Adaptation and validation of the WRF regional climate model for the Carpathian Basin

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Dezső Dévényi Medal
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Introduction

- Aim: To adapt and evaluate the WRF (Weather Research and Forecasting) model as a regional climate model for the Carpathian Basin
- The WRF model has not previously been applied as a climate model in Hungary
- Validation using a wide range of observational datasets to better understand model behavior

Preliminary sensitivity tests

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Validation run (1985–2010)

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Subsequent test runs to improve the results

The WRF modeling system

- Advanced Research WRF (WRF-ARW) is a mesoscale, nonhydrostatic grid-point model developed through a community effort led by NCAR (National Center for Atmospheric Research)
- Hybrid sigma-pressure vertical coordinate
- Arakawa C-grid staggering in the horizontal
- Split-explicit time integration using a 3rd-order Runge-Kutta scheme

WRF namelist options

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cumulus option
 = 0, no cumulus
 = 1, Kain-Fritsch (new Eta) scheme
 = 2, Betts-Miller-Janjic scheme
 = 3, Grell-Freitas ensemble scheme
 = 4, Scale-aware GFS Simplified Arakawa-Schubert (SAS) scheme
 = 5, Grell 3D ensemble scheme
 = 6, Modifed Tiedtke scheme (ARW only)
 = 7, Zhang-McFarlane scheme from CAM5 (CESM 1_0_1)
 = 10, Modified Kain-Fritsch scheme with trigger function based on PDFs (ARW only)
 = 11, Multi-scale Kain-Fritsch scheme
 = 14, KIM Simplified Arakawa-Schubert scheme (KSAS) across gray-zone resolutions
 = 16, A newer Tiedtke scheme
 = 94, 2015 GFS Simplified Arakawa-Schubert scheme (HWRF)
 = 95, Previous GFS Simplified Arakawa-Schubert scheme (HWRF)
 = 96, Previous NEW GFS simplified Arakawa-Schubert scheme from YSU (ARW only)
 = 93, Grell-Devenyi ensemble scheme
 = 99, previous Kain-Fritsch scheme
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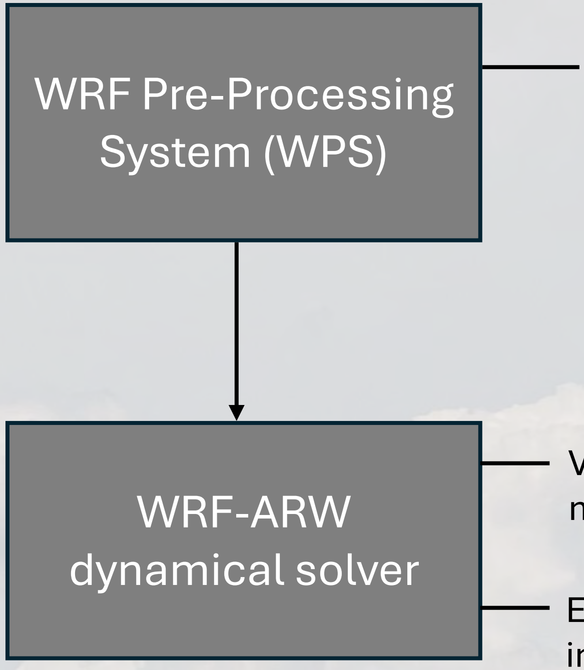


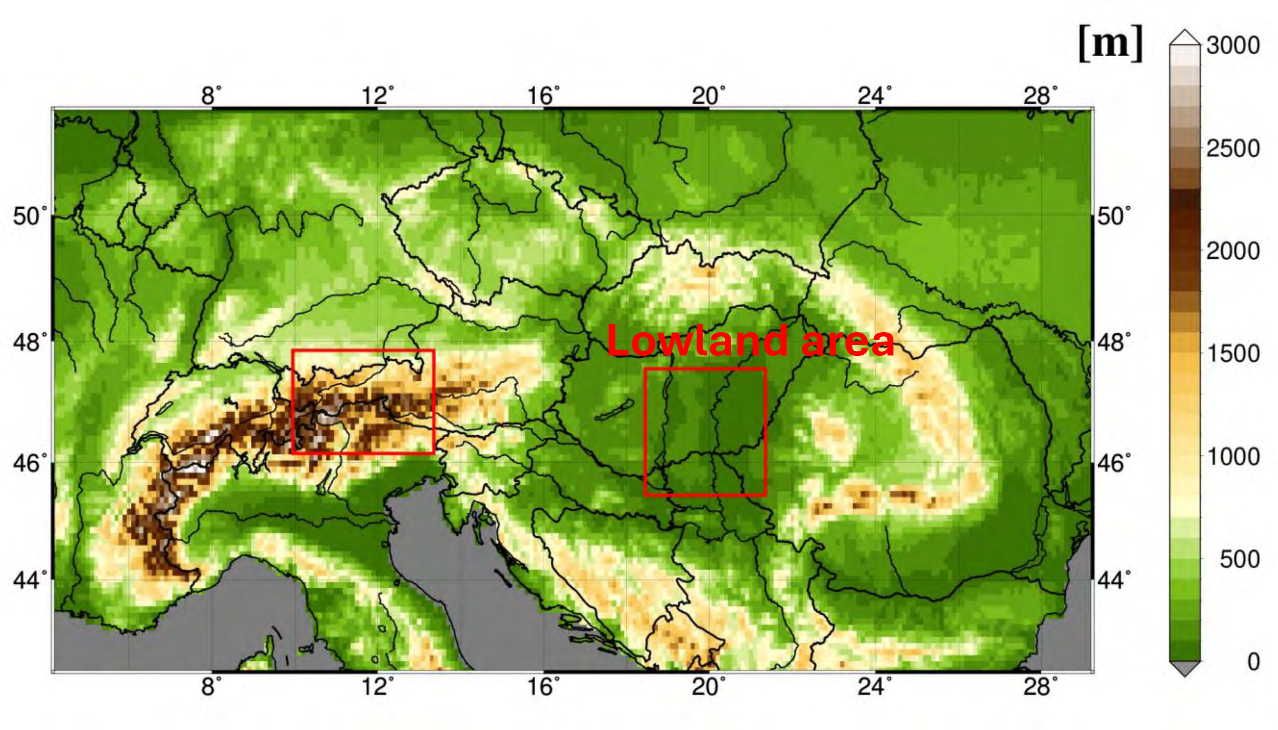
Preparation, horizontal interpolation of:
- Static data
- Meteorological input data

Vertical interpolation of meteorological input data

Executing the time integration, including physics schemes:
- Microphysics
- Radiative transfer (SW, LW)
- Planetary boundary layer
- Surface layer
- Land-surface model
- Urban parameterization
- Deep and shallow convection

Methodology

- Comparison of model results with observational datasets
- Calculation of climate averages (monthly, seasonal, and annual) from daily data series
- Evaluation for a **lowland** and a mountainous area (spatial averages)
- Comparison of meteorological fields on a uniform grid (interpolation)
- Evaluation against station observations by selecting the nearest model grid point



Study area with elevation data from the 0.1° E-OBS dataset

Preliminary sensitivity tests I.

- Short-term sensitivity simulations for the years 1994 and 2013 (>100 runs)
- Δx=50 km, 10 km
- Testing several different physical-dynamic settings:
  - ➢ Parameterization schemes
  - ➢ Number of model levels
  - ➢ Spin-up time
  - ➢ Numerical diffusion
  - ➢ Land-surface model (Noah-MP) parameterizations
  - ➢ Model domain

