Rožnovský, J., Litschmann, T. (ed): „Bioklimatologické aspekty hodnocení procesů v krajině“, Mikulov 9. – 11.9.2008, ISBN 978-80-86690-55-1

RCM ALADIN-CLIMATE/CZ SIMULATION OF 2020-2050 CLIMATE OVER THE CZECH REPUBLIC

Petr Štěpánek[1,] Petr Skalák[1•] and Aleš Farda[1]

[1]*Czech Hydrometeorological Institute,*
e-mail: petr.stepanek@chmi.cz

Abstract

Model ALADIN is being developed in an international consortium of several European and North African countries led by France. Primarily, it is being used as a tool for short time weather forecast but since recently it has been used for climate research purposes, too. It is a barocline, fully three-dimensional regional model of atmosphere based on integration of semi-implicit semi-Lagrangian advection scheme. As such, it has been tested and utilized for climate research purposes at CHMI (as well as at some other Institutes) and proved to be useful and sufficiently well performing yielding reliable information on climate in the Central Europe for the experiments dealing with contemporary and past time periods.

The regional climate model ALADIN-Climate/CZ is employed within the frame of the EU FP6 project CECILIA to provide high-resolution information on future climate conditions over the region of Central Europe. The regional climate model is driven by GCM ARPEGE with the IPCC A1B emission scenario. Here we present the preliminary investigation of the scenario run results with emphasis on the region of the Czech Republic. The obtained results are compared to both 1961-1990 control run outputs and the present time climatological observations from available datasets, including the set of station data transformed into grid points of the model.

Keywords: **RCM simulations, future climate, validation to station data**

1. Introduction

Regional climate models (RCMs) are the state of the art tools employed for downscaling information from the coarse resolution global circulation models (GCMs) on a local scale. With their increasing popularity for climate change studies, it is important to assess the reliability of the information provided by RCMs. Validation of RCMs outputs is based on their comparison with a reference dataset, e.g., re-analysis fields or observed data. It is made much easier when the observed data is available on the same regular grid as model. Real station observations are irregularly spatially distributed and therefore they should be interpolated into a regular grid first. There are already several existing gridded datasets of observations. Many of them have got either shorter time span or cover only a limited region, however. Those covering major parts of Europe and having the records at least for the period 1961-2000 are rather at coarse spatial resolution (~50 km) The best currently available European gridded dataset was prepared as a part of the ENSEMBLES project and it contains high resolution (~25 km) daily data for precipitation and minimum, maximum and mean temperature for the period 1950-2006 (Haylock et al., 2008).

Czech Hydrometeorological Institute (CHMI) is a member of the international consortium developing and using the LAM ALADIN for weather prediction. At the beginning of 2000s the tests showed the models' capability to be run for a longer period and adapted for a climate research purposes (Huth et al., 2004). The further work has led to a development of a regional climate model that is now designated as ALADIN-Climate/CZ. The current version of the RCM ALADIN-Climate/CZ is derived from ALADIN numerical weather prediction version CY28T3. Its description can be found in, e.g., Farda et al. (2007) or Farda (2008). We would like to stress here that ALADIN-Climate/CZ is a different model than the RCM ALADIN-Climat developed at Centre National de Recherches Météorologiques of Météo-France and employed also in other countries of the ALADIN consortium (Spiridonov et al., 2005).

2. Experiment Setups

Two simulations of present climate conditions were performed with ALADIN-Climate/CZ over the Central Europe domain in resolution of 10 km. These runs used either a perfect lateral boundary condition (LBC) represented by the ECMWF ERA-40 re-analysis (Uppala et al., 2005) or LBC coming from a driving model taken also for scenario runs (GCM ARPEGE-Climat in our case). While forcing by the GCM ARPEGE-Climat can be done directly due to the ARPEGE-Climat's high horizontal resolution (~50 km over the Central Europe), we had to apply a nesting technique to enable RCM ALADIN with 10 km grid to be driven by a coarse resolution ERA-40 re-analysis. We took the ALADIN 50 km grid integration forced by ERA-40 re-analysis (originally coming from the EC FP6 ENSEMBLES project) to drive the model at 10 km resolution over the smaller Central European domain. Comparison of both experiments' with regard to station data (validation) can be found in Skalak et al. (2008).

