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Regional Climate Simulations with WRF Model

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Abstract. Regional climate models are commonly used to provide detailed information on climatic conditions at local or regional scale. This work presents preliminary evaluation of simulations with WRF (Weather Research and Forecasting) model for whole Europe in the year 1990. Different options are tested for radiation and convective parameterization and validated against E-OBS reference data. Radiation parameterization RRTM and Goddard for long wave and short wave, respectively, together with Tiedtke and Grell-Devenyi convective schemes provide the best results for both full domain of Europe and central Europe.

Introduction

For the purpose of predictions of future climate, numerical models solving the equations describing atmospheric processes are often utilized. On the global scale, we use Global Climate Models (GCM), which can simulate general circulation patterns on the Earth, but resolution of these models is usually too coarse to capture regional or local scale features. For this reason, Regional Climate Models (RCM) are mostly used, which are limited area models driven with the GCM outputs at the lateral boundaries. This way, large scale features can be transferred into model with higher resolution. This is called nested modeling technique [*Giorgi,* 1990].

WRF (Weather Research and Forecasting) model is numerical weather prediction limited area model, provided by National Center for Atmospheric Research, which is widely utilized in research and operation. It is used as both numerical weather prediction model and regional climate model. For older versions of WRF model, it is necessary to use a set of modifications [*Fita et al.,* 2010] called CLWRF, i.e., with the implementation of some specific features, required for regional climate simulations.

The following paragraphs present simulations by WRF model used as RCM in validation mode. In such a case, instead of using GCM as input data source, reanalysis inputs with resolution close to that of GCMs are used as "perfect" lateral boundary conditions. The comparison of model results is performed to another reanalysis or climate data, which has similar resolution as model outputs, to assess how the RCM captures the same spatial features [*Lo et al.,* 2008].

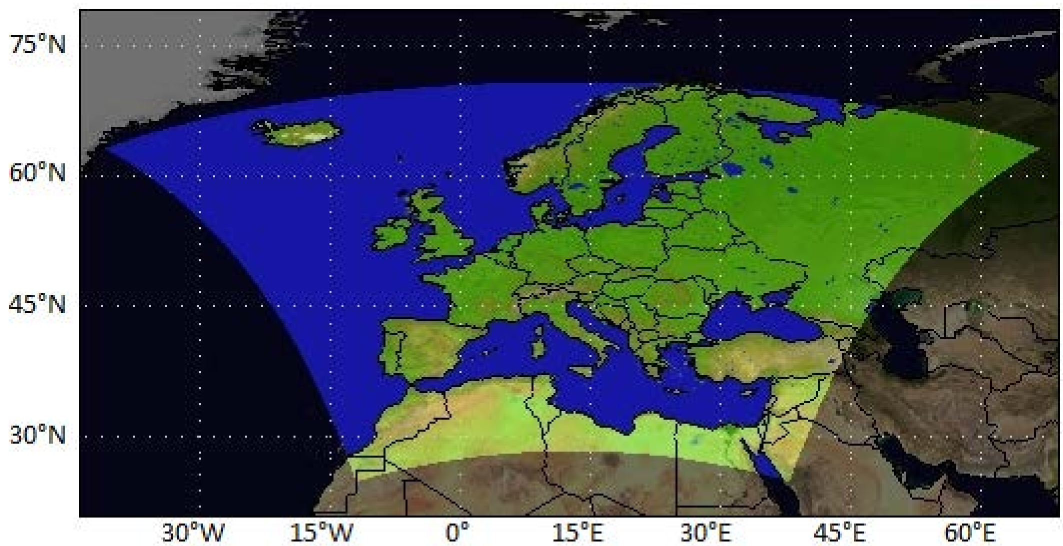

Figure 1. Position of model domain in regular longitude-latitude grid. (Earth view)

Model setup

A version 3.3 of WRF model with CLWRF modification, which were both released in 2011, were applied for presented simulations. The main purpose of CLWRF is providing model outputs as daily averages and extremes of main meteorology values, which is appropriate for fast evaluation of regional climate simulation results. Moreover, it enables the input of some necessary variable parameters.

The model domain includes all of Europe, it is the same domain as in the ENSEMBLE project simulations with another models (Fig. 1). It has horizontal resolution of 25 km; the point in the centre is at 50° N and 13° E. In east-west direction has 190 points, in north-south direction 206 points. The projection of the domain is Lambert conformal.

