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VERIFICATION OF THE WEATHER RESEARCH AND FORECASTING MODEL (WRF) FOR THE DOMAIN OF SILESIAN VOIVODESHIP AND UPPER SILESIA METROPOLITAN REGION

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Abstract
The paper presents the analysis of the statistical errors of the meteorological parameters predicted by the WRF (Weather Research and Forecasting) model. The model is used for forecasting air pollution in the Silesian Voivodeship with an accuracy of about 70-80%. Thus, the main idea of the research was assessing to what extent the error in the forecast of meteorological parameters affects the error of the air quality forecast, which can be evaluated using the system InfoSMOG – MED for the inhabitants of the Silesian Voivodeship at www.slaskiesmogstop. It was also investigated how the reduction of the mesh size of the forecast of meteorological parameters affects the error of the forecast of these parameters, which was necessary for the next project SMART. The research was carried out for 3 computational domains: Poland, Silesian Voivodeship and Upper Silesia Metropolitan Region, each with a different grid resolution. The predicted temperature and wind speed data were compared with the measured data from the Polish synoptic stations and the stations of the METAR airports meteorological shield located in the respective domains. In addition, the error of the predicted parameters was investigated in the grid where the climatological station is located in the Śląskie Planetarium in Chorzów.

Keywords: **Meteorological forecast, WRF model, Model error.**

1. INTRODUCTION

In recent years, in the situation of climate change and its effects on the quality of life of the population, one of the problems to be solved has been the adoption of these changes in various areas of socio-economic life at the local level. In the developed plans for adaptation to climate change, which are becoming one of the local strategic documents of socio-economic development of the cities/municipalities, the impact of climate change on air quality and its effects on the health and life of residents is announced. The basis of the air quality forecasting system is the forecast of meteorological parameters at the local level, based on global forecasting, which is used by the WRF (Weather Research and Forecasting model). Such a solution was adopted in the construction of the air quality forecasting system and health effects for the inhabitants of the Silesian Voivodeship - InfoSMOG-MED [1], in which the forecast of selected meteorological parameters from the WRF model determines, on the one hand, the demand for heat in the housing stock, and this in turn affects the consumption of fuels in the sources installed in municipal housing resources used for this purpose, which generate emissions of pollutants into the atmospheric air, taking into account their efficiency, depending on the type and age of the source.

The amount of emissions from emission areas (from industrial, municipal and road transport sources), constituting input data to the pollution spread model, taking into account the values of forecasted meteorological parameters, gives an air quality forecast with simultaneous information on health threats for residents

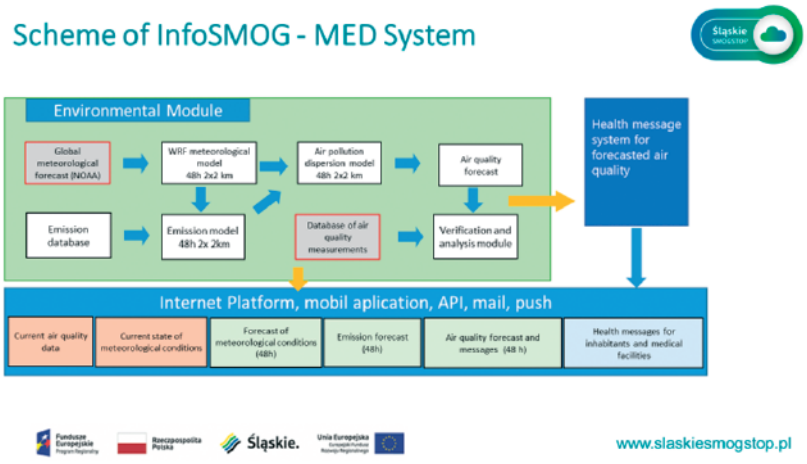


Figure 1.
Scheme of the InfoSMOG-MED system of the air quality forecast with health care warning system based on WRF model

with diseases of the cardiovascular system, respiratory system, diabetes diseases and diseases of the youngest inhabitants of the population Silesian Voivodeship (paediatric). The structure of the above-described air pollution forecasting system is shown on the below scheme (Figure 1.).

