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SENSITIVITY TO THE PARAMETRIZATION OF CUMULUS CONVECTION IN THE REGCM4.3 SIMULATIONS FOCUSED ON BALKAN PENINSULA AND BULGARIA

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Рилка Вълчева, Елисавета Пенева. ЧУВСТВИТЕЛНОСТ КЪМ ПАРАМЕТРИ-ЗАЦИЯТА НА КУМУЛУСОВАТА КОНВЕКЦИЯ В СИМУЛАЦИИТЕ С REGCM4.3 ЗА ТЕРИТОРИЯТА НА БАЛКАНСКИЯ ПОЛУОСТРОВ И БЪЛГАРИЯ

В настоящатата работа е използван регионален климатичен модел ICTP RegCM4.3 с пространствена резолюция 30 km, интегриран за територията на Балканския полуостров с център в България. Симулациите обхващат период от 10 години (от 2000 до 2009 г.), като за начални и гранични условия са използвани данни от метеорологични реанализи EC-MWF ERA-Interim (1,5°×1,5°). Проведени са няколко експеримента с различни схеми, параметризиращи конвекивните валежи. Резултатите са сравнени с анализи на данни от измервания за същия период, с цел да се установи най-подходящата параметризационна схема за конкретния район. Оценките на отклонението BIAS и грешката RMSE между моделните симулации и измерванията показват, че най-подходяща е схемата Grell, Arakawa-Schubert closure. Анализът е представен както за годишните температури и валежи, така и по сезони. Резултатите показват, че моделът симулира по-добре температурата през пролетния сезон, докато през лятото грешките са с по-голяма стойност. За валежите симулациите са по-добри през лятото и есента. В заключение, моделът адекватно представя междугодишните изменения на температурата и валежа и сезонните вариации на температурата, но в по-малка степен сезонните вариации при валежа.

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Rilka Valcheva, Elisaveta Peneva. SENSITIVITY TO THE PARAMETRIZATION OF CUMULUS CONVECTION IN THE REGCM4.3 SIMULATIONS FOCUSED ON BALKAN PENINSULA AND BULGARIA

In this study, ICTP RegCM4.3 regional climate model with spatial resolution 30 km was integrated over Balkan Peninsula domain with a center in Bulgaria. The model simulations cover the period of 10 years (2000 to 2009) using the ECMWF Reanalysis data ERA-Interim (1,5° × 1,5°) as initial and boundary conditions. Several experiments were performed changing various cumulus convection schemes. The results are compared against analysis of measured data for the same period in order to reveal which parameterization scheme is the most suitable to use for this particular area. The estimates of BIAS and RMSE between model simulations and measurements indicate that the Grell scheme with Arakawa-Schubert closure as an appropriate parameterization to use. The analysis is performed for the annual temperature and precipitation, as well as for the averaged temperature and precipitation over four seasons separately. The model simulations are better in winter and spring for the temperature, however in summer the error is larger. The precipitation is simulated better for summer and autumn. The results show that inter-annual variations of both temperature and precipitation is captured adequately from the model, same is valid for the seasonal temperature variations, but not in regard to the seasonal variations of rainfall.

Keywords: regional climate modeling, cumulus convection scheme, Balkan peninsula
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INTRODUCTION

In the last few decades the problems of the climate change and its impact to the human activities is widely discussed and became a basis for global political decisions and economic strategies. Various speculations about the climate projection in future appeared in the scientific journals and in the popular media. Most of the conclusions about the climate change dimensions are derived from the numerical experiments with climate models regarding the impact of greenhouse gases in future. The main problem of these numerical simulations is to estimate their credibility, e.g. to which extend the climate models are capable to represent the climate at present and in future. In attempt to answer this question, lots of studies on the validation and calibration of the numerical models were recently initiated and published. Furthermore, the numerical models depend on a set of initial variables and parameters, as they use a series of simplification and parameterization of natural processes. Sensitivity numerical experiments of the impact of these input parameters on model behaviour are an essential part of the model calibration.

For this purpose in the last 20 years lots of efforts were spent to validate the regional climate models. Several international projects were launched in sequence with the ultimate goal to evaluate the performance of the most used presently "nested" climate models and to develop climate scenarios for future. This activity was initiated in Europe region in 1990s with the project Regionalization of

Anthropogenic Climate Change Simulations [1]. It showed that systematic errors in the general circulation have great impact on the temperature and precipitation fields. During next decade the projects PRUDENCE and ENSEMBLE were launched with the purpose to design an ensemble system of different climate models and thus to improve the model skill and determine the uncertainties [2]. This work continues currently in the project Coordinated Regional Downscaling Experiment CORDEX, where the globe is divided into several focus regions. Another international projects "Central and Eastern Europe Climate Change Impact and Vulnerability Assessment" (CECILIA), was launched in 2006, aiming at valuation of climate models with a focus on Central and Eastern Europe. In general, these extensive international activities showed that the usability of different models and parameterization schemes depend on the local area, model resolution and time-scales of interest.

Among the parameterizations of subgrid physical processes the climate model results are most sensitive to the choice of the convective precipitation scheme. This paper aims to evaluate numerical climate simulations in regard to the most appropriate convective precipitation scheme. The domain of interest is over Balkan Peninsula and the model used is RegCM4.3.

The regional climate modeling system, RegCM, is one of the most used RCMs worldwide, with applications ranging from regional process studies to paleoclimate, climate change, chemistry-climate and biosphere-atmosphere interactions. RegCM is the first model for limited areas designed for long-term simulations of the climate, created in the late 80s at the National Center for Atmospheric Research (NCAR) USA. Currently it is maintained by the International Centre for Theoretical Physics (ICTP) in Trieste, Italy.

A recently published work of Giorgi [3] presents the validation of RegCM4 over Europe. Here, we present a series of numerical experiments, which are performed in order to select the appropriate parameterization scheme of cumulus convective precipitation, taking into account the timescale of the processes which are to be studied.

2. MODEL CONFIGURATION

The latest version of the International Center for Theoretical Physics (ICTP) climate modeling system RegCM4.3 was used as a numerical tool to simulate the climate over Balkan Peninsula. The latest version model, RegCM4, is a hydrostatic, compressible, sigma-p vertical coordinate model run on an Arakawa B-grid in which wind and thermodynamical variables are horizontally staggered. A time-splitting explicit integration scheme is used in which the two fastest gravity modes are first separated from the model solution and then integrated with smaller time steps. This allows the use of a longer time step for the rest of the mode [3].

