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Ensemble modelling of impact of climate change on runoff regime of Latvian rivers

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Abstract: The aim of the present study was to evaluate the impact of climate change on the runoff of the rivers in Latvia. The study was part of the research conducted within the framework of the Latvian National Research Programme on the “Impact of the Climate Change on the Latvian Water Environment”.

Latvia is a northeastern European country on the eastern coast of the Baltic sea. Its area is 64500 sq. km. The Latvian climate is temperate and mildly varies from rather maritime in the western part of the country to rather continental in the eastern part. Despite the presence of several hill areas (highest “peak” being 312 m above sea level), the territory can be characterized as lowlands with rather dense river network. Precipitation is common throughout the year with the heaviest rainfalls in July/August. Permanent snow cover is characteristic for winter months, typically causing spring snow-melt floods.

In this study, a two-way ensemble prediction approach was applied for the evaluation of the future river runoff from the territory of Latvia:

(1) An ensemble of regional climate models (RCMs) accessible via the European Commission research project “PRUDENCE” EVK2-CT2001-00132 (prudence.dmi.dk; Christensen, 2007) was considered for the Eastern Baltic area. The regional climate models have built-in runoff models. Comparison of RCM calculations for the reference (or control) time period 1961-1990 and for the climate change scenario A2 for time period 2071-2100 allows ensemble evaluation of run-off change forecast for territory of Latvia.

(2) The ensemble of hydrological models was used to calculate the climatic time series of runoff from selected catchments in Latvia. The applied models included the conceptual model MIKE BASIN, and the temporally and spatially distributed physically based models MIKE SHE (both commercial models from DHI group, Denmark; www.dhigroup.com) and FIBASIN (academic model by University of Latvia; Bethers, 2007). To proceed with the usage of the ensemble of hydrological models for the runoff forecast, we employed several steps:

- An ensemble of river runoff models was calibrated for the river basins of Latvia using observed climatic (temperature, precipitation) and discharge data series by the Latvian Environmental, Geological and Meteorological Agency (www.legma.gov.lv).
- The regional variation (mainly seasonal) of runoff regime was investigated for Latvian rivers for contemporary climate.
- The RCM calculation results were prepared to serve as input data for the hydrological models via modification of the RCM output by histogram equalization method (Seņņikovs, 2009) to assure statistical compliance of observed and calculated meteorological data series for the control time period. The downscaling procedure was employed for temperature, precipitation and relative humidity data series for contemporary climate (1961-1990) and climate change scenario A2 (2071-2100).
- The ensemble of calibrated hydrological models was used for the calculations of the runoff time series for a selected river basin (Bērze river in central Latvia). The results of hydrological calculations for contemporary climate allowed evaluation of the usage of [modified] RCM data as the substitute for the meteorological observation inputs in the hydrological models. The results of hydrological calculations for future climate allowed ensemble evaluation of future runoff regime.
- Finally, the simplest model (MIKE BASIN) was used to show the expected changes in the regional variation of the runoff regime.

Keywords: *Climate change, hydrological modeling, river runoff, model ensemble*

1. INTRODUCTION

The aim of the present study was to evaluate the expected influence of the climate change on the runoff, and its seasonal and spatial variation, of the Latvian rivers. The geographical location (northeastern Europe) of Latvia is shown in Figure 1.