The WRF model has been elaborated on the basis of the Global Forecast System (GFS) - provided by the Weather Prediction Center (WPC). The applied WRF model (version 4.2) generates 156 meteorological parameters [2], from which 14 were selected. These are:

1. the horizontal component of wind speed [m/sec]
2. the vertical component of wind speed [m/sec]
3. "z" component of wind speed [m/sec].
4. air temperature at 2 m height [K]
5. atmospheric pressure at ground level [hPa]
6. atmospheric pressure reduced to sea level [hPa]
7. the horizontal component of wind speed at a height of 10 m, [m/s].
8. the vertical component of wind speed at 10 m height, [m/s].
9. snow equivalent [kg/m2]
10. the thickness of snow cover [m]
11. daily convective precipitation [mm]
12. daily non-convective precipitation [m]m
13. daily snowfall [mm]
14. relative humidity of the air at 2 m [%].

The worm-up (spin-up) time was 6 hours and the forecast length was 24 hours.

The selection of the domain size was based on the following requirements. The 10 km grid size for the area of Poland was selected as the resolution compatible with the EMEP grid system, both for emission inventory and concentration assessment of air pollution. The 2km grid size for the area of Silesian Voivodeship was selected for the calculation of the forecast of the air pollution concentrations, used in the InfoSMOG system. The 1km grid size for Upper Silesia Metropolitan Region was selected for the calculation of meteorological parameters for determining the boundary conditions of personal physical training in free air for the selected population. The size of the areas and grids were adjusted to the capacities of the computational matrix. WRF 3.9.1.1 version was used, and the initial resolution was 0,5 degree.

The WRF model has been used also for the prediction of the meteorological parameters in the SMART project [3] for the determination of the activities and training rationalization system for different population groups with respect to the forecast of meteorological parameters.

As well for the InfoSMOG-MED as for the SMART project the results of the accuracy of the meteorological parameter prediction are very important because it is connected with the daily and even hourly activities of the inhabitants in the particular locations connected with the air quality and in the case of the SMART project even based on the additional recommendations of the doctors of the physiotherapist on the daily activities patients.

Thus, the main objective of the study undertaken was to evaluate the statistical errors of forecasted values

