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HYDROLOGICAL PROJECTIONS ON A SMALL EUROPEAN CATCHMENT

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1. INTRODUCTION

Hydrological services are clearly important from several aspects, including flood protection, water management, shipping, agriculture, etc. Thus, the hydrological cycle within the complex climate system requires special attention, for which the cooperation of experts in hydrology and climate modeling is a key element. Extreme runoff characteristics (both low and high runoff values) interfering with regional climate change may result in several environmental damages and moreover, economical losses. In order to prepare to these hydrological hazards well in advance, (i) taking into account past experiences and (ii) building appropriate adaptation strategies for the future are essential. To analyze the hydrological consequences of climate change, coupling a hydrological model to a climate model provides more reliable and physically-based results, which conclude to specific suggestions for different users.

Our analysis considers a relatively small catchment, namely, the Upper-Tisza basin (with an area of 9707 km^2), which is one of the most important catchments from the flood-defense point of view in Hungary. Three countries share the area of the basin, namely, Ukraine, Hungary, and Romania. The river rises in the Ukrainian Carpathians and drains southwest into Hungary (Fig. 1). In this mainly mountainous area the annual mean precipitation sum is 500–1400 mm. In the recent decades quite many major flood events occurred in the Upper-Tisza catchment, e.g. 1970, 1998, 2001, 2006.

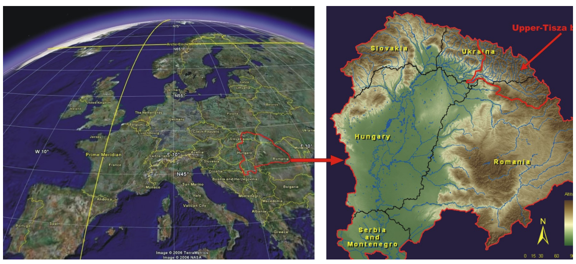

Fig. 1: The geographical location and the topography of the target basin, the Upper-Tisza catchment.

2. DATA AND METHODS

In this study, the distributed, physically-based DIWA (DIstributed WAtershed) hydrological model (Szabó, 2007; Szabó et al., 2010) is driven by the RegCM4 regional climate model's (RCM; Elguindi et al., 2011) meteorological outputs.

Fig. 2 summarizes the main steps of the analysis. First, calibration of DIWA hydrological model is accomplished using historical meteorological data from CARPATCLIM (Spinoni et al., 2015) and observed runoff values. Meteorological data (namely precipitation, minimum and mean temperature) for DIWA are provided by the CARPATCLIM database and RegCM4 simulations. After evaluating the validation results of the raw RCM data, bias correction is applied to the raw RCM outputs when it seems to be necessary. After that, simulations with DIWA (driven by CARPATCLIM, raw and bias-corrected RegCM4 data) are completed for the target catchment. Finally, a detailed evaluation and a thorough statistical comparison of runoff outputs are performed.

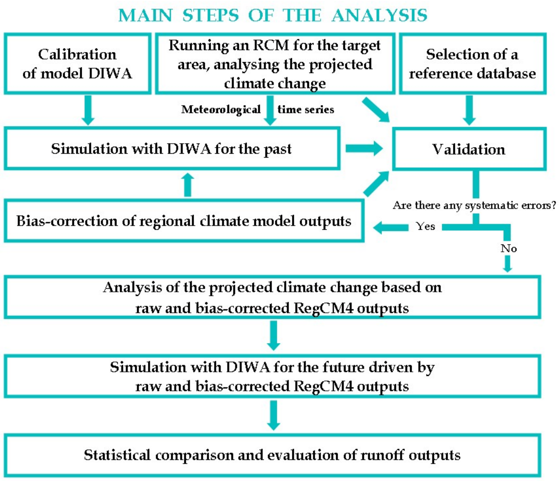

Fig. 2: The flow chart of the analysis.

