Climate Scenarios on a regional scale – Looking for an UHI ‘forecasting model’

Joachim Fallmann, Sven Wagner
Institute for Meteorology and Climate Research (IMK-IFU) of the Karlsruhe Institute of Technology (KIT), Campus Alpine, Germany

Structuring

- The meaning of ‘Forecasting Model’; What is possible?
- Presentation of a case study
- WRF-Model as modeling tool
- Projected climate change for certain project regions
- Regional climate modeling results for Germany
- Comparison with results from ENSEMBLES project

Joachim Fallmann
joachim.fallmann@kit.edu

Forecasting Model ?

Forecast

Climate Scenario

vs.

2 different methods?

What is possible ??

Accurate Near Real Time Prediction

Future trends based on assumptions

Joachim Fallmann
joachim.fallmann@kit.edu

Approach to the project-target…

- Scientific Aspects → Impacts of strategies on Urban Heat Island formation; application on project regions
  - understanding of **feedback-mechanisms**
  - Understanding the relevant **Meteorology**
- Long-term adaption and mitigation s… …ed on model results
  - Urban planning
  - Political measures
  - Arising public awaren…
  - Economic quest…
  - Energy Pol…
  - Contact with … …akeholders
- Downscaling to city, quarter or street scale ?
  - Inner-city air quality problems
  - Health impacts due to air quality and temperature
  - 'Near real time' predictions (heat waves…)

Which results are needed and how should they be used ??

Joachim Fallmann
joachim.fallmann@kit.edu

KIT offers…

Karlsruhe Institute of Technology

High resolution climate modeling (for Germany) using WRF;

(WAGNER 2012 →submitted)

-

Result of the CEDIM-project (Center for Disaster Management and Risk Reduction Technology - KIT):

”Flood risk in a changing climate”

CEDIM

Joachim Fallmann
joachim.fallmann@kit.edu
CENTRAL EUROPE COOPERATING FOR SUCCESS.
EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

Background

Karlsruhe Institute of Technology

IPCC fourth assessment report (AR4)

- Increase of mean annual temperature in Europe due to climate change
- Increase in precipitation in northern-, decrease in southern regions
- **Central Europe**: precipitation increase in winter; decrease in summer
- Extreme precipitation events recurrence frequency 'very likely to increase'
- Extreme heat events 'very likely to increase'

→ Low spatial resolutions leave room for variability (especially for P)

→ Spatial and temporal high resolved climate models essential input for climate impact studies

→ Uncertainties through different global climate models, regionalization techniques, model type, model setup

➡ multi model ensemble of dynamically downscaled climate simulations

Joachim Fallmann
joachim.fallmann@kit.edu
CENTRAL EUROPE COOPERATING FOR SUCCESS.
EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

Overview

- General Circulation Model (GCM) simulate global climate forced by emission scenario A1B → resolution > 100km
  - ECHAM 5: Model of MPI-M Hamburg, modifying of global forecast models developed by ECMWF; MPIOM (MPI Ocean Model) model resolves atmosphere up to 10hPa (30km) for tropospheric studies (documentation: http://www.mpimet.mpg.de)
- Two Regionalization models: WRF; COSMO CLM (DWD)
- Three runs carried out: WRF past (1971-1990) WRF future (2021-2050); Re-Analysis (ERA40; ECMWF) for validation (WRF driven)

Joachim Fallmann
joachim.fallmann@kit.edu

WRF Model

- Non-hydrostatic, mesoscale numerical weather prediction and atmospheric simulation system
- 'Community' model
- suitable for a broad spectrum of applications across scales (m - 1000km).
- NRT numerical weather prediction, data assimilation, physical research, air quality model, regional climate simulations etc..
- real data or idealized configurations
- WRF/chem, WRF Fire, WRF VAR, Global WRF etc.
- Worldwide community → 136 foreign countries
- Registered users (Sept. 2011): 17610
- http://www.wrf-model.org/index.php

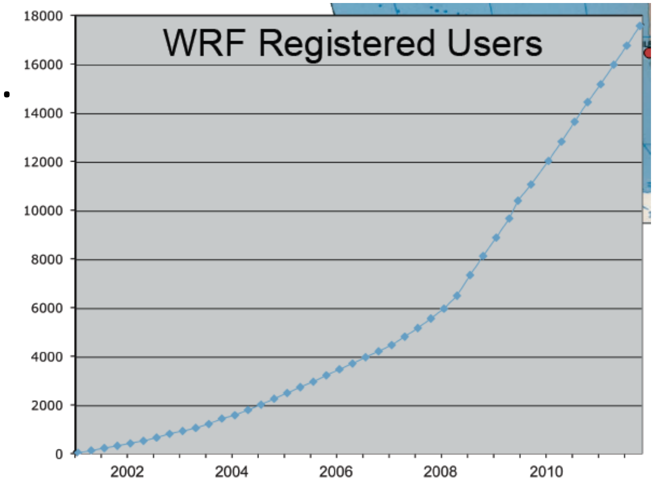


Fig 1: Klemp, 2011

Joachim Fallmann
joachim.fallmann@kit.edu

Setup

- 7km for Germany for 1971-2000 and 2021-2050 (plus 3 years spinup)
- Double nest procedure in Lambert Conformal map projection
- First nest: Europe (125x117 grid points) at 42km resolution
- Second nest: Germany and near surroundings (175x175 grid points) → 7km
- 42 vertical levels; up to 2000hPa
- Main physical options:
  - 5-class scheme microphysical parameterizations (cloud particles and precipitation drops)
  - Kain-Fritsch Scheme for cumulus parameterization
  - Noah land surface model (24 classes)
  - Yonsei University Parameterization of planetary boundary layer
  - MM5 short wave radiation scheme
  - Rapid Radiative Transfer Model (RRTM) long wave radiation

Joachim Fallmann
joachim.fallmann@kit.edu

Domains

Karlsruhe Institute of Technology

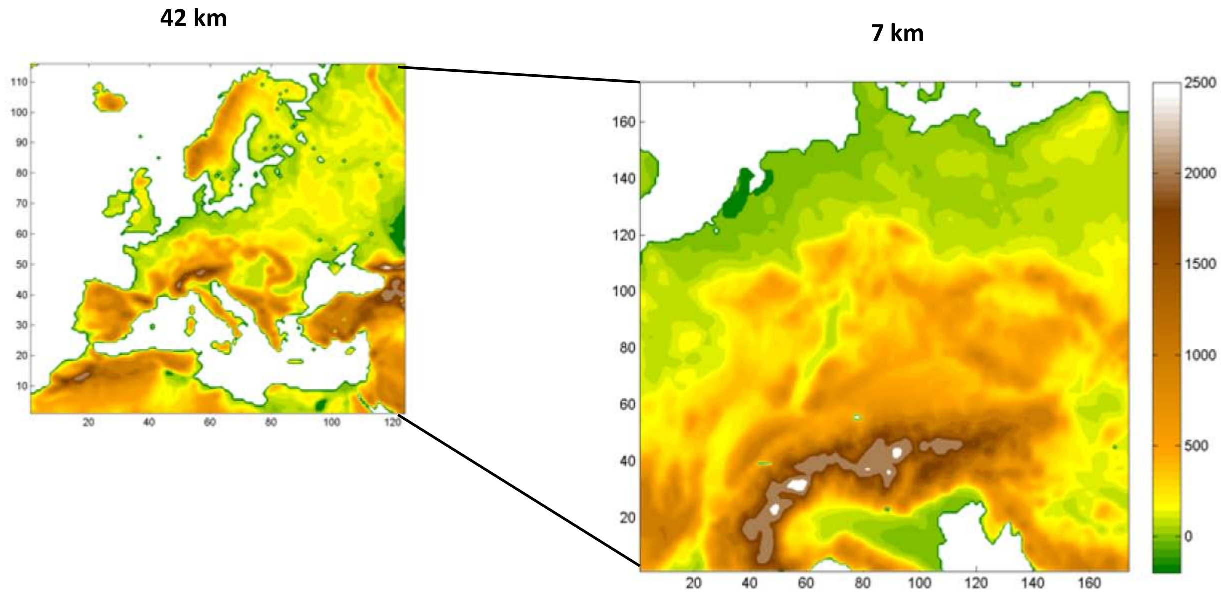


Fig 2: WRF nesting strategy for the regional climate simulations; left: elevation of nest 1 (125 x 117 grid points, 42 km); right: elevation of nest 2 (175 x 175 gridpoints,7km) (Wagner, 2012)