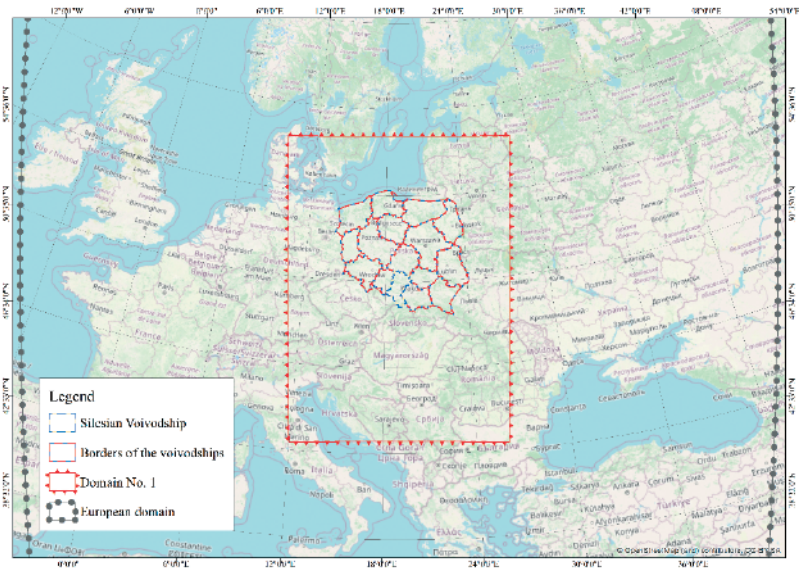


Figure 2.
Spatial coverage of domain no. 1 - the European and Polish domain

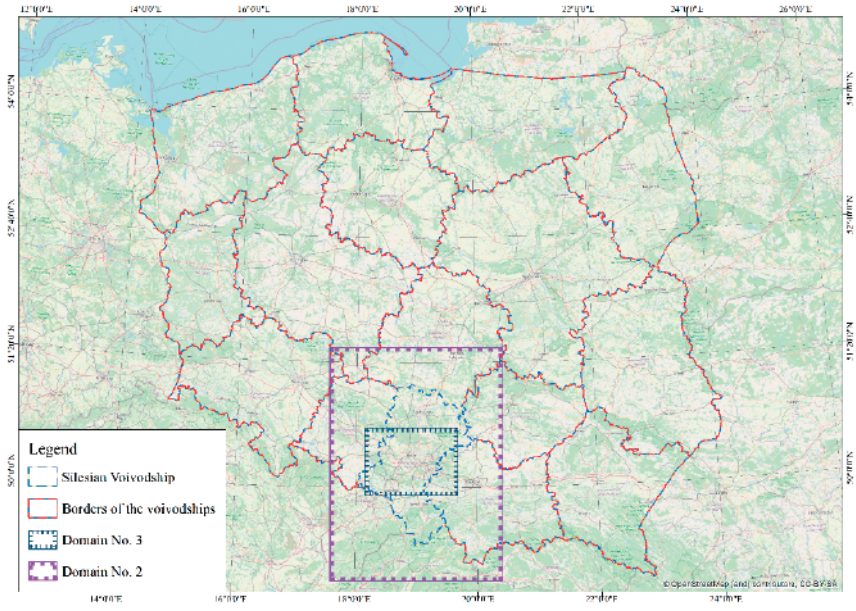


Figure 3.
Nearer spatial coverage - domain no. 2 (Silesian Voivodeship) and domain no.3 (Upper Silesia Metropolitan Region)

of meteorological parameters between modelled data with adjustment derived from data from synoptic stations (IMGW and METAR) relative to model data without adjustment, with respect to 3 spatial domains, and to assess to what extent a reduction in the model's computational grid will reduce the error of forecasted values of meteorological parameters.

The results of the six scenarios of the data comparisons in the 3 computing domains are presented in this article.

2. APPROACH

Statistical studies of errors in forecasted values of meteorological parameters were carried out for 3 computing domains. The spatial extent of the domains is as follows: Polish domain no.1 circa 1 825 196 km^2 (Fig. 2) –D1; Silesian Voivodeship domain no. 2 circa 56 450 km^2 – D2; Upper Silesia Metropolitan Region domain no. 3 circa 8 824 km^2 – D3 (Fig. 3). Additionally European domain circa 15 556 357 km^2 have been used in one scenario.

In domain D1 the grid resolution was 10km x 10km, in the domain D2 2 km x 2 km and in the domain D3 1 km x 1 km. The six scenarios for the statistical analyses of the temperature and wind speed data have been established. Comparisons were made between:

(i) modelled data without adjustment and modelled data with adjustment for the 3 domains (scenarios 1, 2, 3),

(ii) modelled data between domains D2 and D3 without and with adjustment (scenario 4),

(iii) modelled data of domain D3 with adjustment in two input data of the spatial extents: national and "European" (scenario 5), and

(iv) model and measured data from the station at the Planetarium Station in Chorzów in the grid of the station location (scenario 6).

Scenario 1 refers to domain D1 contained 547 992 data pairs for the statistical comparisons, scenario 2 refers to domain D2 contained 154 008 data pairs for the statistical compare and scenario 3 refers to domain D3 contained 215 784 data pairs for the statistical comparisons. Scenario 4 refers to an area covering a common part of domains D2 and D3, which contained 134 136 data pairs for the statistical comparison.

Scenario 5 refers to domain 3 contained 215 784 data pairs for the statistical comparison. Scenario 6 refers to a single point of the meteorological station while in terms of time, it covered a period of 8 months with the 728 pairs for the statistical comparison.

The following designations have been used in the statistical analyses:

D1, D2, D3 data of domains 1, 2, 3

FDDA Four-dimensional data assimilation, forecasted data with adjustment to measured data from SYNOP and METAR stations

NOFDDA Four-dimensional data assimilation, forecasted data without adjustment to measured data

T2 the temperature at a height of 2 metres

WS10 wind speed at 10 metres height

PL national spatial extent

EU "European" spatial extent

For a more complete picture of the variables subjected to comparative analysis, basic statistics were calculated such as minimum, maximum, mean, standard deviation, median and median deviation of MAD (*median absolute deviation from the median*).

Description of the error estimators

Six error estimators were used in the aforementioned scenarios. The calculation formulas of them are shown in the table below (Table 1).

Table 1.
List of error estimators and their calculation formula

Nr	Error estimator	Calculation formula
1	mean error (ME)	$ME = \frac{\sum_{i=1}^{n} O_i - P_i}{n}$
2	mean absolute error (MAE)	$MAE = \frac{\sum_{i=1}^{n} \lvert O_i - P_i \rvert}{n}$
3	mean square error (MSE)	$MSE = \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{n}$
4	root mean square error (RMSE)	$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{n}}$
5	Percent bias (PBIAS)	$PBIAS = \left[\frac{\sum_{i=1}^{n} (O_i - P_i) * 100}{\sum_{i=1}^{n} (O_i)}\right]$
6	Nash-Sutcliffe efficiency (NSE)	$NSE = 1 - \left[\frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - O_{mean})^2}\right]$

where n is the number of observations, O_i is the i-th observed value (or model value with adjustment), O_{mean} is the mean observed value (or mean model value with adjustment), P_i is the i-th model-predicted value without adjustment.