The physically based DIWA considers different processes, which are key-elements in the hydrological cycle (Fig. 3). It takes into account topography, which influences surface gradient as well, as local drainage direction. Streambed gradient and roughness are also taken into account. A critical temperature value determines whether precipitation is rain or snow. If it is snow, accumulation (and melting) is also considered. Monthly LAI (Leaf Area Index) and NDVI (Normalized Vegetation Index) values from satellite data are taken into account too, which are clearly important factors in the case of interception. Evaporation and transpiration

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processes are also involved; potential evaporation is calculated using the method of Varga-Haszonits (1969). Moreover, DIWA involves submodels for infiltration and unsaturated flow. Furthermore, it distinguishes 45 land use types (e.g. broadleaves forest, coniferous forest, pasture, natural grassland, complex cultivation pattern, etc.) and more soil layers (including the O-horizon, which is the uppermost, organic level of the soil).

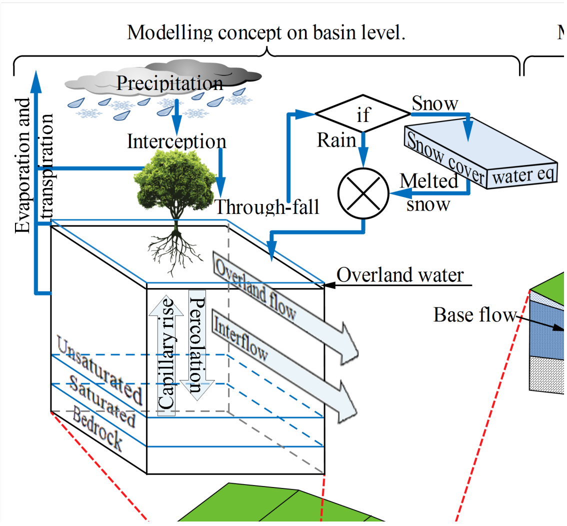

Fig. 3: The schematic description of the physically based DIstributed WAtershed (DIWA) hydrological model.

Reference meteorological data, which are necessary input for the hydrological model, are provided by the CARPATCLIM database. This database is based on observations, which are homogenized (MASH; Bihari and Szentimrey, 2013) and interpolated (MISH; Bihari and Szentimrey, 2013) to a regular grid with a 0.1° horizontal resolution. CARPATCLIM contains 50-year-long time series with daily steps covering the 17–27°E; 44–50°N region.

For the future, evidently no observational database is available, therefore regional climate model's (namely RegCM4) simulation is used in the study. RegCM4 is adapted for the Carpathian Region by the Department of Meteorology of the Eötvös Loránd University (Bartholy et al., 2015; Pieczka et al., 2015). It covers the 6–29°E; 43.8–50.6°N domain with 0.11° horizontal resolution. The necessary initial and boundary conditions are provided by a 50 km horizontal resolution experiment, which was driven by the HadGEM global climate model (Collins et al., 2011). Time series with a daily step are available from 1970 to 2099. Until 2005, the model considers observed greenhouse gas concentrations, while for the future time period (2006–2099) the new RCP scenarios (van Vuuren et al., 2011), namely, RCP4.5 and RCP8.5 are taken into account.

The calibration of the hydrological model is completed for Tiszabecs (48.1°N; 22.8°E), where the river Tisza enters to Hungary. As a reference, observed water level data are available, from which river discharge values can be calculated. We calibrated the DIWA hydrological model for a 2-year-long time period, using the CARPATCLIM observation-based dataset as driving input. The results of the calibration indicate that the timing of simulation is adequate; however, in the winter half-year (from November to March) the simulations slightly underestimate observations. Scatter-plot diagrams show that no systematic errors can be recognized neither in the case of calibration (Fig. 4), nor in the case of validation (Fig. 5), since the symbols are close to the solid, black line (y = x) representing the perfect match between observed and simulated river discharges.

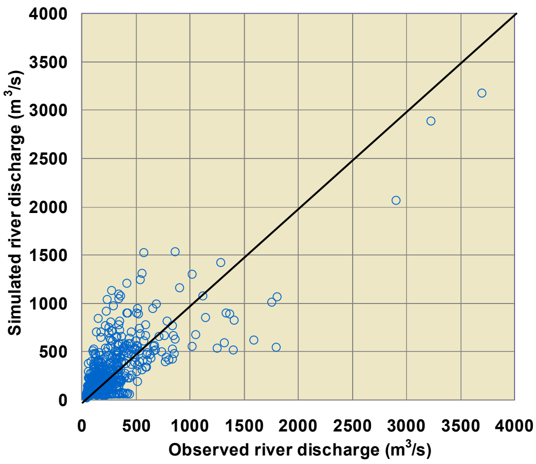

Fig. 4: The scatter-plot diagram of the observed and simulated river discharge for the calibration period (Tiszabecs, 01.05.2000–30.04.2002).