The studied area is chosen to cover the Balkan Peninsula (Fig. 1) with central point in Bulgaria (42°N, 24°E). We use Lambert Conformal projection for the middle latitude [4], the horizontal resolution is 30 km and thus the model domain is resolved with a grid of 64×64 points. The data for the terrain elevation and land use category are taken from United States Geological Survey which is based on satellite information [5].

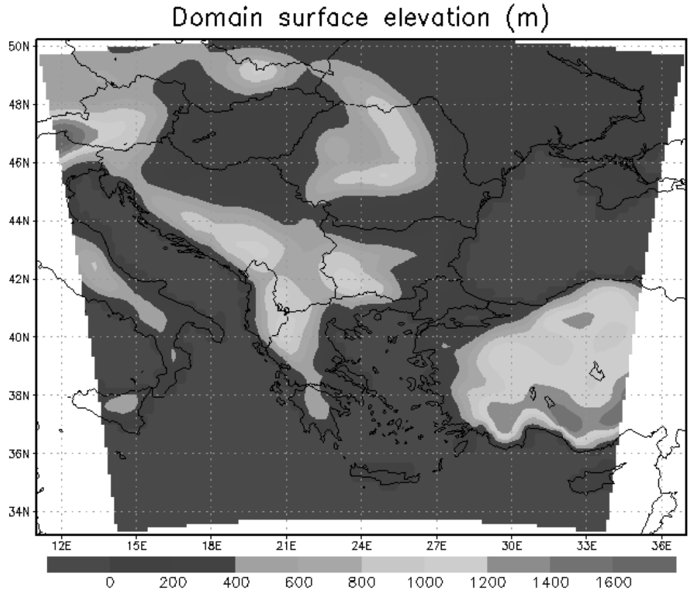

Fig.1. Regional model domain (33.19°N - 50.22°N, 11.01°E - 37.01°E) at 30 km resolution centered over Bulgaria (42°N, 24°E) and topography [m]

The RegCM4 modeling system is based on several modules, which describe different processes of the atmosphere dynamics and air-sea-land interactions. It includes NCAR CCM3 radiation scheme [6] for representing the radiation processes; MM5 hydrostatic dynamic core [7] for atmosphere dynamics; Biosphere-Atmosphere Transfer (BATS) scheme [8] for parameterization of surface air interactions; Holtstag Planetary Boundary Layer scheme [9]. Large scale precipitation processes are treated using sub-grid explicit moisture scheme SUBEX [10]. Various convection precipitation schemes are available: Grell AS [11] with Arakawa-Schubert [12] closure, Grell FC with Fritch and Chappell [13] closure, modified Anthes-Kuo [14], MIT-Emanuel [15] and the combination between Grell over land and MIT-Emanuel over ocean.

The model is configured using the “nesting” approach and as Initial and Boundary conditions we use the global meteorological reanalysis data of European

Center for Medium-Range Weather Forecast (ECMWF) ERA-Interim (1,5˚×1,5˚ spatial resolution). We also use optimum interpolated weekly means sea surface temperatures from satellites with horizontal resolution 1˚×1˚ (Optimum Interpolation (OI) Sea Surface Temperature (SST) V2 [16] of National Ocean and Atmospheric Administration (NOAA).

The model configuration described above was integrated for 10 years from 1 January 2000 using the global climate model initial data. In the beginning of each year the model was reinitialized by the respective initial condition. The spatial resolution is 30 km which leads to time step of 90 sec according to the Courant-Friedrichs-Lewy criterion. The model employs 18 vertical sigma levels, with a model top at 25 hPa and a bottom at 995 hPa.

The results of the simulations are post- processed to obtain the monthly mean fields of air surface temperature and accumulated precipitation. For the validation of results we use the CRU TS3.20 data with horizontal resolution 0,5°×0,5° [17]. This data archive is based on meteorological measurements in the stations all around the globe, interpolated in a regular grid, and give the monthly temperature and precipitation for the period 1901-2010. Note that CRU data cover only the land points, that is why we compare model and reference data only for the land grid points.

The RegCM4 model domain and topography are shown in Fig. 1. The main topographic features are adequately represented, taking into account the spatial resolution of 30 km: we see Carpathians to the north, parts of Alps and the Dinaric-Pindus mountain chains to the west, Black Sea coast to the east. The Adriatic Sea is on the west coast of Balkan Peninsula, the Aegean and the Marmara Sea on the east coast. Part of the Mediterranean Sea located in the south and southeast Turkey, as well as the part of the Apennine Peninsula to the southwest are also presented.

The terrain elevation in the region ranges from 0 to 1600 m, according to the model data. The highest point over the Balkan Peninsula is given ~1200 meters which refers to the area of Rila, Pirin and Rhodope Mountains, the Carpathians and the Dinaric mountains. Alps are identified with ~1400-1600 m.

The quality of the model simulations will be evaluated through statistical error of annual seasonal and mean temperature and precipitation. We calculate the deviation of the model from measured climatic data (BIAS) and the root mean square error (RMSE) of temperature and precipitation [18].

If in a series of N forecasts, F_i represents the i-th forecast and O_i the corresponding observation, the BIAS is given by:

$$\mathrm{BIAS} = \frac{1}{N\left[\sum_{i=1}^{N}(F_i - O_i)\right]}.$$

The Root Mean Square Error for a series of N forecasts is given by:

$$\mathrm{RMSE} = \left[\frac{1}{N} \sum_{i=1}^{N} \left[\left(F_i - O_i \right)^2 \right] \right]^{\frac{1}{2}}.$$

3. SENSITIVITY EXPERIMENT TO THE CHOICE OF THE CUMULUS CONVECTION PARAMETERIZATION SCHEME

The modeling system RegCM4.3 proposes several coded parameterization schemes: Grell with Arakawa-Schubert closure (GAS), Grell with Fritch and Chappell closure (GFC), modified Anthes-Kuo (AK), MIT-Emanuel (EM) scheme and Grell over land and Emanuel over ocean (EM/G). We will not give details on the assumptions and equations these schemes are based on, they are described in the respective articles cited in Chapter 2, we shall focus on the results of simulations using them. Further we denote the results by the abbreviations in the brackets above.

