Modelling meteorological conditions for the episode of measured high PM_{10} air concentrations – application of the WRF model

Maciej Kryza[1*)], Małgorzata Werner[1)], Anthony J. Dore[2)], Marek Błaś[1)], Anetta Drzeniecka-Osiadacz[1)], Paweł Netzel[1)]

[1)] Department of Climatology and Atmosphere Protection, Wrocław University, Poland
[2)] Centre for Ecology and Hydrology, Edinburgh, UK

1. Introduction

Mesoscale meteorological models are widely used to derive spatially continuous meteorological parameters at various temporal scales. The models are used for both: weather forecasting and reanalysis. The output of the meteorological models is also a key component for regional air pollution modelling, as the meteorological processes are important for emission, dispersion and removal of atmospheric pollutants (Borge et al., 2008). Moreover, high concentrations of atmospheric pollutants of adverse effect on human health, are often related with specific meteorological conditions, e.g. frosts or heatwaves, low wind speeds, thermal stratification within the boundary layer or type and mobility of the atmospheric air mass.

This paper presents the results of application and evaluation of the Weather Research and Forecasting (WRF; Skamarock et al. 2008) model for calculation of meteorological parameters at relatively high spatial resolution at the regional scale. The WRF simulation was performed for the winter period with the air quality standards exceeded for particulate matter in SW area of Poland (PM10; 01-30.12.2009). The WRF model results were evaluated with both surface and ravisonde measurements collected in the innermost model domain.

2. Episode selection

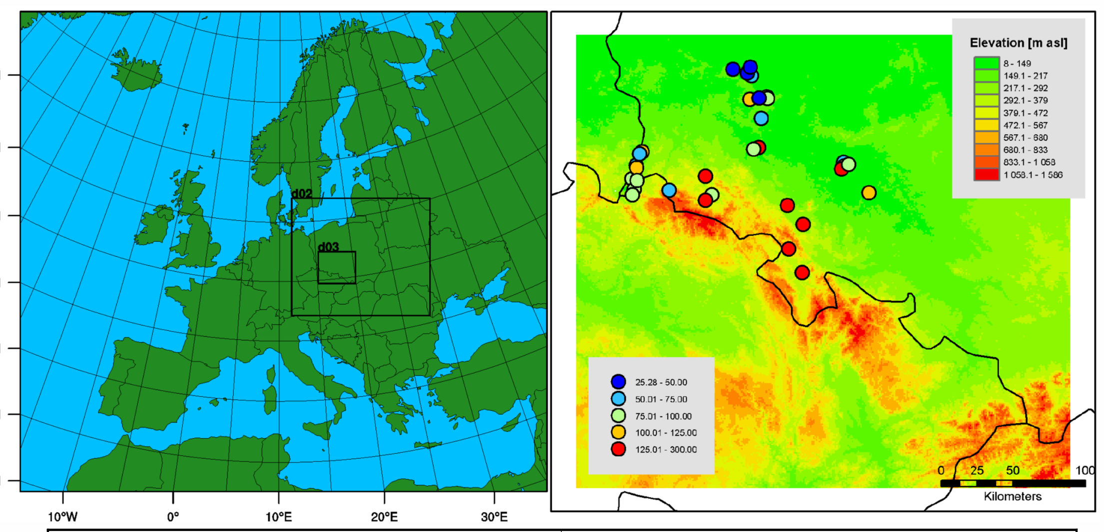
The selection of the period for the WRF simulation is based on the 2009 air quality measurements performed on the national air quality network in SW Poland. The air quality standards for PM10 were exceeded in the period from 1 to 30 December (Fig. 1), mainly due to meteorological condition favourable to high emission and accumulation of pollutants. For all sites (except of 4 out of 41), the 50μg m^{-3} threshold was exceeded at least once, and for five stations the exceedances were measured for more than 15 days, with the daily average maximum at Jelenia Gora reaching 284.7 μg m-3 (03.12.2009).

3. WRF model configuration

The model was configured with three one way nested domains with spatial resolution changing from 50km to 2km (SW Poland; Fig. 1). The simulation was driven by the NCEP FNL Global Tropospheric Analysis, available every 6h with 1° x 1° spatial resolution.