The following error estimators were used in this study: mean error (ME), mean absolute error (MAE), mean square error (MSE), root mean square error (RMSE), percent bias (PBIAS) and Nash-Sutcliffe efficiency (NSE).

MAE, MSE and RMSE are commonly used error estimators in model evaluation. Their purpose is that they specify the error in units of the variable being evaluated, which facilitates the analysis of the results (Moriasi at el. 2007) [4]. Values of the MAE, MSE and RMSE parameters equal to 0 indicate a perfect fit between the data being evaluated and the model data. It is considered that parameter values of MAE, MSE and RMSE less than half of the standard deviation of the analysed variables can be considered low and that each of them is appropriate for the evaluation of the model (Singh at el. 2004) [5]. The value of the error estimator ME determines the global trend in the analysed data. ME values greater than zero indicate an underestimation of the model results, and values less than zero indicate an overestimation of the model values.

Percent bias (PBIAS) is a measure of the mean trend (tendency) of the evaluated data relative to the benchmark data (e.g. simulated data to observed data or adjusted data to unadjusted data). The optimal

Table 2.
Results of error calculations for the air temperature at 2 m above ground level

Scenario	Error	Spring	Summer	Autumn	Winter	Position	Dispersion
Domain	Estimator	2021-03-26	2021-06-14	2021-09-11	2021-12-26	estimator [2]	estimator[3]
S1 - D1	ME	-0.15630	-0.01532	-0.30607	-0.32337	-0.23119	0.12385
S1 - D1	MAE	0.73463	0.68167	0.73945	0.72783	0.73123	0.00862
S1 - D1	MSE	1.36417	1.02354	1.36485	1.34106	1.35261	0.01763
S1 - D1	RMSE	1.16798	1.01170	1.16827	1.15804	1.16301	0.00758
S1 - D1	PBIAS	-2.55566	-0.10064	-1.83415	-0.12036	-0.97725	1.28505
S1 - D1	NSE	0.94355	0.95502	0.95179	0.97117	0.95341	0.00850
S2 - D2	ME	0.20064	0.05034	-0.23402	-1.62159	-0.09184	0.32221
S2 - D2	MAE	1.09889	0.97715	0.93026	1.73495	1.03802	0.12500
S2 - D2	MSE	2.01397	1.40664	1.34395	4.40998	1.71030	0.49668
S2 - D2	RMSE	1.41914	1.18602	1.15929	2.10000	1.30258	0.19263
S2 - D2	PBIAS	2.39929	0.35825	-1.38266	-0.61638	-0.12907	1.29054
S2 - D2	NSE	0.89774	0.94580	0.95861	0.49957	0.92177	0.04512
S3 - D3	ME	-0.08763	-0.05692	-0.10547	-1.75832	-0.09655	0.03598
S3 - D3	MAE	1.13819	0.81963	0.88337	1.78878	1.01078	0.23615
S3 - D3	MSE	2.25661	1.02322	1.18479	4.81939	1.72070	0.91431
S3 - D3	RMSE	1.50220	1.01154	1.08848	2.19531	1.29534	0.36373
S3 - D3	PBIAS	-0.98092	-0.40401	-0.61289	-0.66531	-0.63910	0.19370
S3 - D3	NSE	0.83716	0.95827	0.96268	0.42179	0.89771	0.09305
S4 - D2D3-A[4]	ME	-0.00054	-0.00083	0.00078	0.00304	0.00012	0.00120
S4 - D2D3 -A	MAE	0.05073	0.03423	0.02930	0.02675	0.03177	0.00555
S4 - D2D3 -A	MSE	0.00948	0.00353	0.00304	0.00252	0.00329	0.00075
S4 - D2D3 -A	RMSE	0.09734	0.05943	0.05513	0.05020	0.05728	0.00684
S4 - D2D3-A	PBIAS	-0.00604	-0.00591	0.00455	0.00115	-0.00238	0.00533
S4 - D2D3-K	NSE	0.99932	0.99986	0.99990	0.99970	0.99978	0.00015
S4 - D2D3-U[5]	ME	0.00072	-0.00059	-0.00033	0.00068	0.00018	0.00078
S4 - D2D3-U	MAE	0.04123	0.03298	0.02050	0.02566	0.02932	0.00925
S4 - D2D3-U	MSE	0.00707	0.00287	0.00159	0.00221	0.00254	0.00095
S4 - D2D3-U	RMSE	0.08410	0.05362	0.03991	0.04706	0.05034	0.01016
S4 - D2D3-U	PBIAS	0.00796	-0.00420	-0.00192	0.00026	-0.00083	0.00330
S4 - D2D3-U	NSE	0.99951	0.99985	0.99994	0.99957	0.99971	0.00025
S5 - D3	ME	0.01846	-0.02409	-0.00840	0.01503	0.00331	0.01991
S5 - D3	MAE	0.58717	0.21496	0.28542	0.29217	0.28879	0.05723
S5 - D3	MSE	0.79501	0.10081	0.21460	0.19966	0.20713	0.08436
S5 - D3	RMSE	0.89164	0.31751	0.46325	0.44683	0.45504	0.10804
S5 - D3	PBIAS	0.20663	-0.17095	-0.04883	0.00569	-0.02157	0.13094
S5 - D3	NSE	0.94263	0.99589	0.99324	0.97605	0.98464	0.01471
Mediana	ME	0.00009	-0.00808	-0.05693	-0.16135	-0.03251	0.04227
Mediana	MAE	0.66090	0.44832	0.51243	0.51000	0.51122	0.04753
Mediana	MSE	1.07959	0.56201	0.69970	0.77036	0.73503	0.15445
Mediana	RMSE	1.02981	0.66452	0.77587	0.80244	0.78915	0.10223
Mediana	PBIAS	0.00096	-0.05328	-0.33086	-0.06005	-0.05666	0.04523
Mediana	NSE	0.94309	0.97708	0.97796	0.97361	0.97534	0.00323

