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Sensitivity Study of Different RegCM4.4 Model Set-Ups – Recent Results from the TVRegCM Experiment

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Abstract: *The oncoming climate changes will exert influence on the ecosystems, on all branches of the international economy, and on the quality of life. Global Circulation Models (GCMs) are the most widespread and successful tools employed for both numerical weather forecast and climate research since the 1980s. However, growing demands on accurate and reliable information on regional and sub-regional scale are not directly met by relatively coarse resolution global models, mainly due to the excessive costs affiliated with the use of the model in very high resolution. Regional Climate Models (RCMs) are important instruments used for downscaling climate simulations from GCMs. Main aim of the numerical experiment Tuning an Validation of Regional Climate Model (RegCM-TVRegCM) is to quantify the impact of some tunable factors in the RegCM set-up on the model outputs. Thus, on the first stage of the study, the skill of 20 different model configurations in representing the basic spatial and temporal patterns of the Southeast European (SE) climate for the period 1999-2009, is evaluated. Based on these outcomes, the present work is dedicated on more detailed inspection of the model set-ups with recognizable better performance. The Pearson's correlation coefficient between the time series of the temperature and precipitation of the 6 most promising model set-ups and the E-OBS on monthly basis are calculated. The main conclusion is that this test does not reveal single one model set-up that definitely over performs the other considered ones.*

Keywords: *Regional climate simulation, RegCM4.4, sensitivity study, high performance computing.*

1. Introduction

Regional climate models are tools that greatly enhance the usability of climate simulations made by global climate models for studying past, present and future climate, and its change as well as its impacts on a regional scale. Following the methodology of dynamical downscaling [1, 2], the outputs of Global Circulation Models (GCMs) can be used as driving fields for the nested RCMs running with higher resolution, allowing capturing the smaller scale features of the climate. Although some issues concerning the use of dynamic downscaling are still not well understood, the prevailing opinion is that the approach is really capable to improve simulation/prediction and/or adding more climate information at different scales compared to the GCM or reanalyses that impose the Initial and Boundary Conditions (ICBCs) to the Regional Climate Model (RCM) [3]. Main manifestation of the flexibility of the modern RCMs is the possibility for selection among different Initial and Boundary Conditions data-sets (ICBC), parameterization schemes/modules within the model, various constants and closure assumptions, etc., combining them in practically countless model set-ups. Obviously the simulation output from such model set-ups will differ from one another, and, more or less, from the "reality". Thus a necessary prerequisite before any model implementation is to select the optimal RCM-configuration. Hence such factors as the domain size and location as well as the grid resolution are more or less determinate from the specifics of the concrete model implementation, the sensitivity study have to be focused on the different parameterization schemes and their closure assumptions.

The Regional Climate Model (RegCM) is a flexible, portable, and easy-to-use regional climate model. It is widely employed by various research units to different regions of the Earth particularly over Central and Eastern Europe and thus is a reasonable choice for simulation tool. A lot of sensitivity analyses have been completed regarding the selection of suitable integration domain, adequate horizontal resolution, potential driving models, applied physics schemes, or adaptation tools (see Pieczka et al. [4] for details). Thus, for example, Zeng et al. [5] assess the effects of the spatial resolution on RegCM3 on the simulated summer temperature and precipitation in China. They conclude that the best estimates can be produced only when the horizontal and vertical resolutions are reasonably configured. Using the same model version, Davis et al. [6] compared different convective schemes for a regional domain covering the eastern part of Africa and the adjacent Indian Ocean. Some studies ([7, 8]) are dedicated on sensitivity analysis of the model concerning the Asian summer monsoon conditions. Zanis et al. [9] investigated the sensitivity of RegCM3 to the convective scheme for CE and SE Europe. The spatial and seasonal variations of the discrepancies between the temperature and precipitation simulated with the different schemes are commented in detail. Recently NIMH-BAS researchers studied the capability of RegCM4.4 for description of the Snow Water Equivalent (SWE) over Central and SE Europe. Thus, Chervenkov and Slavov [10] compared the simulated SWE for 14 consecutive winters with the in-situ based GLOBSNOW product [11]. The surface scheme and the ICBCs are altered in other study [12], performed by the same authors, for time window of 10 years. Concerning the spatial and temporal distribution of the SWE, all model outcomes are similar and no configuration outperforms evidently the other. Main finding of the comprehensive sensitivity analysis of Pieczka et al. [4] is that among the factors analyzed, RegCM4.3 is most sensitive to the applied convection scheme. The impact of closure assumption related to the used convective parameterization is secondary, while the use of subgridding has less influence. The latter two works, [4, 11], are geographically focused on the Carpathian basin using the Carpatclim database for the purpose of validation. It is homogeneous gridded database covering 1961-2010 on daily basis with 0.1° horizontal resolution, containing all the major surface meteorological variables (Szalai et al. [13]).

