Simulation of mean and extreme temperature and precipitation conditions over the Carpathian Basin for the 21st century using the regional climate model RegCM

Thesis of the PhD dissertation

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1. Introduction

Evidences of regular and frequent oceanic and land surface measurements beginning worldwide from the middle of the 19th century suggest that the atmosphere of the Earth is getting warmer and warmer. Recognizing this serious problem, four published assessment reports of the Intergovernmental Panel on Climate Change (IPCC), which was established in 1988, provide detailed scientific information on the effect of climate change, and thus, assist to adapt to the challenges associated with global warming. Climate models serve as basic tools of climate research, their simulations are able to reconstruct the recent climate, the variability of present climate conditions, and moreover, to provide climate scenarios for the future using different greenhouse gas emissions and concentrations. Because of the complexity of the climate system and the complex interactions between the subsystems, it is essential to establish coordinated international research network of projects, and thus, the evaluation of regional climatological effects of the projected global changes is possible. Based on model results represented in the IPCC reports, the frequency of extreme events and also their intensity are likely to increase in the near future, which urge regional research activities towards suggesting and evaluating possible adaptation and mitigation strategies. The IPCC Third Assessment Report, published in 2001, drew attention to different model projections indicating that several regions all over the world become vulnerable due to global warming. The Mediterranean region, as well, as the Central-Eastern European countries have been identified as being particularly sensitive to projected global warming. Therefore, it is an important task to provide regional climate scenarios over the region of the Carpathian Basin.

2. Aims

The main purpose of my PhD research tasks was to provide and evaluate regional climate scenario for Hungary and its surroundings on the highest horizontal spatial resolution (10 km), which can be reached by using hydrostatic regional climate model.

For this aim, RegCM (Regional Climate Model) has been chosen, which is a hydrostatic regional climate model. The PhD thesis gives a short summary of the history of the nowadays essential climate models and their evolution. Furthermore the applied climate model has been described in details, and the applicability of the model for the Carpathian Basin is demonstrated through several examples (e.g., Torma et al., 2008; 2011). The projected mean changes of temperature and precipitation conditions for the periods 2021-2050 and 2071-2100 are also analyzed using the IPCC SRES A1B scenario. In addition, the projected changes of extreme indices (i.e., number of frost days, days with extreme precipitation…) are also evaluated.

3. Methods

In order to determine the model performance, test simulations were accomplished using different settings. The model outputs were compared to observation-based data sets, i.e., CRU TS 1.2 compiled by the University of East Anglia. These results led to the conclusion that more sensitivity studies were needed in order to adapt the model for the region of interest.

In the next phase of the PhD work the results of the sensitivity studies were used to finalize the parameterization of the resolvable precipitation of the model. The model version adjusted for the integration domain resulted in smaller precipitation bias values (by around 35-40% over the territory of Hungary) than the original version of the model. Hereafter the developed, improved model version (called RegCM Beta) was validated for the reference period 1961-1990.

For validating the model, not only the CRU database was used but the ERA-40 reanalysis data set (which provided also the driving data at the same time), the E-OBS 1.0 data set of the ENSEMBLES project and time series of two Hungarian cities (Budapest, Debrecen) observed by the Hungarian Meteorological Service. Bi-linear interpolation was used to transform the CRU, ERA-40 and E-OBS databases onto the model's grid. In order to compare the simulation outputs to the reference data, the model bias was represented by the annual and seasonal area-averages of grid point values. Analyses of extremes were also carried out in the validation process of the model. The comparative analyses included the following main components: estimation of variability, monthly anomalies, probability density functions, then, computing scatter plots using daily data.

After the validation phase, the tuned version of the model was applied to our region of interest to simulate the recent and future climate conditions. Simulations were performed for the following time slices: 1961-1990 as reference period, 2021-2050 and 2071-2100 (the applied emission scenario was A1B).

