Optimizing High-Resolution Simulations with the Weather Research and Forecasting (WRF) Model for the German Rhine-Neckar Metropolitan Region

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Introduction

While urban areas are responsible for more than 70% of global CO_2 emissions, reliable bottom-up information on (intra-)urban CO_2 emissions is not readily available at high temporal and spatial resolution and with acceptable uncertainties. Urban monitoring networks can independently quantify anthropogenic CO_2 emissions in cities and thus provide stakeholders with valuable information on (intra-)urban mitigation efforts. In the scope of the joint project 'Integrated Greenhouse Gas Monitoring System for Germany' (ITMS) we will analyze optimal network designs in German urban and metropolitan areas using the well-established WRF-Urban model. The first step in this task is to assure an accurate representation of atmospheric transport in our modeling framework, which we analyze in this study.

Methods

- 4x1 month simulation
  - April, July, September, December 2020
  - representative of seasons (pheonomenological calendar)
- 3 hourly GFDDA to ERA5 data, re-initialization every 7 days
- 3 domains (15, 5, 1km) focussing on Rhine-Neckar region
- 42 vertical layers, 14 layers below 1.5km
  - BEP: lowest level @15m
  - UCM: lowest level @90m
- high resolution input data (CORINE + LCZ landuse [Breuer, 2016; Demuzere, 2022], COP DEM topography)
- 16 combinations of parameters investigated:
  - PBL scheme (Bou-Lac, MYJ, YSU)
  - LSM (Noah, Noah MP)
  - SL model (MO, MM5)
  - UCM/BEP parametrization
- Comparison with:
  - 19 German Weather Service (DWD) stations (5 urban, 14 rural)
  - 2 radiosonde stations

Results

- Higher ensemble spread in winter than in other seasons
  - In winter, ERA5 performs better
- Average performance in rest of year better than ERA5
  - 2m temperature:
    - best configuration: YSU, NMP, MM5, UCM
    - ERA5 performs better
  - 10m wind velocity:
    - best configuration: MYJ, NMP, MO, UCM
    - WRF performs better
  - PBL height:
    - best configuration: YSU, N, MM5, UCM
    - WRF performs better
- BEP underestimates diurnal variability in wind velocity
- UCP outperforms BEP in urban areas

