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Changes of drought characteristics in small Czech and Slovakian catchments projected by the CMIP5 GCM ensemble

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Abstract Simulations of global climate models (GCM) available from the CMIP5 project are used to develop climate change scenarios for four small catchments in the Czech and Slovak Republic with an advanced delta change method. This method applies a nonlinear transformation to precipitation in order to match projected changes in precipitation variability as well as changes in mean precipitation from the GCM simulation considered. However, the precipitation above the 95th percentile is transformed linearly to avoid occasionally very large values of daily precipitation occurring as a consequence of the nonlinear transformation. Similarly, temperature is transformed considering the changes in mean and variability. Simulations for different RCP scenarios are considered. The impact of climate change on hydrological balance is assessed, as well as changes in drought severity. For the latter the deficit volumes are considered. Projected changes in deficit volumes are evaluated with a simple statistical model which assumes that deficit volumes for each basin follow a general extreme value (GEV) distribution. The differences in deficit volumes and their changes between basins and GCM simulations can then be summarized by the changes in the GEV parameters. The results show an increase in the number of minor droughts and an increase in the most severe droughts. There are clear differences in the changes of drought characteristics related to the dominant runoff regime in a catchment.

Key words climate change; CMIP5; drought; deficit volume; GEV model

INTRODUCTION

Despite relatively frequent flooding in the Czech Republic and Slovak Republic in recent decades, the drought assessment is receiving more and more public attention. This is partly due to several very dry years (e.g. 2000 and 2003) with large financial losses (the estimate for 2000 is more than 400 million EUR). This is also reflected in the published studies on possible changes in drought characteristics in the area (e.g. Kašpárek *et al.*, 2006; Hanel *et al.*, 2013). In this paper we present preliminary assessment of changes in drought characteristics according to the ensemble of Global Climate Models (GCMs) from the Coupled Model Intercomparison Project Phase 5 (CMIP5) using simple statistical model for two Czech and two Slovak catchments. The statistical model assumes that the drought indices (here the deficit volumes) follow the Generalized Extreme Value (GEV) distribution (other distributions have also been tested, although the results are not reported here). The statistical model is applied to summarize the changes in drought characteristics rather than to extrapolate them to extreme return periods.

Study areas and data are described in the following sections. The Methods section provides information on the statistical downscaling of the climate model output, the hydrological model BILAN used for modelling hydrological balance and the statistical model for the analysis of drought. In the Results section, the changes in hydrological balance and drought characteristics are presented and discussed.

STUDY AREAS

Two catchments from the Czech Republic (Metuje and Teplá) and two catchments from the Slovak Republic (Belá and Ľupčianka) were considered in this study. The information on the catchments is given in Table 1 and Fig. 1. The Belá River catchment is located where the Západné and Vysoké Tatry Mountains in the north of Slovakia meet the right tributary of the Váh River.

The runoff from this high mountain area is typical, with both temporary snow and rainfall combined. The Ľupčianka catchment is the left tributary of the Váh River. The Ľupčianka stream has its spring on the northern slopes of the Nízke Tatry Mountains in the northern part of central Slovakia. The runoff regime is mainly rain with snow combined in the lower part and mainly snow with rain in the headwater part of the catchment. The Metuje catchment is formed by the Adršspach-Teplické stěny Upland, which is very heterogeneous. It consists of deeply incised valleys, so-called "rocky towns", table mountains and pseudokarst caves. The land cover predominantly consists of cropland and grass fields and forest. In general low precipitation amounts occur in winter. Regular peaks caused by snowmelt can be observed in spring and low discharges predominate in summer. The discharge dominantly consists of groundwater. The Teplá River originates in peat meadows in the western part of the Czech Republic. A large part of the catchment consists of a nature reserve with forested slopes, debris ecosystems and ravines. The runoff regime is dominated by rainfall.

Table 1 Characteristics of the studied catchments.