[1]the number of individual scenarios was six because scenario four includes two sub-scenarios
[2]Median (central value)
[3]MAD – median deviation around the median
[4]A – adjusted data are included in the scenario
[5]U - the scenario includes unadjusted data

value of the PBIAS estimator is zero. Low values of PBIAS indicate an accurate simulation of the model results. Positive values of PBIAS indicate an underestimation of the model values, while negative values indicate an overestimation of the model data.

Nash-Sutcliffe efficiency (NSE) measures the relative magnitude of the residual variance (noise) compared to the measured variance of the data (information) (Nash at el. 1970) [6]. NSE indicates how well a plot of observed versus simulated data fits a 1:1 line. NSE ranges from ∞ to 1.0 inclusive, with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally seen as acceptable levels of performance, while values <0.0 indicate that the average observed value is a better predictor than the simulated value, indicating unacceptable performance (Moriasi at el. 2007).

The temporal extent of the analyses

Calculations of differences between modelling results according to scenarios 1, 2, 3, 4, and 5 were carried out for four selected days representing four climatological seasons: 2021-03-26 (spring), 2021-06-14 (summer), 2021-09-11 (autumn) and 2021-12-26 (winter). Calculations of differences between the results of modelling and measurements for the Silesian Planetarium station were made for data from the period of 1.07.2021-28.02.2022.

Results for scenarios 1 to 5

Changes in error estimators over the year

The results of the error estimators for particular scenarios and seasons are summarised in the tables below, separately for temperature (Table 2) and wind speed (Table 4). The values of the selected error estimators (MAE, RMSE and NSE) are coloured; green represents the best result, red represents the worst result, and yellow and orange colours represent intermediate results. Position estimators (median) and dispersion estimators (MAD) were calculated from the 48 hourly data forecast analyses in the six scenarios. Medians for individual error estimators were also calculated based on the six scenarios included in the analysis.

Analysis of the above table allows for several observations to be made. It can be seen that, for average values, the error estimators for the six scenarios are most favourable for days representing the summer and autumn seasons and least favourable for the days representing the spring and winter seasons. The last one is particularly unfavourable. Similar results were obtained for NSE.

The NSE indicator confirms the obtained pattern of error analysis results, with values close to 1 in scenario 4. The other scenarios achieved a very good result of at least 0.8.

The above analysis is complemented by a ranking made for 4 seasons for the three analyzed error estimators; MEA, RMSE and NSE. The ranking compared the results of error estimators between 4 seasons. The result of the total ranking is presented in the table below (Table 3). The lower the scores, are favourable.