Conclusions

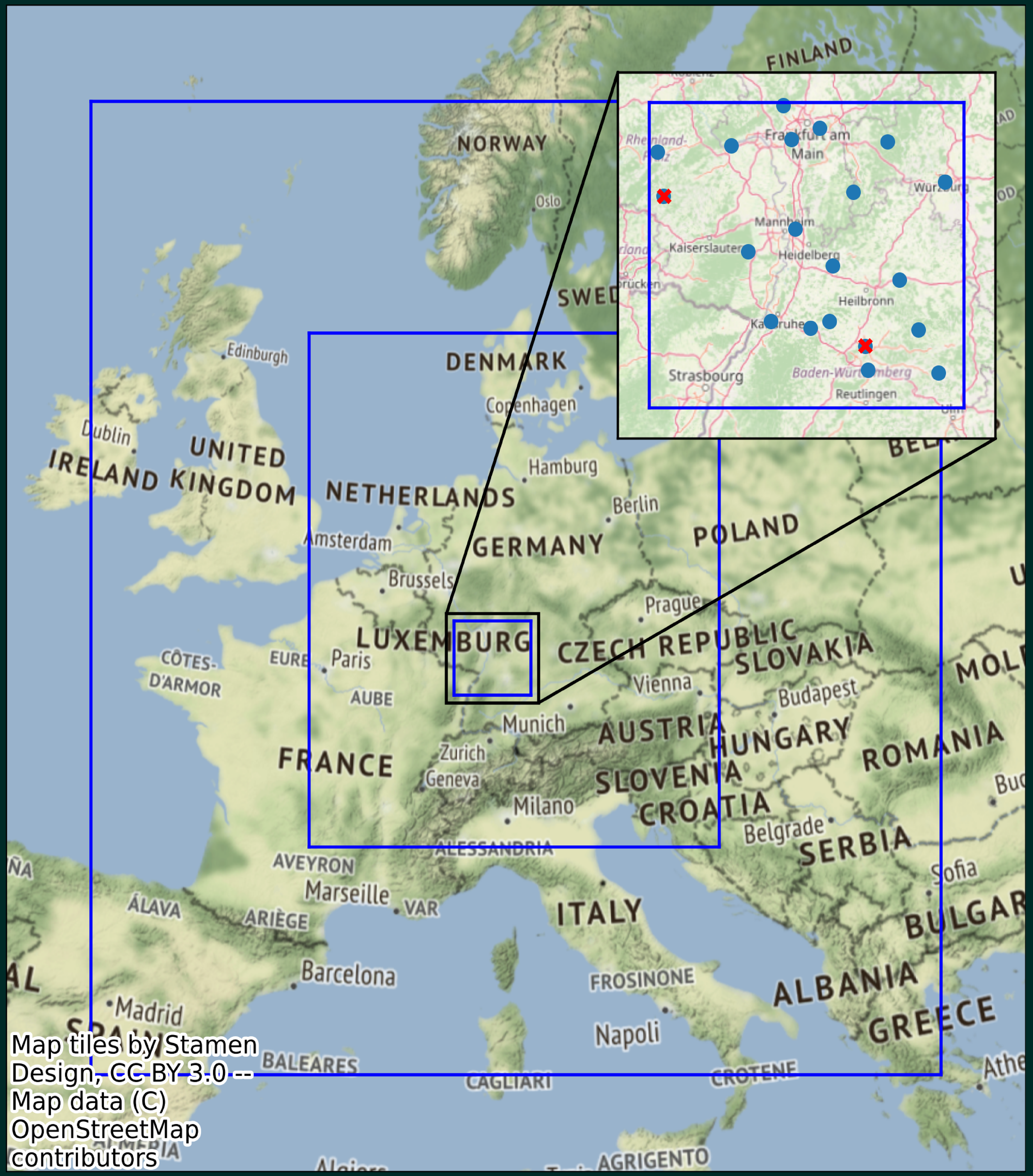
- Even without 4DVar, WRF performs well compared to ERA5
- UCM generates better 10m wind velocity and PBL height
- Underestimation of diurnal winds by BEP probably due to overestimation of wind drag
  - ➔ Optimize building height distribution in URBPARM_LCZ.TBL

References

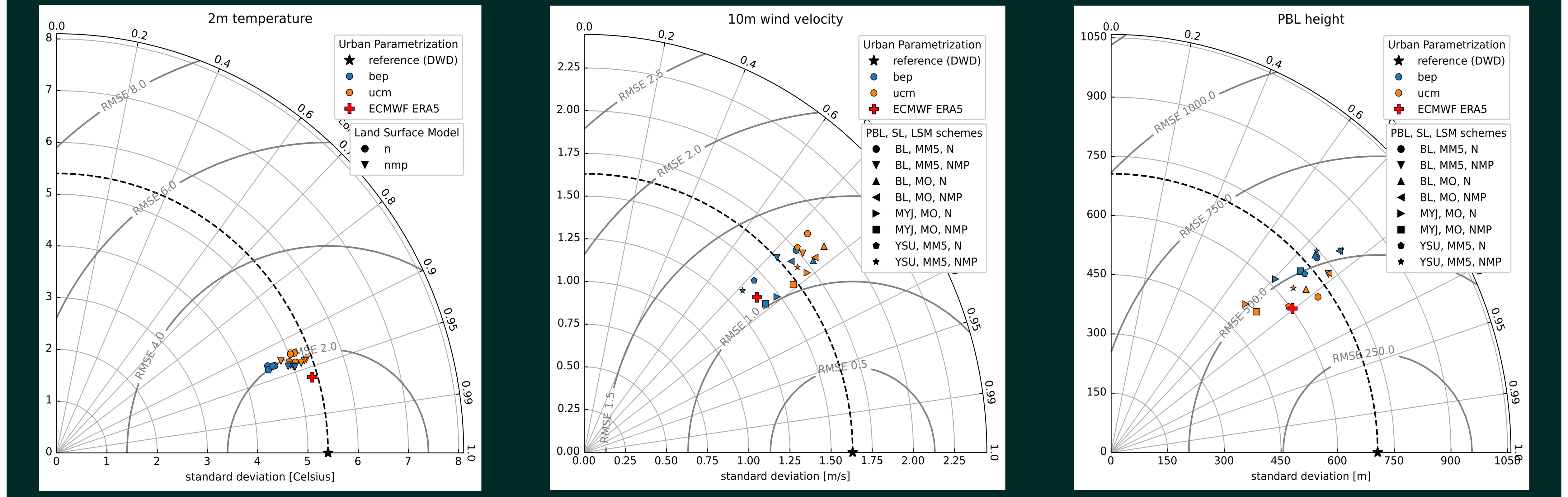
Demuzere, Matthias, et al. "A global map of local climate zones to support earth system modelling and urban-scale environmental science." Earth System Science Data 14.8 (2022): 3835-3873.

