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Hydrological and biogeochemical modelling of carbon fluxes in an Arctic river: the Yenisei (North of Russia)

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Abstract: Permafrost represents one of the biggest organic carbon stocks on Earth. Organic carbon is exported from rivers to oceans by the particulate (POC) and the dissolved (DOC) form. Carbon fluxes represent 22 to 32 teragrams of carbon per year (TgC.yr⁻¹; 1 Tg = 10¹² g) in the Arctic Ocean. This export is a main concern in this time of global changes. With global warming, the superficial layer in permafrost could unfreeze deeper and exports of old organic carbon (accumulated for thousands of years) would be possible and could disturb recent carbon cycles. Based on some sporadic data, experts estimated an export of 7000 to 138 000 TgC from thawing permafrost could be possible by 2100, that is to say 500 to 1000 TgC.yr⁻¹. Only one similar study has been made on a small discontinuous permafrost catchment in Mongolia and modeling difficulties have already been diagnosed. This study tries to analyze, to understand and to quantify the complex processes involved in the carbon export in the Arctic watershed of the most important contributor to the carbon export, the Yenisei river (North of Russia) using the Soil and Water Assessment Tool (SWAT). The main objective is to adapt the model for a permafrost watershed and delineate SWAT possibilities in front of permafrost catchments including the different types of permafrost. By a first conceptualization including modification mainly in climate and soil properties, we want to understand and quantify the hydrological processes occurring in permafrost. The study integrated all permafrost types at a large scale and simulated data were compared first to measured data from 1999 to 2014. Then the model is able to represent the fluxes in the different hydrological components (evapotranspiration, sublimation, surface runoff, lateral flow, aquifer flow). A second conceptualization is presented to link hydrological and carbon processes to analyze the origins, to understand the transfer processes involved and to quantify carbon fluxes to the sea. We adapted DOC and POC equations from previous researches and compared simulated data to observed data (from 1999 to 2014). Then different simulations show the origins and the transfer dynamic at daily time step and finally can give us the fluxes exported to the sea. The first result shows that SWAT is able to represent water fluxes at the outlet at a daily time step once we considered specific climatic and soils conditions adapted to a permafrost watershed with an average water delivery of 164 mm.yr⁻¹ of surface runoff, 110 mm.yr⁻¹ of lateral flow and 8 mm.yr⁻¹ of groundwater flow. The second result reveals that the models for DOC and POC can represent fluxes of organic carbon under climatic forcing and that we will be able to quantify these fluxes in a context of climate change by modeling. The simulated results show a water flux of 282 mm.yr⁻¹ and respective specific fluxes for TSS, POC and DOC of 3.7 t.km⁻².yr⁻¹, 0.11 t.km⁻².yr⁻¹ and 1.73 t.km⁻². yr⁻¹. It reveals that this study is in the range of previous studies for DOC fluxes at the outlet whereas they underestimate water, TSS and POC flows.

Keywords: Permafrost; Model; SWAT; Carbon; Climate change