Table 3.
Results of ranking calculations for the air temperature at 2 m above ground level

Error estimator	Spring	Summer	Autumn	Winter
MAE	21	11	12	16
RMSE	21	11	13	15
NSE	22	11	9	18
Sum	64	33	34	49

The result of the ranking clearly indicates that taking into account the sum of the ranks of the three error estimators for five scenarios, it can be seen that the summer-autumn season is more favourable in the ranking compared to the winter-spring season.

The results of similar analyses for wind speed are presented in Table 4.

Analysis of the above table shows that for average values of these error estimators for scenarios 1,2,3 and 5 are most favourable for days representing the summer and autumn seasons and least favourable for the days representing the spring and winter seasons. The last one is particularly unfavourable. Similar results were obtained for NSE. The results obtained for scenario 4 shove that the most favourable error estimator values are for the days representing the autumn and winter seasons.

Differences in error estimator values are observed between different scenarios. For example, the Nasha-Sutcliffe model coefficient (NSE) obtains the least favourable values for the S3 scenario, which is especially noticeable in the case of wind speed, where it reaches an average value of -0.125.

The above analysis is complemented by a ranking made for 4 seasons for the three analysed error estimators; MAE, RMSE and NSE. The ranking compared the results of error estimators between 4 seasons. The result of the total ranking is presented in the table below (Table 5).

Table 4.
Results of error calculations for wind speed at 10 m above ground level

Scenario	Error	Spring	Summer	Autumn	Winter	Position	Dispersion
Domain	Estimator	2021-03-26	2021-06-14	2021-09-11	2021-12-26	estimator	estimator
S1 - D1	ME	0.04552	-0.09541	0.00715	-0.24460	-0.04413	0.10447
S1 - D1	MAE	0.54591	0.51398	0.50743	0.59942	0.52995	0.02853
S1 - D1	MSE	0.78455	0.57648	0.56932	0.87667	0.68051	0.15955
S1 - D1	RMSE	0.88575	0.75926	0.75453	0.93631	0.82250	0.09727
S1 - D1	PBIAS	1.39532	-3.01777	0.30005	-8.12228	-1.35886	3.27142
S1 - D1	NSE	0.80005	0.87754	0.79459	0.76294	0.79732	0.02751
S2 - D2	ME	0.10079	-0.09948	-0.00108	-0.71883	-0.05028	0.14846
S2 - D2	MAE	1.01678	0.60016	0.74042	1.22122	0.87860	0.30884
S2 - D2	MSE	1.93103	0.62474	0.91707	2.59673	1.42405	0.96835
S2 - D2	RMSE	1.38962	0.79041	0.95764	1.61144	1.17363	0.44419
S2 - D2	PBIAS	2.48116	-4.50417	-0.05206	-29.78070	-2.27811	5.17823
S2 - D2	NSE	0.49164	0.61744	0.07939	-0.38534	0.28551	0.39886
S3 - D3	ME	0.15659	0.23034	0.15476	-1.50933	0.15567	0.05603
S3 - D3	MAE	1.23058	0.58398	0.77824	1.58982	1.00441	0.47932
S3 - D3	MSE	2.75895	0.57833	0.97517	4.35197	1.86706	1.61650
S3 - D3	RMSE	1.66101	0.76048	0.98751	2.08614	1.32426	0.66756
S3 - D3	PBIAS	3.72723	10.55682	6.47603	-42.18699	5.10163	5.06278
S3 - D3	NSE	0.13992	0.54619	-0.38993	-1.58140	-0.12500	0.69395
S4 - D2D3-A	ME	0.00936	0.01620	0.00748	0.00544	0.00842	0.00291
S4 - D2D3-A	MAE	0.06646	0.06343	0.04027	0.03679	0.05185	0.01941
S4 - D2D3-A	MSE	0.01368	0.01408	0.00536	0.00438	0.00952	0.00647
S4 - D2D3-A	RMSE	0.11696	0.11865	0.07319	0.06618	0.09508	0.03370
S4 - D2D3-A	PBIAS	0.22293	0.74220	0.31295	0.15205	0.26794	0.11927
S4 - D2D3-A	NSE	0.99573	0.98896	0.99235	0.99740	0.99404	0.00374
S4 - D2D3-U	ME	0.00279	0.01451	0.00565	0.00092	0.00422	0.00351
S4 - D2D3-U	MAE	0.04670	0.06961	0.02951	0.03325	0.03998	0.01275
S4 - D2D3-U	MSE	0.00690	0.01859	0.00452	0.00354	0.00571	0.00249
S4 - D2D3-U	RMSE	0.08309	0.13636	0.06721	0.05949	0.07515	0.01749
S4 - D2D3-U	PBIAS	0.06898	0.74381	0.25296	0.01807	0.16097	0.17412
S4 - D2D3-U	NSE	0.99777	0.98615	0.99553	0.99886	0.99665	0.00247
S5 - D3	ME	-0.11504	-0.03748	0.01994	-0.11468	-0.07608	0.05749
S5 - D3	MAE	0.76975	0.36655	0.30792	0.40795	0.38725	0.07415
S5 - D3	MSE	1.30383	0.22637	0.18145	0.38284	0.30460	0.14929
S5 - D3	RMSE	1.14185	0.47579	0.42597	0.61874	0.54726	0.14290
S5 - D3	PBIAS	-2.73827	-1.71773	0.83434	-3.20534	-2.22800	1.10277
S5 - D3	NSE	0.59354	0.82237	0.74137	0.77292	0.75715	0.06004
Mediana	ME	0.04552	-0.03748	0.00748	-0.24460	-0.01500	0.06153
Mediana	MAE	0.76975	0.51398	0.50743	0.59942	0.55670	0.06819
Mediana	MSE	1.30383	0.57648	0.56932	0.87667	0.72658	0.22784
Mediana	RMSE	1.14185	0.75926	0.75453	0.93631	0.84779	0.13475
Mediana	PBIAS	1.39532	-1.71773	0.31295	-8.12228	-0.70239	2.30770
Mediana	NSE	0.59354	0.82237	0.74137	0.76294	0.75216	0.06004

