Project No. 037005

CECILIA

Central and Eastern Europe Climate Change Impact and Vulnerability Assessment

Specific targeted research project

1.1.6.3.I.3.2: Climate change impacts in central-eastern Europe

Publishable Final Activity Report

Period covered: 1st June 2008 to 31st December 2009
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Project coordinator organisation name: **Charles University**

Publishable Final Activity Report

SIXTH FRAMEWORK PROGRAMME

SUB-PRIORITY 1.1.6.3

Global Change and Ecosystems

SPECIFIC TARGETED RESEARCH PROJECT

Project full title: **Central and Eastern Europe Climate Change Impact and VulnerabiLIty Assessment**
Project acronym: **CECILIA** Project website: **http://www.cecilia-eu.org**
Contract no.: **037005**
Priority thematic areas: 1.1.6.3.I.3.2 - Climate change impacts in central-eastern Europe
Duration of the project: **1 June 2006 – 31 December 2009**

List of Participants

Participant No.	Participant name	Participant short name	Country
1	Charles University, Prague	CUNI	Czech Republic
2	The Abdus Salam ICTP, Trieste	ICTP	Italy
3	Météo-France, Toulouse	CNRM	France
4	Danish Meteorological Institute, Copenhagen	DMI	Denmark
5	Aristotle University of Thessaloniki	AUTH	Greece
6	Czech Hydrometeorological Institute, Prague	CHMI	Czech Republic
7	Institute of Atmospheric Physics, Prague	IAP	Czech Republic
8	Swiss Federal Institute of Technology Zurich	ETH	Switzerland
9	University of Natural Resources and Applied Life Sciences, Vienna	BOKU	Austria
10	National Meteorological Administration, Bucharest	NMA	Romania
11	National Institute of Meteorology and Hydrology, Sofia	NIMH	Bulgaria
12	National Institute of Hydrology and Water Management, Bucharest	NIHWM	Romania
13	Hungarian Meteorological Service, Budapest	OMSZ	Hungary
14	Forest Research Institute, Zvolen	FRI	Slovakia
15	Warsaw University of Technology, Warsaw	WUT	Poland
17	Eötvös Loránd University, Budapest	ELU	Hungary

Total cost: **4,424,572 € (incl. estimated own resources of AC partners)**
Commission funding: **2,749,891 €**

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1 Project objectives

1.1 Project main goal

The main goal of CECILIA was to provide climate change impacts and vulnerability assessment in targeted areas of Central and Eastern Europe (CEE). This addressed directly the topic I.3.2 "Climate changes in central-eastern Europe" under research area 3.1.3 "Prediction of climatic change and its impacts" in part 3.1 concerning the "Impact and mechanisms of greenhouse gas emissions and atmospheric pollutants on climate, ozone depletion and carbon sinks" within FP6 Sub-Priority Area "1.1.6.3 Global Change and Ecosystems". Our objectives and work plan aimed to contribute to the scientific, technical, social and policy objectives of this topic area. We targeted our analysis on selected key areas of specific interest to the region. The floods and droughts which have occurred in recent summers in the region highlight the importance of the hydrologic cycle and water management in Elbe and Danube river catchments in response to the occurrence of precipitation extremes. Impacts on agriculture and forestry affecting the economy of countries in the region were studied as well. The 2003 heat wave demonstrated the importance of the health impacts of extreme conditions that could also lead to considerable changes in air quality, both regionally and in major urban centres.

The aim of the project was to assess the impact of climate change at the regional to local scale for CEE using very high resolution simulations in order to capture the effects of the complex terrain of the region. This goal was expected to be achieved mainly using very high resolution RCMs run locally for targeted areas. From the viewpoint of climate change scenario production two time slices were planned, for near future 2020-2050 and far future of 2070-2100. Changes in weather patterns and extreme events were addressed within the project as they affect the sectors important for the economies and welfare of individual countries in the region. Uncertainties were evaluated by comparing results with those from previous projects (PRUDENCE, ENSEMBLES). The selected applications of the CECILIA outputs considered water resources and management, agriculture, forestry, air quality and health. In addition, CECILIA was aiming to improve the access of CEE researchers to information and tools for climate change research by providing an efficient use and access to the results of previous and ongoing EC projects which the proposed research will benefit greatly from, e.g.:

- "Modelling the Impact of Climate Extremes (MICE)"
- "Statistical and regional dynamical downscaling of extremes for European regions (STARDEX)".
- "Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects" (PRUDENCE)
- "ENSEMBLE-based Predictions of Climate Changes and their Impacts" (ENSEMBLES)
- "Quantifying the Climate Impact of Global and European Transport Systems" (QUANTIFY)

Thus, the project CECILIA aimed to integrate world leading European expertise in regional climate modelling with high resolution impact studies to provide new policy relevant information on climate change and its interactions with society at the regional scale. It was expected also to feed into adaptation and mitigation strategies in the targeted areas.

1.2 Key issues

Emphasis was given to application of regional climate modelling studies at a resolution of 10 km for local impact assessments in key sectors of the region. Very high resolution simulations over this region are necessary due to the presence of complex topography and land use features. Comparison with the results based on statistical downscaling was also provided. Statistical downscaling methods for verification of the regional model results were developed and applied, and assessments of their use in localization of model output for impact studies were performed. The objectives were outlined to be achieved through the following tasks:

- *To collect, assess and make available for first local impact studies the scenarios and climate simulations produced in previous relevant projects where available (WP1)*
- *To adapt and develop very high resolution RCMs for the region (10 km grid spacing) and perform regional time-slice nested runs driven by ERA40 data and by GCMs for selected GHG change scenarios (WP2)*
- *To verify the model results, compare RCM and statistical downscaling results, analyze and develop the methods for verification, particularly at local scales, to provide the scenarios (WP3)*
- *To estimate the effect of global climate change on extreme events in the region, including the assessment of the added value of high-resolution for the simulation of the relevant processes and feedbacks. To evaluate uncertainties in regional projections by comparing results from previous projects (WP4)*
- *To assess (using high resolution downscaling results) the impacts of climate change on the hydrological cycle and water resources over selected catchments; the effects of climate change on the Black Sea (WP5)*
- *To study (based on the high resolution downscaling results) the impacts of climate change on agriculture and forestry, carbon cycle and selected species (WP6)*
- *To study (based on the high resolution downscaling results) the impacts of climate change on health and air quality (photochemistry of air pollution, aerosols) (WP7)*

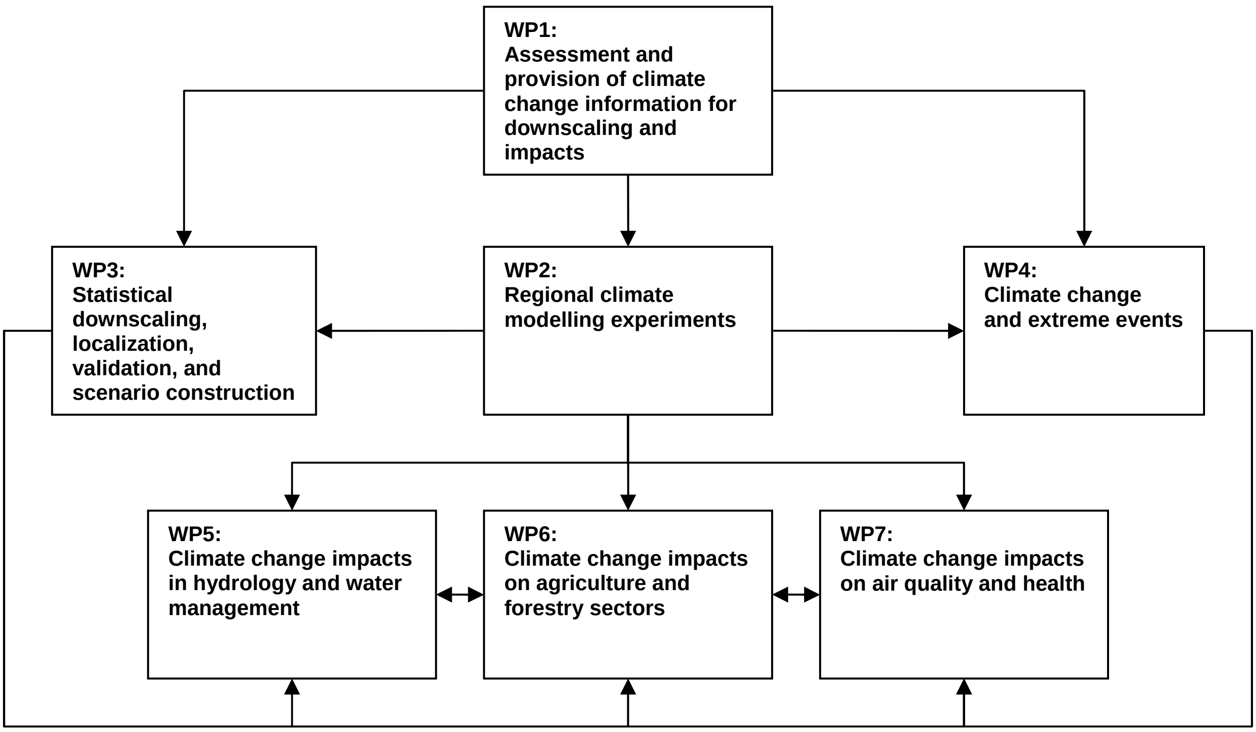

***Figure 1**. Interactions between the workpackages*

Fig. 1 shows the overall structure of the project tasks with their relations, WP2 being the core of the project and together with WP1 supporting the project with outer data, and WP3 and WP4 providing the climatological inputs for impact studies within the individual sectors covered by WP5, WP6 and WP7.

1.3 Technical approach

The project CECILIA brought for the first time very high resolution localization of climate change scenarios into the targeted areas of CEE. Improving upon the project ENSEMBLES where Europe-wide scale has been adopted at high resolution, here we have addressed even higher resolution on a significantly smaller domain. This higher resolution enables not only more detailed description of the topography and land use, but it allows to introduce new processes, as interaction of climate change and air quality, subgrid effects etc. However, it requires the adaptation of parameterizations available at coarser resolution. One of the main objectives of this project was to adapt a few of the models used for ENSEMBLES (ALADIN-Climate and RegCM) for very high resolution (grid spacing of 10 km) simulations over selected sub-domains. The assessment of the role of significant but previously not resolved topographical features and land-use patterns was supposed to be provided in these experiments as well as the evaluation of the sensitivity of the simulations to the choice of the model domain. In the region of CEE the need for high resolution studies is particularly important due to the appearance of complex topography features as Alps, Carpathians basin and smaller mountain chains and highlands in most of the countries that significantly affect the local climate conditions. A resolution sufficient to capture the effects of these topographical and associated land-use features is necessary as illustrated in Fig. 2, where comparison of topography representation in different resolutions is presented in the detailed view on the Czech Republic.

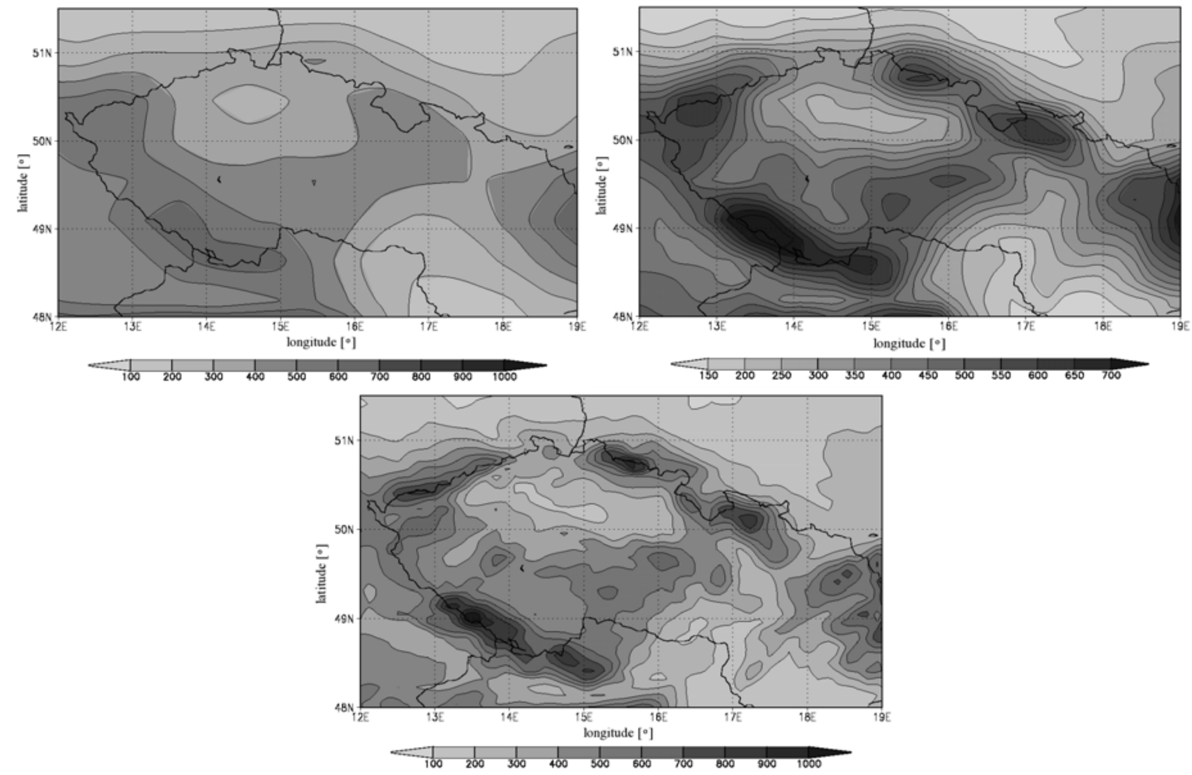

Figure 2. *Detail of topographical features seen in ENSEMBLES' 50 km resolution (upper left) and 25 km (upper right) and 10 km for CECILIA proposal (bottom panel).*

The most reliable source of information on the evolution of the atmospheric environment in the next decades comes from RCMs. Clearly, they are RCMs that can bring the relevant information for impact studies, which are mostly done regionally or locally, while the GCMs are not able to provide such localised information. It was demonstrated in PRUDENCE that the major source of uncertainty for RCM was the driving GCM. It is thus essential to use at least two GCMs (ARPEGE and ECHAM5). Since ARPEGE and ALADIN have been written and developed to work with each other and RegCM has been used already with ECHAM5 as well, it is natural to use these two pairs. As the forcing GCMs introduce their own systematic errors in the regional climate, a first step consists of forcing the high resolution RCM with data as close as possible to observation. The ERA40 reanalysis is used for driving the RCMs runs for validation in 1961-1990 (2000) as well as GCM driven control experiment validating the full model system, the other future simulations are snapshots driven by GCM conditions for 2021-2050, and 2071-2100.

Statistical downscaling (SDS) is an alternative approach to get high resolution insight to climate change issue. SDS consists of seeking statistical relationships between the variables simulated well by GCMs and the surface climate variables of interest. These relationships are usually trained on observed data and then applied to the control and perturbed GCM outputs, the former serving for verification and the latter for climate change scenario construction. As for the methods, the majority of SDS studies employ linear methods, most notably multiple linear regression and canonical correlation analysis. Nonlinear methods have recently begun to emerge as well. The added value in the project consists mainly in a complex inter-comparison of performance between the dynamical and statistical models. The ability to simulate extreme values is also of great importance. RCMs even at high resolutions of less than 20 km still do not provide site-specific information required in many impact models, which becomes relevant especially in regions with complex topographical features as typical in focal areas of the project. Methods for localization of model outputs were proposed based on regression against geographical variables, with the residuals being interpolated using geostatistical methods.

Previous results showed the possibility of the changes of statistical distribution of climate parameters in our targeted domains. Despite the relative agreement of climate-change scenarios concerning the changes in extremes over this region, a significant uncertainty remains with regard to their exact magnitude and the attribution of the causes for these changes. Some studies have highlighted the role of large-scale circulation changes, but land-atmosphere interactions are clearly of key relevance as well. Moreover, certain aspects central to this issue are often not well represented in GCMs (land surface heterogeneity, complex topography, convection), or even in RCMs. Very high-resolution simulations can help investigating some of these open questions and can yield more accurate estimates of future changes in extreme weather events over the targeted regions. Other issues that need investigation are the effects of domain size on the simulated processes, choice of parameterizations and boundary conditions.

