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# Regional climate modeling activities in relation to the CLAVIER project

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**Abstract—**Observational records show that the global climate is changing and these changes are visible in the Central and Eastern European Countries (CEEC). Certainly negative impacts of climate change will involve significant economic losses in several regions of Europe, while others may bring health or welfare problems somewhere else. Within the EU funded project CLAVIER (Climate ChAnge and Variability: Impact on Central and Eastern EuRope) three representative CEEC are studied in detail: Hungary, Romania, and Bulgaria. Researchers from 6 countries and different disciplines identify linkages between climate change and its impact on weather patterns with consequences on air pollution, extreme events, and water resources. Furthermore, an evaluation of the economic impact on agriculture, tourism, energy supply, and public sector will be conducted. CLAVIER focuses on ongoing and future climate changes in CEEC using measurements and existing regional scenarios to determine possible developments of the climate and to address related uncertainties. Three regional climate models are used to simulate the climate evolution in CEEC for the period 1951 to 2050, the future regional climate projection being the first half of the 21st century. The issue of climate change uncertainties is addressed through the multi-model and multi-scenario ensemble approach. As a result, CLAVIER establishes a large data base, tools, and methodologies, which contribute to reasonable planning for a successful development of society and economy in CEEC under climate change conditions. Current regional climate projections show a strong warming and drying during the summer months, which seems partly due to a systematic error in model simulations. Detailed validation of the CLAVIER simulations, which goes much beyond this paper, is needed, and the results have to be related to possible climate changes projected for the region in future simulations.

*Key-words:* climate, climate change signal, regional climate change, regional climate modeling, validation, Central and Eastern Europe, temperature, precipitation

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## 1. *Introduction*

The nations in Central and Eastern Europe (CEE) face triple challenges of the ongoing economic and political transition, continuing vulnerability to environmental hazards, and longer term impacts of global climate change. Domestic development of market economies and democratic institutions is taking place in the context of complying the rules of these international bodies. At the same time, vulnerability to natural and human environmental hazards knows no boundaries in time and space. Examples include a series of extreme floods hitting the Tisza basin in the period of 1998–2001, the catastrophic dam failure such as the Baia Mare gold mine dam failure in Romania which resulted in cyanide pollution of the Lapus-Somes-Tisza-Danube rivers (January 2000; Relief Web, 2000), a number of other flood events such as the Labe/Elbe and Danube rivers (August 2002), a sequence of mostly flash flood disasters throughout Romania in 2005, plus the ongoing menace of air pollution, drought, deforestation, land slides, and soil erosion. In addition to these challenges, long term global climate change may offer opportunities as well as threats to environment, resources, and national well-being amidst the on-going stresses of transition and capricious environmental forces (most of it citation from Climate change in Central and Eastern Europe: Introduction, GeoJournal 57, 2002, 113–115).

It is urgently needed to address the ongoing and future climatic changes and possible consequences in CEEC.

Therefore, CLAVIER addresses the following three scientific goals:

1. Investigation of ongoing and future climate changes and their associated uncertainties in CEEC.
2. Analyses of possible impact of climate changes in CEEC on weather pattern and extremes, air pollution, human health, natural ecosystems, forestry, agriculture and infrastructure as well as water resources.
3. Evaluation of the economic impacts of climate changes on CEEC economies, concentrating on four economic sectors, which are the agriculture, tourism, energy supply, and public sector.

Objective 1 is to provide reliable climate evolution scenarios of the first half period of the 21st century for impacts research in the CEEC region. The issue of climate change uncertainties is particularly addressed. This objective will be achieved through assembling and assessment of existing climate scenarios for the region, the validation and improvement of the regional climate models, the performance of regional climate change simulations, and the detailed assessment of the associated uncertainties.

The evaluation of the economic impacts will be based on representative case study regions located in the three CLAVIER countries Hungary, Bulgaria, and Romania shown in *Fig. 1*.

