Hungarian Meteorological Service

Climate modelling activities

Latest results (2010)

OMSZ

Introduction

It is generally accepted that the only scientifically sound way to understand the behaviour and future evolution of the climate is its numerical modelling.

Recent global climate models (GCMs) are capable of describing the physical processes of each component of the climate system (atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere; **Fig. 1**) and properly characterizing the complicated, non-linear interactions and feedbacks between them. Since these global models represent the Earth in its entire complexity, therefore, they are able to provide global response of the climate system for a hypothetical forcing.

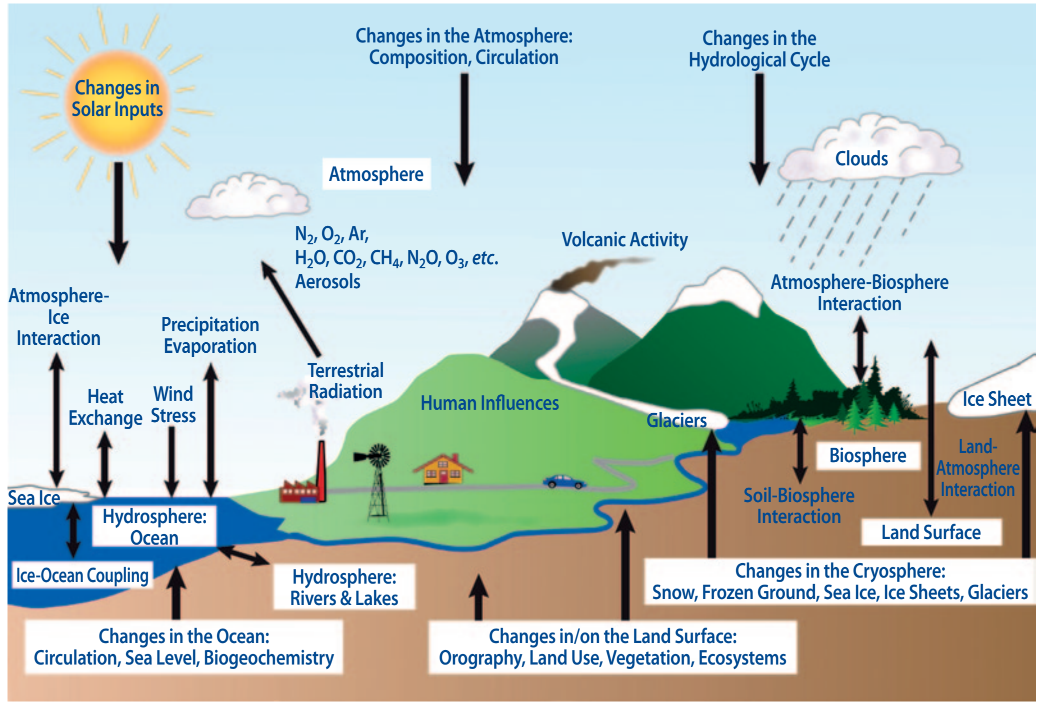


Figure 1: *the global climate system and its key interactions (IPCC AR4, 2007)*

One of the most uncertain elements of the future climate is the human activity. The anthropogenic factors influencing the climate system are quantified for the global climate models in the following way: the radiation constraints of the socio-economic aspects (population, energy consumption, industrial and agricultural structural changes, etc.) are determined (i.e., how much is their impact to the Earth's radiation balance), afterwards their carbon dioxide emission and concentration equivalents are computed (**Fig. 2**).

The uncertainty is coming from the estimation of the future change of the anthropogenic activity. Consequently, in order to assess these uncertainties several scenarios are constructed for future emission tendencies, which include optimistic, pessimistic and realistic versions, as well. The global climate projections are carried out taking into account these scenarios for the entire globe. (In climate terms the expression of forecast is not used for this kind of model simulations, but they are called projections reflecting their hypothetical nature.)

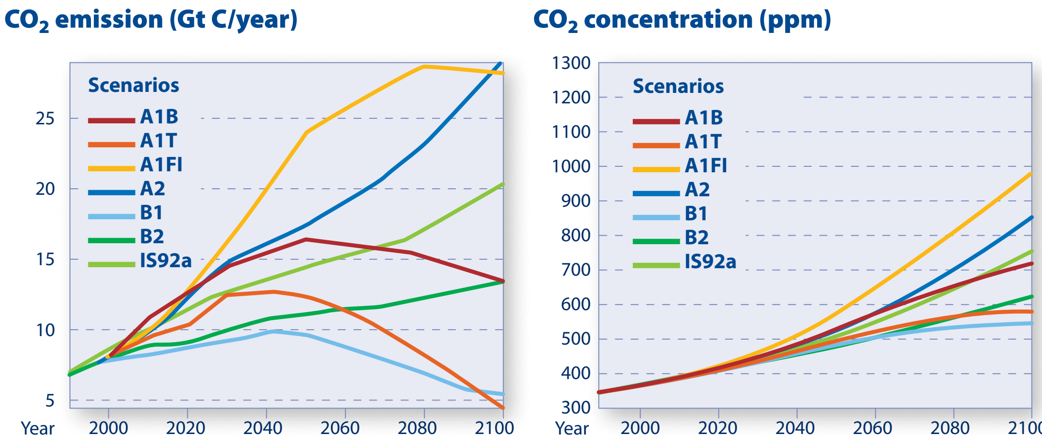


Figure 2: *emission (left) and concentration (right) values (calculated in carbon dioxide equivalent) of the most important global scenarios for the 21st century*

Nowadays, state-of-the-art global climate models are able to realistically simulate the behaviour of the climate system components together with the inter-relations between them, furthermore, they provide a basis for the description of the planetary (global, large-scale) features of the climate change. Contrary to weather prediction models, it is not expected from these projections to reflect weather events in every location and time: the main objective is to represent the mean spatial and temporal characteristics of the global system. Nevertheless, their sparse spatial resolution (mostly around 100 km) and their limited ability to describe the surface characteristics do not allow getting detailed projections about regional aspects of global changes. Therefore, *regionalization (downscaling) techniques* are indispensable to obtain sufficient and reliable information about regional characteristics, furthermore, these methods allow to amend the large-scale global information with the desired fine-scale details over the area of interest (e.g., over Central Europe in our case).

For such interpretation of the global simulations, regional climate models (RCMs) are applied in Hungary. These models (similarly to the short-range limited area weather predictions) dynamically downscale the global results for a smaller region using them as lateral boundary conditions (**Fig. 3**). Mostly, RCMs describe exclusively the atmospheric part of the climate system, consequently, they are usually adapted versions of already existing short-range numerical models. Such adaptation can be realized with modification of the physical parameterization schemes (e.g., radiation and cloud formation) being relevant at the involved temporal and spatial scales.