Within the CECILIA project, the regional climate model ALADIN-Climate/CZ is driven by GCM ARPEGE with the IPCC A1B emission scenario and the experiments are performed for two time slices, 2021-2050 and 2071-2100. Here we present validation of the model outputs and the preliminary investigation of the scenario run results for the time slice 2021-2050 with emphasis on the region of the Czech Republic. A brief summary of the used GCM ARPEGE-Climat experiment is given in the Table 1. The whole integration domain including a coupling zone and illustration of the model's orography is given in Fig. 1.

Table 1. Model setup for the experiments

Integration domain size (C, lat. × lon.)	74 × 148 points	
Horizontal resolution	10 km	
Vertical resolution	43 levels	
Time step	450 s	
Integration period	1. 1. 1960 – 31. 12. 1990	1. 1. 2021 – 31. 12. 2050
Input data	GCM ARPEGE-Climat	GCM ARPEGE-Climat

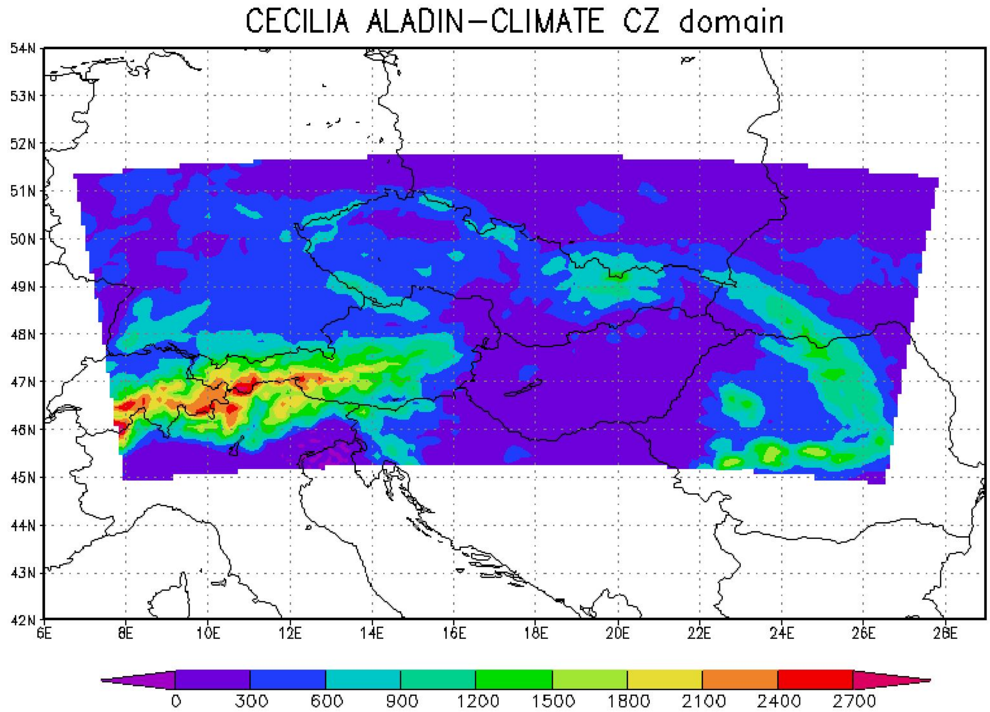

Fig. 1. Integration area and orography details of model ALADIN-Climate/CZ as used in EC FP6 CECILIA project.