Joachim Fallmann
joachim.fallmann@kit.edu
CENTRAL EUROPE COOPERATING FOR SUCCESS.
EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

Project regions of interest

Karlsruhe Institute of Technology

- One grid cell = 49km²
- Regions: Vienna, Stuttgart, Prague, Modena, Venice, Garmisch-P.
- Grid cell size vs. geographical area
- Goggle Earth calculated urban areas:

City	Area [km²]
Wien	320
Prag	260
Stuttgart	200 (100 inner city)
Modena	35
Venedig	20 (?)
Garmisch	6

Google Earth, GE Path

Joachim Fallmann
joachim.fallmann@kit.edu
CENTRAL EUROPE COOPERATING FOR SUCCESS.
EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

Computing characteristic

- Three different runs:
  - → Over 46 million integration time steps over 614250 grid cells for nest 1
  - → Over 69 million integration time steps on 1286250 grid cells for nest 2

➡ moving to high performance computing environment → NEC Nehalem cluster at HLRS Stuttgart to simulate both nests simultaneously (http://www.hlrs.de/)

- In total 3 month pure computational time for each run
- Additional time for data preparation, model testing etc.
- Preparatory work delivered at IMK-IFU in Garmisch-Partenkirchen to find an optimal setup of WRF before transferring to HLRS
- Changing to NEC Nehalem shows an increased performance of 2.5

➡ real time period for simulations approx. **1 year**

Joachim Fallmann
joachim.fallmann@kit.edu

WRF – Δ 2m Air temperatur (1971-2000 vs. 2021-2050)

Karlsruhe Institute of Technology

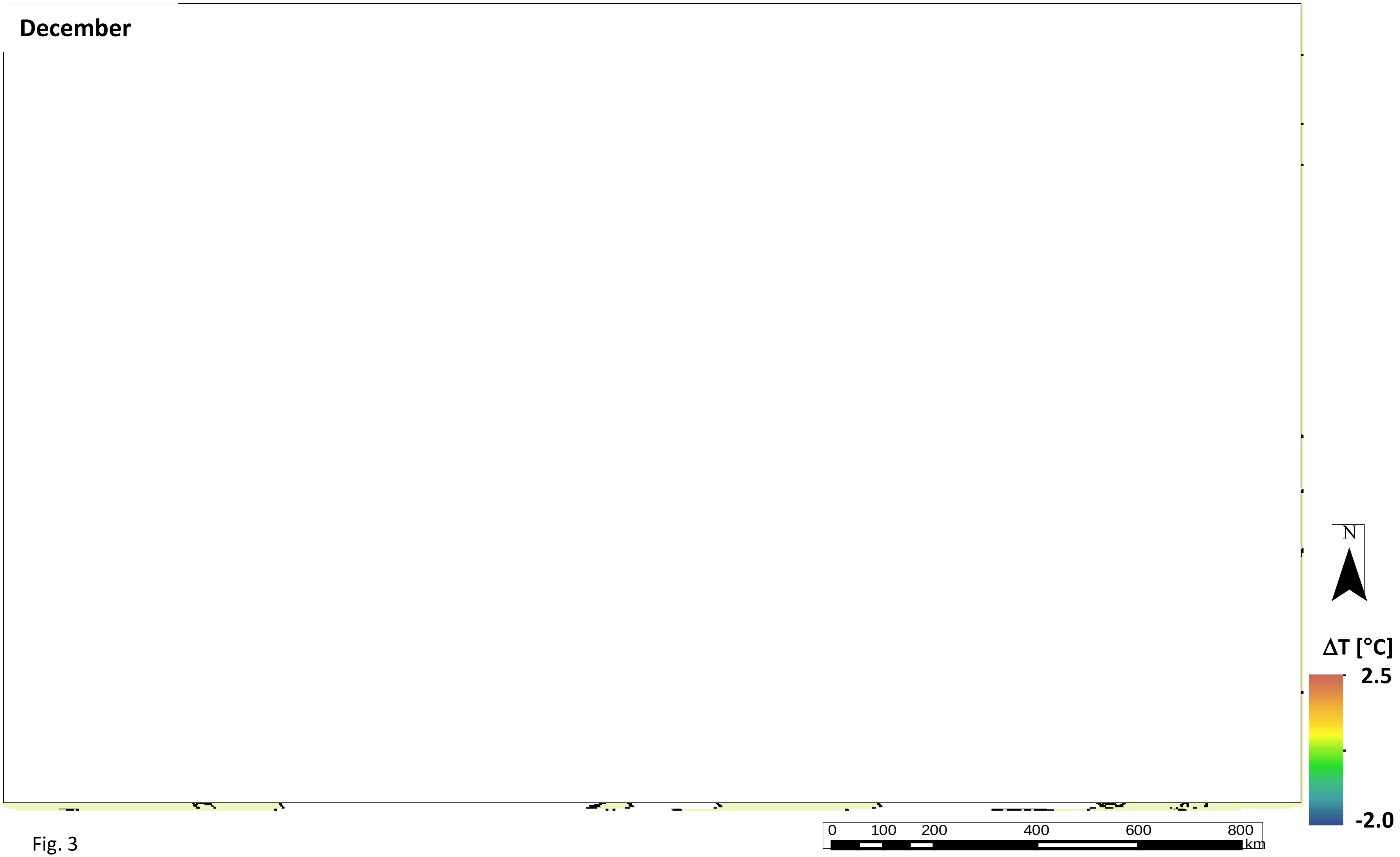


Fig. 3

Joachim Fallmann
joachim.fallmann@kit.edu

CENTRAL EUROPE COOPERATING FOR SUCCESS.
EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

WRF – Δ Precipitation (1971-2000 vs. 2021-2050)

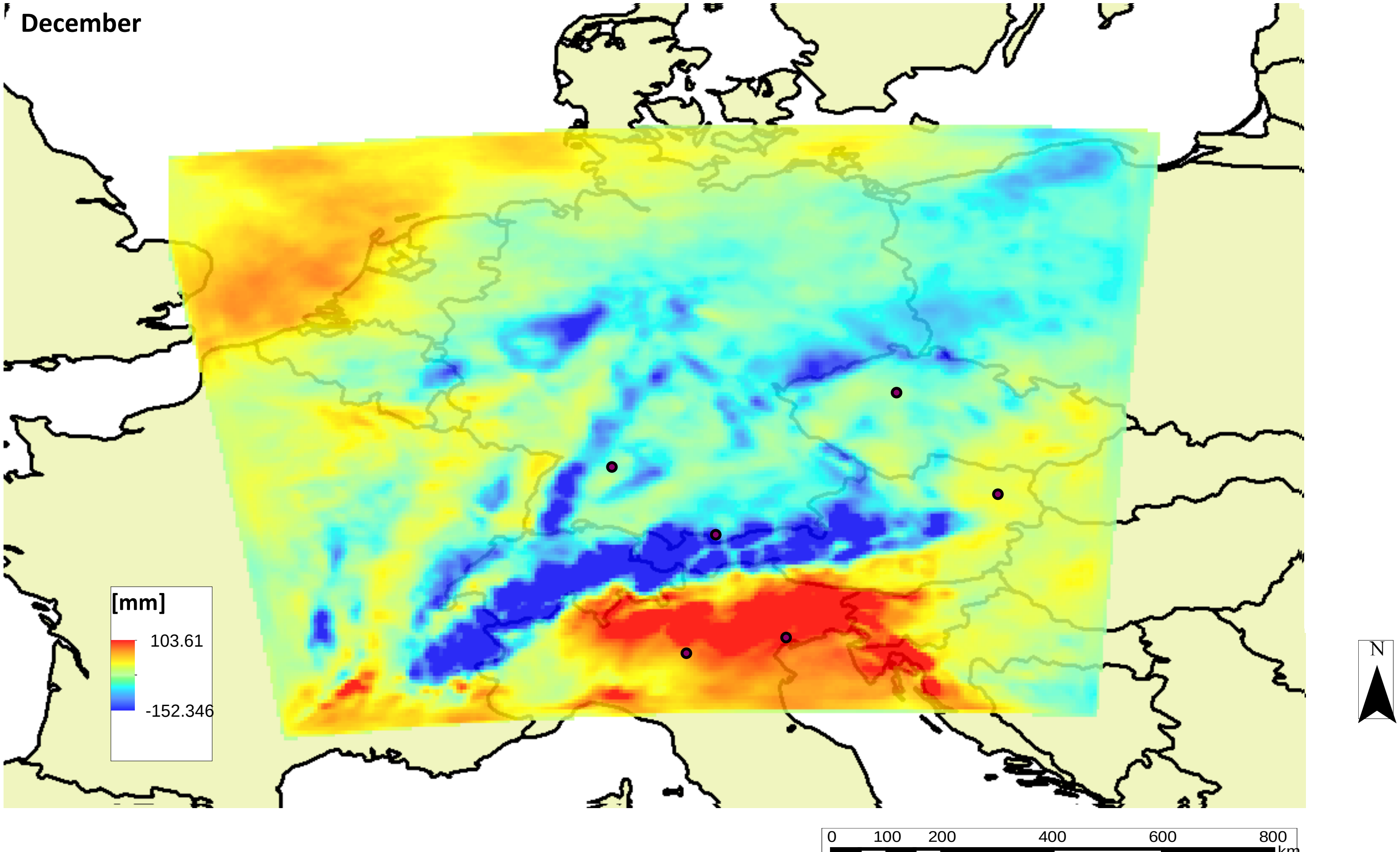
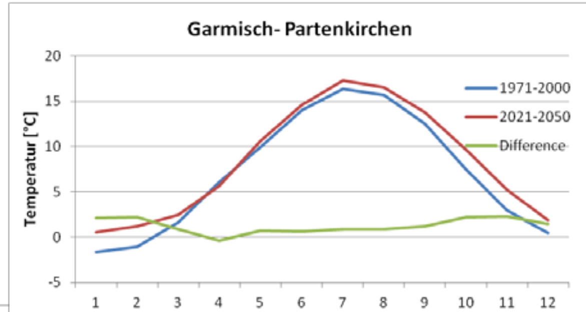
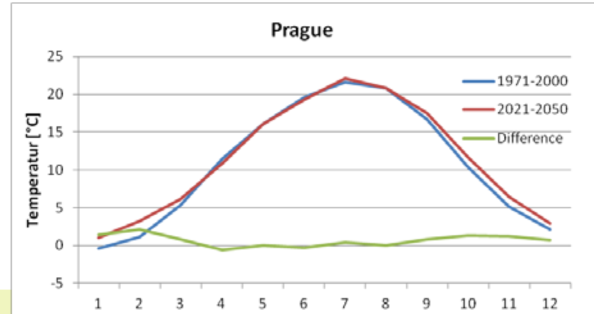