Breuer, Hajnalka. (2021). CORINE dataset for WRF-NoahMP model (v4.3, v4.2) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.4432128

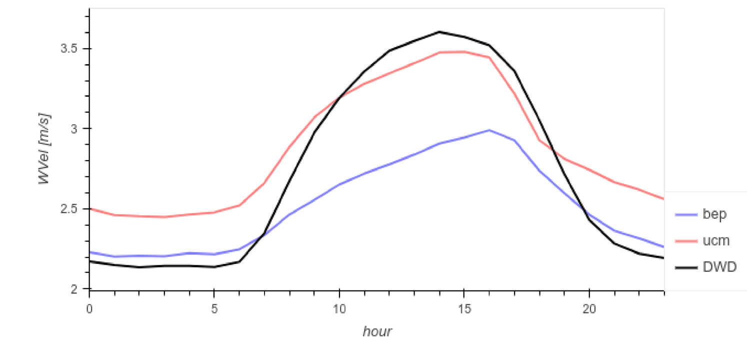
Evaluation of WRF-Urban simulation setups for German urban GHG monitoring network design



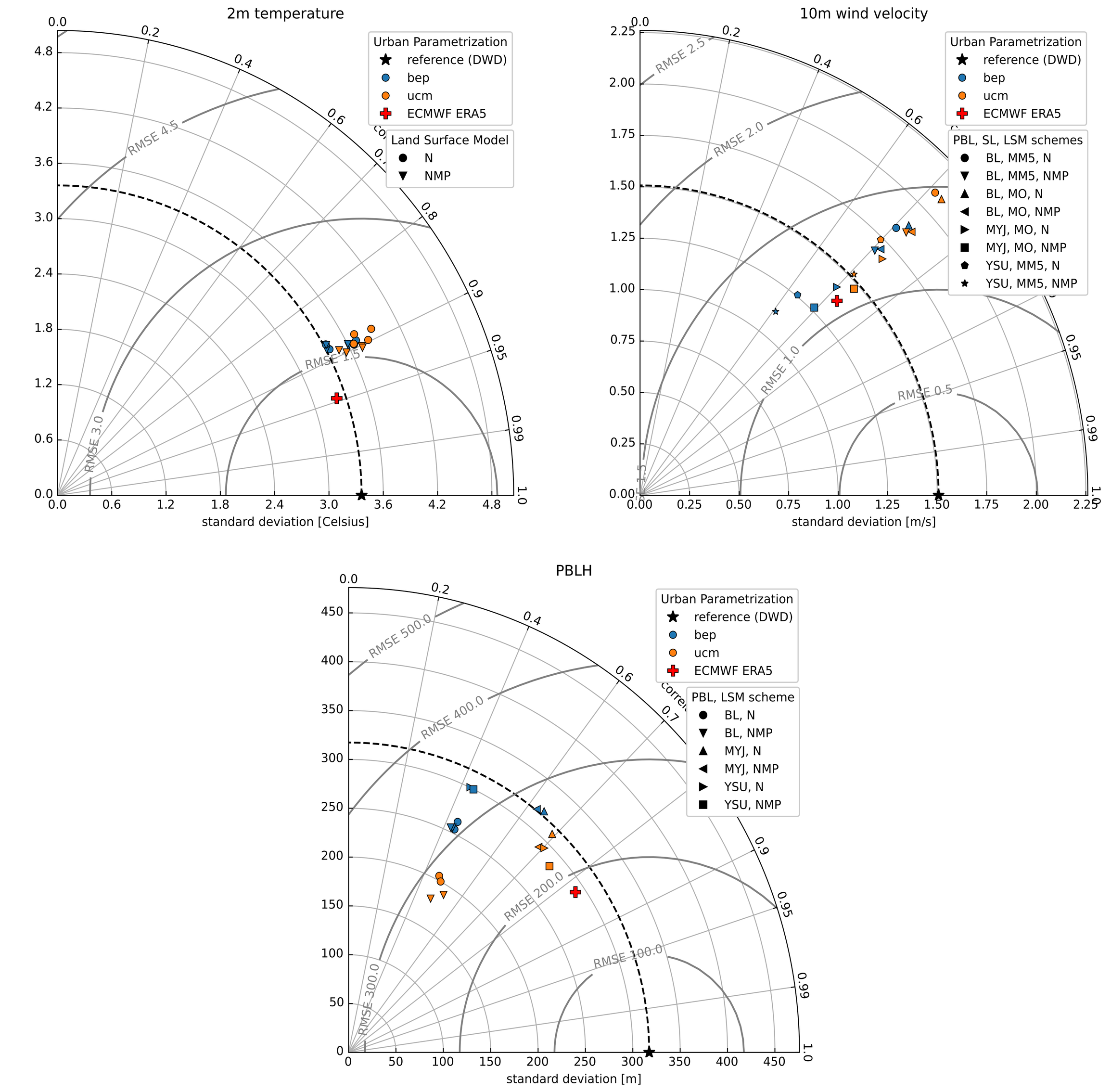
