REGIONAL CLIMATE AND DOWNSCALING

Regional Climate Modelling at the Hungarian Meteorological Service

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Numerical Modelling and Climate Dynamics Division

PREFACE

- One objective of the Summer School: to bridge the gap between climate dynamists and climate modellers
- This talk: the gap will be demonstrated, since basically no theoretical aspects will be considered, just practical questions, issues
- These issues are of interest for us in Hungary and we hope to learn a bit about them during the Summer School
- I don't pretend that I know more about this subject than any of you → let's discuss the raised issues TOGETHER (i.e. your active participation is welcome)!

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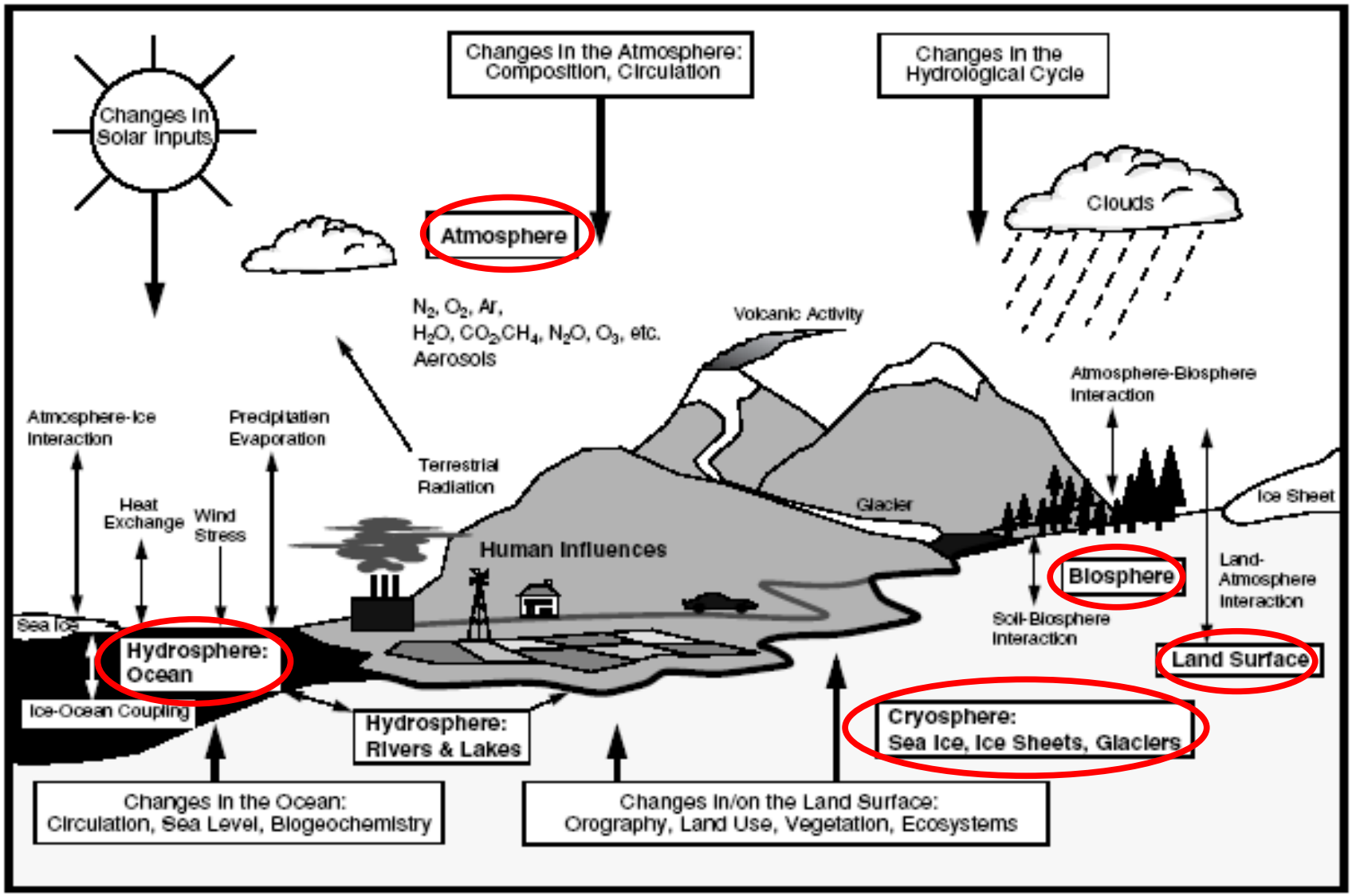
CLIMATE SYSTEM AND MODELLING

THE CLIMATE SYSTEM

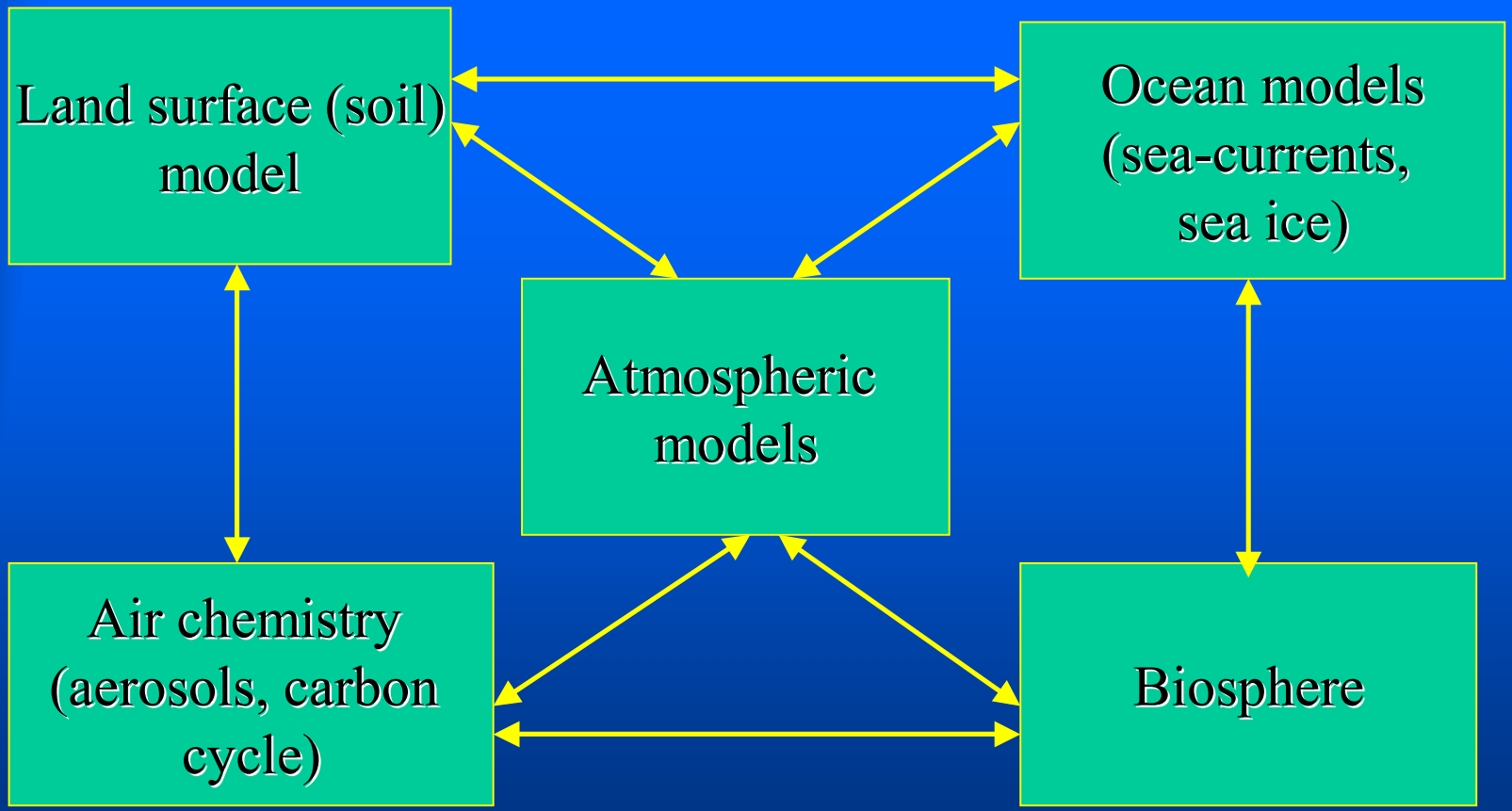


CLIMATE SIMULATIONS

- The simulation of the climate is possible from the principle point of view:
  - the components of the climate system "more or less" known, therefore they can be simulated and the relations between those components can be quantified
  - tools available from numerical weather prediction

- It should be emphasised: the climate (the atmosphere) is a complex, non-linear system, therefore its behaviour cannot be anticipated speculatively → the only available tool is modelling

THE MOST IMPORTANT COMPONENTS OF THE CLIMATE MODELS



BASIS OF NUMERICAL WEATHER PREDICTION (1)

- The atmosphere (and the different elements of the climate system) can be described via its hydro-thermodynamic system of equations (physical laws in mathematical form)

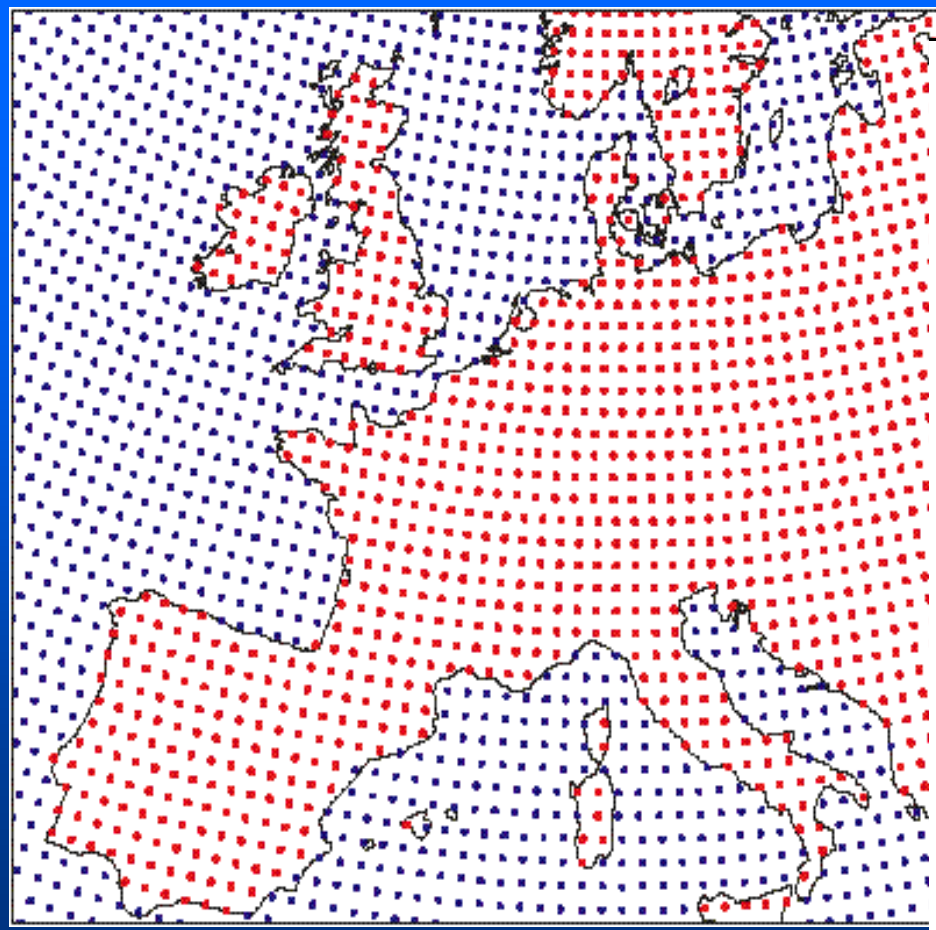
- This system of partial differential equations can be solved numerically (there is no analytical solution) with the help of mathematical models

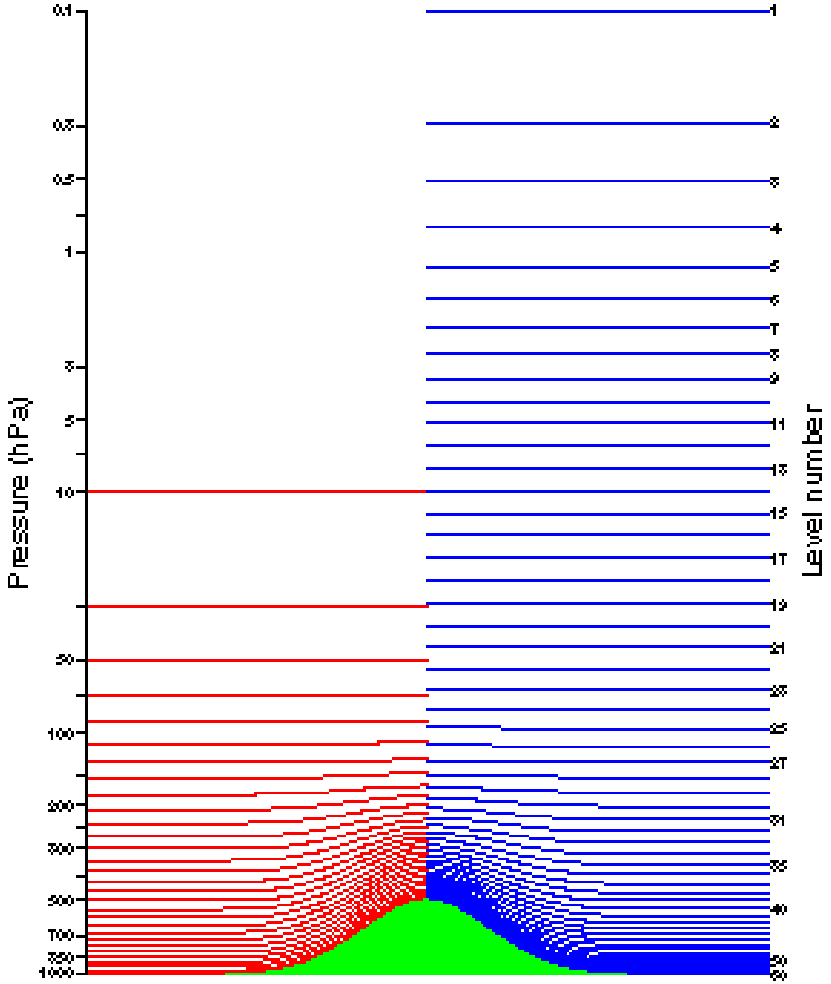
- Initial and boundary conditions (lower, upper, lateral) are needed

BASIS OF NUMERICAL WEATHER PREDICTION (2)

- Simplifications
  - In the continuous equations:
    - the height of the atmosphere is neglected with respect to the radius of the Earth
    - spherical assumption
    - hydrostatic assumption etc.
  - In the solution:
    - Discretisation
    - Numerical schemes

HORIZONTAL AND VERTICAL DISCRETISATION (MODEL GRID)





WHAT SIMULATIONS (PREDICTIONS) CAN BE EXPECTED BY CLIMATE MODELS?

- The average behaviour of the atmosphere (characterised statistically: mean values, cumulative quantities, standard deviation; anomaly from a reference etc.)

- The uncertainty of the simulation SHOULD BE also quantified (probabilistic form, ensemble technique)

Note: a climate model might provide perfect climate simulation in spite of the fact that in between all the individual weather predictions were wrong

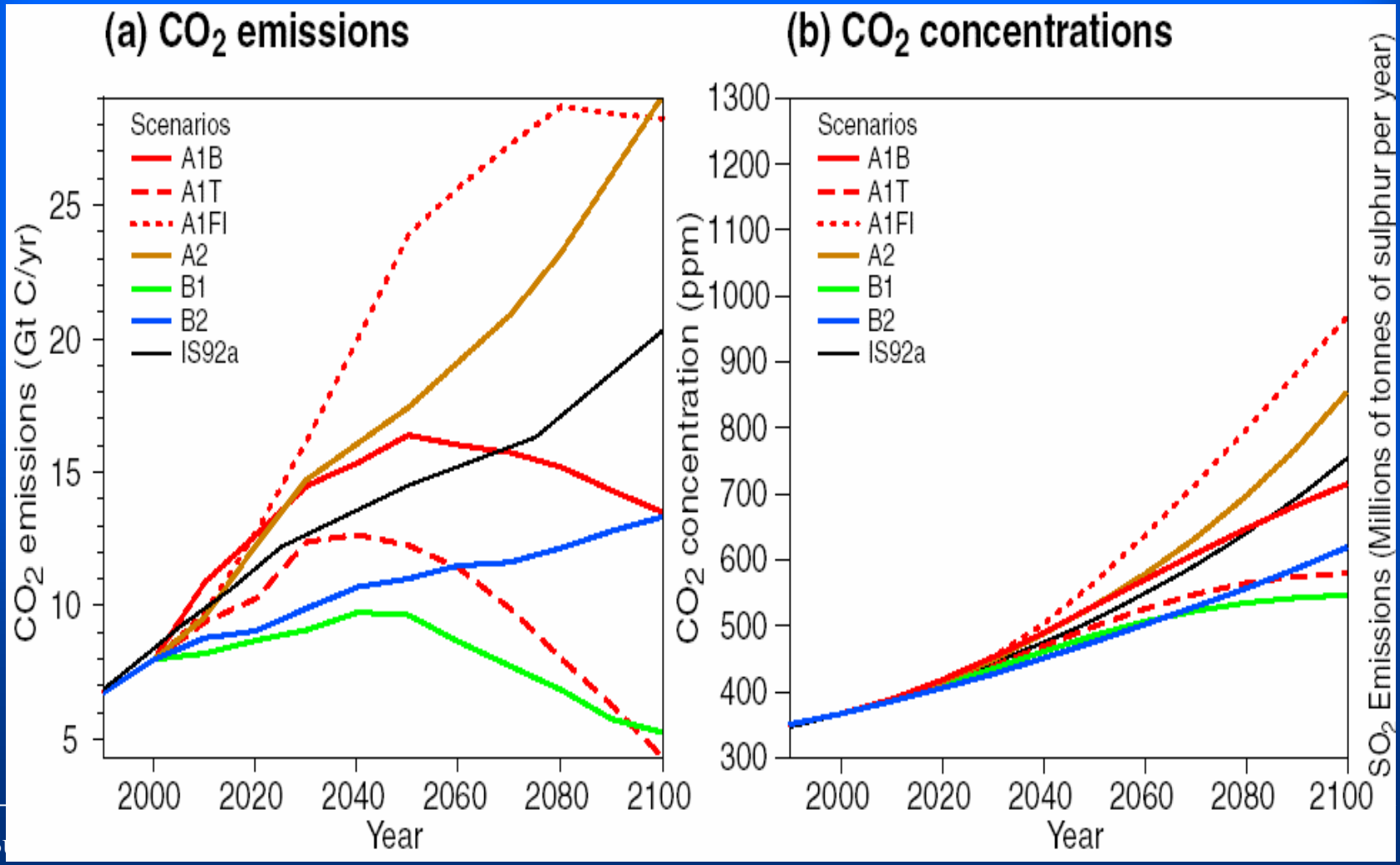
CLIMATE MODELS: BASIC TYPES

- Global Coupled Atmospheric-Ocean General Circulation Model (AOGCM)
- General Circulation Model (GCM)
- Regional limited area Climate Models (RCM)

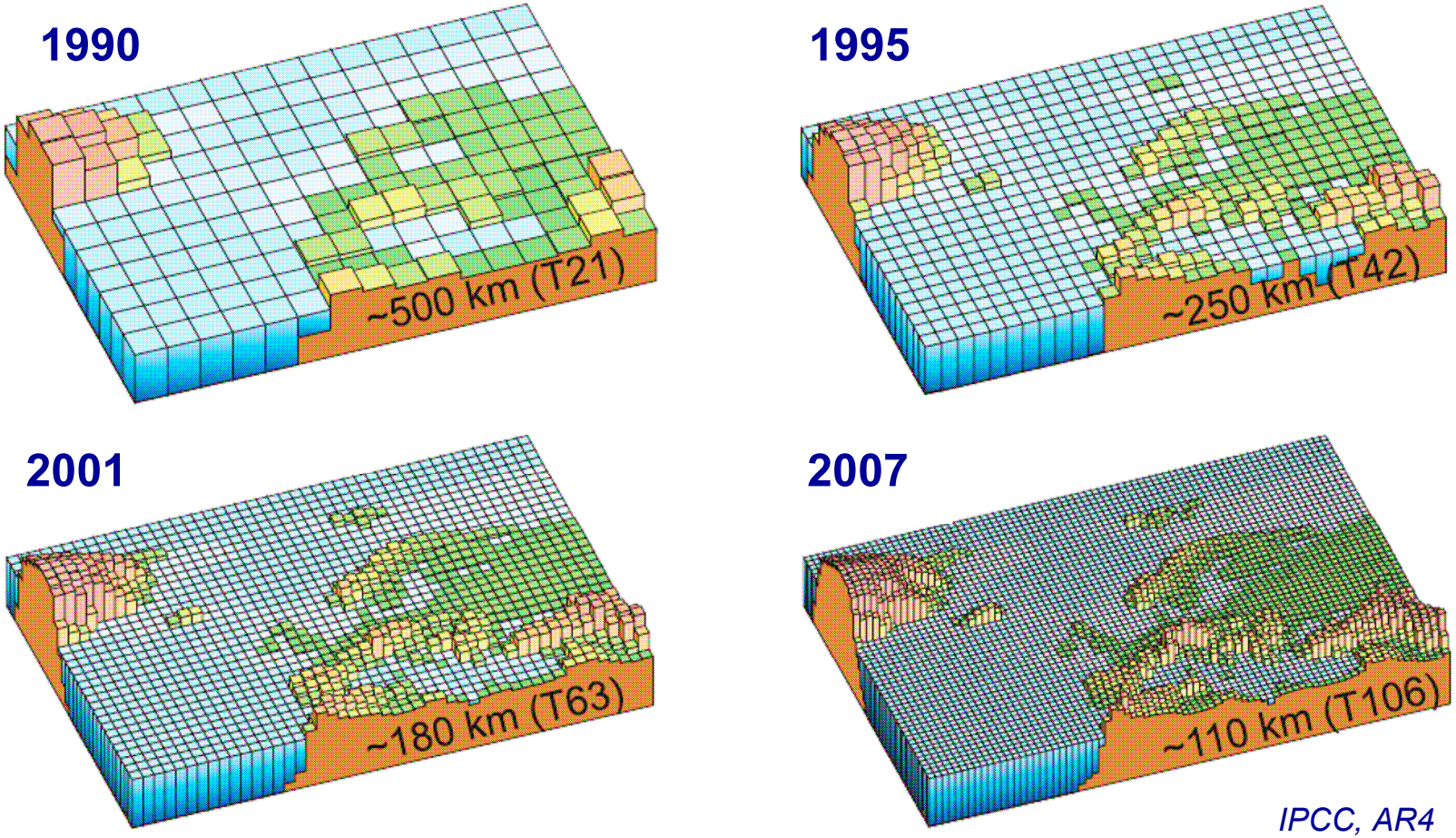
GLOBAL CLIMATE MODELS

- The climate projections are performed over the entire globe (typical resolution: few 100 km)
- The possibility of the consideration of changing external constraints and forcings (e.g. the increase of CO_2 $\rightarrow$ emission scenarios)
- The results are valid on GLOBAL average $\rightarrow$ the regional trends CANNOT be assessed from the global simulations (the direction of the regional changes might be just the opposite than the global ones)