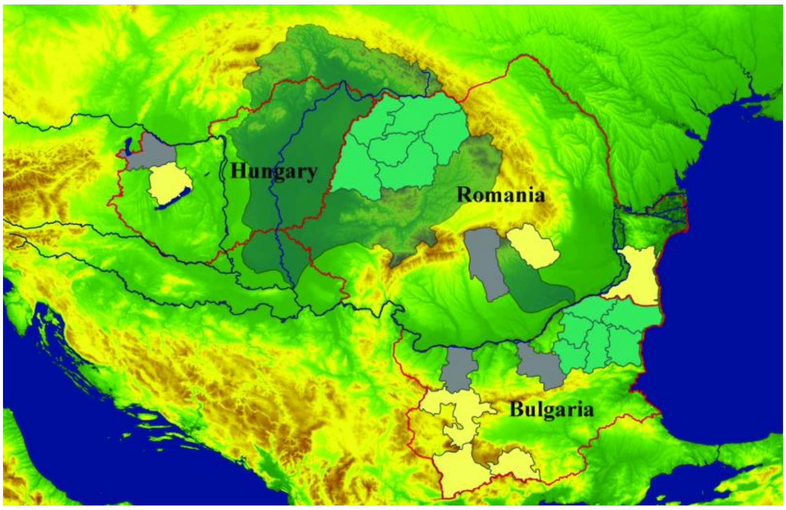


*Fig. 1.* CLAVIER case study regions for economic impact assessment (cyan: hydrological/water management; green: agriculture; gray: energy; yellow: tourism).

*Table 1.* List of CLAVIER project partners

| **Participant name** | **Participant short name** | **Country** |
|---|---|---|
| Max-Planck-Institute for Meteorology, Hamburg | MPI-M | Germany |
| Hungarian Meteorological Service, Budapest | OMSZ | Hungary |
| University of Graz/Wegener Centre, Graz | WegCenter | Austria |
| Centre National de la Recherche Scientifique, Paris | CNRS | France |
| Joanneum Research, Graz | JR | Austria |
| VITUKI Environmental Protection and Water Management Institute, Budapest | VITUKI | Hungary |
| Budapest University of Technology and Economics, Faculty of Civil Engineering, Department of Hydraulic and Water Resources Engineering, Budapest | BME | Hungary |
| Env-In-Cent Consulting Ltd., Budapest | EiC | Hungary |
| National Institute of Meteorology and Hydrology, Sofia | NIMH | Bulgaria |
| University of National and World Economy, Sofia | UNWE | Bulgaria |
| National Institute of Hydrology and Water Management, Bucharest | INHGA | Romania |
| University of Cluj, Cluj | UBB | Romania |
| The Institute of Geography of the Romanian Academy, Bucharest | IG | Romania |

To meet the project goals CLAVIER is split into a number of scientific objectives, for which work is carried out within 7 work packages. Researchers (*Table 1*) from 6 countries and different disciplines identify linkages between climate change and its impact on weather patterns with consequences on air pollution, extreme events, and water resources. A large effort is related to the first objective and includes modeling efforts on different scales, with different models, carried out by several partners. This paper will shortly introduce the modeling activities within CLAVIER, which will be presented in more detail in several other papers within this issue (*Szépszó* and *Horányi*, 2008). Here the focus will be on simulations from the regional climate model used at the Max Planck Institute for Meteorology. In addition, some general information about regional climate change in Europe, which has been achieved through regional downscaling of global IPCC AR4 simulations with the regional climate model REMO, will be presented. These simulations built the basis for more detailed investigations and first climate change assessments within CLAVIER.

## *2. The climate in the region*

A whole suite of studies shows that the climate is already changing and various impacts are visible throughout the world (*McCarthy et al.*, 2001; *Voigt el al*., 2004). The impacts on natural ecosystems and human health may be serious in the emerging but vulnerable regions in Europe, especially in CEEC. In Europe, 64% of all catastrophic events since 1980 are directly attributed to weather and climate extremes, and climate change projections show even an increasing likelihood of extreme weather events (i.e., *Voigt et al*., 2004). The average annual length of the growing season in Europe has increased by about 10 days in the recent four decades and is projected to increase further in the future (*Voigt et al*., 2004). As the annual air temperature increases in Europe, regional differences show that the temperature increase leads to warmer winters in the northeast part of Europe, while the southern part might face even warmer summers. Results from the PRUDENCE project (www.prudence.dmi.dk) show also a clear trend in annual precipitation, with a small increase in the North and a clear decrease in the southern regions of Europe, mainly in summer.