The described in Chapter 2 model configuration was run for the 10-year period altering the 5 schemes. The mean annual temperature and mean annually accumulated rainfall from the 5 simulations are compared with the CRU data analysis (Fig. 2). Furthermore, in order to investigate if there is an error dependency on the season, we have calculated the model and measurements data separately for winter (mean value for the months December, January, February), spring (March, April, May), summer (June, July, August) and autumn (September, October, November) seasons.

The maps of annual mean temperatures for the 5 schemes from simulations with RegCM4 compared with observed CRU data for the period 2000-2009 are given in Fig. 2. Each scheme gives similar temperature compared to CRU data: low values at high altitudes and high values in coastal areas. In all simulations the warm air is over the sea. As the CRU data lack the ocean, we cannot compare the sea surface temperatures. In general there is a good coincidence of the simulated and measure temperature fields.

Fig. 3 shows the maps of mean annual precipitation for the period 2000-2009 from simulations with 5 different convective schemes compared to the amount of precipitation from observation data (below in right). High values are observed over coastal western areas and high mountains and the maximum is along Adriatic coast and Southern Carpathians. The driest regions are Central Anatolia and northwest of the Black Sea. In general, the model simulations overestimate the precipitation. While there are no particular temperature differences between the five experiments, the precipitation distributions significantly differ, particularly in the western and northern part of the model area (Dinaric mountains and Southern Carpathians) where each scheme overestimate the precipitations.

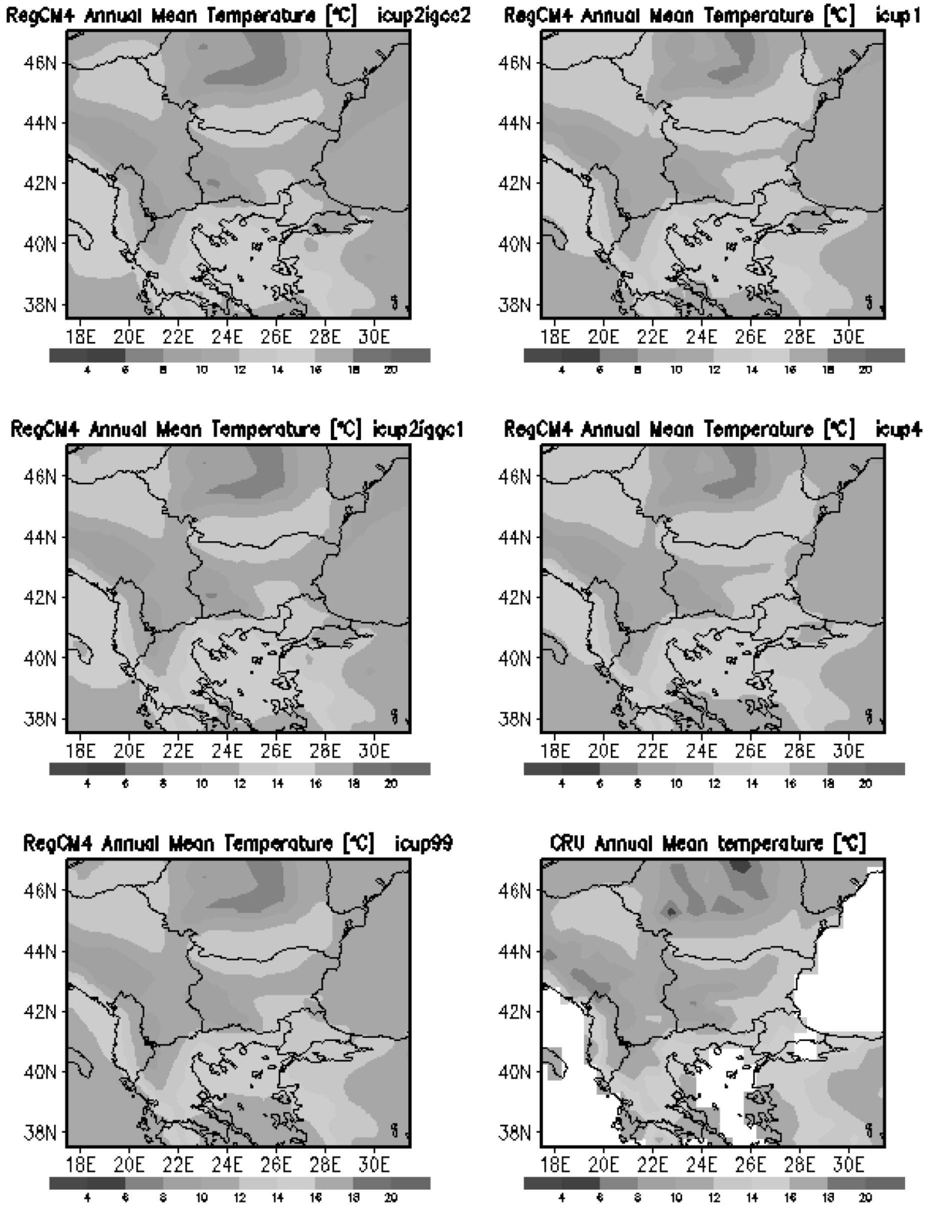

Fig. 2. Annual mean temperatures [˚C] for the 5 schemes (GAS-icup2 igcc1, GFC- icup2 igcc2, AK- icup1, EM- icup4, EM/G-icup99) from simulations (RegCM4 ERA Interim) compared with observed CRU TS3.20 data (below in right)