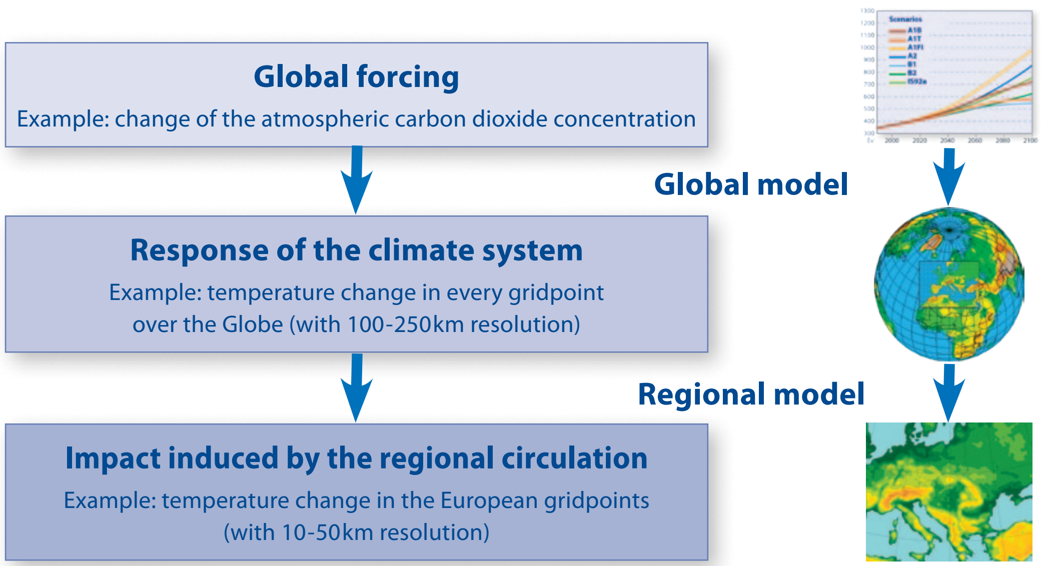


Figure 3: *the regional climate change as a response for a global climate forcing*

Historical overview of the Hungarian climate-dynamics activities

The idea to make initial steps towards climate dynamics research in Hungary dates back to 2003: it was decided to start climate modelling activities besides the statistical-based climate research. The origin of this initiative was the fact that in the last decade a strong numerical weather prediction (NWP) team emerged at the Hungarian Meteorological Service (HMS) together with the necessary computer background, which is indispensable for the use of numerical models. The above-mentioned NWP team had expertise in adaptation and application of short-range numerical models, therefore, the know-how was available for the work with regional climate models. The milestones of the planned research were laid down at an informal workshop organised by a meteorologist member of the Hungarian Academy of Sciences (Rudolf Czelnai). In this discussion experts in the fields of "traditional" climate research and numerical modelling were gathered, and afterwards the basis for a national climate-dynamics programme was sketched and elaborated. Later on, the relevant division of the Hungarian Academy of Sciences also supported the realisation of the research project.

The main initial vehicle for exploitation of the research and development programme was a national R&D project entitled "The dynamical meteorological study and characterization of the climate over Hungary based on numerical models". The project was realised between 1st January 2005 and 31st December 2007 with the leadership of the Hungarian Meteorological Service. Besides HMS, the consortium consisted of the Eötvös Loránd University, Department of Meteorology, the University of Pécs, Faculty of Sciences, and the Env-in-Cent Ltd. The main objective of the co-operation was the establishment of the Hungarian regional climate modelling basis, which can serve as building bricks for climate change estimations over the Carpathian Basin. During the realisation four regional climate models were adapted: ALADIN-Climate and REMO at the Hungarian Meteorological Service, PRECIS and RegCM at the Eötvös Loránd University. Details about this project can be read at the *http://www.met.hu* (in Hungarian).

Thanks to these initial steps, more and more contacts were made with other European researchers in the field of climate modelling, consequently Hungarian colleagues could join the climate modelling network and take part in the European-wide co-operations. As a result of these efforts, the Hungarian Meteorological Service participated in the CLAVIER and CECILIA EU-funded projects. Both projects investigated the ongoing and future climate changes, their possible impacts and related uncertainties over countries in Central and Eastern Europe. In CLAVIER (Climate Change and Variability: Impact on Central and Eastern Europe; from September 2006 to August 2009) the REMO RCM was used in order to study the regional impacts of climate change on circulation patterns, extreme events, air pollution, water- and energy management, and agriculture. Further details about the project are available at the web page *http://www.clavier-eu.org*. In the CECILIA (Central and Eastern Europe Climate Change Impact and Vulnerability Assessment) project (from May 2006 to December 2009) we took part with the results of ALADIN-Climate. CECILIA was also dealing with the impacts of climate change for Central and Eastern European regions, however, emphasis was also put on the exploitation of RCMs and their downscaling for finer spatial and temporal scale. More information about this project can be found at *http://www.cecilia-eu.org*.

Simultaneously, in order to further strengthen our international role, a climate-modelling mini-workshop was initiated and hosted by the Hungarian Meteorological Service (in Budapest) in February 2008. Mostly CLAVIER and CECILIA scientists attended the workshop, and aimed to strengthen the scientific co-operation between the two projects. The Quarterly Journal of the Hungarian Meteorological Service (called "Időjárás") devoted a Special Issue to the selected presentations of the workshop. During early summer of 2009 an international Summer School on climate change and variability ("Climate Variability and Climate Change: Estimating and Reducing Uncertainties") was organised in Visegrád (near Budapest) with active participation of a number of European and US researchers. The programme and the presentations of the mini-workshop, the complete Special Issue of Időjárás and the details (lectures, photos) of the Summer School are available at *http://www.met.hu*.

After completion of the CECILIA and CLAVIER projects, a new EU-project was started with our participation at the beginning of 2010; the ECCONET (Effects of Climate Change on the Inland Waterway Networks) project is planned to be finished at the end of 2012. The project is focusing on the estimation of climate change impacts on the European inland waterway transports with special emphasis on the Rhine and Danube Rivers. The Hungarian Meteorological Service is taking part in this work with its expertise regarding climate modelling and interpretation of climate model outputs for the impact studies. The web page of the project can be found at *http://www.tmleuven.be/project/ecconet/home.htm*.

Regional climate models at the HMS

A couple of years ago two regional climate models were adapted at the Hungarian Meteorological Service, which are as follows (the main characteristics of the models are presented in **Table 1**):

- the ALADIN-Climate model developed by Météo France *(http://www.cnrm.meteo.fr)* on the basis of the ARPEGE-Climat general circulation model;

- the REMO model originally developed by the Max Planck Institute for Meteorology in Hamburg *(http://www.mpimet.mpg.de)* based on the earlier weather prediction model (Europa Model) of the German Weather Service and the ECHAM4 general circulation model.