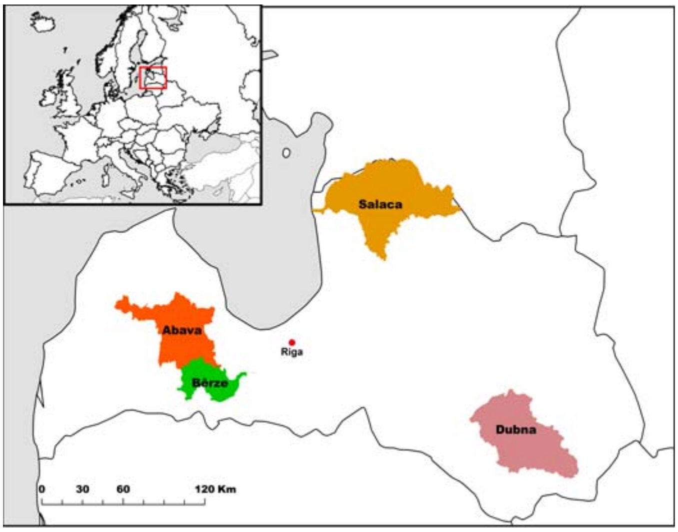

Figure 1. Geographical location of Latvia and considered river basins

The most comprehensive analysis of the climate change in the Baltic Sea region is given by the BACC Author Team (2008). The expected climate change in Latvia for the A2 scenario can be characterized by an increase of mean annual temperature (by 4-5°C) and precipitation (by 5-10%). Further, an increase of winter precipitation along with a decrease of snow and increase of occurrence of dry/hot summer periods are expected.

Studies on the expected response of the river runoff to the climate change are less comprehensive, and usually consider the whole basin of the Baltic sea (e.g. Graham, 2004). One may expect that, in general, the river runoff from the territory of Latvia will not change significantly, as the country lies between the regions of expected distinct change: increase of river runoff from Scandinavia and northwest Russia, contrary to decrease of runoff from central Europe and southern Baltic.

We considered two different ensemble model approaches to evaluate the expected changes in the river runoff regime for the Latvian territory.

The first approach was the usage of the hydrological models built in the ensemble of regional climate models (RCMs). The comparison of the RCM calculations of the contemporary (or control period) climate (1961-1990) with the A2 climate change scenario (2071-2100) for the centrally located river Bērze basin (Figure 1) is given in Section 2.

The second approach was the usage of an ensemble of hydrological models and feeding them with the climatic (temperature, precipitation) data calculated by the RCMs. With this, the expected change of the river runoff regime might be assessed by comparison of hydrological calculation results obtained by using contemporary future climatic input. Following this approach, we (1) calibrated three different hydrological models for the considered basins (Section 3.1), (2) illustrated the regional variability of river runoff in Latvia (Section 3.2), (3) modified the temperature, precipitation and relative humidity (T-p-r) time series from RCM (Section 4.1), (4) compared the effect of substituting the observed T-p-r with the RCM results as the input data for hydrological models (Section 4.2), (5) made the hydrological ensemble forecast for the Bērze river basin (Section 4.3), and, finally, (6) considered the regional variability of the impact of climate change on the river runoff regime (Section 4.4). The area and mean annual (observed) runoff layer for the considered river basins (Figure 1) are given in Table 1.

Table 1. Characteristics of considered river basins, and calibration efficiency

River	Area, km^2	Runoff, mm/yr	R^2
Abava	1830	239	BASIN: 0.804
Bērze	904	180	BASIN: 0.775 SHE: 0.701 FIBASIN: 0.692
Dubna	2060	200	BASIN: 0.819
Salaca	3220	283	BASIN: 0.798

2. RUNOFF CHANGE PREDICTION BY RCM ENSEMBLE

We considered an ensemble of seven regional climate models, accessible via European Commission research project "PRUDENCE" EVK2-CT2001-00132 (prudence.dmi.dk, Christensen, 2007). The pairs of model runs were selected to consider contemporary climate (CTL) and climate change scenario (A2). These pairs were (PRUDENCE abbreviations) "SMHI-RCAO-HCCTL" & "SMHI-RCAO-HCA2", "SMHI-RCAO-

HCCTL_22" & "SMHI-RCAO-HCA2_22", "SMHI-RCAO-MPICTL" & "SMHI-RCAO-MPIA2", "GKSS-CLM-CTLsn" & "GKSS-CLM-SA2sn", "METNO-HIRHAM-HADCN" & "METNO-HIRHAM-HADA2", "ETH-CHRM-HC_CTL" & "ETH-CHRM-HC_A2", and "KNMI-RACMO-HC1" & "KNMI-RACMO-HA2". Each model run produces daily time series for a 30-year period. The runoff calculations from the [different] grids of RCMs were interpolated to the area of Bērze basin (Figure 1).

