Adv. Sci. Res., 6, 69–73, 2011
www.adv-sci-res.net/6/69/2011/
doi:10.5194/asr-6-69-2011

Advances in Science & Research
Open Access Proceedings

10th EMS Annual Meeting and 8th European Conference on Applied Climatology (ECAC) 2010

The future climate characteristics of the Carpathian Basin based on a regional climate model mini-ensemble

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Received: 29 December 2010 – Accepted: 14 March 2011 – Published: 1 April 2011

Abstract. Four regional climate models (RCMs) were adapted in Hungary for the dynamical downscaling of the global climate projections over the Carpathian Basin: (i) the ALADIN-Climate model developed by Météo France on the basis of the ALADIN short-range modelling system; (ii) the PRECIS model available from the UK Met Office Hadley Centre; (iii) the RegCM model originally developed at the US National Center for Atmospheric Research, is maintained at the International Centre for Theoretical Physics in Trieste; and (iv) the REMO model developed by the Max Planck Institute for Meteorology in Hamburg. The RCMs are different in terms of dynamical model formulation, physical parameterisations; moreover, in the completed simulations they use different spatial resolutions, integration domains and lateral boundary conditions for the scenario experiments. Therefore, the results of the four RCMs can be considered as a small ensemble providing information about various kinds of uncertainties in the future projections over the target area, i.e., Hungary. After the validation of the temperature and precipitation patterns against measurements, mean changes and some extreme characteristics of these patterns (including their statistical significance) have been assessed focusing on the periods of 2021–2050 and 2071–2100 relative to the 1961–1990 model reference period. The ensemble evaluation indicates that the temperature-related changes of the different RCMs are in good agreement over the Carpathian Basin and these tendencies manifest in the general warming conditions. The precipitation changes cannot be identified so clearly: seasonally large differences can be recognised among the projections and between the two periods. An overview is given about the results of the mini-ensemble and special emphasis is put on estimating the uncertainties in the simulations for Hungary.

1 Introduction

Climate change is an essential environmental challenge, which is of great interest for the society. Climate models are the most appropriate tools available for the provision of estimates for the future evolution of the climate system, consequently, their use is indispensable for the adaptation to the (positive and negative) impacts of climate change. Evidently, climate projections possess various kinds of uncertainties, therefore, different simulations have different results over the same domain. Uncertainties, among others, can be originated from the emission scenarios, from the model formulations (different numerical schemes and physical parameterisation packages for instance) and the internal variability also existing in the absence of any external radiative forcing. In order to estimate these uncertainties the evaluation has to be realised in an ensemble way, which means considering several model projections together. This multi-model approach was applied within the international ENSEMBLES project (http://ensembles-eu.metoffice.com), where numerous regional climate simulations (RCMs) mainly with 25 km horizontal resolution were conducted and analysed together.

In Hungary four RCMs (ALADIN-Climate, PRECIS, RegCM and REMO) were adapted in the past few years for the dynamical downscaling of global climate projections over the Carpathian Basin giving the opportunity to create a Hungarian mini-ensemble. In this paper the evaluation of this small ensemble is discussed in order to identify the climate uncertainty range over Hungary. It is especially interesting in the case of precipitation change since (as it was also

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Table 1. Main characteristics of the simulations.

	ALADIN-Climate	PRECIS	RegCM	REMO
Horizontal resolution	10 km	25 km	10 km	25 km
Domain	Carpathian Basin	Central Europe	Carpathian Basin	Central and Eastern Europe
LBCs	ARPEGE-Climat/OPA	HadCM3	ECHAM5/MPI-OM → RegCM_25	ECHAM5/MPI-OM
Scenario runs	2021–2050: A1B 2071–2100: A1B	2071–2100: B2	2021–2050: A1B 2071–2100: A1B	2001–2100: A1B

identified already by the PRUDENCE project; Christensen and Christensen, 2007) Hungary is situated in an transition zone between the northern regions characterised by annual precipitation increase and the southern regions by decrease.