Initially, experiments for the past climate were carried out with these regional models in order to investigate and validate their behaviour for a longer period covered by relatively high-density observations. These experiments were executed using "perfect" lateral boundary conditions (with the use of re-analysis data created by blending observational information and some short-range numerical predictions). Based on the identified errors, these past climate results provide valuable information for further improvements of the models. In the ensuing model simulations, the large-scale constraints were already ensured by atmospheric or coupled atmosphere-ocean general circulation models instead of re-analyses, since, for the future solely

	ALADIN-Climate 4.5	REMO 5.0
Basic model ingredients	*Dynamics: ALADIN short-range LAM* Parameterizations: ARPEGE-Climat AGCM***	*Dynamics: Europa Model short-range LAM* Parameterizations: ECHAM4 AGCM***
Dynamics		
Representation of the horizontal spatial derivatives	*Spectral*	*Grid-point*
Vertical coordinate system	*Hybrid: terrain following + pressure system*	
Hydrostatic assumption	*Hydrostatic*	
Prognostic variables	*● Temperature ● Horizontal wind components ● Specific humidity ● Surface pressure*	*● Temperature ● Horizontal wind components ● Specific humidity ● Cloud-water content ● Surface pressure*
Temporal schemes	*Semi-implicit + semi-Lagrange*	*Explicit leapfrog + semi-implicit correction*
Physical parameterizations		
Radiation	*Fouquart and Bonnel, Morcrette*	
Soil model	*ISBA*	*Warrilow*
Soil layers	*4 (temperature) and 2 (humidity)*	*5*
Large-scale precipitation and cloudiness	*Smith, Ricard and Royer*	*Sundquist, Roeckner et al.*
Convection	*Bougeault*	*Tiedtke, Nordeng*

Table 1: *main characteristics of the applied regional climate models*

** LAM: Limited Area Model ** AGCM: Atmospheric General Circulation Model*

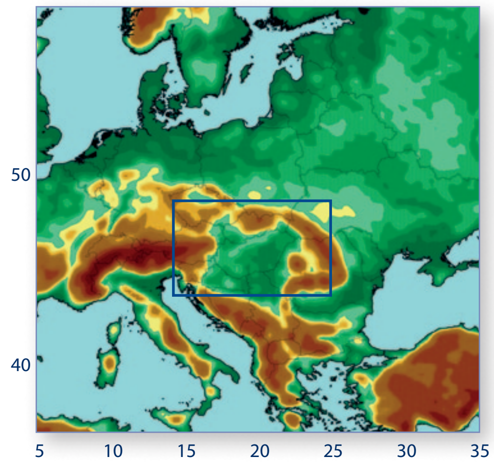
	ALADIN-Climate 4.5			REMO 5.0	
Experiment	*AL_ERA_25*	*AL_ERA_10*	*AL_ARP_10*	*REMO_ERA_25*	*REMO_ECH_25*
Period	*1961–2000*	*1961–2000*	*1961–2100*	*1961–2000*	*1951–2100*
Horizontal spatial resolution	*25 km*	*10 km*	*10 km*	*25 km*	*25 km*
Vertical levels	*31*	*31*	*31*	*20*	*20*
Domain	*Central and Eastern Europe*	*Carpathian Basin*	*Carpathian Basin*	*Central and Eastern Europe*	*Central and Eastern Europe*
Lateral boundary conditions (LBCs)	*ERA-40 re-analyses*	*ERA-40 re-analyses*	*ARPEGE-Climat/ OPA AOGCM****	*ERA-40 re-analyses*	*ECHAM5/ MPI-OM AOGCM****
Resolution of LBCs	*125 km*	*125 km*	*50 km*	*125 km*	*200 km*
Emission scenario	*-*	*-*	*A1B*	*-*	*A1B*

Table 2: *regional climate model simulations at the Hungarian Meteorological Service*

**** AOGCM: Atmosphere-Ocean General Circulation Model*

the global climate models are available to drive the RCMs (and the coupling interactions between the global and regional models are of vital interest in understanding the behaviour of regional climate projections). Simulations in the control period were validated against observational data. However, while the former reanalysis-forced outcomes gave some hints for the possible development paths of the regional climate models, GCM-driven results produce combined information about both the global and regional model deficiencies. It has to be remarked, that there is no direct relationship between the performance in the past and future in terms of the ability of describing climatic conditions, nevertheless, in practice the model being better for the past is anticipated to provide a more solid basis for future climate estimations.

While the REMO model simulations were accomplished on 25 km horizontal resolution, in the case of ALADIN-Climate 25 and 10 km resolution were also performed. The coarser resolution experiments covered Central and Eastern Europe, whereas the finer resolution ones were run over a smaller integration domain including the Carpathian Basin. The large-scale information was provided by global model experiments forced by A1B SRES scenario, which is considered to be an "average" estimation for the evolution of the greenhouse gas concentrations by the end of the 21st century. The most important characteristics of the model experiments are summarized in **Table 2** and integration domains are shown in **Fig. 4.**



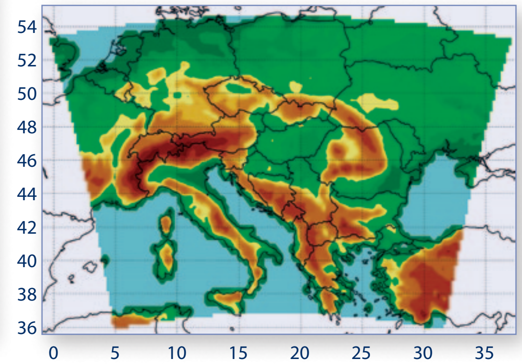


Figure 4: *integration domains: the 25 km (entire image) and 10 km resolution (blue rectangle) ALADIN-Climate areas on the left, the 25 km resolution domain of REMO on the right*

Comparative analysis of the available observational datasets

For understanding and proper interpretation of climate projections, detailed examination of reference databases used for validating regional climate models is essential. The knowledge of the main characteristics of these datasets is important in order to correctly interpret such statements as the summer mean temperature is too high in the control period, for instance. The following datasets were scrutinised from this angle at the Hungarian Meteorological Service:

- ERA-40 re-analysis data by ECMWF (European Centre for Medium-Range Weather Forecasts) – Uppala et al. 2005;
- two CRU (Climatic Research Unit) datasets prepared by different methodologies and (approximately 50 and 20 km) resolutions – Mitchell and Jones, 2005; Mitchell et al., 2004;
- the latest version of ECA&D (European Climate Assessment & Dataset) – van Engelen et al., 2008;
- the gridded, so-called HUGRID data made by Climate Analysis Division of HMS (Szentimrey et al., 2005), and
- some raw observational time series (mainly for precipitation and temperature) in Hungary.

For evaluation and assessment of the datasets it is important to understand their production method. Mostly non-homogenized observations with the use of different interpolation techniques were applied during the preparation process of CRU, ECA and HUGRID resulting in surface gridded values covering the entire globe (CRU0.5), Europe (CRU10' and ECA) or the area of Hungary (HUGRID). Datasets representing a large area often face the problem of insufficient information in data-sparse regions (such as oceans or seas) and in higher atmospheric layers (where fewer observations are available). The largest difference between the above-mentioned data and the ERA-40 re-analyses is that the latter one is prepared by using not only observational data, but also short-term numerical forecasts. The result of this data-assimilation type production is that rather precise information at higher atmospheric levels and at data-poor regions is available, as well. It is essential to note that the precipitation fields of ERA-40 are originated from six-hour model forecasts, therefore, their use for comparison is limited (which is not the case for temperature).