Fig. 4

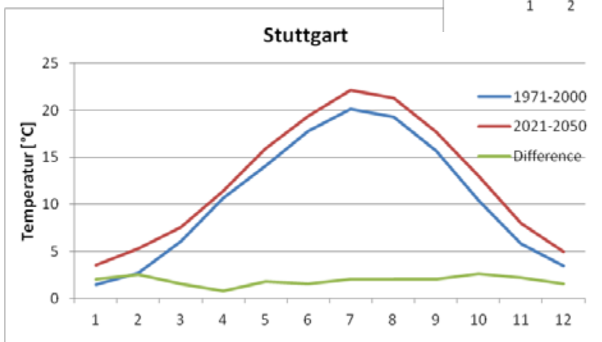
Joachim Fallmann
joachim.fallmann@kit.edu

2m Air Temperature, mean annual variation (7 x 7 km)

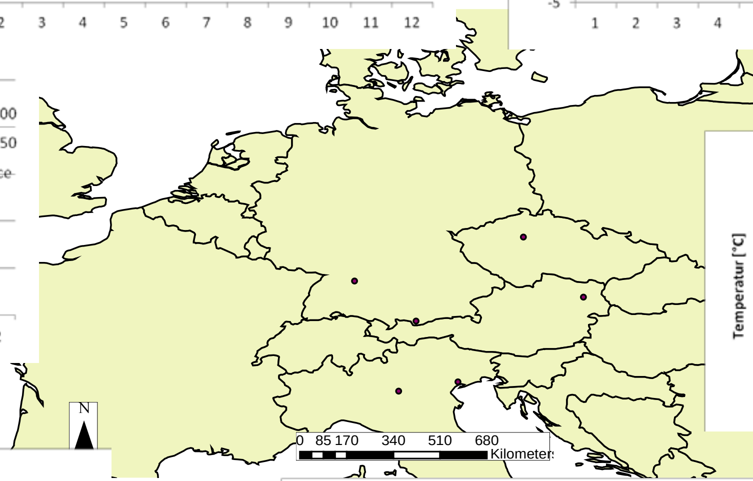


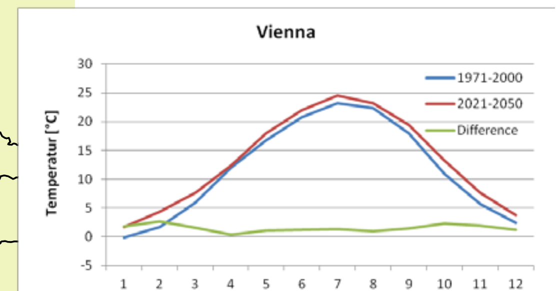


Population: approx. 1.250.000

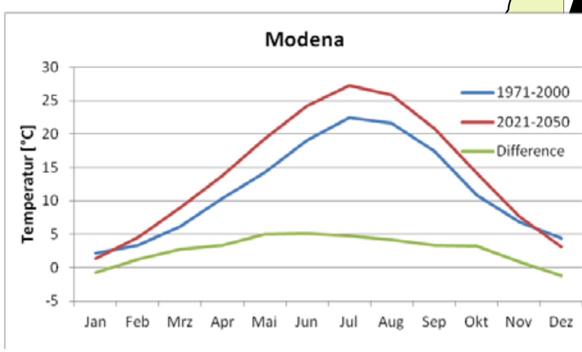


Population: approx. 610.000

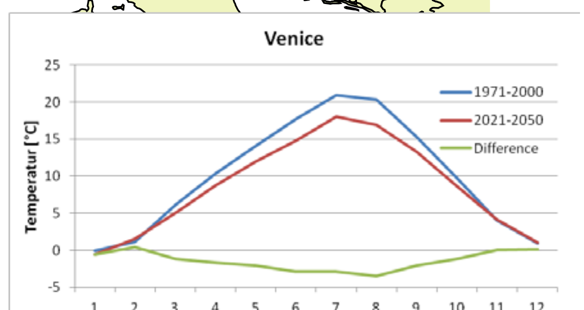




Population: approx. 1.700.000



Emilia Romana: approx. 4.100.000



Population: approx. 280.000

Fig. 5

Joachim Fallmann
joachim.fallmann@kit.edu

