Assessing hydrological sensitivity to future climate change in the Canadian southern boreal forest

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This study develops a physically based hydrological process model using the Cold Region Hydrological Modeling (CRHM) platform to simulate the water budget storages and fluxes in the Canadian southern boreal forest (SBF). Evaluation of the CRHM-based model in a well-gauged SBF basin, White Gull Creek (WGC), Saskatchewan, Canada, indicated quite good performance in reproducing historical observations of streamflow, snow water equivalent (SWE), evapotranspiration (ET) and soil moisture without parameter calibration from streamflow. The entire SBF was then evenly divided into 2243 virtual basins, each of which was structured and parameterized with the same land cover, soil and hydrological parameters as the WGC basin, but with local latitude and topography in order to examine the sensitivity of governing hydrological processes to climate variability and perturbation. Hydrological sensitivity to future climate perturbations in the virtual basins was assessed by examining the differences between hydrological simulations driven by 4-km gridded convection-permitting Weather Research and Forecasting (WRF) outputs in the current period (ctrl, 2001-2013) and a Pseudo Global Warming period (pgw, 2087-2099). The WRF simulation in the pgw period was forced by a perturbation of the same boundary conditions from ERA reanalysis data as for the ctrl period, and the perturbation based on the ensemble-mean of projected changes from the CMIP5 RCP 8.5 emission scenario. Results showed that temperature will increase by 4℃ to 7℃ over the SBF but increases in annual precipitation of 15-24% will more than compensate for the effects of warming on runoff generation and result in greater streamflow volumes. Annual streamflow volumes will increase by 64 mm (35%) and 95 mm (16%) in the west and east, and by 48 mm (17%) in the central SBF. Annual snowfall and maximum SWE will decrease by 89-109 mm (~29%) in the east, 3-8 mm (~6%) in the west, and 31-50 mm (~20%) in the central SBF. Annual mean soil moisture storage will decrease by 54-56 mm (27%) in the west and central, and by only 37 mm (14%) in the east SBF. Decreases in soil moisture will be caused by reduced soil freezing and enhanced thawing under future warming which will enhance soil water loss from evapotranspiration, subsurface runoff and perecolation into groundwater storage. The larger sensitivity of streamflow and snow processes in the east SBF is partly due to the wetter climate and the larger increase in annual precipitation, the later also buffered the sensitivity of soil moisture to warming. These results show that the SBF will switch to a higher water yield region, dominated by rainfall-runoff fed streamflow over a longer snowfree season, and provide first-order guidance for sustainable water management of the SBF in the future.