CO_2 EMISSION SCENARIOS



RESOLUTION INCREASE OF THE GENERAL CIRCULATION MODELS

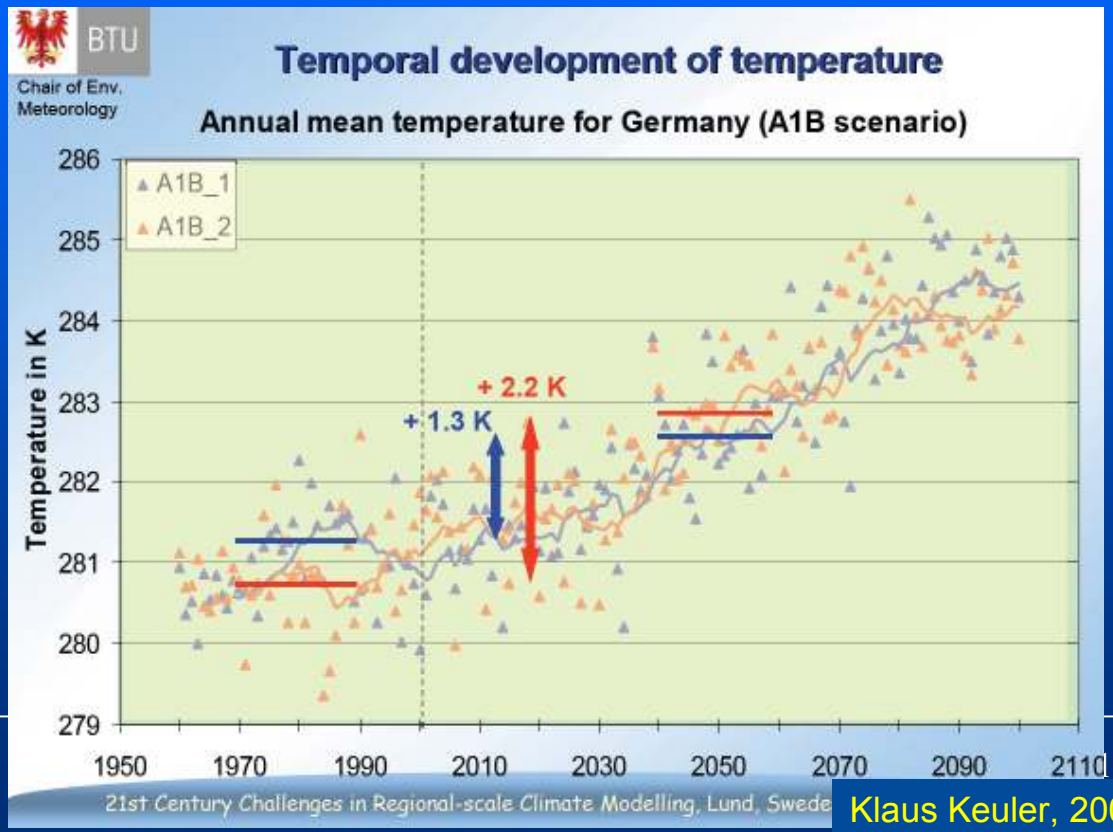


IPCC, AR4

SOME ISSUES

- Uncertainties in the external forcings (scenarios)
- Natural variability (role of initial conditions)

Integrations with different initial conditions



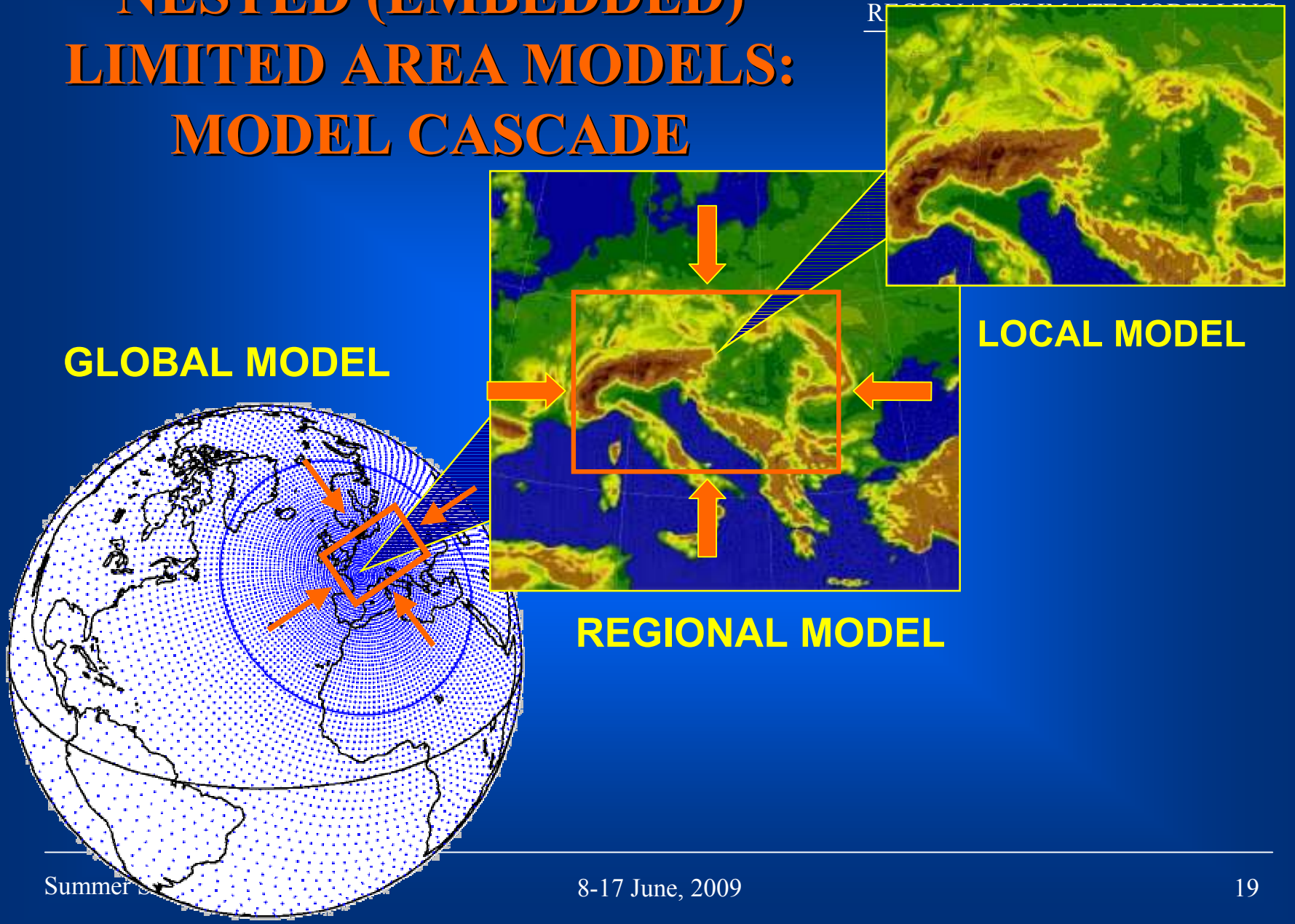
REGIONAL CLIMATE MODELLING

THE SIMULATION OF REGIONAL CLIMATE

Basis: the global climate models provide fairly good quality predictions on global average (without good global models there is no chance to have reliable regional simulations)

- High resolution or variable resolution global models (need for huge computer capacity, no lateral boundary problem)
- **Regional climate models: limited are numerical weather prediction models (lateral boundary condition problem, lateral boundaries from the global models)**
- Statistical downscaling: establishment of statistical relationship between the global and regional climate (based on and computed from the past and considered as valid for the future)

NESTED (EMBEDDED) LIMITED AREA MODELS: MODEL CASCADE

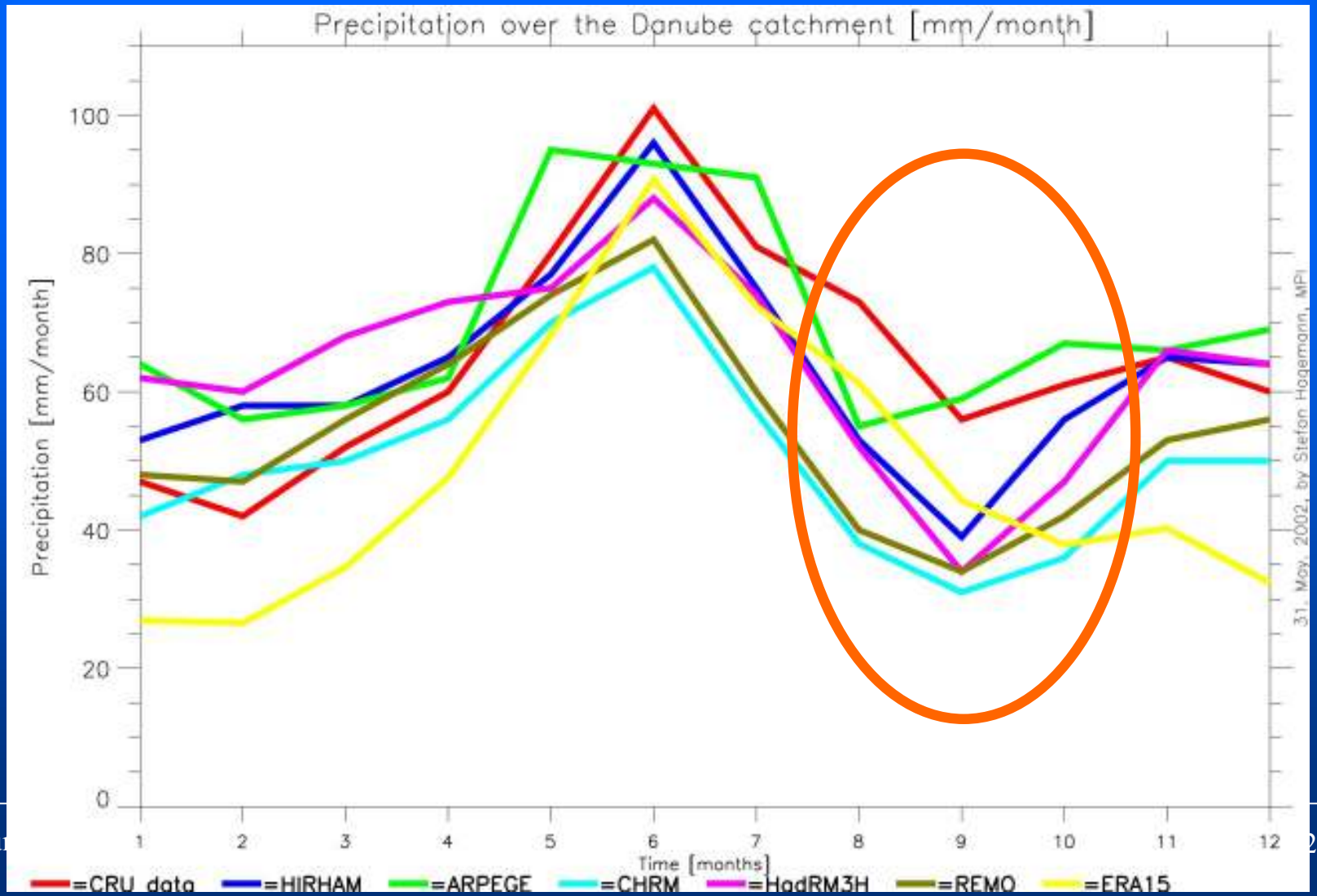


VERIFICATION (TESTING) OF CLIMATE MODELS

- The simulation of past climate: application of global and regional databases
  - Climatic Research Unit (CRU, Norwich, www.cru.uea.ac.uk)
  - Re-analyses data (ERA40 or NCEP)
  - National meteorological databases

- Based on the verification results: continuous further development of the climate models

VERIFICATION OF CLIMATE MODELS



ISSUES TO BE DISCUSSED

1. What we know about the past climate (near past)?
2. Global vs. regional models
3. Impact of lateral boundary conditions
4. Impact of resolution and domain size
5. Model biases: dependence on the simulated values, dependance on the simulation periods
6. Use of model information to impact studies
7. Significance of the changes
8. Sensitivities to scenarios and LBCs
9. Ensemble (probabilistic) evaluation

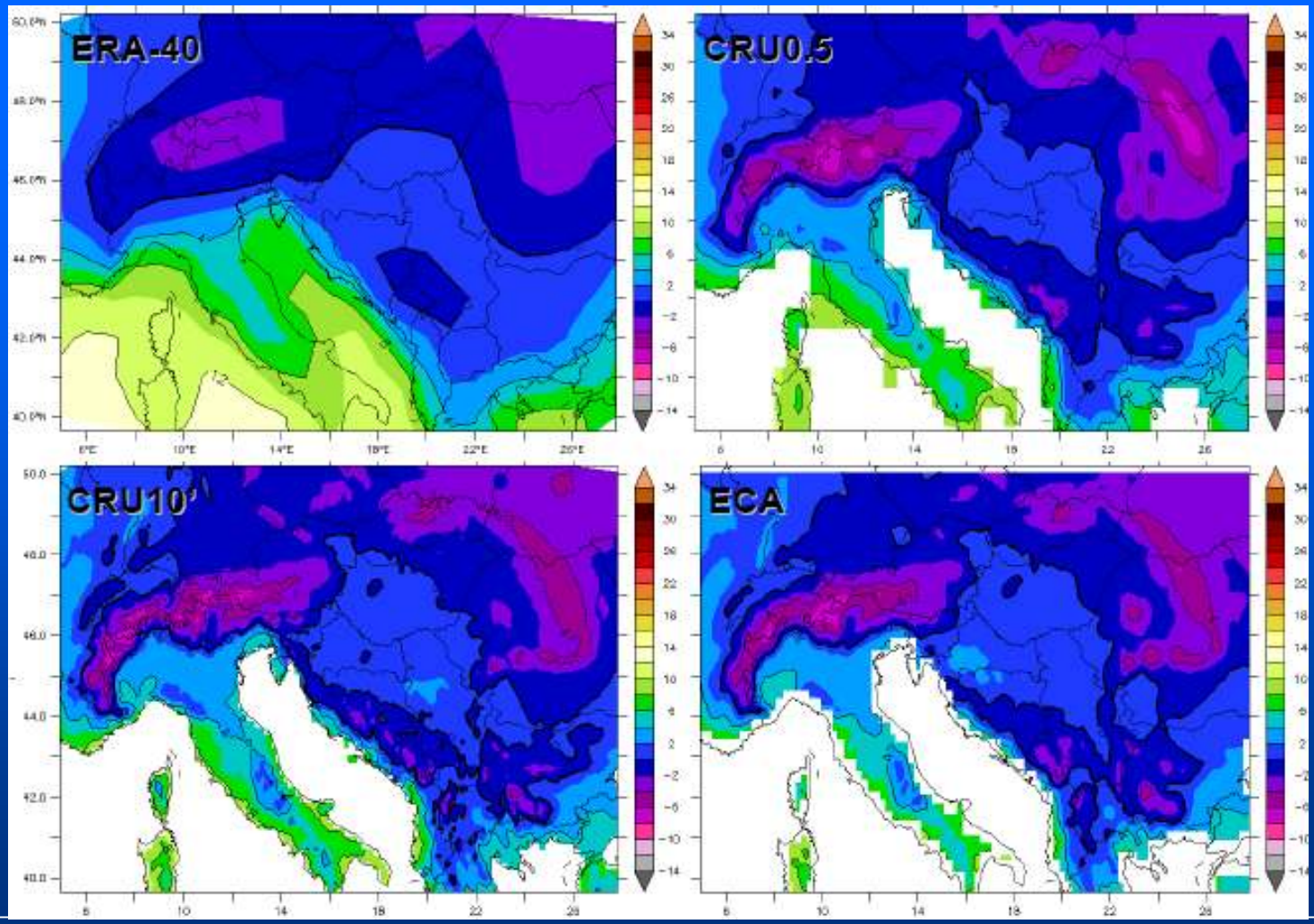
ISSUE NO. 1:

WHAT IS THE TRUTH?

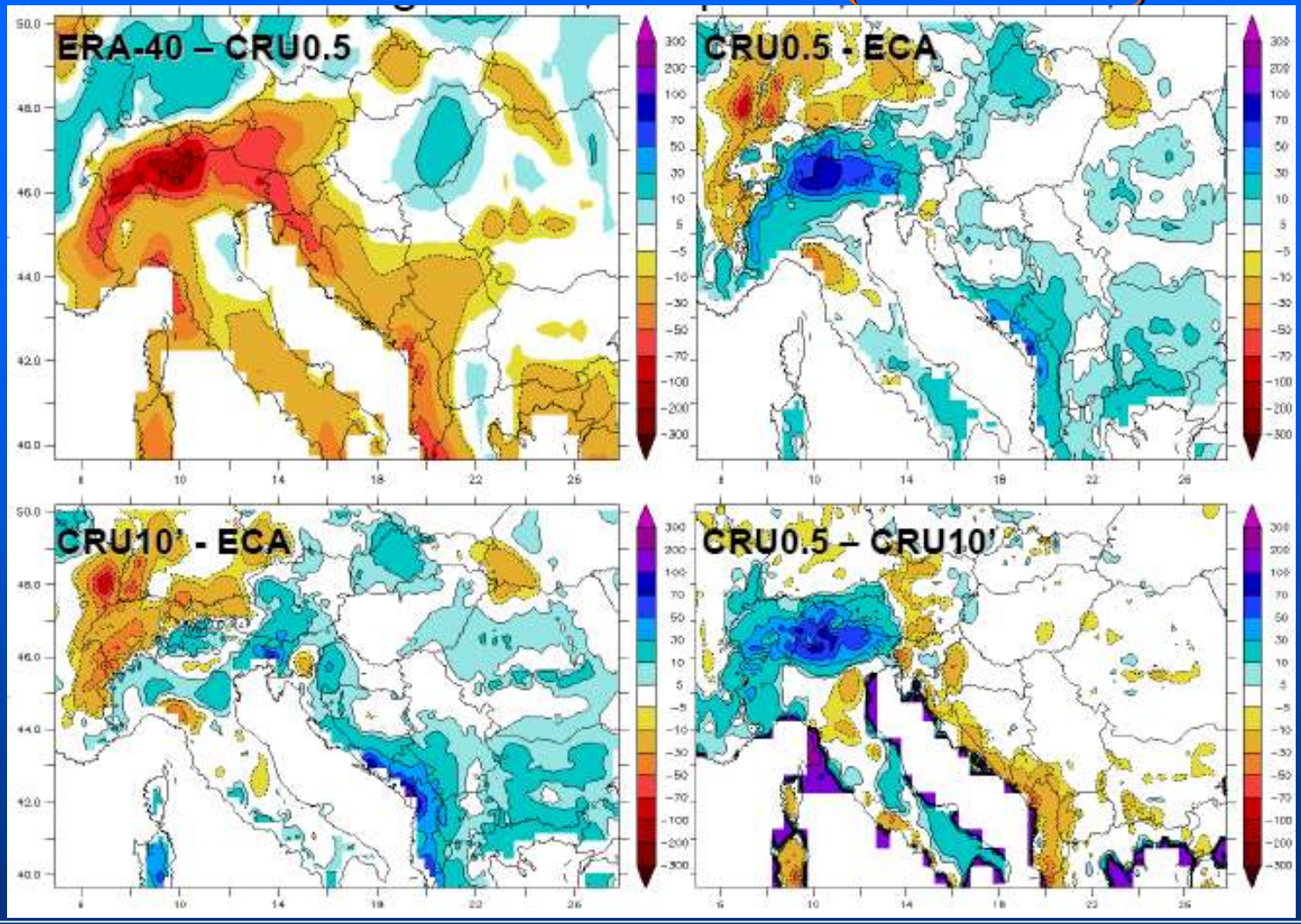
QUESTIONS

- Do we know sufficiently well the (near) past climate?
- What is the best description of the past climate?
- What are the best databases for the description of the past climate?
  - ERA40 (1°, re-analyses)?
  - CRU (0,5° or 10', Climatic Research Unit)?
  - ECA (0,25°, European Climate Assessment)?
  - National observational data (observational and gridded data: 0,1° for Hungary)?

