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Application of a land surface model for simulating river streamflow in high latitudes

Yeugeniy Gusev, Olga Nasonova, and Larissa Dzhogan
Institute of Water Problems, Russian Academy of Sciences, Moscow, Russian Federation (gusev@aqua.laser.ru)

Nowadays modelling runoff from the pan-Arctic river basins, which represents nearly 50% of water flow to the Arctic Ocean, is of great interest among hydrological modelling community because these regions are very sensitive to natural and anthropogenic impacts. This motivates the necessity of increase of the accuracy of hydrological estimations, runoff predictions, and water resources assessments in high latitudes. However, in these regions, observations required for model simulations (to specify model parameters and forcing inputs) are very scarce or even absent (especially this concerns land surface parameters). At the same time river discharge measurements are usually available that makes it possible to estimate model parameters by their calibration against measured discharge. Such a situation is typical of most of the northern basins of Russia. The major goal of the work is to reveal whether a physically-based land surface model (LSM) Soil Water – Atmosphere – Plants (SWAP) is able to reproduce snowmelt and rain driven daily streamflow in high latitudes (using poor input information) with the accuracy acceptable for hydrologic applications.

Three river basins, located on the north of the European part of Russia, were chosen for investigation. They are the Mezen River basin (area: area: 78 000 km2), the Pechora River basin (area: 312 000 km2) and the Severnaya Dvina River basin (area: 348 000 km2). For modeling purposes the basins were presented, respectively, by 10, 57 and 62 one-degree computational grid boxes connected by river network. A priori estimation of the land surface parameters for each grid box was based on the global one-degree datasets prepared within the framework of the International Satellite Land-Surface Climatology Project Initiative II (ISLSCP) / the Second Global Soil Wetness Project (GSWP-2). Three versions of atmospheric forcing data prepared for the basins were based on: (1) NCEP/DOE reanalysis dataset; (2) NCEP/DOE reanalysis product hybridized with observations; (3) measurements from meteorological stations located within the basins. For these three cases, the most important a priori estimated land surface parameters and adjustment factors for precipitation and incoming radiation were optimized.

Model simulations of river runoff were carried out for the three river basins for the period varied from 10 to 33 years, while the calibration period always equalled to 5 years. Comparison of measured daily/monthly streamflow with corresponding hydrographs simulated by SWAP using land surface parameters, taken from the global datasets, and the three versions of forcing data has shown a good agreement. Thus, daily Nash-Sutcliffe coefficient of efficiency ranged from 0.75 to 0.90 and the absolute bias did not exceed 10%. In all cases, automated optimization of model parameters was performed using a global optimization algorithm based on a random search technique. Two objective functions, based on the Nash–Sutcliffe coefficient of efficiency and the mean systematic error, were applied. The number of calibrated parameters ranged from 7 to 11. When the forcing data were taken from the global datasets, the list of calibrated parameters included 7 land surface parameters and 4 adjustment factors for liquid and solid precipitation, as well as incoming longwave and shortwave radiation. When the forcing data from meteorological stations were used, the adjustment factors for precipitation and radiation could be omitted in the case of high quality of meteorological observations (as it was for the Severnaya Dvina River). It should be also noted that all calibrated parameters were kept within a reasonable range so as not to violate physical constraints while providing a close match between simulated and measured daily streamflow.