Despite the relevant differences, both in factors being studied and spatial and temporal dimension of the analysis being performed, there is a general consensus about the absence of the only one RegCM model set-up which outperforms the others under all conditions.

Central and eastern Europe, and especially the Balkan Peninsula, is a region in Europe, where most climate model validations show considerable problems. For example, the coarser and finer version of the EURO-CORDEX ensemble tends to produce warm and dry summer bias for this region (Kotlarski et al. [14]). No obvious benefit of the higher resolution (0.11° vs. 0.44°) is apparent. The bias ranges of the EURO-CORDEX ensemble mostly correspond to those of the ENSEMBLES simulations, but, among other achievements, less pronounced southern European warm summer bias can be identified. Some ensemble members overestimate winter temperatures here, but generally the cold biases are less pronounced. Kotlarski et al. [14] state that the prevailing model tendency to overestimate temperatures, which is consistent with previous findings, is probably related to an underestimation of summertime precipitation and moisture-temperature coupling. Zanis et al. [9] explain schematically the linkage between the overestimated temperatures and the hot half year precipitation: the more (in comparison with the reality) intense convection, which in turn imposes a more effective drying of the atmosphere, consequently less low-level clouds, leads to more shortwave solar radiation absorbed from the ground and hence warmer low level temperatures.

The conceptual frame of the TVRegCM experiment is similar to all these studies: in order to quantify the impact of the use of different parameterization schemes and tuneable modules on the model outputs, extensive hindcast experiments have been completed and the results have been validated. Although the main conclusion from the preliminary results confirms the absence of "universal" model set-up, some configurations show better skill by certain conditions. Thus, the present work is dedicated on more detailed inspection of the model set-ups with recognizable better performance.

The paper is structured as follows: The description of the methodology is placed in the first section. Outlook of the previously preformed calculations as well as the main outcomes of the first stage of TVRegCM and the newer ones is presented in second section. Some general remarks of the main outcome of the study are placed in the conclusion.

2. Methodology

The simulations with the RCM RegCM version 4.4 [15] were made for the SE Europe covering ten years period from 01.12.1999 to 30.11.2009 and are driven by the ERA-Interim reanalysis [16], providing the required atmospheric ICBC as well as sea surface temperatures. The ERA-Interim boundary conditions can be considered to be of very high quality [16], particularly in the Northern Hemisphere extratropical areas where reanalysis uncertainty is negligible [17]. The simulation domain covers entirely the Balkan Peninsula, a minor part of Italy and a part of Asia Minor Peninsula. The model grid is in Lambert Conformal Conic projection with spatial resolution of 10 km. Hence the previous experiments reveal that time step equal to 25 s, and 27 vertical levels are optimal, they are selected for the model integration. The default land surface parameterization method in RegCM4 is the BATS scheme [18]. In the current study, we have used it without the subgridding option. The considered Planetary Boundary Layer (PBL) schemes are those proposed by Holtslag, de Bruijn and Pan [19], and Holtslag and Boville [20] and the University of Washington (UW) one [21, 22]. One of the most significant novelties in RegCM4.4 is the incorporation of the new cloud microphysics scheme (for brevity: M-scheme), proposed by Nogherotto and Tompkins (NT) [23]. This scheme was released after MedCORDEX experiments started. The Cumulus Convection (CC) parameterizations include Grell [24] scheme with Arakawa and Schubert (AS) [25] and Fritsch and Chappell (FC) [26] closure assumption, Emanuel [27] scheme, and Emanuel and Zivkovic-Rothman [28], Tiedtke [29] scheme and Kain-Fritsch scheme [30, 31]. The simulations with Kuo [32] convective parameterization scheme have shown instability and interruptions of the model simulations at some periods, so we do not use it in our research.