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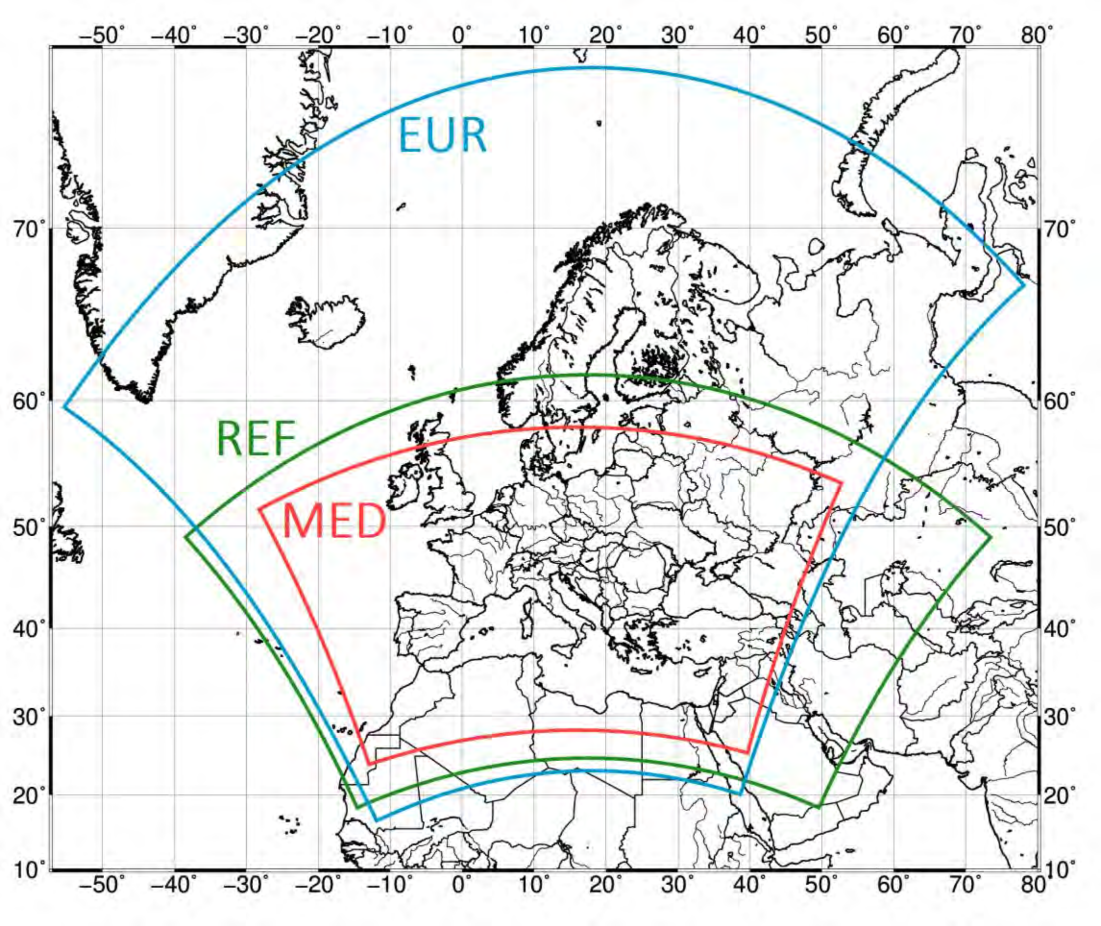
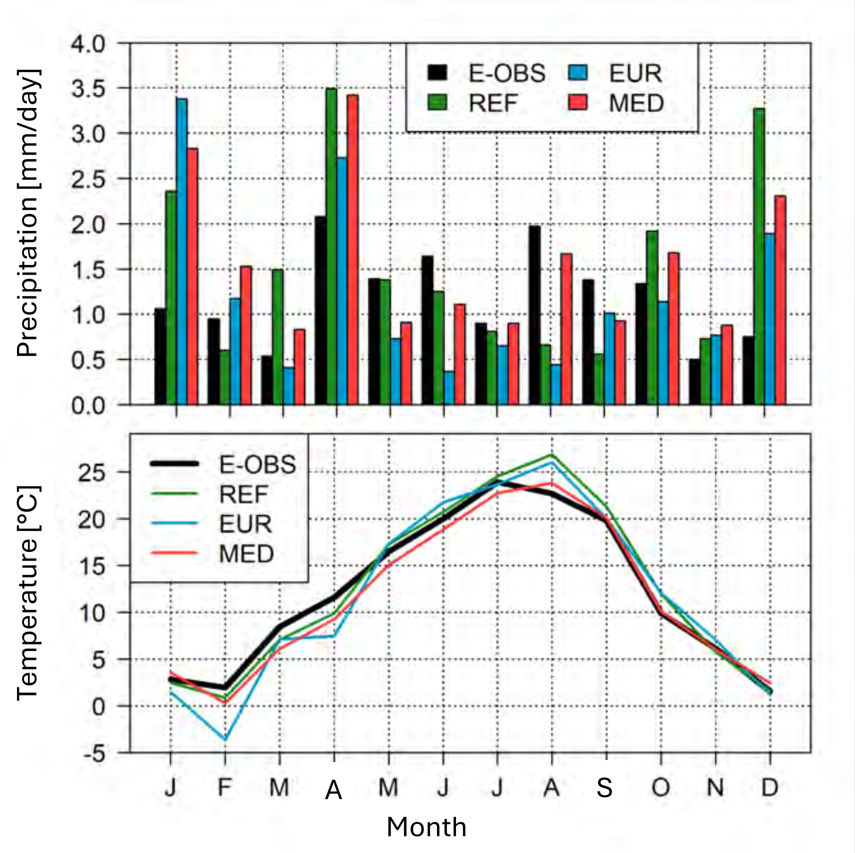
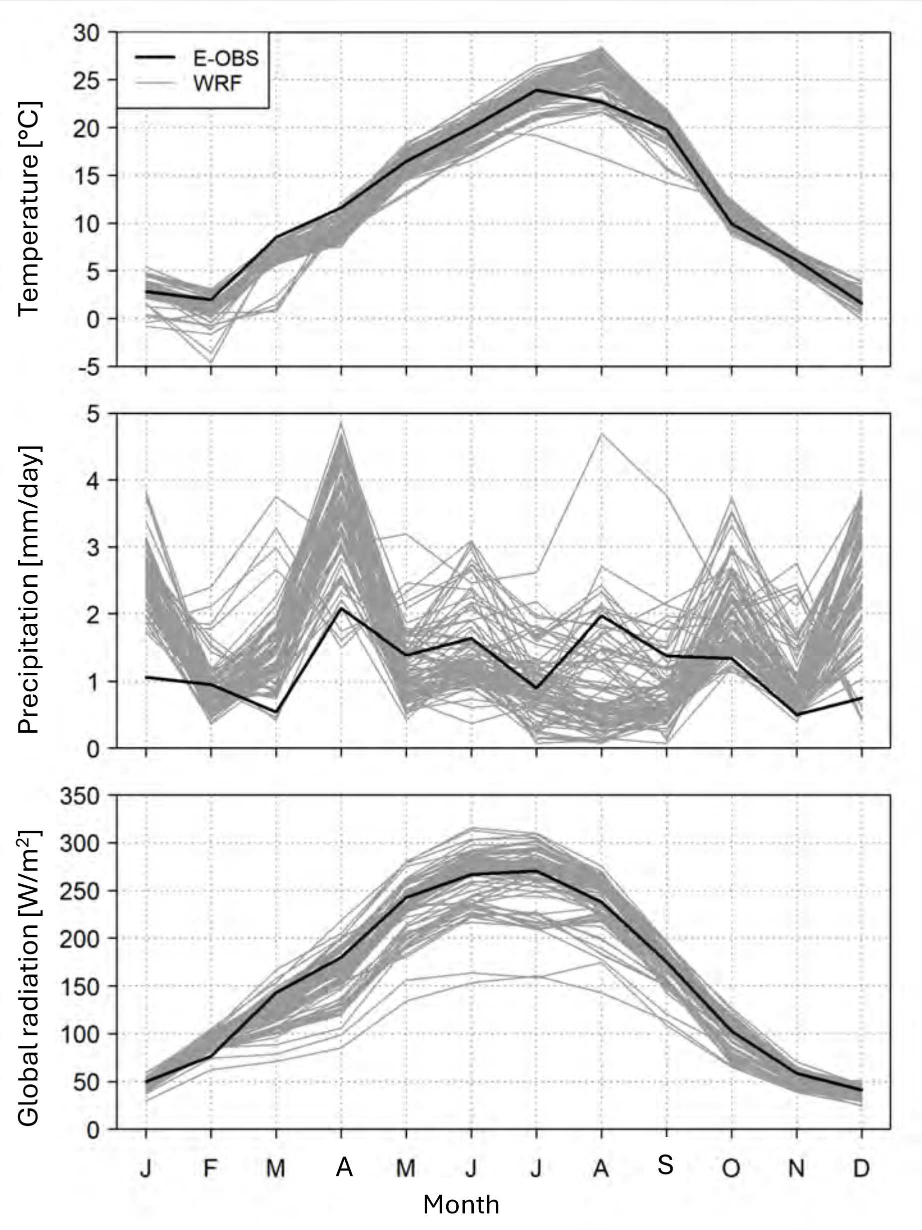


Model domains involved in the sensitivity tests (Reference, EURO-CORDEX, Med-CORDEX)

Preliminary sensitivity tests II.

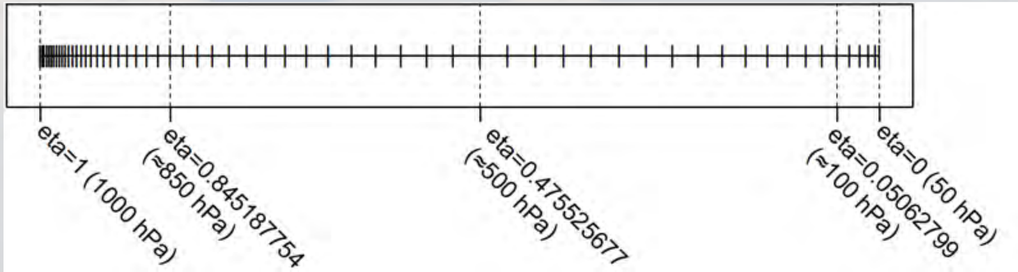
- Year 1994
- Δx=50 km
- Spatial averages (lowland area)
- ERA5 initial and boundary conditions



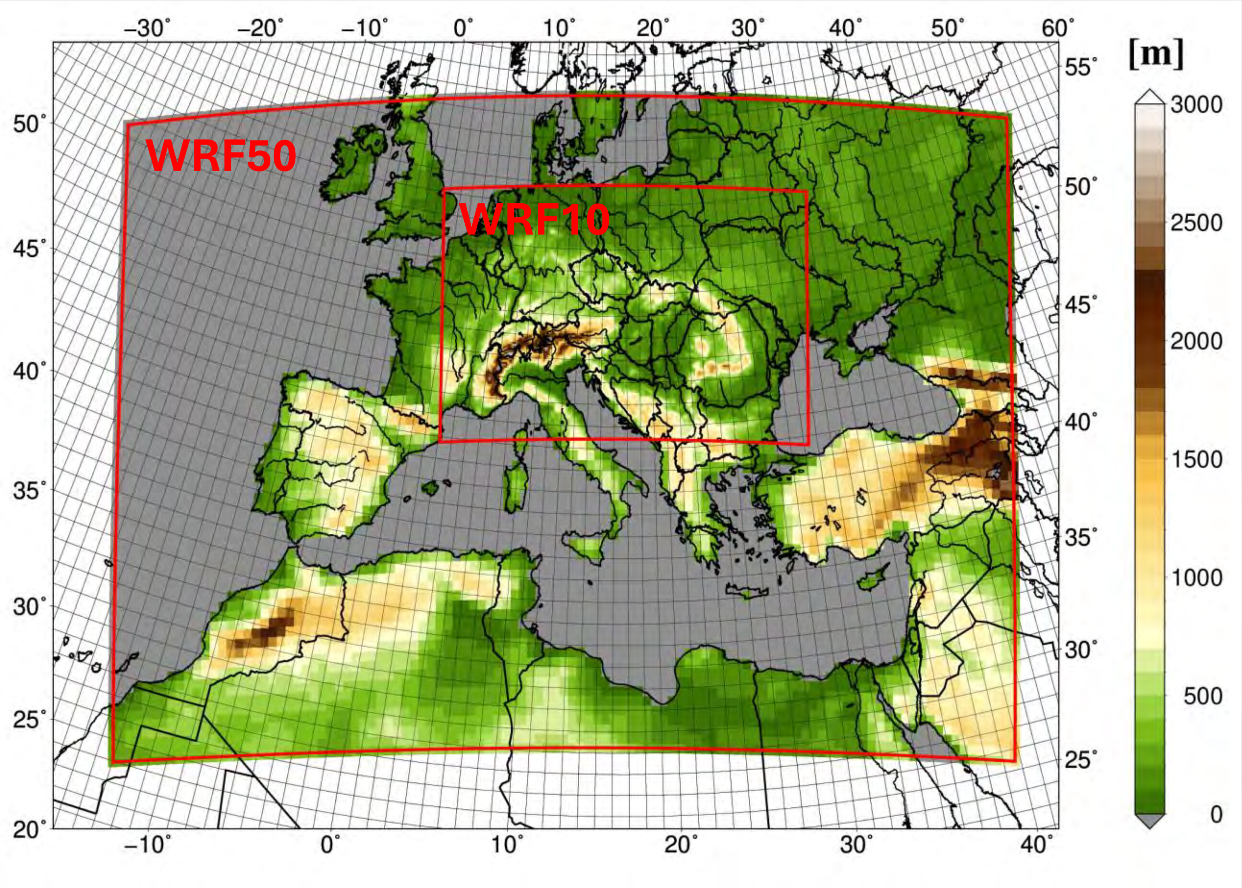


Validation run – Model settings

- WRFv4.2
- Δx=50 and 10 km (**WRF50**, **WRF10**)
- One-way nesting
- Med-CORDEX domain
- Lambert Conformal Conic projection
- Period: 1985–2010
- ERA5 initial and boundary conditions (Δϕ=0.25°, 29 pressure levels)
- 61 σ–p model levels, model top at 50 hPa