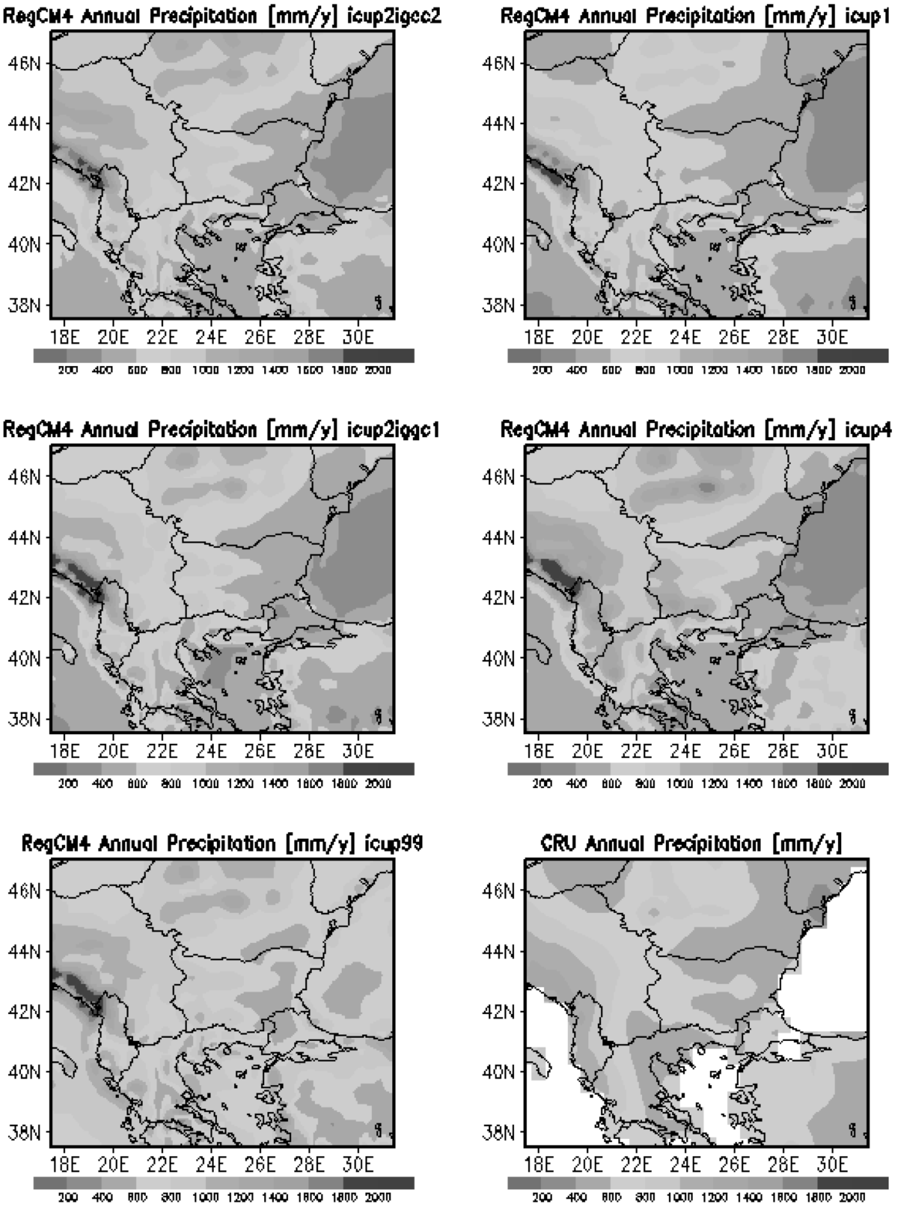

Fig. 3. Annual precipitation [mm/y] for the 5 schemes (GAS-icup2 igcc1, GFC-icup2 igcc2, AK-icup1, EM-icup4, EM/G-icup99) from simulations (RegCM4 ERA Interim) compared with observed CRU TS3.20 data (below in right)

From these maps however is difficult to assess which of the experiments gives the best results. Therefore we calculated the BIAS and RMSE for annual (Table 1) and seasonal (Table 2, 3, 4 and 5) temperature and precipitation respectively. The averaged area is the territory of Bulgaria (41 ˚ - 44.5 ˚ N, 22.5 ˚ -28.5 ˚ E).

Table 1. Annual mean values of temperature [˚C] and precipitation [mm/y] (RegCM4.3, CRU TS3.20), BIAS and RMSE for the territory of Bulgaria for 5 schemes

Parameterization	Temp.,	˚C		Prec.,	mm/y	
Schemes	Reg4	BIAS	RMSE	Reg4	BIAS	RMSE
GFC	11.6	–0.4	1.7	648	67	506
AK	12.2	0.2	2.0	582	–5	483
GAS	11.8	–0.2	1.7	606	24	467
EM	12.2	0.2	1.8	708	130	503
EM/G	11.9	–0.1	1.7	715	127	600
CRU	12.1			593		

Annual mean values of temperature and precipitation, BIAS and RMSE for the territory of Bulgaria using different parameterization schemes are shown in Table 1. Three of the schemes (GFC, GAS and EM/G) show cold bias in temperature. For precipitation most of the schemes show wet bias (exception is the AK scheme). The EM/G, GFC and GAS schemes give the smallest errors (about 1.7 ˚C) for the temperature and GAS (467 mm/y) for the precipitation. All the schemes overestimate the annual rainfall except for AK scheme which shows dry bias (-5 mm/y). As a conclusion the GAS scheme is expected to give optimal results for both temperature and precipitation.

Table 2. Seasonal mean 2m temperature (RegCM4, CRU) and BIAS [˚C] for the territory of Bulgaria for 5 convective schemes

Temp.	Reg4				BIAS			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
GFC	2.4	11.3	21.6	11.3	0.6	–0.3	–0.4	–1.5
AK	2.4	11.8	23.1	11.6	0.5	0.3	1.1	–1.1
GAS	2.4	11.4	21.9	11.4	0.6	–0.1	–0.2	–1.3
EM	2.8	11.8	22.4	11.9	1.0	0.3	0.4	–0.8
EM/G	2.5	11.4	21.9	11.9	0.7	–0.1	–0.2	–0.9
CRU	1.6	11.5	22.3	12.7				

Table 3. Root mean square error (RMSE) of seasonal mean temperature [˚C] for the territory of Bulgaria for 5 convective schemes

Temp	RMSE			
	DJF	MAM	JJA	SON
GFC	1.4	1.1	2.1	1.8
AK	1.4	1.2	2.8	1.7
GAS	1.4	1.0	2.1	1.7
EM	1.6	1.1	2.2	1.5
EM/G	1.5	1.0	2.1	1.6

The climate simulations for Bulgaria region though should represent adequately not only the annual mean values but also the seasonal cycle of meteorological elements. That is why the evaluation of model results is done also separately for different seasons (Table 2, 3, 4, 5). In winter the schemes show warm bias in temperature (0.5 –1˚C) and in autumn - cold bias (1–1.5 ˚C) (Table 2). In spring and summer GAS, GFC and EM/G underestimate the temperature, while AK and EM overestimate it. The best results are obtained using GAS and EM/G schemes in spring period with values of ~1˚ C (Table 3). The worst results for temperature are obtained in summer by AK (2.8˚C RMSE). Overall GAS and GFC show the best results in temperature except for autumn season where the RMSE for EM is the smallest (1.5˚C error).