These results also point to the uncertainties, which are still included in climate change projections in CEE. A special model feature, that is typical for many regional climate models (RCMs) and to a less extent is visible in some general circulation models (GCMs), is the too dry and too warm simulation of climate over CEE during the summer (RAACS project; *Machenhauer et al.*, 1998). Their studies showed that this bias could not be explained by systematic errors in the large scale general circulation. In the MERCURE project (http://www.pa.op.dlr.de/climate/mercure.html), a follow-up of a RAACS, a major task was to understand and reduce or eliminate this model error, referred to as the summer drying problem (SDP). Here the Danube catchment was considered where the SDP is prominent. A major conclusion in MERCURE was that for three of five of the participating models, systematic errors in the dynamics appear which cause the SDP (*Hagemann et al*., 2004). In the fourth RCM, deficiencies in the land surface parameterizations were mainly responsible for its SDP; while the fifth does not have a SDP. (This RCM is not a limited area model but a global model with a stretched grid that had a high resolution over Europe.) As the SDP seems to be related to the dynamics in several models, it was speculated that deficient features in the dynamic part of the fourth and fifth RCM may also exist, which are only overlaid by systematic errors in the surface parameterizations of these two models. Although the SDP was allocated to the representation of the dynamics in the RCMs, an exact cause of the problem was not found nor could it be eliminated. Following studies in the PRUDENCE project (*Christensen* and *Christensen*, 2007; *Jacob et al.*, 2007) have shown that the SDP still exists in 8 of 10 participating RCMs (*Hagemann* and *Jacob*, 2007). The ninth RCM is the stretched GCM mentioned before, and in the tenth RCM large overestimation of precipitation over the Danube catchment throughout most parts of the year might compensate any tendencies of erroneous drying of the area in its climate simulation. A summer warm bias (compared to CRU data: http://www.cru.uea.ac.uk/) over the Danube catchment is present for all 10 RCMs (*Hagemann* and *Jacob*, 2007). The SDP is a systematic bias in the simulation of today's mean climate, and several questions concerning their influence on extremes like floods, droughts, and their interaction with land use changes arise from it if the quality of current and future climate simulations is considered.

The summer drying problem is still an open issue strongly influencing the uncertainty related to climate change projections in CEEC. This issue as well as other factors determining the uncertainty in climate change projections will, therefore, be addressed within CLAVIER taking into account results from past and ongoing climate change investigations, like PRUDENCE and ENSEMBLES.

Within CLAVIER linkage between climate change and its impact on water resources is investigated. Ongoing and future climate changes are influencing the hydrological cycle and its variability as shown in many studies (e.g., *Hagemann* and *Jacob*, 2007; *Vidale et al*., 2007). CEECs are especially exposed to changes in means and extremes of the hydrological cycle, e.g., changes in the water level of Lake Balaton or heavy precipitation events in the mountains of the Carpathian Range, which frequently lead to flash floods. Also the central and lower Danube basin ranks high on the world list of catchments exposed to flooding. Many of the streams have trans-boundary character what underlines the necessity to tackle these questions in a regional manner. The governments are planning measures to improve flood safety across CEE, and these efforts should be supported by reliable assessment of climate change induced modifications of flood hazard and flood risk.

Many regions of CEEC are surprisingly dry on the European scale; those are frequently exposed to droughts of short and long term (*Sharov* and *Koleva*, 1994). *Tran et al.* (2002) analyzed the relationship between atmospheric synoptic conditions over Europe and droughts in Bulgaria. *Szilagyi* and *Vorosmarty* (1997) analyzed the extreme groundwater depletion in the region along the central Danube. A clear connection between the atmospheric pattern and droughts is presented; however, Bulgarian droughts are influenced by even more features, thus many open questions have to be addressed. *Tran et al.* (2002) ask for more studies focusing on the impact of changes in atmospheric synoptic conditions and precipitation over the region. CLAVIER will address this issue and contribute to an improvement in the prediction of droughts in CEEC as well as to the investment of preparedness actions.