Generally, the RCM outputs may not be directly used for quantitative evaluation of runoff due to their disagreement with observed climate (Jacob, 2007; Sennikovs, 2009). Therefore, we used the delta change approach, comparing the differences between the contemporary and future model calculations. The considered parameters were (1) the relative change of the mean annual runoff $(Q_{A2}-Q_{CTL})/Q_{CTL}$ and (2) the relative change of the maximum monthly runoff. The first parameter characterises the overall runoff change, whilst the second shows the trend in the snowmelt flood (or seasonal rainfall) intensity. The forecast of the change of hydrological regime of pilot river basin according to these two parameters by the RCM ensemble is shown in Figure 2. It represents the existing uncertainty whether the river runoff under the climate change conditions will decrease (probably, yes), and illustrates the possibility that maximum monthly runoff (presently determined by the snowmelt flood) may be of the same order in future climate scenario (determined by maximum rainfall season).

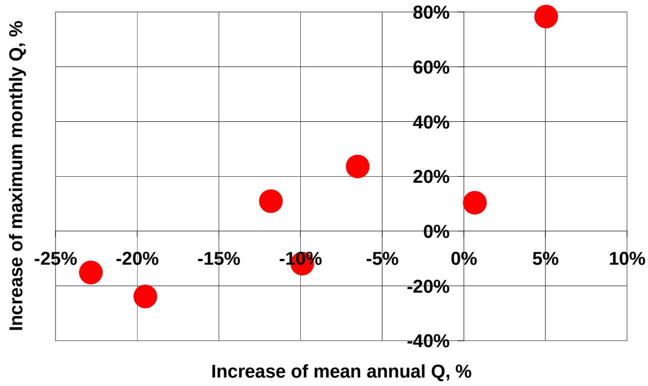

Figure 2. Change of runoff regime from Bērze basin due to the climate change. Forecast by RCM ensemble

3. HYDROLOGICAL MODELS AND RUNOFF VARIABILITY IN LATVIA

3.1. Hydrological models and their calibration

We used three different hydrological models for the runoff calculations in this study.

MIKE BASIN is a conceptual hydrological model by the DHI group (DHI, 2008). We used the conceptual NAM precipitation-runoff model for entire catchments under consideration. We used BASIN for calculations of Bērze, Abava, Dubna and Salaca river basins.

MIKE SHE is a physically-based temporally and spatially distributed catchment hydrology model by the DHI group (DHI, 2008). It was coupled with MIKE 11 model for discharge routing. We used a two-layer groundwater model, 500 m grid spacing, and sub-divided rivers in stretches of comparable length for the river Bērze basin.

FIBASIN is a physically-based temporally and spatially distributed hydrological model by our group, (Bethers, 2007). It is based on finite elements, and has built-in dynamic discharge routing module. We used variable element size (typically close to 2 sq. km.), and one groundwater layer for the river Bērze basin.

The calibration period for all three models was 1961-1990. We used daily meteorological observations (temperature, precipitation, relative humidity) by LEGMA. The daily river discharge measurements by LEGMA from (Zīverts, 2000) were used for calibration. The calibration results are summarized in Table 1.

3.2. Regional variability of river runoff in Latvia

The regional variability of the seasonal cycle of river runoff is illustrated in Figure 3. The monthly mean calculated river runoff of four river basins is shown in this illustration for the climatic reference period 1961-1990. The rivers are selected to illustrate (see also Figure 1) four hydrological regions of Latvia: Western (represented by Abava), Central (Bērze), Northern (Salaca) and Eatern (Dubna). We recalculated the runoff to monthly runoff layer from the basin territory for better comparison.