	Area (km^2)	Altitude (m)	Annual precipitation (mm)	Mean annual daily temperature (°C)	Annual runoff (mm)	Period considered
Belá	93.5	1575	1564	5.2	1244	1983–2000
Ľupčianka	70.4	982	1056	3.4	682	1984–2005
Metuje	250.2	561	746	8.0	334	1972–1995
Teplá	272.2	686	659	5.9	257	1962–1995

DATA

Daily precipitation sums, temperature and runoff were further used for hydrological modelling. Data for the whole control period were unfortunately not available for all catchments. Therefore we subjectively selected the maximum possible series with no significant trend in precipitation and temperature (see Table 1 for the resulting periods). Those series are considered to be representative of the control climate (1961–1995).

The CMIP5 data archive consists of several hundreds of simulations. At the time of retrieving the data, there were 398 simulations of 31 GCMs under four RCPs. Several GCMs have been run with different parameter settings. However, the number of simulations for each RCP is different: in the full CMIP5 data set there are 46 simulations for RCP2.6, 57 for RCP4.5, 30 for RCP6.0 and 66 for RCP8.5. To avoid bias due to a different number of simulations in the assessment of differences between RCPs, we considered a subset of the CMIP5 ensemble such that the runs (i.e. GCMs + parameter settings) are the same for each RCP, except the forcing. This results in set of 29 GCM simulations for each RCP (i.e. 116 simulations in total).

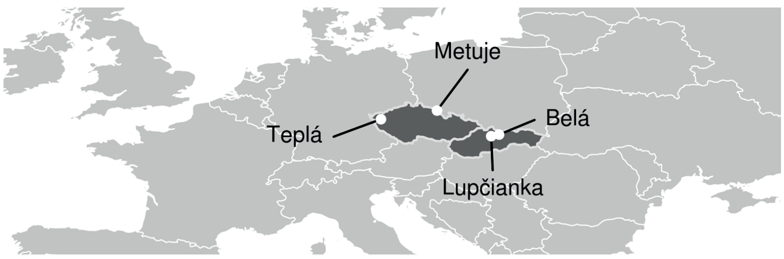

Fig. 1 The study areas.

METHODS

Advanced delta change method

The statistical downscaling of precipitation and temperature is necessary to eliminate/lessen the biases in the GCM simulations and transform the GCM output to a proper spatial scale. It can be done generally in two ways: by correcting the bias in the GCM simulation, assuming that the bias for the future period is the same as for the control period (bias correction method), or by transformation of the observed data such that the changes in precipitation and temperature are the same as in the GCM simulation (the delta change method), assuming that those changes do not depend on bias. The advanced delta change (ADC) method (van Pelt *et al*., 2012) allows for changes in the distribution of precipitation by application of a nonlinear transformation of observed precipitation data such that the changes in the 60% and 90% quantiles of the precipitation distribution match those from the GCM simulation. In addition, inherent to the method is a correction for the biases in these quantiles. Temperature is transformed in a way reflecting the changes in mean and variance from the GCM simulation.

The transformation parameters for a substantial part of Europe have been derived by the Royal Meteorological Institute, together with a system of R scripts allowing for transformation of precipitation and temperature series at whatever location (within the domain, see Kraaijenbrink & Pavlásková, 2013). The derived transformation parameters consider changes between the control period (1965–1990) and near (2021–2050) and far (2071–2100) future periods. In the present paper results are presented only for the far future period (mainly because of space limitation; the calculations have also been done for the near future).

Hydrological model

The hydrological model BILAN (van Lanen *et al.*, 2004) has been used for assessing water balance components of the catchments. The structure of the model is formed by a system of relationships describing basic principles of water balance on the ground, in the zone of aeration, including the effect of vegetation cover, and in groundwater. Air temperature is used as an indicator of energy conditions, which significantly affect the water balance components. The input data of the model are daily series of basin precipitation and air temperature, which are obtained by interpolation of the station data to the area of the basin considering the distance from the centre of the basin and orography. The potential evapotranspiration is calculated using the simple energy balance formula of Oudin *et al.* (2010). For calibration of the six model parameters, a runoff series at the outlet from the basin is used.