As an input data the reanalysis ERA-40 [*Uppala et al.,* 2005] is used, with the horizontal resolution of 0.5°. It consists of three-dimensional fields of temperature, velocity, moisture and geopotencial, and additionally two-dimensional data of values near the ground and three-dimensional fields of temperature and moisture below the ground. As a reference data source the E-OBS database is used [*Haylock et al.,* 2008] with resolution of 0.25°, which is about equal to the model resolution. However, model outputs are in Lambert projection, while E-OBS data comes on the regular longitude-latitude grid. For the interpolation of model outputs to the regular grid (bilinear interpolation is used) and other operations with the data (e.g., seasonal averaging), CDO (Climate Data Operators) [*Wegner,* 2009] is used. Reference database E-OBS contains values only for areas of continents and islands, not oceans and seas. Thus, the comparison of model outputs can be performed only for land.

The setup of WRF model is based on recommended settings for regional climate simulations, described by User's Guide for WRF ARW Modeling system [*Dudhia et al.,* 2012], with only 28 vertical levels instead of 51, with model top at 5000 Pa instead of 1000 Pa and with time step 200 s.

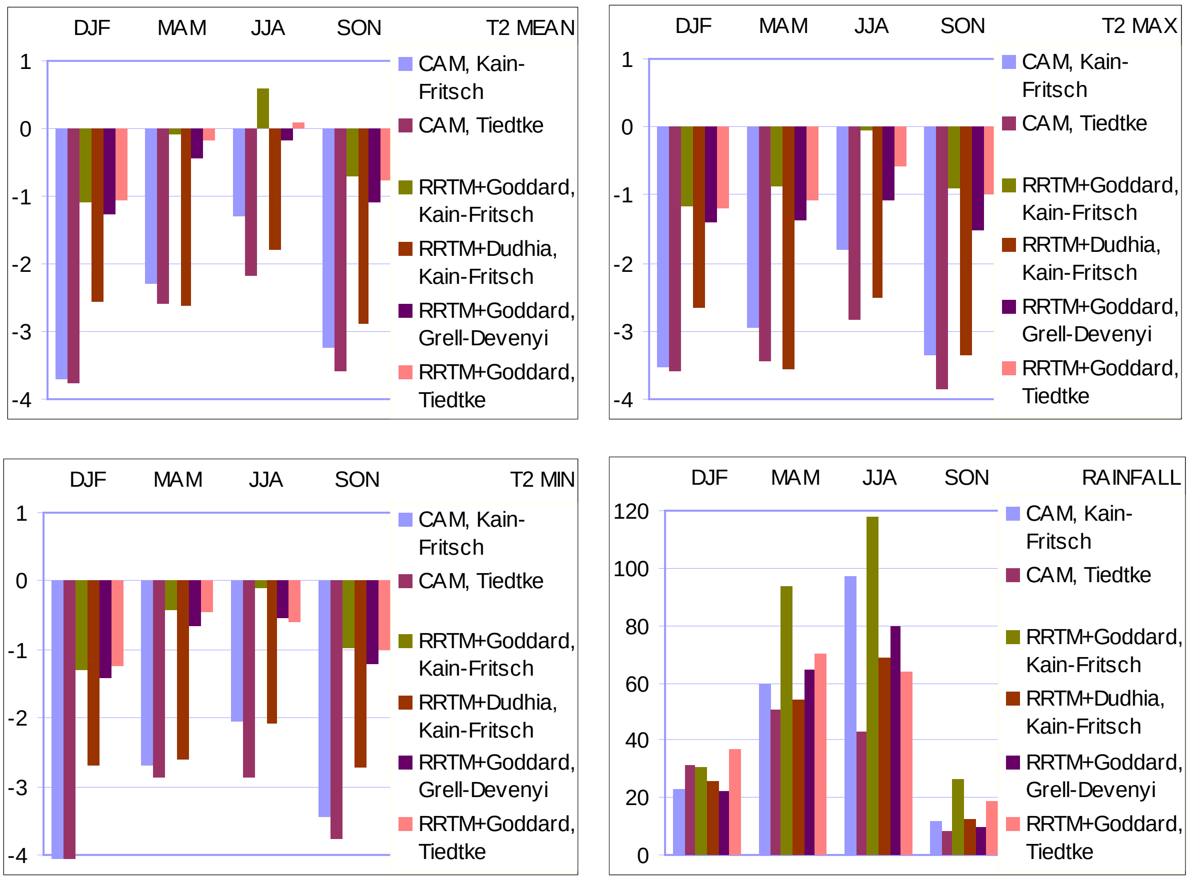

Figure 2. The full-area averages of seasonal biases between model and reference mean temperatures (T2 MEAN — top left panel), daily maxima (T2 MAX — top right), minima (T2 MIN — bottom left) of temperature (°C) and seasonal sums of precipitation (RAINFALL, mm — bottom right), for individual seasons and simulations.