All seasonal cycles may be characterized by a spring snowmelt flood maximum in April, summer and winter low-flow periods. Western and northern regions have higher annual runoff (see Table 1); a secondary flow maximum during the autumn rains, and higher winter runoff are characteristic for these regions. The increased winter runoff may be explained by higher winter temperatures due to maritime influence.

Snowmelt flood may occur earlier in the western region, causing higher March runoff. The central region has the lowest runoff values, whilst the eastern region features the most pronounced snowmelt flood maximum.

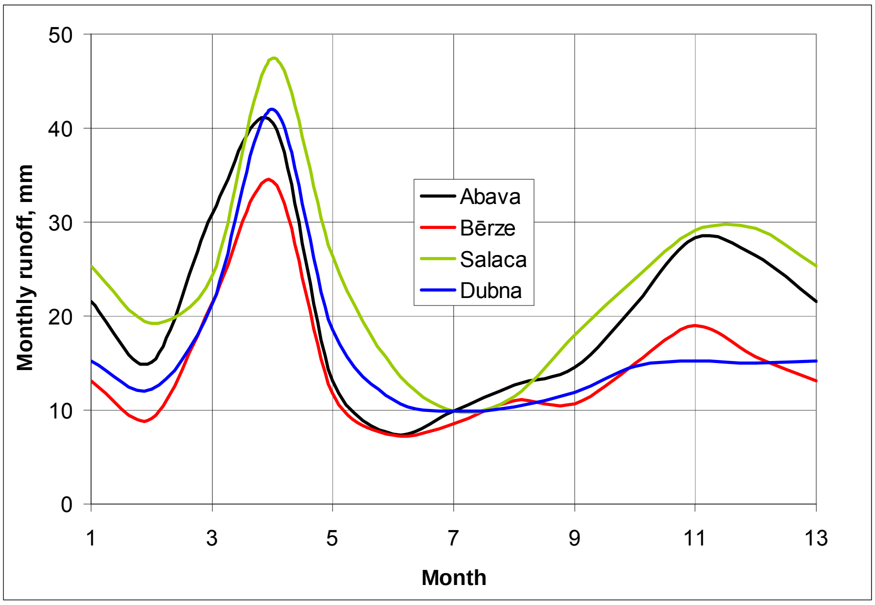

Figure 3. Regional variability of river runoff in Latvia: contemporary mean seasonal runoff cycle.

4. CALCULATION OF IMPACT OF CLIMATE CHANGE ON RIVER RUNOFF

4.1. Forcing data and scope of calculation

The 30-year long data series corresponding to the contemporary climate and climate change scenario A2 calculated by SMHI-RCAO-HC model (abbreviation from PRUDENCE data set) were modified according to the methods given by Sennikovs (2009). The input data for the hydrological calculations were daily temperature, precipitation and relative humidity.

The calculations were performed for two climatic scenarios (contemporary climate and climate scenario A2), for four river basins (Abava, Bērze, Salaca, Dubna) by three hydrological models (MIKE BASIN, MIKE SHE, FIBASIN).

4.2. RCM data usage for hydrological modelling

The effect of usage of [modified] RCM data for the hydrological modeling is illustrated in Figure 4. Monthly mean discharges for the contemporary climate period (1961-1990) are shown in this figure for the river Bērze: (a) observed discharges at Baloži hydrometric station, (b) discharges calculated by FIBASIN model from the observed meteorological input data (i.e. calibration result), and (c) discharges calculated by FIBASIN model from the RCM meteorological input data.