The impacts of climate change on hydrology are estimated using scenarios for changes of climatic inputs to a hydrological model. Improved models have been developed to simulate water quantity and quality involving representation of the physical processes. The climate change has potential effects on the components of the water balance (precipitation, evaporation, soil moisture, groundwater recharge and river flows) and their variability over time. In a river basin the hydrological variability over time is influenced by variations in precipitation over all the time scales. Flood frequency is studied in high resolution scenarios of climate change which bring more precise information based on better definition of the catchments. The frequency of low flows is affected primarily by changes in the seasonal distribution of precipitation, year-to-year variability, and the occurrence of prolonged droughts. Climate change has the potential to affect all of these factors in a combined way that is not yet clearly understood. The local effects of climate change on soil moisture will vary not only with the degree of climate change but also with soil characteristics where high resolution of the simulations might be of great importance. Groundwater is the major source of water, particularly in rural areas in arid and semi-arid regions, but there has been very little research on the potential effects of climate change. The great number of hydrological studies has focused on potential changes of streamflow. To estimate the impact of climate change on the hydrological resources, mathematical rainfall-runoff models were outlined to be used for the reference basins. These basins were selected based on the assessment of the vulnerability of water resources and corresponding adaptation measures. The models can be applied both in the case of present regime and regimes of climate change scenarios taken from downscaled results. When taking the results of statistical downscaling the use of weather generators is required to obtain inputs for most hydrological models, while in the case of very high resolution RCMs both spatial and time resolution could be satisfactory for direct input to the basin models. The assessment of water quality changes and impacts on availability and management of surface water resources is important as well. This implies the analysis of hydrological balance changes, nutrient (N, P) concentrations and eutrophication in a river network with reservoirs used for drinking water supply and recreation.

The increased content of CO_2 in the air stimulates photosynthesis. At the same time, higher ambient CO_2 allows to reduce the transpiration intensity through decreased stomatal conductance, especially under higher temperatures. This should lead to improved water use efficiency by plants and thereby to a lower probability of water stress occurrence. The impact of the changed weather regime brought about by the CO_2 increase is referred to as "indirect effect" or "weather effect". The most important weather variables that directly determine the crop yield are solar radiation, precipitation and temperature. If no management response (e.g., other cultivars, change in the planting date or soil water conserving practices) is applied, cereals in general yields typically decrease with increasing temperature due to a shortening of phenological phases. On the other hand, the crop response to high temperatures clearly depends on the character of the temperature increase as well as the developmental stage of the crop. There are major gaps between the actual and attainable yields of crops, attributable largely to pests, diseases and weeds. Therefore predicting the potential distribution of all pests, both indigenous and introduced, plays a key role in determining the effects of global change effects on agricultural, horticultural and forest ecosystems. The distribution and intensity of current key pests and diseases may be affected, leading to changed effects on yield and on control measures such as pesticides and integrated pest management. However, as it was stated in the IPCC 2001 report only modest progress has been made in understanding pests response to climate change since the last comprehensive overview.

Climate change and other pressures will alter future carbon (biomass) storage in forests, but the regional extent and direction of change is still unknown. Research reported since the early nineties confirms the view that the largest and earliest impacts induced by climate change are likely to occur in mountainous and boreal forests, where changes in weather-related disturbance regimes and nutrient cycling are primary controls on productivity. Forest growth has increased during the past several decades in European forests; climate warming, increasing CO_2, increased nitrogen deposition, and changes in management practices are factors that are assumed to be behind the increase. The impacts of temperature and CO_2 have been shown in experiments and are extrapolated by model calculations.

The concentration of air pollutants depends on both anthropogenic and climate factors. A main issue is the quantity of emissions of primary pollutants as well as of precursors of secondary pollutants. Long range transport to the target regions was taken into account by simulation for the whole Europe, driven by RCM runs with a grid resolution of 50x50 km. These simulations then can constrain nested higher resolution runs (10x10 km) for a smaller domain focusing in CEE both for present and future climate. The key species are ozone, sulphur, nitrogen and PM, which have a central role in tropospheric chemistry as well as the strong health impacts. Emphasis is given to future key species exceedances of the EU limits for the protection of human health, vegetation and ecosystems as well as WHO guidelines. Another risk factor for the human health, which finally goes hand in hand with the issue of air quality through the chemistry of pollutants, are heat waves, and in certain extent even cold waves. The summer of 2003 encompassed one of the most severe heat waves on record in central and western Europe causing both human losses and damage to natural ecosystems. First guess of possible impacts of climate change on mortality and attempt to split the direct effect of heat and cold waves from the effects of air quality can be made on the basis of this study. Climate change may affect exposures to air pollutants by a) affecting weather and thereby local and regional pollution concentrations; b) affecting anthropogenic emissions including adaptive response of increased fuel combustion for fossil fuel-fired power generation; c) affecting natural sources of air pollutant emissions; and d) changing the distribution and types of airborne allergens. In addition, the chemical composition of the atmosphere may in turn have a feedback effect on the local climate. Weather is also associated with energy demands (e.g., for space heating and cooling) that could alter patterns of fossil fuel combustion. In particular, individual responses to extremely hot weather can result in large increases in air conditioner use. In addition, high temperatures cause increased VOC evaporative emissions when people run motor vehicles. The health effects of air pollution are broad and diverse, including dramatic episodes of increased mortality at high concentrations. In humans, the pulmonary deposition and absorption of inhaled chemicals can have direct consequences for health. Nevertheless, public health can also be indirectly affected by deposition of air pollutants in environmental media and uptake by plants and animals, resulting in chemicals entering the food chain or being present in drinking-water and thereby constituting additional sources of human exposure. Furthermore, the direct effects of air pollutants on plants, animals and soil can influence the structure and function of ecosystems, including their self-regulation ability, thereby affecting the quality of life. The most sensitive groups include children, older adults and persons with chronic heart or lung disease.

1.4 Expected achievements/impact

Although the broad response of global climate to increased greenhouse gas concentrations is well established, many unknowns remain in the regional details of projections of future climate change. Thus, the central internal objectives of CECILIA have been to improve regional climate scenarios and their localization for climate impacts models, and comparing these results against the results of previous and ongoing projects to assess the added value of dynamical downscaling at very fine scales. The general aim of CECILIA was to improve Europe's ability to assess the consequences of global climate change at the local scale, and on this basis to assist to formulate more precise response strategies and more scientifically based negotiating positions. Such an effort assists in the successful implementation of the FCCC (Framework Convention on Climate Change) and the Kyoto Protocol, for the negotiations in the post Kyoto process and in regulations to mitigate the possible consequences of climate change as concluded by IPCC. Very high resolution and better regional predictions are required to guide long term planning in sectors such as agriculture and energy.

Several key issues connected with climate change have become of interest in recent years, such as the occurrence of extremes (like heat waves, drought, heavy precipitation and floodings) or effects on air quality, with potentially severe impacts on the quality of life, health and safety. The occurrence of these extreme events, in some cases causing loss of human lives or extensive damages and costs, is affected by the relation between extremes and climate change which can be better explored using high resolution climate modelling. Results allow us to evaluate the vulnerability of different sectors in the regions. CECILIA provides high resolution tools to help anticipate and ameliorate the adverse impacts of climate change on humans both at the individual and at the societal level. It helps to identify and exploit positive impacts. It provides demonstrations of the use of these tools in important economic, environmental or social sectors where the impacts of climate change are likely to be felt. Results of simulations generated within the project are available for other interested institutes in Europe, with the possibility of use in national projects on climate change impacts over the targeted area.

Climate change represents a major factor affecting the global and European environments. Natural ecosystems will become stressed if climatic zones shift at a faster rate than the ecosystems can migrate. Changing availability of natural resources such as water supply may adversely affect the sustainability of European activites. A more stressed environment will be even more vulnerable to natural hazards. CECILIA with high resolution climate simulation can help foresee and reduce the adverse impacts on the local environment and natural resources of the targeted regions. It also provides mitigation information to reduce the hazards concerning these important factors. Concerning the environment, CECILIA, similarly as the EC project QUANTIFY, provides a platform for reducing the gap between climate change and air quality sciences, putting together traditional aspects of climate change impacts and impacts on air quality.

This project brings very high resolution localization of climate change scenarios into the targeted areas of CEE, with the added value of climate scenarios produced locally. This provides necessary policy relevant information concerning the local adaptation and/or mitigation measures. Moreover, it is providing know-how and tools which can be further used for the analysis of the climate change development and climate change impacts on different sectors of the society in the target region. With the emphasis on former Eastern Block countries the CECILIA project is providing new access and contacts for researchers from this area to the European research activities and thus it helps to bridge existing gaps. An important point of innovation consists in the fact that very high resolution climate information will allow application in integrated climate change impact studies, which is in turn providing necessary policy relevant information for decision makers and local authorities in the region.

2 Climate change analysis

The core of the project was based on high resolution simulations for dynamical downscaling in individual targeted regions of CEE covered by WP2. However, it was WP1 starting with preliminary assessment of climate change in the region from previous data available to put the project effort to the overall context of climate change and to provide first stream of data for preliminary studies of other WPs. WP3 used statistical methods for downscaling and further postprocessing for bias removing and localisation of the model outputs. Finally, WP4 analysed the statistical properties of the climate characteristics, including their distribution and long list of indices used in impact studies. All the effort has been made to provide localised climate change scenarios for climate change impact assessment.

2.1 WP1

The objectives of WP1 were 1) to assess a climate change information for Central and Eastern Europe (CEE) from previous projects (PRUDENCE, CMIP3, ENSEMBLES), 2) to provide the climate change information from previous projects for first stream impact work, and 3) to complete ARPEGE and RegCM3 simulations at 25 km grid spacing over Europe for the second half of the 21st century (2051-2100) and the A1B scenario in addition to what is available from ENSEMBLES project till 2050 and to provide the meteorological fields to WP2 for driving the high resolution regional simulations. All these objectives were successfully completed by WP1 partners ICTP (WP1 leader), CNRM, CUNI, ETH, DMI.

The results of WP1 were needed for carrying out the other WPs, in particular they were needed in order to complete the simulations in WP2 and WP3, further for preliminary impact assessments in WP5, 6 and 7. Therefore the WP1 activities took place early in the project. Simulations with both ARPEGE and RegCM3 at 25 km grid spacing were completed for the period 2051-2100 (A1B scenario) extending the corresponding simulations (1950-2050) carried out for the ENSEMBLES project. RegCM3 was driven at the lateral boundaries by large scale meteorological fields from ECHAM5. Output fields from these simulations, both the meteorological fields required for driving higher resolution runs in WP2 and first-stream impact work in WP5-7, were made available in public servers at CNRM and ICTP for access by the rest of the CECILIA community. In addition, other fields from the ENSEMBLES and PRUDENCE simulations were collected by ICTP and made available.

For previous data assessment over CEE region, three sets of available climate projections were analyzed: the global model ensemble CMIP3 (completed in support of the fourth IPCC Assessment report), and the regional model simulations completed for the EU projects PRUDENCE and ENSEMBLES. This analysis leads to important results that were published in the peer-reviewed literature.

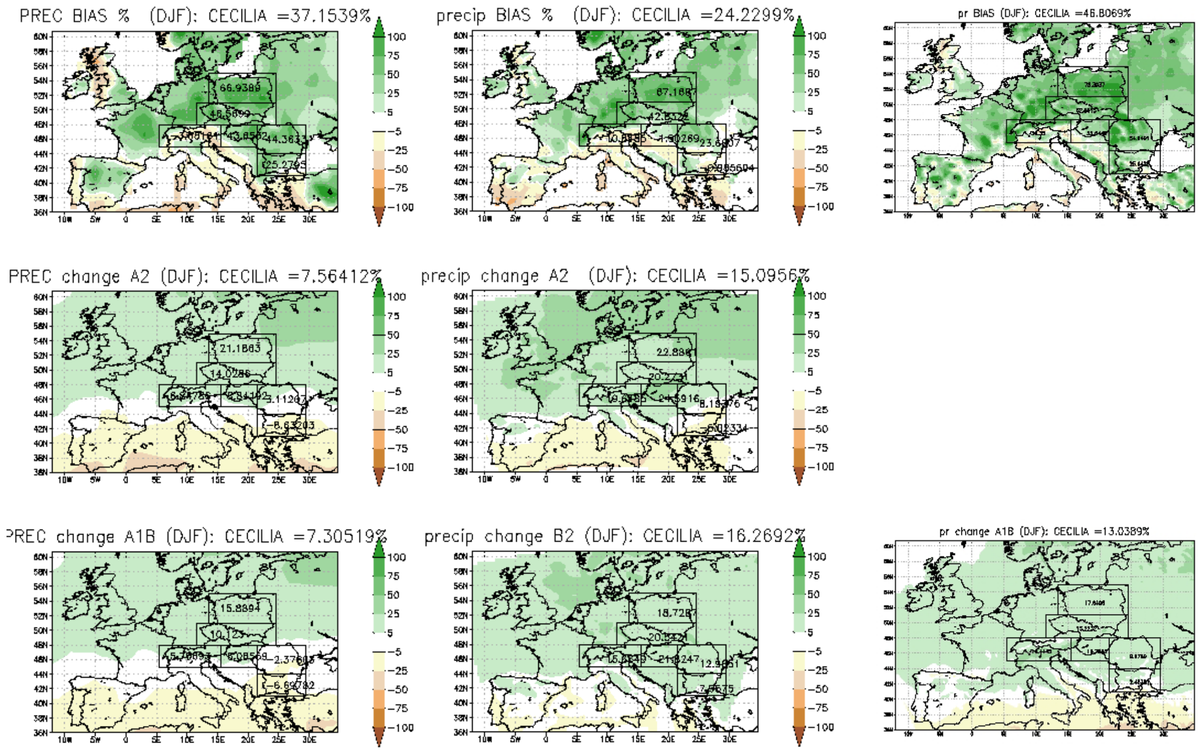

***Figure 3.** DJF precipitation bias (1961-1990) and change (271-2100 minus 1961-1990) from the CMIP3 GCM ensemble mean (left column), PRUDENCE RCM ensemble mean (middle column), and ENSEMBLES RCM ensemble mean (right column). The top row shows the bias, the middle row shows the change for the A2 scenario, and the bottom row shows the change for the A1B and B2 scenario. Units are % of 1961-1990 values.*