Using area-averages of the results for the region of the Carpathian Basin and for Hungary, comparison analyses were carried out on annual and seasonal time scales. Annual and seasonal standard deviations of the projected changes of temperature and precipitation were computed. Empirical probability density functions were determined using daily mean temperatures for winter and summer, here only the grid points over Hungary were taken into account. Extreme indices, defined according to the recommendations of the WMO-CC1/CLIVAR working group, were computed and trend analysis was accomplished over the 21^{st} century for the territory of Hungary.

All the above analyses were carried out using Grads, Matlab and IDL program language, and MS Excel.

4. Results and discussion

1. Using 10 km grid spacing the adaptation of the model has been done successfully for the domain of the Carpathian Basin. The original version of the model showed significant overestimation of the precipitation over our region of interest. In order to decrease the simulated precipitation, the tuning of the parameterization of the resolvable precipitation was essential, and thus, the systematic precipitation bias was decreased significantly by changing simultaneously three parameters, i.e., cloud-to-rain autoconversion rate, the raindrop evaporation coefficient, and the raindrop accretion rate.

2. The mean seasonal temperature bias fields averaged over the inner part of the integration domain (which means buffer-zone-free area) altered according to the applied reference database. The mean biases in with respect to the E-OBS database are: +0.8 ^{o}C in winter, -0.5 ^{o}C in spring, -0.4 ^{o}C in summer, and -0.3 ^{o}C in autumn. In case of using CRU database as a reference the bias values are as follows: +1.0 ^{o}C in winter, -0.4 ^{o}C in spring, -0.3 ^{o}C in summer, and -0.2 ^{o}C in autumn. Comparing to the ERA-40 database higher bias values occured: +0.8 ^{o}C in winter, -0.7 ^{o}C in spring, -0.8 ^{o}C in summer, and -0.2 ^{o}C in autumn.

3. Compared to the ERA-40 reanalyzes database the model overestimated the precipitation over almost the whole integration domain. Over the inner part of the integration domain the bias values are: 47% in winter, 54% in spring, 52% in summer, and 42% in autumn. Compared to the CRU and the E-OBS databases the biases were within ±20% in all seasons over Hungary.

4. A high correlation between the simulated and the observed time series (r = 0.97) shows that the model reproduced well the observed temperature deviations from the mean annual cycle. The largest differences occurred during winter (i.e., in January of 1964, when the bias was around 2.5 °C). The decadal temperature variability was also reproduced with a maximum in the mid-1970s and late 1980s.

5. The area-average of the simulated monthly precipitations for the inner part of the integration domain showed strong relationship with the observations (r = 0.87) for the period 1961-1990.

6. The winter and summer daily temperature and precipitation model outputs were compared to time series observed at two Hungarian meteorological stations (Budapest and Debrecen) with respect of the 5th and 95th percentiles of their probability density functions (PDF). The differences did not exceed 1.5 °C, except for the 5th percentile in winter at Debrecen, where the difference was about 5 °C. The normalized daily precipitation PDFs generally showed good agreement with observations. In fact, the 5th

percentiles are in line with observations, while the 95th percentiles are somewhat underestimated at both stations, especially in summer.

7. Analyzing dry and wet spells (a sequence of at least five consecutive days with daily precipitation of less and more than 1mm, respecively) frequencies for the reference period 1961-1990 led to the conclusion that the frequency of dry spells shows a characteristical annual cycle with a maximum in autumn and a minimum in summer. On the other hand, the frequency of wet spells shows an overall maximum in spring and summer and a minimum in autumn. The model reproduced these features.

8. A1B climate simulations were accomplished on the highest horizontal grid spacing that can be reached using hydrostatic climate model for the periods 1961-1990, 2021-2050, and 2071-2100. As a result of the simulations, the future change of temperature, precipitation or any other meteorological variables can be analyzed on the finest spatial scale ever so far.