Definition of drought and statistical model

Hydrological drought can be defined in many ways. One of the simplest, yet frequently used approaches, is to consider a cumulative volume of discharge below a preselected threshold, i.e. deficit volume (see e.g. Hisdal *et al.*, 2004). To prevent termination of drought by short periods of runoff above the threshold, daily (observed and simulated) runoff has been smoothed by 30 (Ľupčianka, Metuje, Teplá) and 15 (Belá) days running sum, as explored by van Loon *et al.* (2004). The smoothing window was chosen by trial-and-error in order to guarantee sufficient number of droughts in the series, while avoiding frequent termination of drought by increase of runoff. The short value for the Bělá River relates to the mountainous character of the watershed with fast runoff response. In addition, we consider a drought to end only when terminated by more than 3 days of (smoothed) runoff above a threshold. The threshold was set to the 80% quantile of the flow exceedence curve of the smoothed simulated runoff for the control period. For the future periods, the same threshold was used.

To summarize the changes and differences in the characteristics of the deficit volumes, a statistical model for the annual maximum deficit volume was applied. After extracting the annual maximum deficit volume (note that usually not all the years experienced drought), we fitted several distributions to this annual maxima sample by the method of L-moments (Hosking & Wallis, 1997). The goodness-of-fit was assessed visually with standard quantile plots. From the considered distributions: Generalized Extreme Value (GEV), Generalized Pareto (GPD), Exponential, Log-normal, Gumbel, Gamma, Generalized Logistic, Generalized Normal, Kappa, Normal, and Pearson type III distribution, the GEV performed most consistently followed by the GPD. Other distributions usually did not lead to large discrepancies, except for normal and exponential distribution. The results reported in the next section are therefore based on the statistical model assuming the GEV distribution.

The changes in the GEV parameters and the estimated quantiles provide a summary of the changes in the drought regime of a watershed. Since drought did not occur each year, the estimates have to be corrected for the years without drought. Let $H(x)$ be the distribution function of maximal annual (non-zero) deficit volume and p_0 the probability of a year being without drought (estimated as a proportion of years without drought to the total length of the series). Then the corrected distribution function $H^*(x)$ of maximal annual deficit volume is obtained by simple transformation of $H(x)$, as suggested by England *et al.* (2005):

$$H^*(x) = \begin{cases} p_0 & \text{if } x = 0 \\ p_0 + (1 - p_0)H(x) & \text{if } x \neq 0 \end{cases} \quad (1)$$