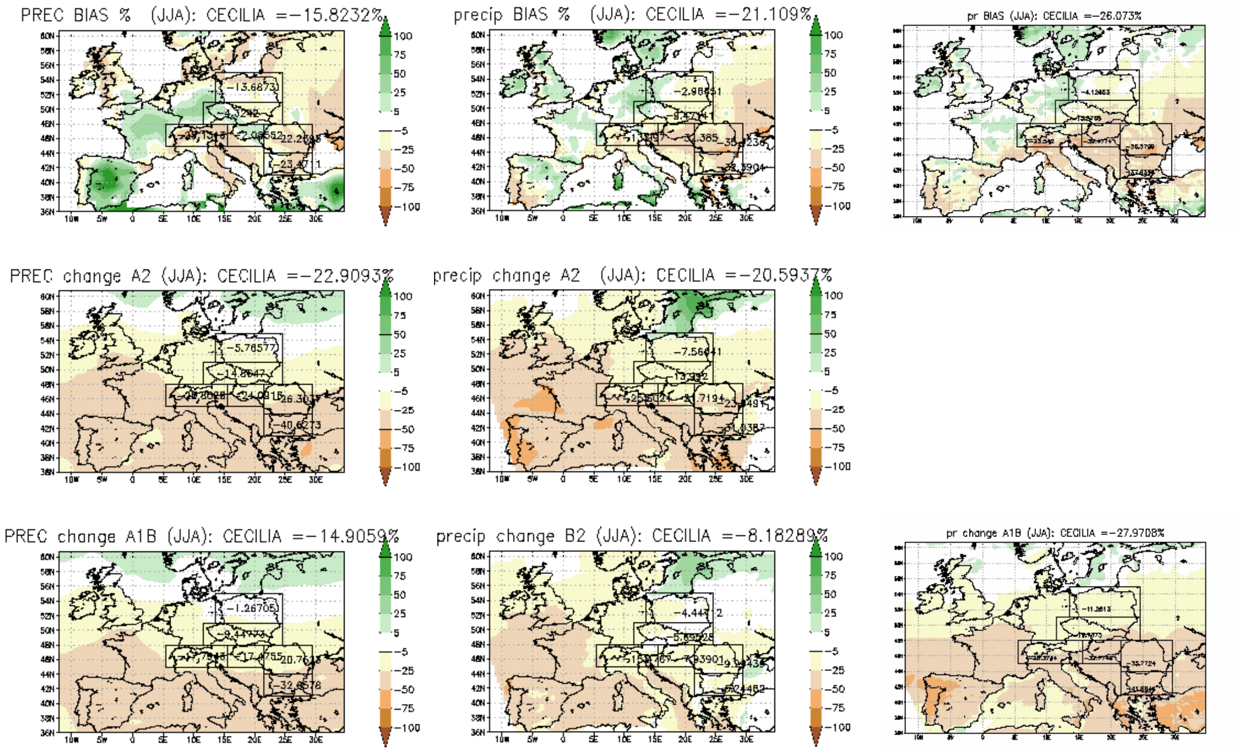

Figure 4. *Same as Fig. 3 but for JJA.*

As an example of this analysis, Figs. 3 and 4 show the December-January-February (DJF) and June-July-August (JJA) ensemble mean precipitation bias and change (for different scenarios) over Europe in the CMIP3, PRUDENCE and ENSEMBLES models. It can be seen that, although the different ensembles show different bias patterns, they all agree in indicating a dipolar precipitation change pattern with increased precipitation over northern Europe and decreased precipitation over southern Europe. The line of precipitation change sign reversal moves latitudinally with season, going from about 40-45 N in DJF to 50-55 N in JJA. This characteristic latitudinal/seasonal migration of the change pattern was also found in other variables, such as mean temperature change and change in temperature and precipitation interannual variability (not shown). Fig. 5 shows a latitude-time cross section of the change in temperature and precipitation mean and their interannual variability. These four variables show a consistent seasonal/latitudinal variation, which thus appears to be a robust feature of the climate change signal over Europe. The discovery of this feature was one of the important findings of WP1. It was named by Giorgi and Coppola (2007) the “European Climate change Oscillation” or ECO and it is tied to a latitudinal migration of the greenhouse gas-induced change in storm track. The ECO can have important applications in impact and detection/attribution studies. The CECILIA region of interest lies in an area that is crossed by the ECO and thus exhibits a marked seasonality of the climate change signal.

Another example of analysis performed in WP1 is illustrated in Fig. 6, which shows seasonal precipitation and temperature anomaly trends throughout the 20th and 21st century in the CMIP3 models over one of the CECILIA subregions (central Europe). The simulated trends are also compared with observed 20th century trends. It can be seen that warming over this region is simulated in all seasons for the 21st century and late 20th century, and the latter is consistent with the observed record. Precipitation trends are small since this region is located in the transition area of the north-south precipitation change dipole (see Fig. 4), and again the model ensemble is consistent with observations.

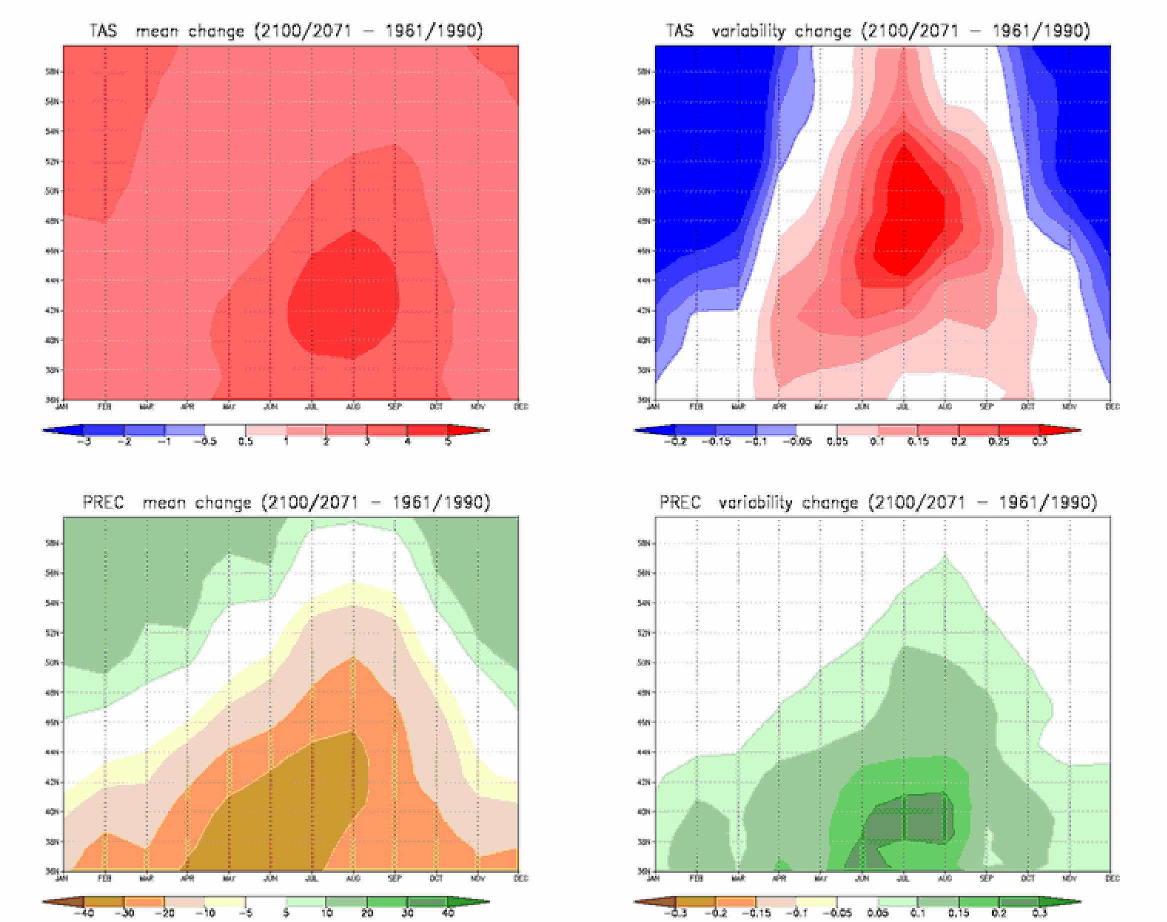

Figure 5. *Monthly values of the zonally averaged changes in mean surface air temperature (top left panel), temperature interannual variability (as measured by the standard deviation, top right panel), mean precipitation (bottom left panel), precipitation interannual variability (as measured by the coefficient of variation) over Europe from the CMIP3 ensemble, A1B scenario, 2071-2100 minus 1961-1990. Units are degrees C for temperature and % of 1961-1990 values for mean precipitation (the coefficient of variation is unitless). The zonal average is taken over the region between 10 W and 25 E.*

A final example of WP1 analysis is provided in Fig. 7, which shows the normalized distributions of seasonal temperature and precipitation anomalies (DJF and JJA) over the CECILIA Alpine region for the late 20th century (1961-1990) and 21st century (2071-2100, A2 scenario) PRUDENCE RCM simulations. The anomalies are calculated with respect to the 1961-1990 mean. The winter temperature anomaly distribution in the A2 scenario mostly shows a shift towards warmer temperatures, without a substantial change in shape. Conversely, for summer the temperature anomaly distributions show not only a shift but also a marked broadening and flattening. This affects especially the occurrence of extreme hot summers, which exhibit an increase in magnitude greater than the mean temperature change. The precipitation anomaly distribution in the A2 scenario shows a slight shift towards wetter winters. In summer, however, a large change is found. In the 20th century case the distribution is symmetric and sharply peaked, while in the 21st century case it becomes more asymmetric and flat, in particular with the occurrence of a much larger frequency of dry summers. These results thus indicate the occurrence of much warmer and drier summers over the Alpine region, and in particular an increase in the occurrence of extreme seasons. Similar results were found for the CMIP3 and ENSEMBLES models.

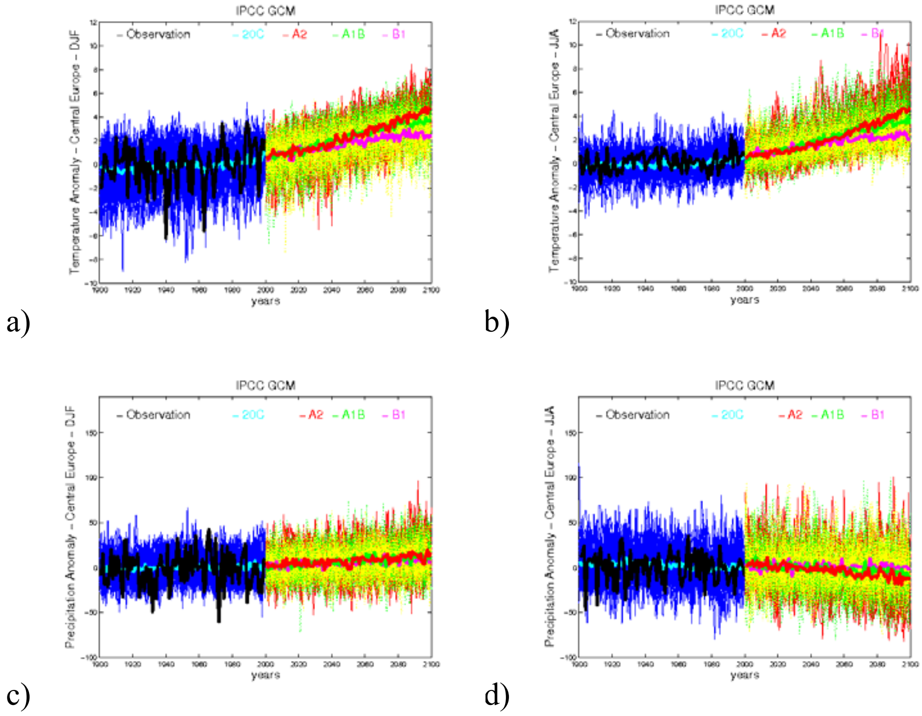

Figure 6. GCM temperature and precipitation anomaly trend (top and bottom row respectively) over central Europe (48-51 N; 11.5-24.5 E) for DJF and JJA [panels (a), (c), (b), (d), respectively]. The blue lines are 20-year running mean individual twentieth century model realizations; the cyan line is the twentieth century ensemble average mean. The black line reports the CRU observations. The yellow, green and red lines are the 20 year running mean of individual B1, A1B and A2 scenario realizations, respectively; the magenta, thick green and thick red lines are the B1, A1B and A2 ensemble average values, respectively. Units are °C for temperature and % of 1961–1990 values for precipitation.*

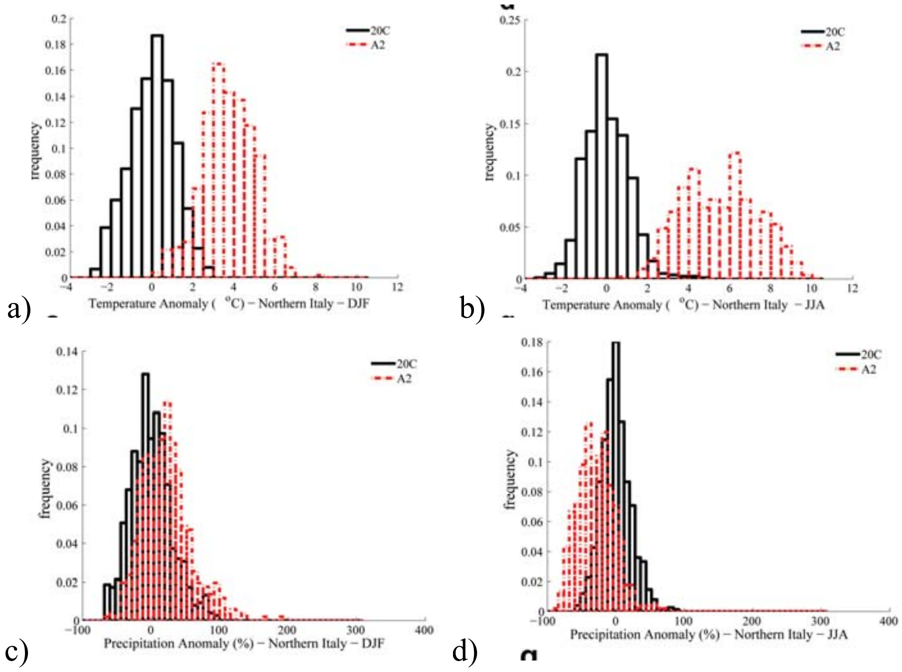

Figure 7. *Normalized distribution of seasonal temperature and precipitation anomalies in the PRUDENCE RCMs (land only) for 1961–1990 (black line) and 2071–2100 (A2 scenario) scenario period (red line) over the Alpine region (44-47 N; 6-15 E) for DJF [panels (a), (c)]), JJA [panels (b), (d)]. The anomaly values are reported in °C for temperature and percent for precipitation on the x axis; the y axis reports the normalized frequency of occurrence.*

Overall, the different types of analyses performed in WP1 and illustrated here indicated a substantial level of consistency across the results obtained in previous projects using different generations of both global (CMIP3) and regional (PRUDENCE, ENSEMBLES) models. This adds robustness to the projected change patterns. The 21st century temperature and precipitation change signal over the CECILIA area of interest follows the ECO behavior in showing a strong latitudinal and seasonal dependence, especially for the northernmost and southernmost CECILIA regions. Some of the CECILIA regions, however, lie in the transition zone of the ECO dipole pattern, so that the change signal exhibits a greater level of uncertainty. These results from previous projects provide a benchmark for comparison of the new high resolution scenarios completed in WP2 and WP3.

2.2 WP2

Regional climate modeling is an important issue for allowing impact studies in any domain where quantitative assessment is possible by the knowledge of laws that will remain valid in another climate (e.g. hydrology, chemistry, agronomy and forestry). The first climate models were global or at least hemispheric (Kasahara and Washington, 1967; Manabe et al., 1965). With increasing computer capacity during the second half of the 20th century, modelers have refined more and more the resolution of the general circulation models (GCMs). Limited area climate models appeared some 25 years after the GCMs (Giorgi, 1990). Though European support, a community has been built around this new tool, and the FP5-PRUDENCE project (Christensen and Christensen, 2007) federated most regional models in western Europe to produce an ensembles of climate scenarios over this continent for the end of the 21st century. The horizontal resolution of these regional climate models (RCMs) was 50 km. More recently, the FP6-ENSEMBLES project has targeted the mid-21st century with twice this resolution.

A resolution as high as 10 km has been typically used in numerical weather prediction for a decade. Such models produce 24h forecasts at country scale. The use of this kind of model for climate scenarios is very recent. Déqué and Somot (2008) demonstrated the added value of this type of model with respect to the PRUDENCE generation in simulating extreme precipitations over France. The geographical target of the CECILIA project is central and eastern Europe (CEE). As in PRUDENCE and ENSEMBLES, a multi-model approach is followed. The difference with the above two projects is that the model domains are different. The aim here is not an assessment of the uncertainties due to the selection of a particular model, but a scenario production oriented towards national impact modelers. WP2 of CECILIA is thus in charge of this production.

In Europe, each country has one or two RCMs, but they have not been built independently. In fact five families of model coexist. In CECILIA two families are involved. RegCM is the oldest family and stems back to the late 1980s. The most recent version is used in Europe (Giorgi et al., 2004) as well as in other parts of the world. ALADIN has been developed in the early 1990s for short-range forecasting, and is used by a large community in Europe and North Africa. Recently (Radu et al., 2008) this model has been used for climate simulations. Except for the horizontal resolution (10 km) and the integration domain (see below), the technical details on the model are not given here and the reader should report to the above quoted literature.

RCMs are not standalone models and need a driver. In the case of ALADIN, a global version of the same model, named ARPEGE, is used. This model has the capacity of increasing progressively horizontal resolution in a region of interest (Déqué, 2007). In CECILIA, we use the same driving simulation as in ENSEMBLES, with a 50 km resolution over Europe. For RegCM, a double nesting approach is used, also based on ENSEMBLES simulations. The ECHAM GCM (Roeckner et al., 2003) with 300 km resolution has driven a Europe-wide version of RegCM with 25 km resolution which in turn has driven the CECILIA versions of RegCM.