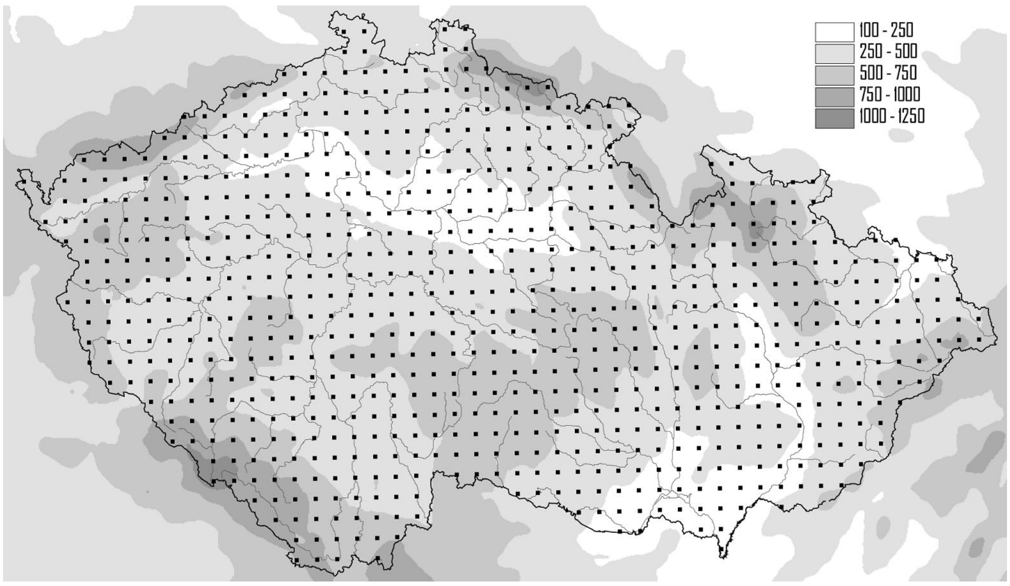

Fig. 2. Model's grid points and orography in the Czech Republic

3. Data and Methodology

It has been already mentioned that the current pan-European gridded datasets of observations are available at rather coarser resolutions, especially when considering high 10 km resolution of the ALADIN-Climate/CZ experiments described here. To validate model results against the station data as well as due to our particular interest in assessing the model's performance over territory of the Czech Republic, we have decided to create a new gridded dataset of comparable spatial resolution based on records stored in the CHMI climatological database. Before processing, input station data were quality controlled and homogenized in daily scale by means of ProClimDB software (Štěpánek, 2008). The daily data of four meteorological parameters (mean, maximum and minimum temperature) were then taken and recalculated to the model's grid (see Fig. 2). The station data were at first reduced to the altitude of a selected grid point by applying a local linear regression. Local regression parameters retrieved from observations at stations and their altitudes in vicinity of the selected grid point were used to recalculate the original station data on the altitude of the grid point. This was done repeatedly for every single grid point and a day. The reduced values were then interpolated to a position of the grid point. We selected the inverse distance weighting (IDW) as the interpolation method. The weight parameter was set as 1/d in case of temperature (or $1/d^3$ for precipitation). In addition, when interpolating, we applied a trimmed mean for temperature characteristics, thus excluding the values smaller than 20th percentile and higher than 80th percentile from the data on the input of every interpolation step. The gridding was done by the ProClimDB application (Štěpánek, 2008).

Additionally model outputs available with 6 hour time step were converted to the dBase format. During this procedure daily characteristics were computed from the 6 hour data. Once the model and station data were on the same grid, a detailed statistical analysis was performed. The ProClimDB software was employed for all the mentioned steps.

Before time slice 2021-2050 analysis, the model data were corrected according to validation results carried out for the period 1961-1990. Gridded dataset of station observations was compared with RCM simulations in each grid point and according to relationship between the two datasets, outputs of scenario run were corrected applying an approach of Déqué (2007) based on variable correction using individual percentiles. After the correction, the model outputs are fully compatible with station (measured) data.

4. Validation of the model results

Here we present some of our results obtained by a comparison of the model outputs with the created gridded dataset of station observations. We focused only on the territory of the Czech Republic. Reference period used for this study is 1961-1990.

Table 2 shows the basic statistics of biases between the model (driven by GCM ARPEGE-Climat) and station data. A column containing mean values refers to an average regional bias calculated from 789 grid points over the Czech Republic, while maximum and minimum values represent an extreme bias belonging to a particular grid point out of all available grid points. Season’s designation is as follows: DJF = winter, MAM = spring, JJA = summer and SON = autumn.

In the Table 3 we present percentiles of daily mean temperature for each of 12 months in a year. The values were calculated as an areal average from the percentile values found in the grid points within the studied area of the Czech Republic. The percentile in a single grid point was derived from the series of daily mean temperatures over the whole period 1961-1990 for each particular month. Values are computed both for ALADIN experiments (designated according to used LBC) as well as the gridded dataset of the same resolution constructed from station observations (labeled as “Stations”).

Table 2**.** Seasonal biases of air temperature fields over the Czech Republic

Season	LBC field	Air Temperature (°C)		
		minimum	mean	maximum
DJF	ARPEGE	-1.8	0.5	1.8
MAM	ARPEGE	-2.8	-1.2	0.1
JJA	ARPEGE	-0.5	0.9	2.6
SON	ARPEGE	-2.8	-1.1	0.3

Table 3. Percentiles of air temperature (°C) found in the model experiments and station data over the Czech Republic