4. Evaluation of the model results

Surface meteorological measurements available from 9 stations operating in the d03 domain were used for model evaluation, together with the radiosonde memeasurements form Wrocław. Atmospheric pressure (PRES), air temperature at 2m (TMP), specific humidity at 2m (SPFH) and wind speed at 10m (WIND) were compared and the results summarized using mean bias (MB), mean absolute error (MAE) and index of agreement (IOA; Willmott, 1982; Yu et al., 2008).



Category	Setup
Shortwave radiation	Dudhia scheme (Dudhia, 1989)
Longwave radiation	Rapid Radiative Transfer Model (Mlawer et al., 1997)
Microphysics	New Thompson scheme (Thompson et al., 2004)
Cumulus parameterization	Kain-Fritsch (Kain, 2004) scheme for d01 and d02, no parameterization for d03
Land surface processes	Noah Land Surface Model (Chen and Dudhia, 2001)
Planetary boundary layer	Asymmetrtic Convective Model version 2 (Pleim, 2007)
Horizontal resolution	d01: Δx=Δy=50km d02: Δx=Δy=10km d03: Δx=Δy=2km
Vertical levels	35 levels

Fig. 1 Configuration of the WRF model domains (left & table) and the highest daily average PM10 air concentrations measured over the domain d03 during the period 1 – 30 Dec 2009 (right)