Six RCMs are used in the project to offer climate scenarios for the other WPs (see Fig. 8) and the simulations data are stored in DMI database:

- CUNI uses a RegCM version covering a large domain including Czech Republic, Poland, Austria, Slovakia and Hungary
- CHMI, who also participated in ENSEMBLES, uses an ALADIN version covering Czech Republic, Slovakia and Hungary
- ELU uses a RegCM version centered over Hungary covering also Czech Republic and Slovakia
- OMSZ uses an ALADIN version on the same domain as ELU. However the presence of the Alps at the western boundary of the integration domain provides poor results over the Czech Republic with this model
- NMA uses a RegCM version covering a large domain centered over Romania, covering Slovakia and Hungary
- NIMH uses an ALADIN version over Bulgaria

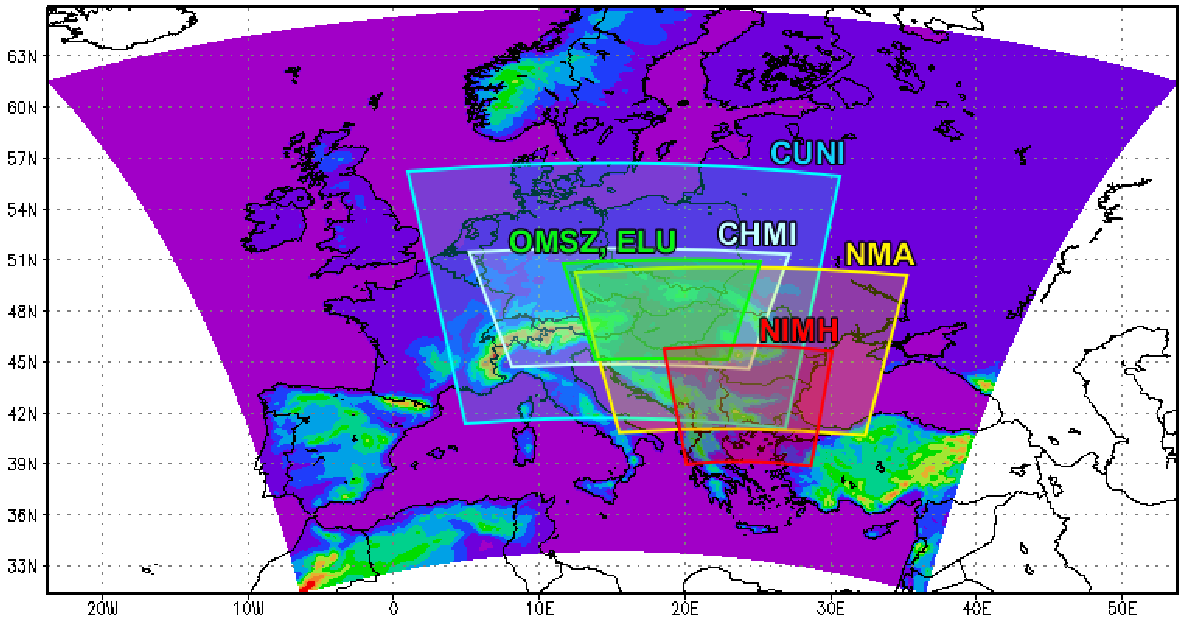

Figure 8. *Integration domains for individual partner simulations*

Before looking at results of the GCM-driven simulations, we need to ensure that our new high resolution RCMs do not produce by themselves spurious features. ERA-40 re-analysis (Gibson et al., 1997) proposes a set of 6-hourly global meteorological fields at 150 km resolution for the second half of the 20th century. This database has been used to drive the 6 RCMs over the period 1961-1990. Such a validation exercise has also been produced in FP6-ENSEMBLES and CECILIA (2009a) provides a comparison at country scale, and extends the result we show just below.

We restricted our analysis to country averages (the validation of weather station scale is in charge of WP3) and seasonal means (the study of weather extremes is in charge of WP4). In this report, we restrict to winter and summer seasons, and for each model, to the country where it has been implemented. Indeed RCM development is often optimized for a particular region, contrary to GCMs which must be acceptable everywhere, and therefore have larger systematic errors than RCMs, irrespective to the fact that they have a coarser resolution.

Tab. 1 shows the seasonal mean error for temperature and precipitation for each partner on its respective country. The verification data are provided by the ENSEMBLES project (Haylock et al., 2008). These errors are not negligible and of the same order as in ENSEMBLES (see CECILIA 2009a for this comparison, for the other two seasons and for other country/model combinations). In the case of Bulgaria, the cold bias may be explained by a difference in elevation between the model and the stations.

Table 1. *Mean systematic error for temperature (°C) and precipitation (mm/day) for different models and countries*

	DJF Temp.	JJA Temp.	DJF Prec.	JJA Prec.
CUNI (Czech Rep.)	0.20	-1.13	1.16	1.24
CHMI (Czech Rep.)	0.10	-0.08	0.19	0.56
ELU (Hungary	1.48	-0.15	0.35	0.43
OMSZ (Hungary)	-1.14	-0.39	0.29	2.78
NMA (Romania)	1.38	-0.18	1.06	-0.09
NIMH (Bulgaria)	-2.23	-1.93	-0.04	2.40

The main goal of the project is to produce scenarios. As we will see in the next section, the natural climate variability makes the local precipitation response hard to detect during the first half of the century. For this reason, which designed the set-up of the PRUDENCE project, we analyze first the response for 2071-2100 with respect to 1961-1990. One can imagine that the course of the century will be a progressive transition (not necessary linear) towards this state, since the radiative forcing increases smoothly. Of course, even if the models are right, the true century will be a superposition of this progressive signal with an unpredictable year to year variability. In addition, if one suspects that the models underestimate the climate change, one can consider that the patterns correspond to an earlier stage in the century. Overall climate change signal is shown in Figs. 9 and 10 for temperature and precipitation, respectively, as composite of the models of RegCM and ALADIN family, respectively. For temperature quite high consistency between the models can be seen and the results are in good agreement with previous data as pointed out in Sec. 2.1 and as further compared within Sec 2.4. For precipitation, rather small changes in Central Europe are consistent again with the previous results and the precipitation signal divide can be seen especially on the results of RegCM (perhaps due to larger coverage). The high uncertainity discussed below will be probably behind the inter-models differences.

Rather than showing one map per model and per variable for more detail analysis, we have aggregated the models. On each country, we averaged the responses which were available for this country. This makes abrupt transitions at the country borders: the maps must not be considered as a single chart, but as a juxtaposition of 5 charts (one per country). Fig. 11 shows the temperature response for a selection of grid points (0.25° grid). In winter, the warming is maximum over Romania. In summer, the warming is larger, in particular in the southern part with a maximum over Bulgaria. Note that Romania and Bulgaria are represented by a single model.

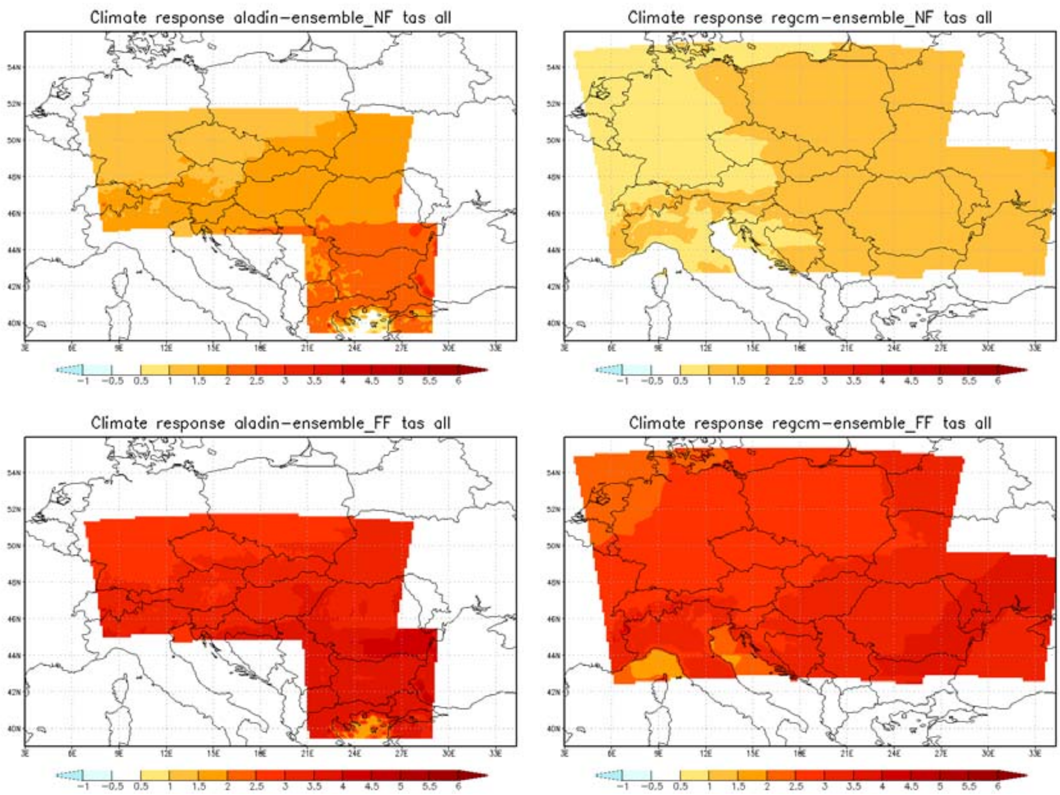

Figure 9. *Climate change signal of annual mean temperature (°C) for 2021-2050 (upper panels) and 2071-2100 (bottom panels) against 1961-1990, composites from ALADIN-Climate models (left panels) and from RegCM models (right panels) for Central and Eastern Europe.*

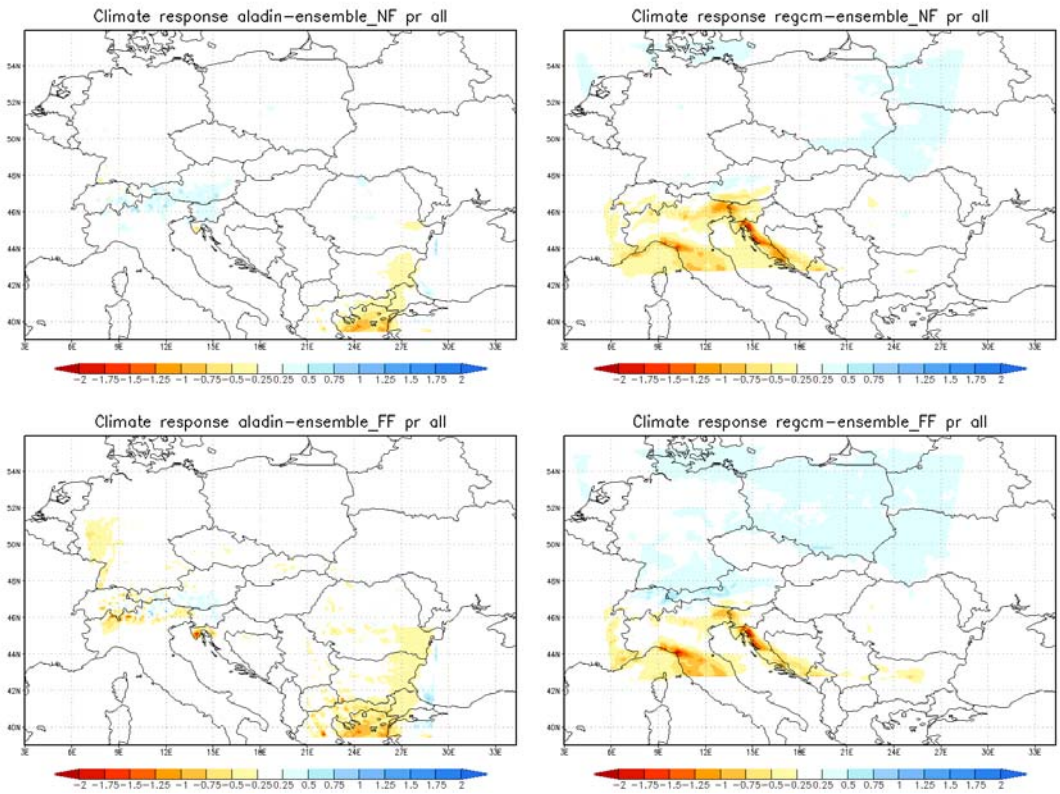

Figure 10. *Climate change signal of annual mean precipitation (mm/day) for 2021-2050 (upper panels) and 2071-2100 (bottom panels) against 1961-1990, composites from ALADIN-Climate models (left panels) and from RegCM models (right panels) for Central and Eastern Europe.*

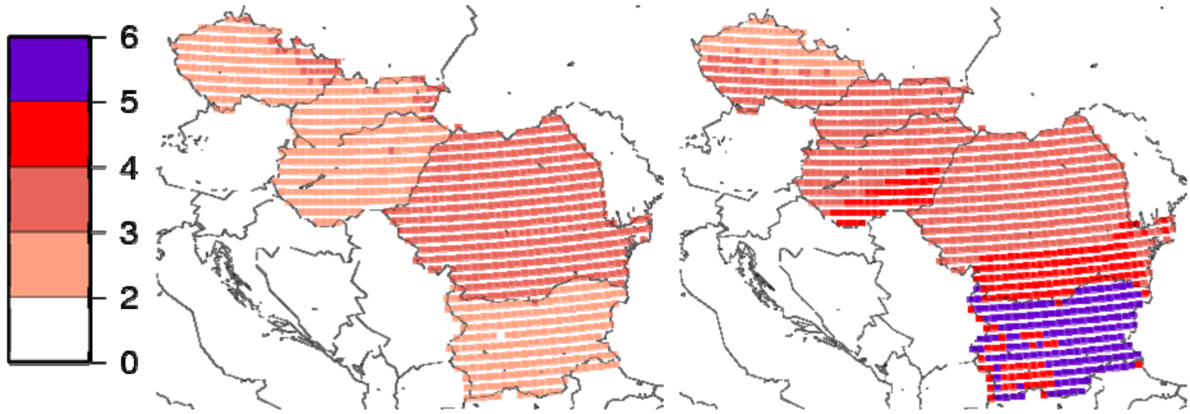

Figure 11. *Temperature response (°C) in 2071-2100 for the CECILIA multi-model (where applicable); winter (left) and summer (right).*

Fig. 12 shows the precipitation response. In winter, the North of the region undergoes a precipitation increase. In summer, precipitation decreases, particularly over Bulgaria. These features are in qualitative agreement with PRUDENCE former results (CECILIA 2009a).

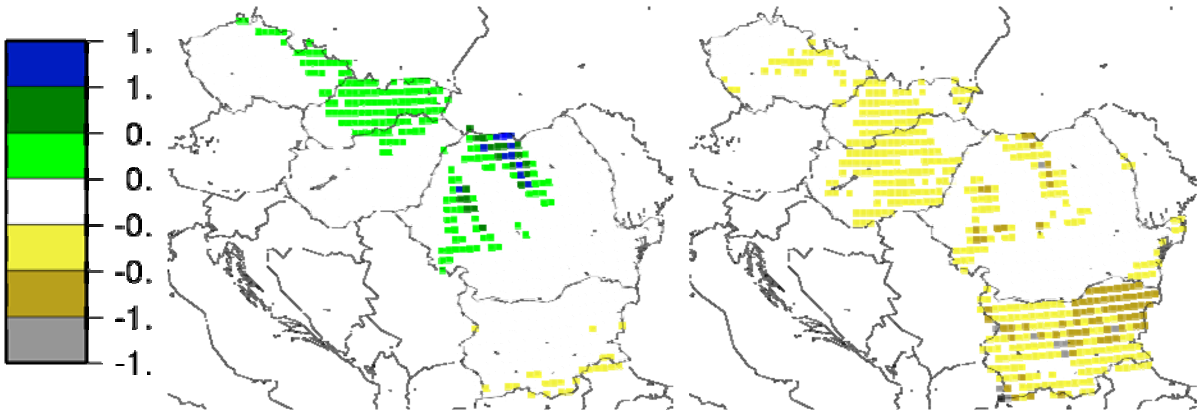

Figure 12. *As Fig. 11 for precipitation (mm/day).*

The 2021-2050 response is less than one half the results shown above. In FP6-ENSEMBLES, a project targeting this period, probability density functions (pdf) have been constructed at different locations using weights to combine the different models (Déqué, 2009). Here it is not possible to combine the 6 RCMs over the whole domain, but we can examine the individual responses at the nearest grid point to Budapest, where 5 models are available. Figs. 13 and 14 show the pdf for temperature and precipitation for each available model. Assuming the conditions for the limit central theorem are met, these pdfs are gaussian laws taking into account the interannual variability. In winter, the models agree upon a warming between 0.5°C and 2°C. In summer, the two ALADIN models (which use a different domain and different physical parameterizations) propose a warmer season, with a larger spread. The winter precipitation change is centered about 0, with less spread for the two ALADIN models. The summer response is model dependent, with two models proposing a decrease (ELU and OMSZ), two models proposing no change (CHMI and NMA) and one model an increase (CUNI). Note that the two extreme responses in winter (ELU and CUNI) are also the two extreme responses in summer.

