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Modeling the spatio-temporal process variability of thoughfall and transpiration in a forest ecosystem

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In terrestrial forest ecosystems the partitioning of precipitation into evapotranspiration, runoff (or recharge) and change in soil moisture is influenced by the forest canopy. The vegetation pattern alters precipitation into spatially variable throughfall. Though highly variable in space, throughfall patterns show some stability in time as they are caused by spatially relatively stable factors such as canopy density, agglomeration of trees and species distribution (Jost et al., 2005, Keim et al., 2005). Transpiration decreases the soil water storage and is mainly controlled by soil moisture, climate and species dependent resistances to water transport. Both processes directly affect the recharge and runoff in space and time. To accurately predict the runoff from forested ecosystems, we need to know how much process information needs to be incorporated in a model and whether including spatial variability helps us to better understand processes in nature. In this study we incorporate different abstractions of process variability (throughfall and transpiration) and preferential flow path variability into a hillslope model to address these questions.

In a mixed European beech and Norway spruce stand spatial variability of soil water storage (SWS) was measured manually 28 times in biweekly intervals at 194 locations across a 0.5-ha plot using time domain reflectometry (TDR). In addition, meteorological data was measured above and below the canopy. Geostatistics was applied for analyzing the spatio-temporal SWS change. We used a 2-dimensional (2 m pixel size) dual porosity model (Weiler and McDonnell, 2004) to simulate soil water balance in 2000 and 2001. Surface and subsurface flow parameters were calibrated from sprinkling experiments (50 m^2) at the same site. Runoff for the entire site was modeled in three different ways: first by spatially uniform precipitation and evapotranspiration, second by incorporating the spatial variation of throughfall and third by also considering the spatial variation of the transpiration process. The model performance was tested by comparing model results with measured spatio-temporal change in soil water storage and evapotranspiration. The TDR measurements show that spatial correlation and variation is not constant in time but shows a hysteresis that depends on the wetting and drying history of the site.

Incorporation of process variability in throughfall and in transpiration shows good agreement between measured and modeled spatial variation of daily SWS throughout both vegetation seasons. Considering only variation of throughfall constantly increases the spatial variation (expressed by the standard deviation of simulated SWS) until the soil water content reaches saturation. This results in an overestimation of lateral subsurface flow since it is more likely that wetter spots exist and connect. Transpiration has an averaging effect on SWS variability. Longer periods without rain decrease spatial variation. Without considering throughfall variability variance decreases faster and the distributed model becomes virtually lumped since no variation is added. Consideration of spatial process variability not only improves the overall model performance but also helps in advancing scientific knowledge on the soil-plant-atmosphere continuum.