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Hydrological impacts of moderate and high-end climate change across European river basins

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ABSTRACT

Study region: To provide a picture of hydrological impact of climate change across different climatic zones in Europe, this study considers eight river basins: Tagus in Iberian Peninsula; Emån and Lule in Scandinavia; Rhine, Danube and Teteriv in Central and Eastern Europe; Tay on the island of Great Britain and Northern Dvina in North-Eastern Europe.
Study focus: In this study the assessment of the impacts of moderate and high-end climate change scenarios on the hydrological patterns in European basins was conducted. To assess the projected changes, the process-based eco-hydrological model SWIM (Soil and Water Integrated Model) was set up, calibrated and validated for the basins. The SWIM was driven by the bias-corrected climate projections obtained from the coupled simulations of the Global Circulation Models and Regional Climate Models.
New hydrological insights for the region: The results show robust decreasing trends in water availability in the most southern river basin (Tagus), an overall increase in discharge in the most northern river basin (Lule), increase in the winter discharge and shift in seasonality in Northern and Central European catchments. The impacts of the high-end climate change scenario RCP 8.5 continue to develop until the end of the century, while those of the moderate climate change scenario RCP 4.5 level-off after the mid-century. The results of this study also confirm trends, found previously with mostly global scale models.

1. Introduction

Climate change is one of the world's most important global challenges, which will have global as well as regional consequences, and is expected to affect all aspects of modern humanity (IPCC WGII, 2014). The Paris Agreement entered in force at the 21st Conference of Parties (COP21) in 2015 indicated a great success of more than 20 years of negotiations, but also imposed a significant challenge to the contemporary society by setting the goal of limiting the global warming to 2 °C, while aspiring to 1.5 °C (Rogelj et al., 2016; Schellnhuber et al., 2016). This goal is ambitious as now the trajectories of the greenhouse gases emissions are pointing to the high-end climate change scenarios above the agreed threshold, and this development still remains probable, if global actions are not taken urgently.

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The flow regimes of rivers are being modified all over the world by anthropogenic impacts, such as water management operations and land use changes. Some measures put freshwater resources at significant stress, and climate change is expected to alter the hydrological conditions further, posing additional pressure on water resources and aquatic ecosystems. The climate change risks have to be understood, quantified and incorporated into water management strategies at the regional level (Döll et al., 2014). All adaptation measures, including those of "no-regret" type have to be based on a solid understanding of the current situation and possible future trends (Harding et al., 2014), both long-term and short-term. Hydrological modelling is a primary tool to obtain projections on how climate change would impact water resources and hydrological patterns of river basins.

In general, there is a voluminous amount of literature on the impact of climate change on hydrological cycle and water resources covering different scales: from river basins to continental and global scales. Most of the continental and global scale studies employ global scale hydrological models, as the application of a regional model to all river basins in a continent, e.g. in Europe, would result in significant calibration efforts and high input data requirements.

At the scale of Europe, Papadimitriou et al. (2016) conducted a study on impacts of the high-end climate change on river discharge in eight selected European river basins applying the non-calibrated global hydrological model JULES (Best et al., 2011). They have found an increase in the number of days with low flow for Central and Southern Europe (Rhine, Danube, Guadiana), and an increase in low flows for Scandinavia (Kemijoki River). Further, several studies, conducted with different global models (e.g. WaterGAP, Mac-PDM.09), have projected an increase of discharge in the high-latitudes and decrease in the Mediterranean and Southern Europe (Arnell and Gosling, 2013; Hagemann et al., 2013; Schneider et al., 2013), and seasonal changes in the snowmelt driven rivers, where discharge in winter is increasing, while the summer discharge is decreasing (Döll and Schmied, 2012; Wanders et al., 2015).

Uncertainties associated with global-scale hydrological modelling are usually higher as compared with those related to the regional-scale hydrological models (Hagemann et al., 2013; Gosling et al., 2017; Hattermann et al., 2017). This can be explained by coarser resolution of the input data and usually poor performance of global models (most of them are not calibrated) in the historical reference period (Hattermann et al., 2017), as well as inability of most of the global models to take into account water management infrastructure (Abbaspour et al., 2015). Due to this, it makes sense to verify trends by application of the basin-scale models.

Further, there are some continental-scale studies performed with the pan-European models, which are partly calibrated. Donnelly et al. (2016) applied a multi-basin model E-HYPE to the entire Europe, which showed good simulation results, and can be used for climate impact studies after some improvements, regarding input data and additional calibration. Roudier et al. (2016), applying three pan-European models, LISFLOOD (Burek et al., 2012), E-HYPE (Donnelly et al., 2016) and VIC (Liang et al., 1994), found that drought events may increase in Southern Europe, in particular, in Southern France and Spain, and the frequency of flood events may increase in Northern Europe, if the global temperature will increase by $+2\,^{\circ}\mathrm{C}$. A study of Alfieri et al. (2015) applied the distributed hydrological model LISFLOOD driven by the high-end climate change scenario in major river basins across the entire European region. They found decrease of runoff in the Southern Europe and increase of runoff in Northern Europe, and no specific trends for the discharges in the Central Europe. However, the abovementioned analyses were focused on the extreme events frequency analysis or on the validation of the pan-European models, and not on the general picture of the hydrological impacts of projected climate change.

Regarding the hydrological impact assessments performed with the regional scale hydrological models, it usually focuses on individual regions, often single river basins, and studies encompassing large areas are rare (Aich et al., 2014; Vetter et al., 2016). Recently, a Special Issue in Climatic Change (see editorial Krysanova and Hattermann (2017)) addressed the issue of intercomparison of the regional-scale hydrological models and climate change impacts across twelve large river basins around the globe (including two basins in Europe: Rhine and Tagus), fulfilled by the efforts of the ISI-MIP project (Warszawski et al., 2014) group.

Our study aims to close the existing gap and provides an assessment of trends in the long-term mean annual dynamics of river discharge in eight representative European basins triggered by climatic change. For that, an eco-hydrological process-based catchment scale hydrological model was applied, which was calibrated and validated for each case study in advance and accounted for water management operations, where applicable. It used a more elaborated approach, when compared to the previous European-scale studies. We provide an assessment and intercomparison of the moderate and high-end climate change impacts on river discharge across different regions in Europe, focused on eight river basins: Tagus in Iberian Peninsula; Emån and Lule in Scandinavia, Rhine in Central Europe, Danube and Teteriv in Central and Eastern Europe, Tay on the island of Great Britain, and Northern Dvina in North-Eastern Europe. These basins were selected within the European Case Study of the EU funded project "IMPRESSIONS: Impacts and Risks from the high-end scenarios: strategies for innovative solutions".

Our assessment considers two future climate change scenarios of moderate (RCP4.5) and high-end (RCP8.5) global warming, and two future time slices: intermediate (2041–2070) and far future (2071–2100), evaluated with respect to the reference period (1981–2010). Current study complements the picture of the European scale assessments done before, and verifies the trends found in the previous studies fulfilled with the global and pan-European scale models.

2. Case study basins

The river basins considered in this study were selected to represent the variety of conditions in the river basins in Europe. The selected basins:

- are situated in different climatic zones, see Annex 1 in Supplementary Material that provides a map of the basins with respect to climatic zones after the Köppen Geiger classification;
- have different basin areas ranging from *meso-* to macroscale basins (from 4500 km^2 for the Emån to 817000 km^2 for the Danube),