One can conclude based on the comparative analysis of the observational datasets that ERA-40 is rough and not suitable for fine-scale validation, but only this data can provide "perfect" initial and lateral boundary conditions for our RCMs for the past

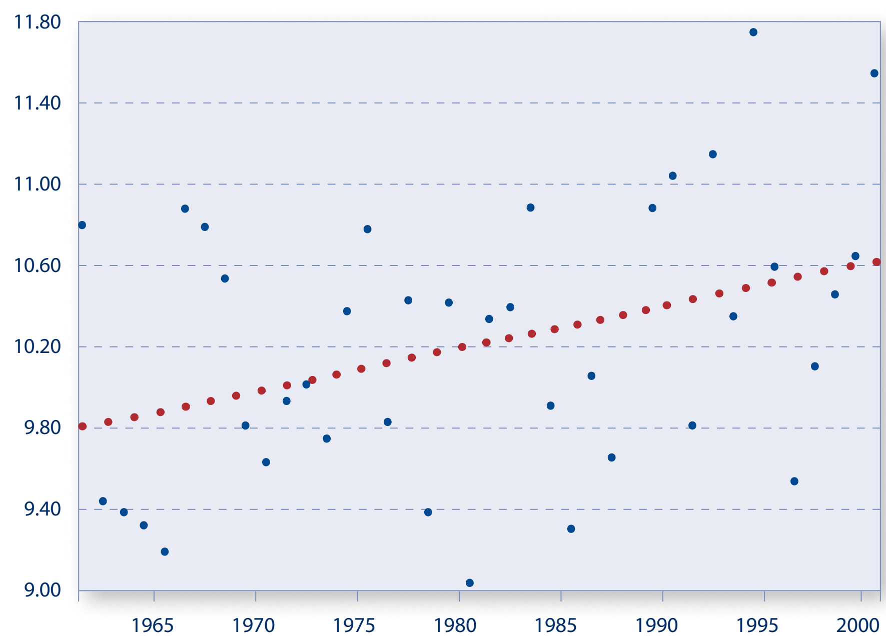


Figure 5: *time series and its linear trend (red) of mean annual temperature (°C) observed in Hungary (based on HUGRID) for 1961–2000*

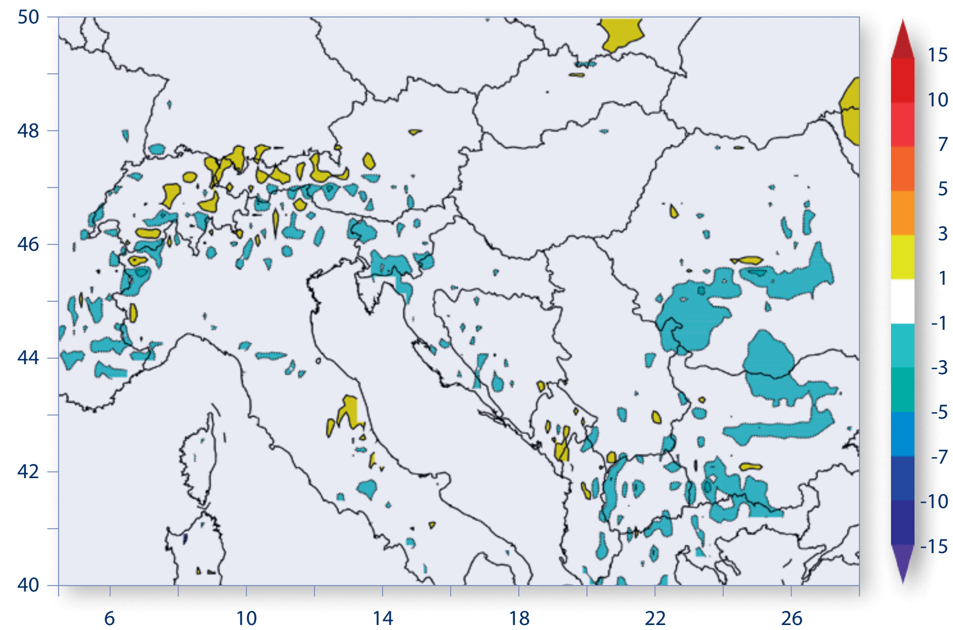


Figure 6: *mean temperature difference in summer of 1961–2000 (°C) between (10' resolution) CRU and ECA*

simulations. Among the CRU datasets the coarse (half-degree) resolution one contains larger number of newer and, presumably, more accurate data. ECA database is similar to the finer (10-minute) CRU, except that the former is updated regularly. As far as the quality of the internationally developed datasets for Hungary is concerned, these data may depict only an approximation of the real climate, since there were relatively few of the available observations used during their production, unlike HUGRID where all the Hungarian stations were included.

Daily data series are available only in ECA and HUGRID, therefore, extreme climate indices and their trends can be calculated uniquely from these datasets. On the other hand, several European and Hungarian institutions prefer to use CRU10' (because of its better resolution) for the evaluation of the general behaviour of their RCMs.

In **Fig. 5** annual mean temperature time series observed in Hungary and its linear trend between 1961 and 2000 based on HUGRID is seen (the increase is significant) and **Fig. 6** shows the mean summer temperature difference for 1961–2000 between CRU10' and ECA.

Validation

Validation of regional climate models means to integrate a model over a control period and to compare its results to observational datasets. Hereinafter the most important validation characteristics of our models are presented for the period of 1961–1990.

Regarding the annual and seasonal mean temperature (**Fig. 7**), REMO simulations driven by ECHAM5/MPI_OM coupled global model provides the best results. Differences between simulated values and CRU data over the Carpathian Basin are less than 1°C. On the other hand, REMO driven by ERA-40 (i.e., by quasi-"perfect" boundary conditions) strongly overestimates the annual and seasonal mean temperature. This characteristic points to the probable fact that consistency between the boundary conditions and the regional model is less adequate in the re-analysis-forced simulations than in the ones forced by global models. For ALADIN-Climate, mean temperature is underestimated in most cases (therefore, ALADIN-Climate is rather a cold model).

Over Hungary all the ALADIN-Climate experiments and the GCM-driven REMO overestimate the annual mean precipitation. The ERA-40-driven REMO is characterized by overestimation of precipitation over the Northern part of Hungary and underestimation over the Southern one. As far as seasonal means are concerned, simulations give different results, but all of them enhance the precipitation in spring. In autumn simulations are generally wetter than the reality, and the best results are obtained in winter.

For both examined parameters ALADIN-Climate model performs better for the large domain with lower resolution than for the smaller and higher resolution one, indicating that the latter ALADIN-Climate domain is most probably too small (the domain boundaries are over mountainous areas, which can cause spurious noises originated from the boundary relaxation zone). Recognizing this problem we are going to carry out some sensitivity tests for the ALADIN-Climate model in order to find the optimal model domain for future integrations.

As a summary, model validation results indicate that the behaviour of the models is complex; they perform better for certain parameters, however, quite erroneously for other ones making the decision on model development extremely difficult.