### *3. CLAVIER simulations*

The issue of climate change uncertainties will be addressed through the multi-model and multi-scenario ensemble approach considering the three steps of the scenario production chain: greenhouse gas emission, climate scenario with coarse resolution global coupled climate model, and regionally-oriented high spatio-temporal resolution climate scenario. The regional climate models used within CLAVIER are REMO from MPI-M (*Jacob,* 2001), used in Version 5.7 by MPI-M and version 5.0 by the Hungarian Meteorological Service, and the LMDZ model, developed at CNRS in Paris (*Hourdin et al*., 2006). The former is a limited-area model and the latter is a variable-grid atmospheric general circulation model with zoom over CEE. Data from two global climate models are used to drive and initialize the regional models. All three models use the ECHAM5/MPI-OM simulations performed for the 4th IPCC assessment report with a horizontal resolution of T63 (*Roeckner et al*., 2006). In addition, the LMDZ model will be forced by boundary data with 2 to 3 degree resolution from the IPSL global model. For the greenhouse gas emission, the scenario is based on the IPCC A1B scenario mainly; additional simulations with the B2 scenario are available for the LMDZ model. Therefore, an ensemble of climate change simulations allows an advanced analysis of uncertainties.

The three regional climate models are used to simulate the climate evolution in CEE for the period 1951 to 2050, the future regional climate projection being the first half of the 21st century. The spatial resolution is around 20 km for most of the simulations, which are currently analyzed. A high resolution (10 km) transient scenario simulation with REMO5.7 is planned on the inner domain shown in *Fig. 2,* covering the CLAVIER target area. The regional modeling activities are carried out in four steps:

*Assembling and assessment of existing climate scenarios for the region:*
Several climate change simulations exist for CEEC carried out either in context of the IPCC report or within European projects, i.e., PRUDENCE, ENSEMBLES. These simulations are, however, not sufficient for advanced impact studies, due to either the too low spatial-temporal resolution, or the partial spatial coverage of our domain of interest.

*Validation and adjustment of regional climate models:*
Both regional models REMO and LMDZ, need to be adapted for the region. In particular, the elimination of the SDP is envisaged. Model parameters will be adjusted in order to break down the summer anticyclone blocking situation, which seems to be too persistent in this region.

*Climate change simulations:*
Once the regional models are validated, climate change simulations will be run from 1951 to 2050 at about 20 km and 10 km horizontal resolutions. The 20 km simulations are directly driven by the global model data, whereas the 10 km simulation will be performed in a two step double nesting approach, i.e., using the coarser regional model simulation results to initialize and drive the high resolution regional model simulation on 10 km.

*Uncertainty due to internal variability of regional climate:*
To further investigate the issue of regional climate change uncertainties, a new technique for quantification of the uncertainties related to model internal variability is being introduced within CLAVIER. A physical consistent perturbation technique of the lateral boundary data as well as the surface boundary data (as for example orography, albedo, or sea surface temperature) has been developed. Therefore, several RCM simulations can be carried out for one given set of forcing data (like global reanalysis data or global climate model output). The simulations are sensitive to the slightly perturbed data at the lateral and lower boundaries, and the differences between the individual runs can be attributed to internal variability. This technique is in a first step tested for single decades. In a second step the developed perturbation method will be applied for longer time periods in order to create an ensemble of simulations with one RCM (in this case REMO) for one forcing data set (in this case ECHAM5/MPI-OM). The results of this ensemble will be analyzed in order to quantify the uncertainty related to model internal variability. This approach is complementary to the multi-model and multi-scenario ensemble approach.

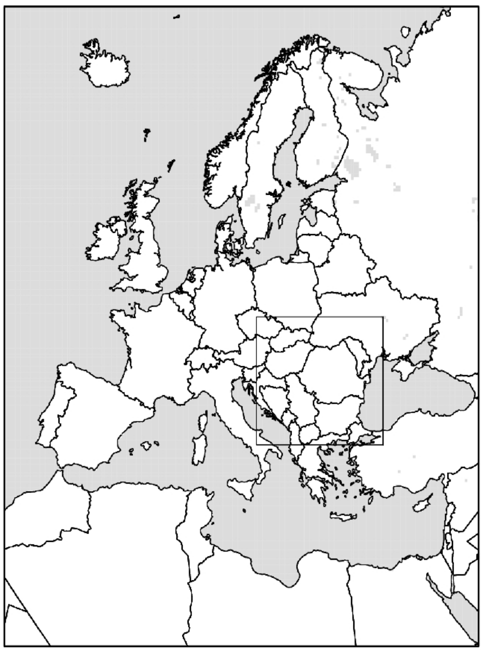

*Fig. 2.* Model simulation domain for the 0.22° (~25km horizontal resolution) domain. Inner box shows the CLAVIER target region.