Distribution of vertical model levels



Model domains and height above sea level

Validation run – Observational data

Surface-based gridded observations

- E-OBS (v26.0e) – 0.1° (≈10 km)
- CARPATCLIM – 0.1° (≈10 km)
- APGD (EURO4M) – 5 km
- HISTALP – 0.083° (≈8 km)

Satellite-based precipitation datasets

- CMORPH – 8 km
- GPM IMERG – 0.1° (≈10 km)
- PERSIANN-CDR – 0.25° (≈25 km)
- TRMM TMPA – 0.25° (≈25 km)
- CHIRPS – 0.05° (≈5 km)

Reanalysis products

- ERA5 – 0.25° (≈25 km)
- ERA5-Land – 0.1° (≈10 km)

Station measurements

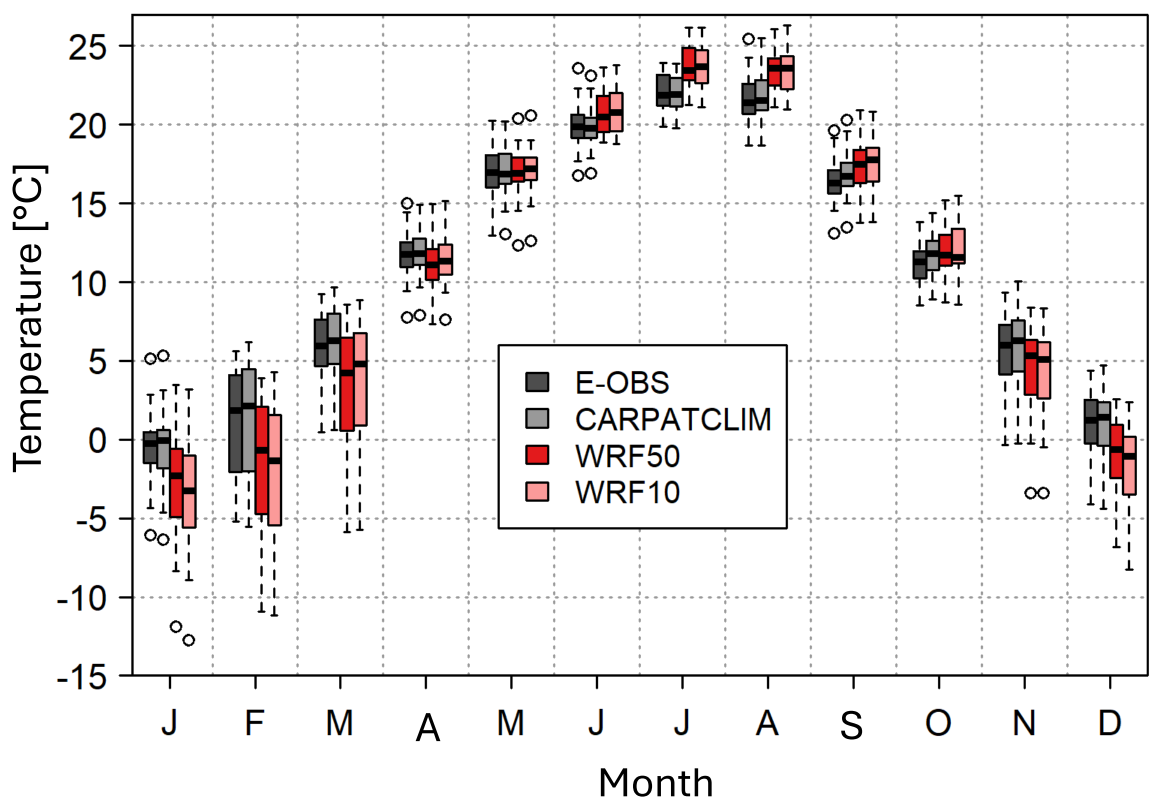
- Snow depth (NOAA ISD)
- Radiosonde data (University of Wyoming)

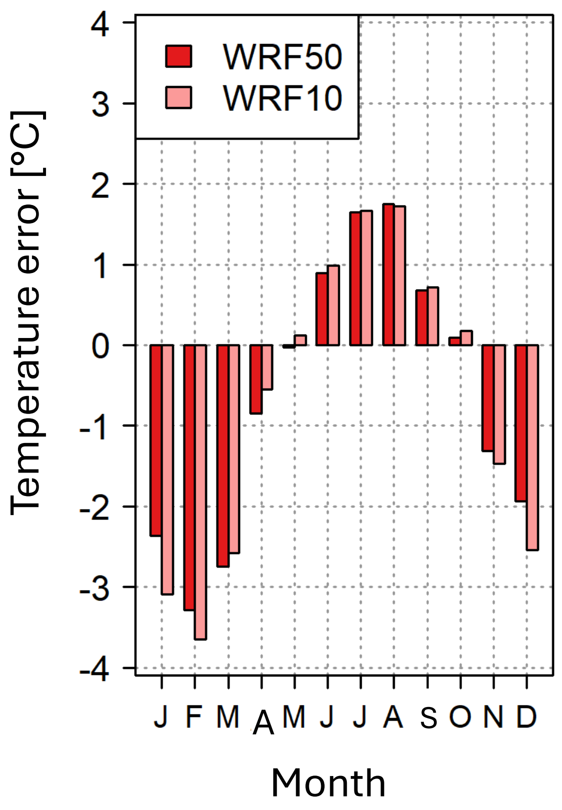
Other datasets

- Soil moisture (ESA CCI SM, GLDAS, GLEAM, SoMo.ml-EU)
- Satellite radiation fluxes (GEWEX SRB, CERES EBAF)

Validation run – Temperature

(1985–2010, spatial averages for the lowland area)