Further, in presented simulations six model configurations with different parameterizations of radiation transfer and convection were tested. As a radiation transfer models for long wave, CAM scheme (recommended) and RRTM are tested; for short wave it is CAM, Goddard and Dudhia scheme. For a parameterization of convection, Kain-Fritsch scheme (recommended), Tiedtke and Grell-Devenyi schemes are tested.

Results and discussion

For one year simulation of 1990, we study biases between model output and reference data in daily mean temperature, daily maximum and minimum temperature in 2 m height and daily sum of rainfall. These values are averaged for individual seasons and the results are further presented. Averages of these values over the whole domain are shown in Fig. 2.

Because of our interest in central Europe mainly, the averages for this region are shown independently, in Fig. 3. The area of this region is defined by a rectangle in regular longitude-latitude grid, with boundaries at 3.75° E, 28° E, 42° N and 58° N.

It can be seen that temperatures in model simulations are predominantly underestimated. The temperature bias is particularly distinct for simulations with CAM radiation transfer, and also for simulation with RRTM and Dudhia schemes for radiation processes. Combination of RRTM scheme for long-wave radiation and Goddard scheme for short-wave radiation significantly improves the cold biases and for summer season produces even slight warm bias, so this combination seems as the best of all tested ones in terms of temperature. These patterns are very similar both for the full-area averages (Fig. 2) and central Europe area averages (Fig. 3).

Precipitation is significantly overestimated by model simulations, mainly in spring and summer seasons. Differences between individual simulations are not as significant as in case of temperature; however, simulations with Kain-Fritsch scheme for convection result in predominantly higher biases than simulations with Tiedtke or Grell-Devenyi scheme.

