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Theses of the PhD dissertation
PAST AND PROJECTED FUTURE TRENDS OF PRECIPITATION EXTREMES, HYDROLOGICAL IMPACTS OF ESTIMATED CHANGES

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1. Introduction and objectives

Precipitation is one of the most important meteorological parameters, as water affects more or less – directly or indirectly – every human action (from key sectors such as agriculture to simple outdoor activities). In the framework of the doctoral dissertation precipitation trends and extremes are analysed for the past as well as the future. Furthermore, their potential consequences on runoff are investigated. The actuality of this issue is quite evident, because global climate change does not only imply higher temperature values but extreme weather events tend to occur more frequently, which may result in different natural, economical and environmental damages. Impact studies aiming to evaluate these potential hazards are especially important in proper adaptation to the changing conditions from global to local levels.

2. Data and methods

To analyse the past (1961–2010) precipitation trends, the homogenized, interpolated CARPATCLIM database is used, which is based on the regular measurements of meteorological stations. Regional climate model (RCM) simulations from the ENSEMBLES project are applied to the future (1951–2100). We considered 11 different RCM-outputs here in order to assess the uncertainty of projections. The precipitation fields of RCM-simulations are validated in a historical time period, for which the CARPATCLIM database served as the reference. In order to eliminate the identified systematic errors, a percentile-based bias-correction method was applied to the raw RCM-outputs. This method is often used and considered as one of the best performing processes. It is based on fitting the empirical distribution functions for each RCM, each month and each grid point, assuming stationarity.

The impact of climate change on runoff is investigated by the physically based, distributed DIWA hydrological model. The necessary meteorological time series were provided by the RegCM4 regional climate model. The reliability of climate model outputs is especially important in the case of impact studies. Since the available RegCM4 simulation also resulted in systematic under- and overestimations, we applied a bias-correction method on the raw simulation outputs. However, several disadvantages of bias
correction are known, therefore the analyses are completed using both the raw and bias-corrected RCM-outputs, so the results can be compared.

Runoff is a complex, non-linear process where even a small change in one factor may result in substantial differences in the final results. In order to assess the statistical characteristics, several possible scenarios of the meteorological variables are used by a weather-generator embedded in a Monte-Carlo cycle. The DIWA hydrological model was driven by all these time series, hence, several hundreds scenarios with equal probability can be evaluated for the historical time period and two future time periods. Validation results for the Uppest-Tisza Basin are satisfactory, so the proposed model system can be considered as an adequate tool to analyse the possible impacts of climate change on runoff.

3. Theses

The results of the doctoral dissertation can be summarized in the following theses points:

1. The precipitation sums of RCM-simulations for the historical time period differ from the CARPATCLIM database, which is based on station measurements and considered as a reference. By applying a bias-correction method, these systematic errors were eliminated.
   - RCM-simulations underestimate precipitation in summer, while overestimation can be found (compared to the CARPATCLIM database) in the rest of the year, especially in winter.
   - Due to these systematic errors, most of the RCMs were unable to reproduce the annual distribution of precipitation properly.
   - Considering the spatial structure, no substantial difference can be recognised between the simulations and the reference database.
   - After applying the percentile-based bias-correction method (i.e. fitting the empirical distribution functions) for each RCM, each month and each grid point, the time series became similar to the real climatic conditions from the statistical point of view. The spatial structure of the bias-corrected RCMs did not change, and the overall annual distribution of precipitation appears properly with summer maxima and winter minima. Furthermore, the mean monthly precipitation sums are close to the CARPATCLIM values.
To estimate the hydrological processes, a more complex method was chosen that takes into account several hundreds possible scenarios (with the same probability), instead of a single, deterministic time series. By applying a weather-generator embedded in a Monte-Carlo cycle, the statistical characteristics of the watershed’s response to climate change can be analysed as well as the uncertainty of the projections.

The overall signs of the estimated changes were not modified by the bias-correction, however, substantial differences can be found in the magnitude of the estimated changes compared to the raw RCM-simulations.

2. According to the RCM-simulations, the intra-annual distribution of precipitation is likely to be restructured in the 21st century in the Carpathian Basin. Drying trend is estimated in summer, while precipitation increase is projected in winter. Therefore, the annual distribution of precipitation will be more balanced in the future, as currently the driest season of the Carpathian region is projected to be wetter, while the wettest season is likely to be drier.

3. Precipitation indices related to drought and small precipitation sums are projected to increase (except in winter), especially by the end of the 21st century.