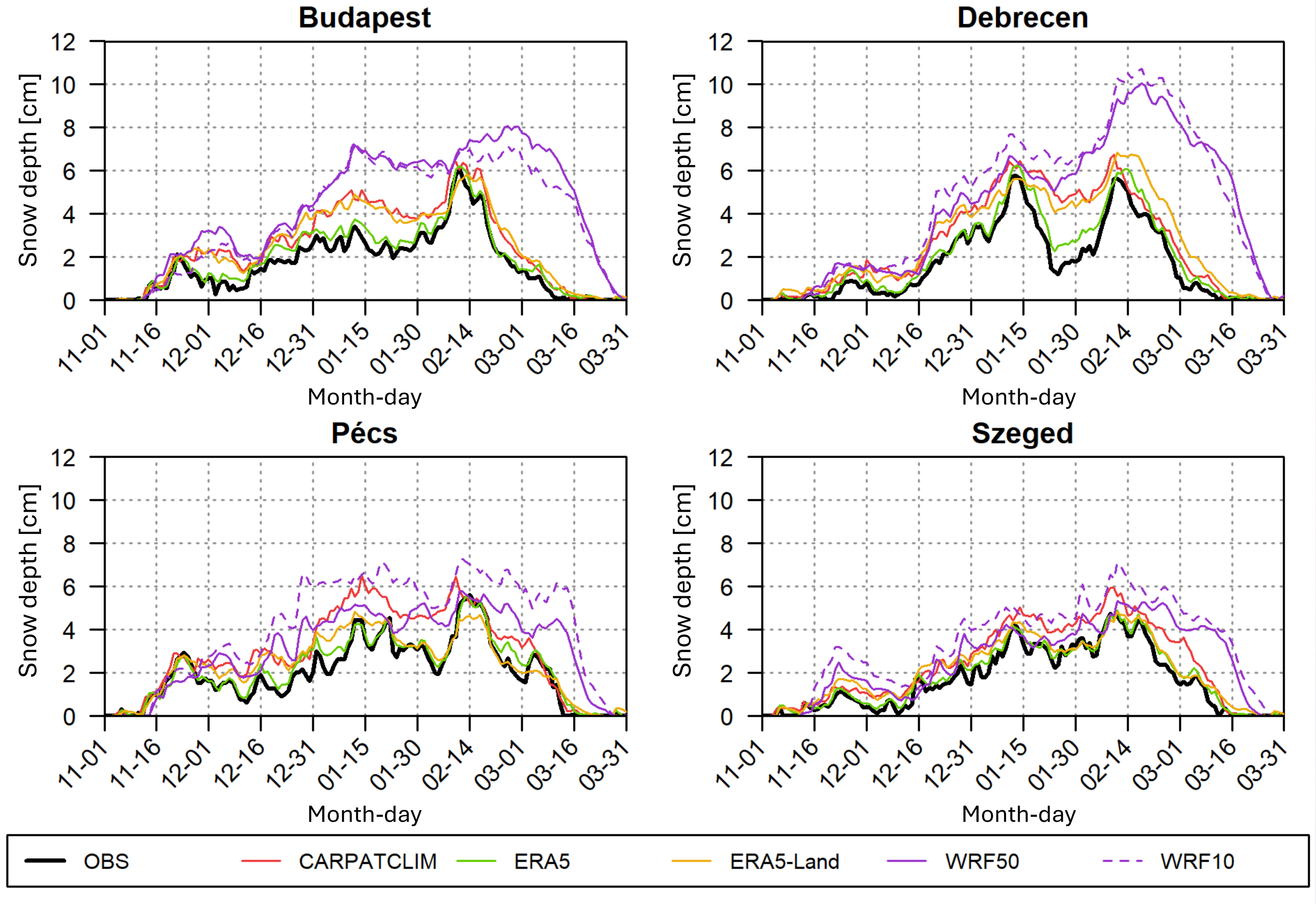


Monthly mean temperatures, including variability across the 26-year period

Monthly mean temperature errors relative to the CARPATCLIM dataset

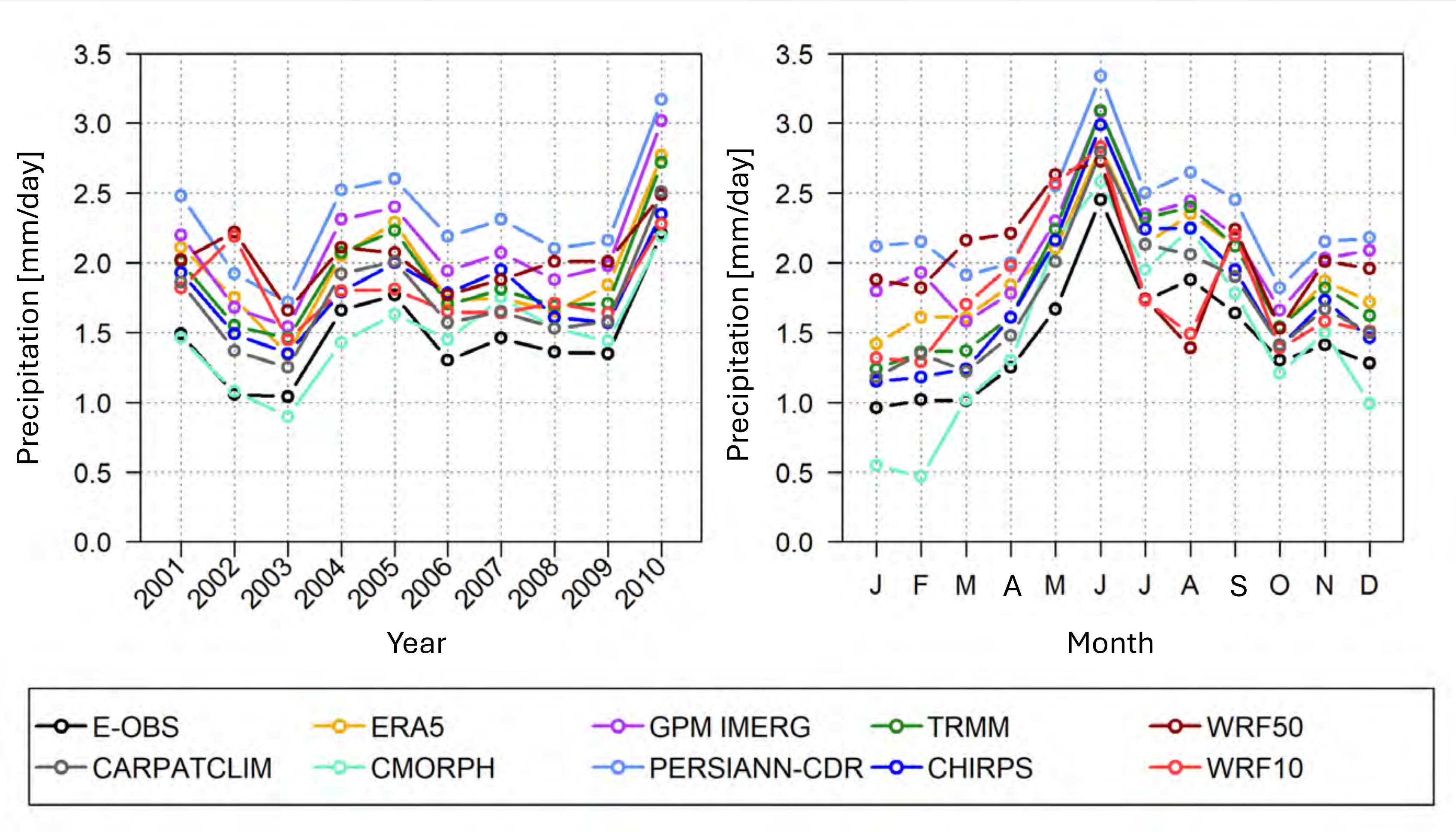
Validation run – Snow depth

(1985–2010, model data from the nearest grid point)



Validation run – Precipitation I.

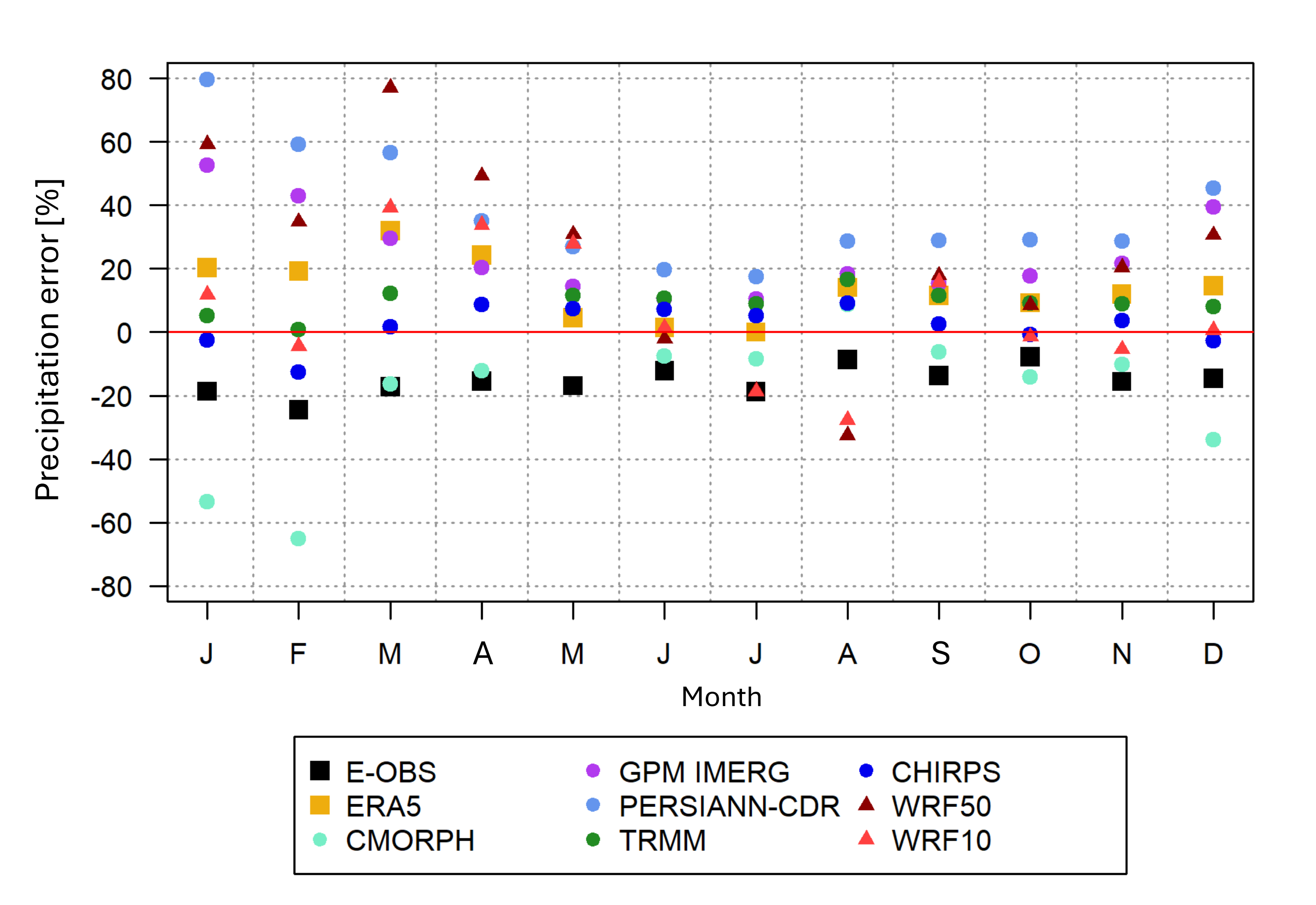
(2001–2010, spatial averages for the lowland area)



Annual and monthly mean precipitation

Validation run – Precipitation II.

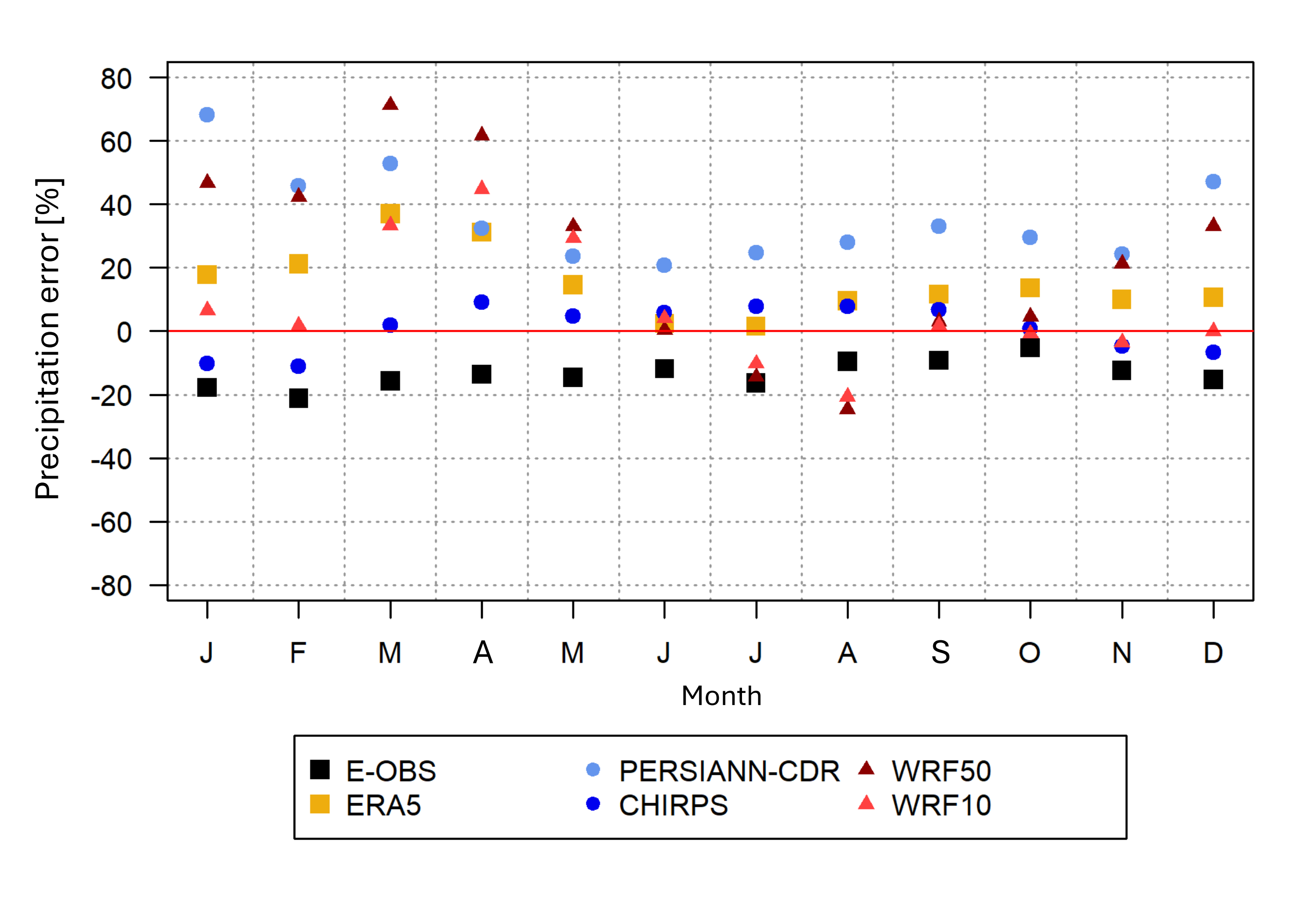
(2001–2010, spatial averages for the lowland area)



Monthly mean precipitation relative errors with respect to the CARPATCLIM dataset

Validation run – Precipitation III.