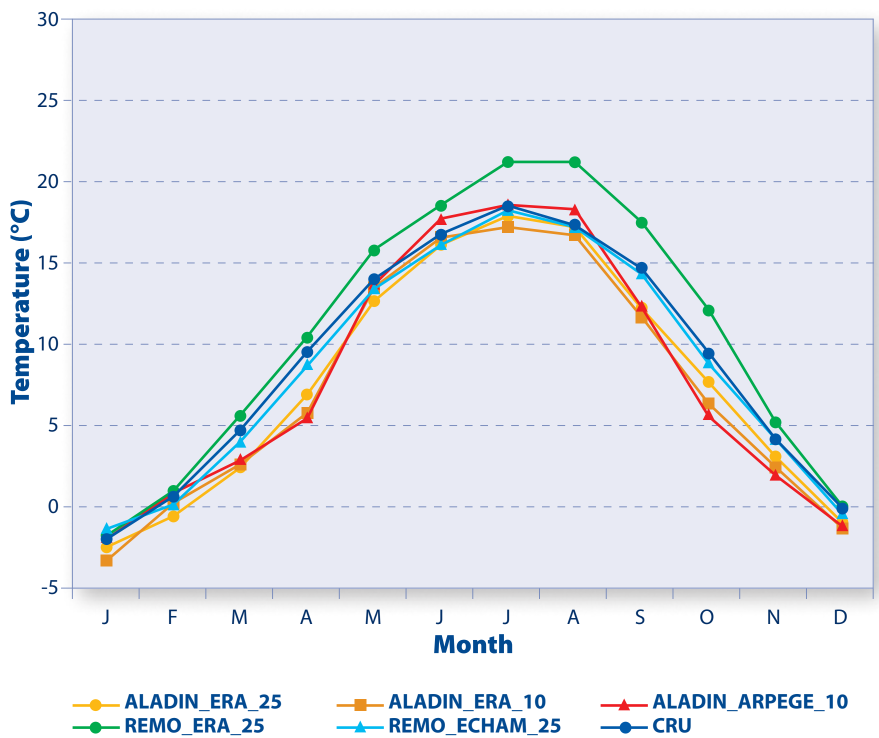


Figure 7: *observed and simulated monthly mean temperature values (°C) averaged over Hungary for the period of 1961–1990*

Projection results

The regional climate models applied at the Hungarian Meteorological Service (ALADIN-Climate and REMO) are different not only in terms of applied numerical schemes and physical parameterization processes, but also in many respects of their simulations (**Tables 1** and **2**). Nevertheless, all the projections are focusing on the climate change over the Carpathian Basin for the 21st century. Therefore, the common (ensemble) evaluation of the results can give a hint for the extent of climate change and the related uncertainties. If the two models project similar changes, the certainty is higher, while in the opposite case when the results are contradicting, the common interpretation should be more careful and more emphasis should be put on the uncertainties. Hereafter projection results for temperature and precipitation (annual and seasonal mean values for both models) are shown for two future periods (2021–2050 and 2071–2100) with respect to the reference period (1961–1990). It is emphasised that climate change signals are determined on the basis of differences between the (future) projection and (past) reference periods in order to avoid the possible systematic model errors (this approach assumes that model error characteristics remain the same for the past and future periods).

Temperature

The two regional climate models "agree" in the increase of the mean temperature during the 21st century in the Carpathian Basin (**Fig. 8**): this statement is valid for all seasons, moreover, in a statistically significant way for every period (i.e., the inter-annual variability is smaller than the degree of the change). The increase is continuous in the sense that for 2071–2100 its value is larger (3.5 degree in average) than for 2021–2050 (1.7 degree in average).

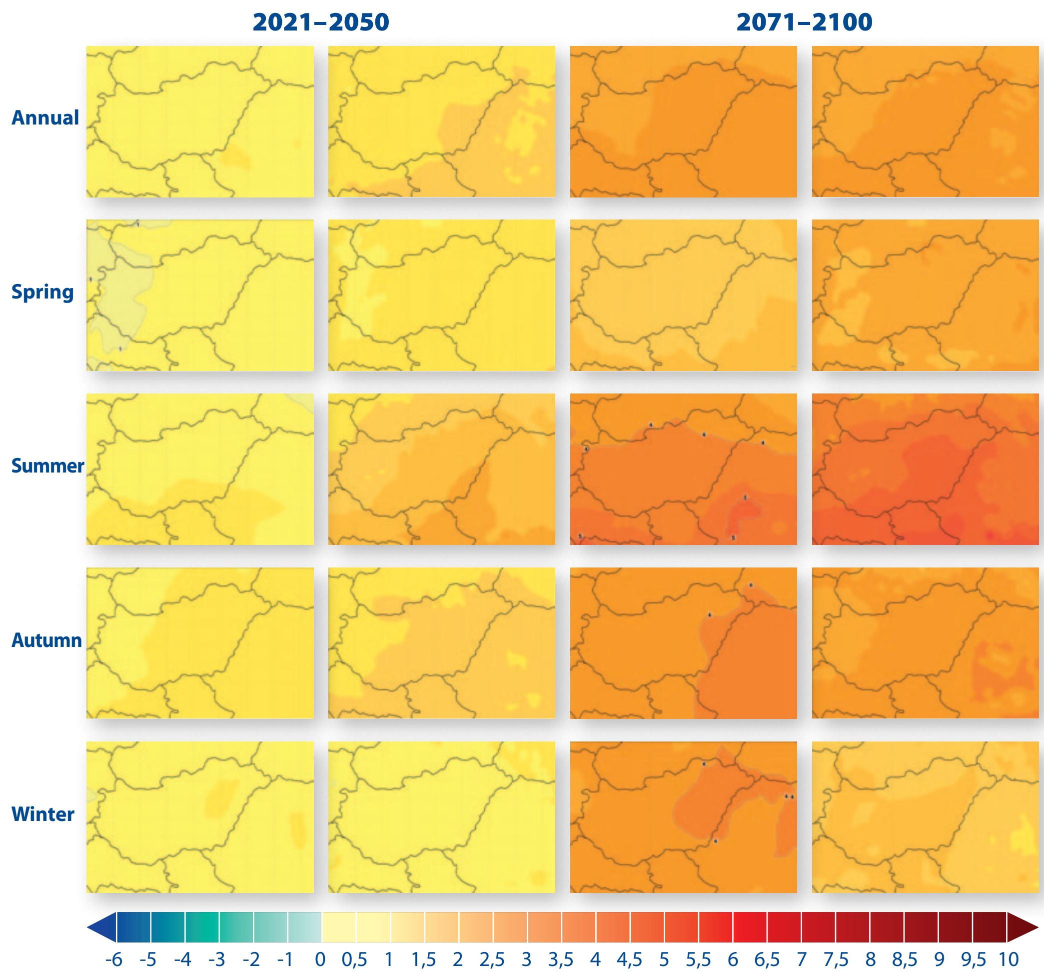


Figure 8: *annual and seasonal mean temperature changes (°C) based on the two applied regional climate models for the periods of 2021–2050 and 2071–2100 with respect to the mean values of 1961–1990*

Certainly, it does not mean that all the forthcoming years in the future will be warmer than the reference period: in spite of the positive trend cooler years and seasons can be anticipated, as well. There is a difference between the precise warming values of the two models, especially considering the seasonal tendencies. The largest departure between the two models is for summer in the period of 2021–2050 between 1.4 and 2.6 degrees, while for 2071–2100 the same values are 4.1-4.9 degrees. The spatial details of the projections show (in agreement of the two models) that the temperature increase will be larger in the Eastern and Southern parts of the country.