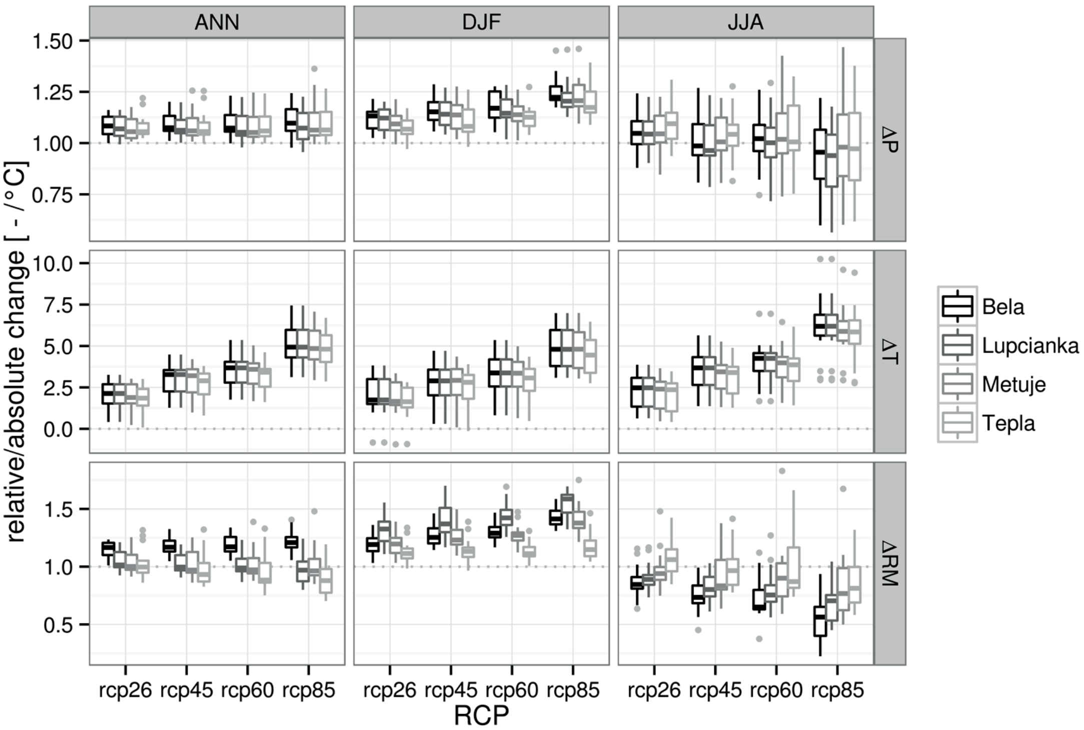

Fig. 2 Relative (precipitation, P, runoff, RM) and absolute (temperature, T) annual (ANN), winter (DJF) and summer (JJA) changes for the studied basins and different RCPs.

RESULTS AND DISCUSSION

Changes in hydrological balance

In all catchments the changes in precipitation are characterized by an increase in precipitation in all seasons except summer (see Fig. 2). The annual change in precipitation is also positive. The changes are most pronounced in simulations under RCP8.5 and also the spread between projections is somewhat larger for stronger forcing. The differences between basins are in general small (usually less than 10%). Temperature is increasing in all seasons, with the median increase ranging between ~2°C for RCP2.6 to ~5°C for RCP8.5 or even 6°C (for RCP8.5 in summer).

The differences in the changes in simulated runoff between catchments and RCPs are far larger than those in precipitation and temperature. There is a clear difference between the mountainous basin Belá and the other three basins. While the annual changes in runoff for the Belá River are positive, the sign of the annual changes for the rest of the basins is not clear. For all catchments, the winter runoff increases while summer runoff decreases. Again, Belá River deviates from the other catchments – there is the largest decrease in summer runoff and a very large increase in spring runoff (not shown, but reflected in annual changes), related to the increase in winter precipitation and snow water storage and to the rising temperature, leading to earlier snow melt and a decrease of the number of days with snow.

