REGIONAL CLIMATE CHANGE SCENARIOS FOR THE CARPATHIAN BASIN

J. Bartholy, R. Pongrácz, CS. Torma and A. Hunyady

Department of Meteorology, Eötvös Loránd University, Budapest, Hungary,
bari@ludens.elte.hu, prita@nimbus.elte.hu, delivitez@nimbus.elte.hu, esox@nimbus.elte.hu

Abstract. The IPCC TAR (2001) suggests that Southern and Central European countries may become highly vulnerable to global warming. In the frame of the Hungarian national climate change program, adaptation of regional models with fine horizontal resolution (10-25 km) is in progress. Since detailed simulations and evaluation of the final results are not available yet for the Carpathian Basin, results of the European project PRUDENCE are presented and discussed here (with 50 km resolution) for 2071-2100. In the second part of the paper, preliminary results of the climate model adaptation using HadCM3/PRECIS (developed at the Hadley Climate Centre of the UK Met Office) are evaluated. Testing runs for the Central/Eastern European region are validated at the Department of Meteorology, Eötvös Loránd University.

Keywords. Regional climate model, Central Europe, model PRECIS, climate change

1. Introduction

In order to make impact assessment studies, or determine mitigation concepts and adaptation strategies, it is essential to provide detailed prediction of the regional climate change due to human activity. Only comprehensive three-dimensional global climate models (GCMs) are able to simulate the key physical processes, which represent the complex non-linear interactions of the climate system. The resolution of GCMs (which is still typically about 300 km) is considered insufficient for many purposes (Bartholy et al., 2003). Therefore, several downscaling methods have been developed to derive fine scale information from GCM simulations (Giorgi and Mearns, 1991). One of these methods is dynamical downscaling, where high-resolution (20-50 km) regional climate models (RCMs) are run in a limited domain using boundary conditions provided by GCM simulations. Projection of future climate change always includes several uncertainities that should be taken into account in climate impact studies.

The European Union funded the project PRUDENCE (Prediction of Regional scenarios and Uncertainities for Defining EuropeaN Climate change risks and Effects, http://prudence.dmi.dk) between 2001 and 2004. One of the main objectives of this project was to analyze uncertainities of regional climate change. On the base of the RCM simulations accomplished in the frame of PRUDENCE, it may be possible to reduce the economical and societal risks of global change in Europe.

In this paper, some results of the project PRUDENCE are summarized for the Central/Eastern European region. Annual and seasonal changes of temperature and precipitation are discussed for the last three decades of the 21st century. Then, preliminary results of the regional climate model PRECIS (developed at the Hadley Climate Centre of the UK Met Office, Wilson et al., 2005) are presented. The installation and adaptation of the model at the Department of Meteorology, Eötvös Loránd University (Budapest, Hungary) started in 2004. Validation phase of the testing runs for the Central/Eastern European region is demonstrated in the last section of the paper.

2. Dynamical regional climate models

Based on national and international studies in the last decade, several projections of future climate change already exist (IPCC, 2001), however, they are insufficient both in terms of characterization of the uncertainities of the projection, and in terms of regional details. The objectives of the project PRUDENCE include the following main items: (i) to quantify the confidence and the uncertainities in predictions of future climate; (ii) to coordinate the GCM and RCM model selection, the resolution, the time-frame, and the selected region; (iii) to interpret the model results in relation to European policies for adapting to or mitigating climate change. 21 participating institutes are involved in the project from 9 European countries, and several additional international collaborator institutes joined. No participant was involved from Central/Eastern Europe. The project ended in October 2004 and the final report was published in spring 2005 (Christensen, 2005), but most of the scientific results will not be in press before early 2006 (in a special issue of the journal Climatic Change).