TEMPERATURE (1961-2000, winter)



PRECIPITATION DIFFERENCE (1961-2000, winter)



ANSWERS TO ISSUE NO. 1

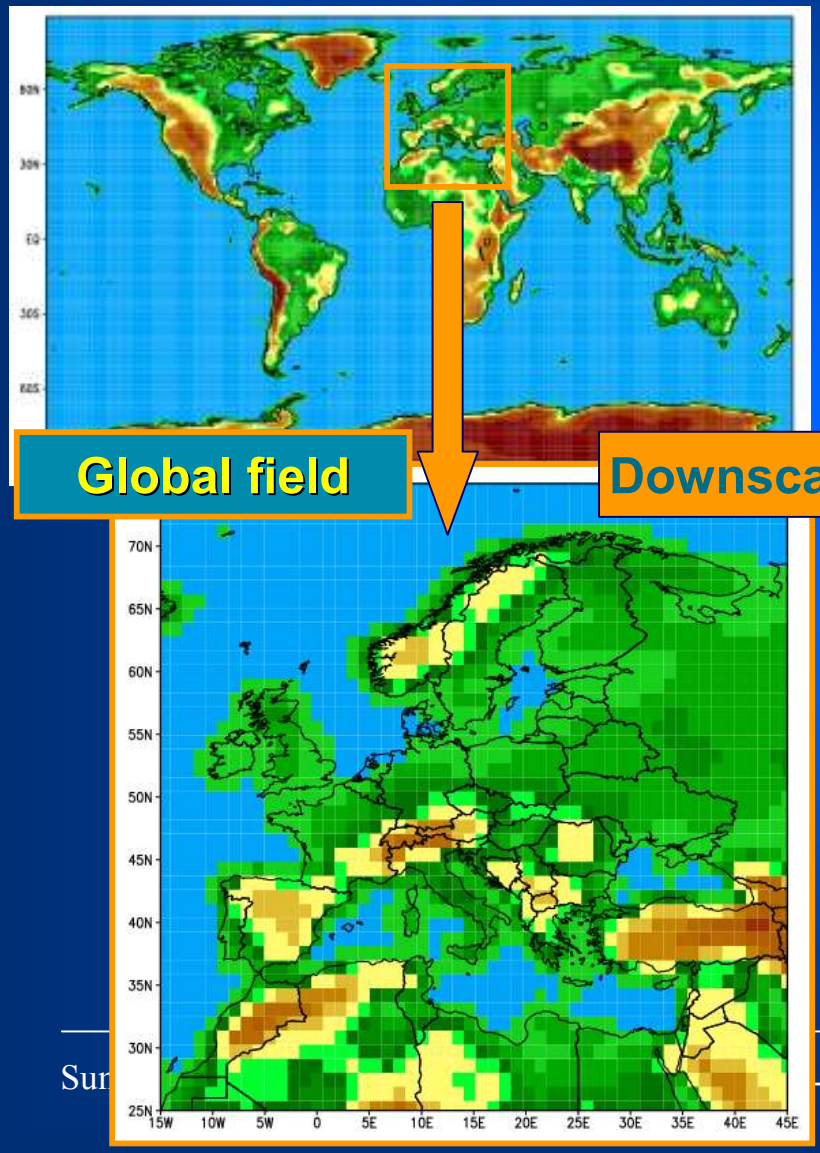
- We don't even know precisely how the past climate looked like („the past is also uncertain")
- The various databases might be rather different (especially near to orography and coastlines)
- One has to be careful while evaluating the climate models with respect to the observational databases

(The ECA database seems to be the most appropriate)

ISSUE NO. 2:

GLOBAL VS. REGIONAL

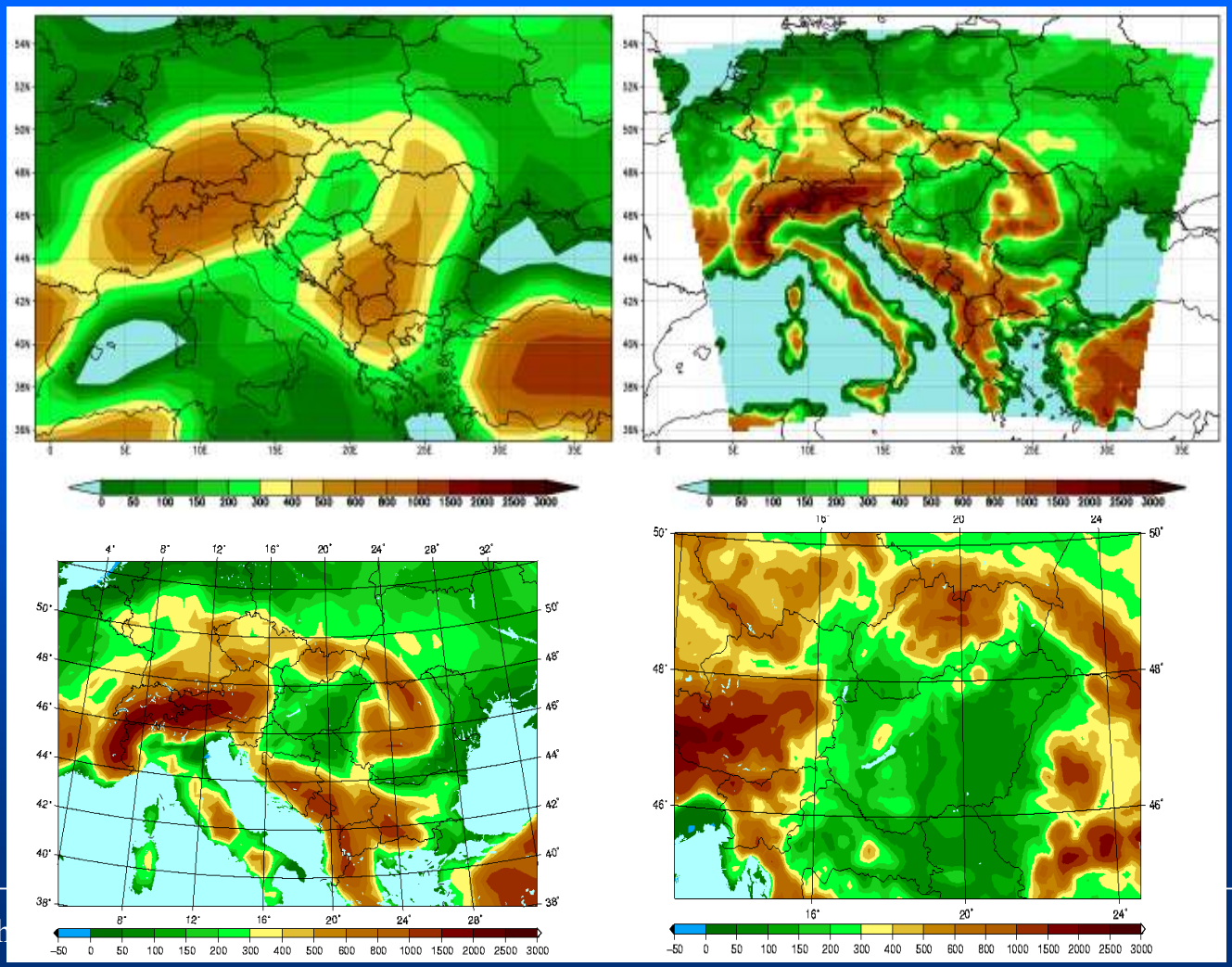
DYNAMICAL DOWNSCALING



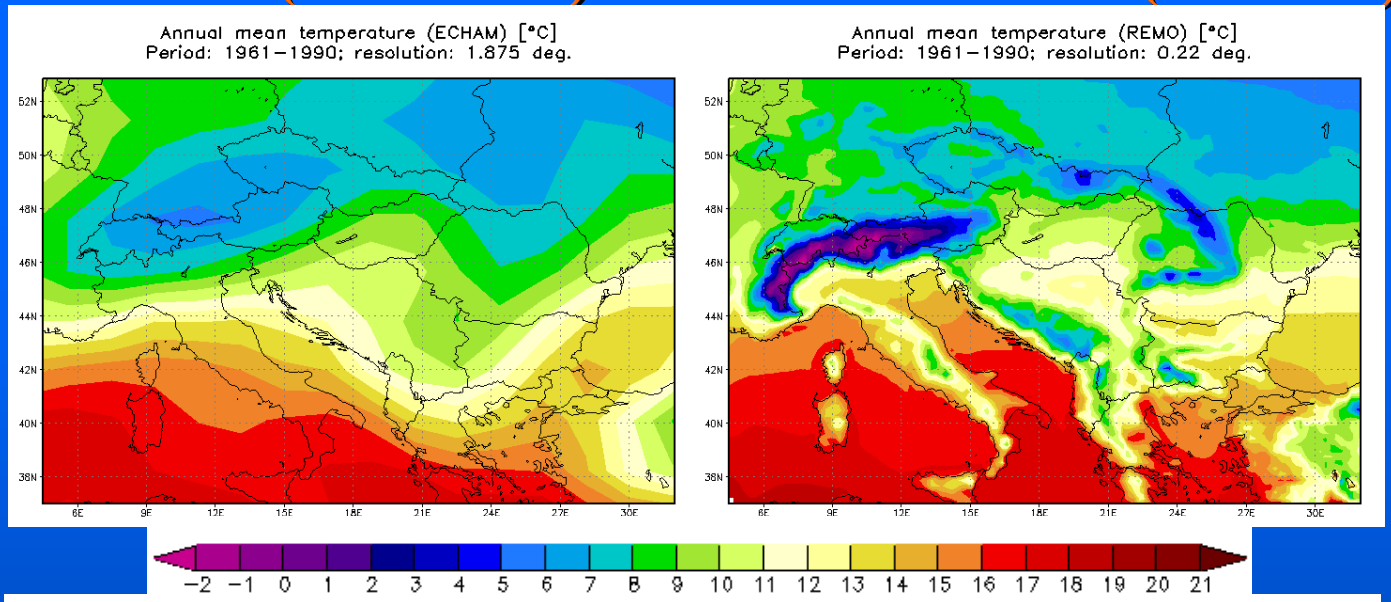
QUESTIONS

- Does the regional (limited area) model bring added value (additional details) to the global simulations (in other words: does it make sense to run regional climate models)?
  - In principle: yes; in practise??
- How to objectively measure the potential added value (bias, RMSE)?
- Can RCMs simulate an own circulation?

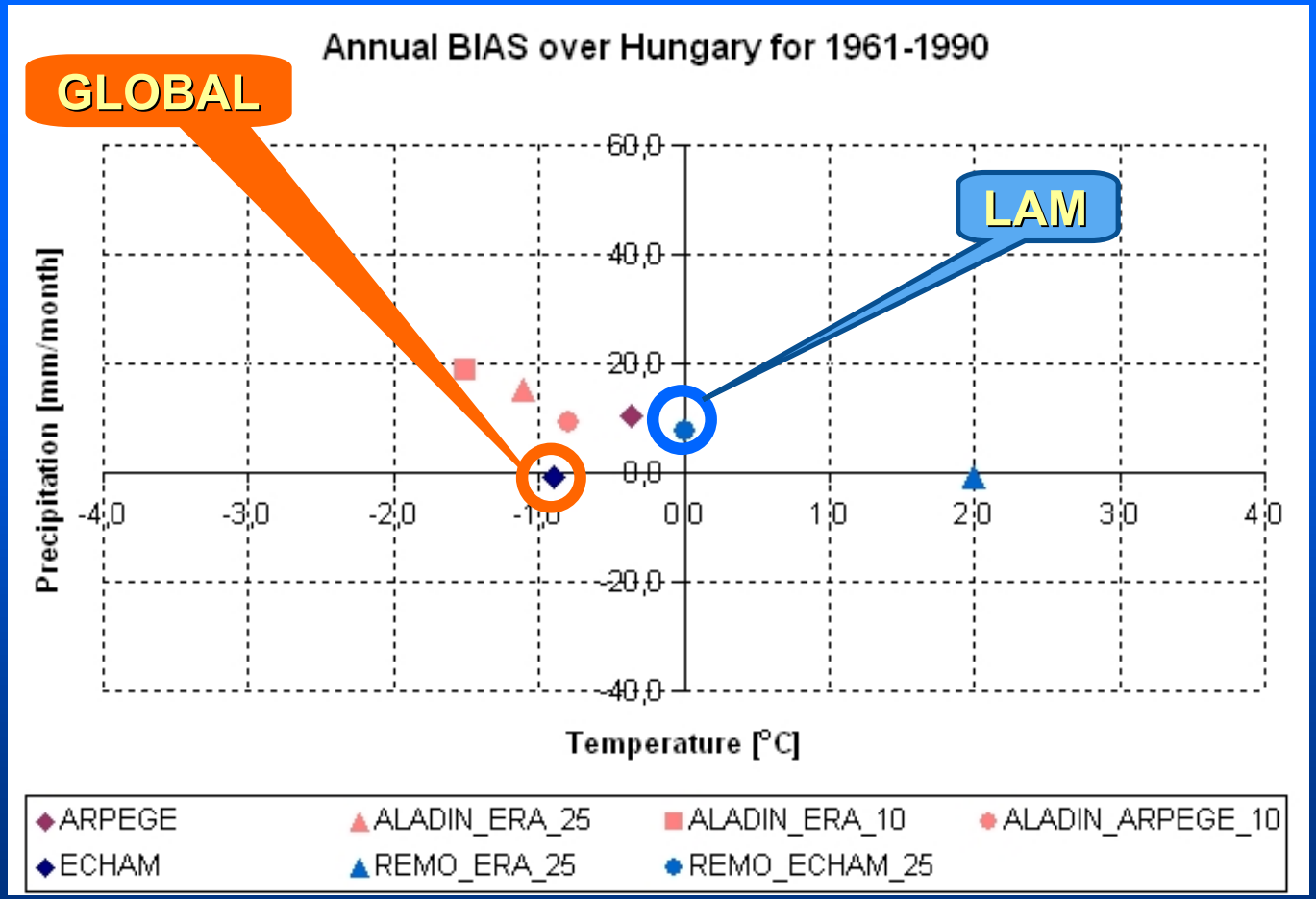
IN PRINCIPLE: YES (SEE OROGRAPHY: ECHAM VS. REMO; ARPEGE VS. ALADIN-CLIMATE)



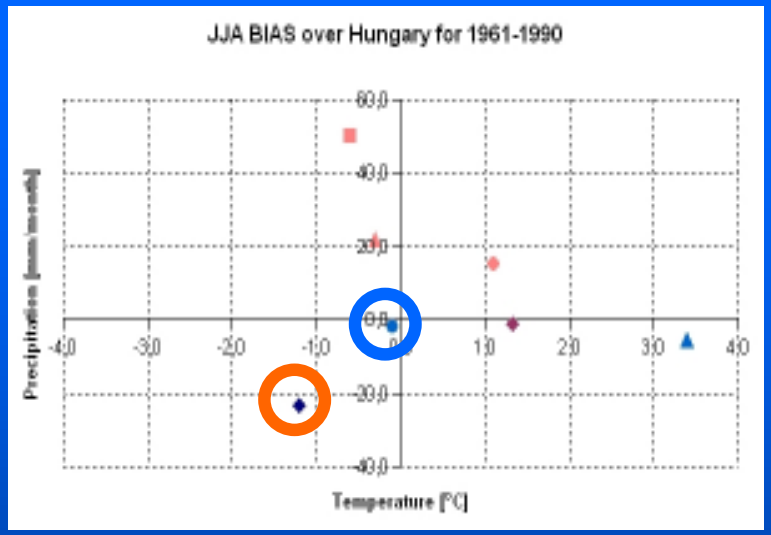
GLOBAL (ECHAM) VS. REGIONAL (REMO)

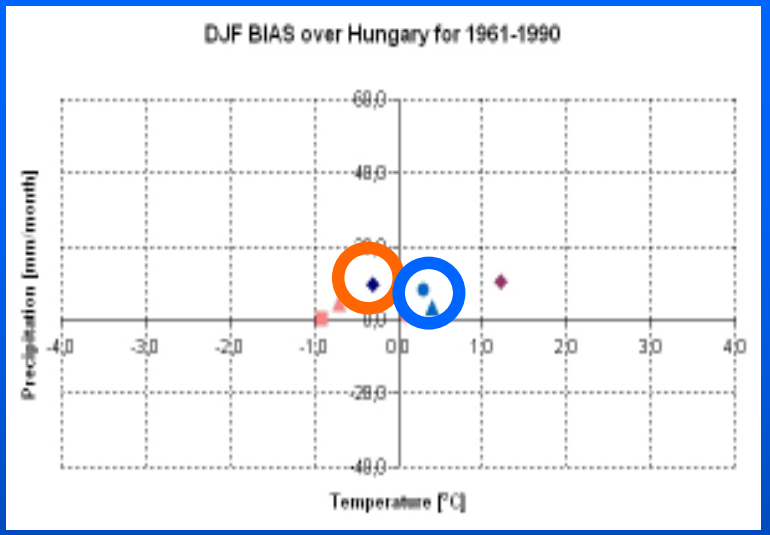


ANNUAL TEMPERATURE and PRECIPITATION BIAS



SEASONAL TEMPERATURE and PRECIPITATION BIAS





ARPEGE
ALADIN_ERA_25
ALADIN_ERA_10
ALADIN_ARPEGE_10
ECHAM
REMO_ERA_25
REMO_ECHAM_25

ANSWERS TO ISSUE NO. 2

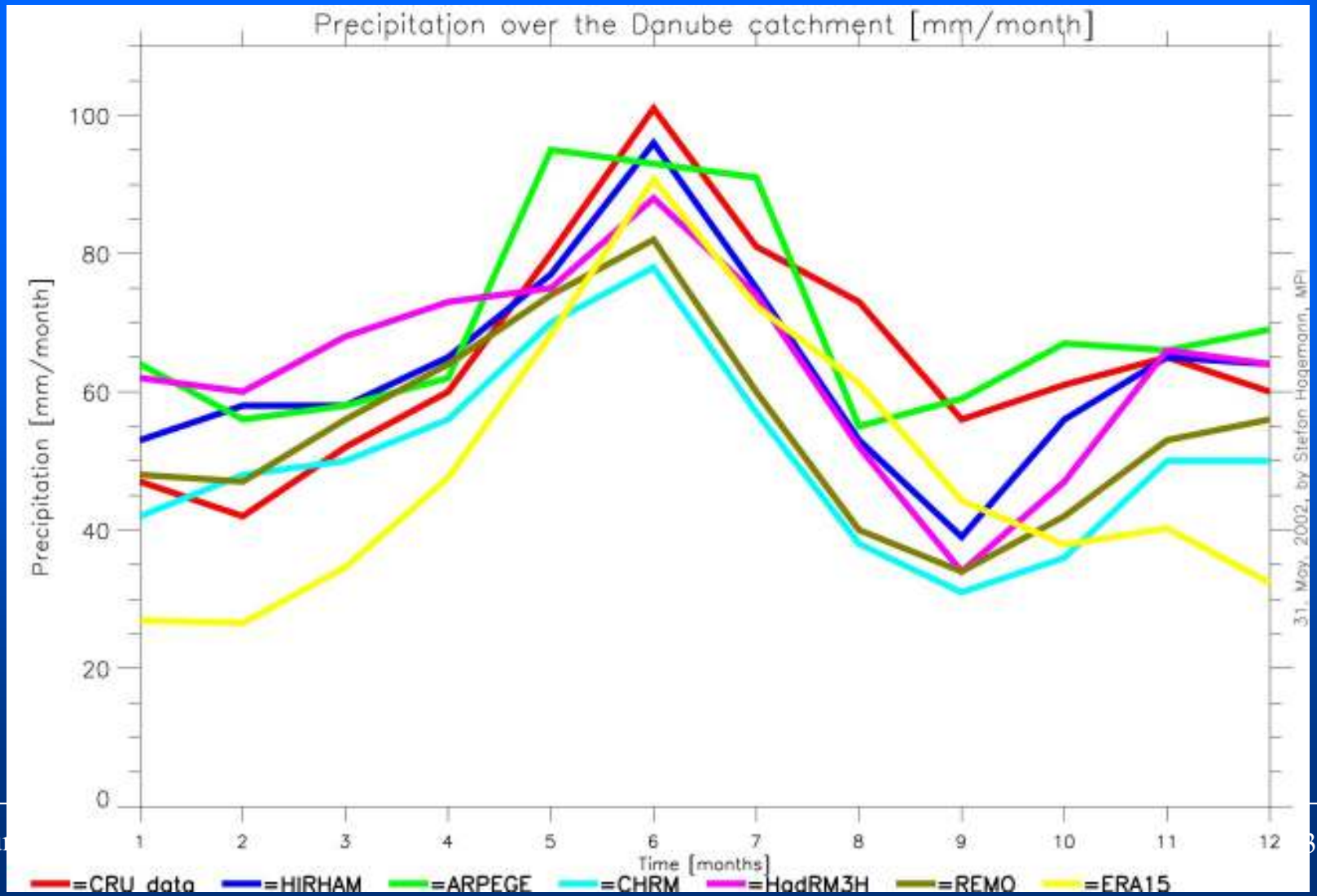
- RCMs can improve regional details with the more precise description of the surface characteristics and with their higher horizontal resolution (possible own circulation)
- However simple statistical scores sometimes don't show real improvements
- One has to be careful since the „traditional" verification characteristics might penalise the higher resolution model

ISSUE NO. 3: ACCOUNTING FOR MODEL ERRORS

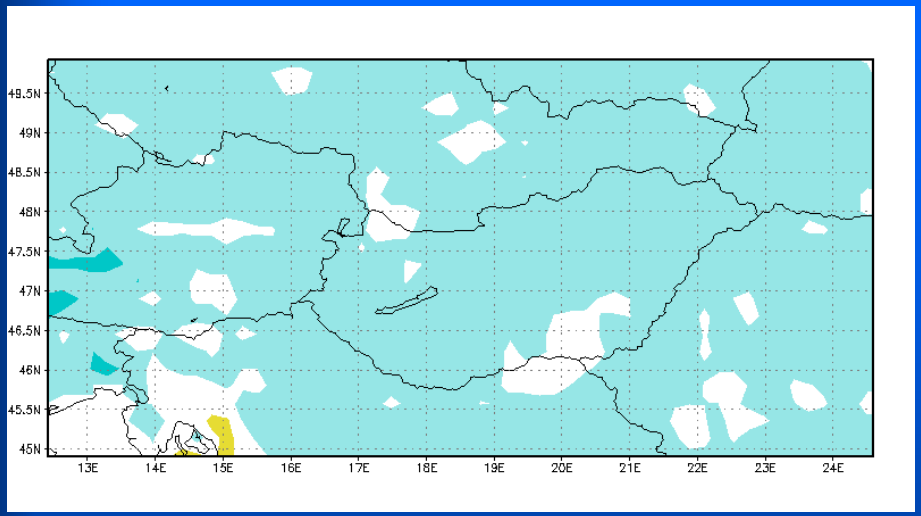
QUESTIONS

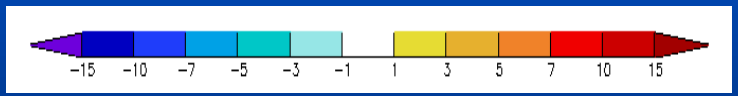
- How can we treat the model errors, which are causing deficiencies in the model simulations in the past?
- How can the model error information based on past simulations be applied to improve the simulations for the future?
- Are the model errors temporally unchanged?
- Can we eliminate model errors?
- Are perfect models for the past perfect also for the future?
- Are bad (biased) models for the past useless to be used for the future?

