First results with the REMO regional climate model at the Hungarian Meteorological Service

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Introduction

Nowadays the global climate models developed and exploited by the world climate centres are rather reliable for providing realistic projections for the synoptic scale patterns and evolution of the climate, however they are insufficient for detailed regional scale estimations. There are several methods to interpret the results of these global coupled atmospheric-ocean general circulation models for regional scale – most recently the dynamical downscaling of the global results with the use of regional (limited area) climate models is the most widely-applied procedure.

A couple of years ago two regional climate models were adapted at the Hungarian Meteorological Service (HMS): the ALADIN/Climate model developed by Météo France on the basis of the internationally developed ALADIN modelling system and the REMO model developed by the Max Planck Institute for Meteorology (MPI-M) in Hamburg. It is anticipated in Hungary that these models will be able to give realistic regional climate estimations for the next few decades particularly for the area of the Carpathian Basin. This latter aspect is essential especially considering that one of the largest climate projection uncertainties can be found over the Carpathian Basin as it was already identified by several large international climate projects (PRUDENCE for instance).

Various versions of the REMO model had already been tested all over the world for different geographical domains and for different past periods, however recently further validations and tests have been starting also at the Hungarian Meteorological Service. This poster is going to briefly summarise the first validation experiments of the REMO model in Budapest.

Description of the model

Dynamical characteristics – based on the Europa Model

- Gridpoint model;
- Rotated spherical coordinate system with *Arakawa* staggering (C-type);
- Hybrid vertical coordinates;
- Prognostic variables (2D and 3D fields): surface pressure, temperature, horizontal wind-components, water-vapour content and cloud-water content;
- Two-time level explicit leapfrog scheme with semi-implicit correction;
- Computational modes of the numerical solutions filtered by an *Asselin*-filter;
- Hydrostatic model – the finest possible resolution is about 10 km;
- Davies' relaxation scheme for the proper treatment of LBCs.

Physical parameterization package

- Two physical parameterizations: global ECHAM4 and original EM;
- Prediction of the soil temperature by solving the diffusion equation using a five-layer model;
- Vertical diffusion and surface fluxes calculated based on the *Monin–Obukhov* similarity theory;
- Runoff scheme based on catchment consideration including sub-grid scale variations of field capacity over inhomogeneous terrain;
- Longwave radiation after *Morcrette* and shortwave radiation after *Fouquart* and *Bonnell*;
- Cumulus convection based on the mass flux scheme described by *Tiedtke* with modifications after *Nordeng*.

The summer-drying problem

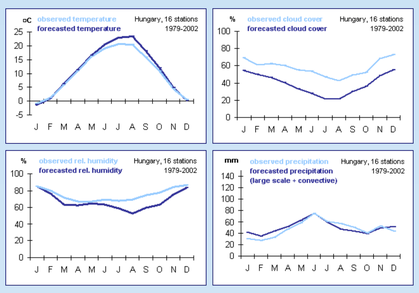
The special model feature over the Danube catchment area is a relatively known problem of the regional climate models. In the framework of the **RAACS** project it was already recognised that many regional climate models (including also REMO) simulate too dry and too warm summer climate over Central and Eastern Europe for the second half of the 20th century.

Later on, in the **MERCURE** project an important task was to understand and reduce (possibly fully eliminate) this model bias referred to as summer drying problem (SDP). The main conclusion from this project was that for most of the participating models the systematic errors in the dynamics appear to be the primary cause for the summer drying (after *Hagemann*'s work it was concluded, that the errors are mainly induced by problem in general circulation of the models where too little moisture is advected into the region). On the other hand for few models some deficiencies in the land surface parameterisations contributed significantly to the excessively dry model climate (the models simulated too weak diurnal soil temperature cycle).

Despite of the results mentioned above the exact cause of the summer drying problem was not identified, therefore the elimination of the bias was not yet possible. The investigations in the **PRUDENCE** project focused on the period of 1961–1990 with the simulations of ten regional models (using a horizontal resolution of about 50 km and with the application of the IPCC SRES A2 scenario run by the HadAM3H global atmosphere general circulation model as initial and lateral boundary conditions). The results have shown that the summer warm bias (compared to CRU data) still exists in majority of the participating RCMs, therefore no model developments in between improved the situation substantially.