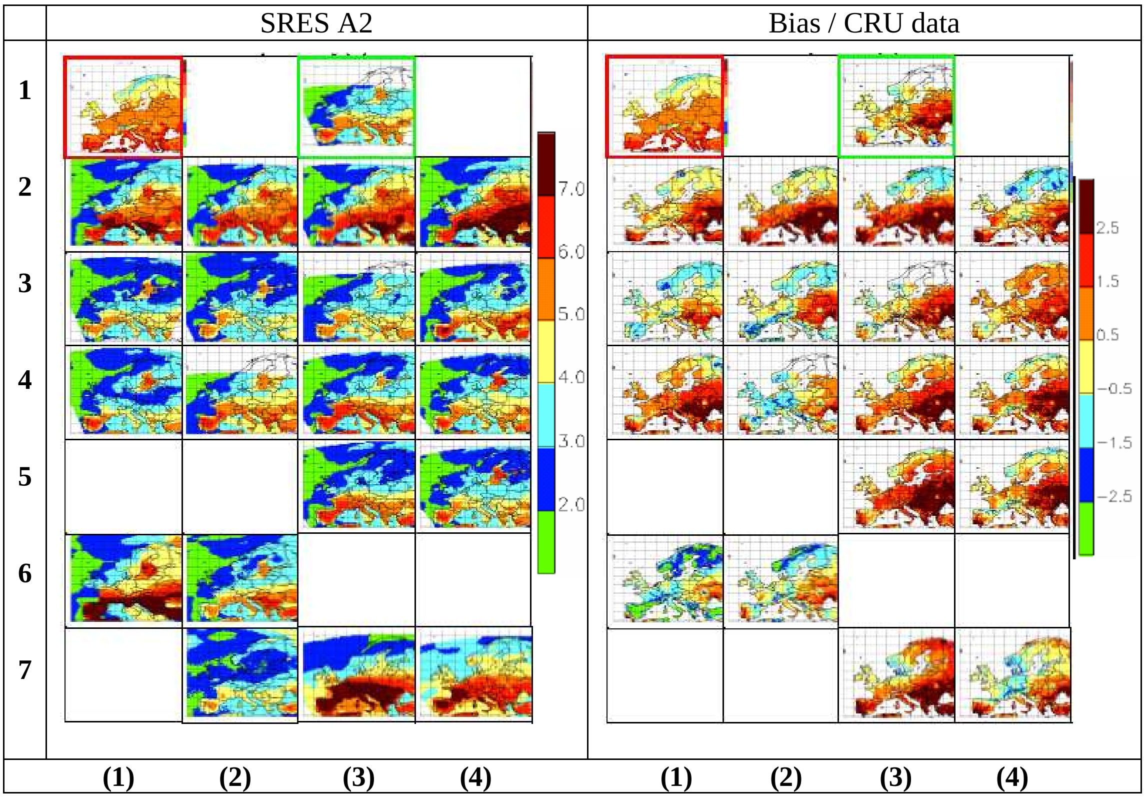

Fig. 1. Mean temperature change (°C) in summer in case of 19 models: projections for scenario SRES A2 (left), difference between the simulated and CRU data for present climate (right).
Maps are ordered as follows: Models in Row 1: (1) CRU control, (3) average of all model simulations
Models in Row 2: (1) HadAM3H, (2) HadRM3H, (3) HadRM3P, (4) HadAM3P - Britain
Models in Row 3: (1) ETH - Switzerland, (2) GKSS - Germany, (3) ICTP - Italy, (4) KNMI – Holl.
Models in Row 4: (1)MPI - Germany, (2) UCM - Britain, (3) SMHI - Sweden, (4) DMI - Danmark
Models in Row 5: (3) SMHI (22 km resolution) - Sweden, (4) DMI (25 km resolution) - Danmark
Models in Row 6: (1) HadCM3 - Britain, (2) CNRM - France
Models in Row 7: (2) CNRM/A - France, (3) SMHI/E - Sweden, (4) DMI/E - Danmark
(Source: Christensen, 2005)

In the frame of the Hungarian national climate change program, adaptations of regional models with fine horizontal resolution (10-25 km) are in progress both at the Department of Meteorology, Eötvös Loránd University, and at the Hungarian Meteorological Service. Since detailed RCM simulations for the Carpathian Basin and evaluation of the final results need more time, available results of the project PRUDENCE are presented and discussed here (on a 50 km spatial resolution). In the frame of project PRUDENCE, annual and seasonal climate change projections are provided for several meteorological parameters (e.g., temperature, precipitation, wind, etc.) in case of scenario SRES A2 for the period 2071-2100. For the validation process, PRUDENCE used the monthly database compiled by the Climatic Research Unit (CRU) of the University of East-Anglia as control data (New et al., 1999).

As an example, mean temperature changes in summer are summarized for the European region in the left panel of Fig. 1 using 19 model projections for scenario SRES A2, while the right panel of Fig.

1 shows the difference between the simulated and CRU data for present climate. Usually, resolution of the RCMs is 50 km, in some cases it is finer (22 km and 25 km), which is indicated in the figure caption. The overall warming trend by 2071-2100 is obvious on the base of the presented maps. The largest temperature increase can be expected in Central and Southern Europe, also, the bias fields indicate the largest uncertainity for the same subregion. On the other hand, zonal distribution of the bias can be detected: temperature is underestimated at the northern part of the selected domain, while it is overestimated in Central and Southern Europe.