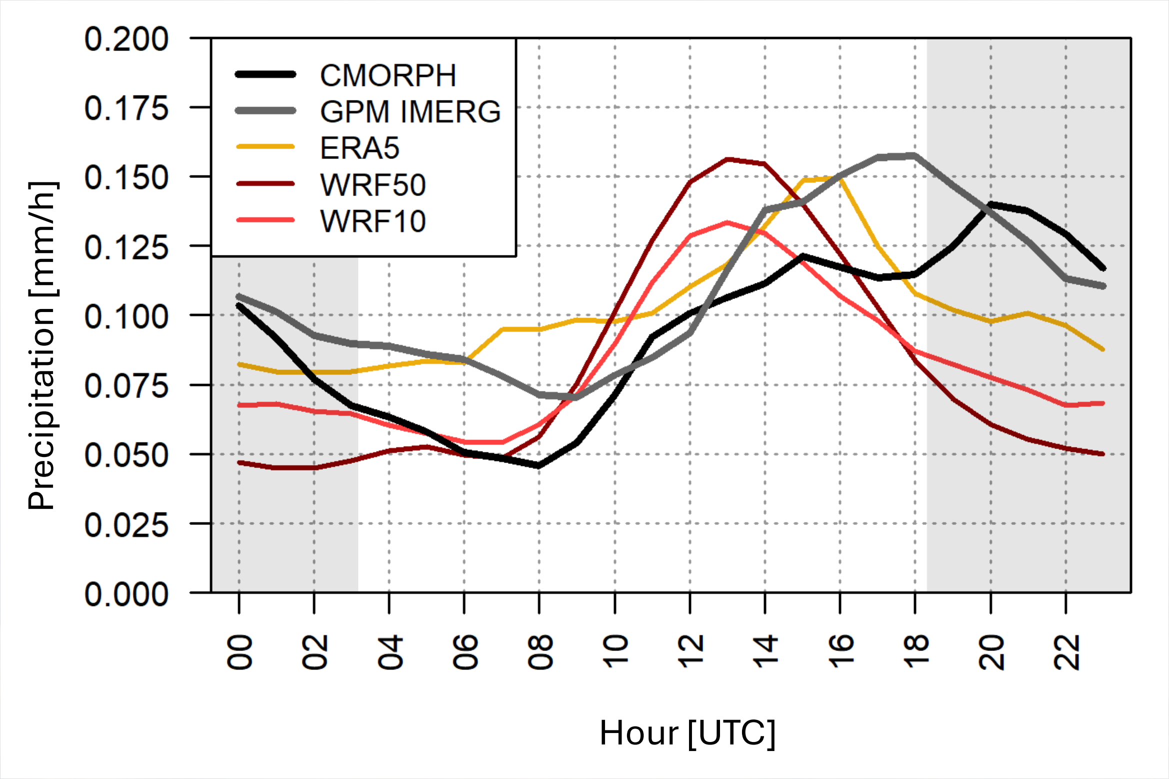
(1985–2010, spatial averages for the lowland area)



Monthly mean precipitation relative errors with respect to the CARPATCLIM dataset

Validation run – Precipitation IV.

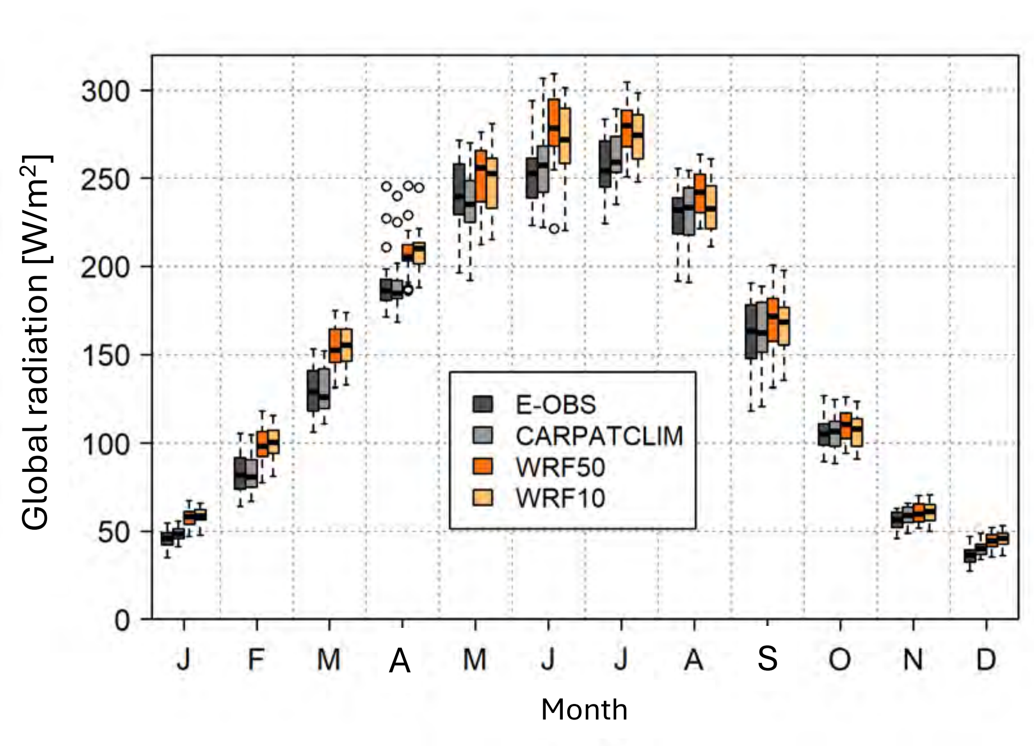
(2001–2010, spatial averages for the lowland area)



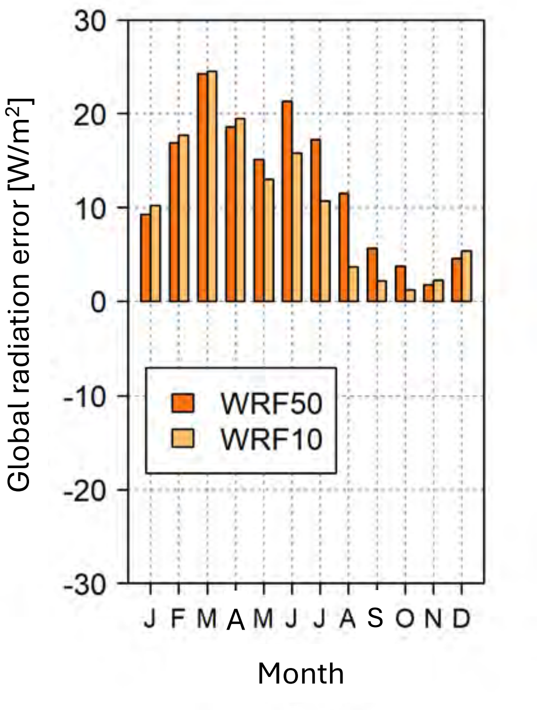
Average diurnal cycle of summer (JJA) precipitation

Validation run – Global radiation

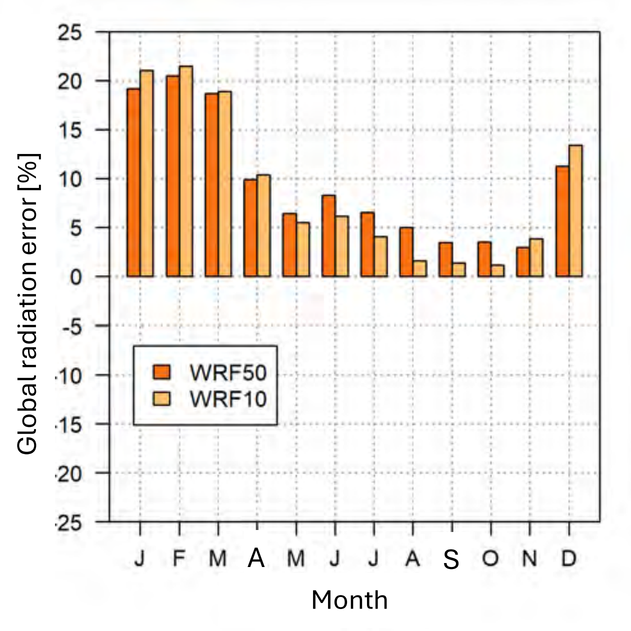
(1985–2010, spatial averages for the lowland area)



Monthly mean global radiation values, including variability across the 26-year period



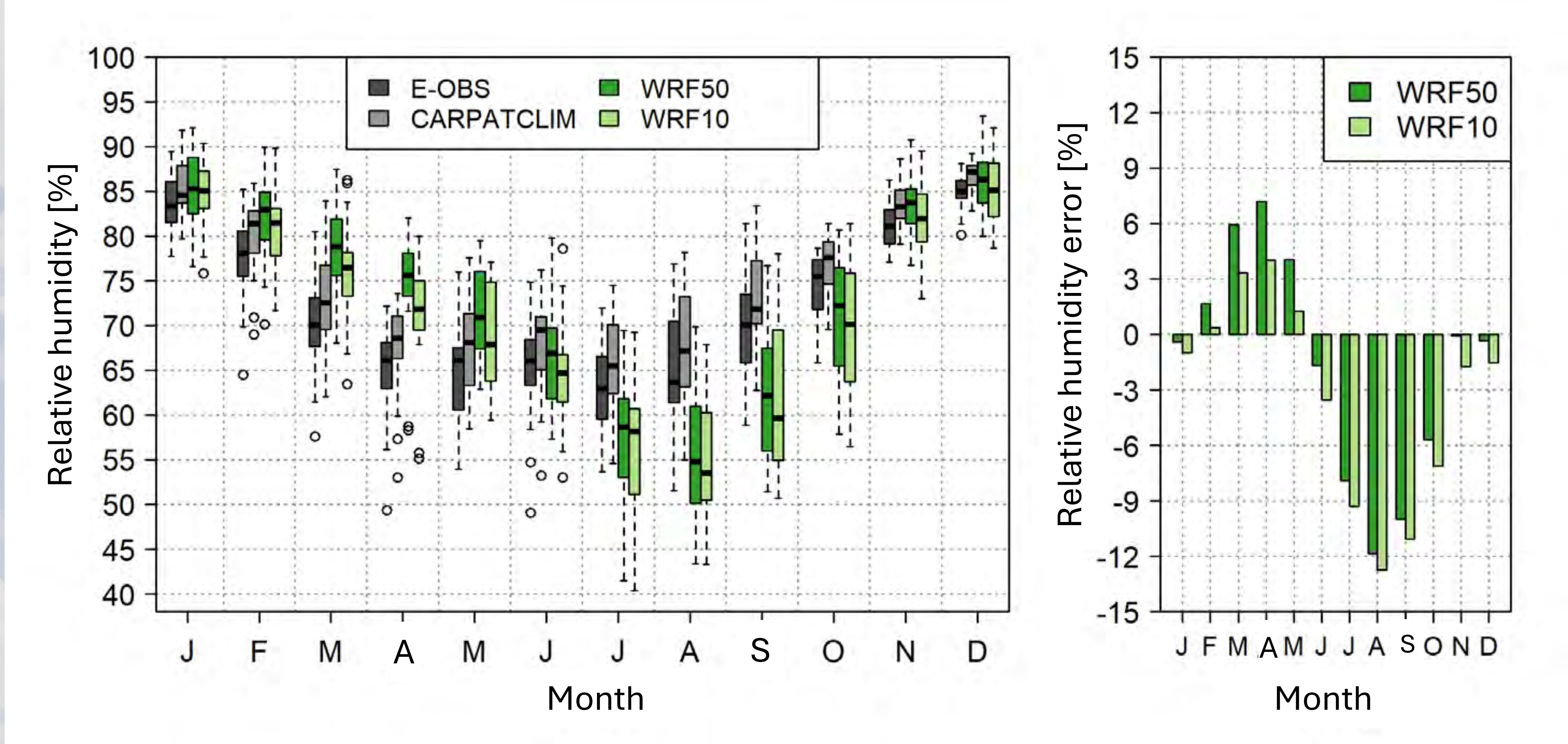
Monthly mean global radiation errors with respect to the CARPATCLIM dataset