Precipitation, mean annual variation

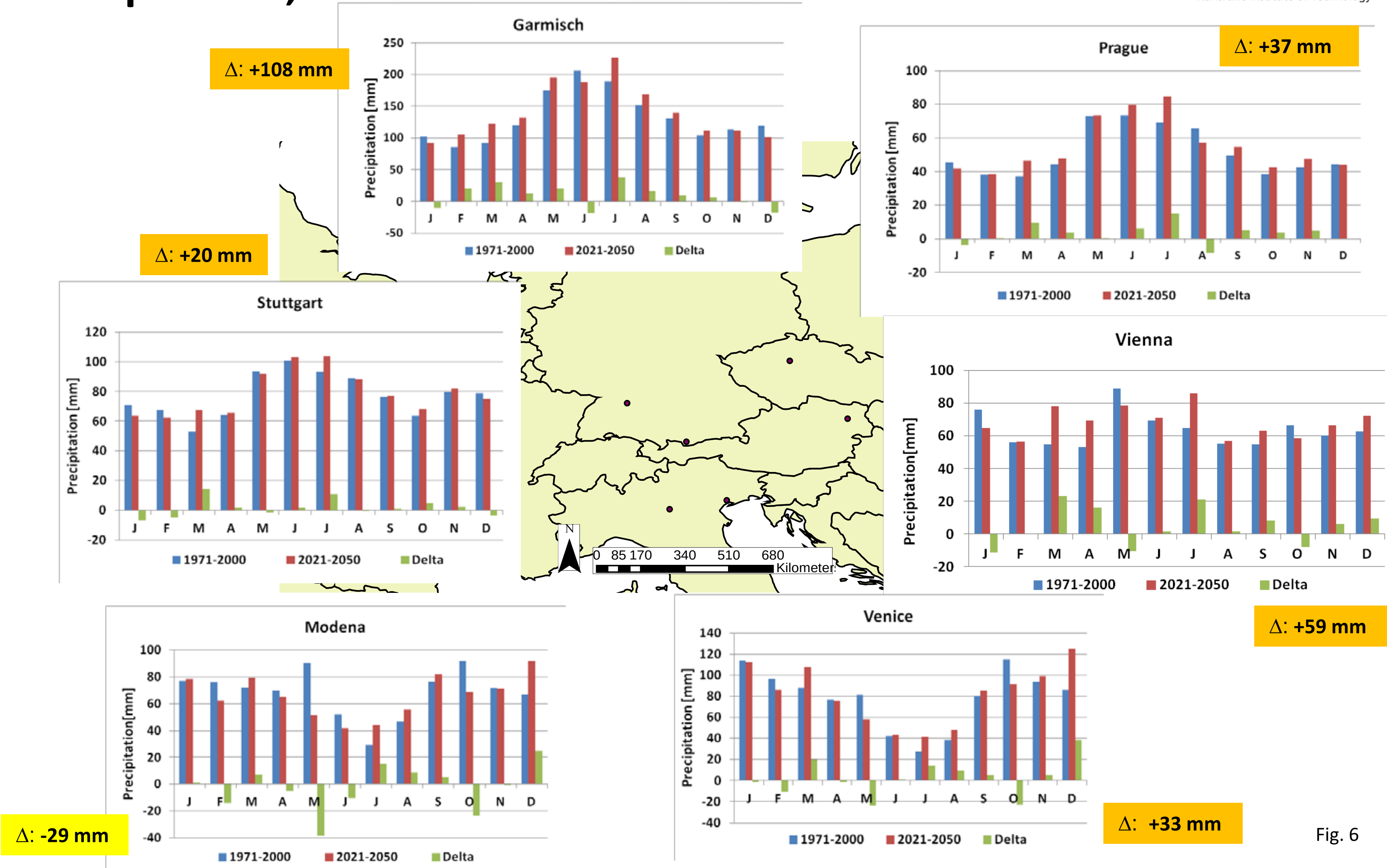
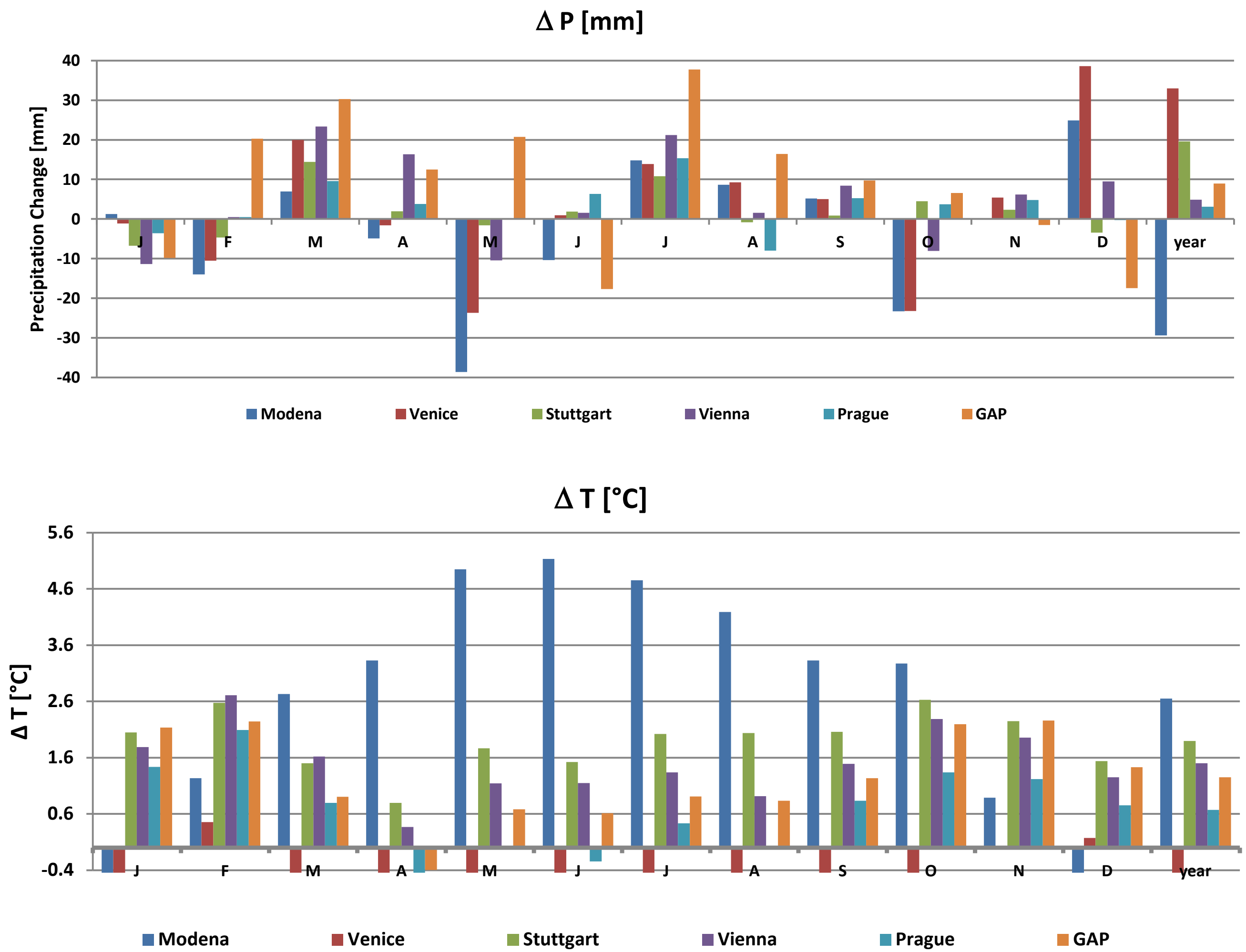


Fig. 6

Joachim Fallmann
joachim.fallmann@kit.edu

Overview

Karlsruhe Institute of Technology



Region	ΔP max [mm]
Modena	25 **(Dec)**
Venice	39 **(Dec)**
Stuttgart	14 **(Mrz)**
Vienna	23 **(Mrz)**
Prague	15 **(Jul)**
GAP	38 **(Jul)**

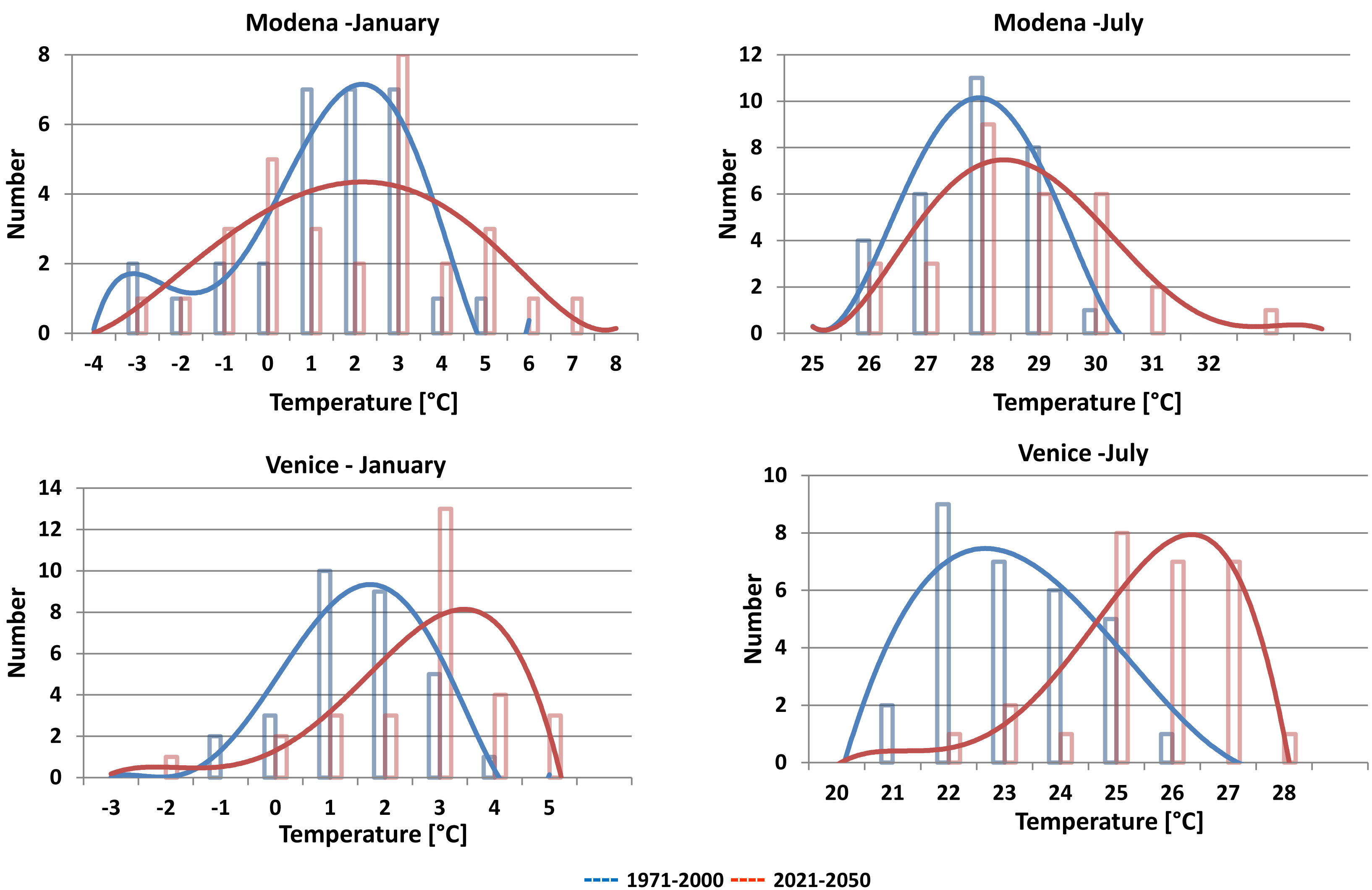
Region	ΔT max [°C]
Modena	5.1 **(Jun)**
Venice	0.4 **(Feb)**
Stuttgart	2.6 **(Oct)**
Vienna	2.7 **(Feb)**
Prague	2.1 **(Feb)**
GAP	2.3 **(Nov)**