Since the expected annual and seasonal changes in precipitation differ considerably, seasonal projections for the scenario SRES A2 are illustrated in this paper (Fig. 2). Only one RCM is selected among the 19 models, the co-called RegCM (Giorgi, 1990; Giorgi et al., 2003), which was developed originally at NCAR (U.S. National Center for Atmospheric Research, Boulder, Colorado), and further at the International Center for Theoretical Physics (ICTP, Trieste, Italy).

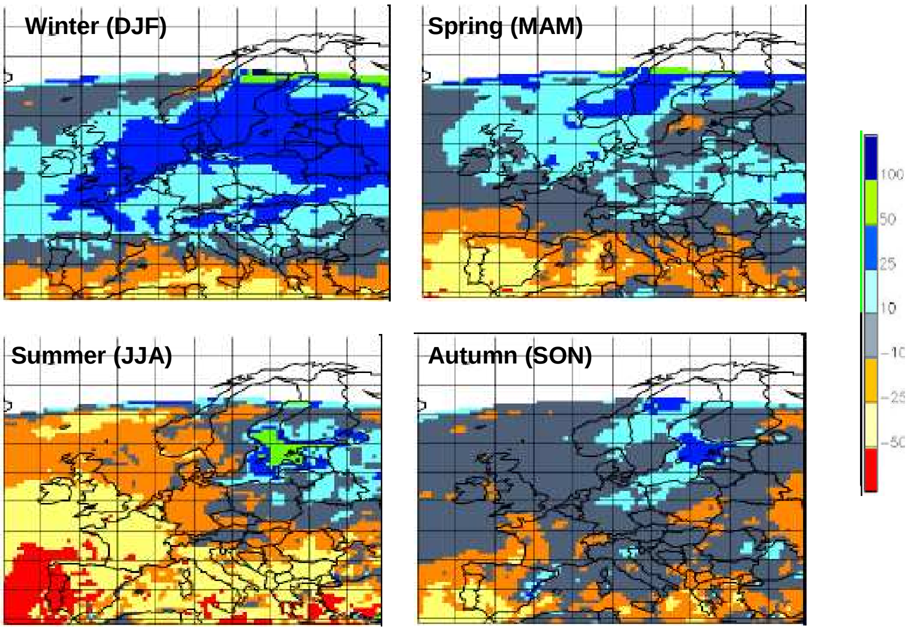

Fig. 2. Seasonal precipitation change (%) based on climate projections of model RegCM (ICTP) in case of scenario SRES A2, 2071-2100.

In general, precipitation is expected to decrease by the end of the 21st century in Southern Europe in all the four seasons, while it is likely to increase in the northern part of the domain. The smallest changes are projected in case of spring and autumn. The largest significant precipitation changes are expected in the solstice seasons (in some subregions by 25-50% in absolute value): winters and summers are likely to become wetter and drier, respectively. For the Carpathian Basin, winter precipitation is expected to increase by 25-50% by 2071-2100, while summer precipitation is expected to decrease by 10-25%. No significant changes can be expected in the region in spring and in autumn.

Fig. 3 shows the seasonal precipitation bias compared to the CRU database for the control period 1961-1990. Based on the simulations, model RegCM overestimates the precipitation in all seasons, except around the Black Sea and the Iberian Peninsula in summer, where precipitation is underestimated by the model. Similarly to the general bias, precipitation is overestimated in the Carpathian Basin in spring, autumn, and winter, while it is underestimated in summer.

Besides the maps of projected climate change for Europe, in the frame of project PRUDENCE a summary of the annual and seasonal mean temperature and precipitation changes was accomplished on a country-by-country basis using 25 models (Christensen, 2005). The entire domain was represented by a grid of 50 km horizontal resolution. For each country all available simulation data for temperature and precipitation were aggregated into one number per field representing this country for each simulation. In order to be independent from the emission scenario, a pattern scaling technique was applied and changes are expressed relative to a 1°C global warming (Christensen, 2005). This way, more than 25 estimations was provided for each country. Mean and standard deviation were used to fit a normal probability distribution function for the projected change. In Table 1 (in case of temperature) and Table 2 (in case of precipitation) results for Hungary for the period 2071-2100 are shown. In this analysis Hungary was represented by 30 gridpoints. Annual and seasonal estimates of mean, standard deviation, and median values are listed based on projections of all models, furthermore, estimates of the 5th, the 50th, and the 95th percentiles of the projected changes and their 95% confidence intervals are included in the tables.

