Uncertainty assessment for climate change scenarios for the Czech Republic

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PERUN: Prediction, evaluation and research for understanding national sensitivity and impacts of drought and climate change for Czechia

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Main goals:

- To develop tools for simulating the atmosphere-hydrosphere system, simulation over the Czech Republic.
- To improve the accuracy of the climate change scenarios for the Czech Republic
- To develop seasonal forecasts of climatological conditions and drought
- To evaluate of risks in the context of climate change
- To extend the system of operational management during a drought episode and to make it more accurate

PERUN climate change scenario development and uncertainty assessment

Core of the scenario: ALARO-Climate (Mašek et al., 2024) in convection permitting mode with app. 2.5 km resolution, historical and scenario runs diven by CNRM-ESM2-1, several socio-economic pathways.

Bias correction; Evaluation and reanalysis simulations for validation; Uncertainty estimate based on available GCM and RCM simulations

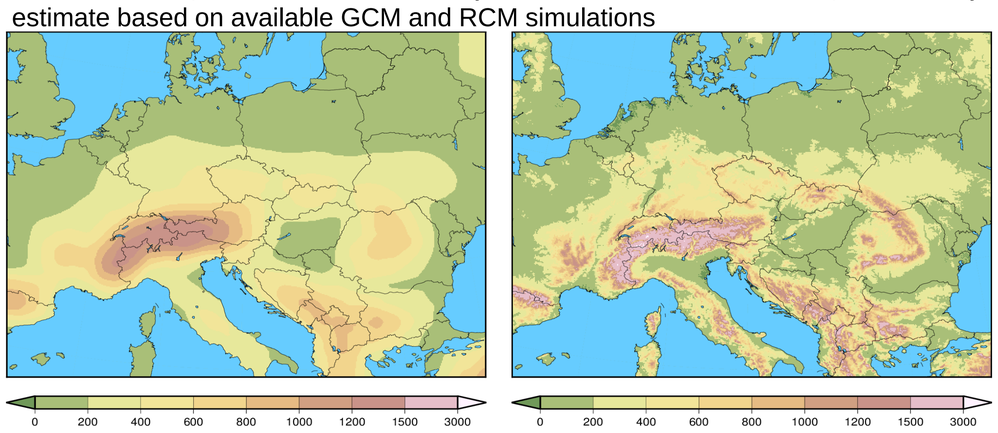


Figure 1: The orography of the driving GCM and the nested CPS simulation

Uncertainty sources - general overview

Climate model outputs

- Initial conditions
- Boundary conditions
- Parametrizations
- Model structure

For regional climate model (RCM):

- driving model
- interaction of RCM and driving global climate model (GCM)

Climate change scenarios

- unknown development of forcing
- Reaction to the forcing
- Internal climate variability

Assessment of internal variability: 'perturbed initial conditions ensembles', i.e., ensembles of simulations of a single model with modified initial conditions.

The uncertainty associated with the structure of the model: ensembles of simulations of different models.

We cannot capture the full range of either "type" of uncertainty, so we assume that the resulting uncertainty estimate tends to underestimate the true uncertainty.

CMIP5 and CMIP6 projections over the Czech Republic *(Holtanová et al., 2022)*

Model performance of state-of-the-art GCMs with a focus on the **mean annual cycle of mean, maximum, and minimum air temperature and precipitation and their inter-annual variability** - characteristics crucial for different sectors of human activities and natural ecosystems.

Differences between CMIP5 and CMIP6 GCM multi-model ensembles: there are no large differences in the resemblance with observed values between CMIP5 and CMIP6 when the whole multi-model ensembles are analyzed. On the other hand, a comparison of selected CMIP5-CMIP6 pairs showed a tendency towards better performance in the new CMIP6 generation.

Projected changes in mean temperature and precipitation annual cycle over Central Europe: Our results indicated considerable future changes in the shape of the annual cycle of both air temperature and precipitation.

Conclusions:

- Projected changes in thermal and ombric continentality of climate over Central Europe;
- Increasing probability of dangerous dry periods and heat waves during summer alongside floods during spring and winter.;
- The uncertainty of projected changes over central Europe connected to internal climate variability (assessed by CNRM_INI sub-ensemble, a perturbed initial condition ensemble of CNRM-ESM2-1) cannot be neglected.
- Higher projected air temperature increase in CMIP6 compared to the previous generation of CMIP5, especially in summer.