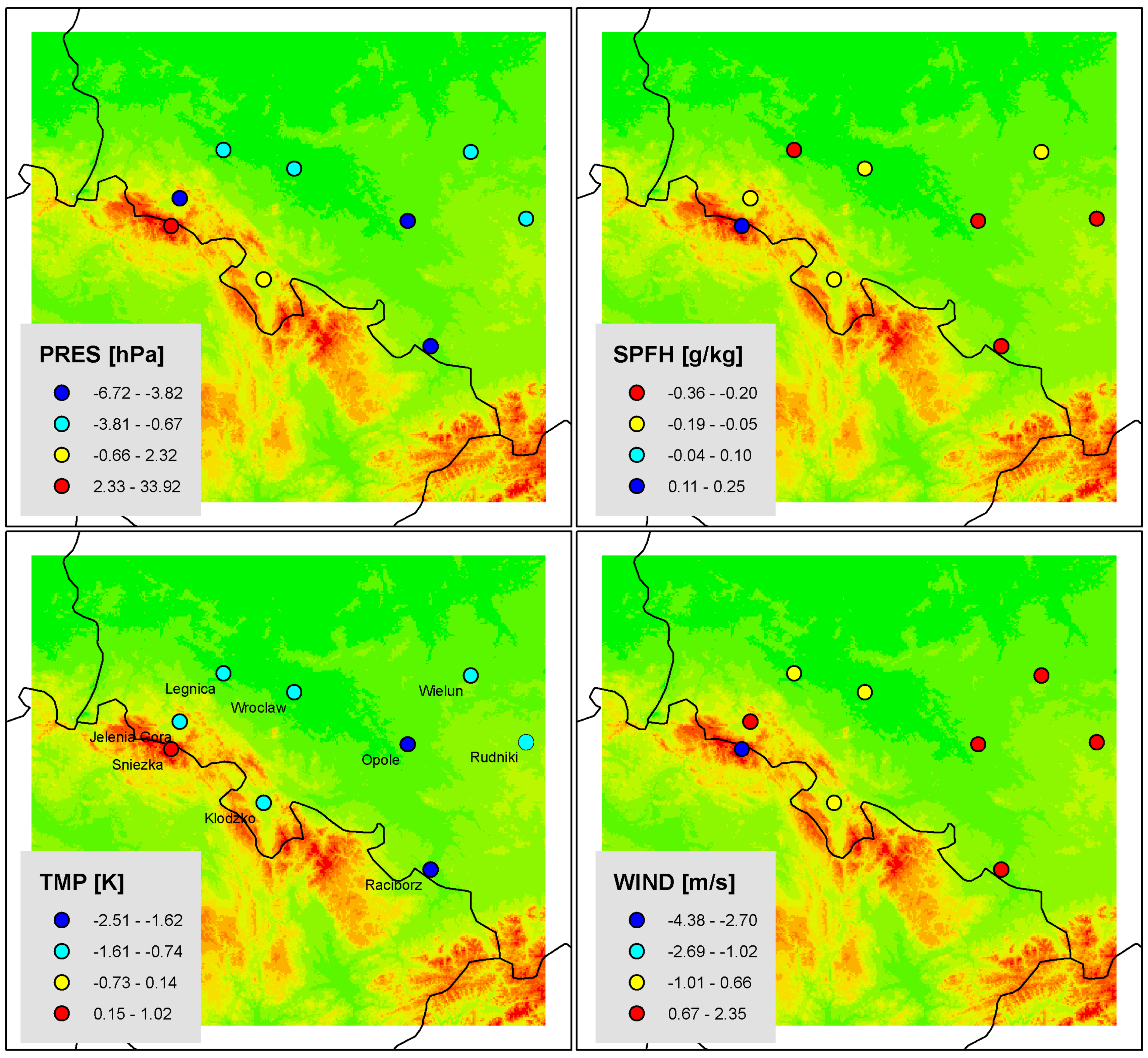


Fig. 2 Mean bias for the meteorological stations operating in d03

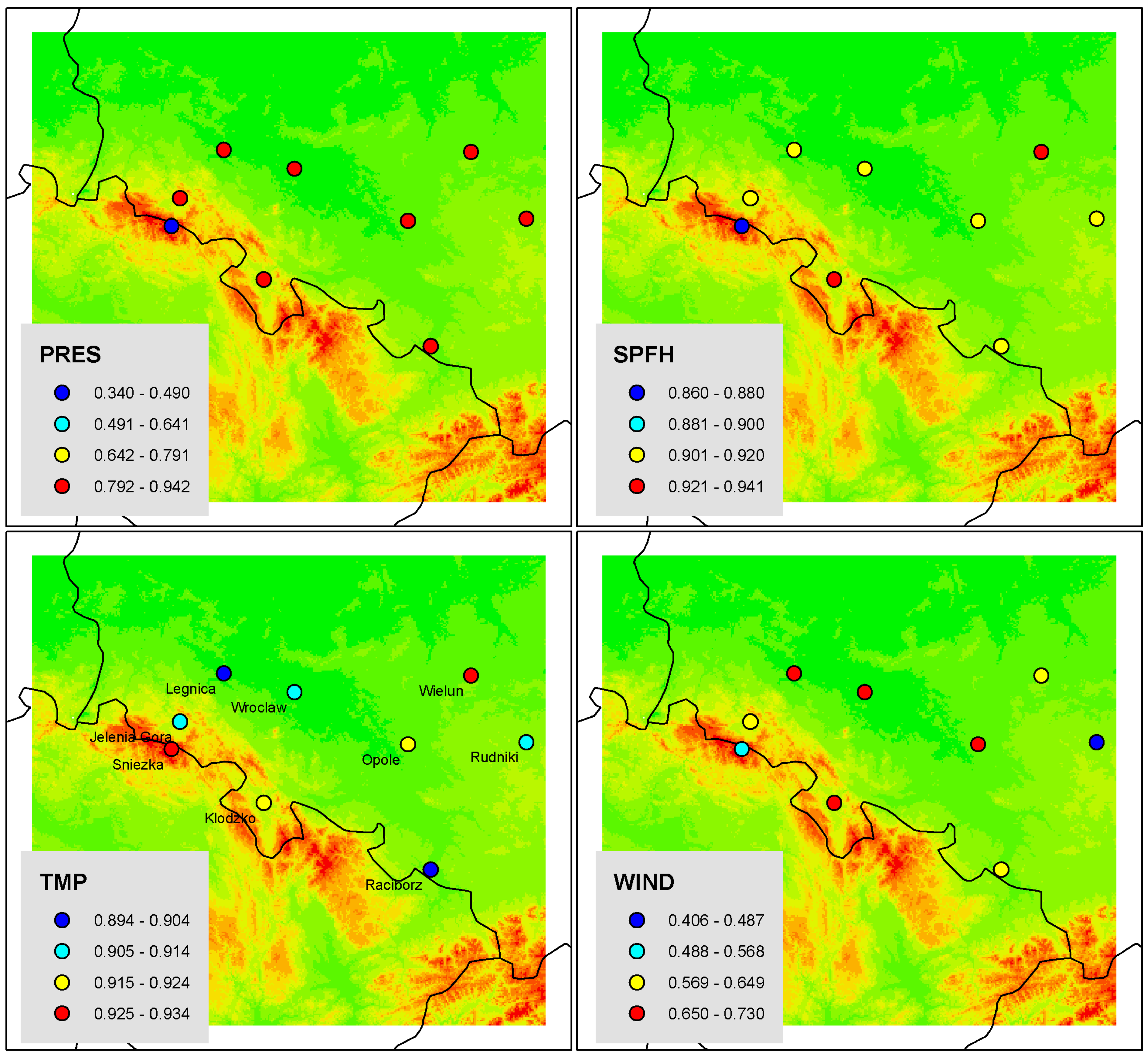


Fig. 3 Index of agreement for the meteorological stations operating in d03

5. Results

The model is able to correctly resolve temporal changes of surface PRES, TMP and SPFH, with the IOA calculated for all measurements >0.9 (Table 1, Fig. 2 and Fig. 3). There is a general tendency of the model to underestimate the observed TMP and SPFH for the selected period, described by the negative MB values for the majority of the stations. The meteorological parameters are overestimated for Śnieżka station, and in case of PRES, for Kłodzko. For Śnieżka, the overestimation can be attributed to the specific location of the station – at the isolated mountain top. The grid height at Śnieżka station is 1293m, while the real station elevation is 1615m asl. This can explain the overestimation of PRES and TMP for Śnieżka, and suggest insufficient spatial resolution of the model for the areas of complex terrain. The terrain features are smoothed at 2km x 2km model grid, and actual deformations of air streamlines produced by topography is more significant than estimated by the model.

The IOA calculated for WIND is lower than for the remaining meteorological parameters used for comparison. The worst results, in terms of IOA, are calculated for Rudniki station, which is difficult to explain in terms of e.g. topographic position of the measuring post (Fig. 2 and 3). The model performance for Śnieżka station is also rather poor, and the WIND values are significantly underestimated by the model. The reasons for the underestimation calculated for Śnieżka are expected to be the same as provided above for PRES and TMP.