Simulation domains with reference meteorological (blue) and radiosonde (red) stations.



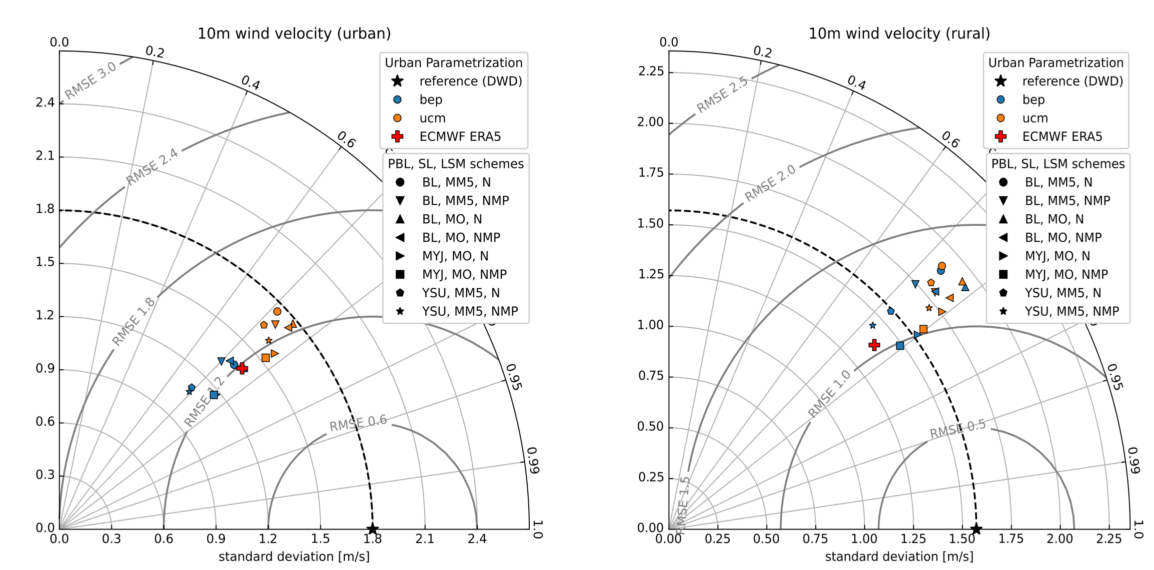
Performance average of WRF simulations over spring, summer and autumn compared to ECMWF ERA5 and reference stations (average over all stations).