Percentile	Dataset	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1st	ARPEGE	-12.9	-9.5	-5.9	-3.4	4.2	9.3	11.8	12.6	5.8	-4.1	-7.8	-11.2
1st	Stations	-17.4	-13.7	-9.6	-0.9	3.2	7.5	10.1	9.5	5.4	-0.2	-7.4	-13.8
5th	ARPEGE	-10.3	-6.9	-3.5	-1.0	5.8	10.9	13.1	13.9	7.2	-0.8	-5.3	-7.7
5th	Stations	-12.6	-9.5	-5.1	1.0	5.8	9.4	11.4	10.9	7.2	1.8	-4.1	-9.7
25th	ARPEGE	-5.7	-2.0	-0.2	2.4	8.7	13.7	15.2	16.1	10.2	2.8	-1.7	-3.0
25th	Stations	-5.7	-3.9	-0.3	4.1	9.4	12.5	14.1	13.7	10.2	5.2	0.1	-3.7
50th	ARPEGE	-2.6	0.6	1.9	4.8	11.2	16.1	17.0	17.8	12.8	5.8	1.1	-0.6
50th	Stations	-1.9	-0.5	2.5	6.9	12.1	15.3	16.6	16.1	12.6	7.9	2.6	-0.7
75th	ARPEGE	-0.4	2.7	4.0	7.1	14.0	18.2	18.8	19.5	15.1	8.7	4.2	1.7
75th	Stations	0.7	1.7	5.3	9.9	14.9	17.9	19.3	18.6	15.1	10.6	5.3	1.8
95th	ARPEGE	2.3	5.7	7.0	10.2	17.4	20.8	21.6	22.2	18.9	12.6	8.1	5.2
95th	Stations	4.1	5.1	9.6	14.1	18.3	21.4	22.4	22.0	18.4	14.1	9.2	6.3
99th	ARPEGE	4.2	7.9	8.8	12.2	19.0	22.7	23.6	24.1	21.9	15.5	10.5	7.5
99th	Stations	6.3	7.8	12.2	17.0	20.6	23.2	24.3	24.0	20.6	16.1	11.5	8.7

Table 4. Seasonal numbers of tropical, warm, ice, arctic and frost days found in the model experiments and compared with the station data over the Czech Republic

Season	Dataset	Number of days (TMA and TMI in °C)				
		TMA □ 30	TMA □ 25	TMA < 0	TMA ≤ -10	TMI < 0
DJF	ARPEGE	0.0	0.0	29.7	0.6	75.8
	Stations	0.0	0.0	33.2	1.2	73.3
MAM	ARPEGE	0.1	0.3	2.1	0.0	40.0
	Stations	0.1	2.5	2.8	0.0	28.8
JJA	ARPEGE	1.4	13.5	0.0	0.0	0.0
	Stations	4.2	26.5	0.0	0.0	0.1
SON	ARPEGE	0.3	1.9	4.6	0.0	28.6
	Stations	0.2	2.7	2.8	0.0	20.9
YEAR	ARPEGE	1.7	15.7	36.4	0.6	144.5
	Stations	4.4	31.7	38.9	1.2	123.0

Tables 4 present the long-term areal means in the occurrence of days with daily maximum (TMA) or minimum (TMI) air temperature over (or under) a defined threshold. The number of tropical (TMA ≥ 30°C), warm (TMA ≥ 25°C), ice (TMA < 0°C), arctic (TMA ≤ -10°C) and frost (TMI < 0°C) days is listed for all seasons as well as for the whole year.

For GCM ARPEGE-Climat used as a source of driving data, positive (negative) biases in air temperature dominate in the summer and winter (spring and autumn) seasons. When considering the results from the Tables 3 and 4 it appears that the positive (negative) biases in air-temperature are not usually associated with the significantly increased number of warm (cold) extreme events defined on the base of daily maximum temperature in the model experiments. Certain exception from above mentioned phenomenon is the reduced number of warm days in spring and arctic days in winter in the model experiments. The cold spring bias is also well expressed in the increased number of frost days. The warm (cold) biases can be identified in the shift of the mean values of the air temperature distribution (between 25^{th} and 75^{th} percentile) in the model experiments toward warmer (or colder) values while the same shift is usually found only in one end of the temperature distribution. (Table 3).

5. Comparison of current and future climate

After correction of scenario runs, the model outputs have been analyzed together with gridded dataset of station observations in the periods 1961-2000 and 2021-2050. Examples will be given for daily mean, maximum and minimum temperature.

Decadal means averaged over the whole are of the Czech Republic (789 model grid points) are given in the Table 5. From the results it follows for example that, compared to 90s of the 20^{th} century, in 40s of 21^{st} century we can expect temperatures higher by 1°C. Individual annual averages of daily mean temperature averaged over the whole Czech Republic varies from 6.3°C in 1996 to 10.2°C in 2049, annual averages of daily maximum temperature varies from 10.8°C (1980) to 15.4°C (2049) and for daily minimum temperature from 2.0°C (1963) to 5.7°C (2045). Linear trends are only positive and for the averaged series of the Czech Republic are statistically significant (confidence level 0.05) for year and all seasons. Values of linear trend for annual averages of daily mean, maximum and minimum temperature are the same (0.24°C / 10 years), while for individual seasons they slightly differ: the highest values are reached in winter (0.32 per decade for daily means, 0.34 for daily maxima and 0.33 for daily minima) and summer (0.31 for daily means, 0.30 for daily maxima and 0.28 for daily minima), the lowest values are encountered in spring (0.16 for daily means, 0.14 for daily maxima and 0.18 for daily minima) and autumn (0.16 for daily means, 0.17 for daily maxima and 0.18 for daily minima).

Fluctuations of annual averages of daily mean temperature are given in Fig. 3. While for year and individual seasons we can see positive linear trends in both current and future climate, in case of autumn the trend is not positive if we consider the periods separately. Similar pattern is found also for daily maxima, while in case of daily minima even autumn values show clear positive trend (statistically significant).

Table 5. Decadal averages averaged over the whole Czech Republic (789 model grid points) for daily mean, maximum and minimum temperature (°C), periods 1961-2000 and 2021-2050, for individual months, seasons and year.

Period	Month												Year	Season			
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	YEAR	DJF	MAM	JJA	SON
Daily mean temperature																	
1961 1970	-3.8	-1.6	1.4	7.8	11.6	15.7	16.7	15.8	13.0	8.4	3.2	-2.7	7.2	-2.7	7.0	16.1	8.2
1971 1980	-2.1	-0.3	3.0	6.2	12.0	15.1	16.4	16.3	12.2	7.0	2.4	-0.1	7.4	-0.9	7.1	16.0	7.2
1981 1990	-2.5	-1.8	2.8	7.3	12.9	15.0	17.2	16.7	13.0	8.4	2.3	-0.4	7.6	-1.6	7.7	16.3	7.9
1991 2000	-1.3	-0.5	3.0	7.9	12.9	16.0	17.8	17.7	12.9	7.8	2.5	-1.0	8.0	-1.0	8.0	17.2	7.7
2021 2030	-2.5	0.8	3.7	7.6	13.3	16.7	17.9	18.9	14.1	8.7	3.9	0.9	8.7	-0.3	8.2	17.9	8.9
2031 2040	-1.9	1.9	3.6	7.3	13.3	16.6	18.3	18.8	13.8	9.4	3.6	1.6	8.9	0.4	8.1	17.9	8.9
2041 2050	-2.3	2.2	3.6	8.0	13.4	16.9	18.2	20.1	13.7	8.7	3.6	1.3	9.0	0.3	8.3	18.4	8.7
Daily maximum temperature																	
1961 1970	-0.9	1.9	5.7	13.4	17.1	21.4	22.7	21.8	19.1	13.6	6.1	-0.1	11.9	0.3	12.1	22.0	12.9
1971 1980	0.6	3.1	7.7	11.4	17.6	20.8	22.1	22.5	17.8	11.8	5.4	2.4	12.0	2.0	12.2	21.8	11.7
1981 1990	0.5	1.9	7.3	12.8	18.5	20.5	23.2	22.9	18.6	13.4	5.5	2.2	12.3	1.6	12.9	22.2	12.5
1991 2000	1.7	3.6	7.6	13.6	18.9	21.7	23.8	24.2	18.6	12.4	5.5	1.6	12.8	2.2	13.4	23.3	12.1
2021 2030	0.3	4.7	8.3	12.2	18.8	22.4	23.5	25.4	20.3	13.6	7.6	3.6	13.4	2.9	13.1	23.8	13.8
2031 2040	0.8	5.6	8.3	12.3	18.6	22.0	24.0	25.3	20.0	14.4	6.9	4.3	13.6	3.4	13.1	23.8	13.8
2041 2050	0.5	6.6	8.4	12.9	19.0	22.5	23.9	26.3	19.4	13.1	6.5	4.0	13.6	3.5	13.4	24.3	13.0
Daily minimum temperature																	
1961 1970	-6.9	-4.9	-2.4	2.9	6.3	10.1	11.0	10.6	8.0	4.2	0.4	-5.5	2.8	-5.8	2.2	10.6	4.2
1971 1980	-4.9	-3.3	-1.1	1.6	6.3	9.6	11.0	10.8	7.5	3.2	-0.3	-2.8	3.2	-3.6	2.3	10.5	3.5
1981 1990	-5.6	-5.1	-1.0	2.2	7.2	9.7	11.4	11.2	8.4	4.4	-0.5	-3.0	3.3	-4.6	2.8	10.8	4.1
1991 2000	-4.3	-4.2	-0.8	2.7	7.0	10.2	12.1	11.8	8.2	4.2	-0.2	-3.6	3.6	-4.1	3.0	11.4	4.1
2021 2030	-5.0	-2.9	-0.1	3.1	7.8	10.9	12.4	13.1	9.5	4.8	0.9	-1.7	4.5	-3.2	3.6	12.2	5.1
2031 2040	-4.5	-1.7	-0.2	2.7	7.9	11.1	12.5	12.9	8.9	5.5	0.7	-1.0	4.6	-2.5	3.5	12.2	5.0
2041 2050	-5.1	-1.4	-0.4	3.4	7.9	11.3	12.5	14.2	9.2	5.1	0.9	-1.4	4.7	-2.7	3.6	12.7	5.1