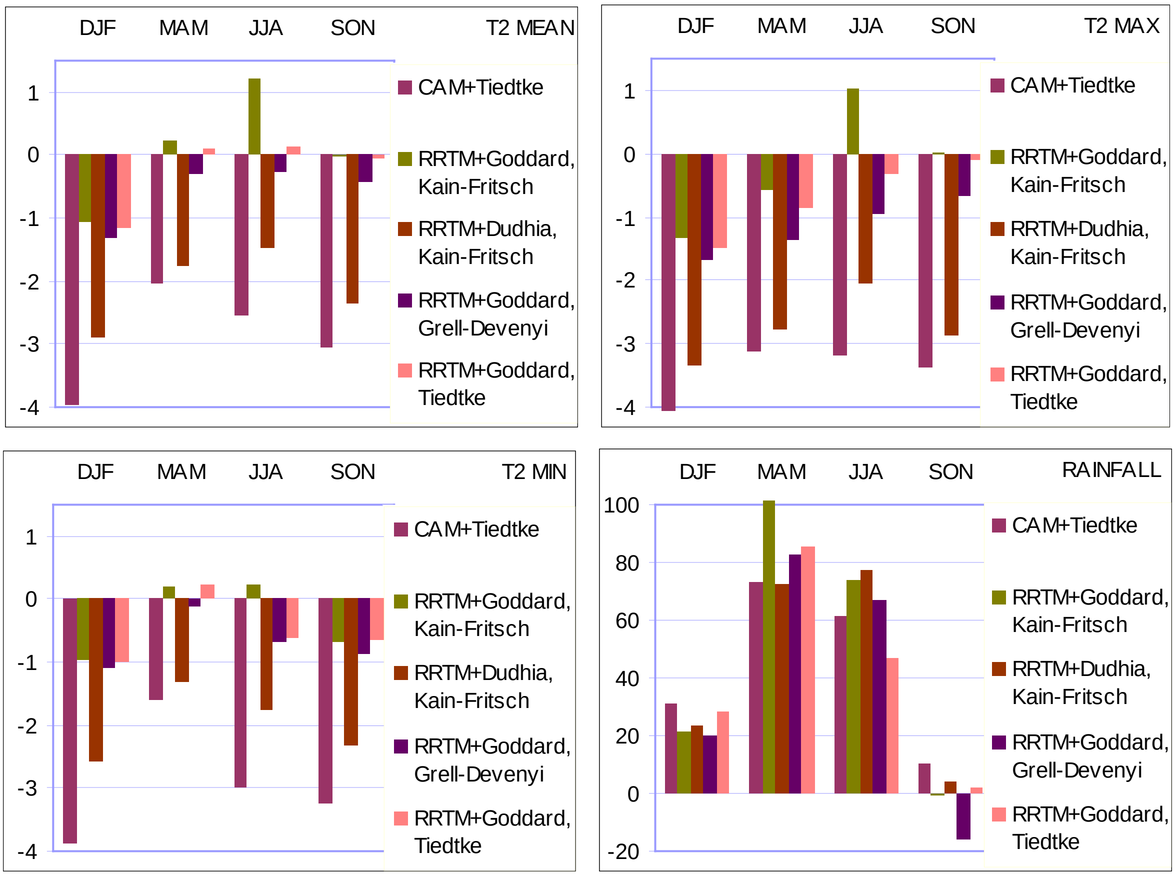

Figure 3. Values for area of central Europe, same as in Fig 2.

It can be seen that the last two configurations provide the best results for the preliminary test of year 1990. For more reliable assessment, it is necessary to run longer simulations, e. g. ten-year simulations after one year spin-up. The spin-up is a time interval, when model can make its own internal environment and balance, which is not so affected by initial conditions. The length of spin-up should be at least about one year. In presented simulations the spin-up was not used.

It should be pointed out that columns in Figs. 2 and 3 represent spatially averaged values, but the values across the model domain can vary substantially. The illustration of spatial variability of temperature bias is presented in Fig. 4, where seasonal temperature biases of simulation with RRTM and Goddard schemes for radiation and Tiedtke scheme for convection are shown. The variability of all simulations in terms of temperature bias is very similar, which is shown in Fig. 5. Only just the simulations with higher temperature bias seem to have higher spatial variability, as well.

The spatial variability of precipitation biases is much greater; the ratio between value of variability and bias is higher for precipitations than for temperatures. It is seen in Fig. 5 that there are differences between individual seasons and simulations. There is higher spatial variability in spring and summer seasons, especially for simulation with Kain-Fritsch scheme.

Conclusions and future plans

We have presented results of six one-year simulations of year 1990 by WRF model in regional climate mode. Model temperature is mostly underestimated, precipitation mostly overestimated. Simulations, in which RRTM and Goddard schemes were used for radiation, result in less temperature bias than the others. Tiedtke or Grell-Devenyi convective schemes provide better results in term of precipitation. Combination of these parameterizations gives the best results overall.

It is necessary to make longer simulations with spin-up interval for more reliable assessment of model results. However, it requires more computational time and it is not possible to make long-time simulations with all configurations. Anyway, one of present plans is to make long-time simulations