Table 4. Seasonal mean precipitation in mm/month (RegCM4, CRU) and BIAS for the territory of Bulgaria for 5 convective schemes

Prec.	Reg4				BIAS			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
GFC	70	69	39	38	19	22	-7	-13
AK	76	59	17	42	24	11	-29	-9
GAS	71	62	33	37	20	14	-13	-14
EM	75	74	48	40	23	27	2	-10
EM/G	80	65	40	54	28	17	-6	2
CRU	52	49	46					

Table 5. Root mean square error (RMSE) of seasonal precipitation [mm/month] for the territory of Bulgaria for 5 convective schemes

Prec.	RMSE			
	DJF	MAM	JJA	SON
GFC	38	47	38	34
AK	40	40	39	32
GAS	39	41	32	34
EM	42	47	34	32
EM/G	49	43	38	49

Regarding the precipitation, all schemes give wet bias in winter and spring and dry bias in summer and autumn (Table 4). The only exception is EM run which shows wet bias in summer and EM/G run-wet bias in autumn. The GAS scheme simulation shows again smallest RMSE (Table 5), especially during the summer season (32 mm/month) but actually, the results with other schemes are not so different. All schemes give greatest errors in spring periods.

Overall, the model overestimates the winter (DJF) and spring (MAM) precipitation and winter (DJF) temperatures and underestimates the summer (JJA) and autumn (SON) precipitations and temperatures. The best performance is given by GAS scheme, although GFC results are similar. Thus we conclude that the best simulation for the territory of Bulgaria with smallest error gives the experiment with Grell convective scheme and with Arakawa-Schubert closure.

Some of the results, summarized in the tables, are shown on 4 spatial maps comparing monthly mean temperatures and precipitations in the model (RegCM4) and measurements (CRU) for each season: DJF (winter), MAM (spring), JJA (summer) and SON (autumn) using only GAS convective scheme which is expected to gives the best simulation performance, as described above.

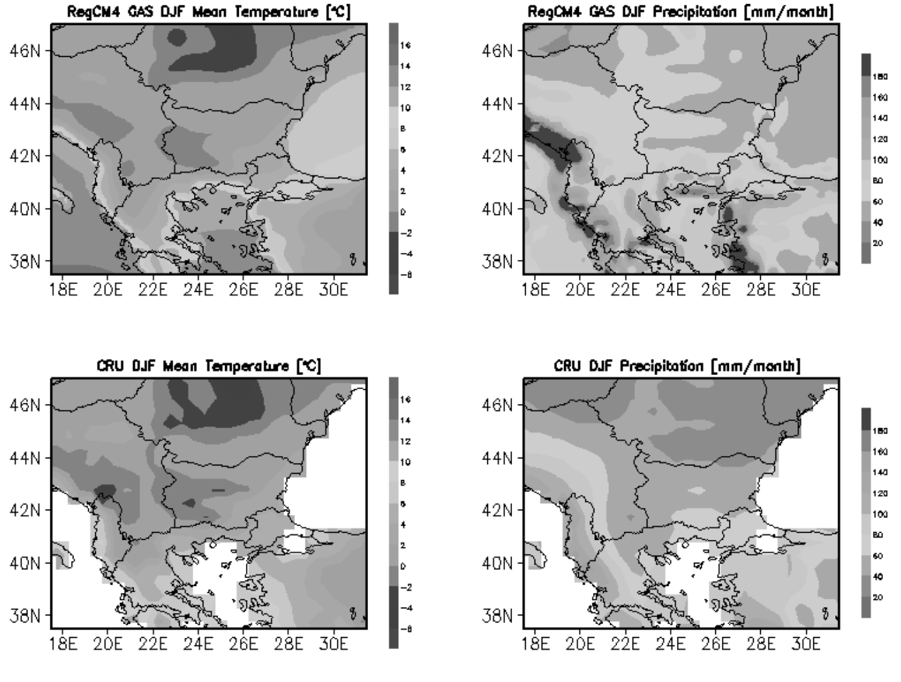

Fig. 4. Mean temperature [˚C] and precipitation [mm/month] for DJF season from the model simulations with GAS scheme compared to the reference CRU TS3.20 data

In winter (Fig. 4) both model and measurements show the low temperature values in the high mountain areas and high – along the sea. The maximum model value is over the Mediterranean Sea. As for the precipitation, the high values are in the southwestern part of the model area (coasts of the Adriatic Sea) where in fact the simulations overestimate the precipitation. For the territory of Bulgaria the model precipitation exceeds the observed CRU precipitation.

In spring (Fig. 5) the mean MAM temperatures in the model and CRU data indicates the warm Mediterranean coastal zone and the cold high mountain areas. The horizontal map patterns match well over Bulgaria, especially in Northern Bulgaria. In fact, for the temperature this is the season with smallest error comparing to the other 3 seasons. On the contrary, when looking at the precipitation distribution, the horizontal correlation is not so good: the maximum rainfall is in the high mountain regions as expected, but in general the model overestimates precipitation over land and underestimates it in the coastal areas.