In the framework of a bilateral cooperation between HMS and MPI-M the behaviour of the REMO model was particularly verified against Hungarian observational data. A long integration of REMO was executed in Hamburg for the period of 1979–2002 with the initial and lateral boundary conditions derived from ECMWF re-analyses. The target domain covered the entire Europe with 50 km horizontal resolution and the number of vertical levels was 20. The model results were compared to measurements of 16 Hungarian stations. The main **conclusions** of this evaluation basically confirmed the earlier findings:

- The modelled **temperature** fits well to the observations except for the summer months;
- There is a systematic underestimation of the **total cloud cover**, however the annual tendency is almost perfect;
- The underestimation of the **relative humidity** exists in the whole year, but it is most significant in summer;
- In summer months the model underestimates the **precipitation** amount, while in winter the opposite is typical.



Comparison of REMO results (dark) to Hungarian observations (light) for 2m-temperature (upper left) total cloud cover (upper right), relative humidity (lower left) and precipitation (lower right) (after Schlanger*'s work). The integration covers the period of 1979–2002, the LBCs were provided by ECMWF ERA40 re-analyses.*

Investigation of the impact of horizontal resolution

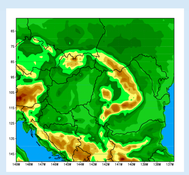
Some tests were already carried out at MPI-M for the investigation of the summer drying problem using increased number of vertical levels. These tests provided negative results: more vertical levels didn't provide better simulations. It was decided at HMS that similar study will be performed just looking at the increase of the horizontal resolution. Due to the fact that the finest possible REMO model resolution is 1/10 degree, therefore this maximal resolution was tested with respect to the "original" 1/6 degree resolution. The results of the two experiments were compared to Hungarian observations; certainly during the evaluation especially the summer months were carefully analysed.

The main features of the results are as follows:

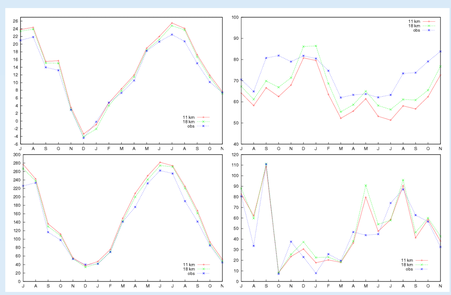
- For the **temperature** the largest differences from the observations can be noticed in the summer months in both cases. At that period systematic overestimation is obtained for every station. For the finer resolution the magnitude of the overestimation is slightly higher: the coarser resolution experiment is closer to the reality all along the year (the difference is around half degree Celsius between the two tests).
- The most significant differences of the **relative humidity** fields between the model outputs and the measurements can be found in the summer-autumn months – it exceeds 10 percent. The departures have generally negative orientation, thus the model underestimates the humidity conditions of the atmosphere. Moreover the finer resolution experiment is farther from the observations (as it is the case for temperature).
- For the **global radiation** the model overestimates the observed values mostly in summer. Significant differences between the two tests occur only in summer – the overestimation is higher in the case of finer resolution again –, in the rest of the year no significant difference can be noticed.
- As far as **precipitation** is concerned spatial averages over the entire domain were compared. The total amount of precipitation is smaller for the higher resolution tests, however it is not clear, which experiment is nearer to the truth.

	Experiment 1	Experiment 2
Gridpoints	121*91	61*51
Resolution	11 km	18 km
Vertical levels	20	20
Timestep	45 s	100 s
Period	July 2001 – Dec. 2002	

The main characteristics of the two experiments.



Orography of the domain to be used for 1/10 degree horizontal resolution.



The monthly mean values of the two model experiments (red: higher resolution, green: lower resolution tests) and the observations (blue) over Hungary for various parameters: temperature (upper left), relative humidity (upper right), global radiation (lower left) and precipitation amount (lower right). Period: July 2001 – December 2002.

Conclusions

After the careful analysis of the results it can be concluded, that **for the summer months both experiments overestimate the temperature and the radiation and underestimates the humidity.** Surprisingly the possible **finest resolution** tests **did not bring any improvements** – the summer drying problem is even more dramatic than it is the case for the coarser resolution experiments. The reasons for these strange results are still unknown and require further experimentation and understanding.

Simulation with REMO for the ERA40-period

As it was indicated above the summer drying problem is still an open and acute issue strongly influencing the uncertainty of past and ongoing climate change projections in Central and Eastern Europe. This issue as well as other factors determining the uncertainty in climate change projections will therefore be addressed within the **CLAVIER** project (Climate ChAnge and Variability: Impact on Central and Eastern EuRope – http://www.clavier-eu.org). In this project REMO 5.0 was adapted for the area of interest at the HMS using 25 km horizontal resolution. An approximately 40-year simulation was achieved for the period of 1957–2000, which was driven by the ECMWF ERA40 re-analysis data.