## 4. *Climate change in Europe*

Within the last years, new global climate change simulations have been produced and published in the IPCC AR4 process. They have also been used for regional downscaling activities, which now provide new regional climate change signals, which are consistent with IPCC AR4 information. As an example, the horizontal pattern of possible climate change signals are shown using REMO5.7 results. Prior to the CLAVIER activities and in context of IPCC AR4, REMO was nested into the global climate model ECHAM5/MPI-OM developed and used at MPI-M. This means that at the lateral boundaries of the regional model domain, air masses are advected into the domain as they are calculated in the global model. Inside the regional model domain they are modulated through the influence of local and regional characteristics. Here REMO was used on a 50 km horizontal grid size for Europe, to analyze different developments of the climate change signals in different regions of Europe assuming an A1B scenario. All members of the ensemble of the A1B scenario, one A2 and one B1 scenario have been downscaled using the MPI-M modeling chain: ECHAM5/MPIOM and REMO5.7. Here only results from one A1B member (Nr. 1) are shown. A more detailed description and analyses of the climate signal are in preparation.

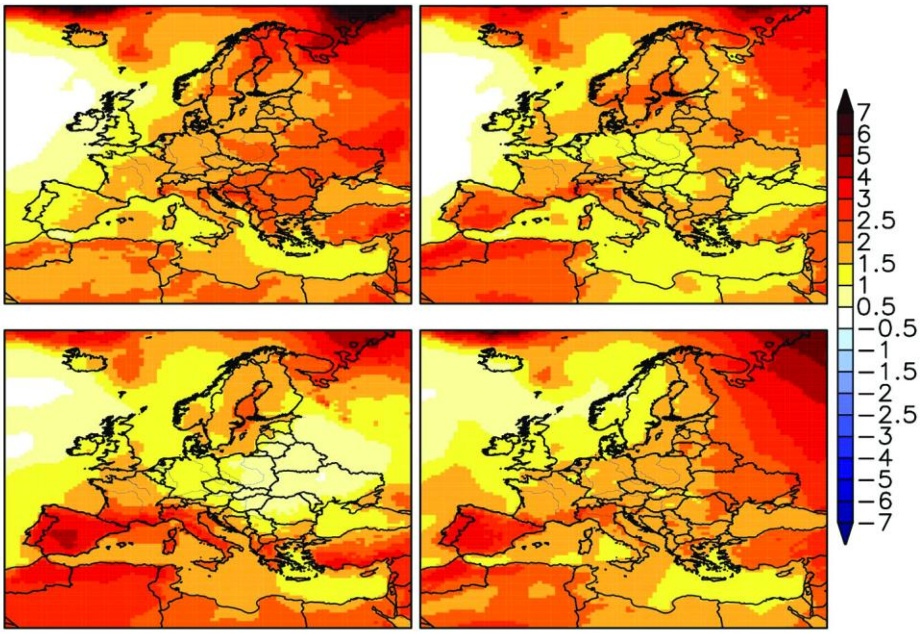


*Fig. 3.* Differences in the seasonal mean 2m air temperature [°C] around 2050 compared to the reference period 1961–1990. Winter (upper left), spring (upper right), summer (lower left) and fall (lower right).

*Fig. 3* shows the change in 2m air temperature for Europe, which is regionally very different. Until 2040–2050 an increase in summer temperatures (*Fig. 3*, lower left) of more that 2.5 °C compared to 1961–1990 is calculated for the south part of France, Spain, and Portugal, while in most parts of Central Europe less than 1 °C increase is projected. In winter (*Fig. 3*, upper left) the simulated increase in temperatures is about 1.5 °C to 2 °C and covers an area from Scandinavia to the Mediterranean. Only in those regions, which are directly influenced by air masses from the Atlantic Ocean, like Great Britain, Portugal, and parts of Spain, a less strong increase is simulated.

The changes until 2100 are displayed in *Fig. 4*. Here a strong warming of more than 3 °C for the entire European region is visible in summer and winter seasons.