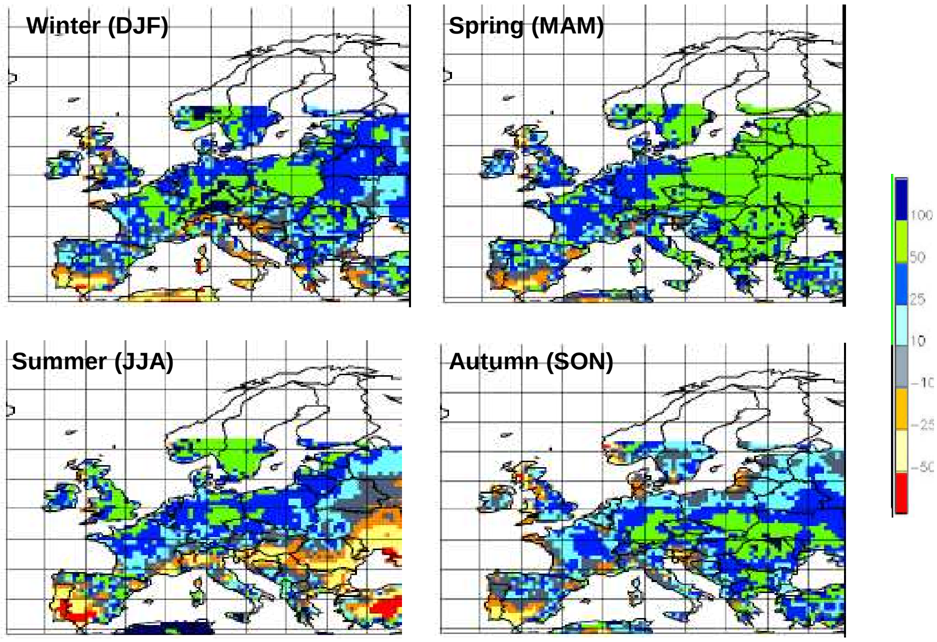

Fig. 3. Seasonal precipitation bias (%) based on model RegCM (ICTP) and CRU data, 1961-1990.

According to Table 1, obviously, temperature is expected to increase in the 21st century. Average change of the annual mean temperature is 1.4°C in Hungary. In summer and in autumn expected temperature changes are larger than this (1.7 and 1.5°C, respectively), while in winter and in spring changes are slightly smaller than the annual change (1.3 and 1.1°C, respectively). Table 2 summarizes the results for the expected precipitation changes in Hungary. Similarly to the maps of Fig. 2, precipitation is likely to increase significantly in winter, while decrease in summer (by about 10% per 1°C global warming).

Table 1. Expected temperature change for Hungary (2071-2100) based on projections of 25 models. In case of the percentile values, 95% confidence intervals are indicated in parentheses (Christensen, 2005).

Temperature (°C)	Annual	Winter (DJF)	Spring (MÁM)	Summer (JJA)	Autumn (SON)
Mean	1,4	1,3	1,1	1,7	1,5
Standard deviation	0,3	0,3	0,3	0,4	0,3
Median	1,3	1,3	1,1	1,6	1,5
95th percentile	1,9 [1,8-2,1]	1,9 [1,7-2,1]	1,6 [1,5-1,8]	2,4 [2,2-2,6]	2,0 [1,8-2,1]
50th percentile	1,4 [1,3-1,5]	1,3 [1,2-1,4]	1,1 [1,0-1,2]	1,7 [1,5-1,8]	1,5 [1,4-1,6]
5th percentile	0,9 [0,7-1,0]	0,8 [0,6-0,9]	0,6 [0,5-0,8]	1,0 [0,8-1,2]	1,0 [0,8-1,1]

Table 2. Expected precipitation change for Hungary (2071-2100) based on projections of 25 models. In case of the percentile values, 95% confidence intervals are indicated in parentheses (Christensen, 2005).

Precipitation (%)	Annual	Winter (DJF)	Spring (MÁM)	Summer (JJA)	Autumn (SON)
Mean	-0,3	9,0	0,9	-8,2	-1,9
Standard dev.	2,2	3,7	3,7	5,3	2,1
Median	0,2	9,2	0,4	-7,5	-2,4
95th percentile	3,4 [2,2-4,6]	15,0 [13,0-16,9]	7,0 [5,0-9,0]	0,5 [(-2,3)-(3,2)]	1,5 [0,4-2,7]
50th percentile	-0,3 [(-1,0)-(0,5)]	9,0 [7,7-10,3]	0,9 [(-0,4)-(2,1)]	-8,2 [(-9,9)-(-6,4)]	-1,9 [(-2,6)-(-1,2)]
5th percentile	-3,9 [(-5,1)-(-2,8)]	3,0 [1,0-5,0]	-5,2 [(-7,2)-(-3,3)]	-16,9 [(-19,5)-(-14,1)]	-5,3 [(-6,4)-(-4,2)]