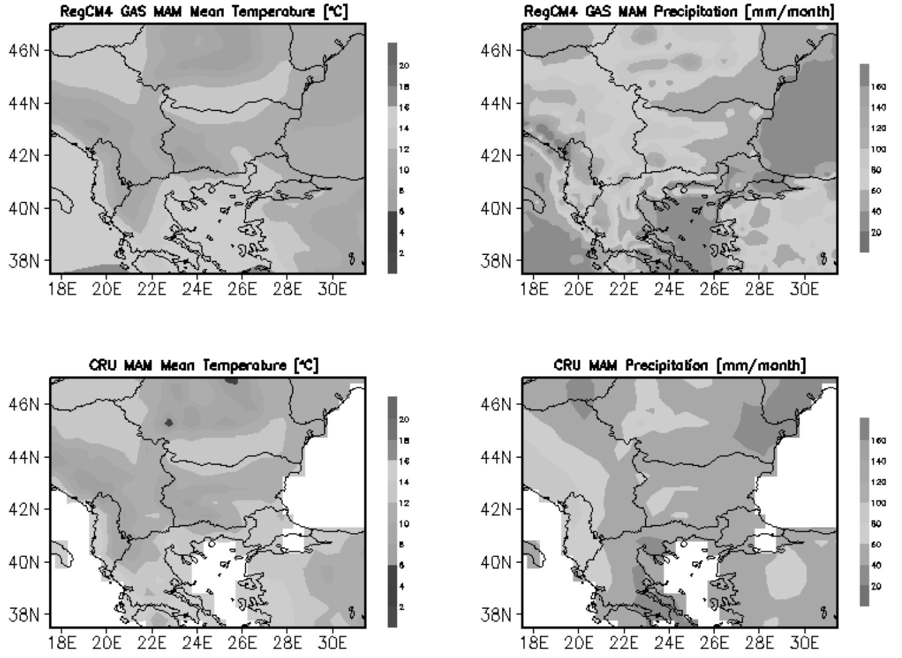

Fig. 5. Mean temperature [˚C] and precipitation [mm/month] for MAM season from the model simulations with GAS scheme compared to the reference CRU TS3.20 data

In summer (Fig. 6) there is a good agreement between temperature horizontal map from model and measurement. Simulations slightly overestimate the temperature in north Bulgaria and underestimate it over south part of studied domain. Looking at the average monthly amount of CRU precipitation, the model overestimates it over land and underestimates it in regions close to the sea.

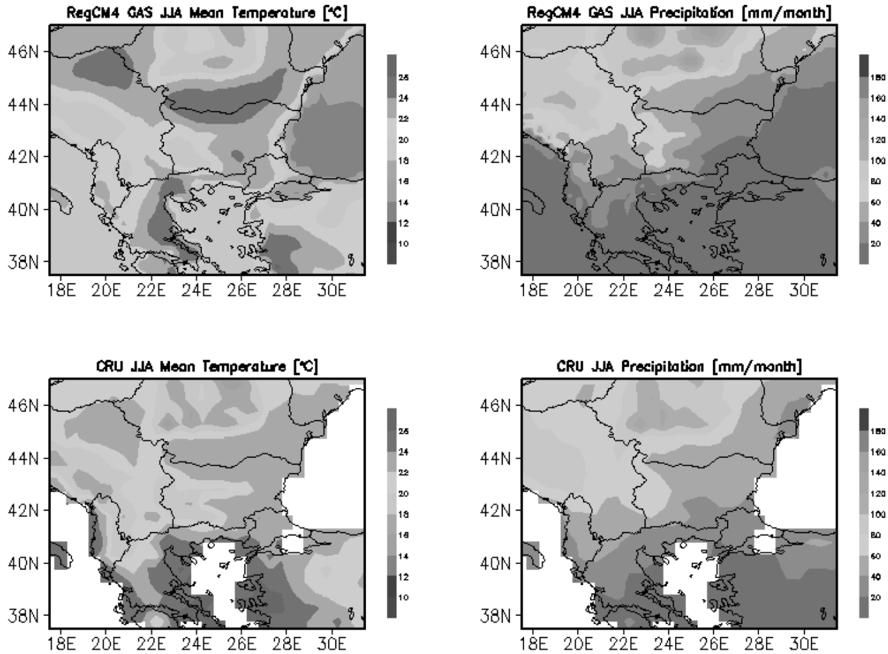

Fig. 6. Mean temperature [˚C] and precipitation [mm/month] for JJA season from the model simulations with GAS scheme compared to the reference CRU TS3.20 data

Finally in autumn (Fig. 7) again we see good agreements with CRU data. For Bulgaria model is colder, in contrast to the winter. The maximum precipitation occurs over the east coast of the Adriatic Sea. For Bulgaria the model gives less rainfall in eastern and more rainfall in western Bulgaria when compared to the observations.

From these estimates one could conclude that the model show different behavior in different seasons when comparing to the real data. In spring and summer the simulated temperature maps match well the measurements. However, the precipitation in spring season is simulated worse than in winter and summer.

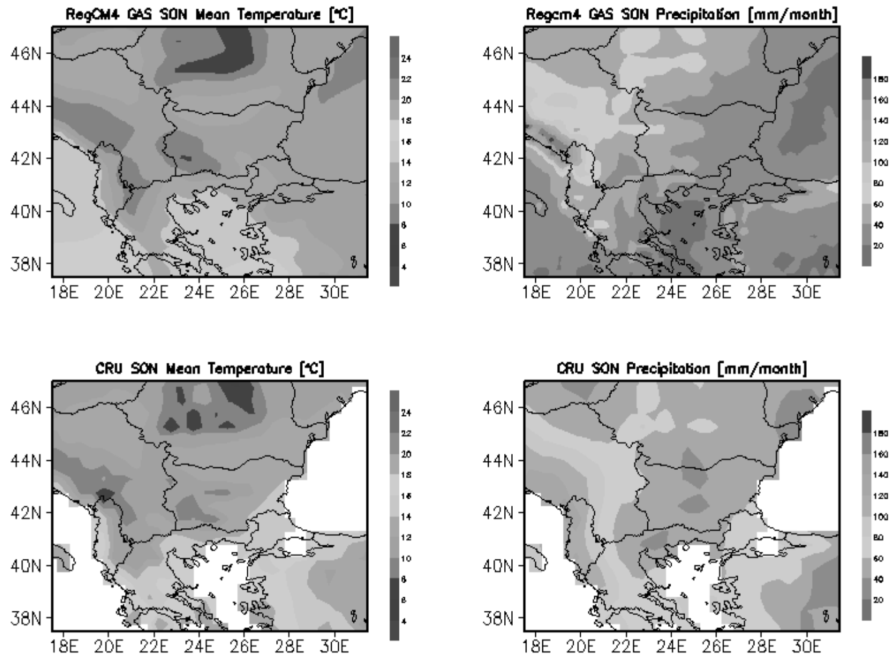

Fig. 7. Mean temperature [˚C] and precipitation [mm/month] for SON season from the model simulations with GAS scheme compared to the reference CRU TS3.20 data

The region of Balkan Peninsula is a climate transition zone where climate is formed by two main factors: Mediterranean influence, characterized by mild and wet winter and dry summer; and continental influence which leads to dry and cold winter and rainy spring. Following the described above one might conclude, that the underestimated annual amplitude of temperature and overestimated winter precipitation indicate that the climate, represented by the model, shows less continental characteristics and is more influenced by the Mediterranean Sea.

