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QUANTIFICATION OF UNCERTAINTIES IN REGIONAL CLIMATE AND CLIMATE CHANGE SIMULATIONS

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Summary

The first of three common model experiments was executed for present-day climate conditions in Central Europe with three different regional climate models. For the same period as simulated several sets of climate data were prepared and collected from different sources. The ensemble of the simulation results provides the possible range for the realization of the same climate conditions by the different models. The ensemble of the climate data demonstrates the range of uncertainty for the determination of the real climate conditions. The comparison between both ensembles with objective distance measures allows the evaluation of the model performance and the identification of necessary model and data improvements. The project is a cooperation of

- **BTU**: Brandenburgische Technische Universität Cottbus, Lehrstuhl für Umweltmeteorologie,
- **MPI**: Max-Planck Institut für Meteorologie, Hamburg
- **IMK**: Forschungszentrum Karlsruhe, Institut für Meteorologie und Klimaforschung, Bereich Atmosphärische Umweltforschung, Garmisch-Partenkirchen
- **DLR**: Institut für Physik der Atmosphäre, Oberpfaffenhofen
- **DWD**: Deutscher Wetterdienst, Referat Klimaanalyse und Klimadiagnose, Offenbach
- **TUD**: Technische Universität Dresden, Professur Meteorologie

1 Aim of the research in the context of DEKLIM

A reliable assessment of future climate development requires an improved understanding of climate and its variability as well as a detailed knowledge of the uncertainties of the climate simulations which provide the requested information about possible future changes. This project focuses on the climate patterns of Central Europe and investigates the quality of currently used regional climate models and regionalization techniques by a model intercomparison, a substantial model evaluation, additional sensitivity studies and an extensive analysis of climate data. The major scientific aims are

- to quantify the uncertainties of regional climate simulations and of observed climate data,
- to investigate the sensitivity of regional climate simulations and interpolated climate data to the influence of different model parameters and data processing techniques,
- and to produce a regional climate change scenario for Europe and particularly for Germany.

To achieve this, a set of common model experiments and data evaluations are realized together with individual sensitivity studies and data preparations by the six project partners.

2 Recent and completed activities

During the past 20 months of the project the first of three large model experiments was completed, the global forcing data for the next two experiments were prepared, a set of surface near climate parameters was produced, the evaluation concept was elaborated, the first version of an extensive evaluation tool was developed, format conventions for a standardized data exchange were fixed, and first sensitivity studies were executed.

In the first model experiment (PDC/ERA), BTU, MPI and IMK have simulated present-day climate conditions for the period from 1979 to 1993 with the regional climate model REMO and the mesoscale climate model system MCCM at a horizontal resolution of about 18 km (see also contributions of the project partners MPI and IMK). The initial and time dependant boundary values for these dynamically nested climate simulations were interpolated from ECMWF reanalysis data. BTU and MPI are using the same model REMO but in a different version (5.0 and 5.1) with modified surface processes and with a different domain size. The 4th modeling partner DLR has prepared and tested a statistical-dynamical downscaling technique with results of a former REMO simulation (see contribution of DLR) and is now about to apply this method to the results of the PDC/ERA experiment.

In addition to the project proposal, two new time slice simulations – a control run for present-day climate conditions and a scenario run based on the SRES B2 emission scenario - were performed at MPI with the global climate model ECHAM4/T106 (see contribution of MPI). The results will provide the driving input data for the two upcoming common model experiments, a control run with present-day climate conditions PDC/GCM and a future climate scenario run FCS/GCM. The supplementary GCM-simulations were decided to be necessary to make the actual development of global scenario calculations available to the DEKLIM project. They replace former time-slice experiments of the IS92a scenario promoted by colleagues at DMI in Copenhagen, which had originally been intended to be used.

The project partner DWD has provided the first sets of climatological parameters (see contribution of the subproject) including values for temperature, sea-level pressure and precipitation. The data represent monthly mean values for the period 1951-2000 on a high resolution regular grid, which covers the whole area of Germany. The data have already been used for detailed model evaluations.

The evaluation concept for the intercomparison of different model simulations and their comparison with observations was elaborated by BTU. The analysis of model results and observations focuses on four categories:

- monthly and yearly means of grid-point values,
- annual cycles of area means of selected subregions,
- frequencies of specific or extreme weather events,
- temporal means of vertical profiles over selected subregions.