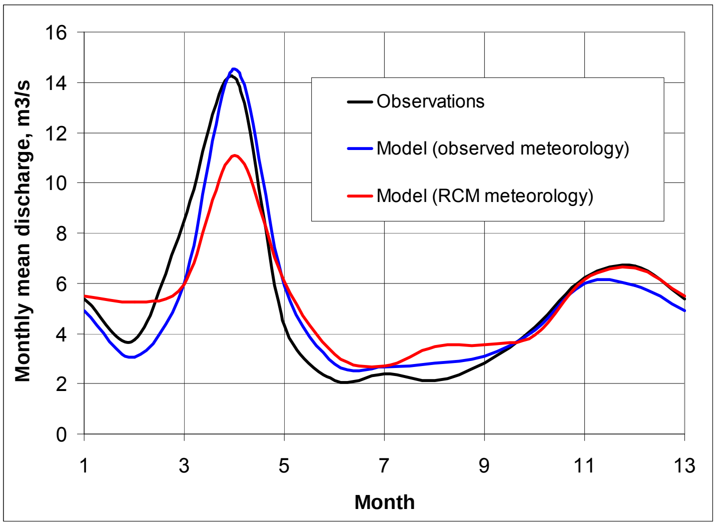

Figure 4. Effect of RCM data usage for hydrological modeling. Bērze river, FIBASIN model, monthly discharges for 1961-1990.

There is a reasonable agreement between (a) and (b), whilst application of RCM forcing results in increased winter runoff and reduced spring snowmelt flood. The same qualitative feature was detected for all models in all considered rivers. We found the reason in the positive and significant correlation between the daily values of RCM temperature and precipitation – correlation coefficient for the cold part of the year (Dec, Jan, Feb) is 0.3 – whilst there is no correlation in the observed data. Thus, although modified RCM data accurately represents the total amount of winter precipitation, it efficiently reduces the amount of accumulated snow, thus both increasing winter runoff and decreasing spring snowmelt volume. Despite this inaccuracy in representing contemporary runoff, we used only RCM forcing for the evaluation of expected change in runoff regime (Sections 4.3 and 4.4).

4.3. Application of ensemble of hydrological models

Three hydrological models were applied for calculation of 30-year long runoff time series of Bērze river for contemporary climate (CTL) and climate change scenario (A2). Modified RCM meteorological data were used as input for all cases. The seasonal runoff cycle (i.e. monthly mean discharges) of these calculations are presented in Figure 5.