Thus, the number of the possible combinations, which means RegCM4.4 model set-ups, between two PBL schemes, two M-schemes and five CC ones, is 20 and we have investigated all of them.

The calculations were implemented on the Supercomputer System “Avitohol” at the Institute of Information and Communication Technologies at the Bulgarian Academy of Sciences (IICT-BAS) that consists of 150 HP Cluster Platform SL250S GEN8 servers, each one equipped with two Intel Xeon E5-2650 V2 8C 2600 GHz CPUs and 64GB RAM per server.

The well-known and freely available for the research community data-base E-OBS version 12.0 of the European Climate Assessment & data-set (ECA&D) project [33] is used as reference in the model validation. E-OBS is based only on observations, covers entire Europe and the surroundings, and the version with 0.25°×0.25° regular grid spacing is implemented. It is worthy to emphasize that E-OBS is the standard validation data-base for the EURO-CORDEX.

3. Results

Hence the multi-annual seasonal mean temperature (referred further for brevity only temperature) and the multi-annual seasonal mean precipitation sum (precipitation) are probably the most important quantities from climatological point of view, the validation study thus far is focussed on them.

The E-OBS is on daily basis and RegCM is set to produce output on every 06 hours. Thus, the climatological quantities are calculated after every successive model integration with the CDO operators [34].

The detailed results from the validation are presented in [35]. Only the most relevant conclusion will be listed briefly here.

According the temperature and as overall, the models can be divided in two groups – those with prevailing warm bias and those with prevailing cold bias. Generally, the biases are more remarkable in the summer than in the winter and are in the interval from about –3.5 to 3.5 °C, but over the bigger part of the domain typically from about –2 to 2 °C.

The simulation outcome from all 20 model set-ups produces almost identical picture for the precipitation distribution in winter: The biases are nearly equally distributed and are positive (i.e., the model overestimates the precipitation), with some minor exceptions. The summer biases however, show significant distinction in their distribution and magnitude. They are positive, with some minor exception in Greece. Generally, the precipitation biases however, are very big. Their values vary from below 100-160 %.

The main conclusions are, first, that the relative weight of the CC-schemes is the biggest and, second, the simulations with the smallest biases are with Grell one with both closures. The sensitivity of RegCM4.4 to the PBL- and M-scheme seems significantly weaker. Thus, there are not clear evidences for clear distinction between the model skill with Holstlag or UW PBL parameterization from one side or for over performance of the NT M-scheme in comparison with the default SUBEX. As overall, 7 from 20 model setups show recognizable better performance. They are listed in Table 1.

Main aim of the current, second stage of TVRegCM is to “narrow” the selection, i.e., to perform further examination of these 7 model configurations.

Table 1. List of the model set-ups with better (in comparison with the others) performance. The original index and notation is preserved from the first stage of TVRegCM experiment

Index	Notation	PBL-scheme	M-scheme	CC-scheme
1	r11111	Holstlag	SUBEX	Grell/FC
2	r11112	Holstlag	SUBEX	Grell/AS
5	r11155	Holstlag	SUBEX	Kain-Fritsch
11	r12121	UW	SUBEX	Grell/AS
12	r12122	UW	SUBEX	Grell/FC
15	r12155	UW	SUBEX	Kain-Fritsch
16	r12221	UW	Nogherotto/Tompkins	Grell/AS

General drawback of the first stage is the chosen climatological quantities themselves: The multi-year seasonal averaging oversmooths important information, in particular the monthly and inter-annual variations. Now, in order to quantify this time dynamics, the Pearson's correlation coefficient, applied on monthly basis, is used as statistical score for estimation of the skill of the considered model set-ups. Again, the E-OBS, this time pre-processed to monthly averages, is used as reference. As far as the length of the configuration r12221 is shorter as of the others, it is not treated. The spatial distribution of the correlation coefficient for the temperature is shown in Fig. 1 and the one for the precipitation – in Fig. 2.