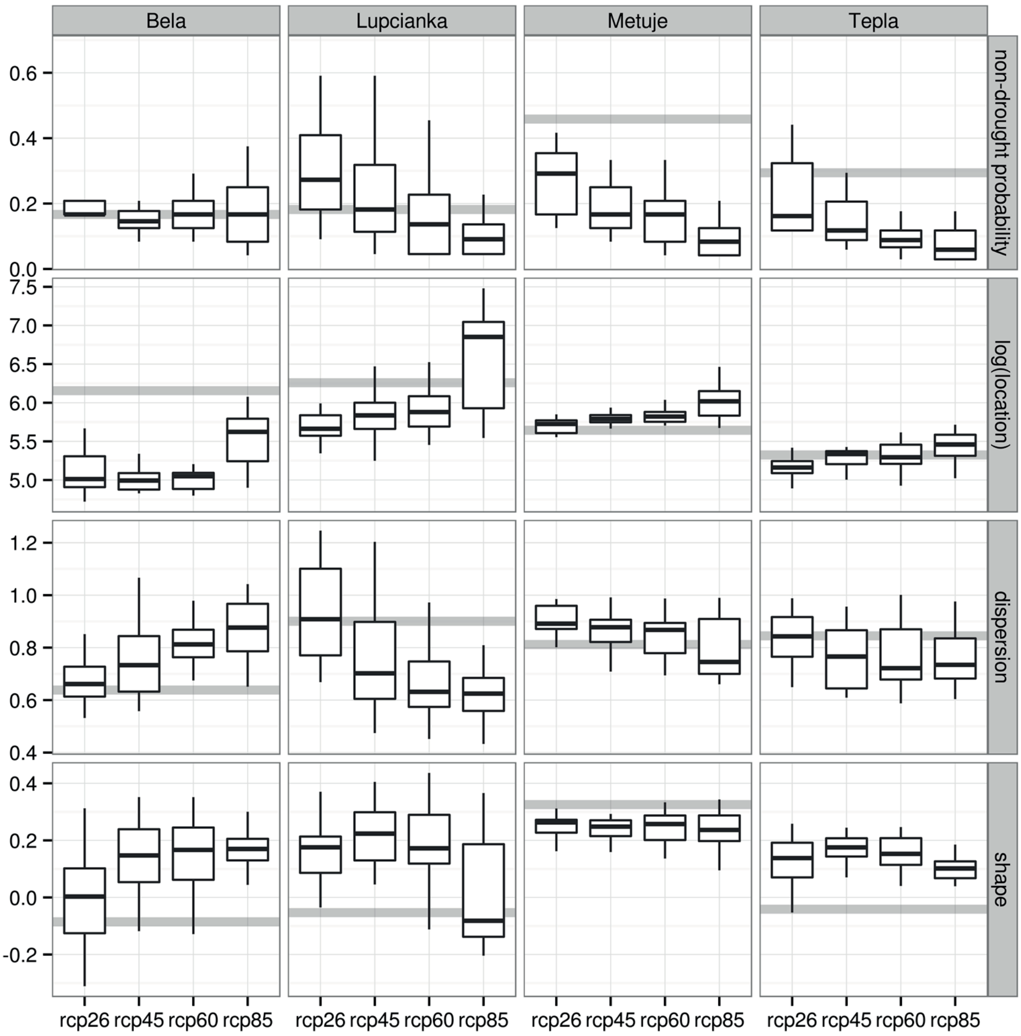

Fig. 3 Probability of year without drought (non-drought probability), logarithm of the GEV location parameter, dispersion coefficient (ratio of the GEV scale and location parameter) and the GEV shape parameter for the four basins and different RCPs. Results according to the hydrological model for present climate are indicated by the grey horizontal lines.

Changes in drought characteristics

The changes in drought characteristics for all catchments are summarized in Fig. 3. For the present climate the probability of a year without drought (non-drought probability in Fig. 3) is in the range of 0.15–0.45 (corresponding to 4–17 years without drought in a 30-year period), with the lowest value for the Belá and the highest value for the Metuje River. This is expected since the runoff in the Metuje basin is relatively stable due to a large contribution of groundwater. This is in contrast to the Belá River, which is mainly driven by snow and rain-induced runoff. As the temperature rises with RCP, the probability of drought increases (for RCP8.5 it is between 0.09 and 0.16, i.e. from a 30-year period we expect 3–5 years without drought) except for the Belá catchment, which shows no significant changes in this parameter.

The GEV location parameter increases with RCP, however (except for the Metuje River), the value for the future is below that for the control climate. This, together with a decrease of non-drought probability, indicates a larger number of minor droughts in the future simulations. The relative variability of drought (represented by the dispersion coefficient – ratio of the GEV scale and location parameter) decreases in future simulations for the Ľupčianka and Teplá catchments and increases for the Belá and Metuje catchments. Except for the Belá catchment, the dispersion coefficient decreases with forcing, at least slightly.