The modelled TMP, SPFH and WIND are in good agreement with ravisonde measurements collected in Wroclaw. The IOA is higher and the MB lower than calculated for surface measurements for all stations and for Wroclaw only (except for SPFH). However, the MAE suggests larger absolute errors than for surface data for SPFH and WIND. The largest errors are found for the lowest model layers. Also, for the specific days, the model is not able to reproduce the vertical profile of air temperature.

A period of large errors for PRES is evident for days 17 – 21 Dec 2009 for all stations (time series for Wroclaw are presented in Fig. 4). The model is not able to reproduce the significant decrease in atmospheric pressure. For the coldest day of the selected period (20 Dec), the modelled air temperature is close to the measured value, but the lowest modelled TMP value is calculated for the next day and not confirmed in the measurements. For WIND, the model is capable in reproducing the time of observed peaks of increased wind speed.

Table 1 Error statistics for PRES, TMP, SPFH and WIND for surface and ravisonde measurements (N – number of measurements)

site	N	PRES [hPa]			TMP [K]			SPFH [g/kg]			WIND [m/s]		
		MB	MAE	IOA	MB	MAE	IOA	MB	MAE	IOA	MB	MAE	IOA
All	2020	0.46	6.46	0.98	-1.49	2.71	0.92	-0.15	0.58	0.91	0.53	2.22	0.62
Wrocław	600	-2.75	3.72	0.92	-1.63	2.74	0.91	-0.12	0.57	0.91	0.84	1.88	0.50
Legnica	180	-1.48	3.31	0.94	-1.59	2.77	0.89	-0.24	0.58	0.91	0.35	1.61	0.73
Wieluń	179	-2.20	3.53	0.92	-1.45	2.40	0.93	-0.19	0.55	0.93	1.67	2.05	0.62
Jelenia Góra	179	-6.72	6.87	0.84	-0.88	2.76	0.91	-0.10	0.57	0.92	0.96	1.87	0.57
Śnieżka	178	33.92	33.92	0.34	1.02	2.36	0.93	0.25	0.65	0.86	-4.38	5.46	0.54
Kłodzko	179	2.32	3.74	0.93	-1.55	2.47	0.92	-0.11	0.47	0.94	0.42	2.32	0.70
Racibórz	166	-3.82	4.46	0.89	-2.51	3.02	0.90	-0.30	0.62	0.92	0.85	1.89	0.58
Rudniki	179	-0.67	3.32	0.93	-2.43	2.99	0.91	-0.31	0.66	0.91	2.35	2.55	0.41
Opole	180	-4.17	4.69	0.89	-2.04	2.79	0.92	-0.36	0.64	0.92	0.95	1.55	0.66
Wrocław ravisonde	265	-	-	-	-0.02	2.31	0.95	0.11	0.77	0.85	-0.61	3.66	0.73