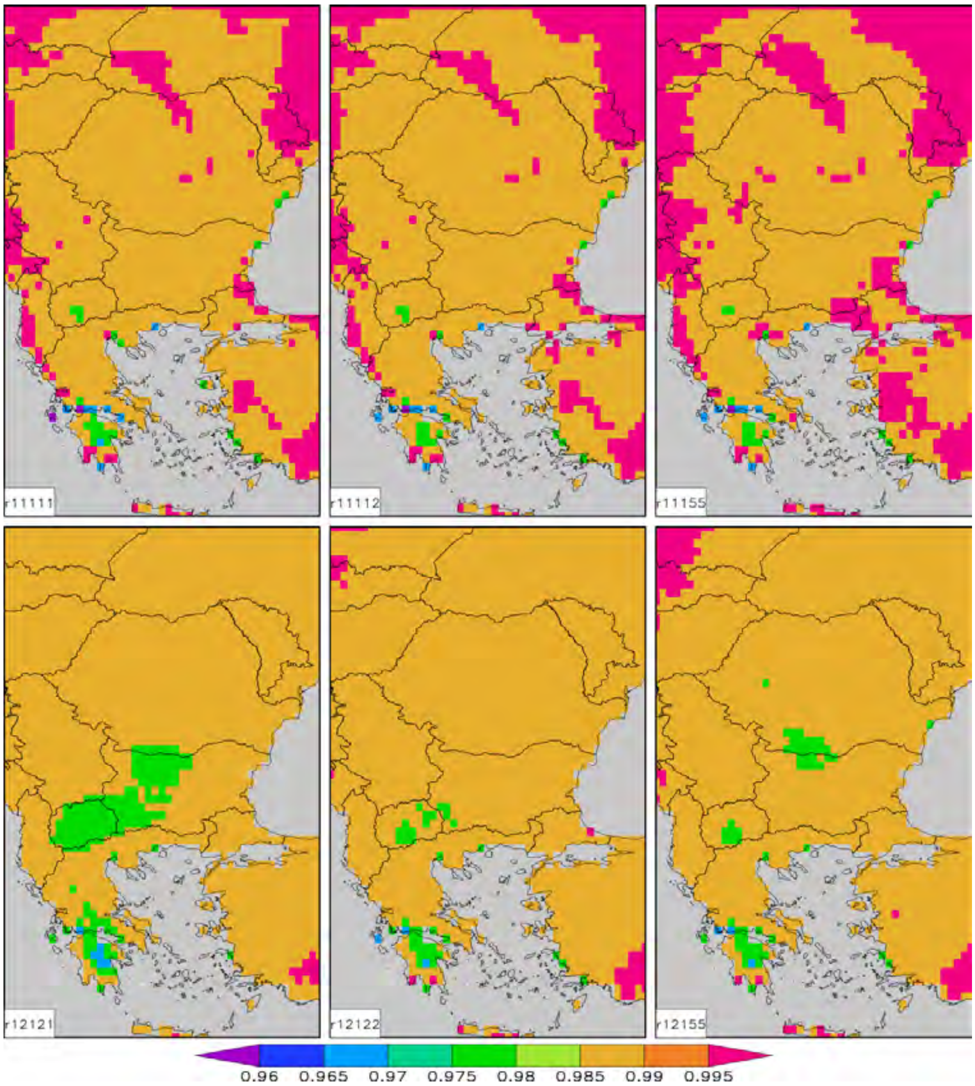

Fig. 1. Distribution of the correlation coefficient for the temperature

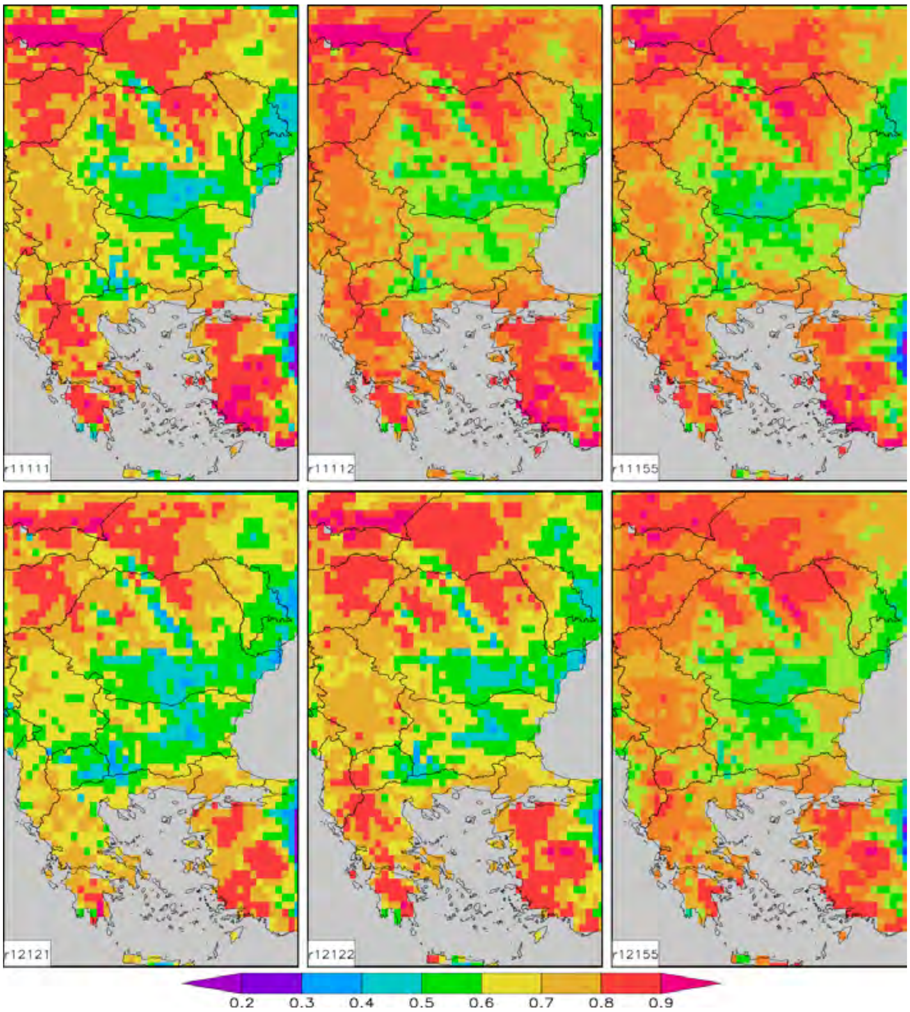

Fig. 2. Distribution of the correlation coefficient for the precipitation

Figs 1 and 2 reveal interesting issues, but most evident are:

- There are no general differences between the considered model set-ups in the spatial distribution of the correlation coefficient both of temperature and precipitation.
- As expected the temperature distribution is much more spatially homogeneous.
- As a whole, the correlation for the temperature is significantly higher than for the precipitation.

4. Conclusion

Main conclusion of the presented part of the RegCM numerical experiment is that our new test does not reveal a single model set-up that definitely overperforms the other considered ones. Nevertheless this exercise was a necessary step forward in the authors' evaluation strategy. The results, together with these from the previous stage, are in general agreement with the outcomes in [4] and [14]. In particular, we confirm the outlined in [4] primary importance of the CC scheme. Obviously, many other factors have to be investigated, including:

- It is relevant to investigate the model option to switch the CC-scheme by transition from land to sea and vice versa. It is worthy to emphasize that the default setting (and it is explicitly recommended from the RegCM authors), which is confirmed in [4], is Grell's over land and Emanuel's over sea.
- The need to perform sensitivity tests over shorter periods, including case studies for warm/cold/wet/dry years.
- To consider other output quantities, which are more or less also relevant for many practical applications, such as cloud cover, soil moisture, radiation fluxes, etc. Although the availability of independent data-sets, which can be used as reference, seems limited, this is reasonable.
- To estimate the computational efficiency of the selected model set-ups.

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