- According to the RCM-simulations the number of precipitation days in summer is likely to decrease by 20–30% in the Carpathian Basin. The maximum number of consecutive dry days and the mean dry spells are projected to increase by about 40% (most of the models estimate significant changes). The drying trend is more pronounced in the southern regions (i.e. Croatia, Serbia, South-Hungary) of the selected domain.

- In winter, a slight decrease is expected in the northern parts of the domain (i.e. Slovakia, Ukraine), while CDD1, MDS2, DD3 will remain the same in the southern areas. Moreover, RR14 and RR55 are projected to increase in winter. The overall spatial mean of the estimated change of the number of precipitation days is 4%, and 10% by the middle and late the 21st century, respectively.

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1 CDD: Maximum number of consecutive dry days
2 MDS: Mean dry spell (when precipitation is continuously below 1 mm/day)
3 DD: Number of dry days (when precipitation is below 1 mm)
4 RR1: Number of precipitation days (exceeding 1 mm)
5 RR5: Number of precipitation days exceeding 5 mm
Similarly to summer, drier climatic conditions are estimated for spring and autumn. For instance, CDD will tend to increase in spring, especially, south from the 48°N. Higher values are likely to occur in autumn over the whole domain, compared to the reference.

4. Extreme precipitation is likely to be more frequent and more intense in the future in the Carpathian region, especially in winter and autumn.
   - The estimated changes are more pronounced by the end of the 21st century. The sign of the changes is the same for the nearer and the further future, except for summer.
   - In winter, precipitation indices related to intensity are likely to increase by 10–20% by the end of the 21st century. According to the simulations, changes are estimated to be larger in the northern regions than in the southern regions.
   - In summer, the analysed indices are likely to decrease, except for RX1 and SDII. In these cases spatial differences are estimated: index values will increase in the northern areas, while decreases are projected in the southern part of the domain.
   - Similarly to winter, precipitation indices related to intensity or extreme precipitation are estimated to increase in spring and autumn. Larger uncertainty appears in spring by the end of the 21st century.

5. The daily mean discharge of the Upper-Tisza Basin (at Tiszabecs) is projected to decrease in the 21st century (both in the case of raw and bias-corrected simulations).
   - DIWA was driven by meteorological time series generated by a weather-generator embedded in a Monte-Carlo cycle using raw and bias-corrected parameters. The results do not differ when considering the sign of the changes only, however, the simulated runoff values are substantially different (since bias-correction eliminated the overall precipitation overestimation).
   - Summer runoff will decrease (especially in July and August) in accordance with the projected precipitation and temperature changes. A slight increase is estimated for January and February.
   - The projected changes are significant from April to October by the end of the 21st century according to the Kolmogorov-Smirnov test (in the case of raw simulations, winter increase is also significant).

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RX1: The highest 1 day precipitation
SDII: Simple daily precipitation intensity index
6. The number of days above the third level of flood warning is estimated to decrease in the 21st century.
   - Due to higher temperature values the overall ratio of snow within the precipitation as well as the accumulated snow will be less in the future, therefore, spring floods are estimated to decrease.
   - Summer floods are also projected to decrease because of (i) the expected precipitation decrease, and (ii) lower water levels due to longer dry spells. Hence, larger precipitation events will not result in such extreme high water levels as in the past.
   - Although the number of days above the third level of flood warning is estimated to decrease, in certain cases flood levels are projected to become more severe than nowadays.

7. The number of days with a critically low level of riverbed-filling is estimated to increase in the future between July and October.
   - The changes are more pronounced by the further future (i.e. the late-21st century).
   - The estimated values are different in the case of raw and bias-corrected simulations, although the signs of the estimated changes are the same.

4. Conclusions

According to our results, the intra-annual distribution of precipitation is very likely to change in the future in the Carpathian Basin. Furthermore, the frequency and intensity of extreme precipitation are estimated to increase in the most of the months. These estimated changes will certainly affect runoff processes: for a detailed analysis, a physically-based hydrological model driven by regional climate model outputs was used. Because of the uncertainty of the estimated changes, raw and bias-corrected simulations are recommended to compare in order to evaluate whether the correction modifies the sign of the estimated changes. Considering our results, the main message for decision makers and users can be summarised as follows: in order to adapt successfully to the potential hazards because of the estimated precipitation and temperature changes for the 21st century, an appropriate water resource management strategy is essential that takes into account the projected climate change and includes water storage plans in addition to the flood-defence actions.
Publications related to the topic of the thesis

Peer-reviewed papers:


Additional publications:


