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Validation of ALADIN-Climate/CZ for present climate (1961–1990) over the Czech Republic

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Abstract—Two present-time climate simulations performed with a regional climate model ALADIN-Climate/CZ in the framework of the EU FP6 project CECILIA were investigated to assess the model's ability to reproduce the main patterns of 2-meter temperature and precipitation in the orographically complicated region of Central Europe. To allow a direct comparison of high-resolution model outputs with the station data over the territory of the Czech Republic, a new gridded dataset with the same 10 km resolution was created. The obtained results of the first evaluation dealing with the model's performance during the control period 1961–1990 are presented here. In term of mean values, the model driven by the ERA-40 re-analyses is in better accordance with the observed data than when it is forced by the global circulation model ARPEGE-Climat. The selected characteristics based on daily maximum and minimum temperatures and sum of precipitation are very similar in both simulations. Although the evaluation has revealed weaknesses originating either from the model itself or driving data, the overall performance of the model is reasonably good in both simulations.

Key-words: regional climate modeling, validation, temperature, precipitation, gridding, ALADIN, Czech Republic

1. Introduction

Regional climate models (RCMs) are the state-of-the-art tools employed for downscaling information from the coarse resolution global circulation models

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(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 the model. Real station observations are irregularly spatially distributed and, therefore, first they must be interpolated into a regular grid. 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 ones 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 temperatures for the period 1950–2006 (*Haylock et al.*, 2008).

The Czech Hydrometeorological Institute (CHMI) is a member of the international consortium developing and using the limited area model ALADIN for weather prediction. At the beginning of the 2000s the tests showed the model's capability to be run for a longer period and adapted for climate research purposes (*Huth et al.*, 2004). The further work has led to development of a regional climate model that is now designated as ALADIN-Climate/CZ. Unlike many other contemporary RCMs, ALADIN-Climate/CZ is a spectral model based on a semi-implicit semi-Lagrangian scheme as described in *Temperton* and *Staniforth* (1987). Physical computations are performed in the conventional grid space, however. The set of parameterizations is briefly described below. The model uses a convection scheme designed according to *Bougeault* (1985), a simple diagnostic cloudiness scheme together with large-scale precipitation parameterization (including evaporation of droplets), and the newly improved version of ACRANEB radiation scheme described in *Ritter* and *Geleyn* (1992). More detailed description of the model and its set of physical parameterizations can be found, e.g., in *Gerard* (2001) or *Farda* (2008). We would like to stress here that ALADIN-Climate/CZ is a different model than the RCM ALADIN-Climat developed at the Centre National de Recherches Météorologiques (CNRM) of Météo-France and employed also in other countries of the ALADIN consortium (*Spiridonov et al.*, 2005). Although both models share the same dynamical core and basic principles and formulations, they differ significantly in their physical parameterization packages. Physical parameterizations of the CNRM's ALADIN-Climat model are derived directly from those used in GCM ARPEGE-Climat 4 (*Déqué*, 2007), while those of the CHMI's ALADIN-Climate/CZ arises from parameterizations in the ALADIN numerical weather prediction version CY28T3 that was in operational use at CHMI in the years 2003 and 2004.

2. *Experiment setups*

Two simulations of present climate conditions were performed with ALADIN-Climate/CZ over the Central European domain in resolution of 10 km. These runs used either perfect lateral boundary conditions (LBCs) represented by the ECMWF ERA-40 re-analyses (*Uppala et al.*, 2005) or LBCs coming from a driving model planned to be taken for scenario runs (GCM ARPEGE-Climat in our case). While forcing by the GCM ARPEGE-Climat could be done directly due to the ARPEGE-Climat's high horizontal resolution (~50 km over Central Europe), a double nesting technique was applied to enable RCM ALADIN with 10 km grid to be driven by the ERA-40 re-analyses with coarse resolution. The ALADIN 50 km grid integration forced by the ERA-40 re-analyses (originally coming from the EC FP6 ENSEMBLES project) was taken to drive the model at 10 km resolution over the smaller Central European domain. The sea surface temperature fields came either directly from the ERA-40 re-analyses (ERA-40 experiment) or from the atmosphere-ocean GCM ARPEGE/OPA data (ARPEGE-Climat experiment). A brief summary of both experiments' setups is in *Table 1*. The whole integration domain and illustration of the model's orography are presented in *Fig. 1*.

Table 1. Model setup for the experiments

Experiment designation	**ERA-40**	**ARPEGE-Climat**
Integration domain size (lat. × lon.)	74 × 148 points	
Horizontal resolution	10 km	
Vertical resolution	43 levels	
Time step	450 s	
Integration period	Jan 1, 1960 – Dec 31, 2000	Jan 1, 1960 – Dec 31, 2000
Input data	ERA-40 re-analyses*	GCM ARPEGE-Climat

* by nesting through the ALADIN 50 km resolution integration

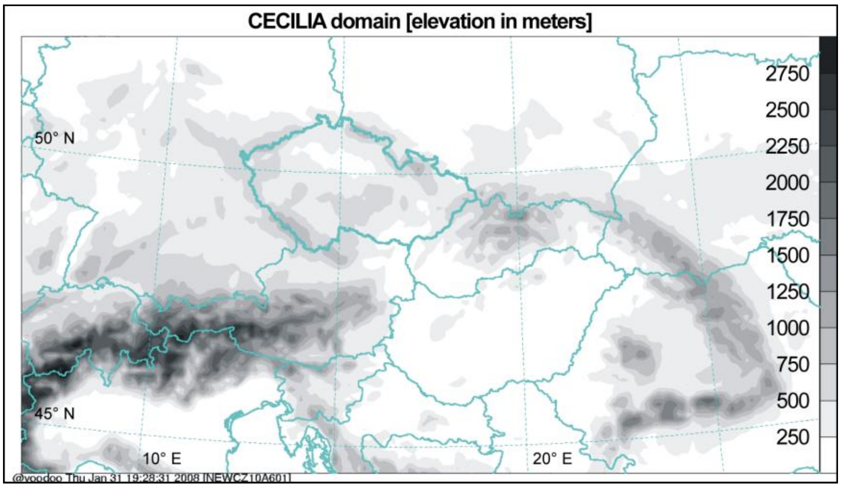

Fig. 1. Orography over the Central European model's integration domain.

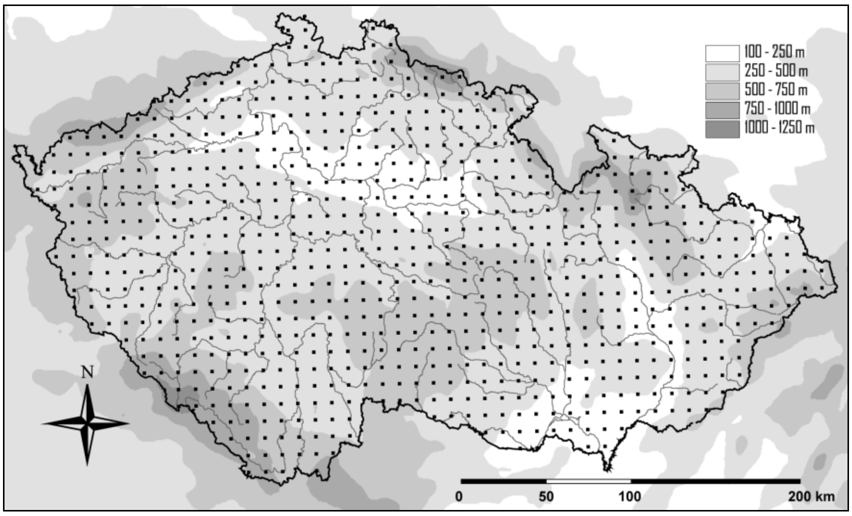

Fig. 2. Grid points and orography of the model in the Czech Republic. Elevation is in meters.

3. Data and methodology

For validation of the model results against the station data over the territory of the Czech Republic, a new gridded dataset of comparable spatial, 10 km resolution was created. It is based on the records stored in the CHMI climatological database. The daily data of four meteorological parameters (precipitation, mean, maximum, and minimum temperatures) from 302 stations measuring 2-meter temperature and 787 stations measuring precipitation were taken and recalculated to the model's grid (*Fig. 2*). The station data were at first reduced to the altitude of a selected grid point by applying a local linear regression and then the reduced values were interpolated to a position of the grid point. The inverse distance weighting was selected as the interpolation method. The weight parameter was set as $1/d$ in case of temperature and $1/d^3$ for precipitation, where the variable stands for d distance. In addition, when interpolating, a trimmed mean was applied for the temperature characteristics, thus excluding the values smaller than the 20th percentile and larger than the 80th percentile from the data of the input of every interpolation step. The gridding as well as quality control and homogenization of the input station data were done by the ProClimDB application (*Štěpánek*, 2008).

4. Results

Some of our very preliminary results obtained by a comparison of the model outputs to the newly created gridded dataset of station observations are presented here. We focused only on the territory of the Czech Republic. The reference period used for this study is 1961–1990.

Table 2 shows the basic statistics of the biases between model and station data. Long-term seasonal means of 2-meter temperature and sums of precipitation (expressed in millimeters per day) are included for both experiments. 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 one particular grid point of the total.

Table 2. Regional average and extremes of seasonal biases (model versus gridded station dataset) of 2-meter temperature and precipitation fields over the Czech Republic in the period 1961–1990. The model experiments are designated according their LBCs. (DJF = winter, MAM = spring, JJA = summer, and SON = autumn)

Season	**Dataset**	**2-meter temperature (°C)**			**Precipitation (mm/day)**		
		minimum	**mean**	**maximum**	**minimum**	**mean**	**maximum**
DJF	ERA-40	–1.8	0.1	1.4	–2.6	0.2	4.1
	ARPEGE	–1.8	0.5	1.8	–1.8	0.7	5.7
MAM	ERA-40	–2.4	–0.9	0.5	–1.3	0.3	3.8
	ARPEGE	–2.8	–1.2	0.1	–0.6	0.9	5.3
JJA	ERA-40	–1.5	0.2	1.9	–0.6	0.6	3.2
	ARPEGE	–0.5	0.9	2.6	–0.7	0.7	3.2
SON	ERA-40	–1.3	0.4	1.9	–1.9	0.0	2.8
	ARPEGE	–2.8	–1.1	0.3	–1.6	0.2	4.1

In term of mean values, the model driven by ERA-40 captures well the 2-meter temperature in winter, summer, and autumn with positive biases less than 0.5 °C. In spring it exhibits a more pronounced cold bias (–0.9 °C), however. The latter can be also detected when GCM ARPEGE-Climat is used as a source of the driving data. The ARPEGE-Climat experiment also exhibits another significant cold bias in autumn (–1.1 °C) which is not corresponding to the warm bias (+0.4 °C) in the ERA-40 experiment. The positive biases, larger than those in the ERA-40 experiment, dominate in the ARPEGE-Climat experiment in winter and summer. The range of the seasonal biases among the grid points on the territory of the Czech Republic is similar in both experiments in all seasons. The high individual seasonal biases, whose extreme values are listed in *Table 2,* are mainly due to the remaining differences between the real and model orography.

Precipitation is corresponding well to the station data in autumn, otherwise in other seasons the model is more humid in both experiments than stations. The highest seasonal bias in the ERA-40 experiment is detected in summer (+0.6 mm/day), while in the ARPEGE-Climat experiment it is in spring (+0.9 mm/day). The seasonal biases in the ERA-40 experiment are always smaller than in the ARPEGE-Climat experiment. The range of the seasonal biases among the grid points on the territory of the Czech Republic is a little larger when the model is driven by the GCM ARPEGE-Climat.

In *Table 3* percentiles of daily mean temperature for each of 12 months in the year are presented. These were calculated as an spatial average from the percentile values computed in the grid points within the studied area. 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.

Table 3. Percentiles of 2-meter temperature derived from the daily data in individual months in the period 1961–1990 and averaged over the Czech Republic in the model experiments (designated according their LBCs), compared with the gridded station dataset

Percentile	Dataset	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1st	ERA-40	-11.7	-9.2	-6.8	-0.4	3.9	8.6	11.3	10.4	7.0	1.2	-5.2	-9.1
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	ERA-40	-8.6	-7.0	-4.1	0.8	6.3	10.2	12.4	11.9	8.6	2.8	-3.2	-6.9
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	ERA-40	-4.2	-3.3	-0.4	3.5	9.5	12.9	15.1	14.4	11.4	6.1	0.0	-3.4
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	ERA-40	-2.0	-1.0	1.5	5.5	12.0	15.0	17.2	16.5	13.5	8.5	2.3	-1.3
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	ERA-40	0.0	0.8	3.4	7.8	14.3	17.2	19.2	18.7	15.7	10.8	4.8	0.9
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	ERA-40	2.9	3.2	6.3	11.4	17.5	19.8	21.8	21.5	18.5	14.0	8.4	4.2
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	ERA-40	4.7	5.1	8.1	13.6	18.9	21.1	23.6	23.1	20.3	15.8	10.8	6.8
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

The p-% percentiles of 2-meter temperature for p = 1 and p = 5 (p = 95 and p = 99) are smaller (larger) in the gridded station dataset than in the model experiments in most cases. A certain exception from above can be found in the ARPEGE-Climat experiment in April, October, and November, when the 1st and 5th percentiles are smaller than in the gridded station dataset, in April and October even significantly (more than 2 °C). Similar exception can be detected in the ARPEGE-Climat experiment in February, August, and September when the 90th and 95th percentiles are larger in the model than station observations, although the differences are rather small (on about several tenths of °C). The mean values of the 2-meter temperature distribution (between the 25th and 75th percentiles) in the ERA-40 experiment are usually closer to those in the gridded station dataset except for March, September, and December when the ARPEGE-Climat experiment is in better accordance. The ARPEGE-Climat experiment also captures the lower end of the 2-meter temperature distribution (represented here by the 1st and 5th percentiles) better in winter and September. For higher end of the 2-meter temperature distribution (represented here by the 95th and 99th percentiles), the ARPEGE-Climat shows better accordance than the ERA-40 experiment approximately in half of the cases.

Tables 4 and *5* present the long-term spatial means in the occurrence of days with daily maximum (TMA) or minimum (TMI) air temperature and sum of precipitation (PR) over (or under) a defined threshold.

Table 4. Long-term (1961–1990) average of seasonal and annual numbers of tropical (TMA ≥ 30 °C), warm (TMA ≥ 25 °C), ice (TMA < 0 °C), arctic (TMA ≤ –10 °C) and frost (TMI < 0 °C) days averaged over the Czech Republic in the model experiments (designated according their LBCs), compared with the gridded station dataset. (DJF = winter, MAM = spring, JJA = summer, and SON = autumn)

Season	**Dataset**	**Number of days (TMA and TMI in °C)**				
		TMA ≥ 30	**TMA ≥ 25**	**TMA < 0**	**TMA ≤ –10**	**TMI < 0**
DJF	ERA-40	0.0	0.0	30.6	0.2	80.9
	ARPEGE	0.0	0.0	29.7	0.6	75.8
	Stations	0.0	0.0	33.2	1.2	73.3
MAM	ERA-40	0.0	0.2	2.3	0.0	39.7
	ARPEGE	0.1	0.3	2.1	0.0	40.0
	Stations	0.1	2.5	2.8	0.0	28.8
JJA	ERA-40	1.2	12.2	0.0	0.0	0.0
	ARPEGE	1.4	13.5	0.0	0.0	0.0
	Stations	4.2	26.5	0.0	0.0	0.1
SON	ERA-40	0.1	2.3	1.6	0.0	19.9
	ARPEGE	0.3	1.9	4.6	0.0	28.6
	Stations	0.2	2.7	2.8	0.0	20.9
YEAR	ERA-40	1.4	14.7	34.5	0.2	140.4
	ARPEGE	1.7	15.7	36.4	0.6	144.5
	Stations	4.4	31.7	38.9	1.2	123.0

In winter the numbers of ice (TMA < 0 °C) and frost (TMI < 0 °C) days are well corresponding to the observed data in both experiments, but the occurrence of arctic (TMA ≤ –10 °C) days is slightly underestimated. In spring the number of frost days is overestimated in both experiments, while the warm events characterized by the number of warm (TMA ≥ 25 °C) days are underestimated. The latter is also valid for the occurrence of warm events in summer. In autumn the number of warm days is slightly lower in both experiments than in the observed data. The cold events are represented well in the ERA-40 experiment in autumn, but they are overestimated in the ARPEGE-Climat experiment, especially considering frost days. In term of annual numbers, good agreement between the experiments and observed data occurs only in the number of ice days, otherwise the model underestimates the occurrence of tropical (TMA ≥ 30°C), warm, and arctic days, and also, it gives higher than observed numbers of frost days. When the model experiments are compared to each other, significant differences are detected mainly in the autumn occurrence of ice and frost days, which are more often in the ARPEGE-Climat experiment, otherwise the performance of the model in both experiments is the same or very similar.

Table 5. Long-term (1961–1990) average of seasonal and annual numbers of rainy days (with daily amount exceeding given threshold) averaged over the Czech Republic in the model experiments (designated according their LBCs), compared with the gridded station. (DJF = winter, MAM = spring, JJA = summer, and SON = autumn)

Season	**Dataset**	**Number of days (PR in mm)**				
		PR > 0	**PR > 1**	**PR > 5**	**PR > 10**	**PR > 20**
DJF	ERA-40	55.4	25.2	8.4	3.1	0.6
	ARPEGE	56.7	29.5	11.2	4.6	1.1
	Stations	45.1	26.2	7.7	2.2	0.3
MAM	ERA-40	66.5	36.7	10.4	3.7	0.8
	ARPEGE	72.2	41.7	13.7	5.9	1.6
	Stations	43.3	27.6	10.2	3.9	0.8
JJA	ERA-40	71.2	50.6	15.7	6.4	2.1
	ARPEGE	75.2	53.7	16.5	6.7	2.2
	Stations	44.7	31.5	15.0	7.2	2.1
SON	ERA-40	49.0	23.1	8.0	3.5	1.0
	ARPEGE	54.8	26.5	9.2	3.8	0.9
	Stations	40.0	24.3	9.2	3.6	0.7
YEAR	ERA-40	242.2	135.7	42.5	16.6	4.5
	ARPEGE	258.9	151.4	50.6	21.0	5.8
	Stations	173.0	109.6	42.1	17.0	3.9

The number of days with precipitation (PR > 0) is always overestimated on 20–70% in the model experiments in all seasons. The ERA-40 experiment captures the seasonal and annual number of days with precipitation over 5, 10, and 20 well, while the ARPEGE-Climat experiment well simulates the occurrence of these precipitation events only in summer and autumn and otherwise it overestimates them. In winter and autumn seasonal number of days with precipitation over 1 mm are close to the observed data in both experiments, while in other seasons they are overestimated by the model. When the model experiments are compared to each other, in the ERA-40 experiment the number of precipitation days are less than in the ARPEGE-Climat experiment and in better accordance with the observed data in most cases.

5. Discussion

Our primary interest was to study the model's performance over a small target region. Therefore, we have not chosen the common available pan-European gridded datasets for model's validation because they offer rather coarse resolution and low 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, 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 and compared the model's results with it.

As for seasonal mean values, the model is generally in a good accordance with the observed data, although some weaknesses have been identified as well. The spring cold bias of 2-meter temperature detected in both experiments indicates that its origin is rather in the regional model itself than the driving fields. The similar pattern in its extent covering large parts of Central and Eastern Europe, has been already found in the previous, coarse resolution experiments and it has been associated with a snow accumulation over the winter season and consecutive prolonged snow melting during the spring (*Farda et al.*, 2007). On the other hand, the autumn cold bias in the ARPEGE-Climat experiment not corresponding to the positive bias in the ERA-40 experiment is perhaps a consequence of a stronger zonal flow in the driving GCM.

The warm (cold) biases can be also identified in the shift of the mean values of the 2-meter temperature distribution (between the 25th and 75th percentiles) 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*). When considering the data from *Tables 3* and *4* it appears, that the positive (negative) biases in 2-meter 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 the above mentioned phenomenon is the reduced number of warm days in spring and arctic days in winter in the model experiments. The spring cold bias is also well expressed in the increased number of frost days.

Positive precipitation biases can be linked with the tendency of the model "to precipitate" more often than in the station measurements (*Table 5*). In all seasons the increased number of rainy days could be attributed to more frequent occurrence of drizzling or little rain with daily precipitation sums ≤ 1 mm (≤ 5 mm in spring and summer).

Although some biases of precipitation and 2-meter temperature in the model experiments can be linked with other phenomena and their sources can be identified either in the regional model or the driving data, further analysis is still needed to confirm these hypotheses.

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

6. 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 with coarse resolution, see e.g., *Farda et al.* (2007). The model is capable to capture the main features of the 2-meter temperature and precipitation fields in the region of Central Europe, and it is working well even over smaller areas with a rather complex orography represented here by the territory of the Czech Republic. The overall performance is better when the model is driven by the ERA-40 re-analyses, especially in terms of mean values, however, the results obtained with the model forced by the GCM ARPEGE-Climat are very satisfactory as well. The increased differences between the model driven by GCM and the observed data are mainly due to the use of less perfect driving data than the re-analyses. Nevertheless, some weaknesses and problems in simulating 2-meter temperature and precipitation detected in this study can be attributed directly to the model. It is the spring cold bias caused by winter snow accumulation and later prolonged snow melting in spring of the model or the tendency, to generate more precipitation than in the reality. Although the mean values vary between the described experiments, the analysis of selected characteristics based on daily maximum and minimum temperatures and sums of precipitation have revealed that the model experiments provide results which may differ from the observations, but they are similar when compared to each other.

To validate the model under the high resolution of 10 km, the gridded dataset of the station observations has been created. It is planned to broaden the dataset to cover the region of the common CECILIA target area (CECILIA project: http://www.cecilia-eu.org). Before that, a more detailed investigation of the gridding technique and its affect on the quality of the final dataset is necessary to be carried out, however.

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