Precipitation

The precipitation change results are much less clear, since the models mostly "disagree" even in the sign of the changes (which are mostly not significant on top of that). For 2021–2050 the models are in agreement regarding the unchanged amount of annual precipitation and in the slight summer decrease (5-10%; **Fig. 9**). At the same time, there are also such areas (especially over the Northern regions) where both models indicate slight summer precipitation increase. For spring and winter the RCMs provide rather different projections: less than 10% increase and decrease are equally possible for both seasons.

For the end of the century both models render a slight annual precipitation decrease, which is around 5%. The main directions of changes simulated for the middle part of the century are going to continue with different amplitudes, though. The summer precipitation decrease can exceed 20% on average for Hungary. In winter one model shows the possibility of 5% decrease, while the other one projects 30% increase. Otherwise, the enhanced amount of winter precipitation is confirmed by the lower resolution RCM results of the former European PRUDENCE project *(http://prudence.dmi.dk)*.

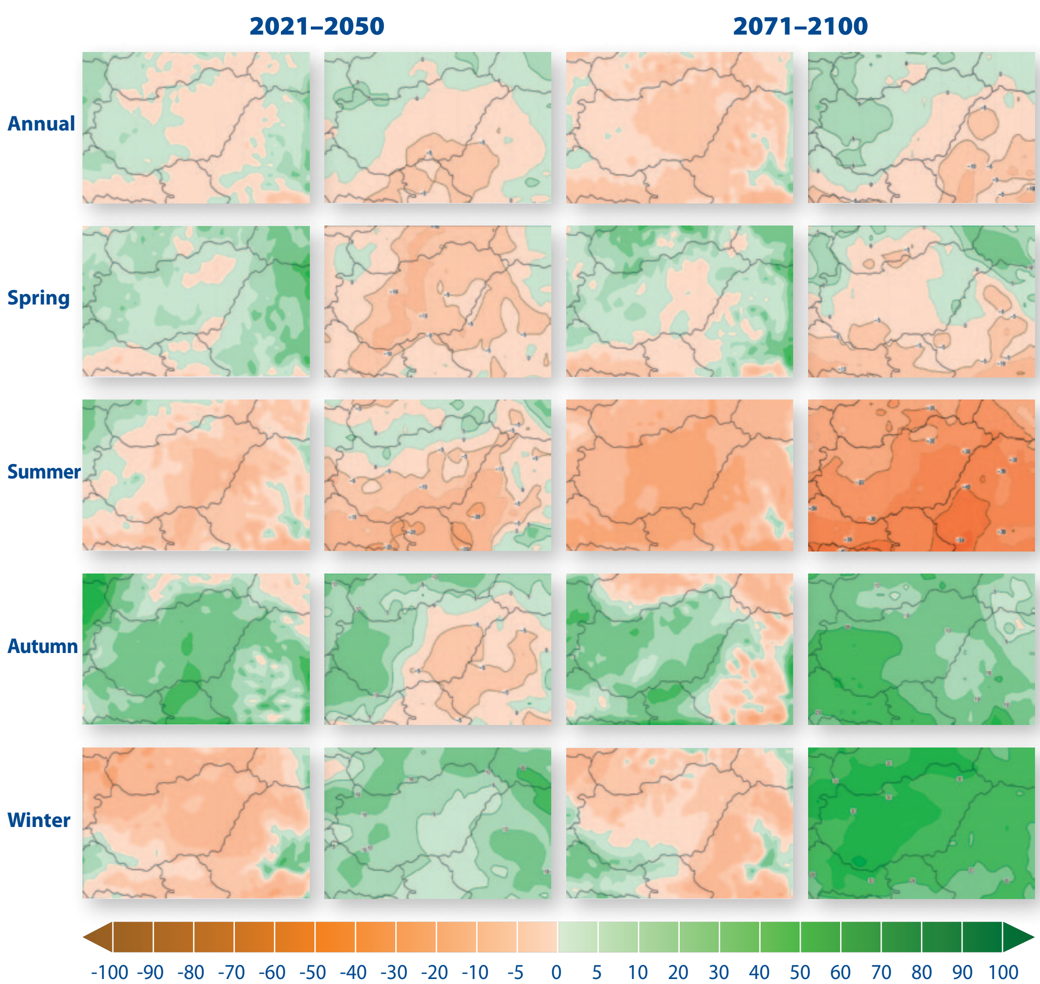


Figure 9: *annual and seasonal relative precipitation changes (%) based on the two applied regional climate models for the periods of 2021–2050 and 2071–2100 with respect to the mean values of 1961–1990*

Evaluation of extreme climate indices

Besides the general behaviour of the climate, characterization of climate extremes is an important part of the assessment of climate models, and consequently, for the exploration of climate change. In order to realise this aspect, various climate indices were defined by number of international programmes and projects dealing with climate change (for instance, CCL/CLIVAR/JCOMM – Commission for Climatology of WMO/Climate Variability and Predictability Research Programme/ Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology –, ECA&D project, and some climate research teams from meteorological services, like KNMI from the Netherlands or Hadley Centre from the United Kingdom). The definitions of extreme indices are available at *http://www.clivar.org/organization/etccdi/indices.php.*

Index	Name	Definition	Unit
FD	frost days	$T_{min} < 0$ °C	days
CFD	annual maximum number of consecutive frost days	days, when $T_{min} < 0$ °C	days
TX0LT	winter days	$T_{max} < 0$ °C	days
TN-10LT	extremely cold days	$T_{min} < -10$ °C	days
TN20GT	tropical nights	$T_{min} > 20$ °C	days
SU	summer days	$T_{max} > 25$ °C	days
TX30GE	hot days	$T_{max} \geq 30$ °C	days
TX35GE	extremely hot days	$T_{max} \geq 35$ °C	days
HEAT	heat waves (1st, 2nd, 3rd degree)	$T_{ave} \geq 25$ °C for 1 day / 3 days or $T_{ave} \geq 27$ °C for 1 day / 3 days	days
CDD	annual maximum number of consecutive dry days	days, when $R_{day} < 1$ mm	days
CWD	annual maximum number of consecutive wet days	days, when $R_{day} \geq 1$ mm	days
RR0.1	precipitation above threshold 0.1 mm	$R_{day} \geq 0{,}1$ mm	days
RR1	precipitation above threshold 1 mm	$R_{day} \geq 1$ mm	days
RR5	precipitation above threshold 5 mm	$R_{day} \geq 5$ mm	days
RR10	heavy precipitation days	$R_{day} \geq 10$ mm	days
RR20	extremely heavy precipitation. days	$R_{day} \geq 20$ mm	days
RX1	annual maximum 1-day precipitation	max (R_{day}) in a year	mm
RX5	annual maximum 5-day precipitation	max ($R_{day\,i,\,i+1,\,i+2,\,i+3,\,i+4}$) in a year	mm
SDII	simple daily intensity index	precipitation amount/rainy days ($R_{day} \geq 1$ mm)	mm/day
SPI	standardized precipitation index	on annual or seasonal basis $(R-R_{ave})/R_{stdev}$.	–
CEI	climate extreme index	it quantifies how an area is affected by extremes	–

Table 3: *extreme climate indices used at the Numerical Modeling and Climate-Dynamics Division*

At the Numerical Modeling and Climate-Dynamics Division 11 precipitation and 9 temperature-related indices and a complex index were analysed so far. In the future some additional, less common indices are planned to be computed. The applied indices are listed in **Table 3.**

Together with the Climate Analysis Division of HMS we have analysed various daily-resolution, gridded databases. For the Carpathian Basin the following datasets were examined: HUGRID, the latest ECA&D dataset and the two regional climate model (ALADIN-Climate and REMO) results for different periods. Similarly to the mean climate behaviour, the significance of changes (or significance of errors in the reference period) is also investigated for extreme indices (using different statistical tests, like Welch or t-test, for instance; see more details about significance tests at *http://www.statsdirect.com/help/statsdirect.htm#parametric_methods/ptt.htm*).