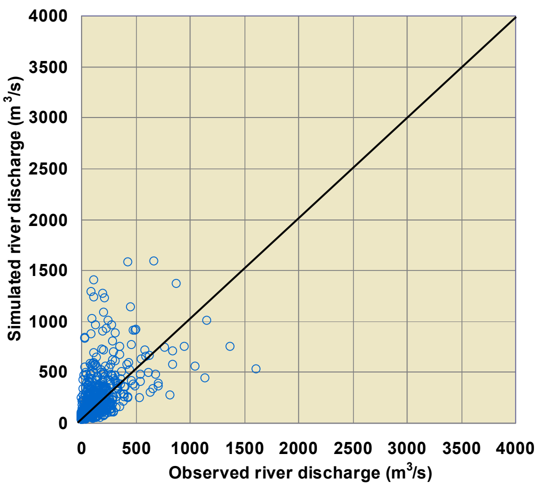

Fig. 5: The scatter-plot diagram of the observed and simulated river discharge for the validation period (Tiszabecs, 01.05.2002–30.04.2004).

3. RESULTS

In subsection 3.1 the projected changes of precipitation totals and mean temperature values are presented for 2021–2050 and 2069–2098 in the Upper-Tisza catchment considering both RCP4.5 and RCP8.5 scenarios. Then, seasonal runoff values simulated by DIWA are analyzed in subsection 3.2, based on CARPATCLIM, raw, and bias-corrected RegCM4 outputs for a historical time period (1971–2000), and also, for the future (2021–2050 and 2069–2098).

3.1 *Projected climate change in the Upper-Tisza catchment*

In the Upper-Tisza catchment the warmest season is summer and the coldest is winter (based on the CARPATCLIM dataset), with an overall average of 15.1 °C and –3.5 °C, respectively (Fig. 6). The historical run of RegCM4 overestimates mean temperature from May to August, while there is a general underestimation in the rest of the year. Therefore, bias correction of raw RCM data would certainly improve the annual cycle. For the future warmer climate is projected by RegCM4 in the target catchment. By 2021–2050 no significant difference can be recognized between the two scenarios. However, by the end of the 21st century, clearly higher temperature values are estimated in the case of RCP8.5 than for RCP4.5. The differences between the estimated warming rates are 1–3 °C.

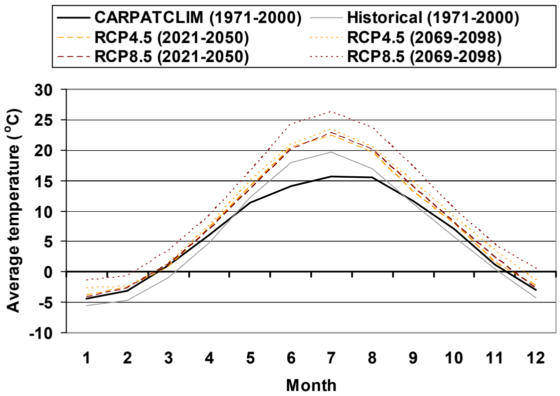

Fig. 6: Monthly average temperature values (°C) in the Upper-Tisza catchment based on the CARPATCLIM (1971–2000) database and RegCM4 simulations (1971–2000, 2021–2050, 2069–2098) considering RCP4.5 and RCP8.5 scenarios for the future.