The following models are applied in Hungary and their results are examined in this paper: (i) ALADIN-Climate model (Spiridonov et al., 2005) developed by Météo France within an international cooperation; (ii) PRECIS model (Wilson et al., 2005) available from the UK Met Office Hadley Centre; (iii) RegCM model (Giorgi et al., 1993a, b) originally developed at the US National Center for Atmospheric Research and improved at the International Centre for Theoretical Physics in Trieste (it has to be mentioned here that a tuned and calibrated version of the model was applied in order to reduce the model biases for the Carpathian Basin; Torma et al., 2008); and (iv) REMO model (Jacob and Podzun, 1997) developed by the Max Planck Institute for Meteorology in Hamburg.

After validation of (monthly) mean temperature and precipitation, their annual and seasonal changes (including their statistical significance) have been evaluated focusing on two 30-year future periods (2021–2050 and 2071–2100) with respect to the past reference (1961–1990).

In the following sections first the details of the regional climate simulations are introduced, which is followed by the validation and projection results, and finally conclusions are drawn.

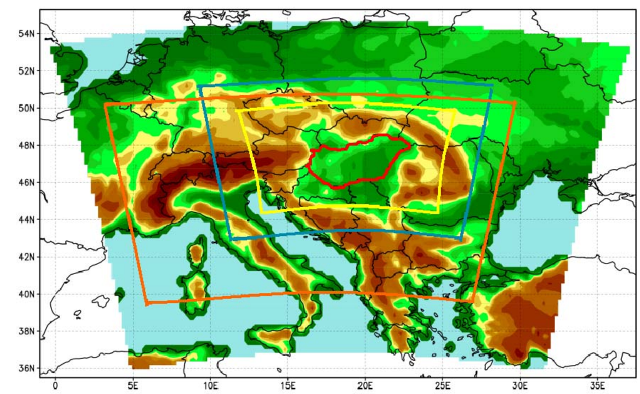

Figure 1. Model integration domains: yellow, blue and orange curves represent the domains covered by ALADIN-Climate, RegCM and PRECIS, respectively; the largest domain and its orography belongs to REMO.

Scenario simulation for REMO was a transient run for 2001–2100 while the other models were accomplished in time slices focusing on two 30-year periods (2021–2050 and 2071–2100). The anthropogenic forcings were taken into account according to A1B SRES scenario (Nakicenovic and Swart, 2000) except for PRECIS, where B2 SRES scenario was available. The main characteristics of the simulations are presented in Table 1.

2 Simulations

First, some validation experiments were performed for the past (1961–1990) using on the one hand, ERA-40 re-analysis data (Uppala et al., 2005) provided by the European Centre for Medium-Range Weather Forecasts, and on the other hand, the results of global climate models (GCMs) as lateral boundary conditions (LBCs). The simulations were accomplished on 10 and 25 km horizontal resolutions covering the Carpathian Basin (Fig. 1).

After identification of the strengths and weaknesses of the models, simulations for the future were carried out.

3 Validation

Figure 2 shows the normalised Taylor diagram (Taylor, 2001) for monthly mean temperature and precipitation values over Hungary for the period 1961–1990 using model simulations and the 10-min horizontal resolution Climate Research Unit (CRU, Mitchell et al., 2004) observational data set. (Monthly mean calculations were performed on the own grid of each simulation data set in order to avoid the interpolation of the raw model data.) It can be seen that models describe better the temporal characteristics for temperature than for precipitation, especially for REMO driven by GCM. This