Monthly mean global radiation **relative** errors with respect to the CARPATCLIM dataset

Validation run – Relative humidity

(1985–2010, spatial averages for the lowland area)

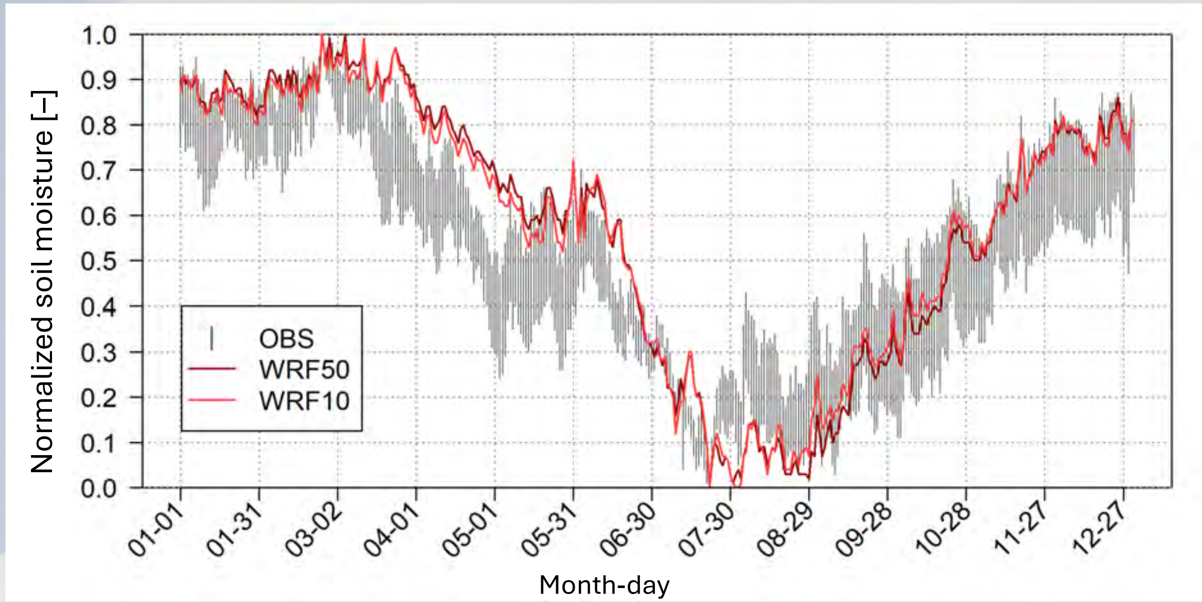


Monthly mean relative humidities, including variability across the 26-year period

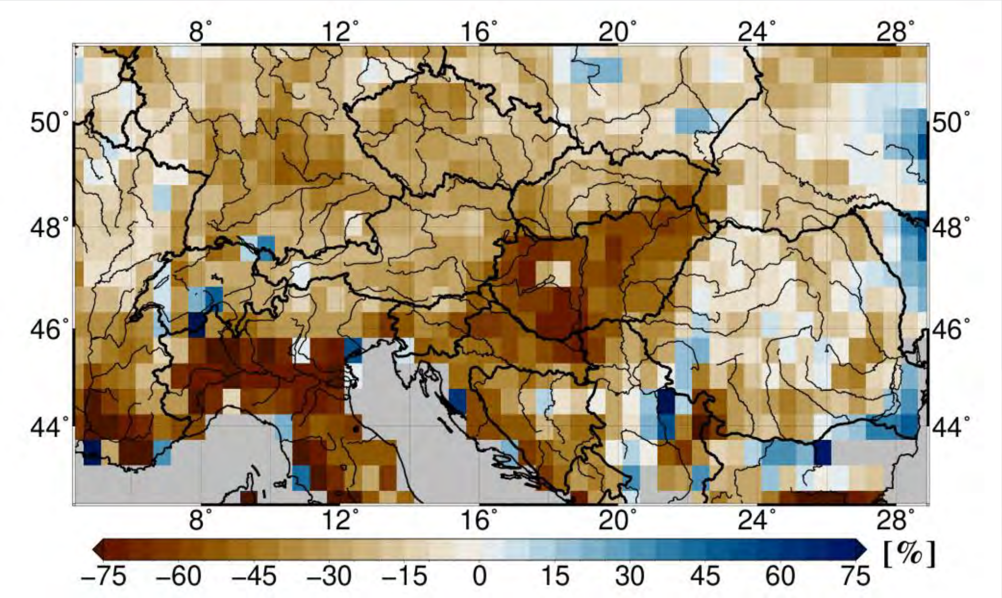
Monthly mean relative humidity errors with respect to the CARPATCLIM dataset

Validation run – Soil moisture

(2003–2010)



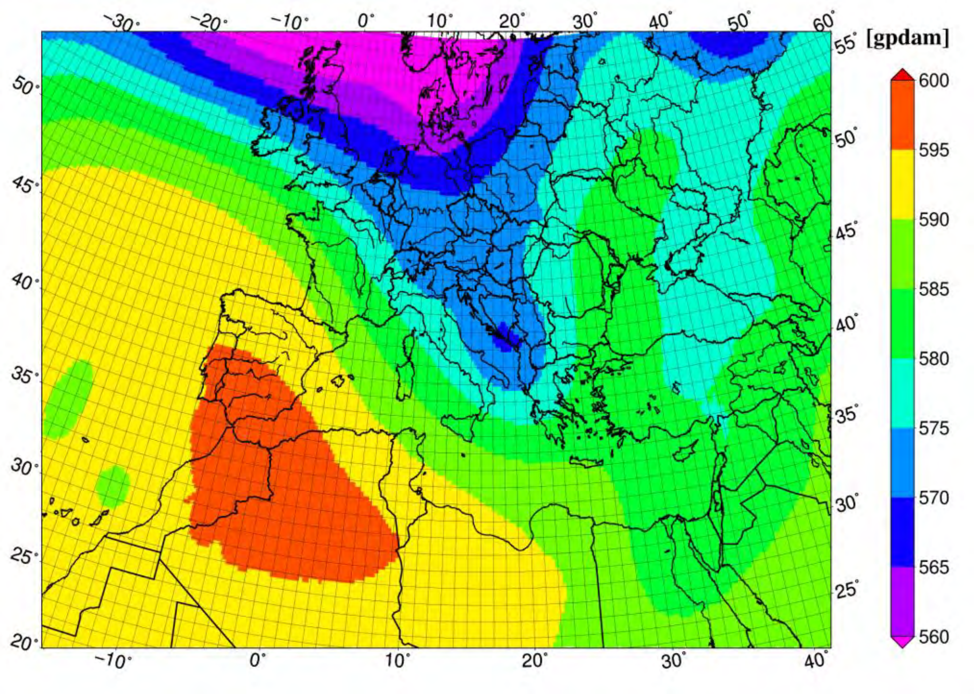
Annual cycle of normalized soil moisture content (lowland area)



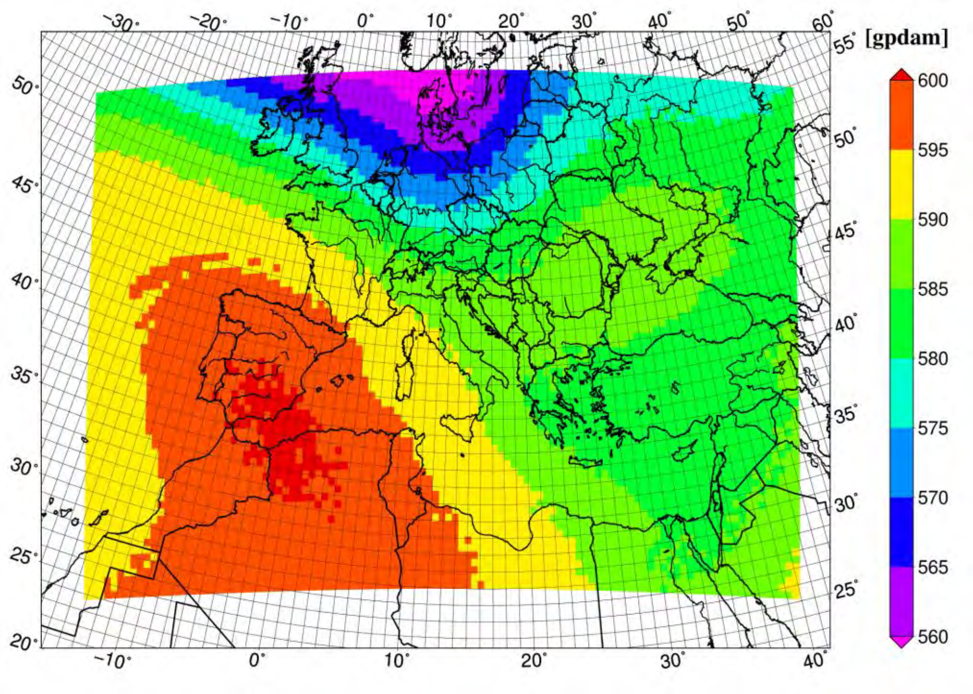
Relative errors of normalized mean soil moisture from WRF10 compared to the ESA CCI SM dataset for August

Validation run – Circulation patterns

- In summer, the general circulation in the WRF model is often modified relative to the driving reanalysis
- Specific synoptic patterns are missed, zonal winds are too strong, and upper-level ridges are overly pronounced