Fig. 7: Deviations of monthly mean values (T) and sums (P) for period 2021-2050 compared to 1971-2000 for Central Europe regions

Joachim Fallmann
joachim.fallmann@kit.edu

Number Distributions

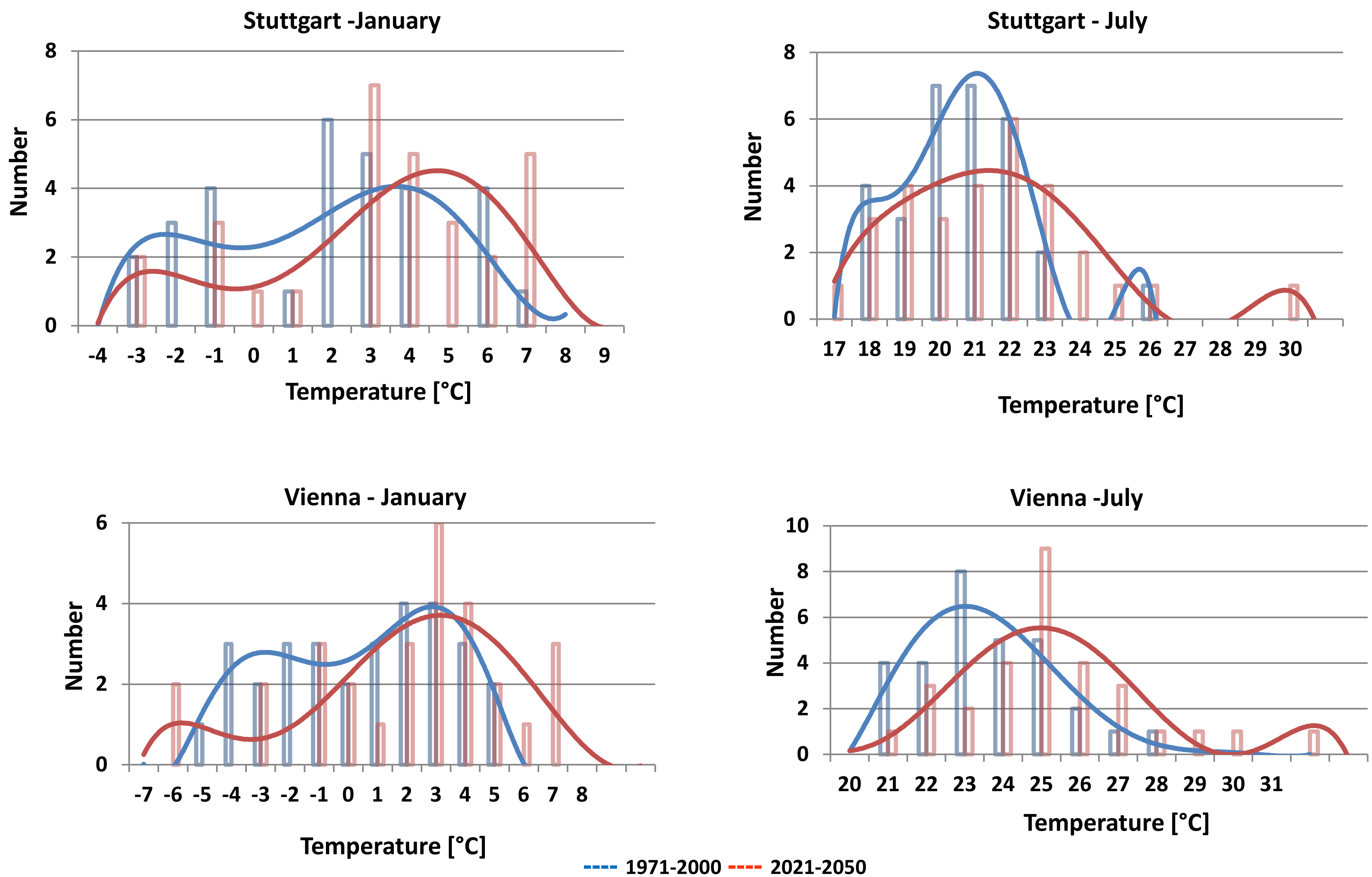
Karlsruhe Institute of Technology



Joachim Fallmann
joachim.fallmann@kit.edu

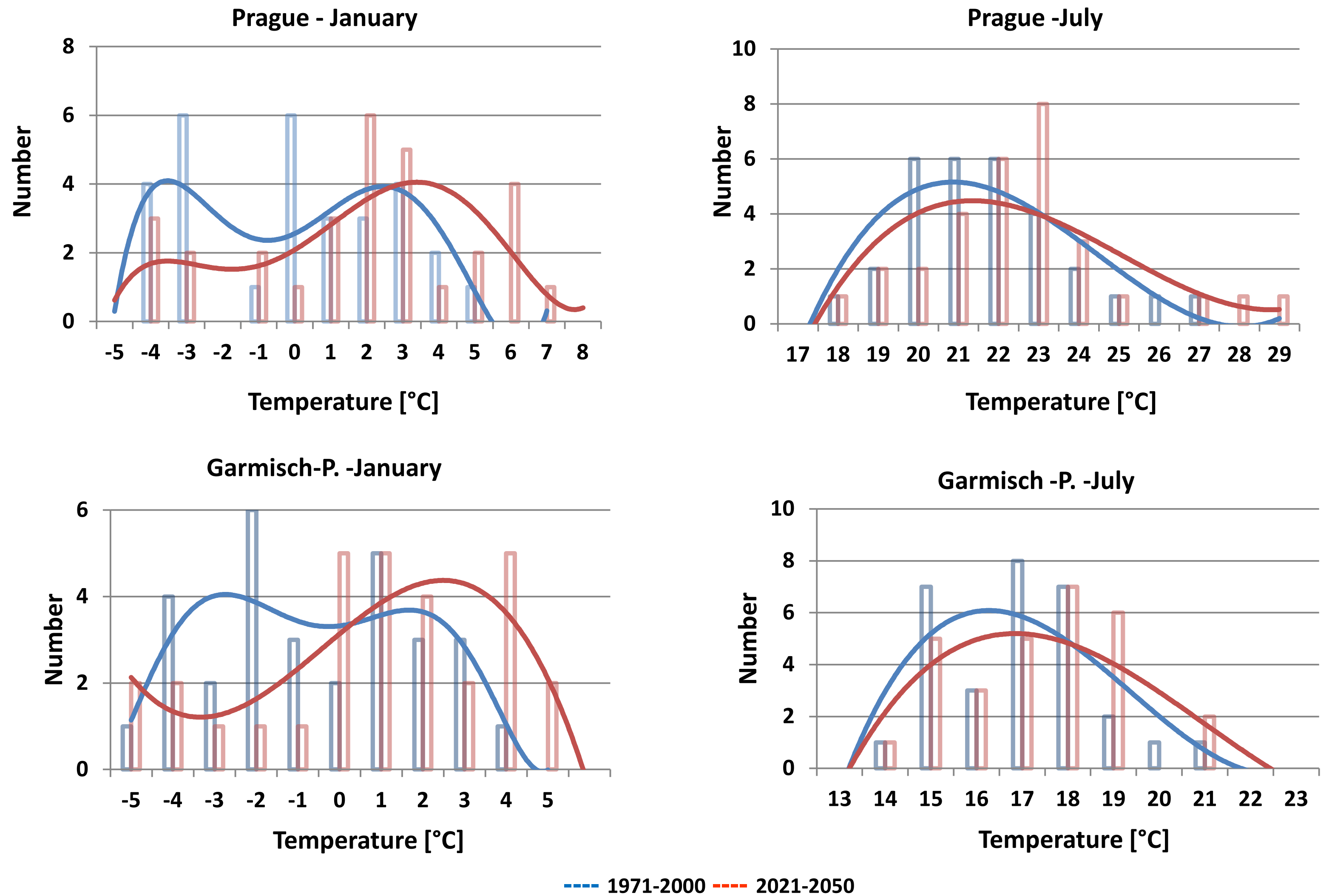
CENTRAL EUROPE COOPERATING FOR SUCCESS. EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