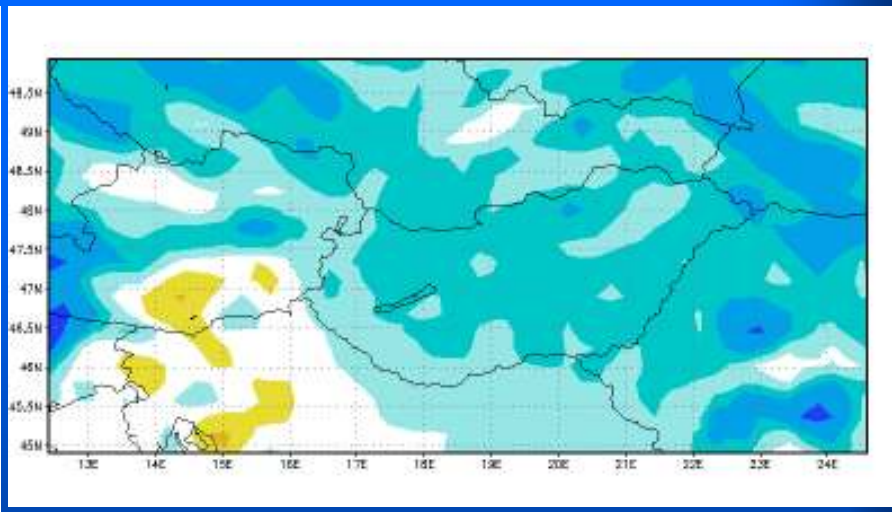
THE EXISTENCE OF MODEL ERRORS

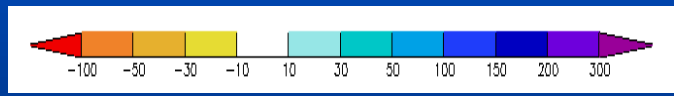


MODEL ERRORS: AN EXAMPLE (BIAS WITH RESPECT TO CRU, TEMPERATURE and PRECIPITATION, ALADIN-Climate)



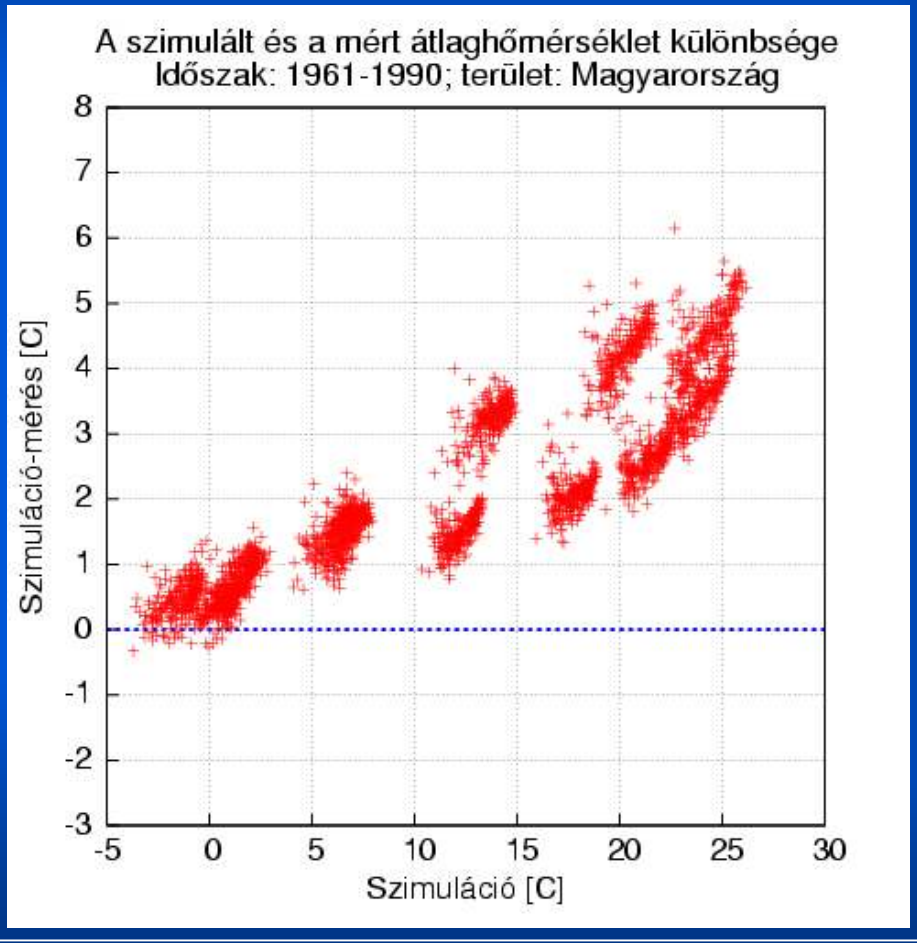






DEPENDENCE OF MODEL ERRORS FROM THE SIMULATED VALUES (REMO)

LBC: ERA40



TEMPORAL BIAS BEHAVIOUR

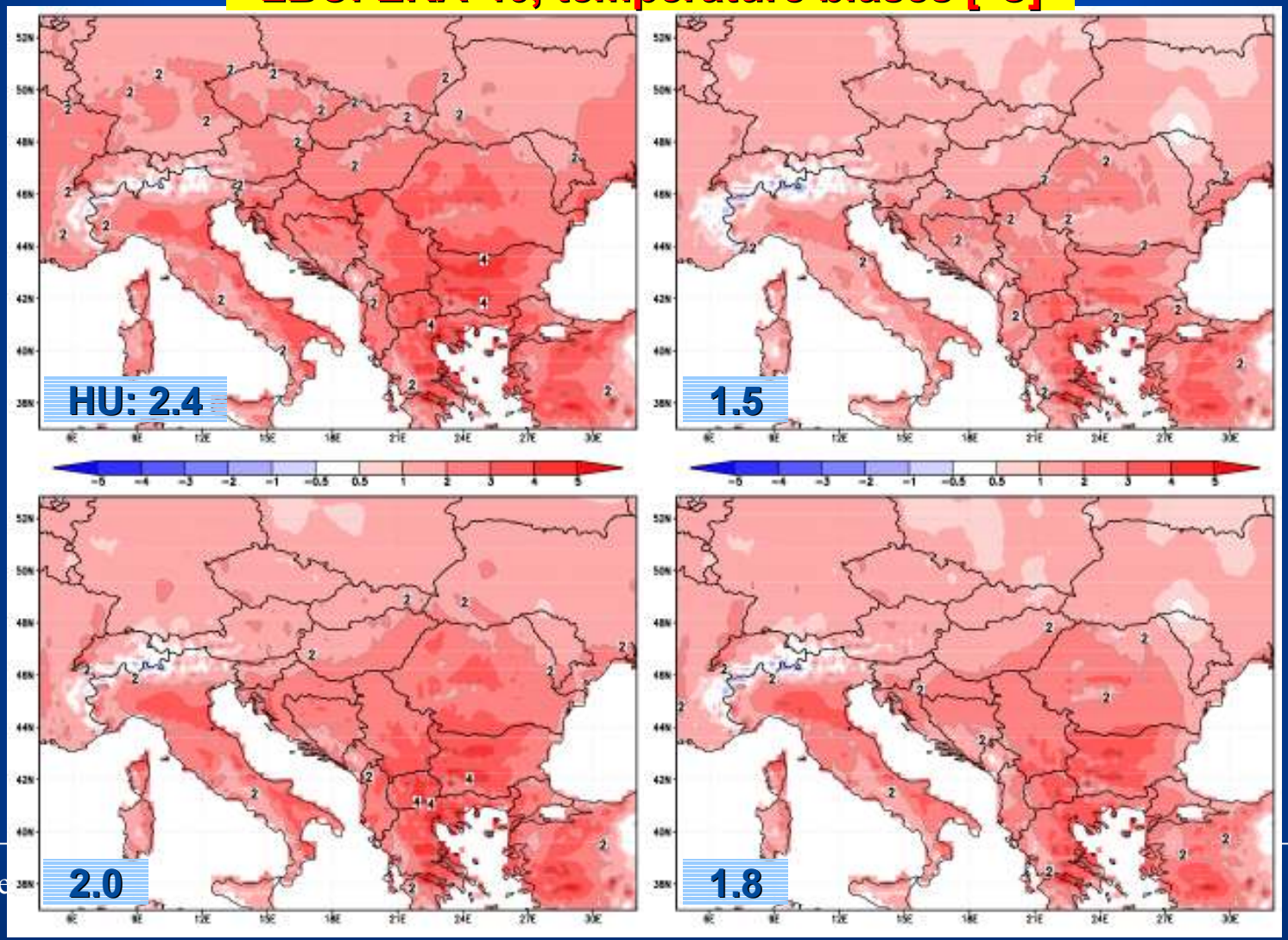
LBC: ERA-40, temperature biases [ºC]

1961 – 1970

1971 – 1980

1981 – 1990

1991 – 2000



ANSWERS TO ISSUE NO. 3

- There are important biases of the models, which should be accounted for (BUT how?)
- The model errors are depending on the season, on the simulated values and also on the period (therefore it is not easy to use past model errors to „de-biase" future simulations)
- In practise: differences are taken between past and future model simulations (does anybody know something MUCH better?)

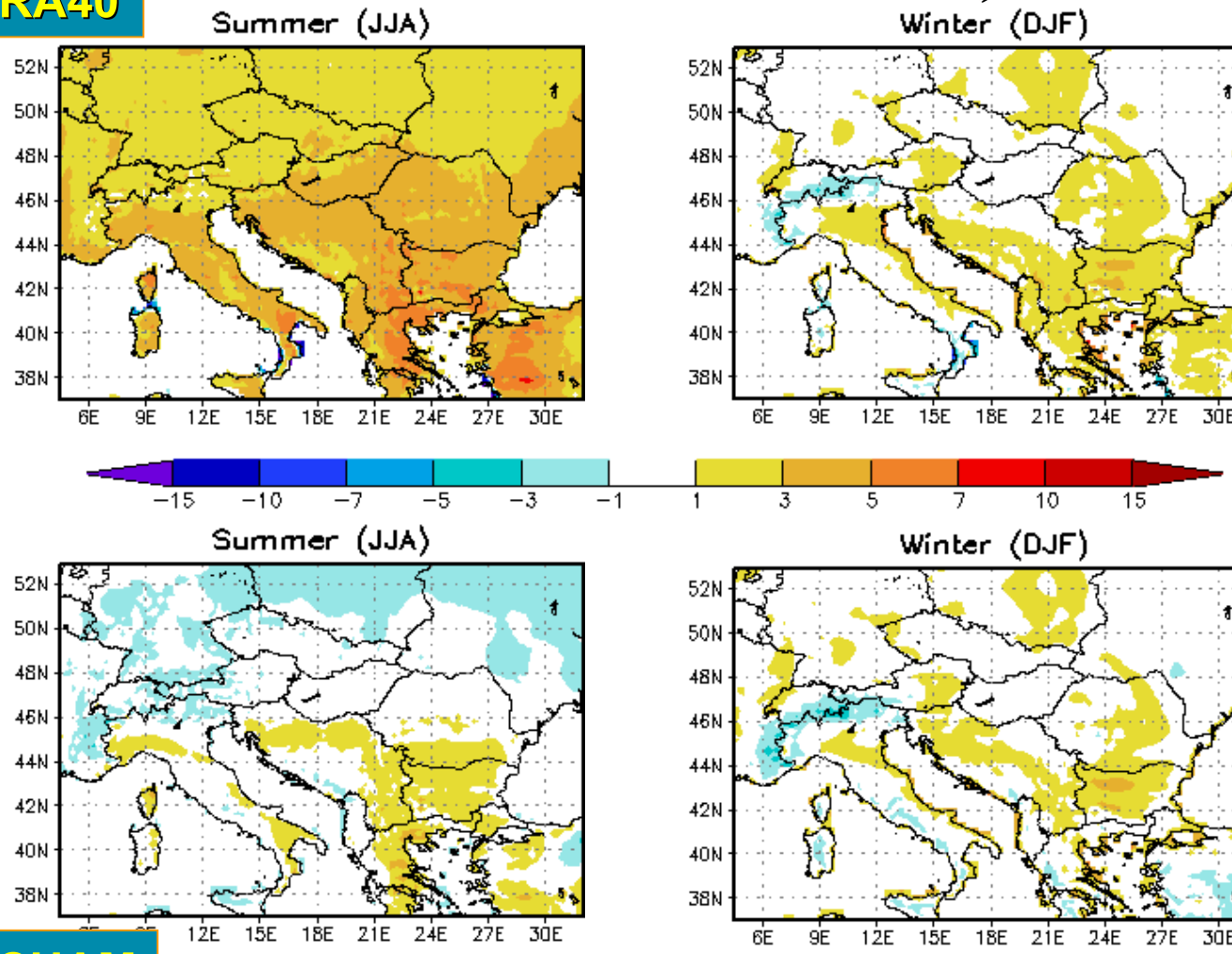
ISSUE NO. 4: THE ROLE OF LATERAL BOUNDARY CONDITIONS

QUESTIONS

- What is the role of the lateral boundary conditions (in principle they are the main driving factors)?
- What is more important?
  - Perfect boundaries (re-analyses)?
  - Dynamically (and physically) consistent boundaries?
- How to treat the sometimes ambiguous information obtained from the integrations for the past (based on perfect boundaries and global model's boundaries)

ERA40 VS. GLOBAL LBCs (1961-1990, TEMPERATURE BIAS)

LBC: ERA40

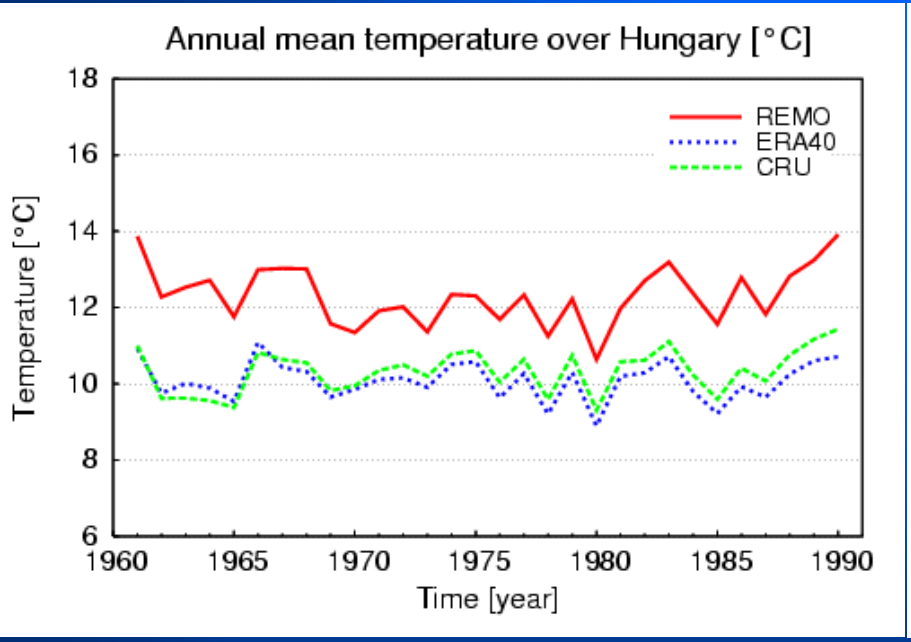


LBC: ECHAM

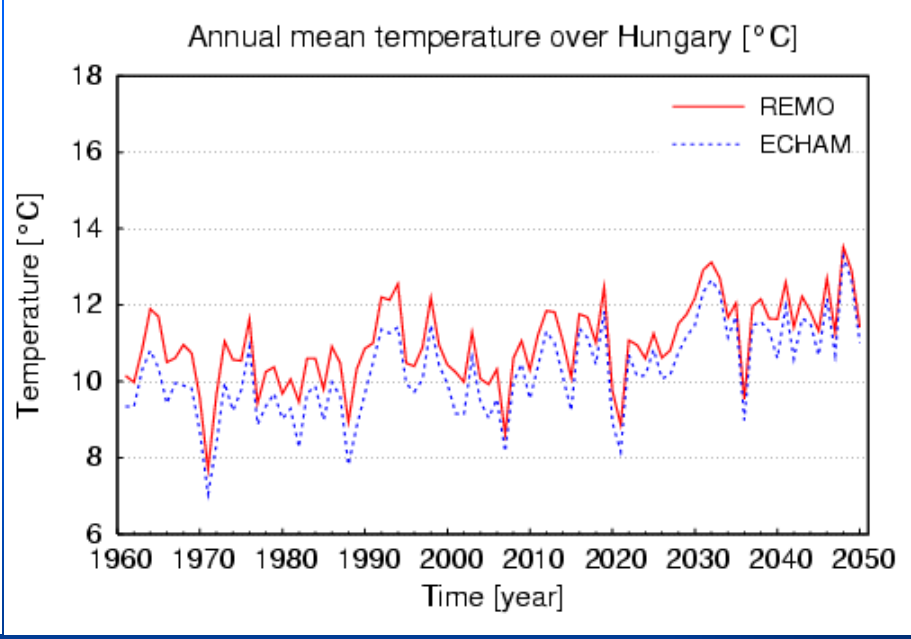
RELATION BETWEEN GLOBAL LBC-s AND REGIONAL RESULTS

Temperature [°C]

LBC: ERA40



LBC: ECHAM



ANSWERS TO ISSUE NO. 4

- Our experiments show that the dynamical consistency is more important than the „perfectness” (the errors are significantly different for re-analyses and global driving favouring the global LBCs)
- The ERA40-driven runs are used to improve the model formulation (especially the physics)
- On the other hand the global model driven simulations are used for the determination of the climate change signals…

ISSUE NO. 5: IMPACT OF RESOLUTION AND DOMAIN SIZE

QUESTIONS

- Are higher resolution simulations better than the coarser ones?

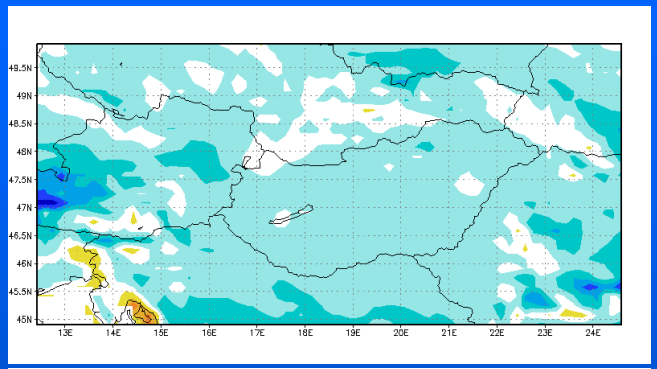
- Is the precise position of the applied domain important?

MODEL ERRORS (TEMPERATURE and PRECIPITATION, ALADIN-Climate)

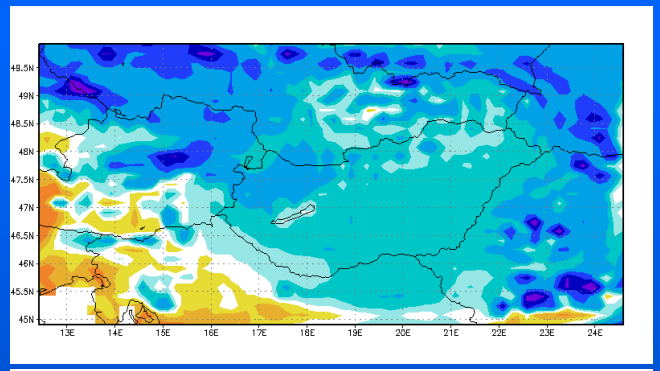
TEMPERATURE

PRECIPITATION

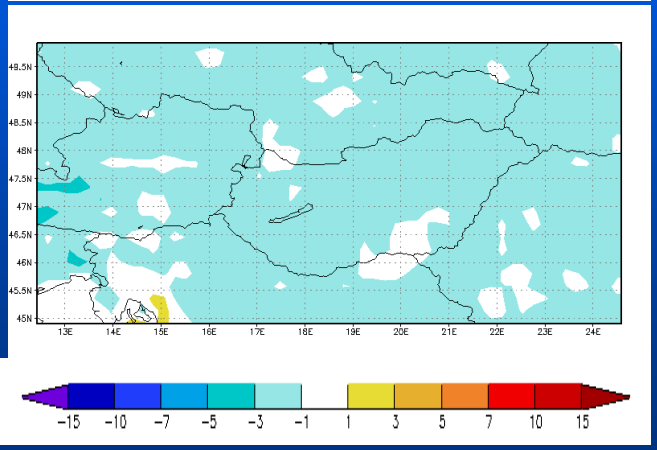
10 km



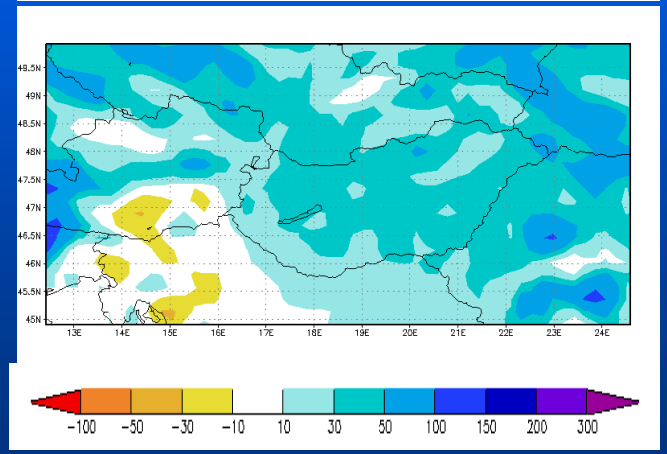
10 km



25 km



25 km



ANSWERS TO ISSUE NO. 5

- The increase of resolution might not improve the results (it is not a magic „solution”…)

- There are other factors controlling the quality of the outputs (LBCs, domain size etc.): cancellation of errors?

