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A functional model of annual water balance variability and similarity for regionalization studies: Horton, Budyko and L'vovich revisited

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This paper presents a systematic analysis of annual water balance variability: (i) regional (between-catchment) variability of mean annual water balances, and (ii) between-year (inter-annual) variability in individual catchments, and the symmetry between the two. For this analysis, we adopt the theoretical framework pioneered by L'vovich (1979), subsequently extended by Ponce and Shetty (1995a,b), which involved analysis of the annual water balance in terms of a two-stage partitioning, firstly, of annual precipitation into quick flow and soil wetting, and secondly, of the resulting soil wetting into slow flow and vaporization (i.e., evaporation + transpiration). The nature of this water balance partitioning is explored by completing the L'vovich-type analysis in 431 MOPEX catchments located across continental United States. We fitted theoretical relationships suggested by Ponce and Shetty (1995a,b) to the partitioning at each level, producing expressions for the three components of quick flow, slow flow and vaporization. The associated parameter values for the 431 catchments exhibited coherent regional patterns, although the physical causes of such patterns remain unexplored. Conversion of the Ponce & Shetty-type analytical relationships into non-dimensional forms showed that the partitioning at each stage represents a competition between alternative catchment functions, the form of which appears to be universal. For example, they revealed that the spatial heterogeneity of water balance partitioning amongst the 431 catchments is underlain by a parameter-free universal relationship that is transferable regionally and even globally. Key non-dimensional similarity parameters are identified that then serve to connect this regional or universal behavior to site-specific behavior characteristics. The analytical formulations are next extended to derive common metrics of annual water balance such as the Budyko curve and the Horton Index (Troch et al., 2009), and these were successfully evaluated through their ability to predict regional patterns of mean annual water balance, and inter-annual variability in selected individual catchments. In this way this analysis demonstrated a close symmetry between regional variability of mean annual water balances and inter-annual variability in individual catchments. The L'vovich-Ponce-Shetty theory can thus be the basis for data-based assessments of hydrologic similarity, and to assist with predictions of the effects of long-term climate variability and change, by providing a framework for "space for time" substitution.