example of a distributed, conceptual hydrological model of the Attert basin in Luxembourg, i) a dimensionless approach to express dynamical similarity, ii) the temporal evolution of dynamical similarity in a 5-year period, iii) an approach to dynamically cluster and re-cluster model elements during run time based on an analysis of clustering stability, and iv) the effect of dynamical clustering with respect to computational gains and the associated losses of simulation quality.

For the Attert model, we found that there indeed exists high redundancy among model elements, that the degree of redundancy varies with time, and that the spatial patterns of similarity are mainly controlled by geology and precipitation. Compared to a standard, full-resolution model run used as a virtual reality 'truth', computation time could be reduced to one fourth, when modelling quality, expressed as Nash-Sutcliffe efficiency of discharge, was allowed decreasing from 1 to 0.84. Re-clustering occurred at irregular intervals mainly associated with the onset of precipitation, but on average the patterns of similarity were quite stable, such that during the entire six-year simulation period, only 165 re-clusterings were carried out, i.e. on average once every eleven days.