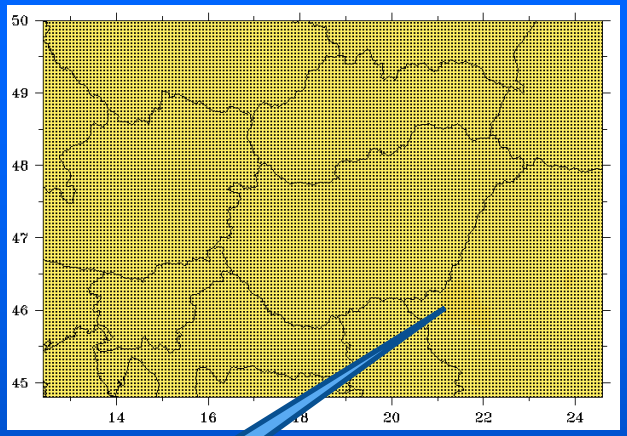
ISSUE NO. 6: SIGNIFICANCE OF THE CHANGES

QUESTIONS

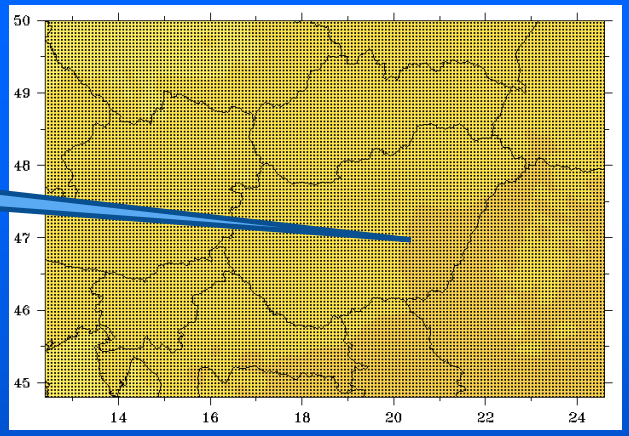
- How significance tests are important for demonstrating the changes?

CHANGE OF ANNUAL TEMPERATURE (TARGET PERIOD VS. 1961-1990)

REMO 2021-2050



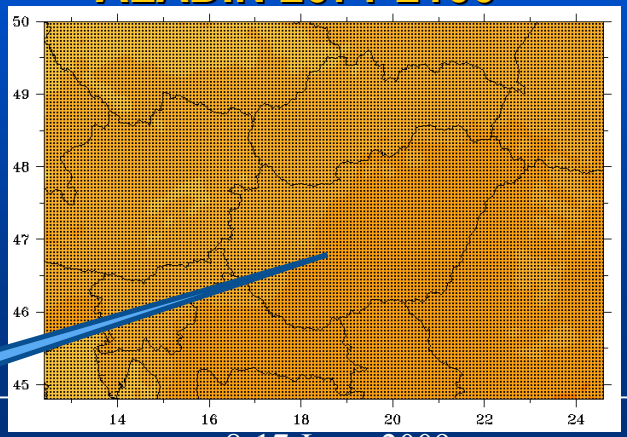
ALADIN 2021-2050



2.0 °C

1.5 °C

ALADIN 2071-2100

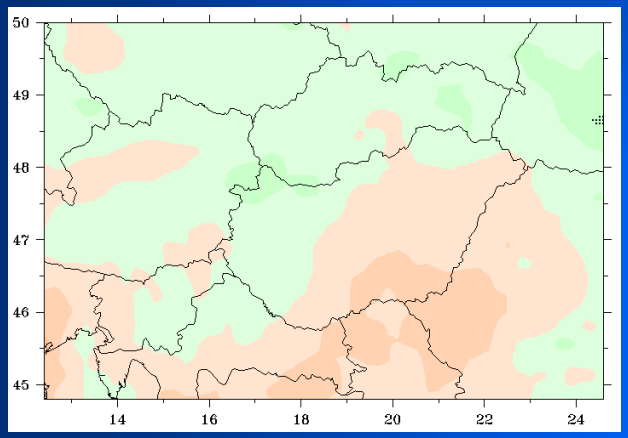


3.5 °C

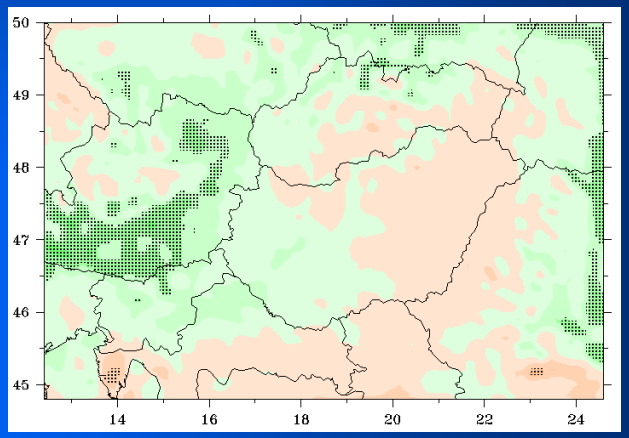
All the changes are significant!

CHANGE OF ANNUAL PRECIPITATION (TARGET PERIOD VS. 1961-1990)

REMO 2021-2050

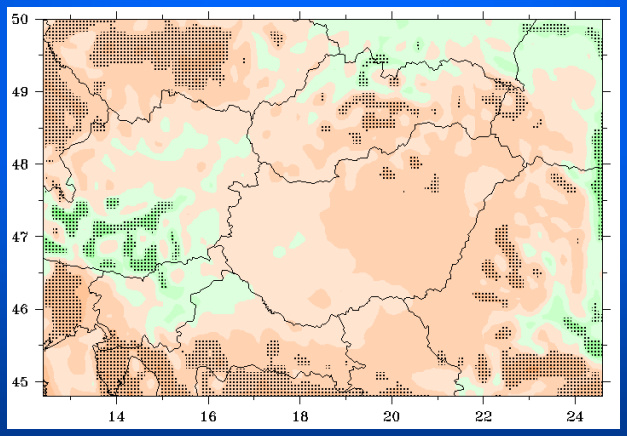


ALADIN 2021-2050

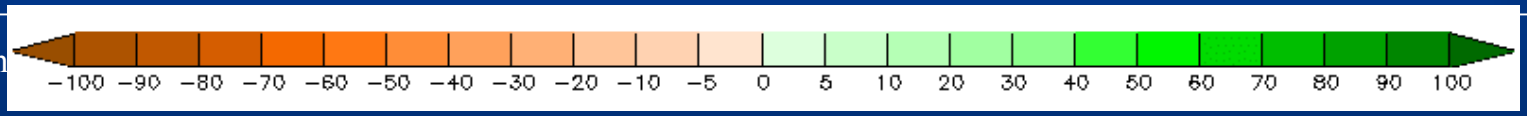


No significancy over Hungary!

ALADIN 2071-2100

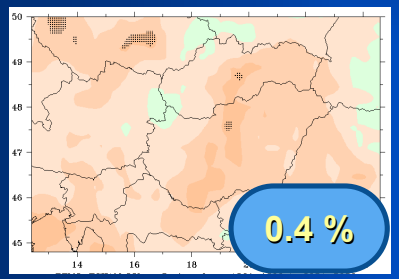


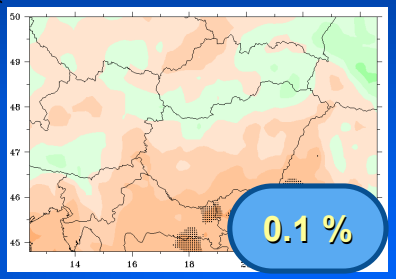
Only 1.4 % of the Hungarian territory is significant

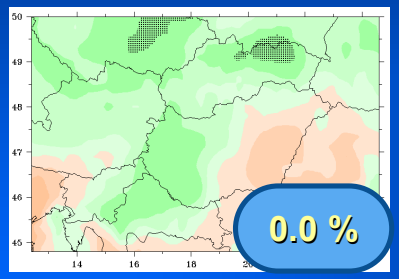


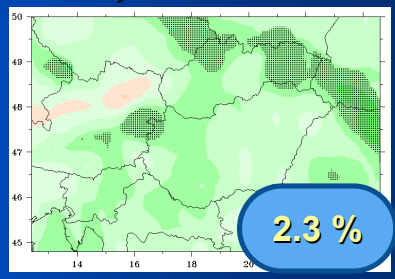
CHANGE OF SEASONAL PRECIPITATION (TARGET PERIOD VS. 1961-1990)

REMO 2021-2050

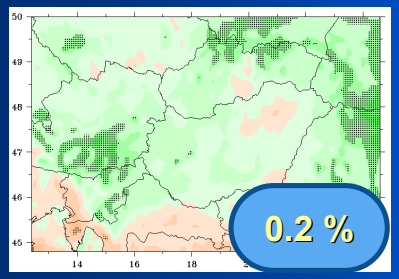


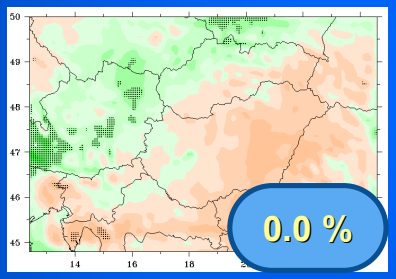


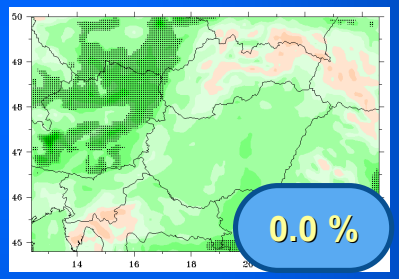


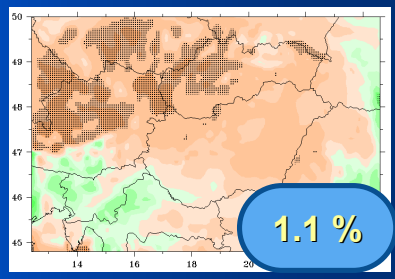


ALADIN 2021-2050

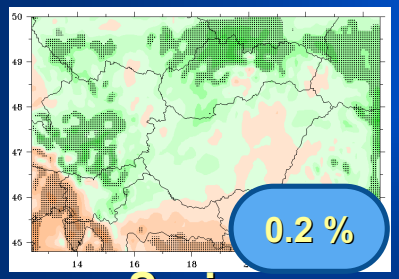


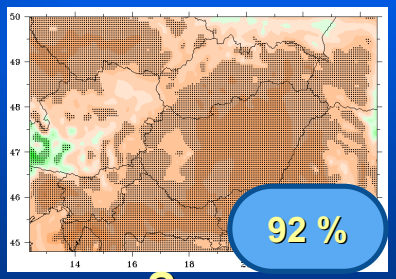


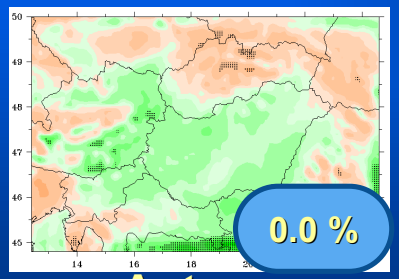


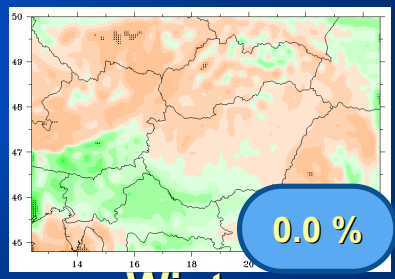


ALADIN 2071-2100

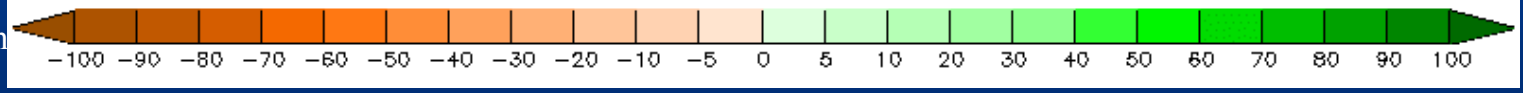




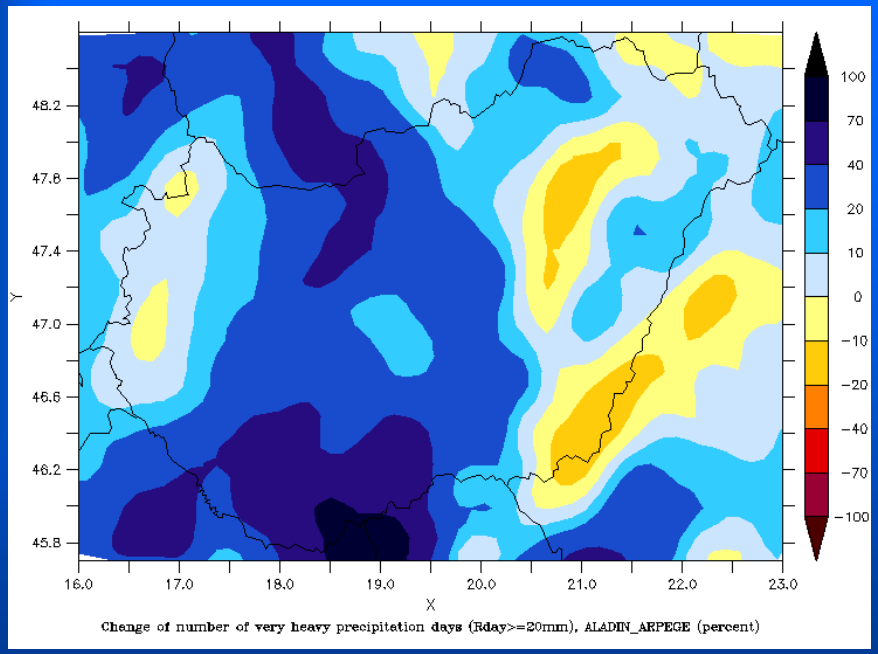


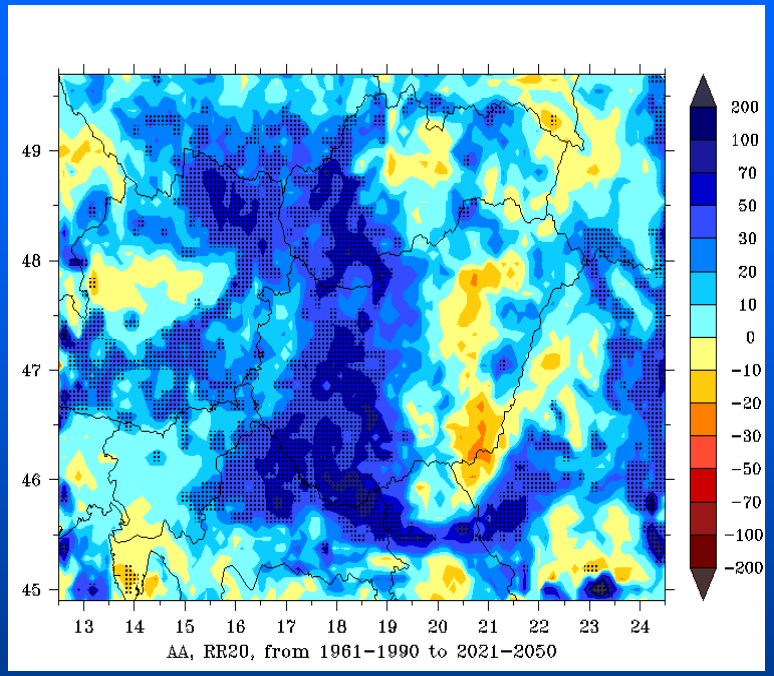


Spring Summer Autumn Winter



CHANGES IN PRECIPITATION EXCEEDING 20 MM (ALADIN-Climate, 2021-2050 vs. 1961-1990): WITH AND WITHOUT SIGNIFICANCE





ANSWERS TO ISSUE NO. 6

- Significance tests are essential, since otherwise the results can be easily misinterpreted.

- One has to be very careful to interpret non-significant changes

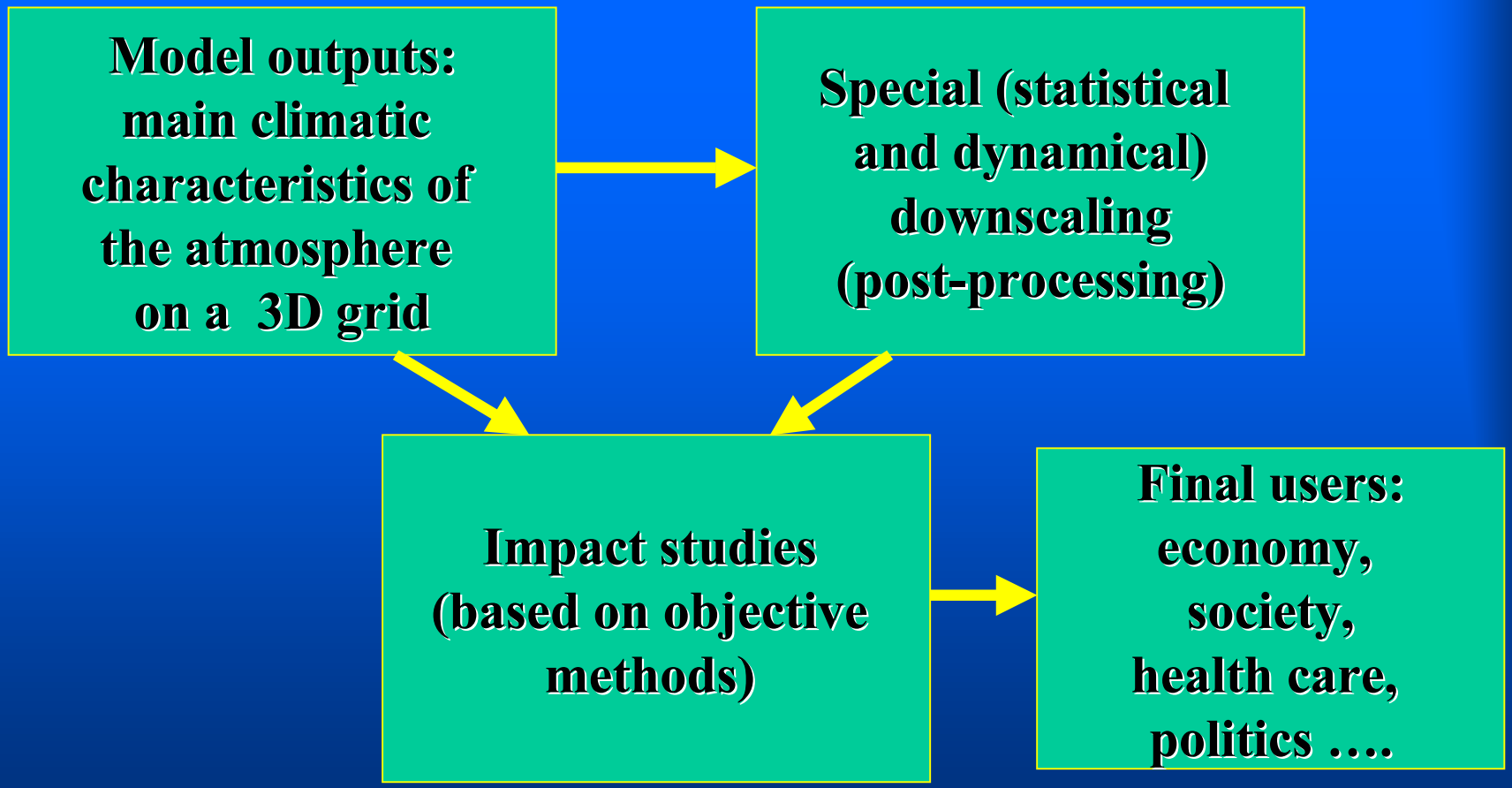
ISSUE NO. 7:
USE OF RCM OUTPUTS TO IMPACT STUDIES

QUESTIONS

- Can the raw model outputs be used directly for impact studies?

- How to bridge the gap between the resolution of the models and the resolution of the required information (statistical and/or dynamical methods?)

HOW THE OUTPUTS OF THE CLIMATE MODELS CAN BE USED IN PRACTISE?