[6]Median (central value)
[7]MAD – median deviation around the median

Table 5.
Results of ranking calculations for wind speed at 10 m above ground level

Error estimator	Spring	Summer	Autumn	Winter
MAE	20	13	9	18
RMSE	19	14	10	17
NSE	14	12	18	16
Sum	53	39	37	51

The result of the ranking clearly indicates that taking into account the sum of the ranks of the three error estimators for five scenarios, it can be seen that the summer-autumn season is more favourable compared to the winter-spring season.

Discussion of analysis results for scenario 6

In scenario no. 6, the modelling results for the square of the D3 domain, in which the point representing the Planetarium Station is located and were compared with the results of measurements from the above station. The results cover a period of 8 months. The below tables 6 and 7 present the results of statistical analyses for the temperature.

Table 6.
Statistics of air temperature at 2 m height for measured and modelled data for the period 1.07.2021-28.02.2022

Id.	Parameter	PS_T2	D3_FDDA_PS_T2
1	N	728	728
2	Minimum	-11.200	-12.130
3	Maximum	30.800	33.480
4	Arithmetic mean	9.226	8.305
5	Standard deviation	8.713	9.383
6	Median	8.050	7.090
7	MAD	10.304	10.571

Table 7.
Statistics of air temperature differences at a height of 2 m calculated for measured data and model data. Data from the Planetarium Station - reference data

Id.	Error estimator	Result
1	ME	0.9212
2	MAE	1.6792
3	MSE	4.6590
4	RMSE	2.1585
5	PBIAS	9.9845
6	NSE	0.9385

The results of the analysis performed in this scenario allow observing that the central measures (mean and median) of the temperature (Table 6) for the measured data are higher than the central temperature measures of the modelled data. In turn, the temperature dispersion measures for the measured data are lower than the position measures of the modelled data. It should be noted, however, that these differences are not too large. The positive values of the ME and PBIAS estimators confirm the higher values of the measured data compared to the modelled data. The MAE and RMSE values for air temperature are less than 1/2 of the standard deviation, indicating a moderate level of divergence. The value of the NSE parameter, which is 0.9385, indicates a very good match between the two analysed series of data. A percentage deviation of about 10 percent and an average absolute error (MAE) or RMSE of about 1.7-2.2°C indicate an acceptable error level. It should be noted that there are compare point values with values representing a larger area. Most likely, with the density of the network of squares, the matching error will decrease.

The below tables 8 and 9 present the results of the statistical analyses of the differences in wind speed between modelled and measured values of this parameter.