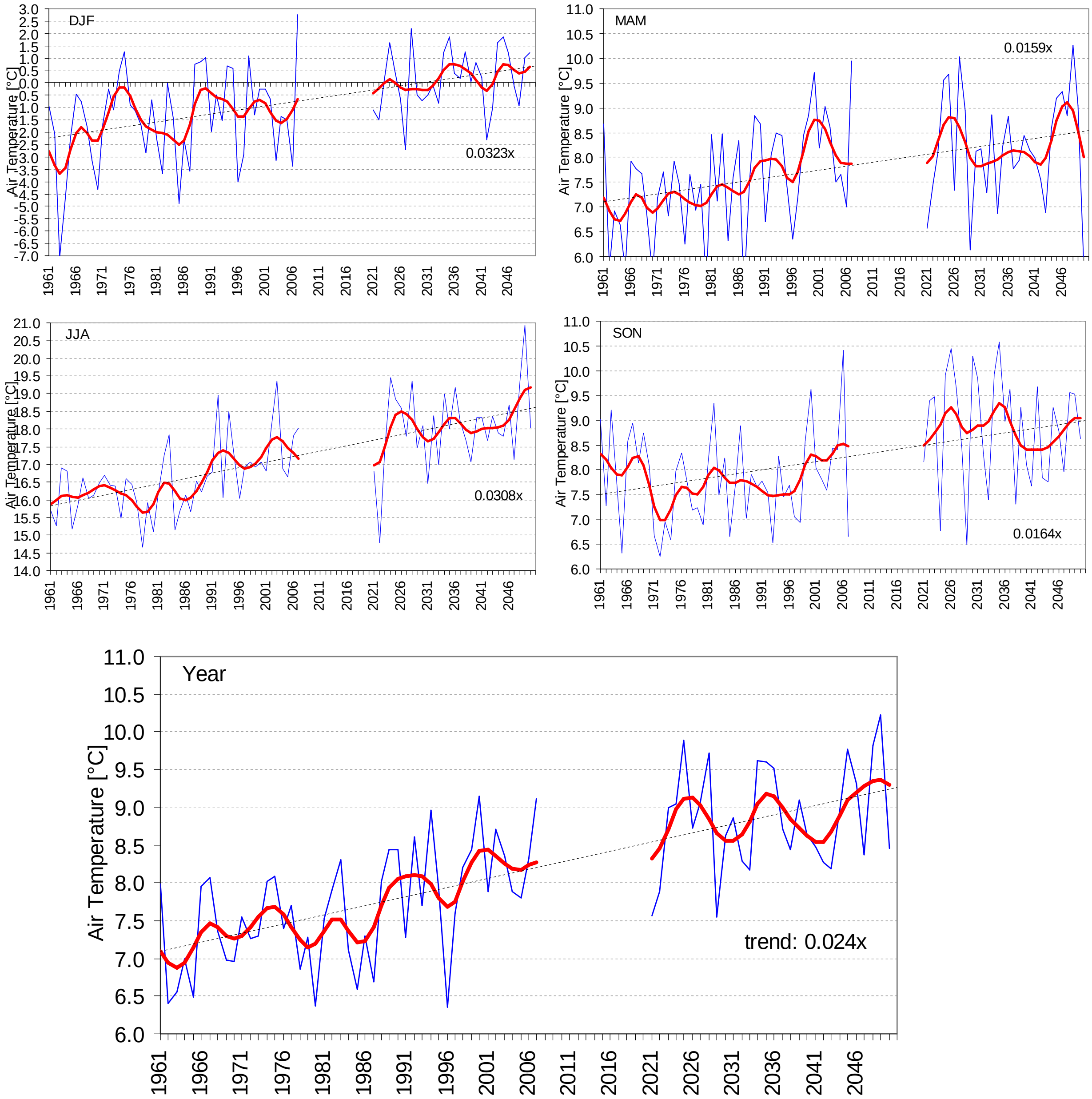

Fig. 3. Fluctuations of averaged air temperature for the Czech Republic calculated from gridded dataset of station observations and corrected scenario model runs (789 model grid points), 1961-2007 and 2021-2050, for individual seasons and year. Smoothed by Gaussian low-pass filter for 10 years.

Fig. 4 compares spatial patter of absolute maximum temperature per decades 1991-2000 and 2041-2050. Mean difference for the whole area is 2.6°C, but there are some areas with considerably higher differences, especially in Bohemia and higher altitudes. The highest temperatures reached in the late years of scenario model runs are around 44°C.

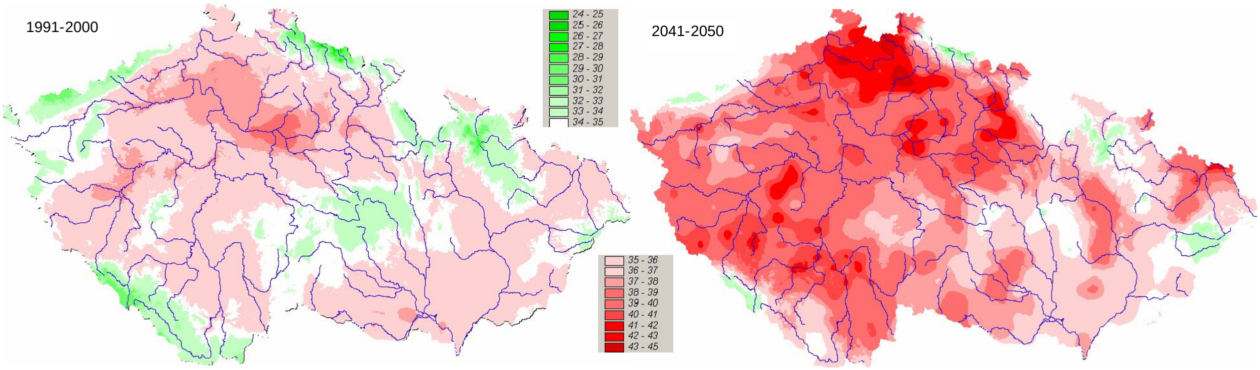

Fig. 4. Absolute maximum temperature (°C) for decade 1991-2000 (left) and 2041-2050 (right) for the area of the Czech Republic.

Further analysis will focus also on other meteorological elements (first of all precipitation) and further characteristics such as heat and cold waves, growing season length etc.

6. Discussion

We have created a new gridded dataset of station observations corresponding to the RCM ALADIN grid at 10 km horizontal resolution in the CECILIA project climate simulations. For gridding, we have made several choices on the interpolation method and its configuration. Since the models are representing area averaged rather than point processes, it is important to construct the gridded dataset from observed data in a similar way. This is what led us to use factor (1/d), where the variable d stands for a distance, for weighting the temperature data, allowing more distant stations influence the grid point value. In case of precipitation (results were not shown in this article) we have considered a possible high variability in the spatial distribution of daily precipitation over a small area. Owing to the high density of the model grid points at 10 km resolution we have taken a weight factor with a higher power of the distance ($1/d^3$) to ensure that a local pattern in the precipitation field will be fully preserved in the gridded dataset. It is a subject of further investigation whether this approach is correct or not in case of such a high-resolution dataset and whether some averaging and smoothing of the original station precipitation data should be introduced to allow the comparison with RCM data of 10 km resolution.

It is also important to stress here that when the similar pan-European datasets are created, more sophisticated methods of interpolation are used, e.g. kriging (*Haylock et al.*, 2008). Our choice to use the IDW interpolation reflects a relative simplicity of this method leading to lower requirements on computational resources and also positive previous experience with the method when constructing surfaces (maps) from a set of sample points. The influence of the interpolation method and selected approach to interpolate daily data on the quality of the final dataset needs to be further investigated, however.