ERA5



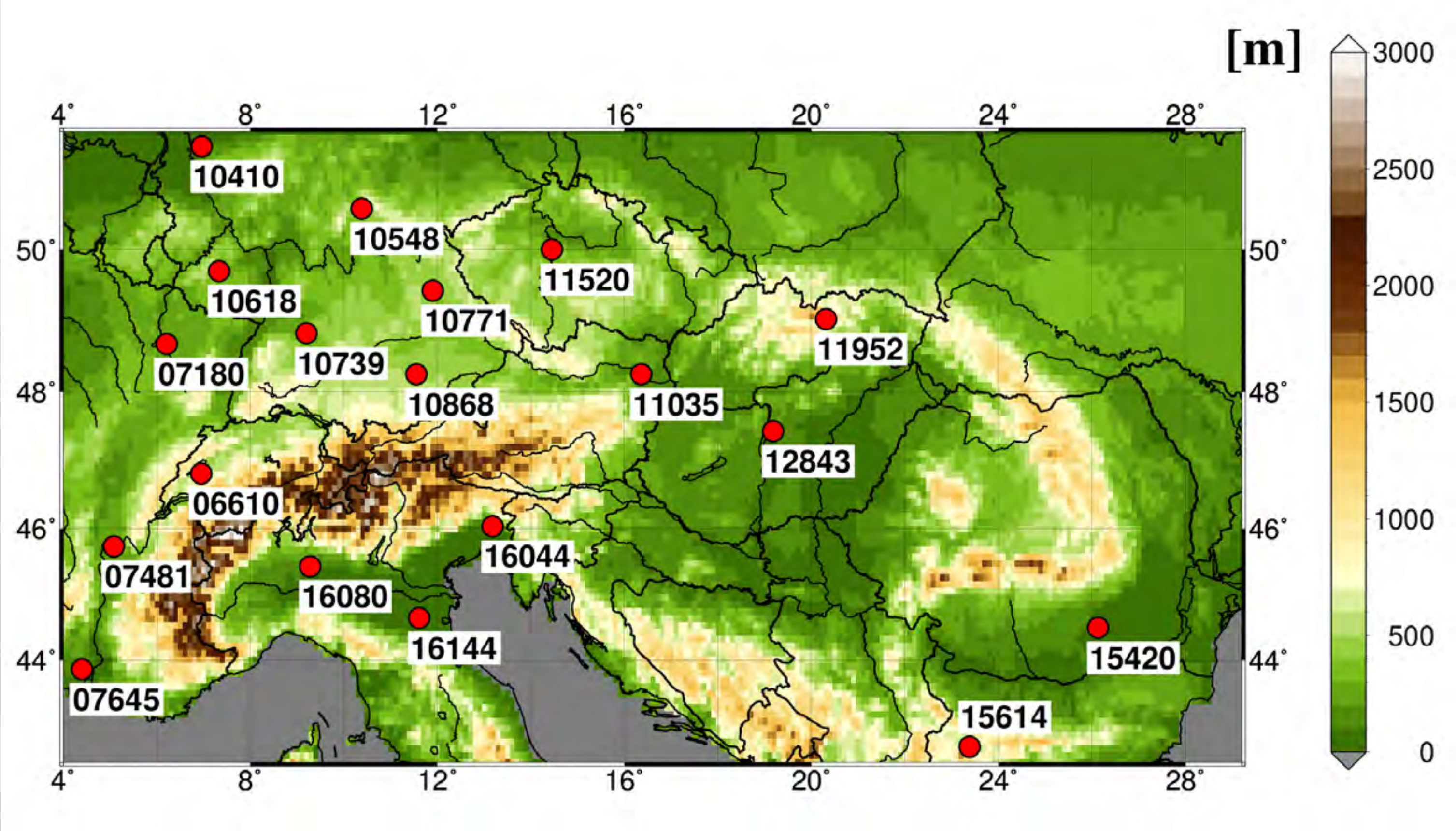
WRF50

Example case: 500 hPa geopotential height from ERA5 (left) and WRF50 (right), at 12 UTC on 4 August 2005

Validation run – Convective parameters I.

(1985–2010)

- Computation of variables characterizing the convective environment from radiosonde measurements and simulated profiles (ERA5, WRF)
- Reference: 12 UTC observations from 19 sounding stations in Central and Eastern Europe
- Strict quality control criteria for measured profiles and computed parameters



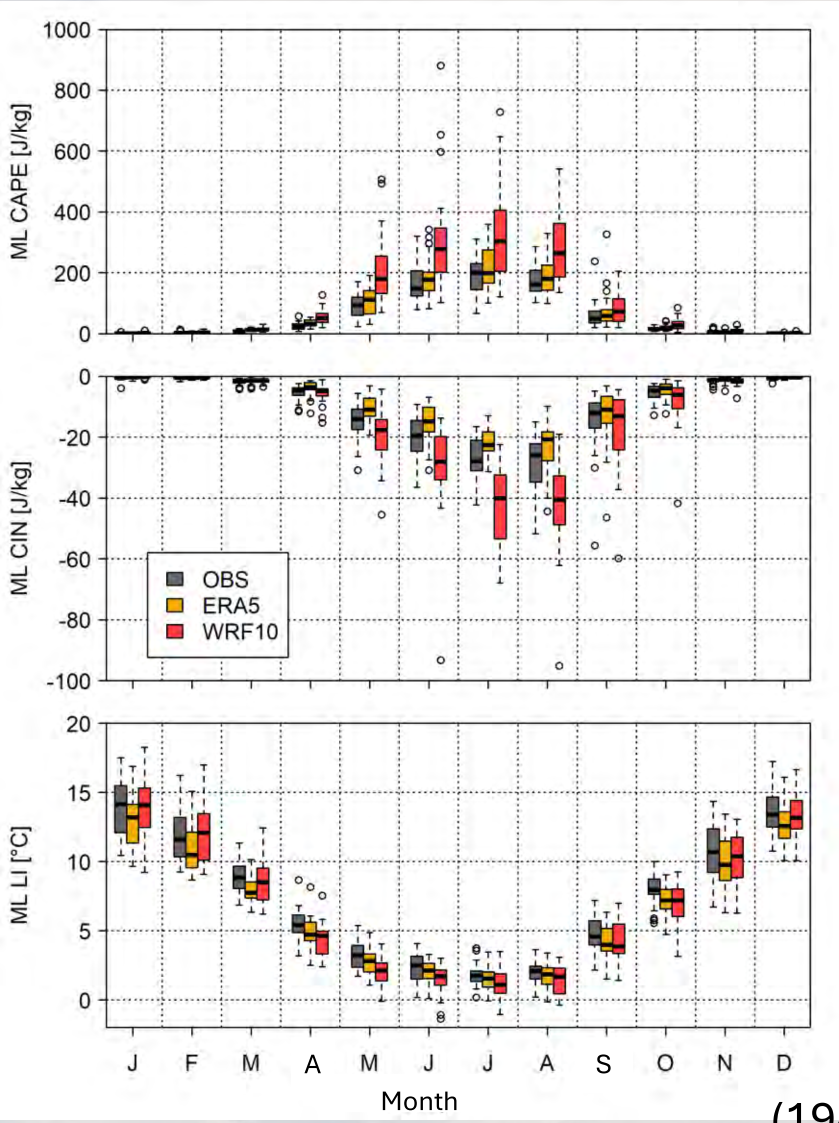
WMO identifiers of the synoptic stations used in the analysis

Validation run – Convective parameters II.

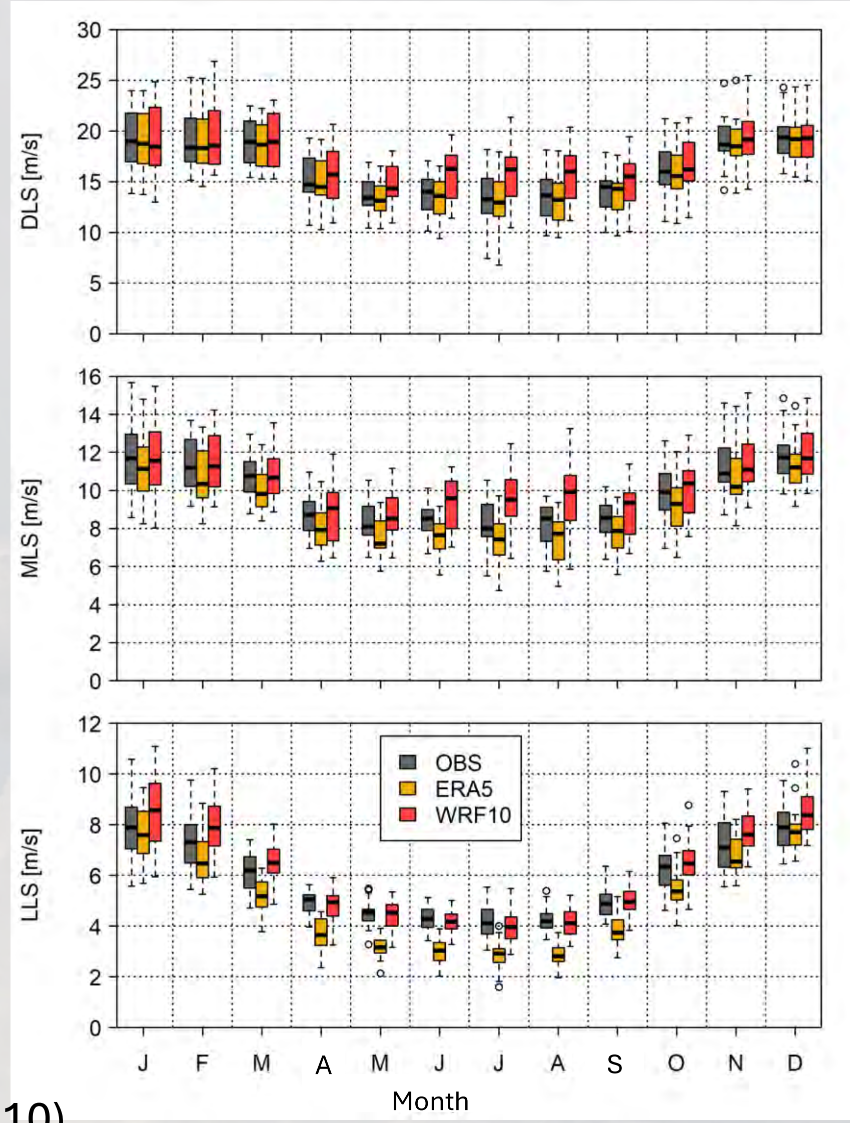
Convective Available Potential Energy

Convective Inhibition

Lifted Index



(1985–2010)



