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Spatiotemporal variability of evapotranspiration in boreal forest catchments: a novel upscaling by process models and open GIS data

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Boreal forest landscape is a mosaic of different-aged stands and is characterized by topography-driven heterogeneity in soil texture and moisture. Within a given climatic region, the spatial variability of evapotranspiration (ET) and water balance of these ecosystems is driven by vegetation characteristics, such as stand density, leaf-area index (LAI), species composition and water-use strategies, and further mediated by topography, soil texture and drainage conditions. We propose a relatively simple and computationally efficient spatial hydrologic model (SpatHy) that propagates this landscape heterogeneity into spatiotemporal variability of ET and soil moisture based on daily or sub-daily meteorological data and open GIS data. In SpatHy, distributed solution of above-ground and root zone hydrology by a 2-layer canopy–soil scheme is coupled with TOPMODEL approach for landscape connectivity and streamflow generation.

The predictions of the canopy – soil scheme, a simplification of a detailed biophysical multi-layer APES-model (Launiainen et al. Ecol. Mod. 2015, 312: 385-405), are first evaluated against measured stand-level ET and soil moisture at several eddy-covariance (EC) flux sites in the Nordic region. The proposed spatial upscaling of ET is further evaluated against streamflow data from 17 boreal headwater catchments in Finland, and SpatHy is shown to reproduce the annual partitioning of precipitation into ET and specific discharge reasonably well without any catchment-specific calibration. The impact of projected 21st century climate change on streamflow and ET is addressed using climate-model ensembles based on rcp4.5 and rcp8.5 emission scenarios. Throughout, the model parameter uncertainty is included by Monte-Carlo simulations.

In Finland, open GIS data sources such as soil maps, digital elevation models and multi-source National Forest Inventory data (mNFI, http://kartta.luke.fi/index-en.html) provide strong foundation for upscaling water and carbon fluxes from point to landscape scale. The mNFI in particular includes several datasets relevant to spatial hydrologic and biogeochemical models; it contains stand attributes such as tree volumes per species, leaf/needle biomasses, forest height and site type at 16x16m grid throughout the country. To demonstrate the use of open GIS data, we show ET maps at this resolution, and identify the key factors driving spatial variability of transpiration, forest floor evaporation and interception across the landscape.

The proposed bottom-up approach can provide alternative for ‘ground-truthing’ the remote-sensing estimates of ET and its spatiotemporal variability, and reduces the need for catchment-specific ET calibration in hydrologic models.