ANSWERS TO ISSUE NO. 7

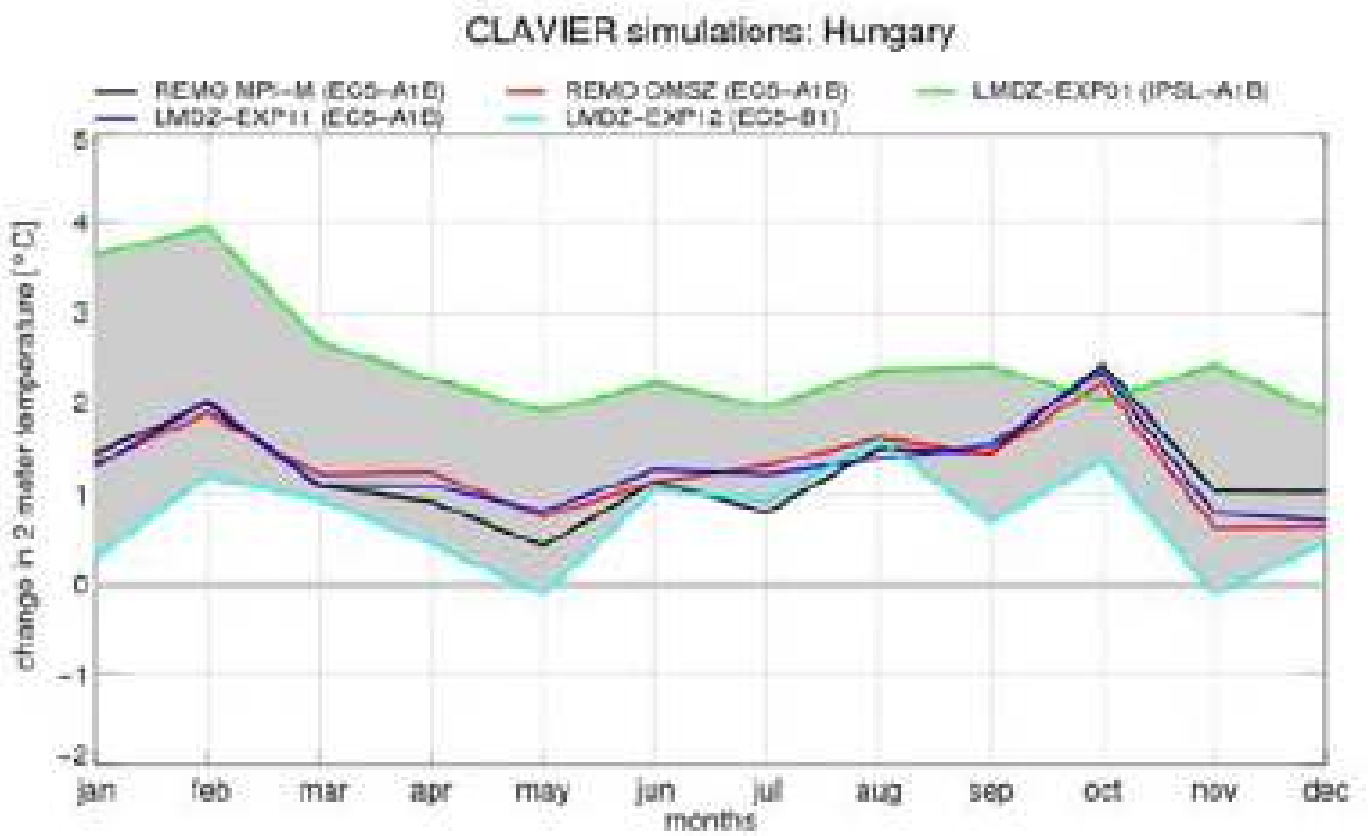
- For impact studies the direct RCM outputs mostly cannot be used
- Either a downscaling (improve the temporal and spatial information content) or a post-processing (compute such fields which are not model variables) is needed
- This further downscaling is a difficult job…
- The dynamical downscaling methods are recommended

ISSUE NO. 8: SENSITIVITY TO MODEL FORMULATION AND SCENARIO

QUESTIONS

- What is more „important”: LBC, model type or scenario?

DEPENDENCE ON THE MODEL FORMULATION, LBCs AND THE SCENARIO (TEMPERATURE, 2021-2050)



ANSWERS TO ISSUE NO. 8

- The LBC-s are more important than model formulation and scenarios for the near future (2021-2050)

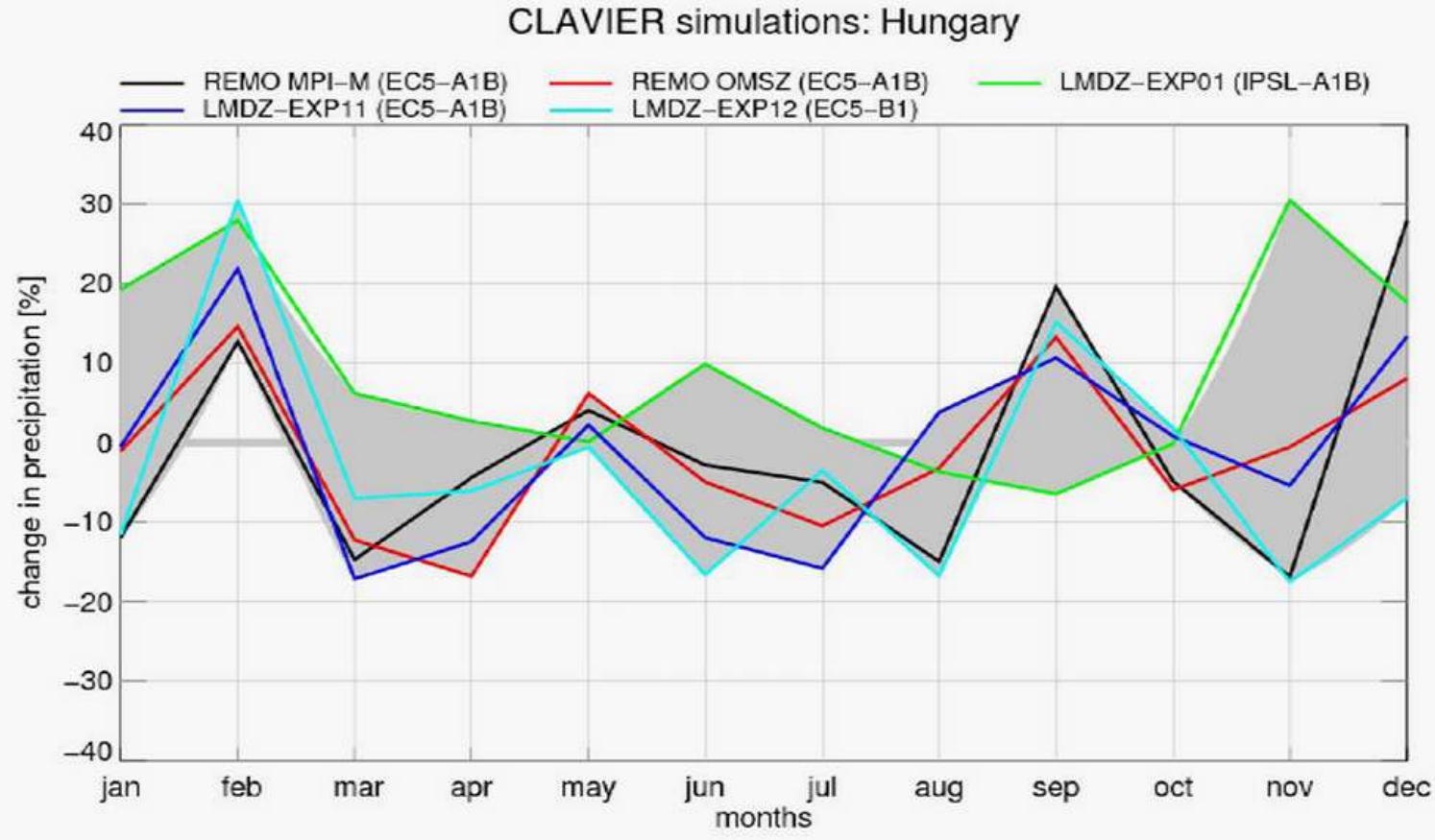
- Later (2071-2100) the scenarios are the main driving forces

ISSUE NO. 9: ENSEMBLE EVALUATION

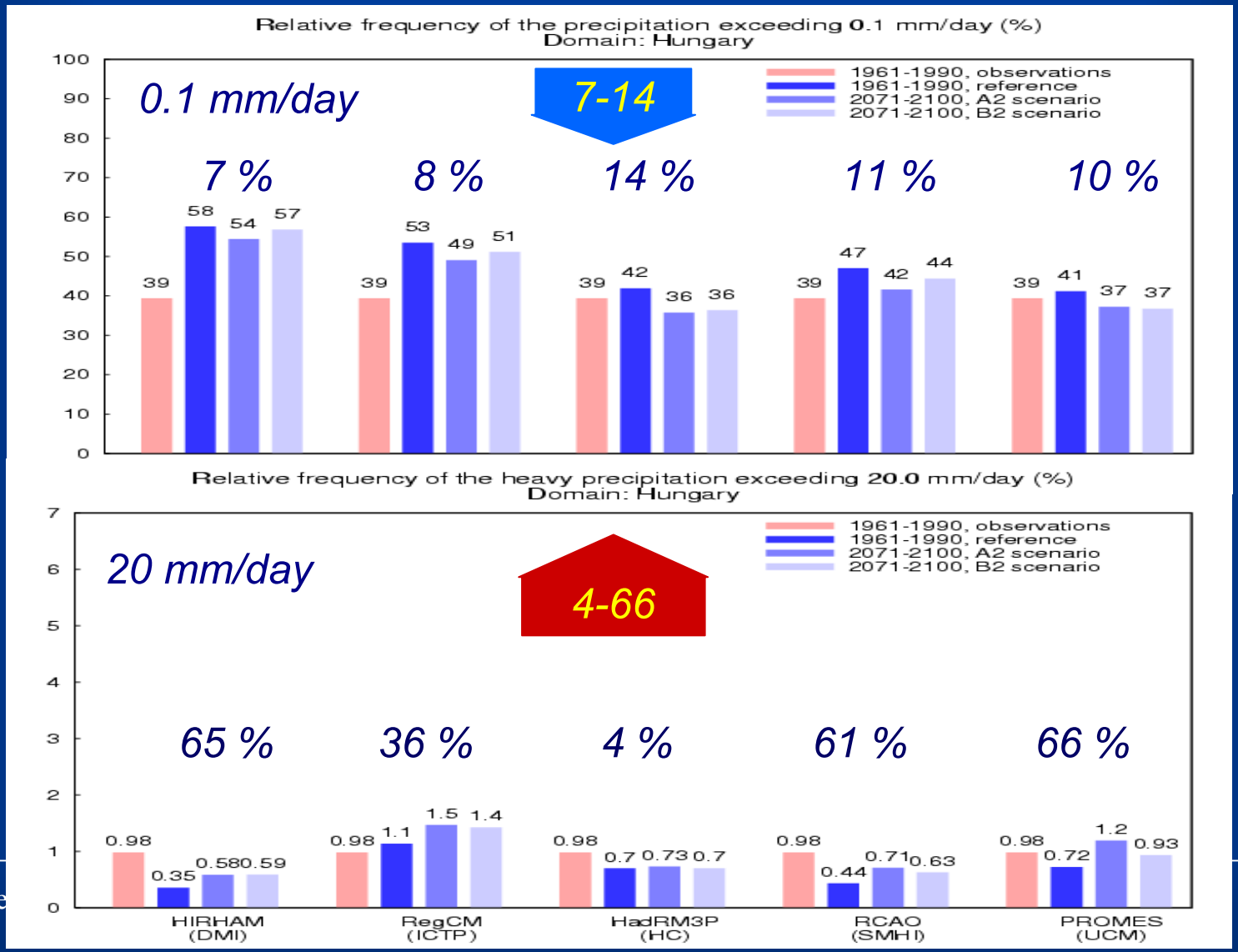
QUESTIONS

- What is the best way to provide information to the users?
- How to quantify uncertainties?

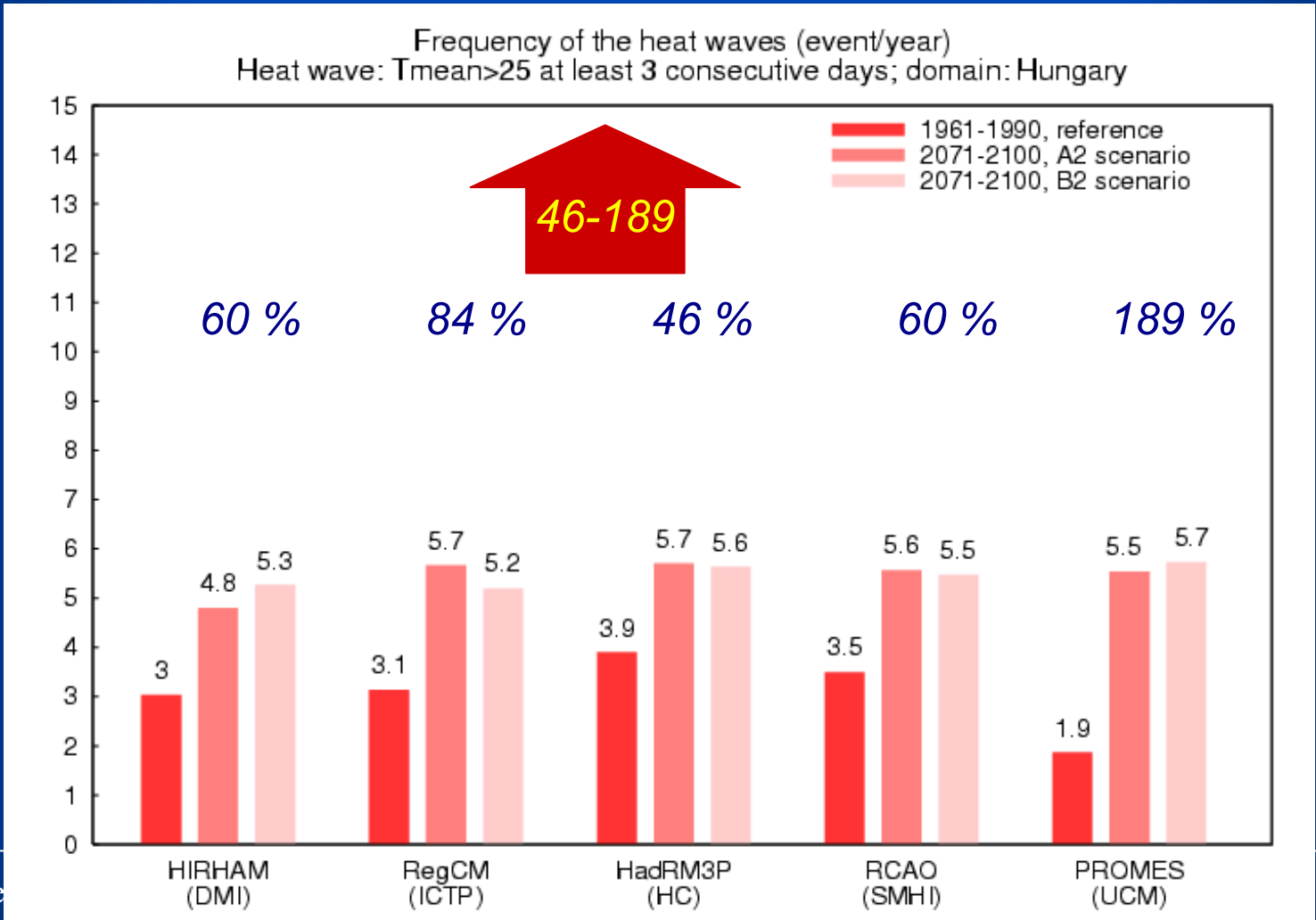
ENSEMBLE EVALUATION OF MORE MODEL'S OUTPUT (PRECIPITATION)



PRECIPITATION (BASED ON PRUDENCE RESULTS)



HEAT WAVES (BASED ON PRUDENCE RESULTS)



ANSWERS TO ISSUE NO. 9

- In principle: all the uncertainties of the simulations should be understood and then in practise quantified

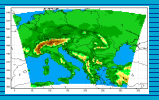
- In practise: the easiest way is to consider the outputs of more RCMs

REGIONAL CLIMATE MODELS AT THE HUNGARIAN METEOROLOGICAL SERVICE

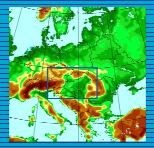
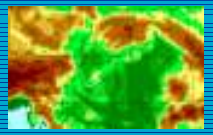
SOME INTRODUCTORY REMARKS

- The climate modelling activities in Hungary had been started for 5 years
- Two regional climate models are adapted, tested, developed and applied: ALADIN-Climate (international cooperation) and REMO (Max Planck Institute)
- Cooperation with ELTE (Eötvös Loránd University)

MAIN CHARACTERISTICS OF THE REMO SIMULATIONS

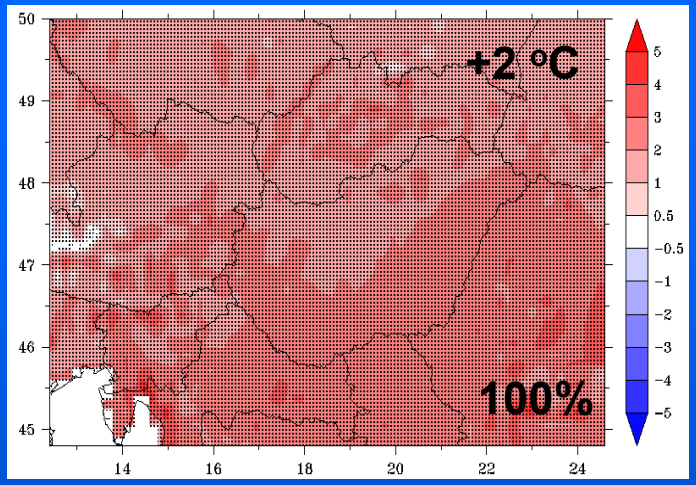
	ERA40	TRANSIENT
Integration period	1961–2000	1951–2050
Lateral boundary conditions	ERA40 (125 km)	ECHAM5/MPI-OM (200 km)
LBC coupling frequency	6 hours	
Horizontal resolution	0,22° ~ 25 km	
Vertical levels	20	
Domain		
Scenario	A1B	

MAIN CHARACTERISTICS OF THE ALADIN-Climate SIMULATIONS

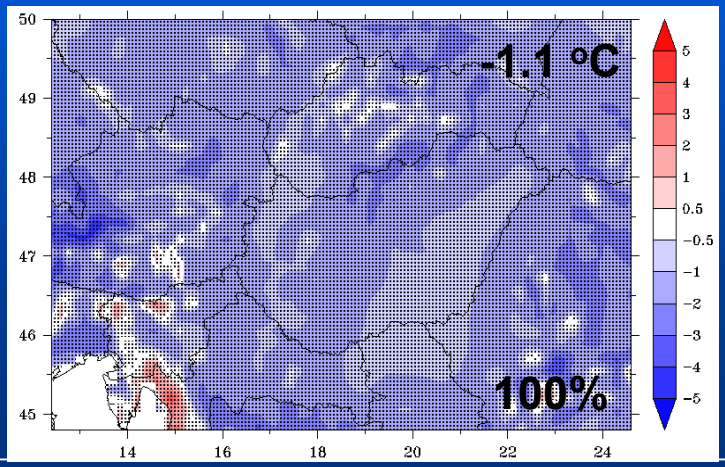
	ERA40	TIME SLICES
Integration periods	1961–2000	1961-1990, 2021-2050, 2071-2100
Lateral boundary conditions	ERA40 (125 km)	ARPEGE/OPA (~50 km)
LBC coupling frequency	6 hours	
Horizontal resolution	25 km and 10km	
Vertical levels	37	
Domain		
Scenario	A1B	

VALIDATION EXPERIMENTS: ERA40 LBC-s (ANNUAL TEMPERATURE BIAS)

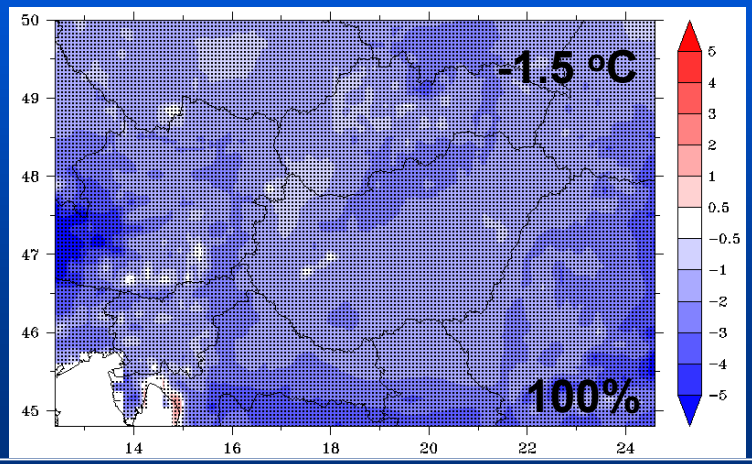
REMO, 25km



ALADIN, 25km

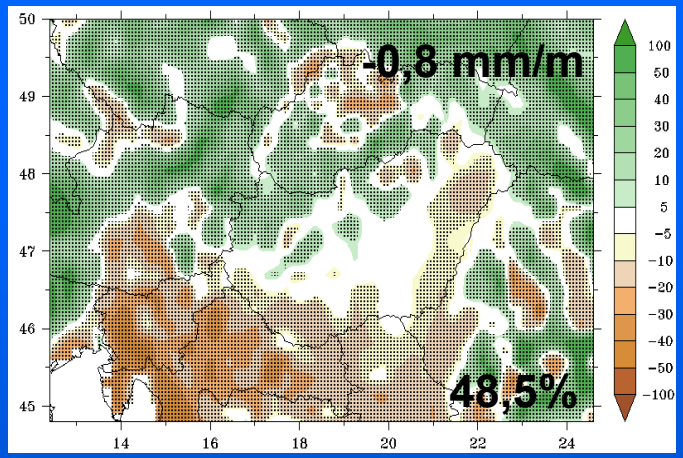


ALADIN, 10km

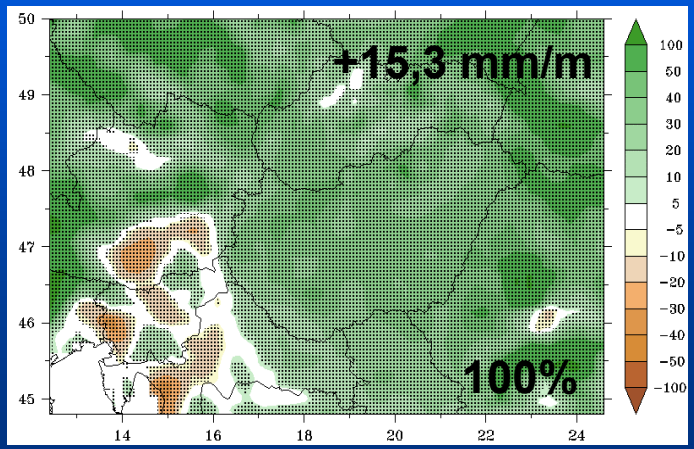


VALIDATION EXPERIMENTS: ERA40 LBC-s (ANNUAL PRECIPITATION BIAS)