The first two categories have already been implemented in an extensive analysis tool for automatic data processing. This tool calculates statistical quantities for a fixed set of climatological parameters, projects the data onto a common reference grid, and determines predefined distance measures between the data to be compared on specified subdomains of different spatial scales, i.e. Europe, Germany and six different subregions in Germany.

3 Principle results and Conclusions

A major task of this project is to compare the results of different model simulations for the same climate conditions and validate the results with observed data. In the first common model experiment (PDC/ERA) the period between 1979 and 1993 was simulated with three regional climate models, the MCCM/MM5 used by IMK and two versions of REMO conducted by BTU and MPI. ECMWF reanalysis were used as initial and time-dependent boundary values, updated every six hours, to drive the continuous regional simulation for 15 years. For a first evaluation, the results are compared for Germany with gridded monthly mean values of daily mean-, minimum-, and maximum-temperature, precipitation, and sea-level pressure, which have been interpolated by DWD from station observations. Only a very few of the results can be presented in this context but should give an impression of possible deviations and uncertainties of regional climate models.

To quantify the differences between model results and observations, all data are first projected onto a common reference grid. Then the deviation between a certain model and the DWD data is calculated for every grid-box of this reference grid. Figure 1 shows the accumulated frequency of these grid-box differences for the climatological (15-year) mean of near surface temperature and precipitation. The curves represent the probability function for unsigned deviations between two spatial distributed data sets and allow identifying percentiles for given threshold values. In the best case (Model I) 50% of all grid-boxes in Germany show deviations of less than 0.2 K in the annual mean temperature. In the worst case, the median of the deviations reaches a value of 0.9 K. The 95%-percentile varies between 0.5 K and 1.2 K. For the annual precipitation, the median of the relative deviation/error between model and observation is below 12.5% in all three models. The 95%-percentile of the relative differences ranges between 27% and 41%.

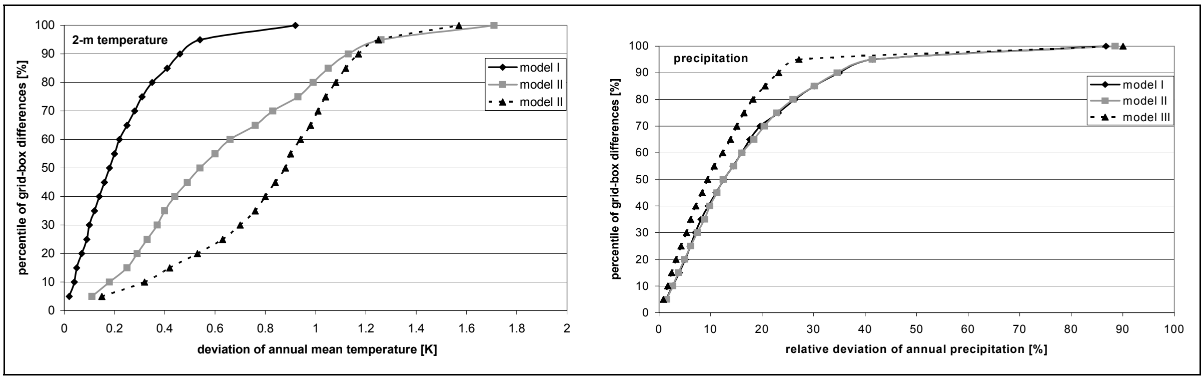

Figure 1. Deviations between model results and observations for the climatological annual means of temperature and precipitation: The data points represent the percentiles of all grid-box differences for the area of Germany.

It is worth mentioning, that the model with the largest deviations in temperature yields the smallest deviations in precipitation. The temperature deviations of Model II and III are related to a systematic warm and cold bias, respectively, whereas Model I shows positive as well as negative deviations for the area of Germany, which result in the small overall BIAS listed in Table 1. This table summarizes some fundamental distance measures between model simulations and interpolated observations which are calculated from the climatological annual mean values of the investigated subregion.

Temperature	BIAS	RMSE	PACO	Precipitation	BIAS	RMSE	PACO
Model I	+0.08 K	0.28 K	0.96	Model I	-30.7 mm	194 mm	0.63
Model II	+0.61 K	0.72 K	0.90	Model II	-27.7 mm	194 mm	0.63
Model III	-0.80 K	0.87 K	0.92	Model III	+5.3 mm	118 mm	0.89

Table 1. Distance measures for the deviations of simulated climatological annual means from DWD observations for the area of Germany: difference of the area means (BIAS), root mean square error (RMSE) of the grid-box differences, and spatial pattern correlation (PACO) of the grid-box deviations from the area mean.