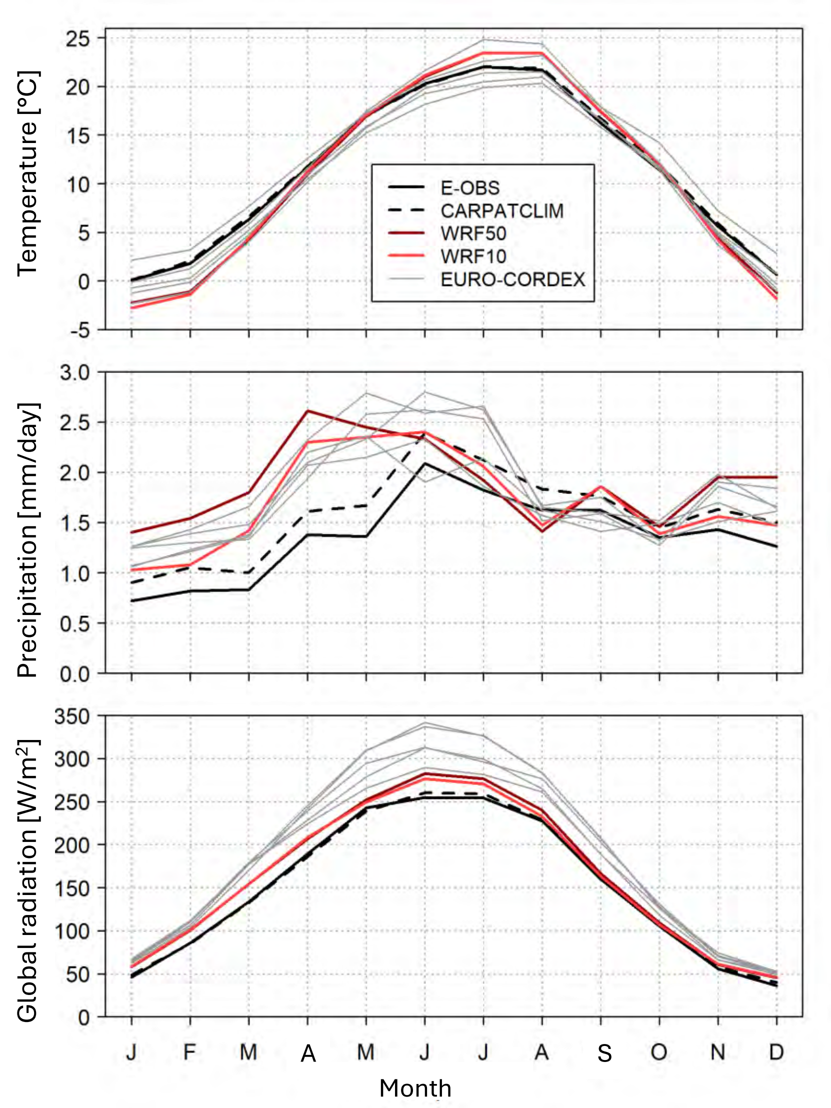
Deep-layer (0–6 km) wind shear

Mid-level (0–3 km) wind shear

Low-level (0–1 km) wind shear

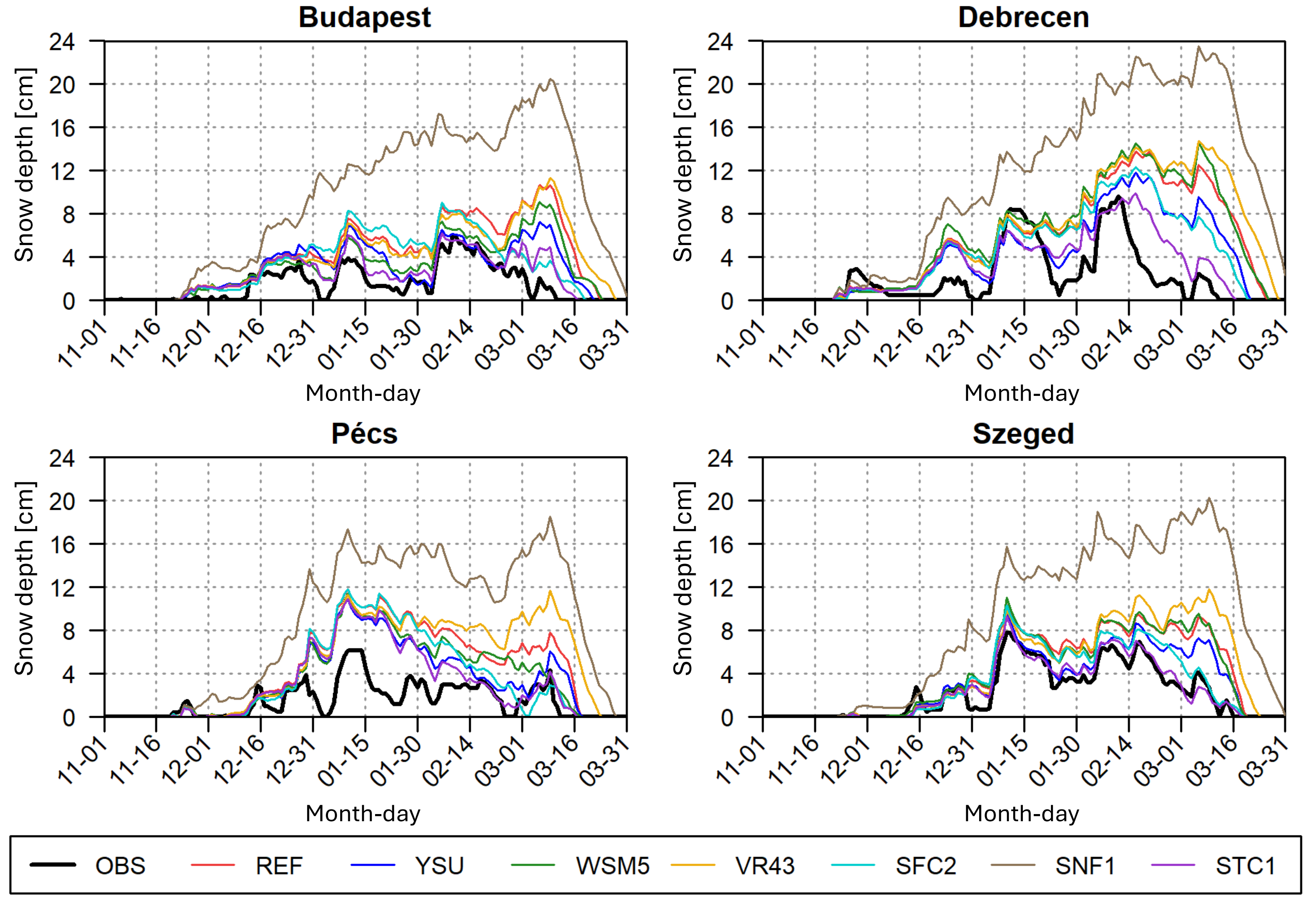
Validation run – Comparison with EURO-CORDEX model results

- 1989–2008 period
- Spatial averages (lowland area)
- EURO-CORDEX WRF simulations (using ERA-Interim initial and boundary conditions, with varying grid spacing and physical parameterizations)



Sensitivity analysis of snow depth I.

(2001–2006, model data from the nearest grid point)



(Δx=10 km, ERA5 ICBCs)

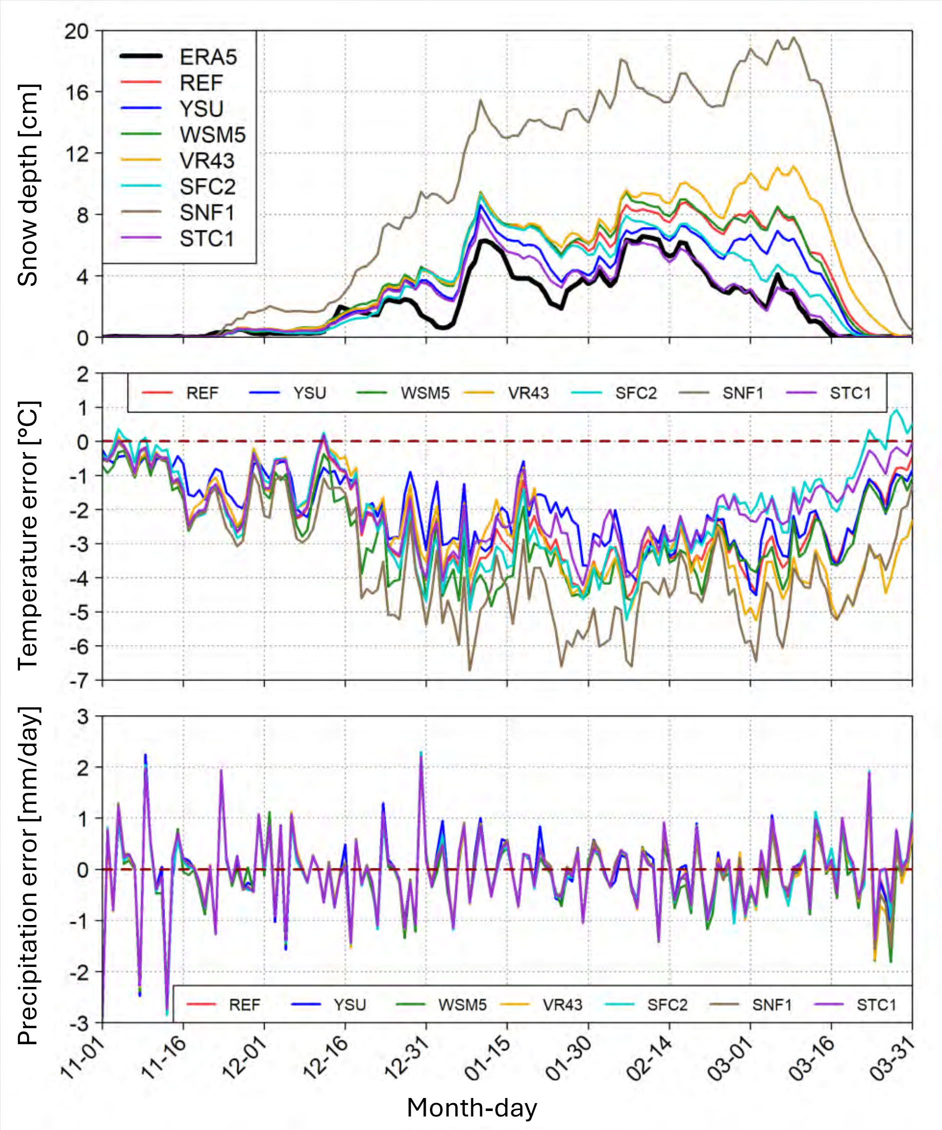
Sensitivity analysis of snow depth II.

(2001–2006)

Daily mean snow depth:
ERA5 vs. seven WRF simulations

Daily mean temperature errors
(reference: CARPATCLIM)

Daily precipitation errors
(reference: CARPATCLIM)



(Spatial averages for the lowland area, Δx=10 km, ERA5 ICBCs)

Future outlook

- In progress: GCM-driven historical and near-future simulations using the MPI-ESM1-2-LR model with the SSP585 scenario (CMIP6)
- A detailed investigation of land-surface interactions during the summer is required
- Longer-term plans: refining the horizontal resolution to convection-permitting scales (preliminary tests are in progress)

Thank you for your attention!

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