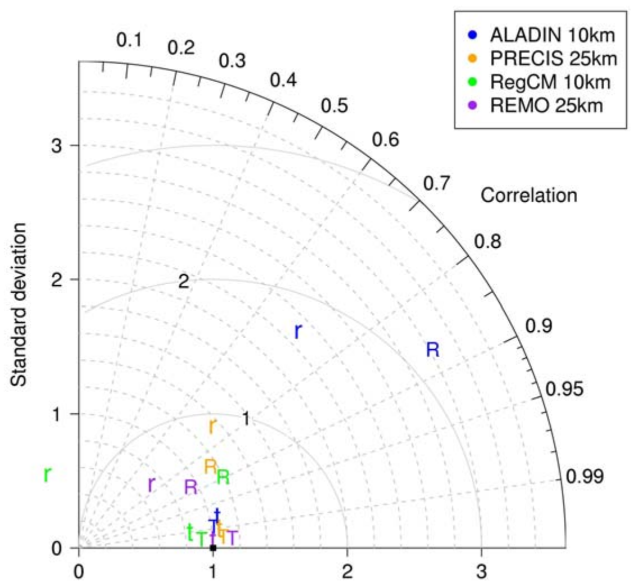

Figure 2. Taylor diagram (normalised by the reference standard deviation) for monthly mean temperature (T: ERA-40-driven case, t: GCM-driven case) and precipitation values (R: ERA-40-driven runs, r: GCM-driven runs) over Hungary for 1961–1990. CRU data are used as observational dataset (represented by black dot).

latter simulation provides the smallest bias for temperature. Otherwise ERA-40 and GCM-driven runs significantly differ in case of precipitation: one can generally conclude that ERA-40 runs have better performance in terms of correlations and that is particularly true for ALADIN-Climate and RegCM. Precipitation of GCM-driven RegCM has negative correlation with observations, which indicates that this run cannot reproduce the annual cycle. The fact, that the REMO simulation using the same GCM forcings as RegCM does not possess this deficiency, implies the question whether the same calibration used to eliminate the bias from the ERA-40 run can be applied in the GCM-driven case, when the simulation biases consist of the RCM and GCM errors simultaneously. Models usually overestimate monthly precipitation, particularly ALADIN-Climate in summer.

It can be seen from the validation process that the applied models carry different kind of errors. More details about the validation results can be found in Csima and Horányi (2008); Torma et al. (2008); Szépszó and Horányi (2008); Bartholy et al. (2009). This information is essential for the further development of these RCMs. For future projections the delta-approach is used, which computes the deviations of the model values between two periods (future and past) in order to eliminate systematic errors (which are supposed to be unchanged).

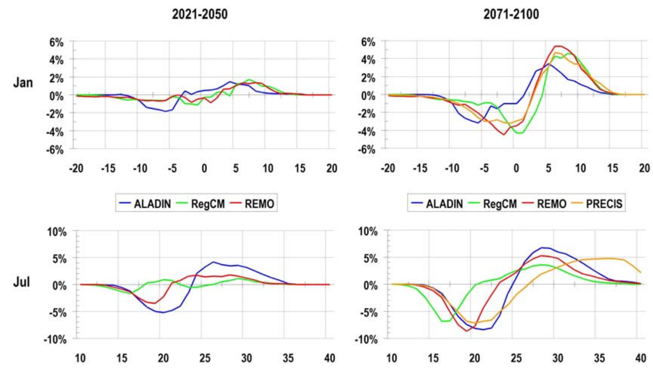

Figure 3. Changes of probability density function for daily temperature values over Hungary for 2021–2050 and 2071–2100 relative to 1961–1990.

4 Projections

Two future periods (2021–2050 and 2071–2100) are analysed. In 2021–2050 three models were accomplished, which are forced by A1B scenario, while for the further future four models are used, among them one is using B2, the others are using A1B scenario. Uncertainties coming from different (global and regional) model formulations are quantified for the first period and additionally the scenario-uncertainties, which is expected to be more robust for temperature in the larger lead time (i.e., after 2050; Hawkins and Sutton, 2009), are also addressed for the end of the 21st century.