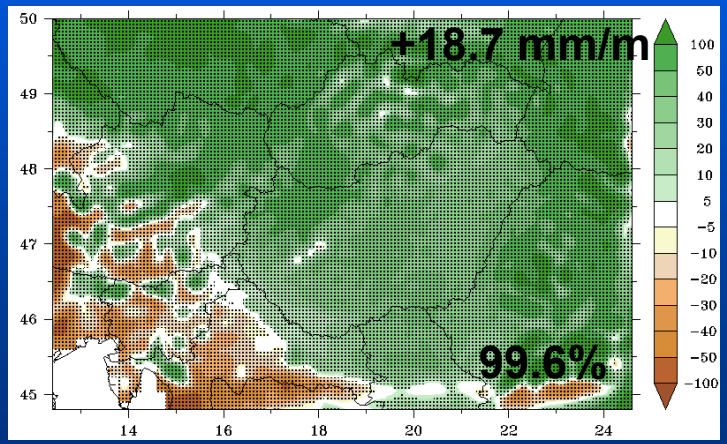
REMO, 25km



ALADIN, 25km

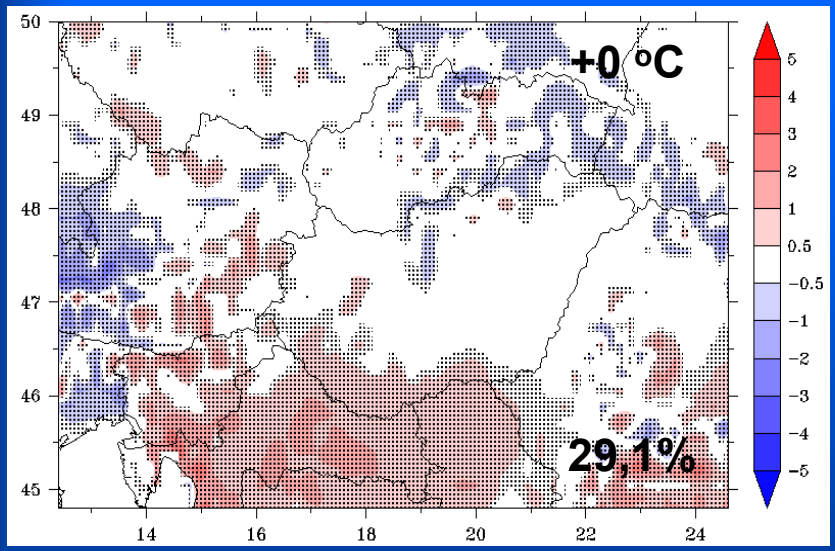


ALADIN, 10km

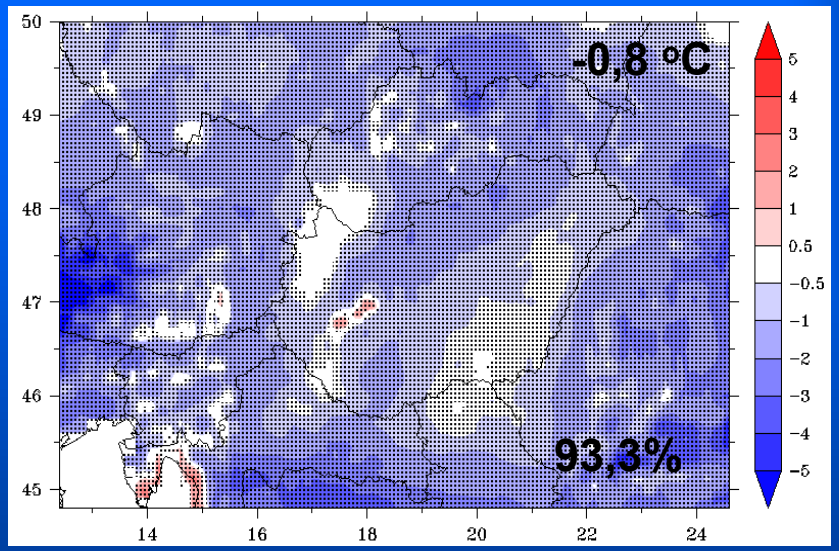


VALIDATION EXPERIMENTS: GCM LBC-s (ANNUAL TEMPERATURE BIAS)

REMO-ECHAM, 25km

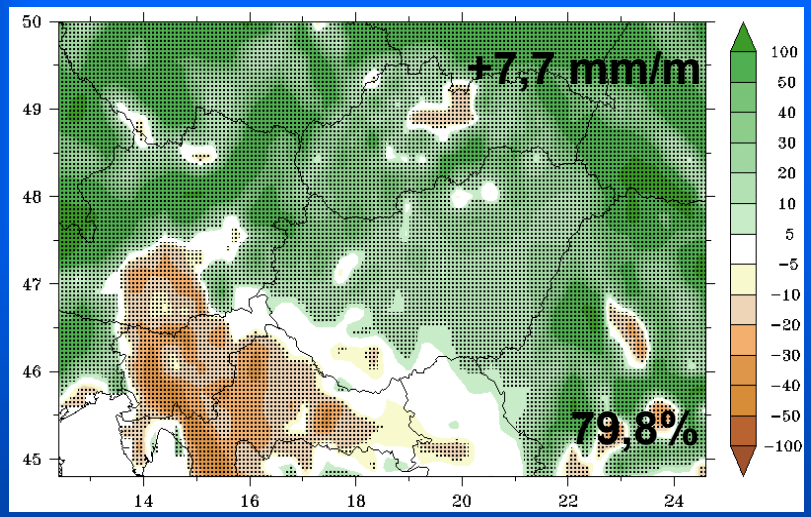


ALADIN-ARPEGE, 10km

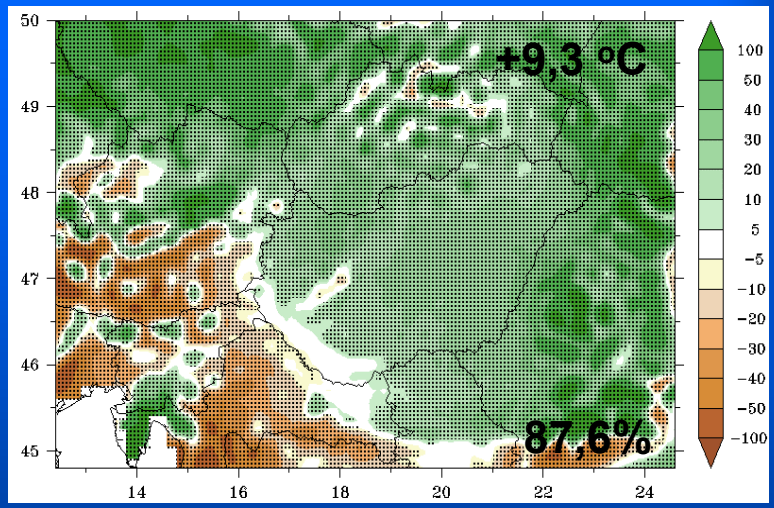


VALIDATION EXPERIMENTS: GCM LBC-s (ANNUAL PRECIPITATION BIAS)

REMO-ECHAM, 25km



ALADIN-ARPEGE, 10km

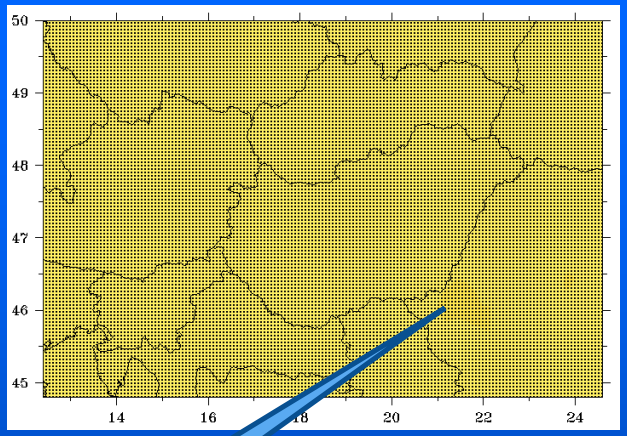


VALIDATION: SUMMARY AND QUESTIONS

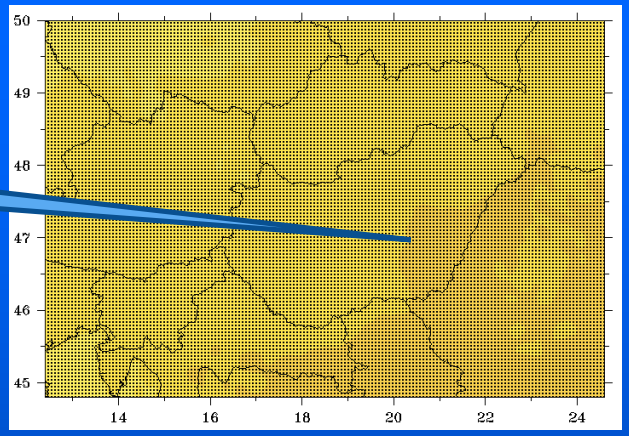
- ERA40 coupling:
  - REMO: warm and dry
  - ALADIN-Climate: cold and wet
- GCM coupling:
  - REMO: perfect temperature and wet
  - ALADIN-Climate: cold (but warm summer) and wet (but dry autumn)
- Question:
  - How to interpret the contradicting behaviour of the experiments for the past (especially for the REMO model)?

CHANGE OF ANNUAL TEMPERATURE (TARGET PERIOD VS. 1961-1990)

REMO 2021-2050



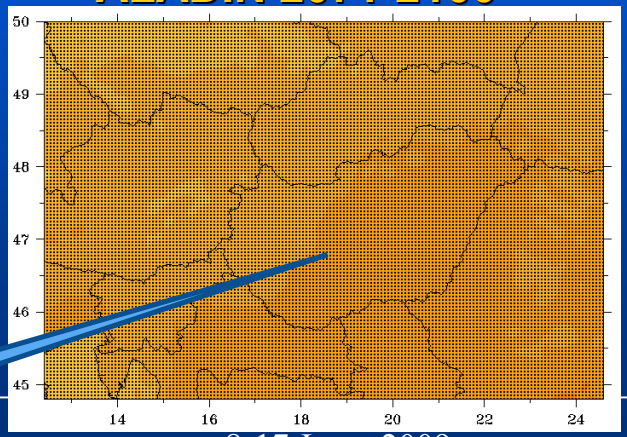
ALADIN 2021-2050



2.0 °C

1.5 °C

ALADIN 2071-2100

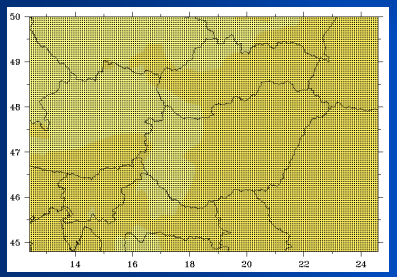
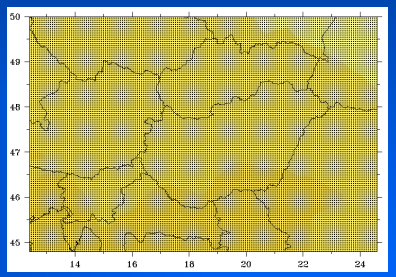
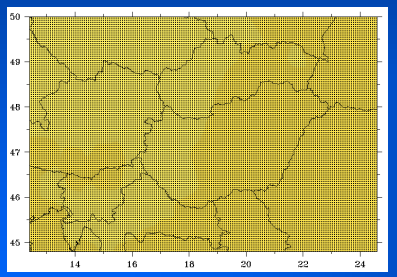
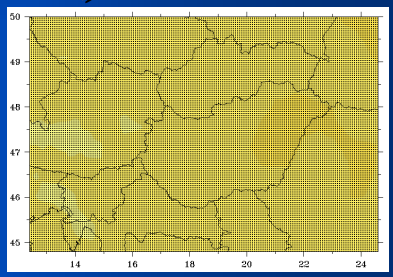


3.5 °C

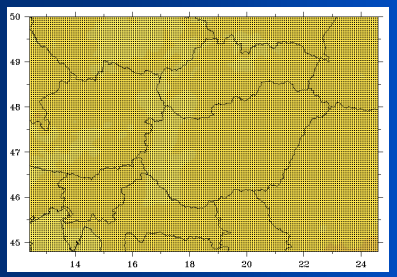
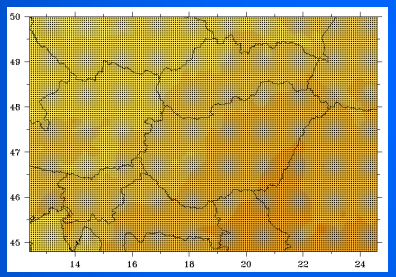
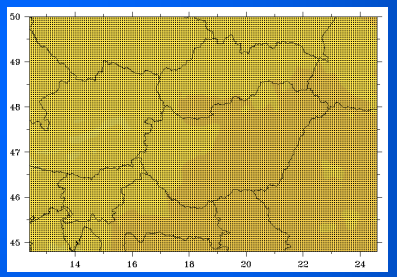
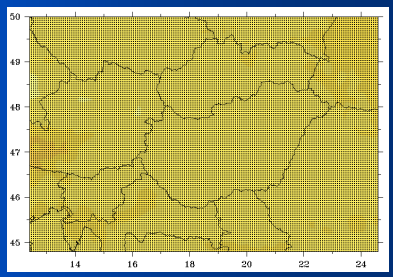
All the changes are significant!

CHANGE OF SEASONAL TEMPERATURE (TARGET PERIOD VS. 1961-1990)

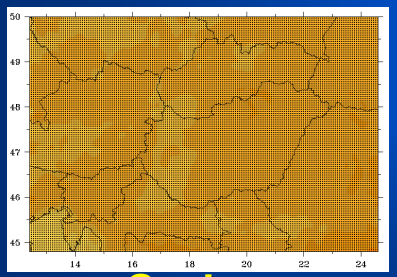
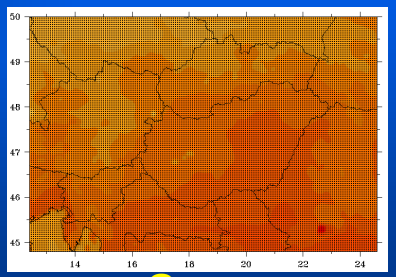
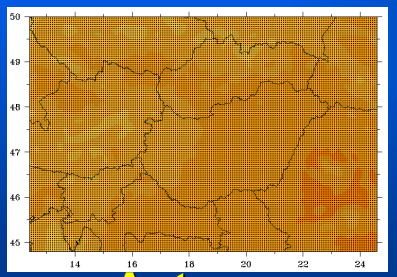
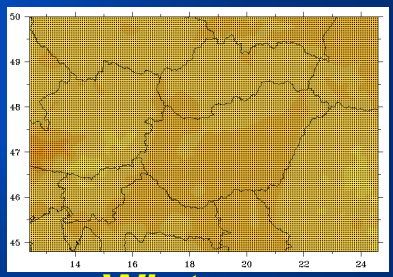
REMO 2021-2050

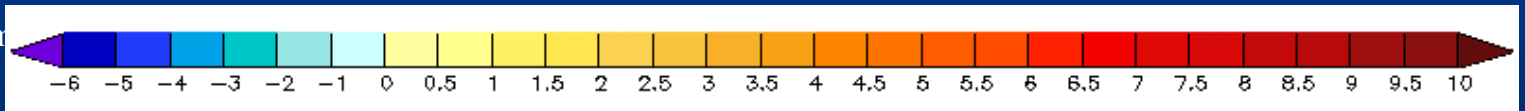
ALADIN 2021-2050

ALADIN 2071-2100

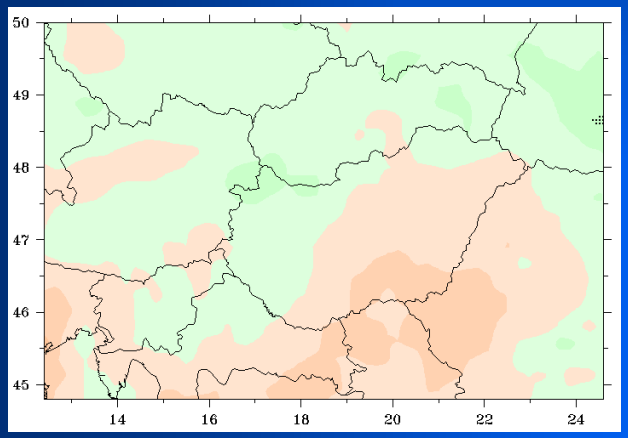





Spring Summer Autumn Winter

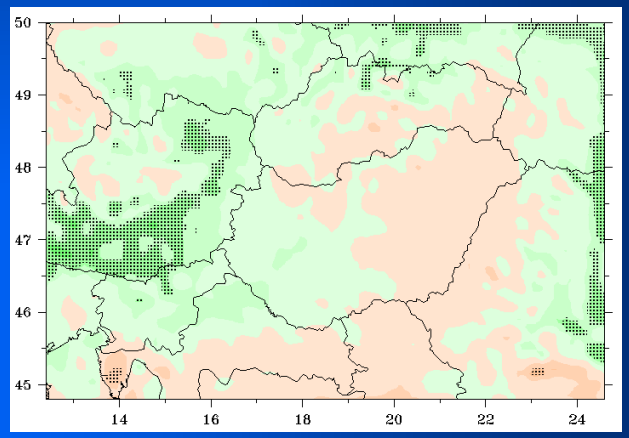


CHANGE OF ANNUAL PRECIPITATION (TARGET PERIOD VS. 1961-1990)

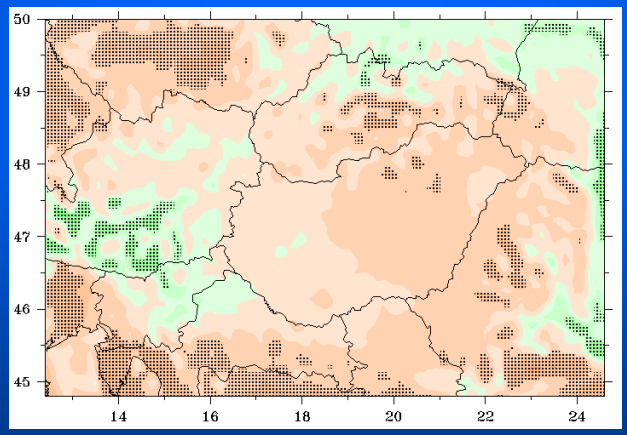
REMO 2021-2050

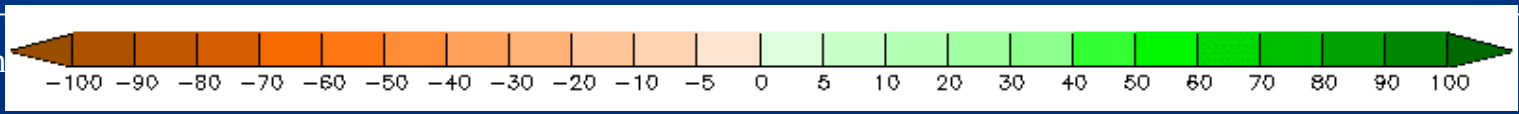


ALADIN 2021-2050



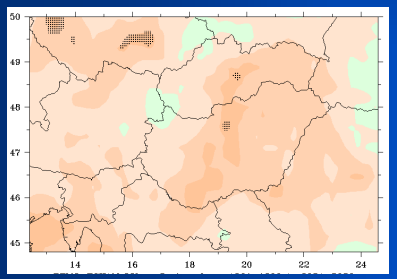
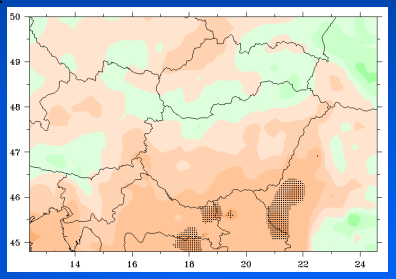
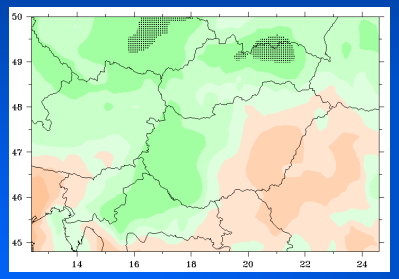
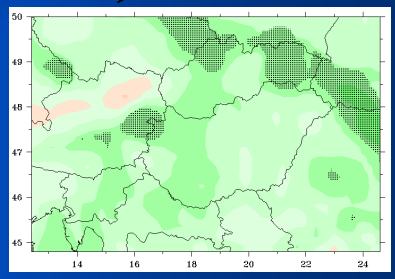
ALADIN 2071-2100



