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Assessing predictability of a hydrological stochastic-dynamical system

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The water cycle includes the processes with different memory that creates potential for predictability of hydrological system based on separating its long and short memory components and conditioning long-term prediction on slower evolving components (similar to approaches in climate prediction). In the face of the Panta Rhei IAHS Decade questions, it is important to find a conceptual approach to classify hydrological system components with respect to their predictability, define predictable/unpredictable patterns, extend lead-time and improve reliability of hydrological predictions based on the predictable patterns. Representation of hydrological systems as the dynamical systems subjected to the effect of noise (stochastic-dynamical systems) provides possible tool for such conceptualization.

A method has been proposed for assessing predictability of hydrological system caused by its sensitivity to both initial and boundary conditions. The predictability is defined through a procedure of convergence of pre-assigned probabilistic measure (e.g. variance) of the system state to stable value. The time interval of the convergence, that is the time interval during which the system losses memory about its initial state, defines limit of the system predictability.

The proposed method was applied to assess predictability of soil moisture dynamics in the Nizhnedevitskaya experimental station (51.516N; 38.383E) located in the agricultural zone of the central European Russia. A stochastic-dynamical model combining a deterministic one-dimensional model of hydrothermal regime of soil with a stochastic model of meteorological inputs was developed. The deterministic model describes processes of coupled heat and moisture transfer through unfrozen/frozen soil and accounts for the influence of phase changes on water flow. The stochastic model produces time series of daily meteorological variables (precipitation, air temperature and humidity), whose statistical properties are similar to those of the corresponding series of the actual data measured at the station. Beginning from the initial conditions and being forced by Monte-Carlo generated synthetic meteorological series, the model simulated diverging trajectories of soil moisture characteristics (water content of soil column, moisture of different soil layers, etc.). Limit of predictability of the specific characteristic was determined through time of stabilization of variance of the characteristic between the trajectories, as they move away from the initial state.

Numerical experiments were carried out with the stochastic-dynamical model to analyze sensitivity of the soil moisture predictability assessments to uncertainty in the initial conditions, to determine effects of the soil hydraulic properties and processes of soil freezing on the predictability. It was found, particularly, that soil water content predictability is sensitive to errors in the initial conditions and strongly depends on the hydraulic properties of soil under both unfrozen and frozen conditions. Even if the initial conditions are “well-established”, the assessed predictability of water content of unfrozen soil does not exceed 30-40 days, while for frozen conditions it may be as long as 3-4 months. The latter creates opportunity for utilizing the autumn water content of soil as the predictor for spring snowmelt runoff in the region under consideration.