Number Distributions



Joachim Fallmann
joachim.fallmann@kit.edu

Number Distributions



Joachim Fallmann
joachim.fallmann@kit.edu

Regional climate modeling results (Germany)

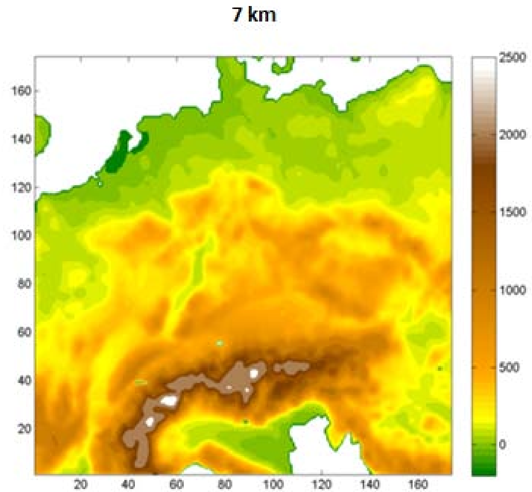


Fig.8: Wagner, 2011

Joachim Fallmann
joachim.fallmann@kit.edu

Fine nest results (7km) for Germany

Karlsruhe Institute of Technology

- Significant warming over Germany 0.8 – 1.3 K
- Annual precipitation change in range of -2% - 9% (ensemble mean 3%)
- Number of wet days annual changes +/- 4%
    - Ensemble mean increase in spring of 5%
    - Decrease -4% in summer
- Changes in number of dry periods more than 5 consecutive days

- Significance test of changes in mean temperature show robust increase for all ensemble members

Joachim Fallmann
joachim.fallmann@kit.edu

Climate Change – Temperature

- Warming over Germany larger in winter (**+1.6 K**) and autumn (**+ 0.9 K**) than in summer and spring (**+ 0.6 K; + 0.3 K**) → average **1 K**
- Agreement with IPCC AR4; Scenario A1B

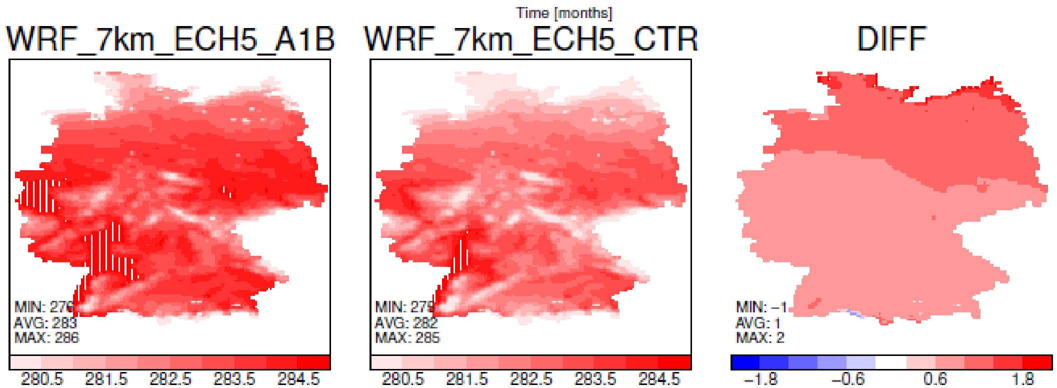


Fig. 9: Simulated annual mean temperature [K] for 2021–2050 (A1B) and 1971–2000 (CTR); right: climate change signal in annual mean temperature [K] (Wagner, 2012)

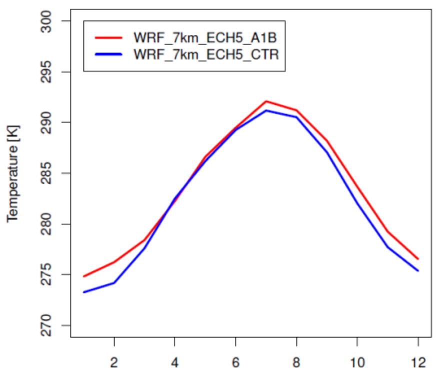


Fig 10: Annual cycles of simulated (WRF 7km ECHAM5) temperature [K] for 2021–2050 (A1B) and 1971–2000 (CTR) averaged over Germany (Wagner, 2012)

Joachim Fallmann
joachim.fallmann@kit.edu

Climate Change – Precipitation

- Largest differences in precipitation: **30%** (March)
- Shift of minimum monthly sum from March to April
- Increase of high densities in the range of **160-240mm**
- Increase for central and north-east Germany
- On average **8%** increase of annual precipitation

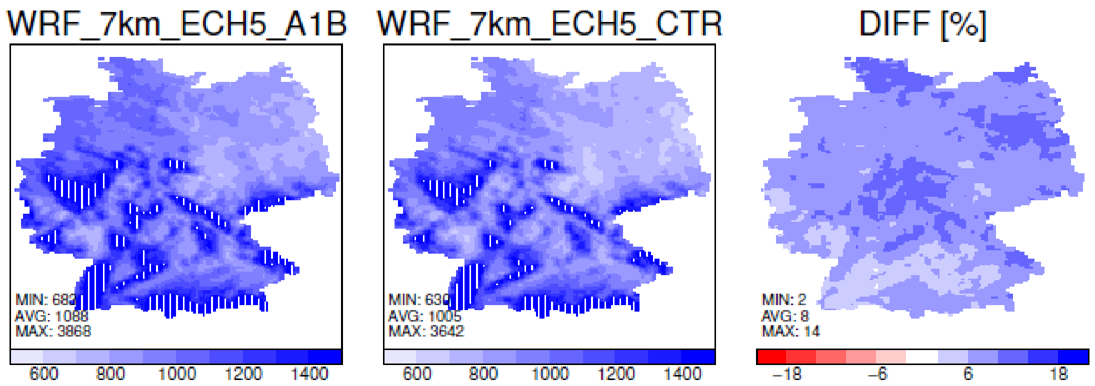


Fig 11.: Simulated annual precipitation sums [mm] for 2021–2050 (A1B) and 1971–2000 (CTR); right: climate change signal [%] in annual precipitation sum

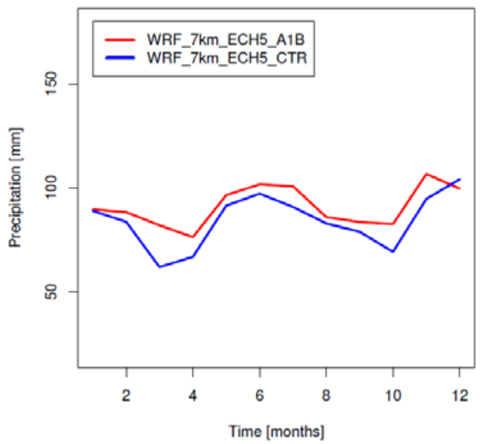


Fig 12: Annual cycles of simulated (WRF 7km ECHAM5) precipitation [mm] for 2021–2050 (A1B) and 1971–2000 (CTR) averaged over Germany