In order to valuate the results of the comparisons above it is important to know the uncertainty the observational data are afflicted with. Therefore, different climate data sets from other sources were collected to get an idea of the possible range of the observed and processed real climate conditions for the relevant period. Figure 2 summarizes the climatological annual cycle of monthly mean values of temperature and precipitation as calculated from different data sets of the Climate Research Unit (CRU, New et al., 1999; Mitchell et al., 2003), the ECMWF, and the DWD together with the results of the model simulations. The data sets differ in resolution and the method of processing or interpolating the available observation data. The 15-year monthly means of the near surface temperature show only small variations between 0.1 and 0.7 K but with the exception of the ECMWF reanalysis data which are up to 2.5 K colder than the interpolated observations in the winter months. The variations in the observed precipitation values are much higher. They partly differ by more than 20 mm/month.

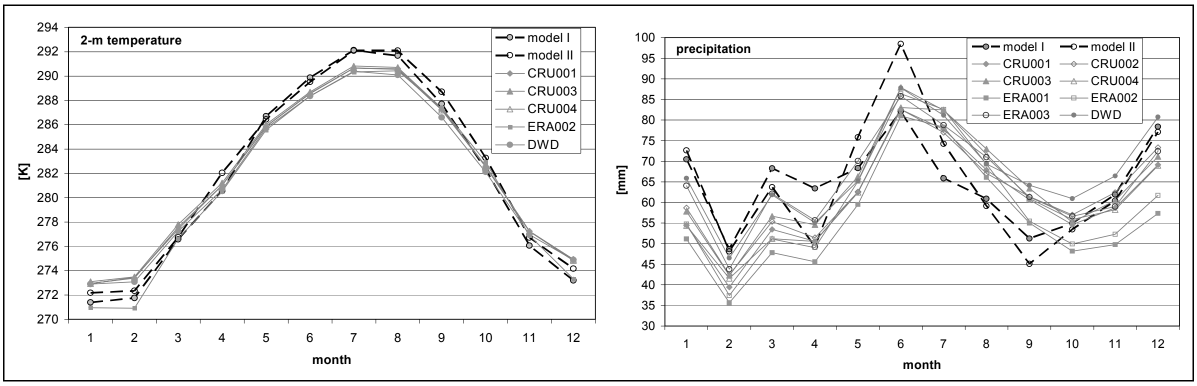

Figure 2. Annual cycle of climatological monthly mean values averaged over the area of Germany for model results (dashed lines) and analysed observations (solid lines). CRU001: 0.5° data set TS 1.0 of CRU; CRU002: as CRU001 with corrections of PIK in Potsdam; CRU003: 0.5° data set TS 2.0 of CRU; CRU004: 10’ data set TS 1.2 of CRU; ERA001, ERA002, ERA003: ECMWF reanalysis from 6h, 12h, and 24h forecasts, respectively, processed by MPI/DKRZ in Hamburg, DWD: 1km data set of DWD.

The simulated climatological annual mean temperatures for Germany differ by 1.4 K (see table 1). This range is larger than that of the observational data (0.8 K) but encloses it completely. Independent of a warmer or colder area mean (BIAS) the spatial distribution of the climate patterns is reproduced quite well by all simulations (high PACO values). The seasonal amplitude, however, is overestimated in all simulations. Particularly the summer temperatures lie significantly outside the range of the observations (up to 1.3 K). The winter temperatures are lower than the observed ones but are still warmer than those of the reanalysis data. The area mean of the simulated annual precipitation is exactly inside the range of the observational data. The spatial distribution of the annual precipitation, however, shows considerable larger deviations from the observations, as can be seen from the RMSE and PACO values of table 1. The differences between the simulated monthly precipitation values are not larger than the differences between the observational data, but the seasonal cycle tends to overestimate winter and spring precipitation and to underestimate summer precipitation. These conclusions differ slightly, when other parts of the model domain or smaller subregions within Germany are investigated with the same methods. Again several distance measures were defined, like the temporal correlation, the RMSE, the figure of merit, and the ratio of the annual amplitudes, to allow an objective quantification of the differences between the annual cycles of two data sets for different spatial scales.

The differences between simulations and observations, as quantified in this project for a large set of climate parameters, enable to identify deficiencies of the regional climate models and thus give evidences of the reliability of the climate simulations and indications for further model improvements. The calculated distance measures allow an objective validation of these improvements which may affect the overall model performance or only certain model components or processes.