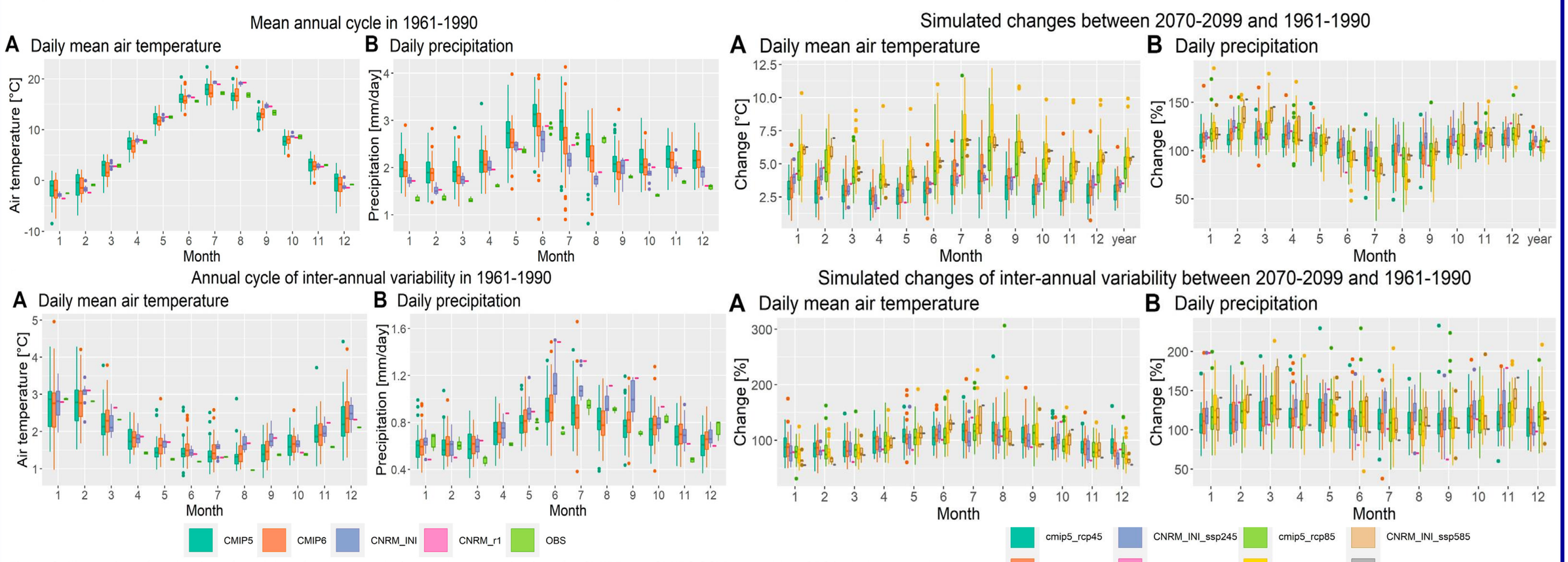


Figure 2: Illustration of evaluation of model performance and climate change projections for CMIP5 and CMIP6 GCM ensembles. OBS includes several observed datasets to sample observational uncertainty. CNRM_r1 corresponds to the CNRM-ESM2-1 member used as the driving GCM for ALARO-Climate scenario simulations. "rcp" and "ssp" stands for different socio-economic pathways (adopted from Holtanová et al., 2022).

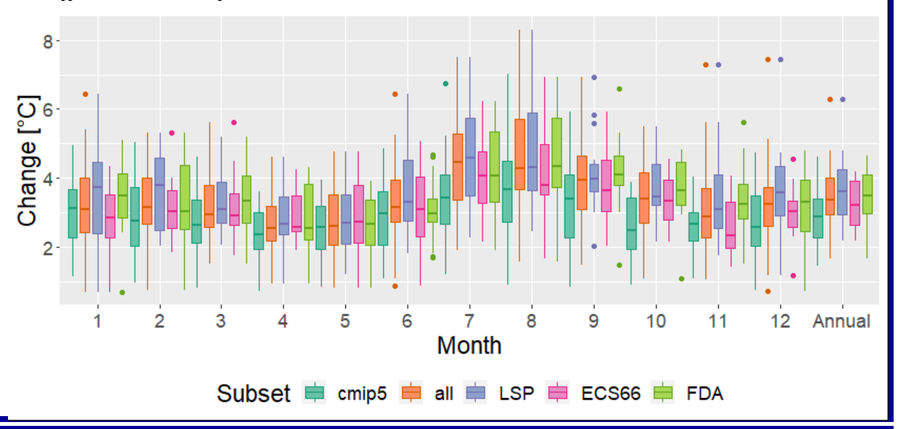
Hot model problem

The most recent CMIP6 GCMs represent undoubtedly a considerable step forward in the model development. However, there is a distinct (and potentially unrealistic) **increase in climate sensitivity in some CMIP6 GCMs**, which results in higher projected changes in global mean temperature. A regional manifestation of this “hot model problem” (Hausfather et al., 2022) was also pointed out by Holtanová et al. (2022). Understanding the reasons and consequences of higher climate sensitivity and formulation of a physically based constraint (Hall et al., 2019) is essential for greater confidence in future climate change projections and is a major challenge for current climate research. As potential constraints have been investigated mainly on the global scale, their impact in Central Europe remains to be assessed.

We have been exploring ways of constraining the projected changes for Central Europe to enable narrowing the uncertainty:

Preliminary results (Fig. 3): monthly mean air temperature changes for the Czech Republic under a medium-range SSP2-4.5: "All" stands for the whole CMIP6 ensemble, "LSP" shows results for a best-performing subset according to large-scale criteria following Palmer et al. (2023), "ECS66" represents subset of GCMs with climate sensitivities in a realistic range according to the latest IPCC report, and "FDA" denotes a subset based on performance in simulating mean annual cycle using functional data analysis approach.

Figure 3: Comparison of monthly mean air temperature changes according to different subsets of CMIP6 multi-model ensemble and CMIP5 GCMs.



Future outlooks

- Thorough analysis and evaluation of the PERUN ALARO-Climate simulations, application of bias correction, preparation of the climate change scenario - input for impact studies and adaptation strategies
- Other convection-permitting RCM simulations for comparison with PERUN ALARO-Climate outputs - uncertainty estimate, together with CMIP5 and CMIP6 data
- Construction of physically-based constraint to be applied on CMIP5 and CMIP6 for projections over Central Europe, with the aim of narrowing the uncertainty estimate
- Comparison of different methods for bias correction - including the methods accounting for inter-variable dependencies
- Comparison of differences between ALARO-Climate scenario simulations and its driving GCM CNRM-ESM2-1
- Recommendations for end-users - instruction on the usability of the climate change scenario data and their limits, explanation of the uncertainties
- Analysis of boundary conditions and potential influence of revealed errors on the nested RCM simulation - paper under review (Holtanová et al., 2024)
- Investigation of alternative approaches to scenario construction - global warming levels, storylines
- Internal climate variability as a benchmark for both model performance and projected changes

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