9. For the periods 2021-2050 and 2071-2100 the annual mean temperature is likely to change over Hungary by +1.1 ^{o}C and +3.1 ^{o}C, respectively. The largest changes are projected over the southern part of the domain. The projected seasonal warming for the period 2021-2050: 1.1 °C in winter, 1.6 °C in spring, 0.7 °C in summer, and 0.8 °C in autumn; whilst for the period 2071-2100: 3.0 °C; 2.8 °C; 3.5 °C, and 3.0 °C, respectively. The period 1961-1990 was used as a reference period.

10. The annual precipitation is likely to be changed slightly during the 21st century over the territory of Hungary: by -6.8% for 2021-2050, and by -2.4% for 2071-2100. The signs of the seasonal changes may differ from the near future to the further future period. The projected precipitation changes for the period 2021-2050 are as follows: -10% in winter, -10% in spring, -2% in summer, and -4% in autumn; whilst till the end of the century (2071-2100): +8% in winter, -5% in spring, -18% in summer, and +5% in autumn.

11. Analyzing the projected change of temperature and precipitation indices, considering only the grid points over Hungary, the following results can be summarized (the first value refers to the period 2021-2050, while the second value refers to the period 2071-2100):

- number of summer days: +17%, +75%;
- number of frost days: -21%, -54%;
- number of days with first order heat alert: +50%, +370%;
- number of days with precipitation higher than 1 mm: -10%, -13%;
- maximum number of consecutive dry days: +6%, +18%;
- number of days with extreme precipitation: +11%, +34%;
- single daily precipitation intensity: +4%, +12%.

5. Summary of the new results, conclusions

Tuning the parameters of the RegCM regional climate model a successfully applied regional climate model has been achieved for the Carpathian Basin. The presented results confirm the applicability of the regional climate model adapted for Hungary and for the Carpathian Basin, and the availability of producing various climate scenarios with the applied regional climate model. In our country the regional climate model RegCM is one of the main tools of the currently ongoing regional climate research studies. Three times 30-year-long regional climate simulations for the A1B emission scenario on the finest spatial resolution (10 km) so far using dynamical approach have been successfully accomplished among the very first all over the world. As a result of the analyses and experiments carried out, a comprehensive database has been created consisting daily and monthly data, on which for instance human and animal health (Solymosi et al., 2010) studies can be based in the future. The final database containing 51 different climate variable fields (including variables for the surface, for the atmosphere, and also, for the radiation) can serve as a basis for Hungarian impact assessment studies.

6. Publications related to the thesis work

Bartholy, J., R. Pongrácz, Z. Barcza, L. Haszpra, Gy. Gelybó, A. Kern, D. Hidy, Cs. Torma, A. Hunyady, P. Kardos, 2007: A klímaváltozás regionális hatásai: a jelenlegi állapot és a várható tendenciák. - Földrajzi Közlemények. CXXXI. (LV.) kötet, 4. szám, pp. 257-269.

Bartholy, J., R. Pongrácz, Cs. Torma, I. Pieczka, P. Kardos, A. Hunyady, 2008: Analysis of regional climate change modeling experiments for the Carpathian basin. - International Journal of Global Warming. - Conference Proceedings (Eds: Dincer, I., Karakoc, T.H., Hepbasli, A., Midilli, A., Colpan, C.O., Gunduz, S.), CD-ROM. Paper 561: pp. 1050-1059. www.gcgw.org, Istanbul, Turkey, ISBN: 978-605-89885-0-7

Torma, Cs., J. Bartholy, R. Pongracz, Z. Barcza, E. Coppola, F. Giorgi, 2008: Adaptation and validation of the RegCM3 climate model for the Carpathian Basin. - Időjárás, 112. (No.3-4.), pp. 233-247.

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Krüzselyi, I., J. Bartholy, A. Horányi, I. Pieczka, R. Pongrácz, P. Szabó, G. Szépszó, Cs. Torma, 2011: The future climate characteristics of the Carpathian Basin based on a regional climate model mini-ensemble, Adv. Sci. Res., 6, 69-73, doi:10.5194/asr-6-69-2011