The model results were compared to various observational datasets: with the 10-minute (approximately 20 km) version of CRU-database and with the gridded (0,1-degree resolution) Hungarian observational dataset. The necessity of the intercomparisons with the detailed Hungarian dataset can be explained by the fact, that most probably during the preparation of the CRU database too few Hungarian observations had been used (therefore its quality might be occasionally poor). The gridded Hungarian dataset is based on Hungarian surface measurements post-processed by a special interpolation technique. The irregularly distributed observations were interpolated to a 0,1-degree resolution latitude-longitude grid covering Hungary. The interpolation was realised with the use of the so-called MISH-software (Meteorological Interpolation based on Surface Homogenized Data Basis), which had been originally developed for that purpose by the Hungarian Meteorological Service (it also uses climatic information beside the observations). This regular gridpoint database covers the three decades of 1971–2000 – so the evaluation hereafter is restricted for that period. The validation was mostly concentrating on two parameters: the mean temperature and the precipitation amount. These parameters were investigated at monthly, seasonal and annual scale both for the entire period and for the single decades. The departure fields between the model results and the observational data are visualised.

The evaluation results

Precipitation

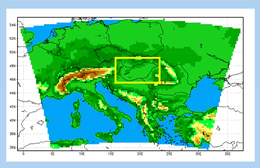
- Over the two highest orographic features in Europe (the Swiss, Italian and Austrian ranges of the Alps and the ridge of the Carpathian Mountains) the model overestimates the **annual** mean precipitation. The level of overestimation exceeds sometimes even the 70 mm in the Alpine region. At the same time opposite tendencies can be detected in other elevated parts of Europe – like the Adriatic side of the Alps, the Dinarian Mountains or the Apennines.
- Over Hungary a separation line can be found which isolates the too wet and too dry regions of the model: North from the Carpathians REMO overestimates the amount of precipitation, while over large part of the Basin and for the Southern part of Europe it provides too dry past climate. Otherwise the simulation for Hungary is fairly realistic: the departures from the observations generally don't exceed 10 mm (the error exceeds 10 mm only in Southwest) and in the major part of the area it remains under 5 mm.
- The features of the middle (1981–1990) decade are similar to the 30-years mean departure fields, however the decades before and after are rather different: while there is overestimation for the large part of Hungary for 1971–1980, the period 1991–2000 is rather characterised by dry features.
- The **summer** mean precipitation for the thirty years has similar distribution like in the annual case: the too wet and too dry regions predicted by the model are nearly the same, there are some differences only in the (generally larger) degree of misestimation. In **winter** the relative amount of wet areas increases. This tendency is further maintained in **spring**, where the dry regions are focused only on a small spot of the Adriatic Sea. Contrary to that, in **autumn** the underestimation is dominant almost on the entire study area, and its magnitude grows seriously at the Adriatic coast exceeding even 70 mm.
- The departure fields of the **monthly** precipitation amount for the entire period confirm the conclusions of the seasonal results, namely, that the REMO model mainly overestimates the precipitation in winter and spring; and underestimates in summer and autumn. Over Hungary the largest negative anomaly can be found in August and September (the differences vary between 5 and 30 mm) and the greatest overestimations occur in April and May.

Temperature

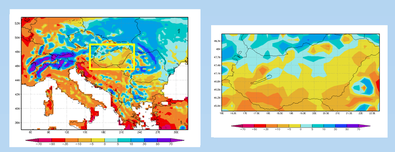
- The departure fields of the mean temperature do not show such large temporal and spatial variance. In the case of **annual** results the model overestimates the observed values with 1-3 degrees everywhere (both for the single decades and for the complete period), however over Bulgaria it is even higher.
- The same is typical also in **spring** (for the thirty years), but in **summer** the overheating grows up to 3-5 degree over the southern regions (Italy, Balkan Peninsula, Southern Hungary). Then the overestimation is rather moderate in **autumn** and in **winter** the model is quite perfect.
- The differences in the **monthly** mean temperatures for the whole period bring again some details compared to the seasonal results (as it is the case for precipitation): the model error is the largest in August – 5-7 degree – over and South of the Carpathian Basin. The bias is reduced step-by-step towards winter months, where the projections are almost perfect (December, January and February).