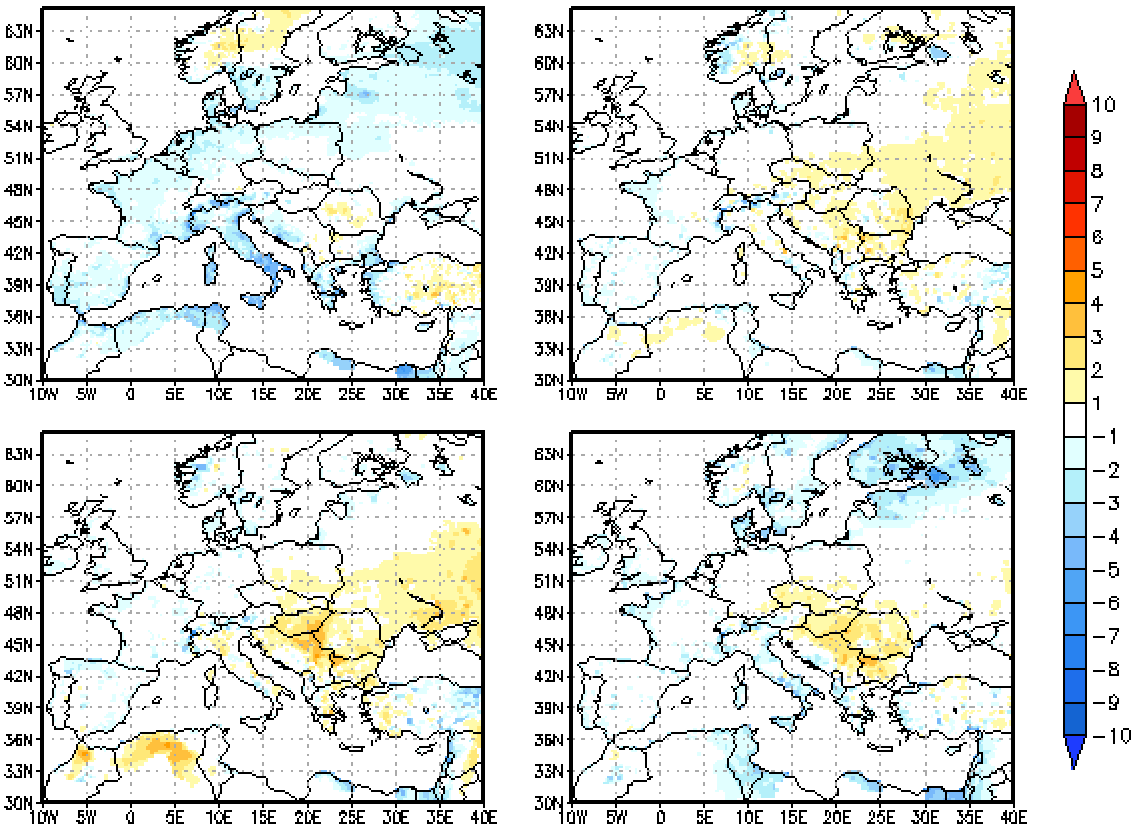

Figure 4. Temperature bias between model simulation and reference data (°C), for winter (top left panel), spring (top right), summer (bottom left) and autumn (bottom right) seasons. Configuration RRTM+Goddard, Tietdke.

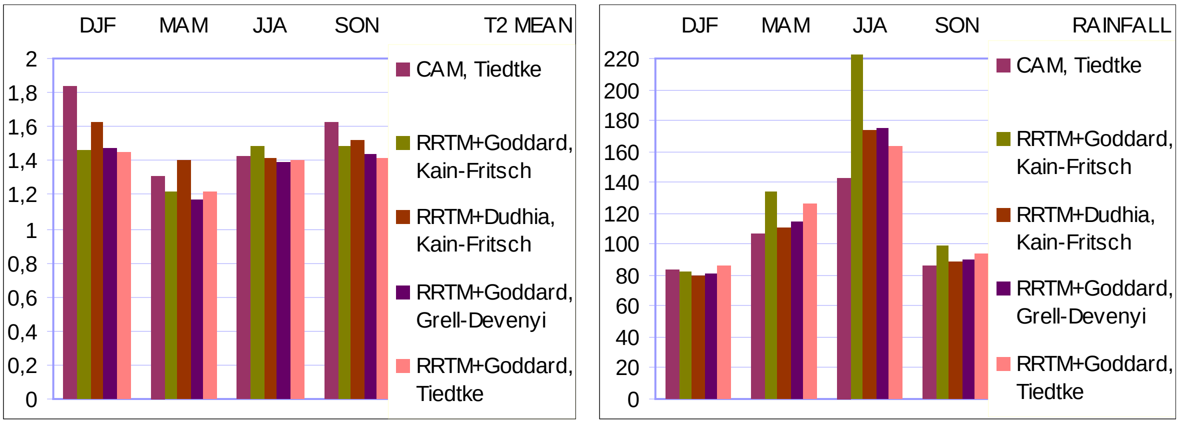

Figure 5. Spatial variability of temperature biases (T2 MEAN — left panel) and biases between model and reference sums of precipitations (RAINFALL — right panel). The values represent standard deviations, in °C and mm, respectively.

with the two best options chosen within this preliminary study. The length of these simulations will be ten years with spin-up over the period 1990–2000, then followed by another model run covering thirty years with spin-up over the standard climatic period 1960–1990.

Other future plan with WRF model involves the feedbacks from aerosol radiation and atmospheric chemistry to radiation in regional climate simulations. For this purpose, WRF-chem model is available. WRF-chem model is online coupled model of weather and atmospheric chemistry and it is capable to include aerosol direct and indirect effects to atmospheric chemistry and weather [*Forkel et al.,* 2012]. Therefore, it can be used to investigate the direct and indirect aerosol impact or effect of atmospheric chemistry to regional climate. WRF-chem offers also modelling of regional air quality at different time scales.

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