4.1 Temperature

The annual and seasonal mean temperature values are projected to increase over Hungary during the 21st century. These statistically significant changes are larger for the far-future; annual temperature rises are 1.1–1.9 °C by 2021–2050 and 3.1–4.0 °C by 2071–2100. The largest changes, 0.7–2.6 °C and 3.5–6 °C and related uncertainties are expected to occur in summer. The 10 km resolution ALADIN-Climate simulation indicates some fine-scale spatial details: the temperature change has a northwest-southeast gradient, i.e., the warming has larger magnitude over the southeastern part of Hungary. The uncertainty is growing for the end of the century (not shown), which can arise from the use of more RCMs and different emission scenarios.

Change of probability density function for temperature (Fig. 3) indicates that the mean temperature increase is accompanied by the decreasing frequency of lower and increasing frequency of higher temperature values. This tendency is even more intensified at the end of the century, when probability density functions are shifted towards warmer temperature values.

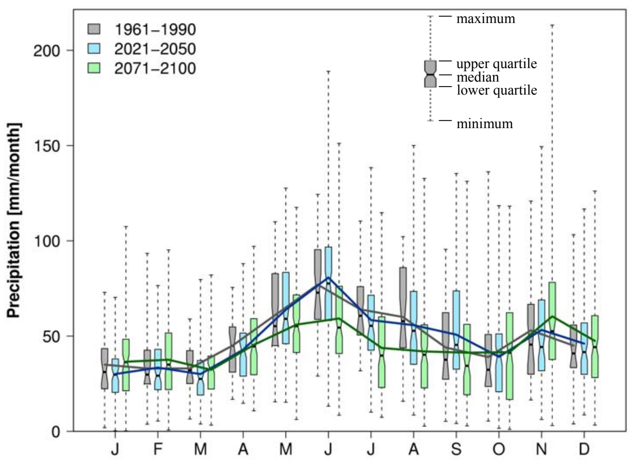

Figure 4. Box diagrams of the simulated monthly precipitation (mm/month) area-averaged over Hungary for 2021–2050 (blue) and 2071–2100 (green) and the observations (CRU, grey) for the period of 1961–1990. The future precipitation amounts are calculated by adding the simulated relative changes to the reference mean observed in 1961–1990. Curves are indicating 30-year average values, while lower and upper whiskers of the plot represent the minimum and maximum of the time-series of the given month.

4.2 Precipitation

Precipitation change is more ambiguous, i.e., in certain cases models disagree even in the direction of change, and in contrast to temperature values, the changes in precipitation are mostly non-significant. Annual, spring, and summer mean precipitation will probably slightly decrease, among them the summer decrease is clearly projected by all models. Annual changes are (−10)–0% and (−21)–(+3)% for the near- and far-future periods, respectively. In autumn and winter the precipitation amounts are likely to rather increase, however, the sign of the winter precipitation change is very uncertain in the near-future period, with higher chance for decrease. The uncertainty grows larger towards the end of the 21st century (not shown).

Figure 4 shows box diagrams of simulated area-averaged monthly precipitation compared to observations for 1961–1990 over Hungary. The future monthly values are not purely the model output values, they are calculated by adding the simulated monthly changes to the reference mean as observed in 1961–1990. Curves representing the corresponding 30-year average values indicate that the annual cycle may slightly change in the far-future. In the past, there was a primary maximum in June and a secondary one in November, while in 2071–2100 these months seem to become equally wet. Moreover, in some months (January, February, October), especially in the far-future, it can happen that almost no rain occurs. June in 2021–2050 and November in 2071–2100 can become the months with the largest inter-annual variability.

Probabilities of winter precipitation change exceeding certain thresholds can be seen in Fig. 5. In 2021–2050 it is probable that the decrease will be less than 20% (not shown), but there are some chances for both increase and decrease larger than 10%, as well. In the far-future this tendency changes: precipitation increase is more likely than decrease. It is suspected that this important change of direction is not due to the use of the fourth model with another scenario, since one of the three RCMs available also for the near-future period projected precipitation change with different sign in near- and far-future, which is the indication of the non-linear change between the two periods.