Conclusions

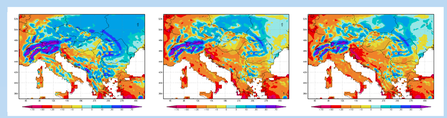
The main motivation for the long REMO past experiment was on the one hand to explore the weakness of the model for a longer past period (and check the existence of the summer drying problem) and on the other hand to prepare a high-resolution dataset for further hydrological investigations in the CLAVIER project (for the validation of the hydrological impact procedures). As a summary generally it can be said (based on the subjective verification for the time being), that the **REMO** model **overestimates the temperature and underestimates the precipitation in summer and autumn** seasons **over the Carpathian Basin.** At the same time **the precipitation is overestimated in the winter and mostly in the spring months (in winter** the prediction of **the temperature is rather correct all over Hungary)**. The comparisons to the Hungarian data shed some light into some more fine scale details, however basically it confirmed the main conclusions of the comparisons to the CRU data. After the careful analysis of the results one can conclude, that the summer-drying problem can be caught also in our model version (REMO 5.0) for our domain of interest and further investigations are really needed to eliminate this bias from the climate projections.



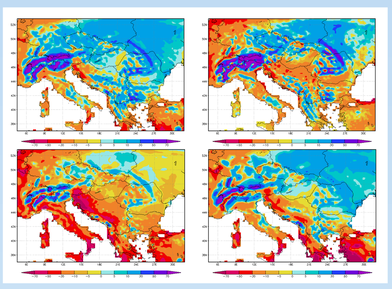
*Orography of the domain to be used for the long past integration. The domain consists of 101*81 gridpoints and its horizontal resolution is 25 km (exactly 0,22 degree), which allows 2 minutes integration timestep. Using this value the integration for the whole period took approx. 5 months on 16 CPU-s of the HMS' IBM Regatta (p690) supercomputer. The yellow rectangle represents the domain where the high-resolution Hungarian observational dataset is available.*



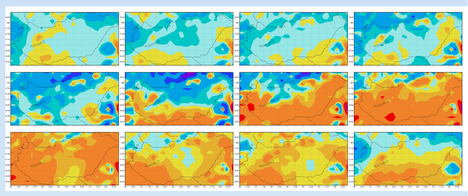
Difference of the annual precipitation amount between the model results and the 10-minute resolution CRU dataset (left) or the gridded Hungarian observational dataset (right) for the period 1971–2000. The intercomparisons were carried out on the 0,22 degree resolution original model grid.



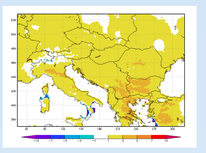
Difference of the annual precipitation amount between the model results and the 10-minute resolution CRU dataset for the single decades of the period 1971–2000.



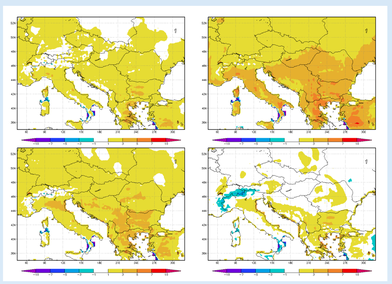
Difference of the seasonal precipitation amount between the model results and the 10-minute resolution CRU dataset for the period 1971–2000. From left to right and from top to bottom: spring, summer, autumn, winter respectively.



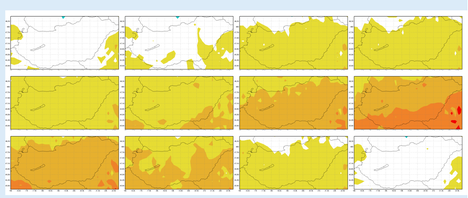
Difference of the monthly precipitation amount between the model results and the gridded Hungarian observational dataset for the period 1971–2000. The panels are read horizontally from January at the upper left corner and December at the lower right corner.



Difference of the annual mean temperature between the model results and the 10-minute resolution CRU dataset for the period 1971–2000.



Difference of the seasonal mean temperature between the model results and the 10-minute resolution CRU dataset for the period 1971–2000. From left to right and from top to bottom: spring, summer, autumn, winter respectively.



Difference of the monthly mean temperature between the model results and the gridded Hungarian observational dataset for the period 1971–2000. The panels are read horizontally from January at the upper left corner and December at the lower right corner.

Summary

In this poster a short overview was given about the various validations of the REMO regional climate model at the Hungarian Meteorological Service. The outputs of a longer model experiments in Hamburg (with 50 km horizontal resolution) were validated with Hungarian observational station data and the summer drying problem was diagnosed also based on the Hungarian data. Studying the impact of the finer horizontal resolution for the SDP it can be concluded, that the resolution increase doesn't improve the model predictions. Finally the experiment for the ERA40 period (which was verified against a detailed Hungarian observational dataset) confirms the significant errors in temperature and especially in precipitation over the Carpathian Basin in the summer months. According to the results as a general conclusion one can say, that the model is far from being perfect requiring further improvements and tests in the future.

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