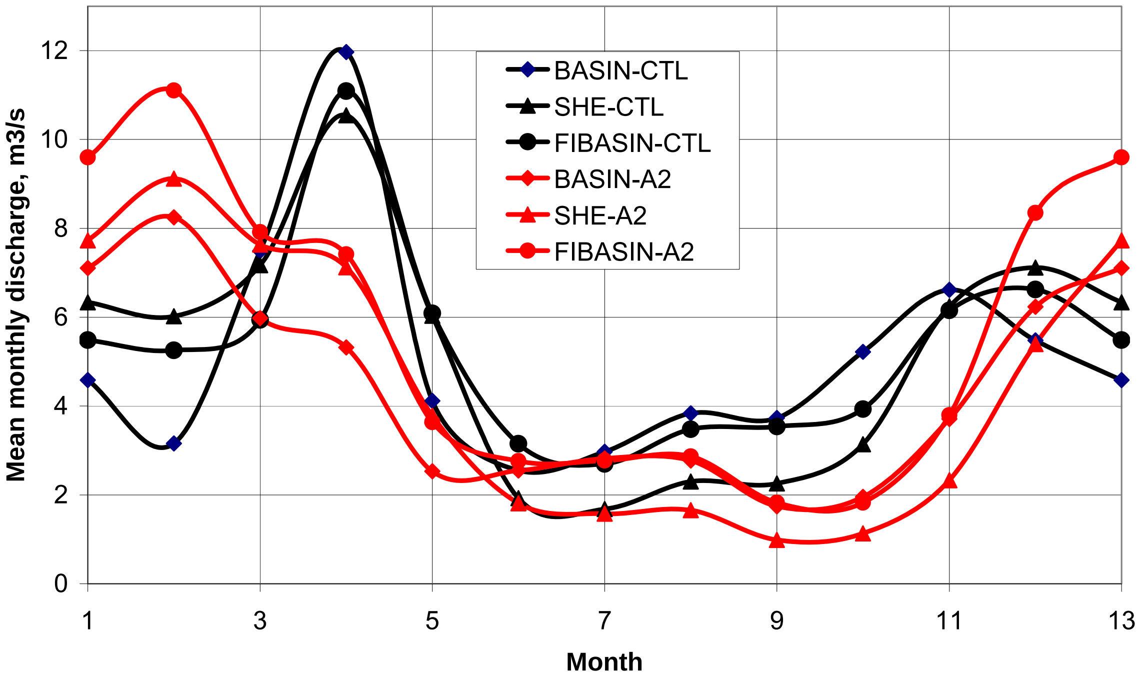

Figure 5. Runoff calculations for the river Bērze by different models. Contemporary climate (CTL) and climate change scenario A2.

Although there is both quantitative and qualitative differences between the model predictions of the effect of the climate change on the runoff regime, one may conclude that some distinct features are independent of the used hydrological model: (1) the spring snowmelt flood in April will become less distinct, (2) the winter runoff during January-February will significantly increase, and (3) the prolongation of summer will cause less runoff during August-November.

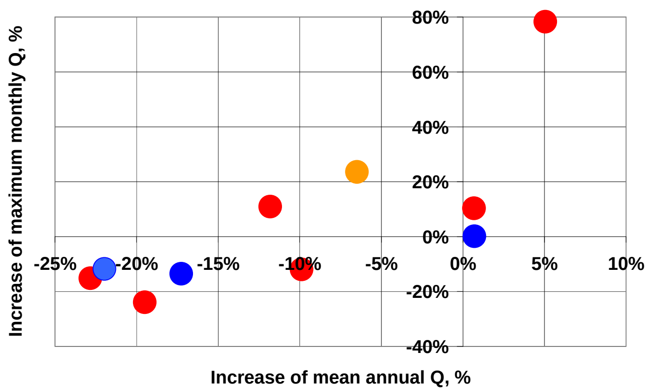

Figure 6. Impact of runoff from Bērze basin due to the climate change. Combined ensemble forecast.

The uncertainty of the relative change of the mean annual runoff and the relative change of the maximum monthly runoff of Bērze river due to the usage of different hydrological models is shown in Figure 6 (compare with Figure 2). One may consider that the initial uncertainty (discussed in Section 2) of the mean annual runoff change is almost the same both for the ensemble of RCM (red dots, RCM used in forcing hydrological model – orange dot) and ensemble of hydrological models (blue dots). Thus, uncertainty is not reduced by the performed study – the river runoff will most probably decrease, but not more than by 25%. However, the uncertainty in the maximum monthly runoff is decreased – according to hydrological modelling maximum monthly runoff will most probably decrease, but not more than by 20%. Figure 5 illustrates that the seasonal runoff maximum will shift from the snowmelt flood (April) to winter rainfalls (February).

4.4. Regional variability of runoff change

Let us consider the regional variability of the impact of the climate change on the regime of river runoff in Latvia. Hydrological model MIKE BASIN was applied for calculation of a 30-year long runoff time series of four rivers (Abava, Bērze, Salaca, Dubna) for contemporary climate (CTL) and climate change scenario (A2). Modified RCM meteorological data were used. Calculation results – seasonal cycles of rivers runoff – are illustrated in Figure 7. We recalculated the runoff to monthly runoff layer from the basin territory for better comparison.