4. INTERANNUAL AND SEASONAL VARIATIONS OF TEMPERATURE AND PRECIPITATION

In this section we check the model capabilities to capture the seasonal and inter-annual variations of the elements. The model simulations with GAS scheme and reference data are compared as area averaged for Bulgaria values. Fig. 8 and 10 present the seasonal and inter-annual variations of temperature, while Fig. 9 and Fig. 11 – same for the precipitation. Fig. 8 clearly indicates a good agreement between the seasonal variations of CRU and RegCM4 temperature. A slight

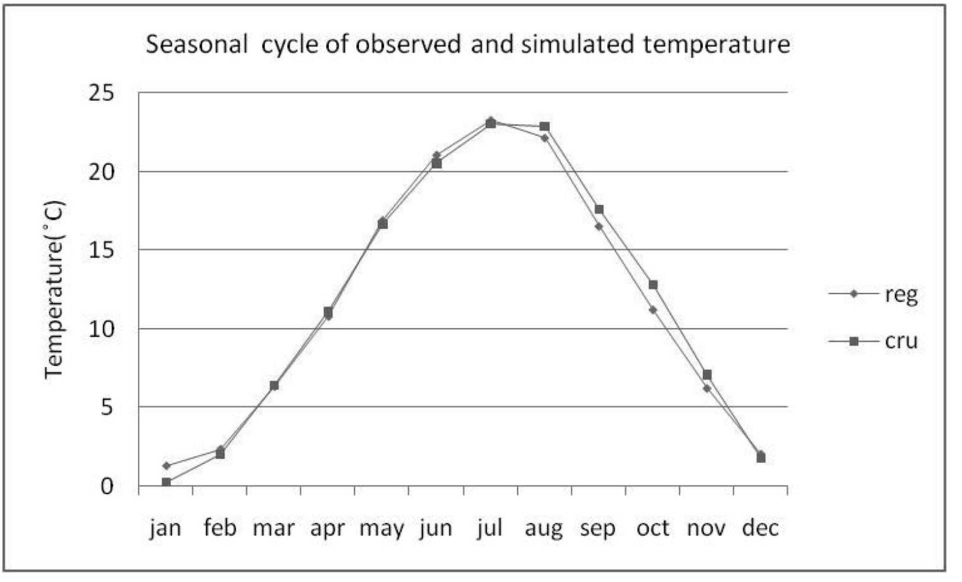

Fig. 8. Seasonal variations of temperature [˚C] in the simulation with GAS scheme

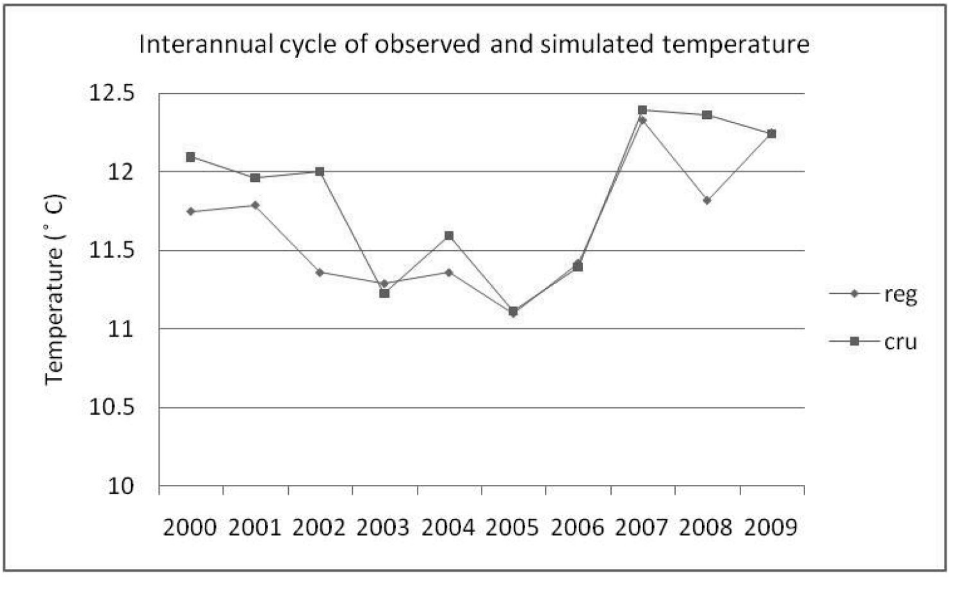

Fig. 9. Inter-annual variations of temperature [˚C] in the simulations with GAS scheme