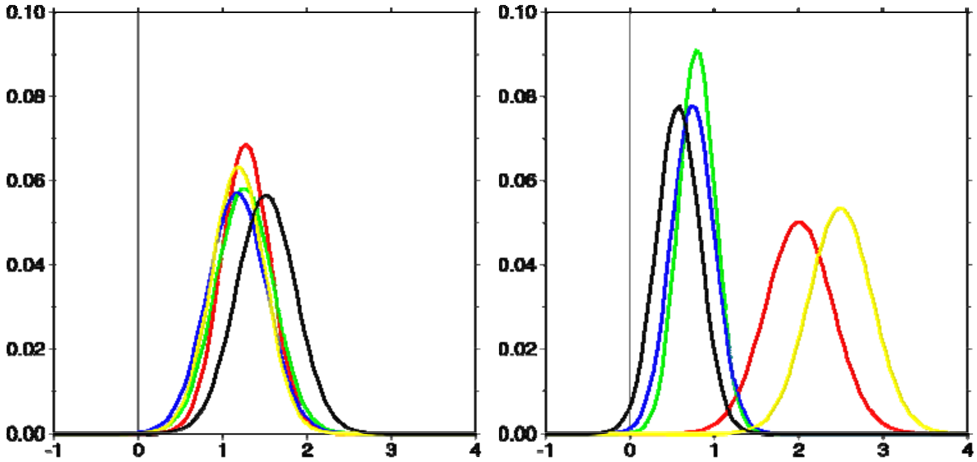

Figure 13. *Probability density function for temperature response (°C) in Budapest for CHMI (red) CUNI (green) ELU (blue) OMSZ (yellow) and NMA (black); winter (left) and summer (right).*

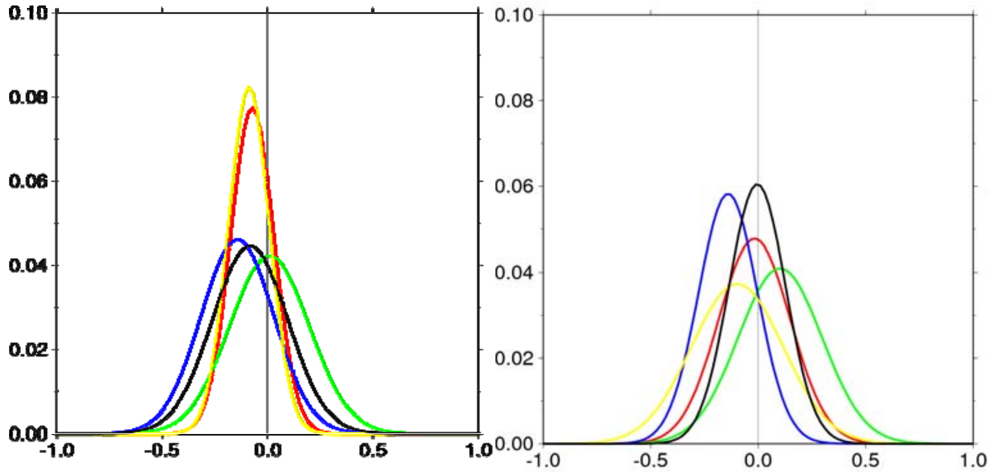

Figure 14. *As Fig. 13 but for precipitation (mm/day).*

Different conclusions may be drawn from the above results, and from other information produced by the project. The fact that we use a small area and a high resolution does not degrade the mean climate in general at country scale, but it does not improve it as well, except providing local details, which, however, are still of significant errors or uncertainties. This new generation of RCM must be improved by modification in the physics if we look for a more realistic climate than with versions at 50 km resolution. In CECILIA (2009b) we propose several tracks:

- change the convection scheme to take into account the fact that the convective column has not to parameterize vertical motions that occur in the 10-50 km range
- improve the planetary boundary layer discretization and physics to get better low clouds
- take into account the sub-grid elevation in mountain areas to improve snow cover and hydrology

A second conclusion is that at the end of the century, we get a stable climate response with a NW-SE gradient over the domain, warmer and drier in the SE in summer, wetter in the NW in winter. During the first half of the century, the warming is almost certain in sign, but with some spread in amplitude. The precipitation response is both statistically little significant and model dependent. In this case a probability approach is necessary, and a multi-model scenario for each country seems to be the future design of new experiments in CEE.

2.3 WP3

The main tasks of WP3 are connected to statistical downscaling techniques, the alternative approach used for downscaling the results of originally rather spatially coarse GCMs. The primary objective was to make comparison of the methods on the common region (central European area along the Czech-Slovak-Austrian-Hungarian borders) against observed data grided within the WP3 in 10km resolution. Actually, the purpose was to compare individual downscaling methods, i.e. statistical downscaling techniques (multiple linear regression, multiple linear regression on data stratified by circulation types, canonical correlation analysis, various kinds of non-linear methods, including neural networks, classification-based methods, and stochastic downscaling approach) between themselves, as well as with respect to the dynamical downscaling by the RCMs involved, models ALADIN-Climate/CZ and RegCM. Characteristics of temporal and spatial structure were analyzed, namely, the 1-day lag autocorrelation (persistence) and spatial autocorrelation. It can be summarized that RCMs systematically overestimate persistance while underestimate spatial autocorrelations. This behaviour is different from statistical downscaling models, for which underestimation of both temporal and spatial autocorrelations is typical.

To construct specific regional climate change scenarios using full advantage of information from RCM simulations it was found that some method of bias correction has to be used, especially for precipitation. Different methods were tested within the activities of WP3 and finally applied in most scenarios constructed. The evaluation of their performance was done by comparing the original model data (reanalysis driven, control) and the corrected model data with observational data. The example of BOKU technique presented in Fig. 15 is based on using the differences of the empirical cumulative density functions (CDF) of model and observation and it is applied to the model data so that the statistics of the observations are retained. The method uses correction factors that correct the model data depending on the CDF values. The correction factors are defined either as additive, which were used e.g. for the temperature data, or as multiplicative, used e.g. for precipitation.

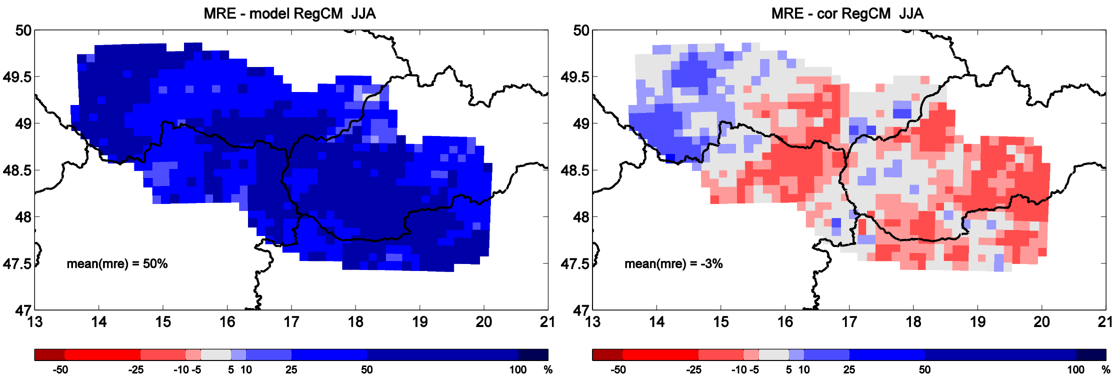

Figure 15. *Spatial distribution of mean relative errors for the model (left) and the corrected model (right) for JJA precipitation (simulation by the RegCM model, run at CUNI and postprocessed at BOKU).*

A low-parametric alternative to the percentile-matching bias-corrective procedure applied at BOKU was implemented at CUNI and used to modify data representing daily maximum and minimum temperature and daily precipitation, generated by the RegCM3 and ALADIN-Climate/CZ models. The method was demonstrated to successfully rectify major systematic errors in the model data: It was able to reduce substantially the bias of mean values, amend the spread of the values and bring a more realistic number of dry/wet days in case of the precipitation series (Fig. 16). A substantial improvement was also achieved for the representation of extreme tails of the statistical distributions of the target variables, including the highest/lowest quantiles, important for reliable assessment of the occurrence of extreme phenomena. However, some of the problems associated with the RCM outputs remained unsolved even after the correction, at least to some extent (e.g., sometimes unrealistic temporal persistence in the time series and potentially distorted physical consistency of the multivariate fields).

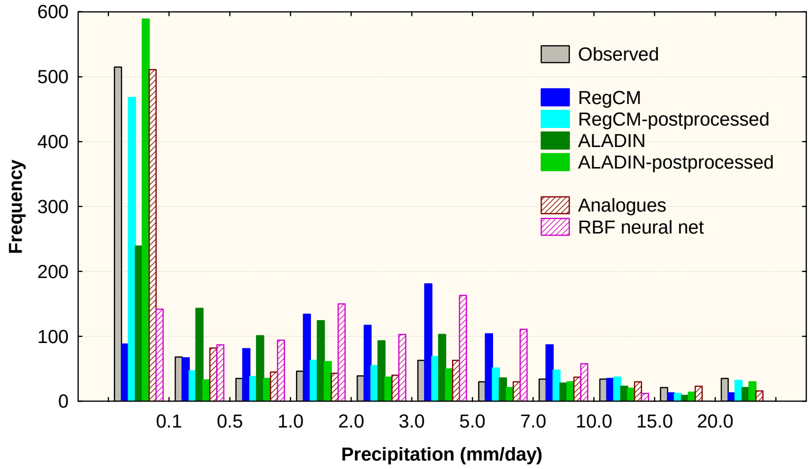

Figure 16. *Distribution of values of daily precipitation in the series obtained by different downscaling methods, dynamical or statistical (displayed for a single grid point, located at 49°00' N, 15°28' E) – JJA season. The RCM runs as well as the statistical downscaling mappings were driven by the ERA-40 data.*

Another important issue is the model output localization based on statistical downscaling techniques, developed and adapted for the project. Attention was paid particularly to techniques compensating for a simplified representation of the terrain elevation in the RCMs. It was shown that localization can substantially improve the model outputs for temperature-related characteristics, the relation of which to terrain elevation is very strong and well represented by the CECILIA regional models (see Fig. 17). By using the model-simulated vertical gradient, the correction could be applied for the climate data in the control period as well as for simulations of the future, on daily basis. The localization was carried out and tested for precipitation data as well; in this case, however, the connection of daily/monthly precipitation sums to terrain elevation was weaker and less realistically simulated by the RCMs (especially the RegCM model). The eventual improvement achieved by precipitation localization was therefore rather small on average and its benefit usually less significant compared to sources of error not related to the elevation mismatch.

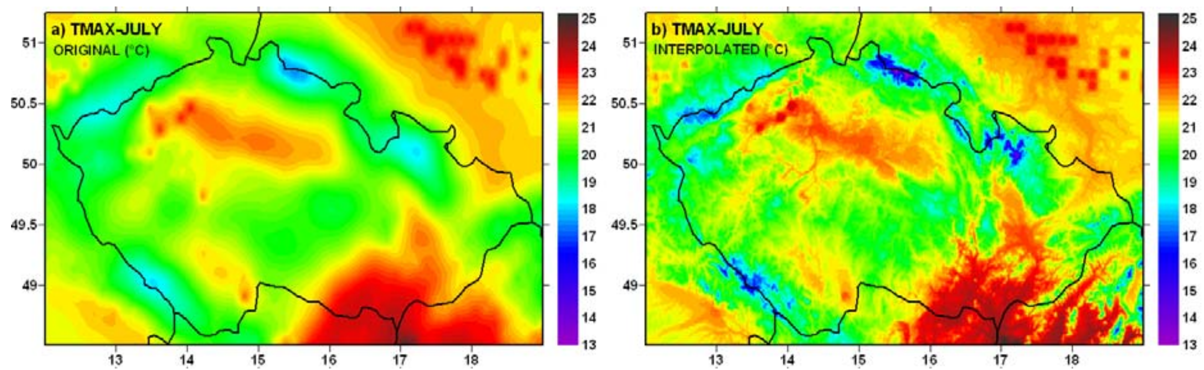

Figure 17. *Monthly maximum temperature in July, simulated by the RegCM model (left panel) and after the altitude-based localization of the model outputs (right panel).*

To obtain fields of temperature and precipitation both devoid of major systematic errors and detailed enough to be used for studies at very fine scales, bias-correction and localization were combined (see Fig. 18). The application was carried out for the outputs of the RegCM model, for maximum and minimum daily temperature and daily precipitation in the periods 1961-1990 (control climate), 2021-2050 (near future) and 2071-2100 (far future). While usually generating fields with spatial patterns close to reality, the procedure did not produce data which could be considered completely flawless. Specifically, insufficient density of the network of weather stations providing the observations seems to be a limiting factor for this type of postprocessing: In the 10 km grid, some local areas were underrepresented or characterized by an anomalously behaving measuring site, which introduced artifacts and unrealistic values into the postprocessed climatic fields, located usually in a vicinity of a single node of the original model grid. The point-wise debias/localization approach, although actually retaining the maximum amount of details available from local observations, may therefore be replaced with a correction constructed for a broader local area in future postprocessing applications.

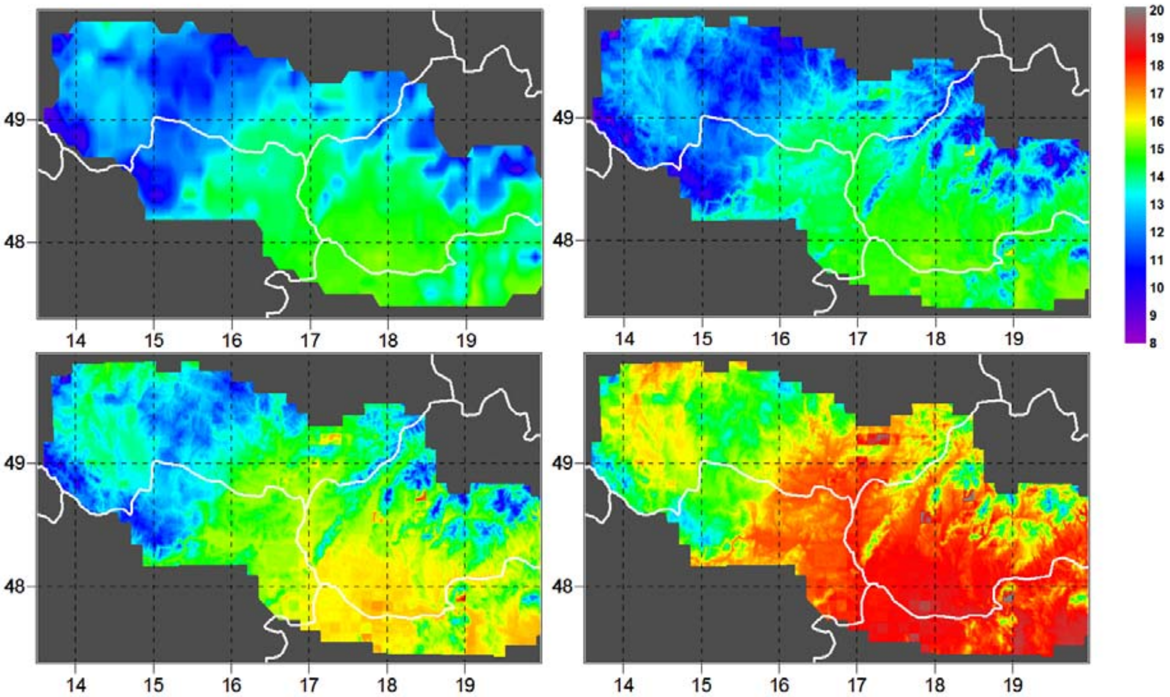

Figure 18. *Annual mean of maximum daily temperature (°C): Data simulated by the RegCM model after the bias correction (top left), localized data for the control period 1961-1990 (top right) and the future periods 2021-2050 (bottom left) and 2071-2100 (bottom right).*

2.4 WP4

While WP1 and WP2 limited their analyses to the basic climatic characteristics, WP4 focused on the comparison of statistical distribution characteristics in terms of 131 indices both from observations and from model runs, that were stored at DMI (http://cecilia.dmi.dk/) serving as a basis for the analyses, it was extensively used by the partners for other tasks including for the impact assessments. Outputs from the 10 km high-resolution simulations were analyzed in each domain by the partners involved, focusing on trends and on the validation with observational indices. This was done by individual partners for their domain (CHMI, CUNI, OMSZ, ELU, NMA, NIMH), a synthesis for the whole CECILIA region including an inter-comparison with pre-existing RCM data sets was provided by ETH and DMI (see Fig. 19).