The spring snowmelt flood during April almost disappears in the Western (Abava) and the Northern (Salaca) regions. It becomes much less distinct in the Central region (Bērze), and merges with winter runoff maximum in the more continental, Eastern region (Dubna). The yearly runoff maximum shifts from April to February (W, N, C regions) or March (C region). Monthly maximum runoff value decreases but for the Western region. The summer (June-August) runoff slightly decreases, especially in the Northern region. Significant decrease of runoff is expected in late summer and throughout the autumn (Sep-Nov).

The effect of the climate change on the regional runoff characteristics, i.e. relative mean annual runoff and

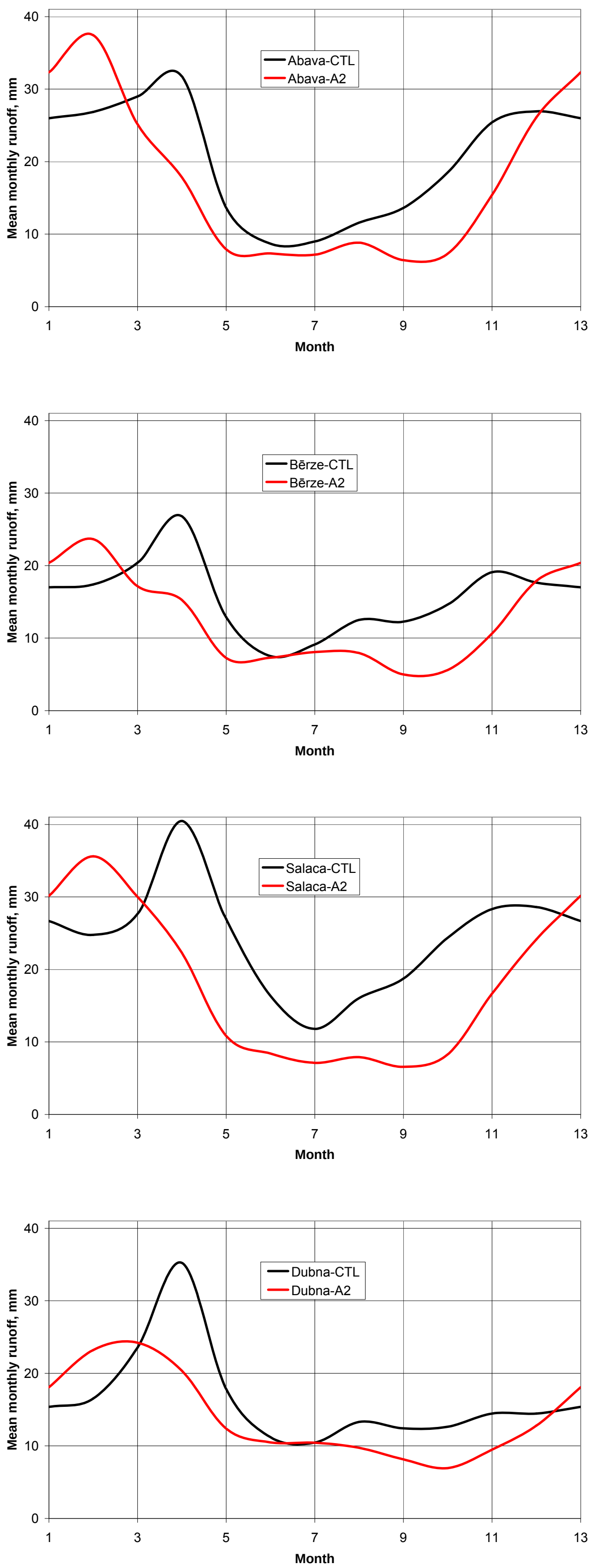

Figure 7. Regional impact of climate change on the seasonal runoff cycle. FIBASIN model, modified RCM forcing. Contemporary climate (CTL), and climate change scenario A2.

maximum monthly mean runoff, is shown in Figure 8. The integral characteristics of the four rivers typical of four hydrological regions of Latvia indicate that (1) one may expect that the regional differences in river runoff regime will decrease in Latvia as a consequence of climate change, (2) the runoff characteristics for the Western and the Northern hydrological regions as well as for the Central and the Eastern regions will become similar. As a consequence, we may predict that, under climate change conditions, two hydrologically different regions ("maritime" and "continental") will be distinguishable in Latvia instead of present four regions.