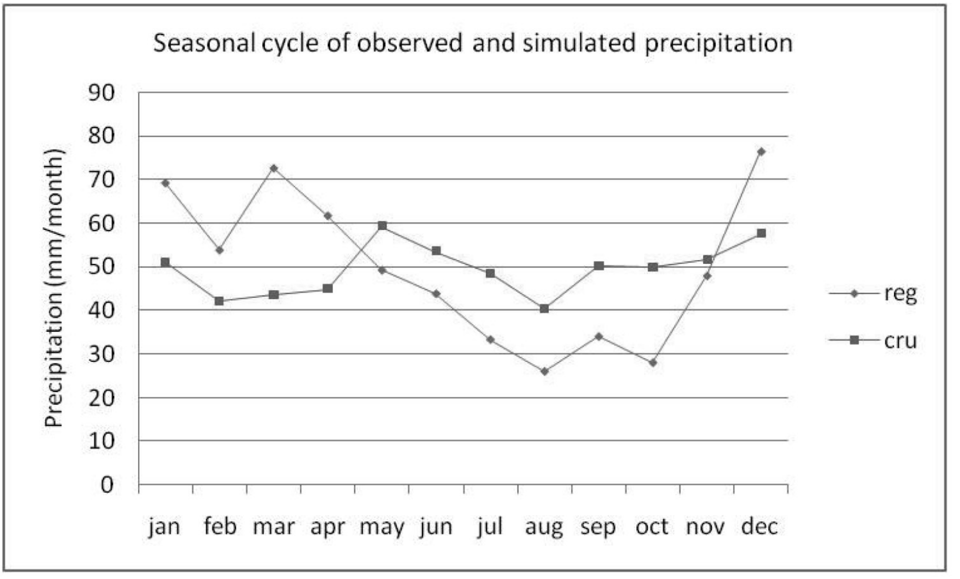

Fig. 10. Seasonal variations of precipitation [mm/month] in the simulations with GAS scheme

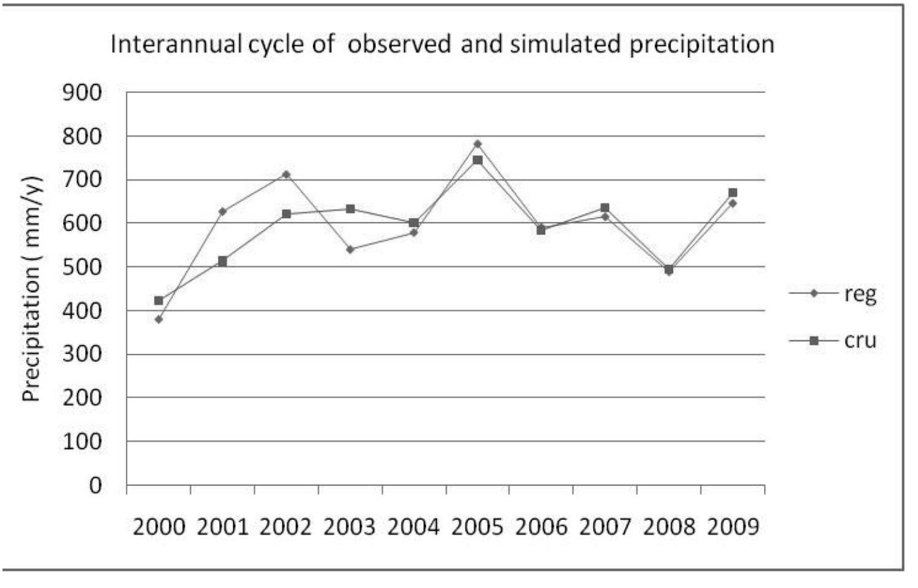

Fig. 11. Inter-annual variation of precipitation [mm/year] in the simulation with GAS scheme

discrepancy is found in the autumn and summer, but overall the correlation coefficient is high 0.99 (Table 6). On the contrary, for the precipitation model results differ from the CRU data (Fig. 10), the correlation coefficient is low 0.20 (Table 6). In the inter-annual variations of temperature (Fig. 9) the largest differences between CRU and RegCM4 are observed in 2002 and 2008. Nevertheless, the correlation coefficient (0.85) is quite high and indicates good agreement. Inter-annual variations of precipitation (Fig. 11) are well correlated to the CRU data – coefficient 0.83 (Table 6).

Table 6. Seasonal and inter-annual correlation coefficients (COR) between RegCM4 GAS and CRU TS3.20.

COR	Temp.	Prec.
Seasonal	0.99	0.20
Inter-annual	0.85	0.83

When looking only at annual mean temperature and precipitation one could miss the effects of opposite seasonal behavior during the years. For example, if the next winter is colder than the previous, but the summer is warmer, the annual temperature will not change. That is why, the inter-annual variations of seasonally averaged temperature and precipitation are also very interesting to be investigated. Table 7 shows correlation coefficients between simulated and observed temperature and precipitation averaged seasonally (DJF, MAM, JJA and SON) for each of the 10 years. Very good correlation is observed for the temperature in all seasons, especially in winter (0.97). For the precipitation, the agreement is rather good for winter, summer and autumn, but not in spring.

Table 7. Correlation coefficients (COR) between averaged RegCM4 GAS and CRU TS3.20 data for DJF, MAM, JJA and SON for 2000-2009.

Temp.	COR	Prec.	COR
DJF	0.97	DJF	0.83
MAM	0.83	MAM	0.37
JJA	0.84	JJA	0.67
SON	0.83	SON	0.89

From Table 6 and 7 we can conclude that in general the model RegCM4.3 forced with ERA-Interim meteorological reanalysis for the given area could be used in studies of the inter-annual cycle of temperature and precipitation and seasonal cycle of temperature. In regard to the seasonal variations of the rainfall, the credibility of the model results is questionable.

5. CONCLUSION

The limited area climate models are proven to be a very useful tool when simulating the present climate and its future projections. However, it is very important to choose the right initial parameters which tune best the model performance. In this study we have performed regional climate simulations with the climate model RegCM4.3 in the area of the Balkan peninsula (centered in Bulgaria). The comparison between model and observations data show that model is sensible to the choice of cumulus convection schemes and the most appropriate convective precipitation scheme over Bulgaria is Grell scheme with Arakawa-Schubert closure (GAS). The choice of this scheme leads to the smallest errors in simulating both for temperature and precipitation. The error in the simulations is 1.7 ˚C for the annual mean temperature and 467 mm/y for the annual accumulated precipitation. The further investigation separating the data by seasons reveals that the most part of the model error is caused by differences in summer months for the temperature and in spring – for the precipitation. Interesting result appears when we look at the inter-annual and seasonal variations of the area mean temperature and precipitation. The inter-annual variations are captured very well by the model (correlation coefficient 0.99 for temperature and 0.83 for the precipitation) but in regard to the seasonal cycle, the precipitations are not adequately represented. The conclusion is that for this given region the described configuration of the climate model could be used in studies of the inter-annual cycle of temperature and precipitation and seasonal cycle of temperature, while for the seasonal precipitation one can expect errors especially during the cold part of the year.

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