Except for the Metuje catchment the shape parameter increases in the future simulations. However, its estimation is very difficult from short series and the changes in the shape parameter are thus rather uncertain. The changes in parameters affecting larger quantiles (dispersion coefficient, shape parameter) indicate that the changes in distribution of the deficit volumes are affected mainly by the minor droughts.

CONCLUSIONS

For Ľupčianka, Metuje and Teplá catchments the results suggest frequent appearance of minor droughts accompanied with the increase of the most severe droughts. On average, the changes in drought characteristics might be positive for the low end RCPs, with only moderate warming and increase in summer precipitation. It has to be noted that due to development of the scenario series with the advanced delta change method, the temporal structure of rainfall is exactly the same as for the control period. This ignores possible changes in dry spell length. It is nevertheless not a solution to use a bias corrected climate model simulation, since the common bias correction methods do not correct the temporal structure of rainfall and might lead to unrealistic drought characteristics. This topic requires further research.

The GEV model for drought is a useful summary of the projected changes. However, the typical length of the time-slices considered in the climate change studies is somewhat limiting, especially with respect to the estimation of the shape parameter. Advanced techniques such as spatial pooling can be easily applied to reduce the uncertainty in the estimates.

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REFERENCES

Engeland, K., Hisdal, H. & Frigessi, A. (2005) Practical extreme value modelling of hydrological floods and droughts: a case study. *Extremes* 7, 5–30.

Hanel, M., Kašpárek, L., Peláková, M., Beran, A. & Vizina, A. (2013) Evaluation of changes in deficit volumes: support for protection of localities suitable for construction of reservoirs. In: *Considering Hydrologica Change in Reservoir Planning and Management* (ed. by A. Schumann *et al.*). IAHS Publ. 362. IAHS Press, Wallingford, UK.

Hosking, J. R. M., & Wallis, J. R. (1997) *Regional Frequency Analysis: an Approach Based on L-moments*. Cambridge University Press.

Hisdal, H., Tallaksen, L. M., Clausen, B., Peters, E. & Gustard, A. (2004) Hydrological drought characteristics. In: *Hydrological Drought Processes and Estimation Methods for Streamflow and Groundwater* (ed. by L. M. Tallaksen & H. A. J. van Lanen), 139–198. Elsevier Science B.V, Developments in Water Science, 48.

Kašpárek, L., Novický, O. & Peláková, M. (2006) Climate change and water regime in the Czech Republic. T. G. Masaryk Water Research Institute Collection of Papers 1.

Kraaijenbrink, P. & Pavlásková, A. (2013) *Advanced Delta Change Method. Application Manual*. Royal Netherlands Meteorological Institute. De Bilt.

van Lanen, H. A. J., Kašpárek, L., Novický, O., Querner, E. P., Fendeková, M. & Kupczyk, E. (2004) Human influences. In: *Hydrological Drought Processes and Estimation Methods for Streamflow and Groundwater* (ed. by L. M. Tallaksen & H. A. J. van Lanen,), 347–410. Elsevier Science BV, Developments in Water Science, 48.

van Loon, A. F., van Lanen, H. A. J., Tallaksen, L. M., Hanel, M., Fendeková, M., Machlica, A., Sapriza, G., Koutroulis, A., van Huijgevoort, M. H. J., Bermúdez, J. J., Hisdal, H. & Tsanis, I. (2011) Propagation of drought through the hydrological cycle. Watch Technical Report n. 31.

Oudin, L., Moulin, L., Bendjoudi, H. & Ribstein, P. (2010) Estimating potential evapotranspiration without continuous daily data: possible errors and impact on water balance simulations. *Hydrological Sciences Journal* 55(2), 209–222.

van Pelt, S. C., Beersma, J. J., Buishand, T. A., van den Hurk, B. J. J. M. & Kabat, P. (2012) Future changes in extreme precipitation in the Rhine basin based on global and regional climate model simulations. *HESS* 16, 4517–4530.