4 Planned activities

The project is on a good way to a systematic quantification of the uncertainties of the applied regional climate models. The next step is to collect and summarize the detailed results of the model intercomparison and evaluation for the numerous selected parameters, only a small part of which could be presented here. The analysis tool has to be extended especially for the evaluation of frequencies of specific or extreme weather events – like the number of rain-days or summer- and frost-days - and for the determination of significant or non-significant differences. The observational data sets are continuously extended. Wind velocity from DWD and cloud cover and radiant fluxes at the top of the atmosphere from (TUD) will be available soon. An additional set of precipitation data has just been provided by the DEKLIM project VASClimO and will be integrated into the evaluation process.

After DLR has finished the climatological processing of the first MPI simulation, the results of this statistical-dynamical downscaling approach will be integrated into the evaluation process.

The second common model experiment (PDC/GCM) is in the pipeline. The global input data are available and have to be adapted to the individual model requirements. The results of this control run will serve for two purposes. On the one hand, they provide quantitative measures for the potential offset of the GCM driven present-day climate run against the simulated climate conditions driven by reanalysis data. This information is used to analyze the influence of deviations in the boundary conditions on the regional simulation results for all three models. On the other hand, this experiment represents the reference for the third experiment, the regional scenario run (FCS/GCM) under modified global climate conditions, which follows in the last phase of the project.

Parallel to these activities a number of sensitivity studies is executed to investigate the influence of boundary values and of soil and surface parameters on the variability of the simulated regional climate.

5 Cooperation within DEKLIM and with other programs

VASClimO (DEKLIM): Development of an observational data basis for DEKLIM. The data are used in QUIRCS for model evaluation and for the comparison with other observational data sets.

EVA-GRIPS (DEKLIM): Determination of area integrated surface fluxes by combining high resolution satellite observations with 1D-SVAT modeling results. Extension and evaluation of the analysis method used in QUIRCS.

BALTIMOS (DEKLIM): Development and validation of a coupled model system for the Baltic region. The results of QUIRCS will help advancing the coupled model system, which is using REMO as the atmospheric component.

VALIUM (AFO200): Development and application of a method to analyze and compare spatial patterns of atmospheric parameters from irregular distributed station observations and regular model grids. Method is applied and tested in QUIRCS.

VERTIGO (AFO200): Determination of radiant and energy fluxes at the earth surface from satellite data. Development and test of the method being used in QUIRCS.

PRUDENCE (EU project): Quantification of uncertainties in the prediction of future climate and its impacts. The results of the evaluation and uncertainty analysis of the dynamical nested REMO and the statistical-dynamical approach in QUIRCS contribute directly to this project and vice versa.

COST action 719: Interpolation methods for climatological and meteorological data.

The regional climate model REMO is applied in several national and international projects (KLIWA, GLOWA, BALANCE, PRUDENCE, BALTEX). Uncertainty assessments and model development within QUIRCS will therefore also contribute to these projects and vice versa. In addition, climate impact studies (e.g. CLIMPACT) will strongly benefit from the findings within QUIRCS.

6 Policy relevance and application

The demand for effective and efficient strategies to prepare and protect the earth system and its different compartments against the impacts of a possible future climate change requires a detailed knowledge of the natural and by anthropogenic activities induced climate variability of the 21st century. Climate models are an appropriate, perhaps even the best, but under no circumstances a perfect tool to solve this task. Therefore it is indispensable to investigate the efficiency of currently used climate models and the reliability of climate change simulations performed by these models. This challenge of modern climate research requires a detailed and quantitative evaluation of the quality of the models being used, particularly under consideration of the individual characteristics of the region of interest.

The results of this project will help to assess the possible consequences of future climate changes for Central Europe and particularly for Germany. They will not yield an exact number but a certain range for the probable changes of selected parameters with a high horizontal resolution. The knowledge of these ranges is essential for further impact studies because they determine the possible variation of the required input parameters and through this provide a more realistic bandwidth for the consequences of future climate changes. The detailed uncertainty analysis and the deduced improvements of the widely used regional climate models REMO and MCCM/MM5 in this project together with other international activities in this field will narrow this bandwidth as far as possible and will provide reliable information about regional patterns of future changes in Europe, which are essential for the assessment of different adaptation and mitigation options.

In addition to this, the elaboration of a basic long-term set of gridded high resolution climate data for Germany and the derivation of a Trans-European data set for radiant and energy fluxes at the earth's surface from satellite observations represent a large progress in climate research. These data are indispensable for the identification and quantification of the uncertainties of regional climate simulations not only in this project and can additionally be used for further investigations on local and regional climate variability and trends.

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