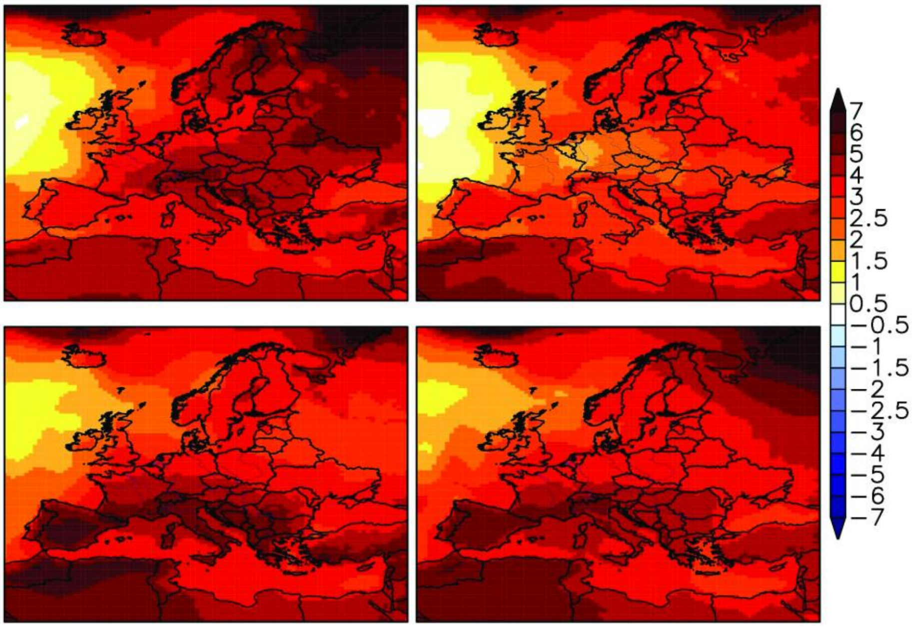


*Fig. 4.* Differences in the seasonal mean 2m air temperature [°C] around 2100 compared to the reference period 1961–1990. Winter (upper left), spring (upper right), summer (lower left) and fall (lower right).

At the same time, changes in precipitation pattern are projected. Until the middle of this century (~2050, *Fig. 5*) a clear decreasing trend of about 50% and more is calculated for the Mediterranean region in all seasons. Scandinavia might face more precipitation than today, especially in winter. During summer months precipitation seems to decrease with more than 30% in Great Britain. These changes are most likely related to an extension of the Azores High, which stretched further northeast into parts of Western Europe. The simulated pattern changes are developing further until 2100 (*Fig. 6*), with precipitation decreases in summer up to the southern part of Scandinavia.

For the CLAVIER region (as well as for the entire Europe) a strong warming is projected, which needs to be considered in view of the well-known SDP. Associated with the warming, a dividing line between areas with precipitation increase and decrease is calculated. The position of this line is still very difficult to project and its location can vary with emission scenarios or models under consideration. Therefore, CLAVIER emphasizes model validations and aims to analyze the robustness of the climate change signals from different simulations in the CLAVIER region.