Average diurnal cycle of 10m wind velocity over spring to autumn. BEP significantly underestimates amplitude.



Performance average of WRF simulations in winter compared to ECMWF ERA5 and reference stations (average over all stations).



Performance average of WRF simulations over spring to autumn compared to ECMWF ERA5 and reference stations (average over all stations). In urban areas, UCM significantly outperforms BEP.

	T2 [Celsius]		WVel [m/s]		WDir [°]		PBL height [m]	
	best WRF	ERA5	best WRF	ERA5	best WRF	ERA5	best WRF	ERA5
RMSE	2.21	1.89	1.30	1.39	55.71	57.97	414.08	448.35
R	0.94	0.96	0.83	0.80	0.55	0.51	0.8	0.76
MB	0.30	0.20	-0.07	-0.26	38.44	41.11	-50.82	-53.56
WRF config	YSU, NMP, MM5, UCM		MYJ, N, MO, UCM		MYJ, N, MO, UCM		YSU, N, MM5, UCM	

	T2 [Celsius]		WVel [m/s]		WDir [°]		PBL height [m]	
	best WRF	ERA5	best WRF	ERA5	best WRF	ERA5	best WRF	ERA5
RMSE	1.82	1.69	1.21	1.26	53.83	55.60	412.40	416.42
R	0.94	0.96	0.78	0.75	0.47	0.47	0.87	0.86
MB	0.39	0.28	-0.16	-0.30	40.18	40.18	-8.27	-42.25
WRF config	YSU, NMP, MM5, UCM		MYJ, NMP, MO, UCM		BL, N, MO, BEP		BL, N, MM5, UCM	

	T2 [Celsius]		WVel [m/s]		WDir [°]		PBL height [m]	
	best WRF	ERA5	best WRF	ERA5	best WRF	ERA5	best WRF	ERA5
RMSE	1.90	1.68	1.15	1.28	59.13	64.16	388.68	357.48
R	0.95	0.96	0.77	0.72	0.47	0.42	0.73	0.77
MB	0.57	0.17	-0.33	-0.13	42.48	47.41	-2.19	-7.25
WRF config	YSU, NMP, MM5, UCM		MYJ, NMP, MO, BEP		MYJ, N, MO, BEP		YSU, N, MM5, UCM	

	T2 [Celsius]		WVel [m/s]		WDir [°]		PBL height [m]	
	best WRF	ERA5	best WRF	ERA5	best WRF	ERA5	best WRF	ERA5
RMSE	1.72	1.34	1.36	1.46	51.84	52.38	229.70	208.42
R	0.90	0.95	0.73	0.72	0.57	0.63	0.74	0.82
MB	-0.54	0.17	-0.13	0.06	36.04	37.9	72.22	101.94
WRF config	YSU, NMP, MM5, UCM		MYJ, NMP, MO, UCM		MYJ, NMP, MO, UCM		YSU, NMP, MM5, UCM	

Performance of best WRF simulation vs ERA5 for all 4 seasons (left to right, top to bottom spring, summer, autumn, winter)

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Deutscher Wetterdienst Wetter und Klima aus einer Hand

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