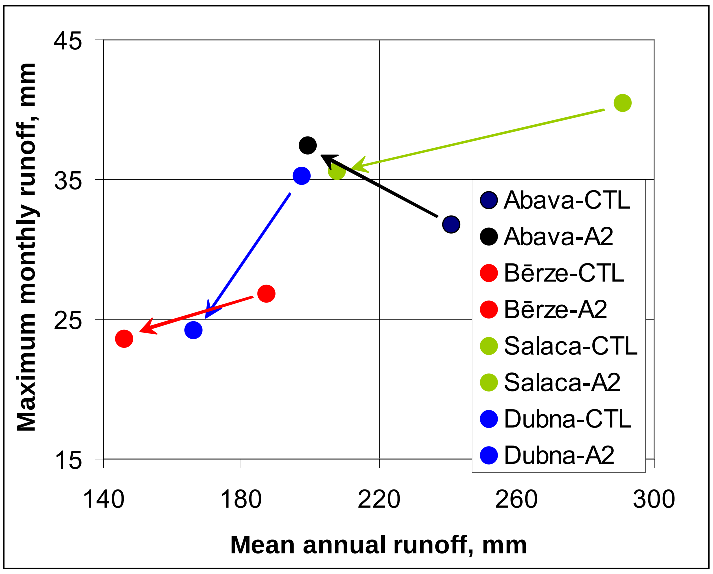

Figure 8. Effect of RCM data usage for hydrological modeling. Bērze river, MIKE Basin model, monthly discharges for 1961/90.

5. DISCUSSION AND CONCLUSION

The study indicated that the usage of the ensemble of hydrological models (calibrated for contemporary situation) introduces an uncertainty regarding the impact of climate change on river runoff, although this uncertainty is less than the one introduced by the ensemble of regional climate models. We showed that the expected features of future river runoff regime in Latvia are: (1) slight reduction of annual runoff, (2) a decrease of snowmelt flood combined with increased winter runoff, and (3) a reduction of regional differences.

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REFERENCES

The BACC Author Team (2008), Assessment of Climate Change for the Baltic Sea Basin. Springer Verlag, 474 p.

Bethers, U. and Seņņikovs, J. (2007), Mathematical Modelling of the Hydrological Processes in the Aiviekste River Basin. In: Climate Change in Latvia, Riga, 96-119.

Christensen, J.H. and Christensen, O.B. (2007), A summary of the PRUDENCE model projections of changes in European climate by the end of this century. *Climatic Change*, 81:7–30.

DHI (2008). DHI product suite 2008. Set of manuals. Danish Hydraulic Institute.

Graham, L.P. (2004), Climate Change Effects on River Flow to the Baltic Sea. *AMBIO*: *A Journal of the Human Environment* 33(4):235-241.

Jacob, D., Bärring, L., Christensen, O.B., Christensen, J.H., de Castro, M., Déqué, M., Giorgi, F., Hagemann, S., Hirschi, M., Jones, R., Kjellström, E., Lenderink, G., Rockel, B., Sánchez, E.S., Schär, C., Seneviratne, S., Somot, S., van Ulden, A. and van den Hurk, B. (2007), An intercomparison of regional climate models for Europe: model performance in present-day climate. *Climatic Change*, 81:31-52

Sennikovs, J. and Bethers, U. (2009), Statistical downscaling method of regional climate model results for hydrological modelling. 18th World IMACS / MODSIM Congress, Cairns, Australia.

Zīverts, A. and Strūbergs, J. (2000), Hydrological calculations for Latvia. University of Agriculture, Jelgava (in Latvian).