5 Conclusions

In this paper four RCMs adapted for the Carpathian Basin were studied in order to evaluate the uncertainty of their climate projections over Hungary. First, their validation was presented, then, projection results were demonstrated concerning mean temperature and precipitation changes.

Past simulations showed that model performance depends on the LBCs (ERA-40 or GCM), the considered variables (temperature or precipitation), the resolution (not shown). The validation results provide solid basis for the model developments, however, until the improved RCMs are available the delta-approach is used to eliminate systematic model errors (which are considered to be constant in time).

The Hungarian mini-ensemble projections provide one important addition with respect to previous results: while winter precipitation is decreasing in 2021–2050 it is increasing in 2071–2100 in opposition to the negative trend for the end of the 21st century discussed in earlier studies (Bartholy et al., 2008) based on the RCM results of the PRUDENCE project. Increasing mean and extreme temperature and decreasing annual and summer precipitation are the main characteristics of the results. For the annual precipitation, the mini-ensemble projects a slightly decreasing trend. However, there are some uncertainties over Hungary in the magnitude of summer warming and winter precipitation. Note that this mini-ensemble has only four members, hence, it is hard to determine the entire uncertainty range of climate change valid for the Carpathian Basin, therefore, this limitation should be considered when evaluating the results. Finally, we are planning to place our mini-ensemble into a larger uncertainty field based on the 25 km resolution model runs for Hungary provided by the ENSEMBLES project (van der Linden and Mitchell, 2009).

Acknowledgements. The authors are very grateful to Gabriella Csima and Adrienn Hunyady for their contribution to this study. This work was supported by the European Commission's 6th Framework Programme in the framework of CECILIA project (contract number 037005) and in the framework of CLAVIER project (contract number 037013). Research leading to this paper has been supported by the following additional sources: the

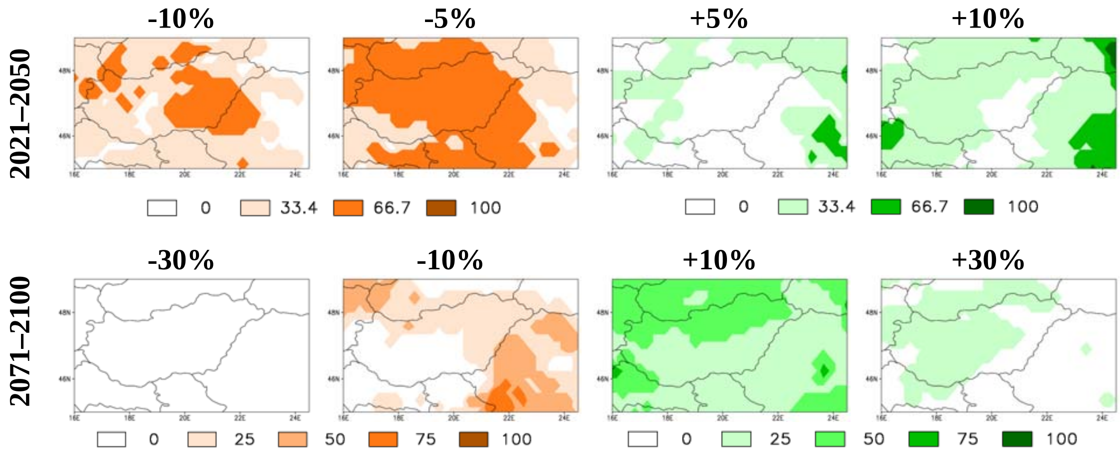

Figure 5. Probability (%) of winter precipitation change larger than 5, 10 and 30 percent for 2021–2050 and 2071–2100 relative to 1961–1990. Colors indicate in percentage how many out of three/four models are projecting a signal exceeding a selected threshold.

Hungarian National Science Research Foundation under grants K-78125, and the European Union and the European Social Fund (TÁMOP-4.2.1/B-09/1/KMR-2010-0003).

Edited by: S. Gualdi
Reviewed by: two anonymous referees

The publication of this article is sponsored by the Swiss Academy of Sciences.

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