3. Testing the regional model PRECIS

The installation and adaptation processes of the regional climate model PRECIS at the Department of Meteorology, Eötvös Loránd University (Budapest, Hungary) started in 2004. The model was developed at the Hadley Climate Centre of the UK Met Office (Wilson et al., 2005). The boundary conditions for the regional model are taken from the HadCM3 ocean-atmosphere coupled GCM. HadCM3 has a horizontal resolution of 2.5º×3.75º (latitude-longitude), 19 vertical levels in the atmosphere (from the surface to about 30 km height), and 20 vertical levels in the ocean. Horizontal resolution of the model PRECIS is 25 km or 50 km, which enables us to estimate regional details of climate change covering a limited area of the globe, typically 5000×5000 km2. In order to provide climate information (i.e., robust climate statistics of temperature, or distribution of daily rainfall or interseasonal variability), at least 30 years of simulation is needed. For instance, in our studies the period 2071-2100 is selected. Currently, we are in the validation phase of the model PRECIS, for which we used the ERA-40 reanalysis database (Gibson et al., 1997) compiled by the European Centre for Medium-range Weather Forecasts (ECMWF). The validation period may be shorter than three decades, in our case it is considered between 01.12.1978-31.05.1982. The selected domain covers the Central/Eastern European region, and we use 25 km resolution in the test runs. However, the horizontal resolution of ERA-40 database is only 1° (~100 km), therefore, during the validation process this coarse resolution must have been used.

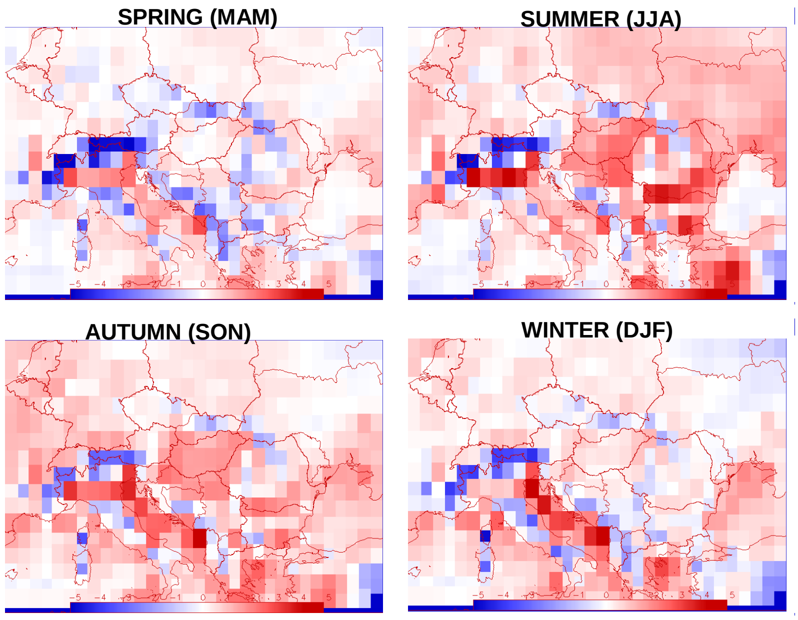

Fig. 4. Seasonal temperature bias (°C) based on simulations of model PRECIS compared to ERA40 reanalysis data, 1978-1982.

In this paper, we are illustrating the validation results of the HadCM3/PRECIS test runs for temperature on seasonal scale for the selected region. Fig. 4 shows the differences between mean simulated and reanalysis temperature fields for each season. Red and blue colors indicate overestimation and underestimation of the model PRECIS, respectively. In general, red color dominates the maps in all seasons, which suggests that the model overestimates the temperature values. Usually, large underestimation of temperature can be recognized around the high mountain subregions (especially, the Alpes). In case of Hungary, the model overestimates the temperature by about less than 0.5°C both in spring and in winter. In summer and autumn the overestimation is larger, especially in summer at the southeastern part of the country, where the bias can be as large as 1.5-2.0°C.

Histograms of Fig. 5 provide the seasonal empirical distributions of gridpoint differences between simulated and reanalysis temperature data for each season. Dark columns of the histogram indicate bias being larger than 1°C in absolute values. Considerable difference can be detected between the seasons. The smallest bias values are detected in spring and in winter, when the ratio of the small bias (within the interval [-1°C;+1°C]) is 80% and 73%, respectively. Summer and autumn temperature values are estimated with larger bias, the ratio of small differences is 57% in summer, and 63% in autumn. In these two seasons the distributions are asymmetric with considerable overestimations of temperature values.

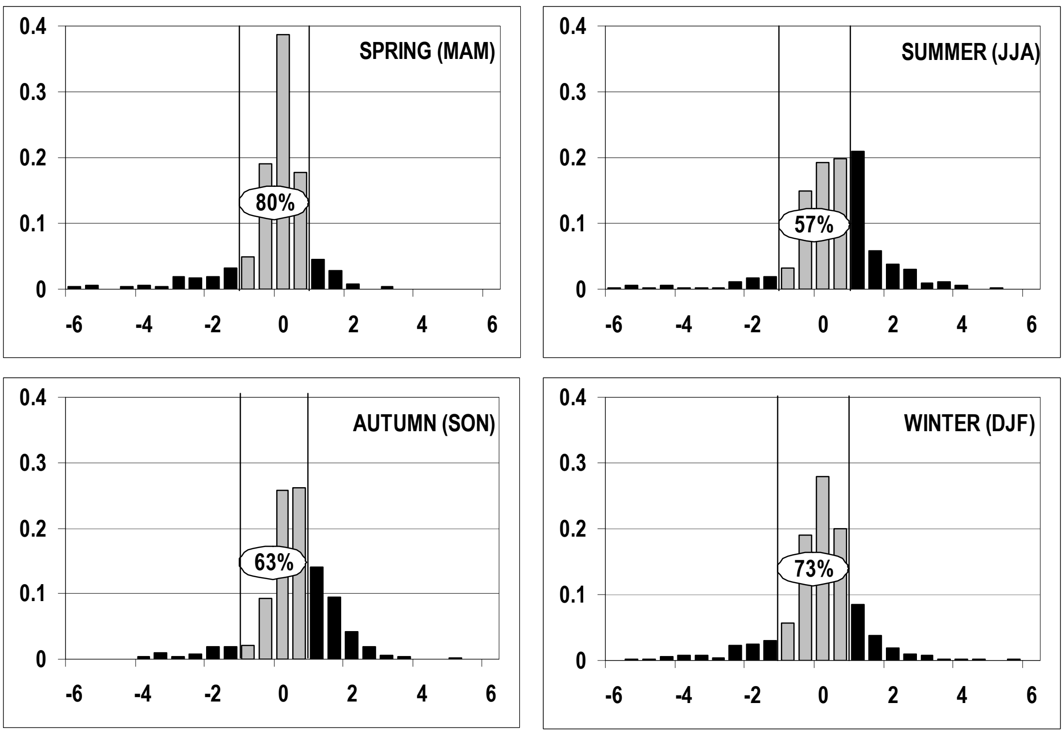

Fig. 5. Seasonal distribution of temperature bias (°C) based on simulations of model PRECIS compared to ERA40 reanalysis data, 1978-1982.

Besides the mean temperature values, also, the standard deviation fields of simulated temperature are compared to the ERA-40 reanalysis database. Figs. 6 and 7 provide the seasonal standard deviation fields of simulated temperature (left), and the difference between the simulated and the reanalysis fields (right). According to the maps, the contrast between the standard deviation values of the oceans and the lands is much smaller in winter and autumn than in summer and spring. Furthermore, the bias of temperature standard deviation fields is smaller in spring and winter than in summer and autumn (Bartholy et al., 2006). The maps suggest that the model PRECIS overestimates considerably the variance of the temperature in summer and autumn. In the Carpathian Basin, the temperature variability is estimated very well in spring and winter. The largest bias can be detected in summer at the southeastern part of the country (similarly to Fig. 4).

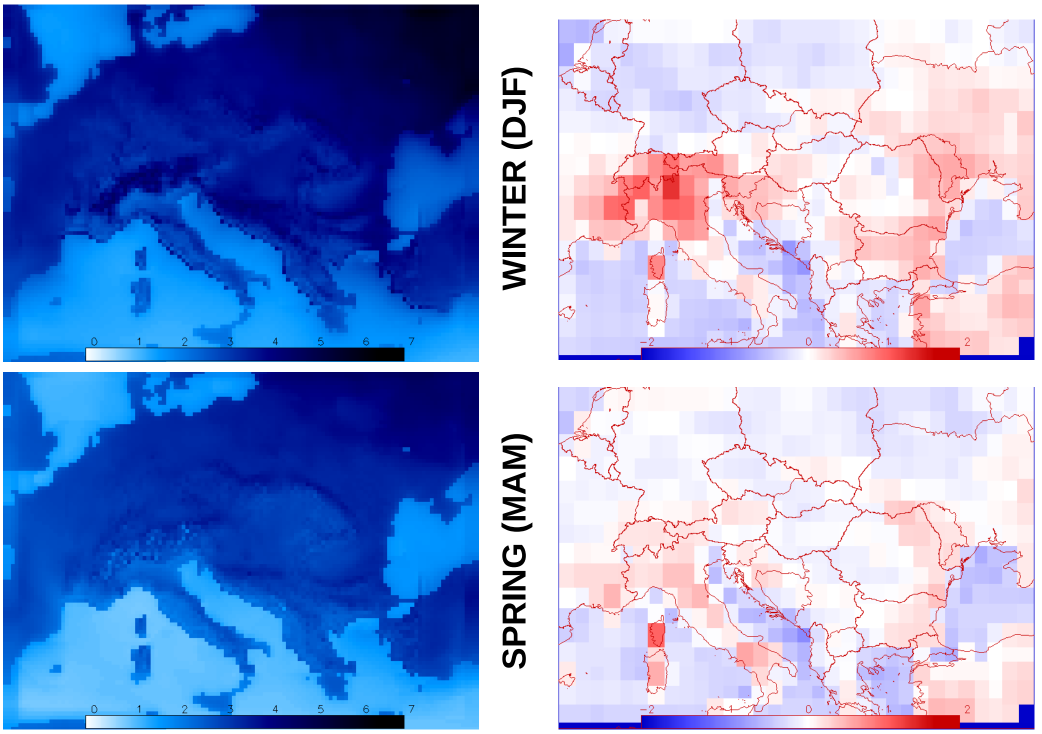

Fig. 6. Seasonal standard deviation of temperature (°C) simulations of model PRECIS, and its difference from the standard deviation of ERA40 temperature reanalysis data, winter and spring, 1978-1982.

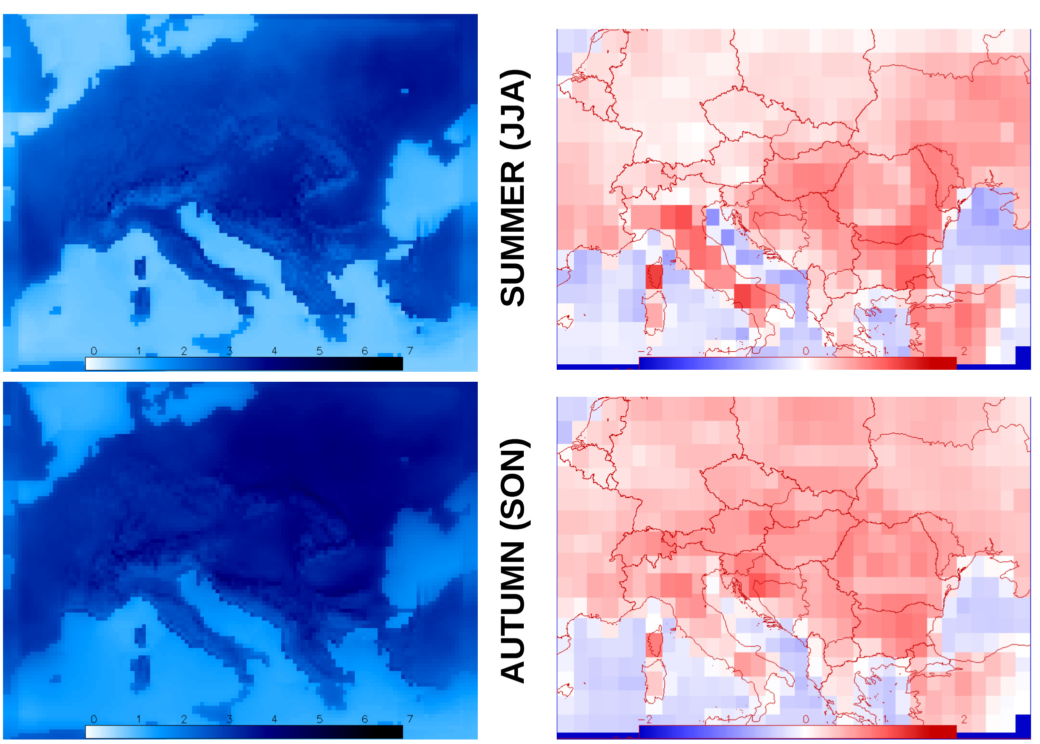

Fig. 7. Seasonal standard deviation of temperature (°C) simulations of model PRECIS, and its difference from the standard deviation of ERA40 temperature reanalysis data, summer and autumn, 1978-1982.

The seasonal standard deviation bias of gridpoints is evaluated in the form of histograms in Fig. 8. Dark columns of the histogram indicate bias being larger than 0.3°C in absolute values, while grey columns contain the ratio of gridpoints with small bias within the interval [-0.3°C;+0.3°C]. The best estimation of standard deviation of temperature in the validation period is detected in spring (73% of bias are considered small). The estimation is weaker in winter and in summer, when the ratio of small bias is 59% and 44%, respectively. In case of autumn, two maxima of the histogram can be detected, which explains the very small ratio value of small bias, only 28%.