Joachim Fallmann
joachim.fallmann@kit.edu

Heavy Precipitation (> 20mm/day)

- Regional climate change signal is very heterogeneous
- Slightly decrease in SE-Germany; large increase in central-/NE-Germany

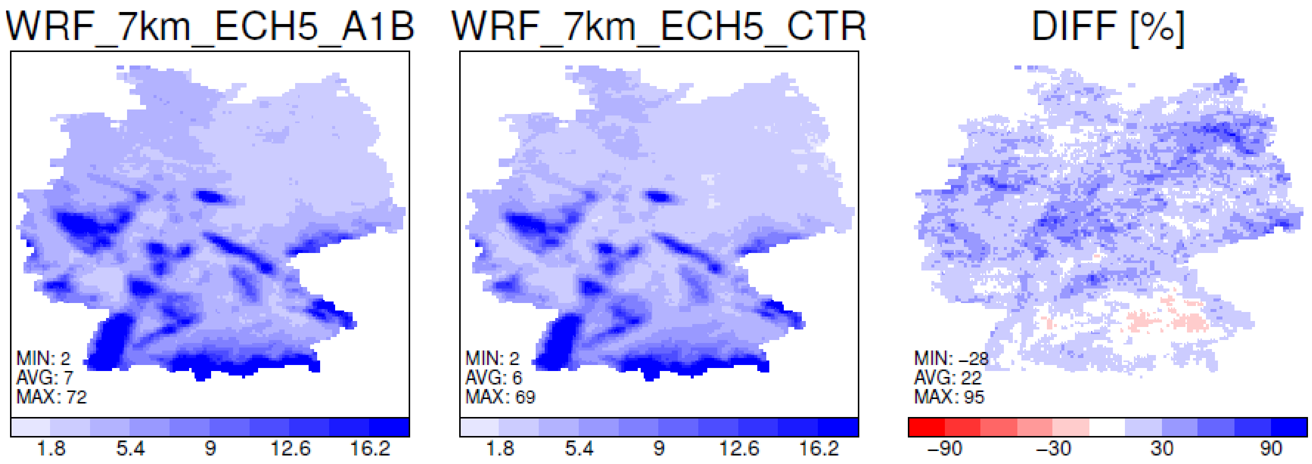


Fig 13: Simulated heavy precipitation (> 20mm/day) days for 2021–2050 (A1B) and 1971–2000 (CTR); right: climate change signal [%] of number of very heavy precipitation per year over Germany

- Snow season is projected to shorten by **20 days** or **39%**

Joachim Fallmann
joachim.fallmann@kit.edu

Number of dry periods (>5 days)

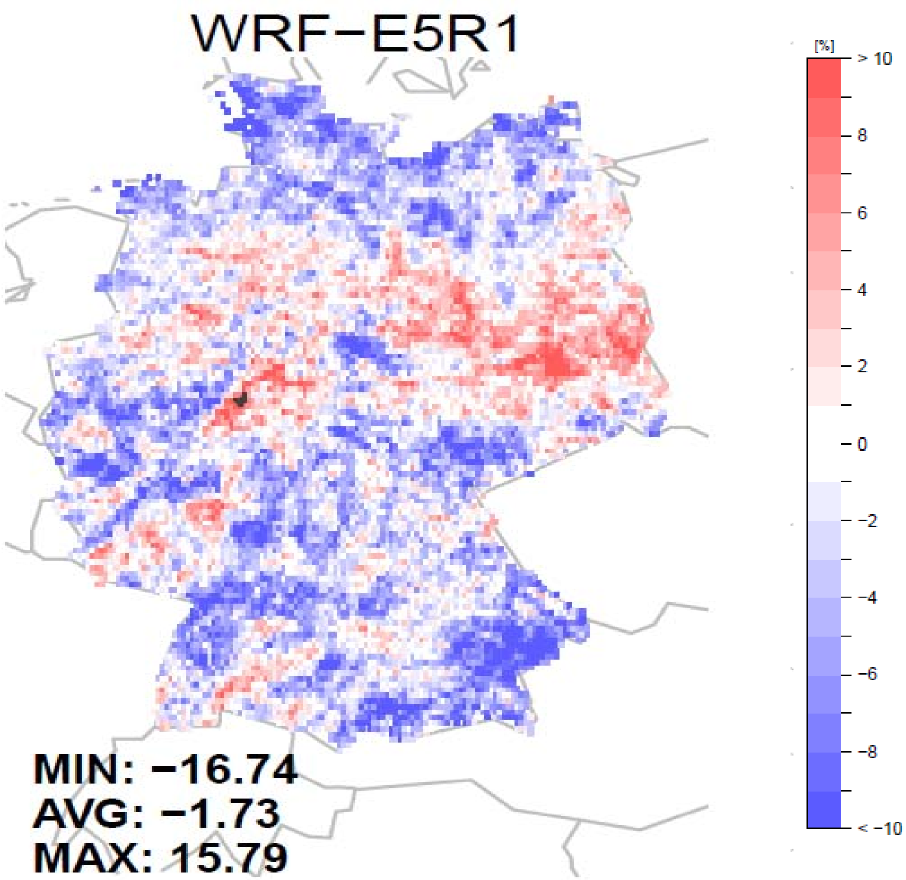


Fig 14: Projected percentage change of number of dry periods of more than 5 days over Germany between 1971 to 2000 and 2021 to 2050 (Wagner, 2012)

Joachim Fallmann
joachim.fallmann@kit.edu

ENSEMBLES – A European Study to evaluate future climate projections

Karlsruhe Institute of Technology

ENSEMBLES

Met Office

- Creating temperature and precipitation PDF's by using several Model-Ensembles
- 16 simulations available for 25 km with A1B Scenario
- Seasonal means of 2m Air temperature and precipitation
- Scenario period (2021-2050); reference period (1991-1990)
- Analysis over 35 capitals in the EU
- Project funded for 5 years (2004-2009)
- Coordination by Hadley Centre Met Office UK

- Climate change projections of extreme air temperature over Europe
- increasing in the 10th and 90th percentile of mean air temperature projected by global and regional climate models over Europe, in all seasons and for different periods of time

Joachim Fallmann
joachim.fallmann@kit.edu
CENTRAL EUROPE COOPERATING FOR SUCCESS.
EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

Case Study Bologna

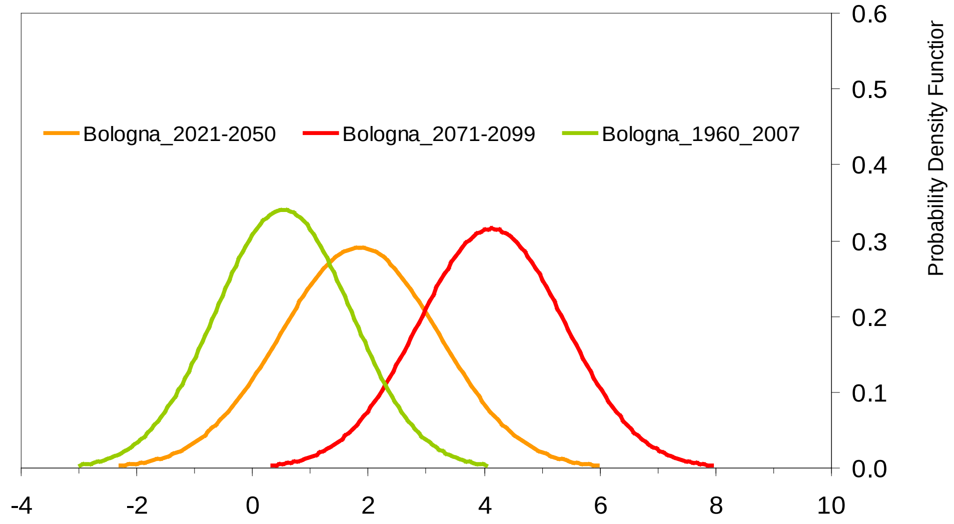


Fig 15: Probability density functions for summer maximum air temperature in Bologna as result from the Ensemble Mean of 6 GCMs for the period 2021-2050 and 2071-2099, with respect to 1961-1990 (green PDF) A1B scenario (Tomozeiu et al 2009)