Our primary interest was to study the model's performance over a small target region and to correct the model outputs with regard to station data for further comparison and analysis. Therefore we haven't chosen the common available pan-European gridded datasets for model's validation because they offer rather coarser resolution and lower density of input information (station data) from which they were created. Instead we took the advantage of the access to the observation data in its best available quality in the studied region and compared the model's results with it. Since there are 789 model grid points over the Czech Republic in the described experiments, their density is comparable with or even higher than the density of the stations, where approximately 200 stations measuring air temperature and 800 stations measuring precipitation exist in maximum at one time.

Studied area is rather small as compared to the regions on which the RCMs are often validated, e.g., PRUDENCE project regions. Due to a local variability of climate conditions mainly with the altitude in the selected area, the further improvement of results of the model's validation could be achieved by performing the analysis in the sub-regions defined according to the altitude or climate classifications.

7. Conclusions

The presented results of the first evaluation of the historic run experiments performed with the RCM ALADIN-Climate/CZ confirm the findings of previous studies made with the model under a coarse resolution, e.g., Farda et al. (2007). The model is well capable to capture the main features of the present-time climate in the region of the Central Europe and is working well even over the smaller areas with a rather complex orography represented here by the territory of the Czech Republic.

To validate our model under the high resolution of 10 km we have created the dataset of the station observations. Our next step in its development will be an extension of the dataset to cover the region of the common CECILIA target area, more detailed investigation of the gridding technique and how it affects the quality of the final dataset.

From the corrected future climate simulations (the regional climate model driven by GCM ARPEGE with the IPCC A1B emission scenario) and comparison with the period 1961-2007 it e.g. follows, that compared to 90s of the 20th century, in 40s of 21st century we can expect temperatures higher by 1°C. Increase in temperature is expected especially in winter and summer and less in spring and autumn, both in daily mean, maximum and minimum temperature. Higher increase of temperature is expected in Bohemia then in Moravia and in higher altitudes.

Acknowledgments:

The present work was supported by the European Commission under the Contract No. 037005.

References:

Déqué, M. (2007): Frequency of precipitation and temperature extremes over France in an anthropogenic scenario: model results and statistical correction according to observed values. Global and Planetary Change, 57, 16-26.

Farda, A., Štepánek, P., Halenka, T., Skalák, P. and Belda, M. (2007): Model ALADIN in climate mode forced with ERA-40 reanalysis (coarse resolution experiment). Meteorological journal, 10, 123-130.

Farda, A. (2008): Dynamical downscaling of Air Temperature in the Central Europe (PhD. thesis, in Czech with extended abstract in English). Faculty of Mathematics and Physics, Charles University in Prague (submitted).

Haylock, M., R., Hofstra, N., Klein Tank, A., M., G., Klok, E., J., Jone,s P., D. and New, M. (2008): A European daily high-resolution gridded dataset of surface temperature and precipitation. Journal of Geophysical Research (submitted).

Huth, R., Kyselý, J., Pokorná, L., Farda, A., Mládek, R., Kliegrová, S. and Metelka, L. (2004): One month-long integrations of the Aladin model in the climate mode: effect of selected parameters (in Czech). Meteorological bulletin, 57, 41-46.

Spiridonov, V., Deque, M. and Somot, S. (2005): ALADIN-CLIMATE: from the origins to present date. ALADIN Newsletter, 29.

Skalak, P., Stepanek, P. and Farda, A. (2008): Validation of ALADIN-Climate/CZ Present Climate Air Temperature and Precipitation over the Czech Republic. IDŐJÁRÁS (submitted).

Štěpánek, P. (2008): ProClimDB – software for processing climatological datasets. CHMI, http://www.climahom.eu.

Uppala S. M., Kallberg P. W., Simmons A. J., Andrae U., da Costa Bechtold V., Fiorino M., Gibson J. K., Haseler J., Hernandez A., Kelly, G. A., Li, X., Onogi K., Saarinen S., Sokka N., Allan R. P., Andersson E., Arpe K., Balmaseda M. A., Beljaars A. C. M., van de Berg L., Bidlot J., Bormann N., Caires S., Chevallier F., Dethof A., Dragosavac M., Fisher M., Fuentes M., Hagemann S., Hólm E., Hoskins B. J., Isaksen L., Janssen P. A. E. M., Jenne R., McNally A. P., Mahfouf J.-F., Morcrette J.-J., Rayner N. A., Saunders R. W., Simon P., Sterl A., Trenberth K. E., Untch A., Vasiljevic D., Viterbo P., and Woollen J., 2005: The ERA-40 re-analysis. Quart. J. R. Meteorol. Soc., 131, 2961-3012.