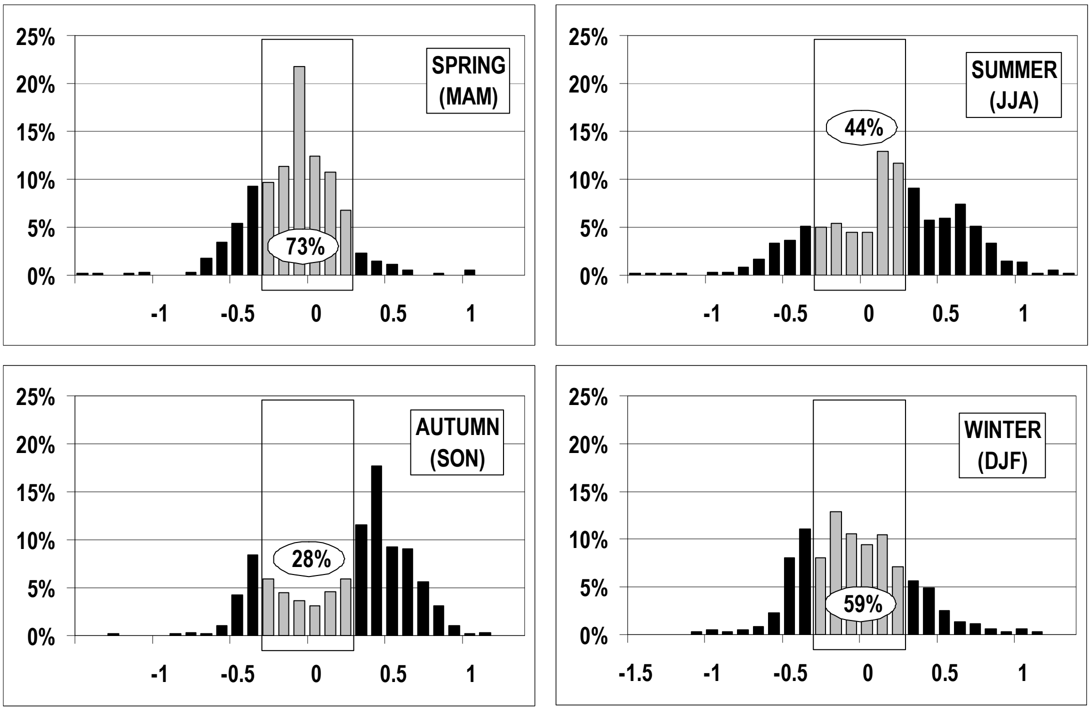

Fig. 8. Seasonal distribution of difference between standard deviations of temperature (°C) based on simulations of model PRECIS compared to ERA40 reanalysis data, 1978-1982.

4. Conclusions

In the frame of project PRUDENCE (funded by the European Union and finished at the end of 2004), regional climate change scenario for SRES A2 are provided for Europe with horizontal resolution of 50 km. On the base of the climate projections for 2071-2100, the following conclusions can be drawn. (i) Temperature is very likely to increase in the Carpathian Basin. Expected change of the annual mean temperature is 1.4°C. Larger temperature changes can be expected in summer and in autumn. (ii) The expected annual precipitation change is slightly decreasing, however, expected winter increase and summer decrease of precipitation are significant (around 10% in absolute value).

Regional climate model adaptation using HadCM3/PRECIS (developed at the Hadley Climate Centre of the UK Met Office) has started at the Department of Meteorology, Eötvös Loránd University. Based on the validation process of the testing runs (01.12.1978-31.05.1982) for the Central/Eastern European region, the following conclusions can be drawn. (i) In general, model PRECIS overestimates the temperature in the selected domain compared to the ERA-40 reanalysis database. (ii) In case of Hungary, the overestimation is less than 0.5°C both in spring and in winter. In summer and in autumn the overestimation is larger, especially in summer at the southeastern part of the country, where the bias can be as large as 1.5-2.0°C. (iii) Model PRECIS overestimates the variance of the temperature in the selected domain, especially, in summer and autumn. (iv) In the Carpathian Basin, the temperature variability is estimated very well in spring and in winter. The largest bias can be detected in summer at the southeastern part of Hungary.

After the final evaluation of the validation process and setting the boundary conditions of model PRECIS, regional climate projections can be provided for the Carpathian Basin for the last three decades of the 21st century with fine spatial resolution (25 km or 10 km).

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