The Hungarian climate impact studies mainly focused on the extreme indices listed in **Table 3**, however, sometimes special needs should be met and fulfilled with the calculation of additional derived indices (since more and more impact assessments are computed on the basis of the RCM results).

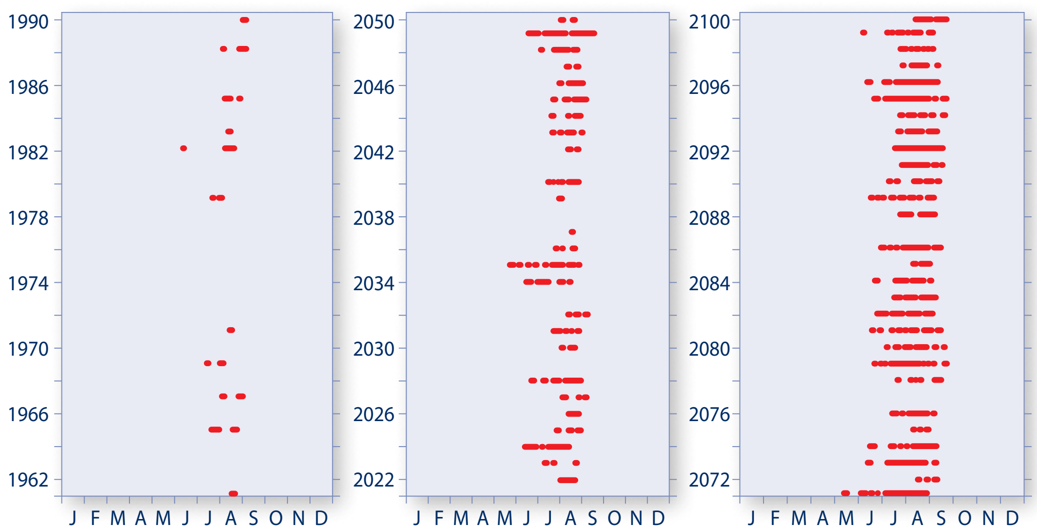


Figure 10: *the frequency of extremely hot days affecting at least 10% of the Hungarian territory by the ALADIN-Climate model for different periods (1961–1990, 2021–2050, and 2071–2100, respectively). The variability can be seen, however, the precise annual frequencies cannot be read from the figure.*

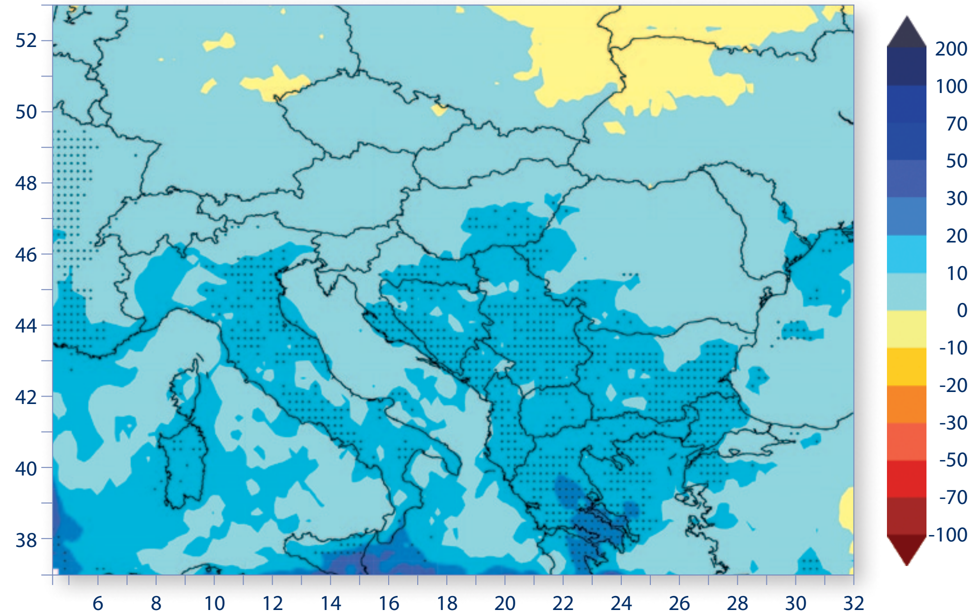


Figure 11: *expected change (%) of simple daily intensity index simulated by REMO for 2021–2050 with respect to 1961–1990 (dots indicate areas of significant change)*

In **Fig. 10** and **Fig. 11** some examples can be seen, for instance, **Fig. 10** indicates the occurrence of extremely hot days (TX35GE), which affects at least 10% of the Hungarian territory as for the ALADIN-Climate model for different periods. This clearly shows that while for the control period (end of the 20th century) the TX35GE episodes over some parts of Hungary are rare (mostly in July and August), it becomes much more frequent for the first and second half of the 21st century (might occur any time from May to September). The amplitude of change between the past and near-future periods is much larger than it is the case for the near- and far-future ones. **Fig. 11** represents the expected change (in %) of the simple daily intensity index (SDII) simulated by REMO for 2021–2050 with respect to 1961–1990 (areas with significant changes are indicated by dots). This result supports earlier finding of European projects based on coarser (50 km and lower) resolution model outputs: the daily precipitation intensity index mainly increases over Europe. According to the simulation results this means if rainfall occurs in the future its intensity will be higher than in the past. This intensification is around 10% for Hungary, however, it is only significant in the Southern part of the Great Hungarian Plain.

Future plans

There are several plans on the one hand, concerning improvement of the regional models, and on the other hand, regarding application and interpretation of the RCM results for the impact studies. Hereafter, the most important plans are briefly summarised.

■ One essential objective is to complete an ensemble evaluation of the regional climate models available in Hungary (ALADIN-Climate, PRECIS, RegCM, and REMO). The projections of the four climate models are evaluated together using ensemble techniques in order to quantify not only the possible climate change over Hungary, but also the related uncertainties. The work is realised in co-operation with Eötvös Loránd University.

■ In 2010–2012 it is planned to extend and enhance the available model experiments with emphasis on the following aspects:

1. preparation of the 10 km resolution version of the REMO model in a new model domain and its integration for the period of 1951–2100

2. determination of the optimal domain for ALADIN-Climate and rerun of the 10 km integration (most probably with an updated model version).

■ The liaison with the public and the contact with experts on impact studies are essential ingredients of our work, therefore, we would like to extend further those activities, which are in connection with these user groups. We have to emphasise that future evolution of the climate system can be only determined with the help and use of climate models and impact studies should be constructed on the outputs of those models (**Fig. 12**). We are convinced that the successful adaptation work should be based exclusively on results taking the climate model outputs into account. We are going to compile a questionnaire in order to see what the common knowledge is with respect to the climate change and what the frequent misinterpretations are.

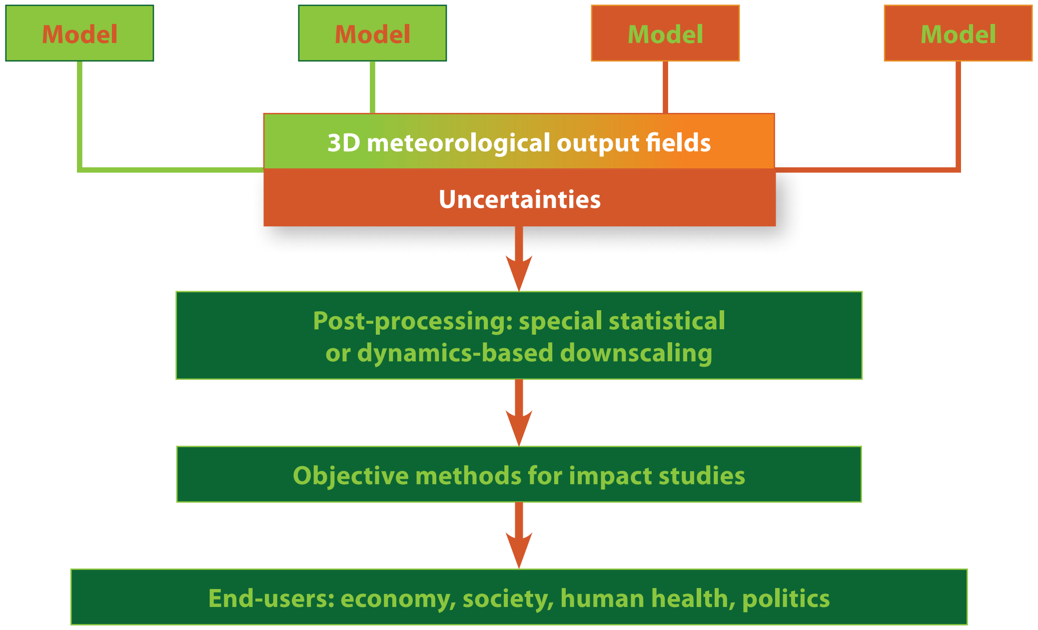


Figure 12: *schematic flow-chart about applicability of regional climate model outputs for climate impact studies*

Further information

(The articles and presentations below are available on the webpage *http://www.met.hu*)

■ Csima, G. and Horányi, A., 2008: Validation of the ALADIN-Climate regional climate model at the Hungarian Meteorological Service. Időjárás 112, 3-4 (Special Issue), 155-177.

■ Csima, G., 2009: High resolution experiments with the ALADIN-Climate regional climate model. Presentation at European Meteorological Society Annual Meeting 2009, Toulouse (France).

■ Horányi, A., Csima, G., Szabó, P., and Szépszó, G., 2008: Regional climate models and their applicability for climate impact assessment, Part I-II (in Hungarian). Presentation for Adaptation to Climate Change Research Group at Corvinus University, Budapest.

■ Horányi, A., Csima, G., Szabó, P., Szépszó, G., Bartholy, J., Hunyady, A., Pieczka, I., Pongrácz, R., and Torma, Cs., 2009: Application of a regional climate model mini-ensemble for the Carpathian Basin. Presentation at European Meteorological Society Annual Meeting 2009, Toulouse (France).

■ Horányi, A., Krüzselyi, I., Szabó, P., and Szépszó, G., 2010: Projected climate change around the Lake Balaton based on meteorological modelling (in Hungarian). Presentation for stakeholders around the Lake Balaton, Siófok.

■ Szabó, P., 2008: Comparison of precipitation and temperature fields in different data sets used for evaluating Regional Climate Models at the Hungarian Meteorological Service. Internal report.

■ Szabó, P., 2009: The evaluation of extreme precipitation and temperature indices based on regional climate models at the Hungarian Meteorological Service. Presentation at European Meteorological Society Annual Meeting 2009, Toulouse (France).

■ Szépszó, G., 2008: Regional change of extreme characteristics over Hungary based on different regional climate models of the PRUDENCE project. Időjárás 112, 3-4 (Special Issue), 265-284.

■ Szépszó, G. and Horányi, A., 2008: Transient simulation of the REMO regional climate model and its evaluation over Hungary. Időjárás 112, 3-4 (Special Issue), 203-231.

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■ IPCC 4th Assessment Report: Climate Change 2007: The Physical Science Basis. Edited by Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller. Cambridge University Press, Cambridge, United Kingdom and New York, USA, 996 pp.

■ Mitchell, T. D. and Jones, P. D., 2005: An improved method of constructing a database of monthly climate observations and associated high-resolution grids. International Journal of Climatology 25, 693–712. *http://www.cru.uea.ac.uk/~timm/grid/CRU_TS_2_1.html*

■ Mitchell, T. D., Carter, T. R., Jones, P. D., Hulme, M., and New, M., 2004: A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901–2000) and 16 scenarios (2001–2100). Working Paper 55. Tyndall Centre for Climate Change Research, University of East Anglia, Norwich, UK. *http://www.cru.uea.ac.uk/~timm/grid/CRU_TS_1_2.html*

■ Szentimrey, T., Bihari, Z., and Szalai, S., 2005: Meteorological Interpolation based on Surface Homogenized Data Basis (MISH). Geophysical Research Abstracts 7.

■ Uppala, et al., 2005: The ERA-40 re-analysis. Quarterly Journal of Royal Meteorological Society 131, 2961–3012. *http://www.ecmwf.int/research/era/do/get/era-40*

Related links

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- **ECA&D** *http://eca.knmi.nl/documents/ECAD_report_2008.pdf*
- **ECCONET** *http://www.tmleuven.be/project/ecconet/home.htm*
- **ENSEMBLES** *http://ensembles-eu.metoffice.com*
- **ERA** *http://www.ecmwf.int/research/era*
- **IPCC** *http://www.ipcc.ch*
- **PRUDENCE** *http://prudence.dmi.dk*

Authors:

Numerical Modeling and Climate Dynamics Division
András Horányi, Ilona Krüzselyi, Péter Szabó, Gabriella Szépszó

E-mail: klimadinamika@met.hu

HUNGARIAN METEOROLOGICAL SERVICE

H-1024 Budapest, Kitaibel Pál street 1.
Phone: (+36-1) 346-4600 • Fax: (+36-1) 346-4669

http://www.met.hu • e-mail: omsz@met.hu

Postal address:
Hungarian Meteorological Service
H-1525 Budapest P.O.Box 38.