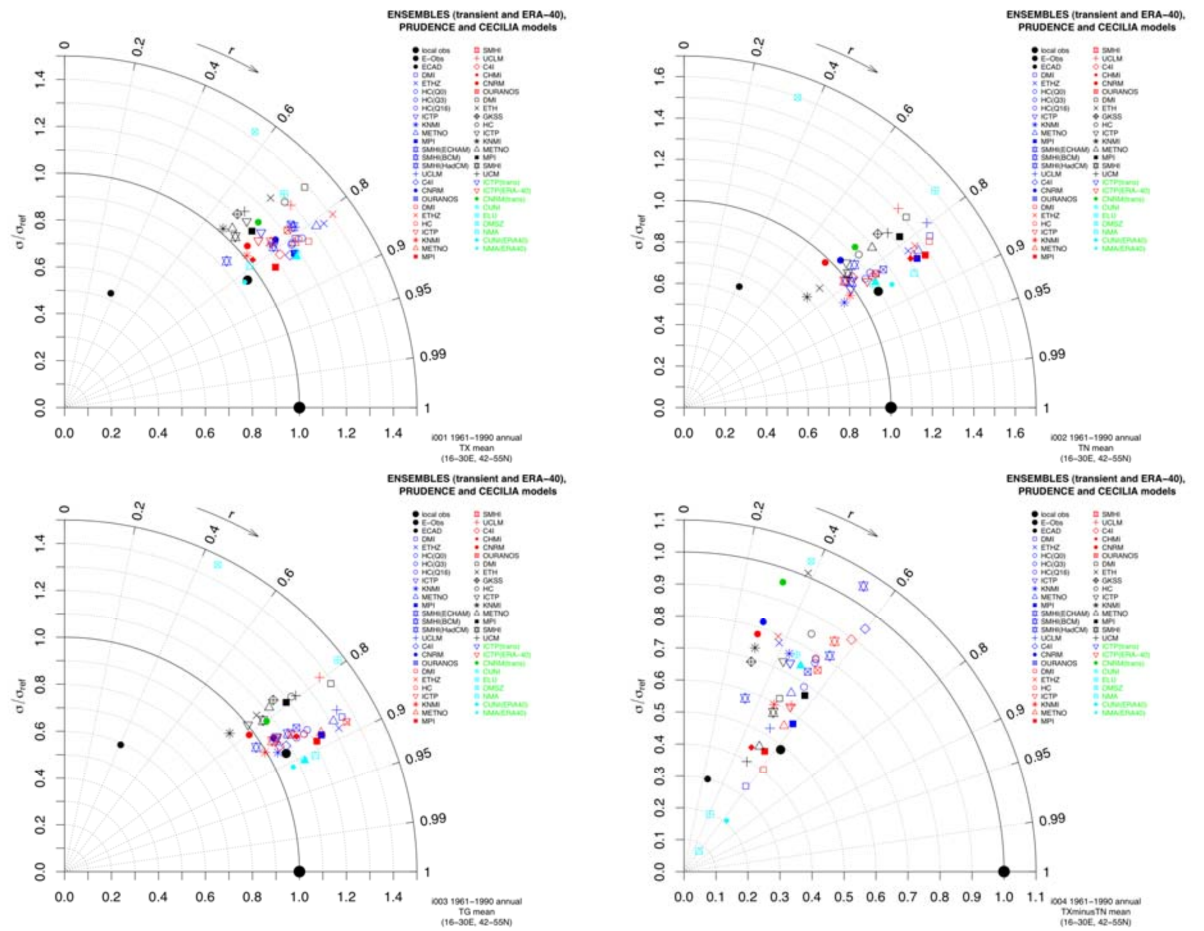

Figure 19. *Taylor plots including the ENSEMBLES transient (blue symbols) and ERA-40 (red symbols) simulations, the PRUDENCE RCMs (black symbols), and the CECILIA driving and high-resolution runs (green model acronyms, cyan symbols for high-resolution runs) compared against the local observations. For comparison, also the ECA&D and the E-Obs observations are included (also relative to the local observations). The CECILIA driving runs from ICTP coincide with the respective ENSEMBLES runs with the same model, they share the same symbols and colors. (Top left) maximum temperature, (top right) minimum temperature, (bottom left) mean temperature, (bottom right) daily temperature range. Annual values displayed for the period 1961–1990 and for the East European domain (16°E–30°E, 44°N–55°N). σ - spatial standard deviations (normalized by the standard deviation of the observations) and r the correlation coefficients.*

Moreover, sensitivity experiments investigating feedback processes that are relevant for the occurrence of extreme events were carried out and investigated. These highlight the role of land-atmosphere coupling for temperature variability in Central and Eastern Europe. Also, temperature extremes, as investigated by climate extreme indices and PDFs, are strongly affected by the absolute value and to a smaller extent also by changes in temporal variability of soil moisture. This is mainly due to intra-seasonal as well as inter-annual soil moisture variability. A study investigating the impact of soil moisture on temperature extremes showed a strong impact of soil moisture deficit (as expressed by the standardized precipitation index SPI) in particular for the upper quantiles of temperature extreme indices. This is the case in a Southeastern domain (encompassing Bulgaria and Romania) with a soil-moisture limited evapotranspiration regime.

3 Impact assessment

Another three WPs are dealing with the climate change impact assessment in selected sectors, like hydrology and water management (WP5), agriculture and forestry (WP6) and air quality (WP7). There are many connections in between these sectors, clearly the impacts on hydrology and water cycle result in impacts in agriculture and forestry, the latter perhaps with feedbacks back to hydrology. Air quality is connected as well, pollutants interact with water along water cycle and thus having the impact on water quality. Similarly, the exceedances of some pollutants are critical for plants growing and vice versa, biogenic emissions from plants, especially from trees, play an important role in ozone photochemistry. All these factors and processes are of interest in connection to changing climate because of possible serious consequences for human health.

3.1 WP5

One of the main tasks of WP5 partners (NIHWM – leading partner, CHMI, IAP, FRI, and NMA) was dealing with the direct consequences of precipitation within the catchments, i.e. with the rivers flow and runoff. Several catchments shown in Fig. 20 were used for modelling studies. After tuning the models using observational data and further application of primary stream of data from WP1 (previous model results, both GCMs and RCMs) in the simulations of monthly river flow under changed climate conditions, finally, the partners used as input data for their models new ALADIN and RegCM models results with 10 km spatial resolution obtained in WP2. For Hron river basin, Slovakia, and for two catchments of Jihlava River, Czech Republic, the climate characteristics were simulated by the ALADIN model, runoff values simulated for time period of 2021-2050 are from January to April and from August to September lower than 1971-2000, from May to July both values are essentially without any change and from October to December the values are higher than in the reference period 1971-2000. The mean monthly flow simulation for Ialomita and Buzau area, Romania, was based on the RegCM model results for the same periods (2021-2050, 2071-2100) and it is presented in Fig. 21. The simulated monthly discharges show an increase in winter period, especially for the near future period (2021-2050) and a general decrease for the end of the century period (2071-2100). These last results were compared with the results of simulations based on the RegCM model outputs in 25 km resolution, but there is not big difference between these two simulations.

***Figure 20**. Catchments used for simulations within WP5: 1 – upper Vltava river (HSPF model), 2 – Dyje-Jihlava (BILAN), 3 - Hron (KVHK) and 4 - Ialomita and Buzau (WATBAL)*

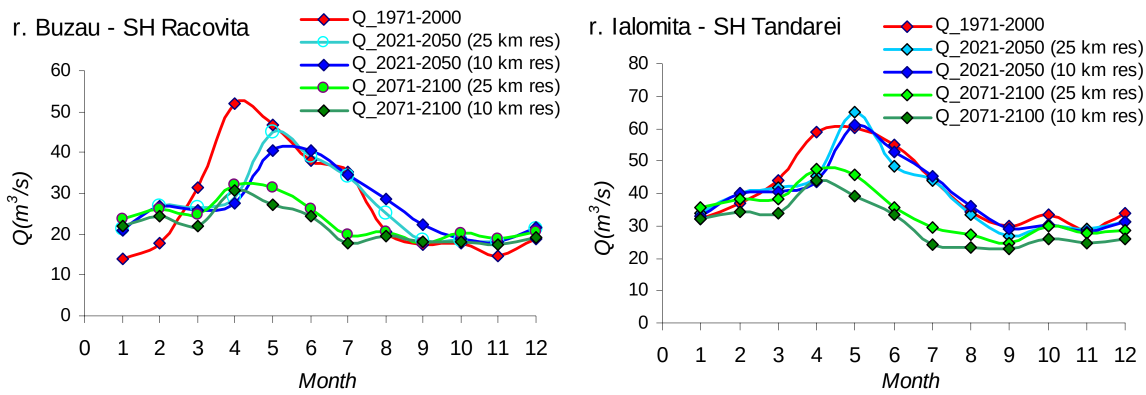

Figure 21. *Comparison of mean monthly discharges modification in climate change conditions from RegCM with 10 and 25 km resolution.*

In connection to the runoff simulations, extreme events were of significant interest in WP5 as well. Similarly as in WP4, where the changes of extreme parameters were studied, floods occurrence belonged to the WP5's objectives. The simulations of flood occurrence during 2021-2050 and 2071-2100 in the Dyje catchment (the final profile Podhradí, catchment area 1756 km^2) based on the ALADIN scenarios were evaluated (D5.7) and compared to the previous runoff calculations based on the global climate model. Tab. 2 shows some differences which are caused by different approaches of downscaling. All the flood waves were evaluated, the return time period maximum discharges were calculated and it is obvious that based on the ALADIN climate scenarios, the return time period peak discharges could be about 10% higher in future. It is also important to stress that the whole process of flood simulation is very uncertain and it is strongly dependent on the ALADIN-CE climate scenarios.

Table 2. *Comparison of measured and simulated return time period maximum year discharges.*

Return period [year]	Discharge based on measurement (1933-2009) [m^3/s]	Discharge based on measurement and simulation 1961-2000 [m^3/s]	Discharge based on measurement and simulation 2021-2050 [m^3/s]	Difference [%]	Discharge based on measurement and simulation 2071-2100 [m^3/s]	Difference [%]
1000	681	685	806	18	756	11
500	595	602	703	18	663	12
200	491	500	578	18	551	12
100	419	429	491	17	472	13
50	353	363	412	17	399	13
20	274	282	316	15	309	13
10	220	227	250	14	248	12
5	172	176	191	11	191	11

Another aim of WP5 was to deal with the impacts on water quality and ecosystems which is in close connection to water management. Further studies explored water quality responses in a temperate, stratified reservoir to climate change scenarios (D5.8) that were modelled with the atmosphere-catchment-reservoir simulation system. The scenarios of climate change were developed using the pattern scaling techniques from the outputs of 3 global and 2 high-resolution regional climate models, representative scenarios for the development of emissions of greenhouse gases and aerosols, and a range of climatic sensitivity to emissions. The anticipated climate change with its increase in temperature and impacts to the runoff can affect water quality in water bodies especially due to three groups of factors: changes in runoff paths through the soil, changes in the hydrologic conditions and modifications of hydrodynamics and seasonal mixing and stratification pattern. Water quality in the reservoir will be worsened by the increase in the scale of anoxia in the water column due to the smaller volume of hypolimnion and higher sedimentation rates under the conditions of decreased pool of accumulated water. All these phenomena together will result in a higher stress on aquatic ecosystem, especially on the littoral communities and fish.

To ensure future water requirements for the population, industry and agriculture, certain structural and non-structural measures are needed (D5.9). The adaptation measures to climate changes, proposed by NIHWM for Buzau-Ialomita area, are based on estimated future water resources and on the analysis concerning the vulnerability of these resources presented in D5.5.

Finally, one of the WP5 objectives was the analysis of the role and interaction of Black Sea. The main goal of the study was to identify the role of regional sea surface temperature anomalies on extreme precipitation in Romania under present and A1B conditions. For the validation, we used daily precipitation amounts from 104 Romanian stations to build a seasonal time series of extreme precipitation for the period 1961-2000. Canonical correlation analysis of the observed extreme precipitation and sea surface temperatures (SSTs) over the Mediterranean and Black Seas suggests that local extreme precipitation is significantly affected by the Black Sea surface temperatures in winter. This result is confirmed for present climate by sensitivity experiments with a regional climate model in which the Black Sea surface temperature is raised by 2 K. As for the A1B scenario conditions, analyzed in the present project, the SST variability seems to have an important impact especially on the climate of the regions situated in the vicinity of the Black Sea. Extreme precipitation characterized by higher amounts are likely to occur both in summer and winter season, especially over South-Eastern part of Romania, due to a higher precipitable water amount present in the air column.

3.2 WP6

WP6 aimed at three topic – (i) agriculture, inclusive drought, crop production and pest; (ii) forestry, inclusive forest growth, mortality and pests; and (iii) carbon, focusing on changes in the land carbon sink and productivity of forest and grassland ecosystems. Most simulations were used to draw the recommendations on improved agriculture and forest management under regional climate change scenarios and thus contribute to adaptation options. It should be said that in agriculture applications the RCM model biases seemed to be a quite serious problem limiting the direct model outputs use.

In the Marchfeld, NE Austria, the results of simulations indicate a shortening and an earlier occurrence of phenological development stages of winter wheat and spring barley yields, as well as yield stagnation or decrease in the near future for these current cultivars. An exception represents impact assessment based on NCAR PCM (GCM), with a slight increase of winter wheat as well as spring barely yield on medium soils. The interannual yield variability of both crops would increase for almost all soils, which leads to a higher economic risk for farmers. Without the fertilizing CO_2 effect, mean yield would diminish even more, especially on sandy and shallow soils. As recommendations and development of management options, a shift of average sowing dates, a replacement of ploughing by minimum tillage and direct drilling as well as support irrigation and improved irrigation efficiency for winter wheat and spring barley were studied. A replacement of ploughing by minimum tillage and direct drilling within the 2035 scenario would lead to an increase of mean yield of winter wheat (up to 10 %) and of spring barley (up to 8 %) in 2035. Further recommendations for the target area would be crop rotation (less summer crops), applying surface mulch (reduction of evaporation) and change to more drought and heat tolerant cultivars in the midterm (adapting breeding strategies).

Analysis of a Water Use Efficiency (WUE) parameter, which is vital for plant growing, was studied as well. WUE represents the plant ability to use water for reproductive growth, which is, actually, connected to CO_2 absorption by the plant. The different plant species absorb CO_2 at different rates, so WUE can be different between crops such as winter wheat and maize. The example in Fig. 22 presents the changes in near future horizon both with and without the effect of increasing CO_2. In the rainfed conditions, without taking into account the CO_2 effect, WUE would decrease significantly by 22% in 2020 up to 74% in 2050, but when CO_2 increase following the scenario is considered, slight increase of about 8% appears finally. For irrigated growing, present conditions could be expected to be preserved, but with CO_2 increase positive change of 8-19% is projected.