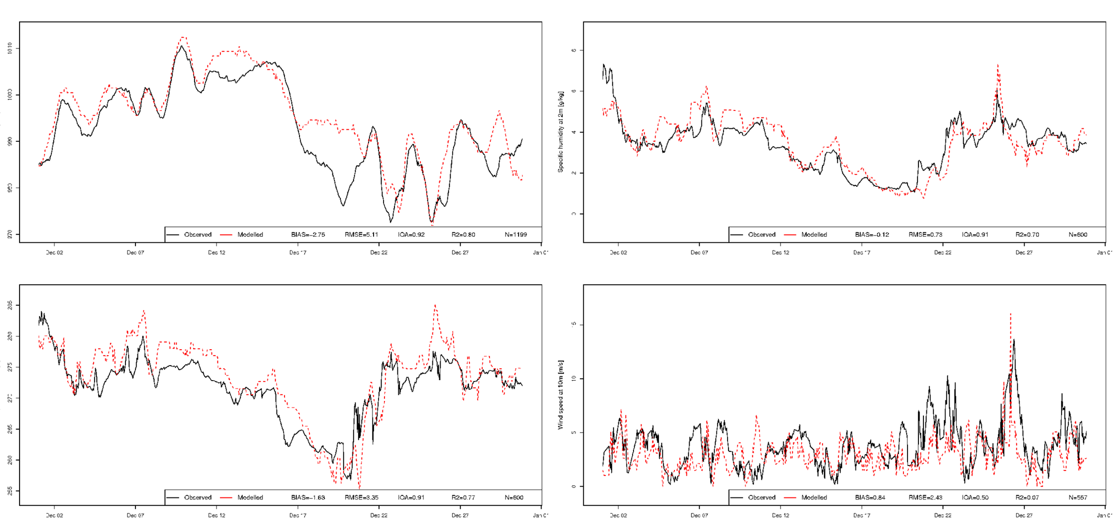


Fig. 4 Modelled and observed PRES (top left), TMP (bottom left), SPFH (top right) and WIND (bottom right) at Wroclaw station

Acknowledgements:
The authors are grateful to the Voivodship Inspectorate for Environmental Protection in Wrocław for providing the air quality measurement data for the study. Calculations have been carried out in Wroclaw Centre for Networking and Supercomputing (http://www.wcss.wroc.pl), grant No. 170.

*) Contact author: maciej.kryza@uni.wroc.pl

6. Summary and conclusions

In this paper Weather Research and Forecasting model was applied to estimate meteorological parameters in SW Poland for the selected period of high concentrations of PM10. The main findings are:

- The model is capable of reproducing the temporal changes of atmospheric pressure, surface temperature and specific humidity for the majority of the stations.
- The sites for which the model performed worse are located in the mountainous area of the domain, and insufficient spatial resolution is expected to be the reason for this.
- The model constantly underestimates the measured air temperature at 2m and overestimates the wind speed.
- The model capabilities of reproducing observed wind speed below 1m s^{-1} threshold are limited (15% of successful cases). This is important in terms of dispersion of atmospheric pollutants, including PM10.
- The model failed to reproduce the vertical profile of air temperature for several cases of strong inversion layer was measured near the ground. This is also crucial for air quality modelling and may suggest insufficient vertical resolution of the domain. Further studies will be undertaken for different model settings and cases with poor air quality standards

References:

Borge, R., V. Alexandrov, J. J. Del Vas, J. Lumbreras, E. Rodriquez, 2008: A comprehensive sensitivity analysis of the WRF model for air quality applications over the Iberian Pennisula. Atmos. Environ., 42, 8560-8574.

Skamarock, W.C., Klemp, J.B., Dudhia, J., Gill, D.O., Baker, D.M., Duda, M.G., Hwang, X.Y., Wang, W., and J.G. Powers, 2008: A description of the advanced research WRF version 3. Technical Note 475+STR, National Centre for Atmospheric Research, Boulder, CO.

Willmott, C., 1982: Some comments on the evaluation of model performance. Bull. Am. Meteorol. Soc., 63, 1309-1313.

Yu, S., B. Eder, R. Dennis, S.H. Chu, E. Schwartz, 2006: New unbiased symmetric metrics for evaluation of air quality models. Atmos. Sci. Lett., 7, 26-34.