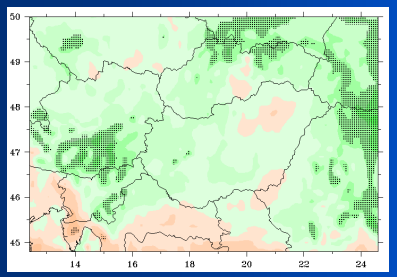
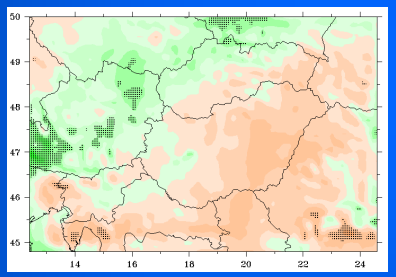
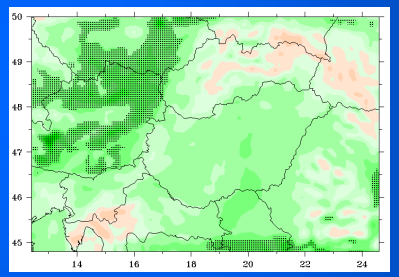
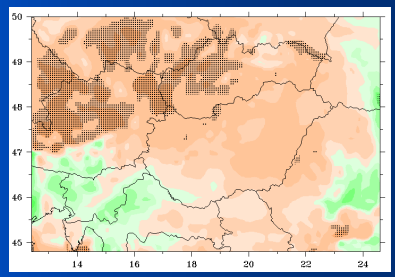


CHANGE OF SEASONAL PRECIPITATION (TARGET PERIOD VS. 1961-1990)

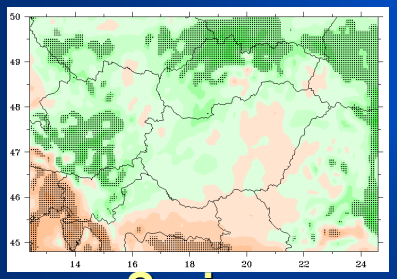
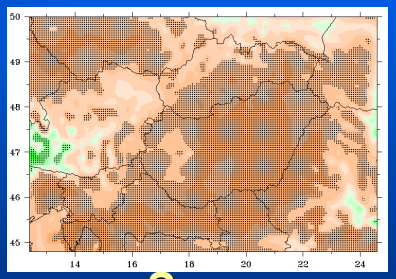
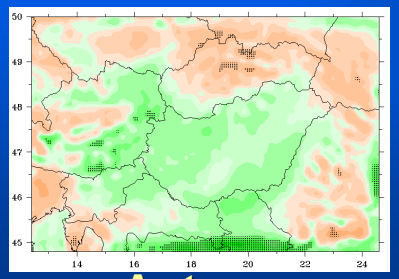
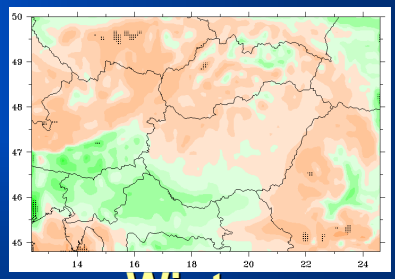
REMO 2021-2050

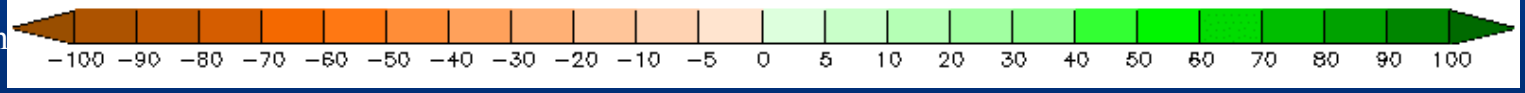
ALADIN 2021-2050

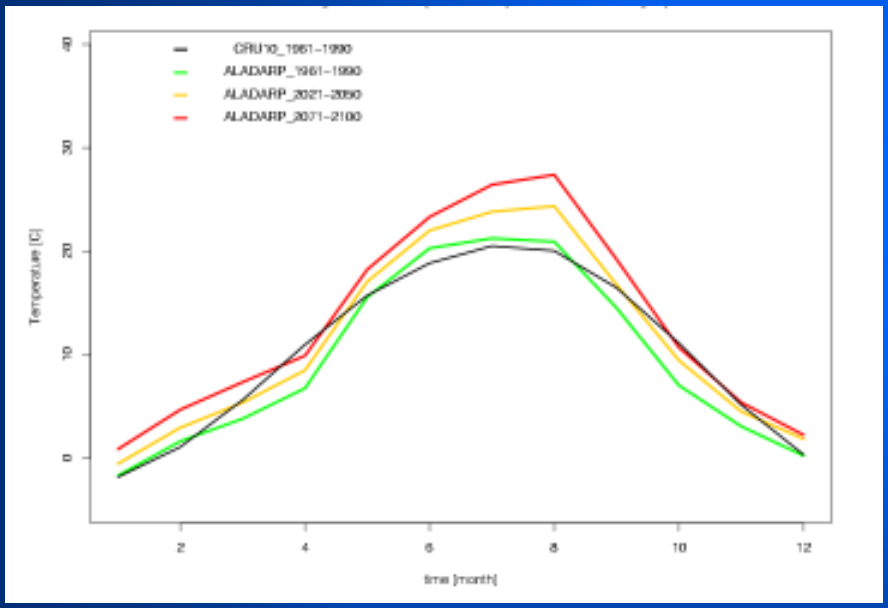
ALADIN 2071-2100

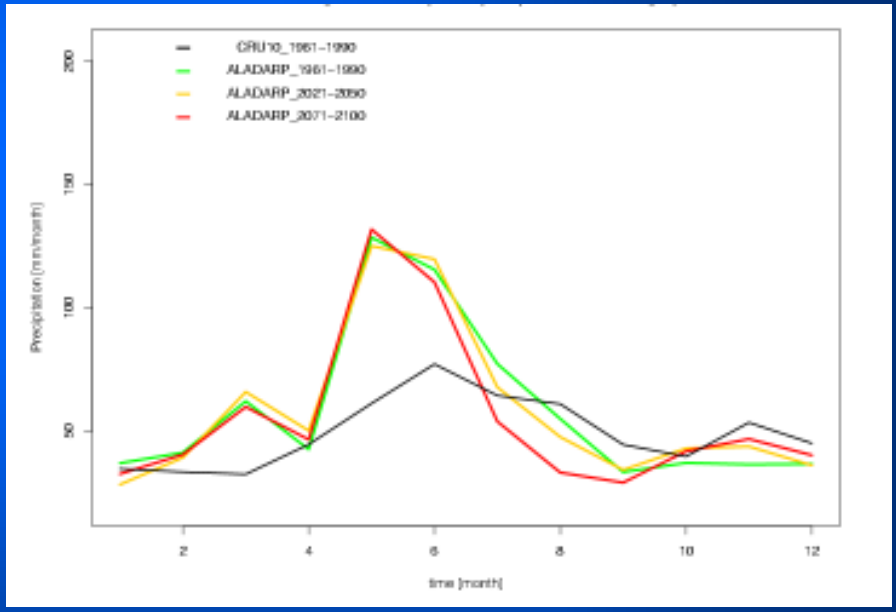





Spring Summer Autumn Winter



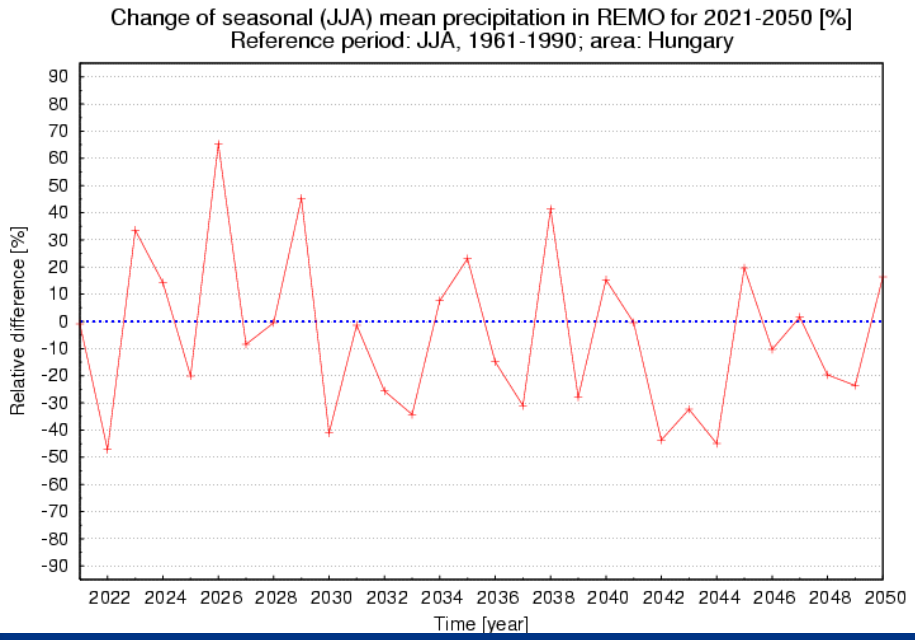
MONTHLY MEAN TEMPERATURE AND PRECIPITATION OVER HUNGARY (ALADIN MODEL)



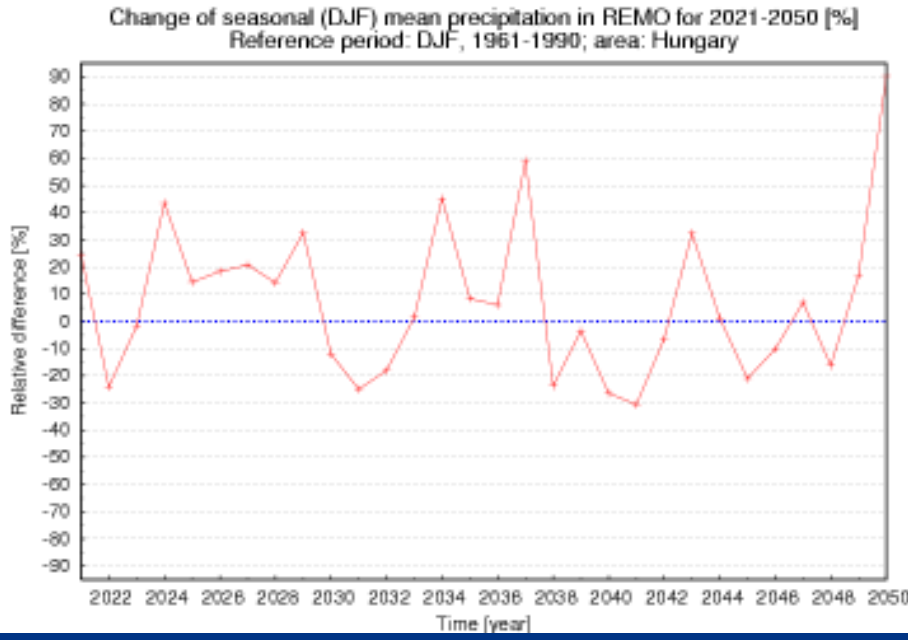


CHANGE OF MEAN PRECIPITATION OVER HUNGARY (reference: mean of 1961-1990; REMO model)

Summer

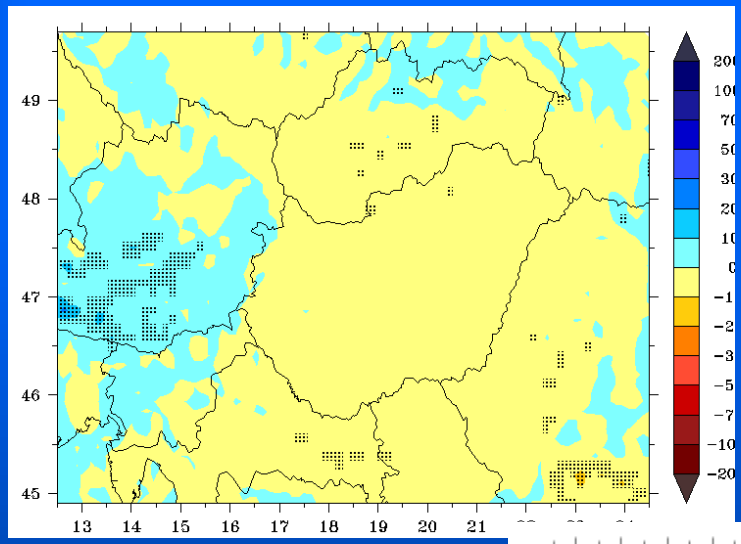


Winter

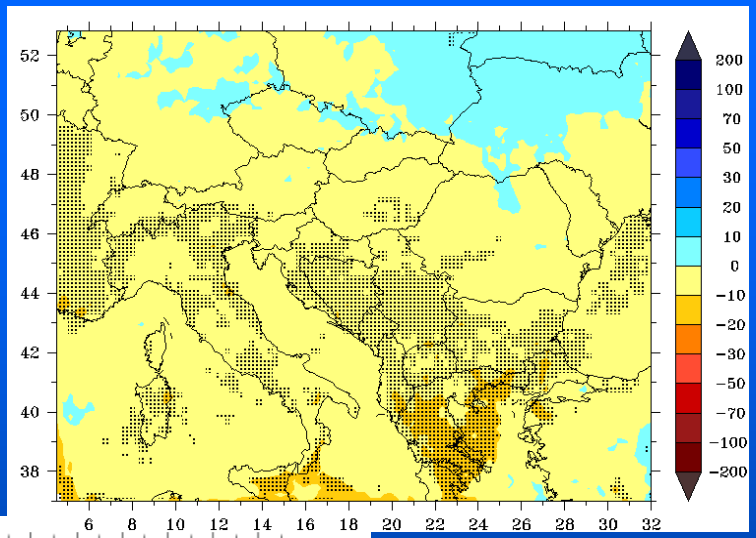


CHANGES IN PRECIPITATION EVENTS (RR>0,1mm)

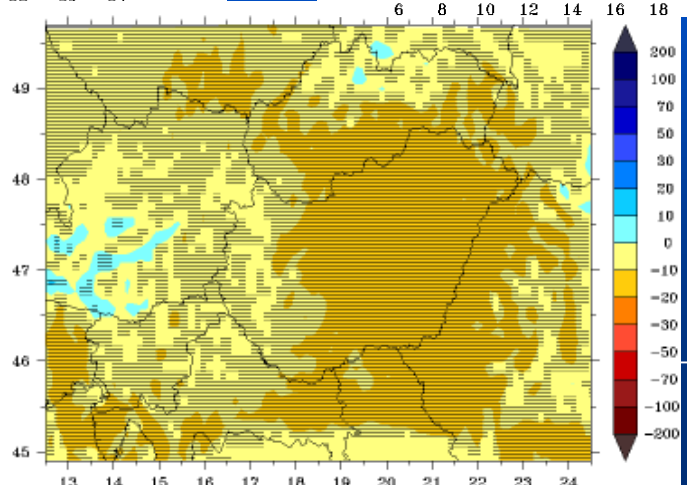
ALADIN 2021-2050



REMO 2021-2050

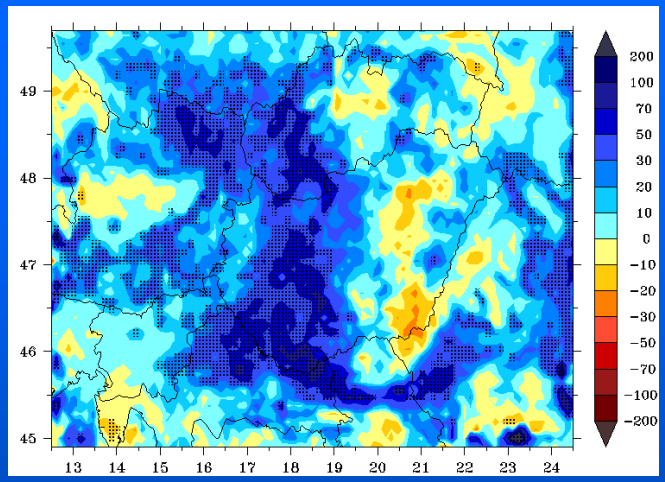


ALADIN 2071-2100

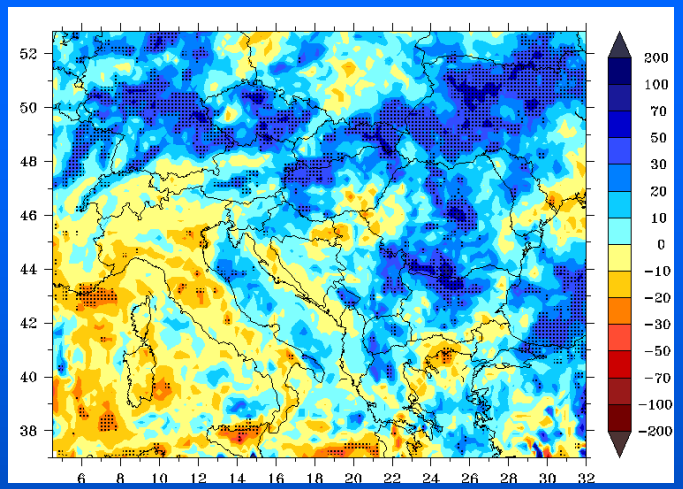


CHANGES IN EXTREMES: HEAVY PRECIPITATION EVENTS (RR>20 mm)

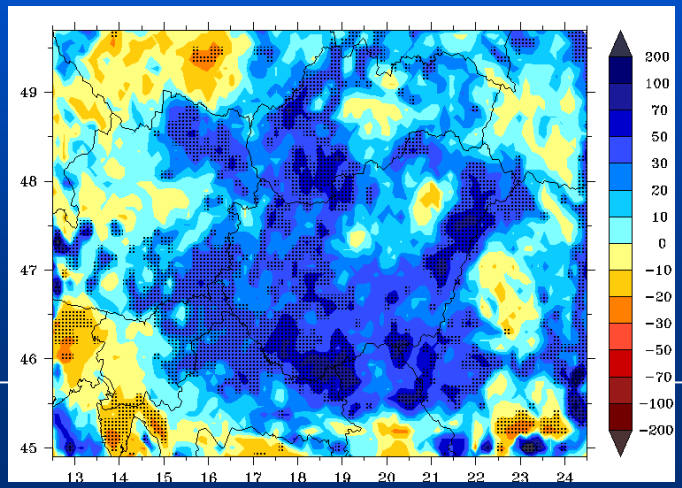
ALADIN 2021-2050



REMO 2021-2050

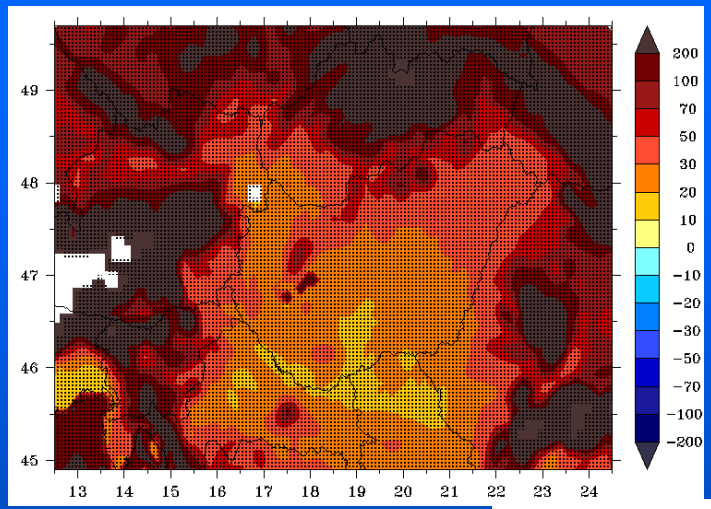


ALADIN 2071-2100

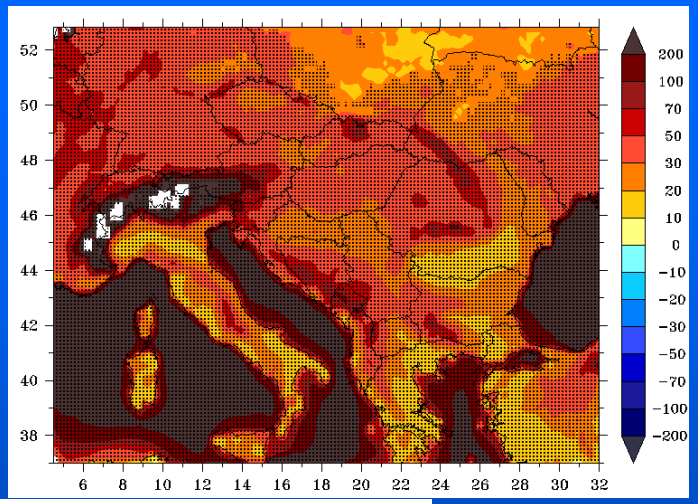


CHANGES IN EXTREMES: SUMMER UNITS

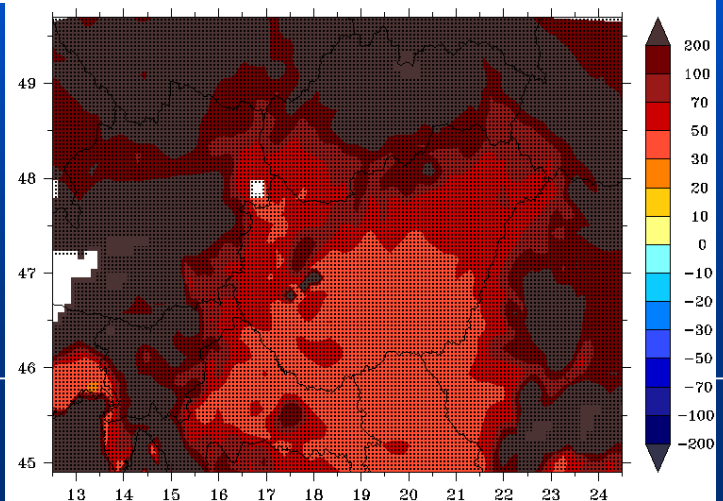
ALADIN 2021-2050



REMO 2021-2050



ALADIN 2071-2100



SUMMARY

- There are more questions than answers around regional climate models
- Some questions were raised and some hints were provided
- Some results obtained in Hungary were briefly introduced…


Thank you for
your attention!
horanyi.a@met.hu


Any question?