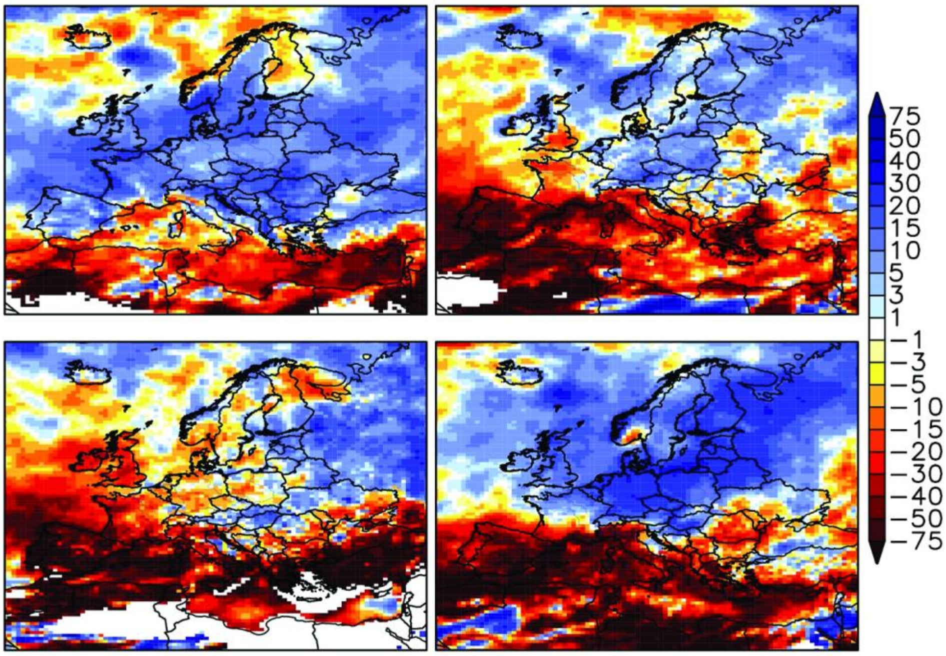


*Fig. 5.* Differences in the seasonal precipitation [%] around 2050 compared to the reference period 1961–1990. Winter (upper left), spring (upper right), summer (lower left) and fall (lower right).

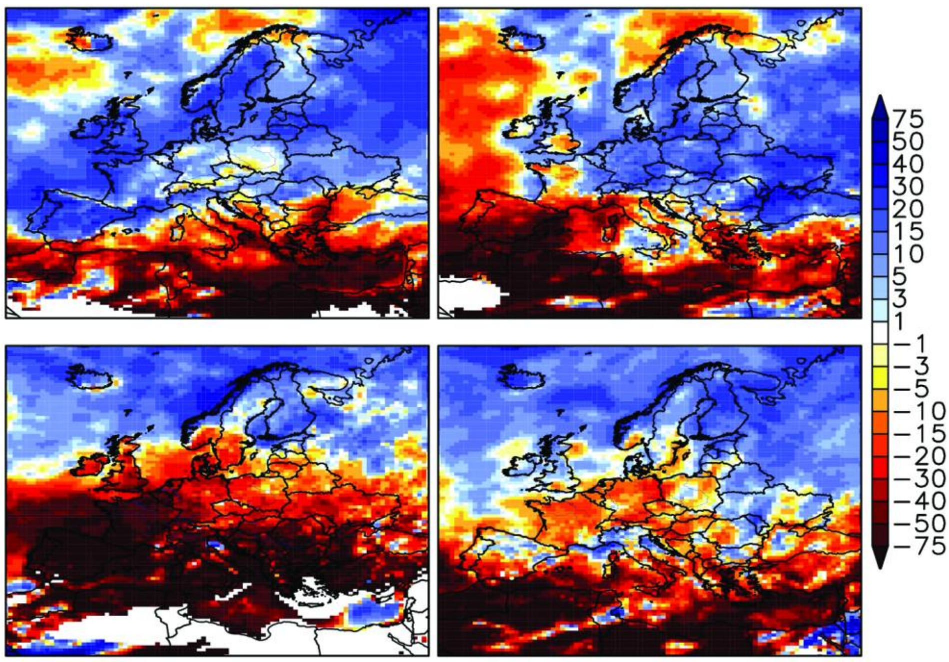


*Fig. 6.* Differences in the seasonal precipitation [%] around 2100 compared to the reference period 1961–1990. Winter (upper left), spring (upper right), summer (lower left) and fall (lower right).

## 5. *Validation of model performance in the CEEC region*

The CLAVIER project is still ongoing, therefore, results of the model validation will be shown exemplarily for the MPI-M REMO5.7 simulations. Similar work is done for the LMDZ model and for the REMO5.0 simulations done at the Hungarian Meteorological Service.

To assess how well the REMO model is suited to simulate the climate in Central and Eastern Europe, a validation based on a REMO simulation with a horizontal resolution of 0.22° driven by ECMWF ERA-40 reanalysis data has been performed. Initializing and forcing the regional model with reanalysis data ensures that the model results represent the real observed climate in the best possible way. These kinds of model simulations are thus well suited for a detailed comparison to meteorological observations. The model domain is shown in *Fig. 2*, where the small inner box denotes the area used for the evaluation. The model simulation covers the whole ERA-40 period from 1958 to 2001. For the analysis, seasonal mean values of simulated temperature and precipitation for a 20-year period from 1960 to 1979 have been compared to observed values. The observational dataset used was a gridded dataset of daily temperature and precipitation provided by the ENSEMBLES project (*Haylock et al*., 2007).