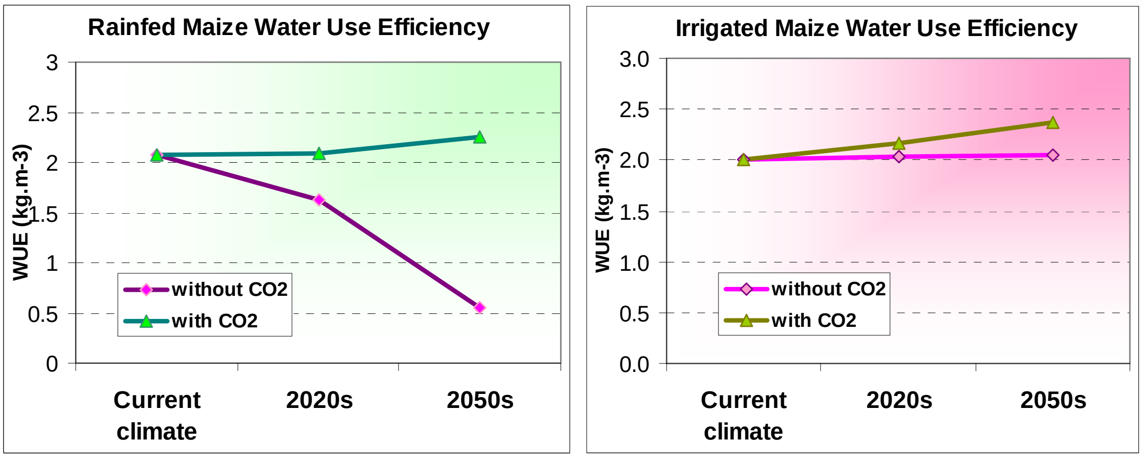

Figure 22. *Water use efficiency for rainfed (left panel) and irrigated (right panel) maize crop (without/with CO2 effect) in the current and future climate conditions, at the pilot station Calarasi*

In the S-E Romania, simulation results indicate that in 2020-2050 the climate may have important effects upon crops and they are conditioned by an interaction between the current climate changes on a local scale, severity of climate scenario-forecasted parameters, increased CO_2 concentrations influence on photosynthesis, and the genetic nature of plant types. Winter wheat can benefit from the interaction between increased CO_2 concentrations and higher air temperatures, while maize is vulnerable to climate change, mainly under hot and droughty conditions.

At least parts of the territories of Austria, Czech Republic, Germany, Hungary, Poland, Romania, Slovakia, Switzerland and Ukraine show an increase in the mean production potential as a whole (expressed in terms of effective global radiation and number of effective growing days). This is however not true for the Pannonian and Mediterranean parts of the domain where increases in the water deficit will further limit rainfed agriculture. The increase in the severity of the 20-year drought deficit and the more substantial water deficit during the critical part of the growing season are very likely over the central and western part of the domain. Sowing conditions during spring will deteriorate due to the unfavourable weather that might increase the preference given to winter crops, which is already likely due to their ability to withstand spring drought stress events. Harvesting conditions in June (when harvest of some crops might take place in the future) are not improving beyond the present level. The rainfed agriculture will face more climate-related risks, but the overall conditions will likely allow for acceptable yield levels in most of the seasons. Risk of extremely unfavorable years resulting in poor economical return is likely to increase as well.

The results show that during the climate change in Bulgaria in the 21st century, the most vulnerable will be: a) spring agricultural crops, due to the expected precipitation deficit during the warm half-year; b) crops cultivated on infertile soils; c) crops on non-irrigated areas; d) arable lands in south-east Bulgaria where even during the present climate, precipitation quantities are insufficient for normal growth, vegetation and productivity of agricultural crops. Adaptation options in Bulgarian agriculture were considered, such as measures for improving irrigation under climate changes, measures for improve management, use and protection of water resources in irrigated agriculture, adaptation measures to improve management efficiency and use of existing irrigation systems and elaboration of technological and technical means for irrigation, and adaptation measures for use of rational and economically viable irrigation regimes. A questionnaire on adaptation options in agriculture was developed and disseminated. Finally, the following options were recommended as feasible adaptation options: changes in irrigation, changes in sowing dates, changes in crop cultivars and varieties, and new crop zoning.

Important aspect of the future agriculture production is appearance and development of pests or deseases under changed climate conditions. The potential occurrence of the Colorado potato beetle and the European corn borer was examined in the domain of the Czech Republic. The results show the likely widening of the pests' areas and an increase in their generation number. According to the HadCM-high scenario, the increase of the ratio of arable land affected by the occurrence of third generation of Colorado potato beetle in 2050 could be about 45% higher, and the occurrence of a second generation of the European corn borer is nearly 61% higher.

Another target of WP6 activities is forestry and analysis of the climate change induced consequences there. Impacts of predicted climate change on forest ecosystems sensitivity to atmospheric deposition of sulphur and nitrogen were studied in Poland. The increase of critical loads (CL) estimated for future time slices in two selected (mainly coniferous) forest regions (the Karkonosze domain in the Sudety natural-forest region and the Kampinos domain in the Mazowsze-Podlasie natural-forest region) means an enhancement of tolerance of the terrestrial ecosystems to acidifying and eutrophying depositions. However, due to estimated increase of nitrogen deposition, the significant increase in exceedances of CL of nutrient nitrogen was predicted. Therefore, the summary effect of climate change on the ecosystem protection against eutrophication caused by excess atmospheric deposition of nitrogen is negative for the structure and functioning of the ecosystems. The main risk which potentially results from the permanent nutrient nitrogen critical load exceedance is the loss of biodiversity in the present species constitution of ecosystems.

The assessment of impacts in forests of Slovakia is summarized. Climate change impacts studies on forests show dependence on the elevation of cultivation. It indicated that beech (*Fagus sylvatica*) and spruce (*Picea abies*) production will decline at species receding edge (lower limit), while significant increase in production is projected at the leading edge, in the higher elevations. The mortality pattern differs between the species. In case of oak (*Quercus sp.*), almost no change in production is projected in the lower elevations, while the growth slightly increases (by 3-9% on average) in the elevations above 600-1 300 m a.s.l.. Such response is accompanied by unchanged mortality over the all span of natural conditions.

For forests the appearance of pests and deseases is crucial as well. Analysis of bark beetle (*Ips typographus*) related risk to spruce stands in Fig. 23 indicates that one-generation increase of bark beetle (comparing to 1961-1990) will occur over 42% in 2021-2050 and over more than 90% of current distribution of spruce stands in 2071-2100 in Slovakia. The third generation is the highest reached in the current distributional range of spruce. Recommendations for optimized forest management are mainly aimed at optimizing forest distribution and species composition to respond the projected changes in forest production, natural mortality as well as changes in pest's activity. The maintenance of valuable genetic material is addressed as well.

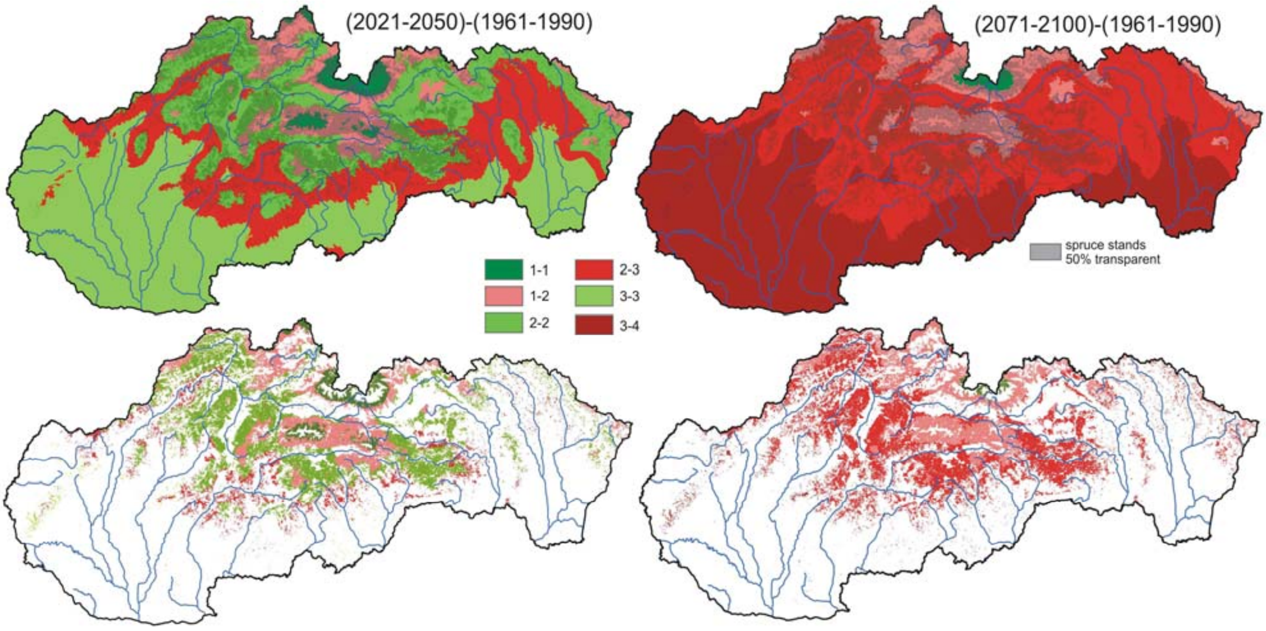

Figure 23. *Differences in number of bark beetle generations projected to develop in the near future (left panels) and far future (right panels) vs. the reference climate. The upper panels showing the differences in full number of developed generation (Example: 1-2 – number of developed generations increased from 1 to 2) in the whole country, the bottom panels describe the increase in bark beetle generations within actual distribution of spruce.*

As certain degree of general view carbon cycle development under climate change was one of the objectives of the WP6 as well. The purpose is to estimate how carbon as important element playing role in CO_2 sources and sinks acts. Carbon cycle related simulations were conducted in Slovakia and Poland. No feedback mechanism between climate change and carbon cycle was detected for the Kampinos pine forest in Poland. It will likely remain carbon sink in the future. For the Čifáre Turkey oak forest, Slovakia, we found positive feedback between changes in the carbon cycle and climate change. This feedback has implications on timber production. In case of the managed grassland we found negative feedback between carbon cycle and climate change. Assuming unchanged management, due to the increasing ambient CO_2 concentration the grassland will be a lower source of CO_2 to the atmosphere than it is currently. For croplands because of the lack of information on management and fate of carbon we were not able to detect any feedback mechanism. According to our results the annual cycle of agricultural productivity will be modulated in the future, mainly because of the CO_2 fertilization effect. The changes might be beneficial as productivity might increase in the first half of the growing season (i.e. winter wheat production might increase).

The cropland related simulations from Hungary based on high resolution simulations of the CECILIA project show that although the net biospheric carbon exchange (NEE) seems to be unchanged in the future, the two large carbon fluxes (GPP and Reco) and also net primary production (NPP) will increase in magnitude as the consequence of climate change and increasing air pollution (Fig. 24). Increasing nitrogen deposition and CO_2 concentration will amplify the changes, but there is no simple answer about the importance of the two pollutants. Taking into account both the unchanged NEE (biospheric carbon balance from the atmospheric point of view) and the increasing NPP (which causes increasing anthropogenic CO_2 emission caused by human and animal consumption) we were not able to estimate the direction and magnitude of the carbon cycle related feedback to climate change and air pollution. Human intervention substantially alters the carbon cycle of croplands, and at present we do not have enough information to estimate the fate of cropland carbon cycle in the future, more research is needed in this topic.

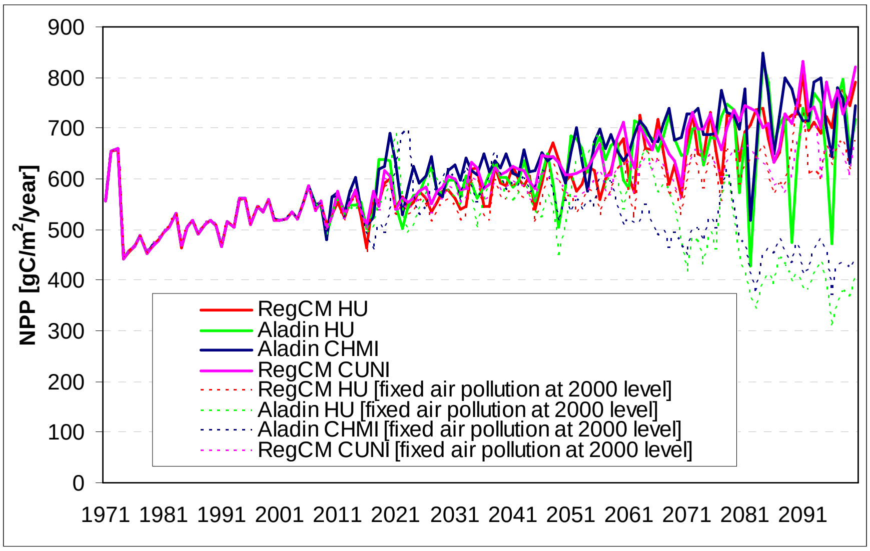

Figure 24. *Modelled evolution of agricultural net primary production between 1971 and 2100 based on the regional climate model simulations. Solid lines show the estimated net primary production (NPP) with climate change and air pollution impact, while dashed lines show the effect of climate change alone without the air pollution impact (N deposition and CO_2 concentration were held at their respective year 2000 value).*

According to our results the annual cycle of agricultural NEE will be modulated in the future, mainly because of the CO_2 fertilization effect. The changes might be beneficial as productivity might increase in the first half of the growing season. Some models indicate that without the air pollution effect there can be decrease in productivity and by 2100 crop growth might even decrease.

3.3 WP7

The main objective of WP7 was to assess the impact of climate change on air quality using coupled model system, i.e. with air quality model (chemistry-transport model, CTM) connected to the RCM. Using such a model system, present and future simulations to analyse the interaction between climate and air quality were performed to obtain predictions of present and future air pollution levels and loads in the target regions on Central Eastern Europe. Particulate matter (PM) and ozone, which are priority species regarding human health as well as sulfur dioxide and nitrogen dioxide, having complex impacts on the human health and the ecosystems, were chosen as key species. Six modeling groups from five countries were involved in WP7 activity, i.e.: WUT (WP leader), CUNI, CHMI, AUTH, BOKU, and NIMH.

For the purpose of WP7 activities, the modeling systems working in the high resolution of 10 km were implemented and the interface developed for photochemical runs in the targeted areas of CECILIA project, namely: CUNI domain (Central-Eastern Europe), WUT domain (Central-Eastern Europe, centered over Poland), BOKU domain (Central-Eastern Europe, centered over Hungary) and NIMH domain (Bulgaria). The majority of partners (BOKU, CUNI and WUT) used RegCM3(Beta)-CAMx modelling system driven by ECHAM5 Global Climate Model outputs under A1B scenario of IPCC. NIMH used ALADIN-CMAQ modelling system driven by ARPEGE Global Climate Model outputs. For the validation of the modeling systems, the simulations were performed for the present day decade, 1991-2000, with ERA-40 meteorological fields to drive RCM. To study climate impacts on air quality, the simulations were performed for three decades with RCM forced by GCM: 1991-2000 as control run, and two future decades 2041-2050, and 2091-2100 for investigating the near future (NF) and far future (FF) climate response.

As lateral boundary conditions hourly concentrations from the corresponding runs at BOKU or AUTH with the 50 km model were used. Clean-air conditions were assumed at the model top. Biogenic emissions were calculated in RCM-AQM pre-processor. In order to study exclusively climate impacts on air quality, the anthropogenic emission were kept constant at the values of year 2000 for all time slices. For CUNI and BOKU domains emissions databases were prepared based on EMEP data, with area and point sources treated as surface area emissions. For the Pannonian countries, a detailed 5 km x 5 km emissions inventory from the year 1995 was used for the spatial distribution of the EMEP 50 km data. For Poland, the emission model was developed, based on a detailed 1 km x 1 km emissions inventory of area and point sources for reference year 2000. For large points sources, a detailed emission and stack parameters database was prepared. Finally, area sources were treated as surface area emissions, while large point sources were simulated individually. For Bulgaria emissions were prepared based on TNO high resolution (0.25° x 0.125°) area and point sources inventory. Finally, area sources were treated as surface area emissions, while for large point sources 3D emission file was produced with zero-values at the surface and non-zeros at the respective model levels.