In the case of precipitation (Fig. 7), larger differences can be found between the monthly totals calculated from CARPATCLIM and RegCM4 historical run. The RCM does not properly simulate the annual distribution: the wettest month is July and the driest is February according to CARPATCLIM, while RegCM4 historical simulation suggests the opposite, i.e., July is the driest, February is the wettest month. In order to eliminate these systematic errors, a percentile-based bias correction method is applied to the raw RCM data (Pongrácz et al., 2014). Considering the future, there is not any substantial difference between the RegCM4 simulations taking into account RCP4.5 and RCP8.5, except for February, May, and October, when the directions of the projected changes differ. Overall, for summer a precipitation decrease (by about 20–30%) is estimated, whereas for winter a general increase (by 10–15%) is projected in the case of both scenarios.

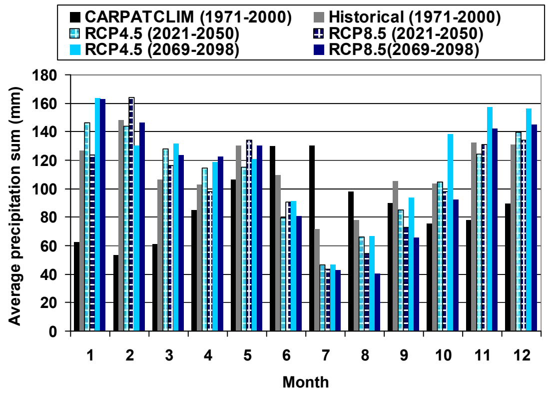

Fig. 7: Monthly average precipitation totals (mm) in the Upper-Tisza catchment based on the CARPATCLIM (1971–2000) database and RegCM4 simulations (1971–2000, 2021–2050, 2069–2098) considering RCP4.5 and RCP8.5 scenarios for the future.

3.2 *Seasonal runoff simulated by DIWA*

The distributions of winter and summer runoff values simulated by DIWA are analyzed in this section.

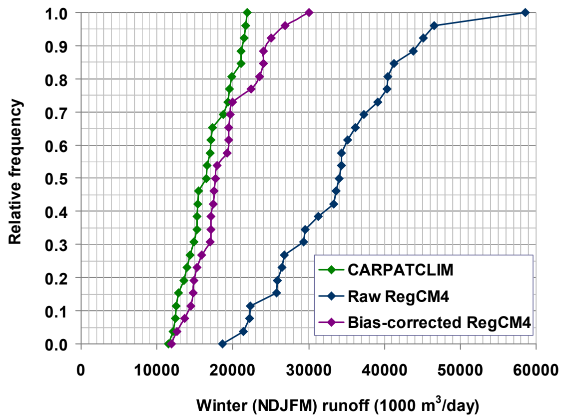

Fig. 8: The distributions of winter (from November to March) runoff values for 1971–2000, based on the CARPATCLIM, the raw and bias-corrected RegCM4 driven DIWA simulations.

Fig. 8 and 9 refer to the 1971–2000 historical time period; the necessary meteorological data for the hydrological model are provided by the CARPATCLIM (indicated by green), the raw (indicated by dark blue) and bias-corrected (indicated by purple) RegCM4 outputs. The raw RegCM4 driven DIWA-simulated values are significantly higher in winter and somewhat lower in summer compared to the reference (CARPATCLIM). These results can be explained by the under- and overestimations of the monthly precipitation totals by raw RCM outputs (shown in Fig. 7).

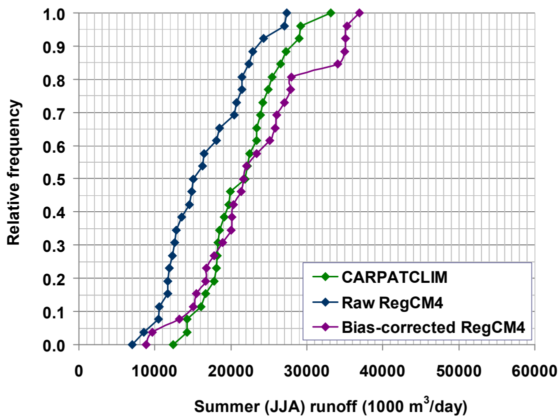

Fig. 9: The distributions of summer (from June to August) runoff values for 1971–2000, based on the CARPATCLIM, the raw and bias-corrected RegCM4 driven DIWA simulations.