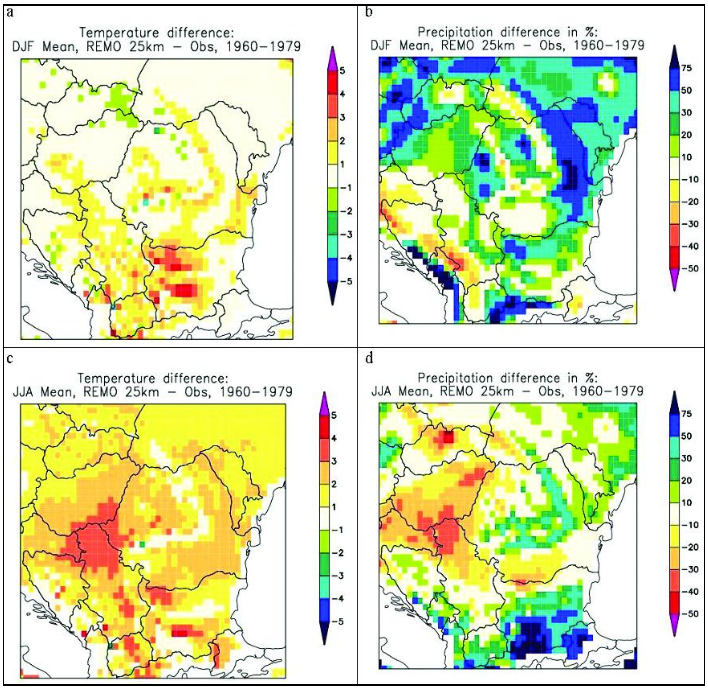


*Fig. 7.* Difference between REMO-ERA-40 simulation and ENSEMBLES observations for temperature [°C] (a, c) and precipitation [%] (b, d), for winter (upper panels) and summer (lower panels).

*Fig. 7* shows the deviations between simulated and observed 20 year mean winter and summer temperature and precipitation. For temperature (*Fig. 7a, c*) a warm bias of the model can be seen, which is larger in summer than in winter, and which is typical for the above mentioned summer drying problem. Associated with the summer warm bias there is a dry bias shown in *Fig. 7d*. The summer dry bias is prevalent in the lower regions, whereas precipitation in higher elevations is overestimated by the model (e.g., over the Carpathians and the mountain areas of Pirin, Rila, and Rhodopes in Bulgaria). Winter precipitation seems to be overestimated by the model in most regions (*Fig. 7b*). Part of the differences in winter precipitation, especially in mountainous areas might be related to a systematic underestimation of snow in the observational dataset, which is known as undercatch the measuring gauge, and which can be as large as 30 to 50% of the actual solid precipitation (e.g., *Frei* and *Schär*, 1998; *Fassnacht*, 2004). The warm bias and the underestimation of summer precipitation by the model are a substantial part of ongoing model development in the CLAVIER project.

## *6. Conclusions*

The validation of the REMO model for the Central and Eastern European region revealed that the summer drying problem known from previous modeling studies like MERCURE and PRUDENCE is still present in actual REMO simulations. The knowledge of such model biases is indispensable for the assessment of climate change impacts. The CLAVIER strategy to deal with the known model deficiency is firstly to examine the possible reasons for the SDP in detail in order to improve the responsible part of the model physics/dynamics. Secondly, existing biases have to be communicated to the users of the climate model data and solutions have to be provided to cope with the known uncertainties. This is especially important in a multidisciplinary climate change impact assessment project, like CLAVIER. For the CLAVIER project this means that the climate change information are provided as ‘delta change approach’, i.e., only changes of climatic variables are considered, not the absolute values calculated by the model. This approach is based on the assumption that model biases do not change under climate change conditions. In case that absolute values are inevitable, e.g., for the calibration of impact models, a bias correction based on observational data will be performed. Currently, the climate change simulations are in progress and first results are analyzed and distributed to CLAVIER partners.

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