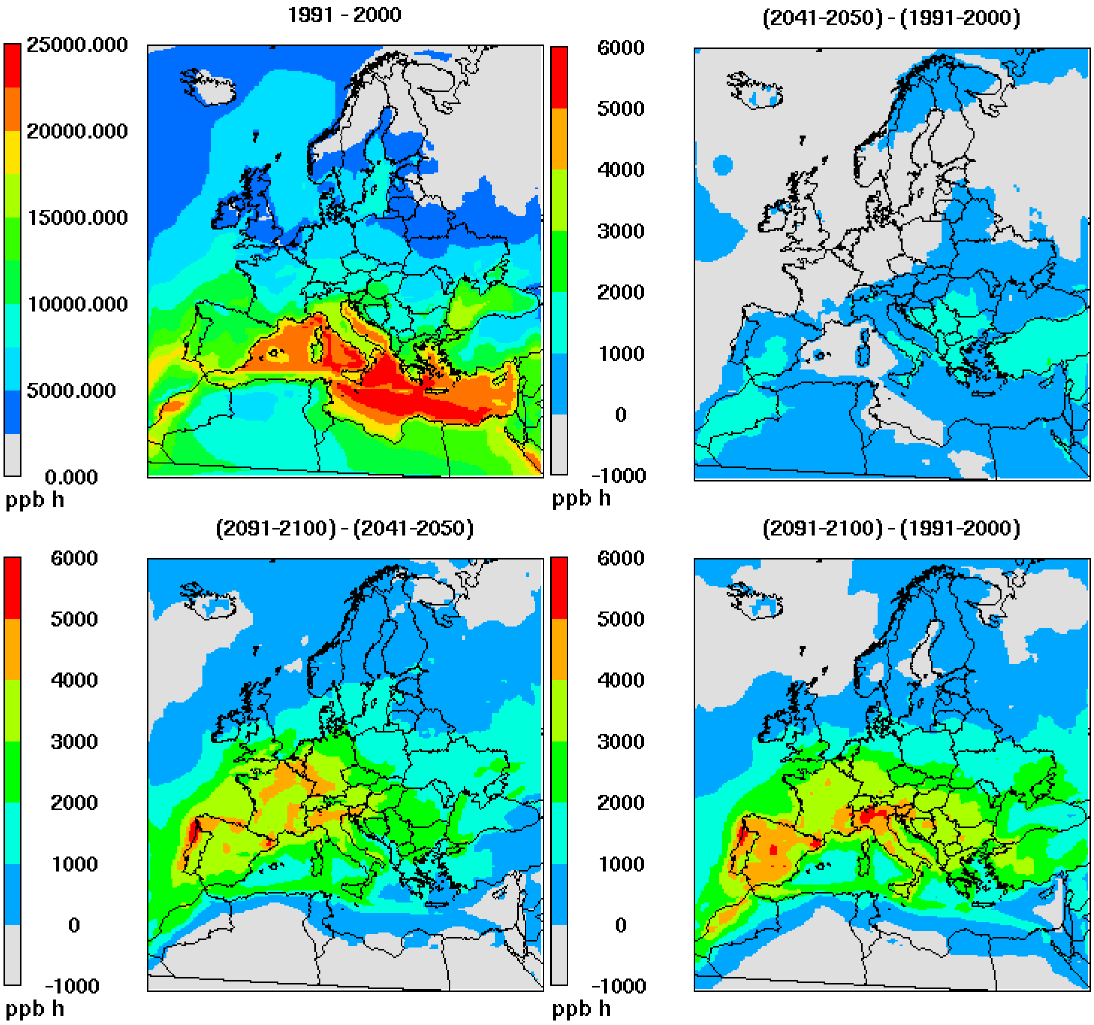

Figure 25. *AOT40 from May to July in the control decade 1991 – 2000 (upper left) and differences of AOT40 from May to July between the calculated decades: mid-century – control (upper right), end-century – mid-century (lower left), and end-century – control (lower right).*

The model results for the wide Europe domain providing chemical boundary conditions for nested runs are presented in Fig. 25 and were compared with measurements of ozone and NOx in the case of the ERA40-driven run. The model reproduces the expected spatial and temporal distribution of the trace species well. Simulated O3 concentrations were validated using surface O3 measurements from the sixty nine EMEP stations. For mean daily values the Fractional Gross Error (FGE) calculated for the period 1990-2001 was ranging between 20-35 % while the Modified Normalized Mean Bias (MNMB) was within the range of ± 15% indicating a satisfactory model performance. Comparisons between the results of all decades show for ozone, that the ERA40 results are higher than the control run ones. The difference between the control run and the mid-century run (2040-2050) is small in the range of 1-2 ppb, while the end-century run shows higher ozone up to by 5 ppb, mainly in the second half of the year. Since the anthropogenic emissions were not changed, this clearly indicates the influence of a changing climate on ozone formation.

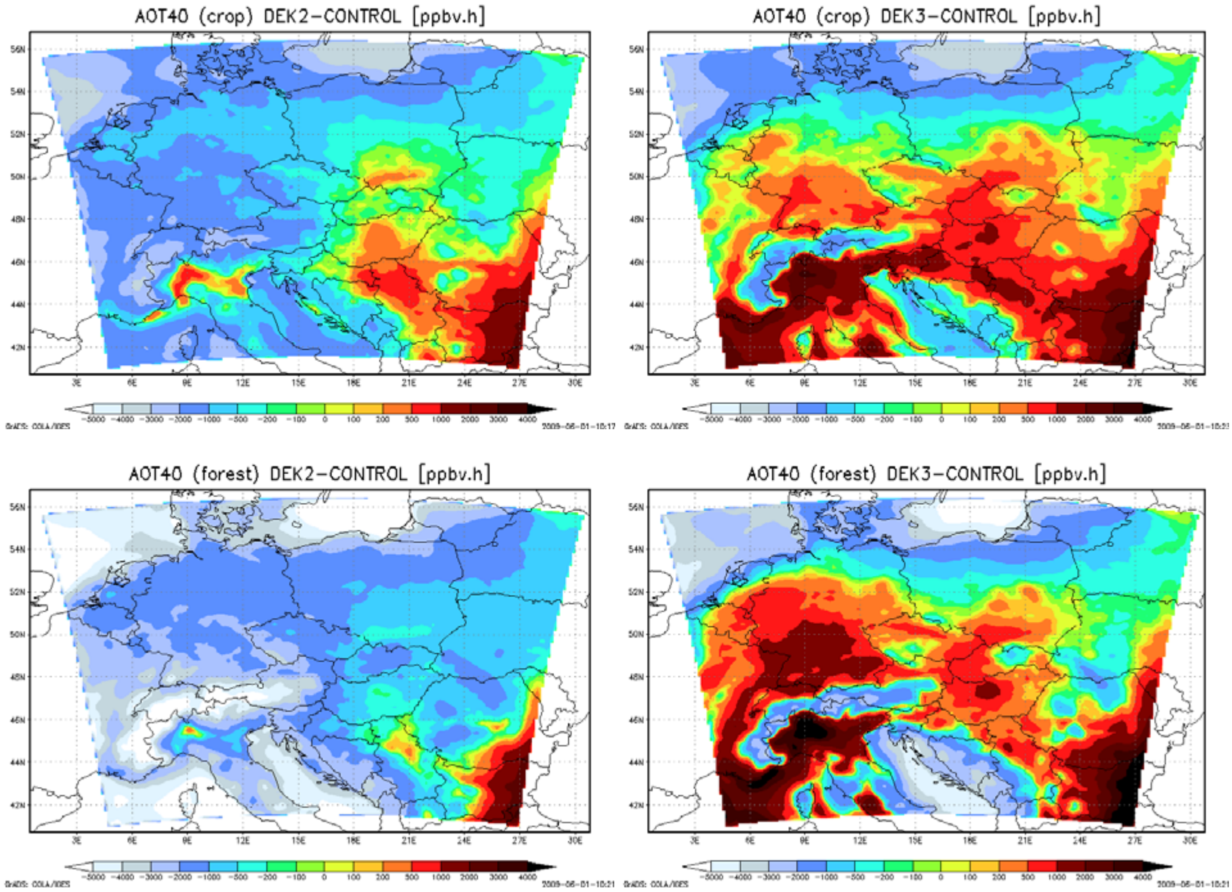

***Figure 26**. Difference in AOT40 for crop impacts assessment (May-July, upper panels) and for forest impacts assessment (April-September, lower panels) between years 2041-2050 (left panels) and 2091-2100 (right panels) against control period 1991-2000.*

High resolution experiments were performed as well showing some regional and local effects. The guidelines for models evaluation and results analysis has been prepared (see D7.4 Appendix), final evaluation exercise showed satisfactory to weak performance of modelling systems, depending on the pollutant under concern. The best performance was obtained for summer O_3, while the worst for NO_2. For PM_{10} and SO_2 we obtained reasonable good evaluation results, with better model performance for long-term estimates than for short-term ones. Seasonal species variation was well captured. Extreme values were simulated much better with those models, which employed detailed emission inventory and proper treatment of point sources. The reasonable performance of the applied modelling tools for the present time simulations justifies its use for future time projections. Example of ozone results are shown in Fig. 26 in terms of AOT40 again. Despite of underestimation of AOT40 in validation, significant climate change signal can be seen, especially for last decade of the century.

The main conclusions from high resolution simulations are that climate change impacts on air pollution levels and loads are small to moderate, and have different direction depending on pollutant under concern. For all investigated species the differences between near future (NF) and control run (CR) is rather small with respect to the difference between far future (FF) and CR. For ozone, concentrations are increasing with climate change. The highest increase in O_3 concentrations occurs in Southern Europe. If the response of the ozone concentration to a changing climate is compared between the model runs with different spatial resolution (BOKU domain), the found absolute differences of ±2 ppbv are much smaller. The 10 km calculation also leads to higher $AOT40_{crops}$ values over the mountains of the Alps and the Carpathians and over Italy and Western Croatia. Over Poland and Hungary the results of the two model calculations are very similar. The concentrations of SO_2 are also increasing with climate change. For NIMH domain the maximum differences are about 2 ppbv that is of order of 10% from the maximal values. These maximums are distributed mainly in the region of the main pollution sources, thermal power plants. Also deposition of all acidifying species (SO_x, NO_x, NH_x) are increasing in future climate. The exception is sulphur deposition in the vicinity of large point sources which is decreasing with descending trend in future climate. For WUT domain, the maximum differences are of order of 10% (NH_x), ±20% (SO_x), and 35% (NO_x) from the maximal values. These maximums are distributed mainly in the mountains areas within the domain: Bohemian Forest, Ore Mountains, Sudety Mountains and Carpathian Mountains. In opposite, PM_{10} and $PM_{2.5}$ concentrations are decreasing with climate change. For WUT domain, the maximum differences (FF-CR) were about 4 $\mu g/m^3$ that is of order of 10% from the maximal values.

The key species exceedances of the EU limits (relating to human health and to vegetation) and of WHO guidelines were calculated as well. In the target region of CECILIA, the number of O_3 exceedance days per year is increasing in the FF decade (see Fig. 27), however, the allowed number of such days is not overshot. The $AOT40_{crops}$ and $AOT40_{forest}$ values are increasing in future climate, causing in FF climate exceedances in the majority of CEE countries, which have no exceedances in present climate. Annual limit values for PM_{10} and $PM_{2.5}$ are not exceeded for both CR and FF, while short-term PM_{10} limit values are exceeded in FF period only in some urban areas. For the majority of targeted domains, there were no exceedances of both SO_2 criteria relating to human health and vegetation. The exceedances occurred only in the surroundings of large point sources for both CR and FF, without relevant change of the shape and area of these regions between the time slices.

From individual pollutants exceedances we are close to the health effects which were addressed within WP7 as well. For assessing possible health effects, the case study for Poland was performed. We estimated the adverse health effects caused by $PM_{2.5}$ air pollution for present day decade as well as for both future decades. Estimated average and population average exposures to $PM_{2.5}$ in Poland decreased in future decades. The differences between both exposures of the present day decade 1991-2000 in comparison to two future climate decades were statistically significant. Results indicate that climate change might reduce the exposure to PM air pollutants and resulting premature death estimates in the region under concern.

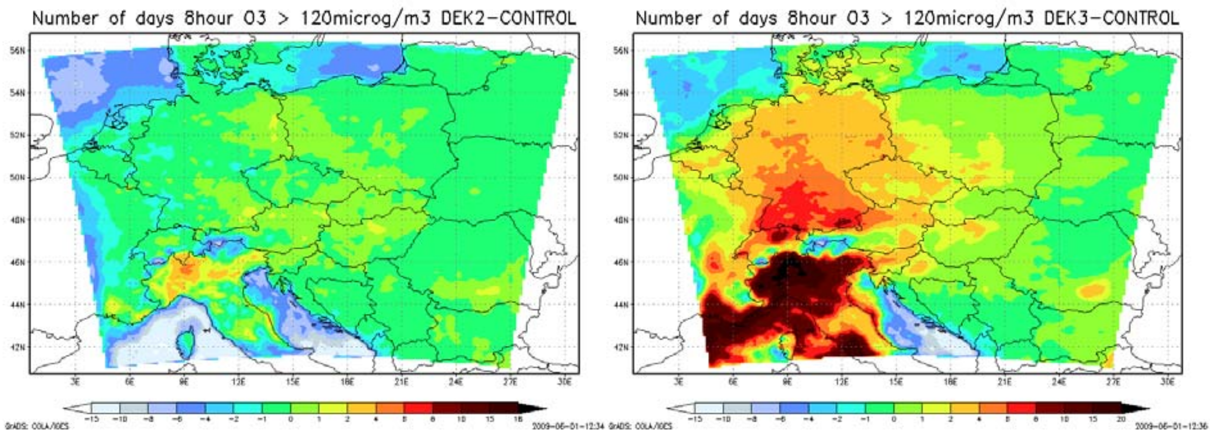

Figure 27. *Climate change impact on number of ozone exceedance days, i.e. days per year with 8-hours ozone concentration above the threshold of 120 μg/m*^{3} *(EU limit) in terms of the difference for 2041-2050 period (left panel) and 2091-2100 period (right panel) against the control period 1991-2000.*

4 Conclusions

All the main goals of the project were completed succefully. High resolution regional climate modelling showed the potential to advance climate change impact science. Although this does not improve overall climate change information, it can provide regional to local details and to certain extent better information on statistical distributions, annual cycle, etc. However, there is a clear shortcoming, which limits use of high-resolution RCMs for their primary purpose, i.e. providing data for regionalized or localized impact studies: Biases and other systematic errors. While in application of simple incremental scenario based on climate change signal from GCM or coarser resolution RCM, even though considering the change of variation and using some statistical technique to get time series of selected variable, the information is relative to present (observational) state, the direct use of the results from the biased models is not possible. This is a challenge for the RCMs outputs postprocessing that has i) to reduce the bias significantly and ii) to get the model results from model grids to the point of interest, taking into account topography, land use and other factors not captured by the RCM directly. In the high resolution, there is enough data for statistical procedures in the vicinity of the point of interest to make the appropriate analysis in quasi-homogeneous region and to apply the postprocessing. Indeed, the density of the model grid of 10km resolution becomes comparable (or often even higher) than standard observational network. However, it can be the availabilitity of observational data that finally becomes a limiting factor. Further development of the models, introducing better parameterizations and more efficient schemes should move the high resolution RCMs closer to become useful tools in climate change impact assessment, diminishing the need for statistical postprocessing.

While in the climate-modelling part of the project the work was performed quite uniformly and despite of different simulation regions and two different models we can compare the results to certain extent, on the side of impact WPs the situation looks to be less consistent. The sampling of the issues, methods and knowledge is evident and perhaps it is not possible (and actually, it was not planned) in such a project to provide a comprehensive coverage of full subjects. However, presented examples show clearly the potential of use of high resolution simulations by RCMs in concrete case studies of climate change impacts. As the conclusions in these practical applications support the decision making process and contribute to development of adaptation measures, information provided should be precise and reliable. This is stimulating for further development of RCMs in high resolution.

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