Due to the applied percentile-based bias correction method, the resulting bias-corrected simulated values are much closer to the reference both in winter and summer. However, the shape of the distribution of runoff is slightly different, especially in summer in the case of high extremes. Therefore, a more appropriate bias correction method should probably be used here.

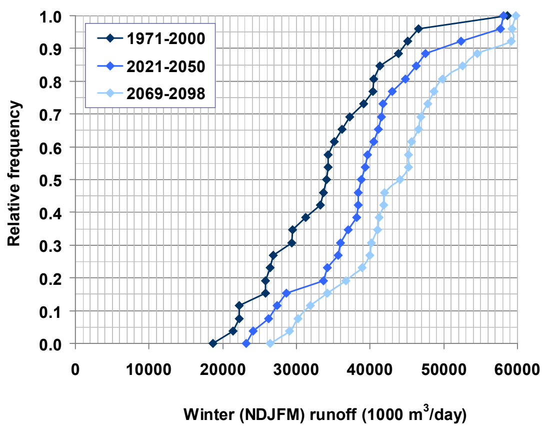

Fig. 10: The distributions of winter (from November to March) runoff values for 1971–2000, 2021–2050 and 2069–2098, based on the raw RegCM4 driven DIWA simulations.

To investigate the estimated future changes, we analyze DIWA-simulations for three 30-year-long time periods (dark blue: 1971–2000, blue: 2021–2050, light blue: 2069–2098) driven by the raw RegCM4 outputs (Fig. 10 and 11). In the winter half-year (from November to March) larger runoff values are projected for the future time periods (the largest values are estimated by the end of the 21st century); and the shapes of the distributions are similar to each other. These results can be confirmed by the generally projected precipitation increase in winter.

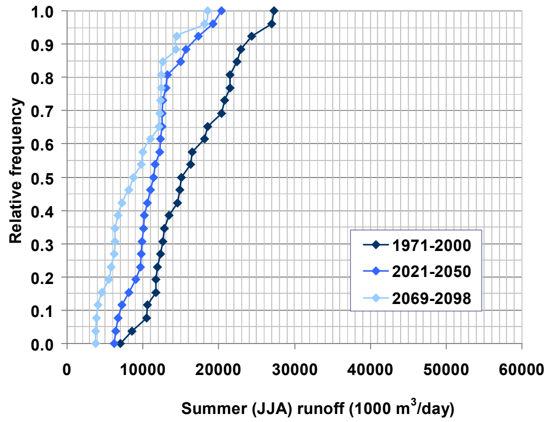

Fig. 11: The distributions of summer (from June to August) runoff values for 1971–2000, 2021–2050 and 2069–2098, based on the raw RegCM4 driven DIWA simulations.

In summer (from June to August) clearly smaller runoff values are estimated for the future than for the past (Fig. 11). The decrease of runoff is more pronounced by 2069–2098 than by 2021-2050, especially, in the case of runoff values, which are below the median. The shapes of the distribution curves referring to the past and to the late 21st century are quite similar, while the distribution of summer runoff regarding to the mid century somewhat differs form these two periods. One of the main reasons of this decrease can be the projected increase of the mean dry spell duration in the future (Pongrácz et al., 2014).

4. CONCLUSION

Estimated changes of seasonal runoff characteristics were investigated in this study based on the simulations of the DIWA hydrological model. Runoff values simulated by CARPATCLIM, raw and bias-corrected RegCM4-driven DIWA were compared to each other for a historical time period (1971–2000). The analysis show that raw RCM outputs result in larger runoff values in winter, and slightly lower values in summer compared to the reference. Because of the applied bias correction method, hydrological simulations are closer to the CARPATCLIM-driven runoff values; however, the shape of the distribution is modified.

Considering the future, substantial changes are projected in the Upper-Tisza catchment. For winter, larger runoff values are estimated, while in summer generally lower values are likely to occur by the end of the 21st century than in the past according to the raw RegCM4 driven hydrological simulation.

As hydrological processes are especially sensitive to input precipitation data, bias correction of RCM-simulations is necessary for a detailed, precise analysis. However, it is a great challenge to find the most appropriate method to provide as reliable results as possible. These climate change related hydrological studies are essential in order to prepare appropriate adaptation strategies for the future on different scales from national to local level.

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