Table 8.
Statistics of wind speed at 10 m height for measured and modelled data for the period 1.07.2021-28.02.2022

Id.	Parameter	PS_WS10	D3_FDDA_PS_WS10
1	N	716	716
2	Minimum	0.000	0.090
3	Maximum	6.000	16.890
4	Arithmetic mean	1.378	4.375
5	Standard deviation	0.928	3.043
6	Median	1.100	3.545
7	MAD	0.741	2.513

Table 9.
Statistics of wind speed differences at a height of 10 m calculated for measured and modelled data. Data from the Silesian Planetarium station - reference data

Id.	Error estimator	Result
1	ME	-2.9971
2	MAE	3.0414
3	MSE	14.8203
4	RMSE	3.8497
5	PBIAS	-217.5056
6	NSE	-16.2466

In the case of wind speed, the differences in the measures of position (mean and median) and scattering (standard deviation, median deviation) are already significant. Above model data measures are on aver-

age 3.3 times higher than those measures of measurement data. Negative values of ME and PBIAS estimators confirm lower values of measurement data compared to model data.

The MAE and RMSE values for wind speed are much higher than 1/2 of the standard deviation, indicating a large level of divergence. A negative NSE value of about 10,24 indicates a bad match between the modelled data and the measured data.

3. CONCLUSIONS

The conducted research and analyses showed that the verification of the Weather Research and Forecasting Model (WRF) for the domain of Silesian Voivodeship and Upper Silesia Metropolitan Region in the range of the air temperature and wind speed can be assessed as positive and it can be stated that system used for forecast meteorological parameters in the projects InfoSMOG-MED and SMART using the WRF model in terms of air temperature and wind speed forecast with sufficient accuracy, reproducing real conditions. However, when the seasonal changes in error level were compared it can be seen that, on average, the values of three error estimators (MAE, RMSE and NSE) for the five scenarios were most favourable for days representing the summer and autumn seasons and least favourable for days representing the spring and winter seasons. The last one is particularly unfavourable. This pattern is corroborated by the results of NSE.

Comparing the effect of data adjustment on the final result for 3 domains (scenarios 1, 2, 3) it can be seen that the highest influence pertains to domains no. 2 and 3. This means that for the domain D1 (nationwide) the correction of model data with measurement data can be omitted due to small differences between the model data without correction and the model data with correction. In the case of domains D2 (Silesian Voivodeship) and D3 (Upper Silesia Metropolitan Region), it is necessary to correct model data with measured data from synoptic and METAR stations.

The average of the aggregated errors (MEA, MSE and RMSE) for the four seasons is 1.05, 1.65 and 1.64 °C for the D1, D2 and D3 domains, respectively.

It shows a slight difference in aggregate error values between the D2 and D3 domains, which indicates that the density of the calculation grid in the model does not improve the quality of the air temperature forecast while increasing the time required to perform the forecast calculations. This conclusion is supported by an analysis of the differences in scenario four.

The differences in the values of the forecasted temperature (obtained on the basis of modelled data nationwide and European domains) for scenario 5 and domain D3 are small. The use of European data for correction of the model results to a small extent overestimating the forecasted temperature values in relation to the forecast values using Polish measured data for correction.

In scenario 6 the measured data were compared with modelled data for the grid in which the Planetarium climate station is located. The percentage error of PBIAS obtained for the temperature was on the level of about 10%, while the average of aggregated errors (MAE, MSE and RMSE) was on the level 2.8 °C. It shows that the modelled data are underestimated.

When it comes to wind speed, it can be seen the greater differences in relation to air temperature. For scenarios 1, 2, 3 and domains D1, D2, D3, the error increases with the increase of the density of the model calculation grid. The average of the aggregate errors (MEA, MSE and RMSE) calculated for the four seasons was 0.69 m/s (domain D1), 1.2 m/s (D2) and 1.53 m/s (D3), respectively. In the case of the third domain, the differences between the data with and without correction are so large that the value of the NSE indicator is less than 0, i.e. -0.321.

Particularly large discrepancies were obtained for the winter season and also, to a lesser extent, for the spring season. For winter, the PBIAS value is -42.19%, which means that without correction, the modelling results are very overstated. The errors calculated for scenario 4 are small for both the corrected data and the non-adjusted model data. The differences obtained in the 5th scenario are moderate and are around 0.5m/s (average of aggregated errors).

Scenario 6 shows a high level of discrepancy between modelled and measurement data for wind speed. The NSE is approximately -16.2 and the PBIS is at the level -217.5%. The results obtained indicate that the selected station is not suitable for correcting the model data for wind speed.

The final conclusion is that continuation of the research is necessary on the improve the wind speed forecast data during the autumn and winter seasons and improve the wind speed forecast data in a particular location due to forecasted data for the calculated grid.

It also can be concluded that reducing the mesh of the model calculation does not reduce the error of

the forecasted values of meteorological parameters in this case air temperature and wind speed.

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