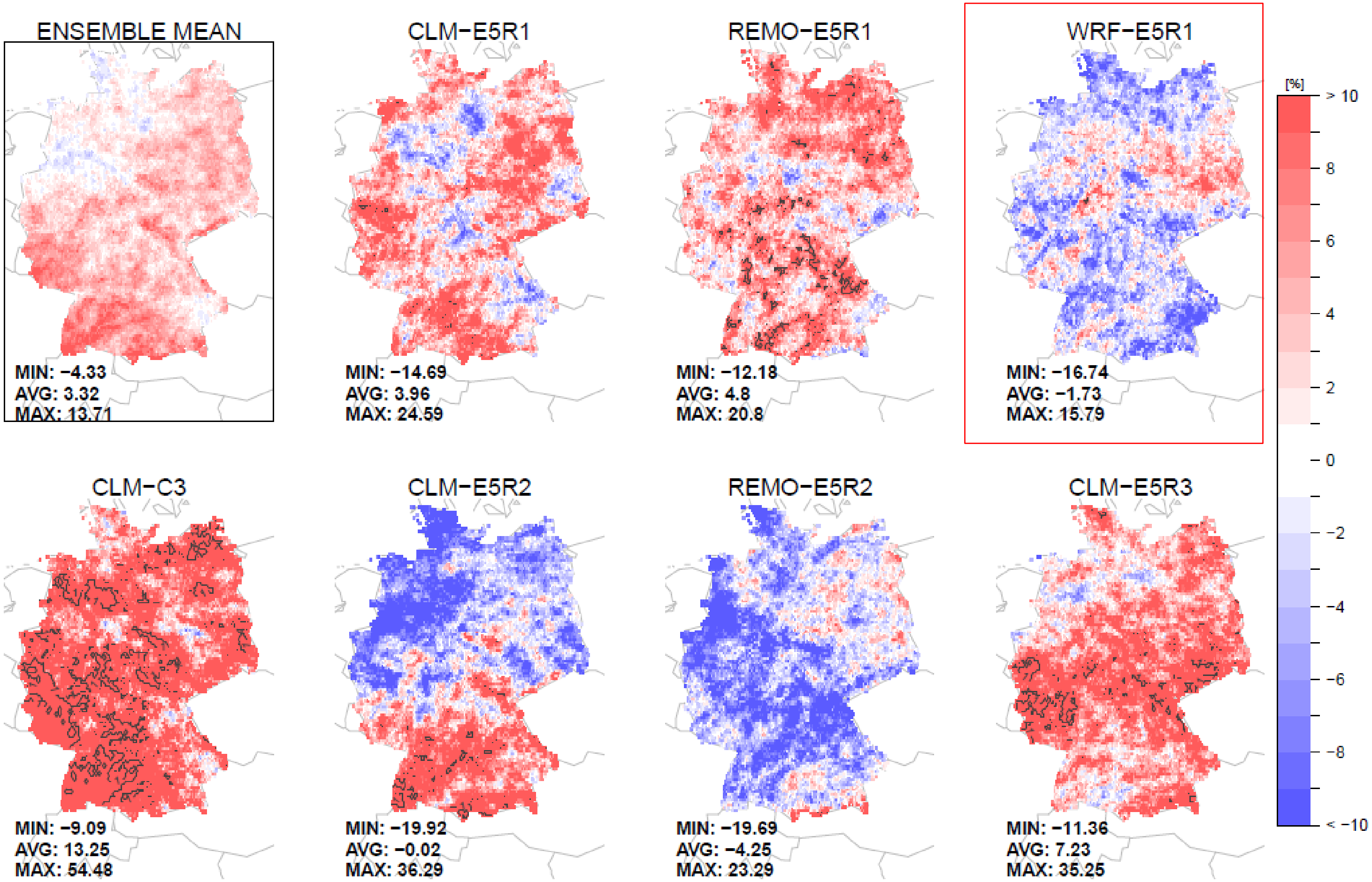
Joachim Fallmann
joachim.fallmann@kit.edu

Thank you very much for your attention !

References: Wagner, S., 2012: High resolution climate modeling for Germany using WRF (submitted for publication).
Wagner, S., 2012: High resolution RCM simulations for Germany: Part II – projected climate change (submitted).

Tomozeiu R. et al., 2007: Climate change scenarios for surface temperature in Emilia-Romagna (Italy) obtained using statistical downscaling models. Theoretical and Applied Climatology, 90, 25-47.

Number of dry periods (>5 days)



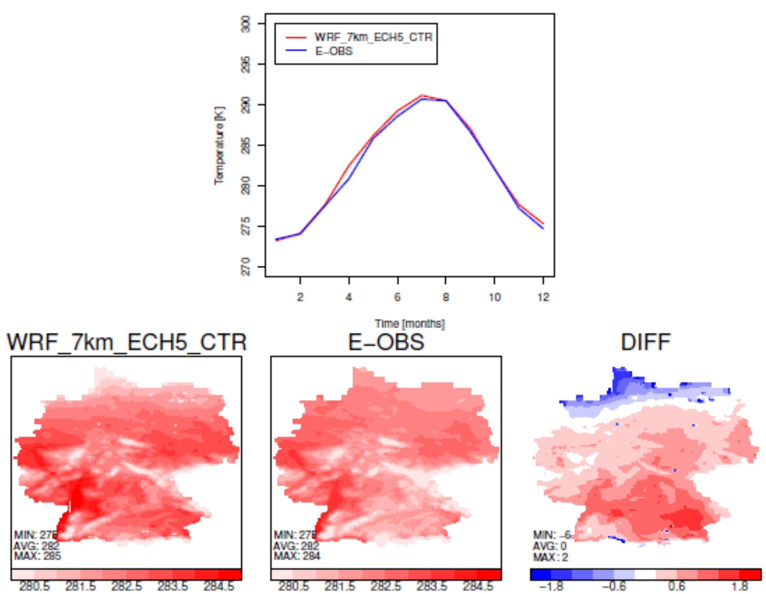
Wagner, 2012

Joachim Fallmann
joachim.fallmann@kit.edu

Validation

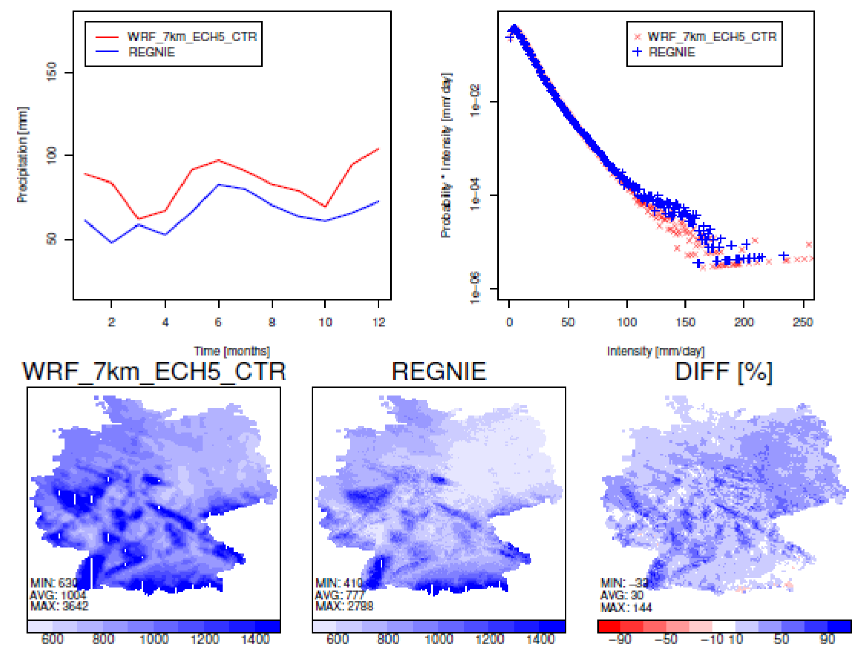
- Ability of RCM WRF in simulating present climate of ECHAM5 simulation
- Validation Data: european E-OBS data set (25km) for temperature
  REGNIE data set (1km) of the German Weather Service (DWD)

2m – Air Temperatur



Wagner, 2011

Precipitation



Wagner, 2011

Joachim Fallmann
joachim.fallmann@kit.edu
CENTRAL EUROPE COOPERATING FOR SUCCESS.
EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND