Validation of meteorological forecasts in fine spatial and temporal resolution produced as an input for dispersion models

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Abstract: In conditions of complex terrain, modelling of air pollutant dispersion still has a number of scientific challenges. Ideally, appropriate meteorological data should be available for modelling. Unfortunately, for many purposes, there is no time to carry out suitable measuring campaigns. Therefore the results of prognostic weather forecasts (NWP models) are being widely used. However, these models still have quite a few disadvantages when their results are used as input for dispersion models over complex terrain. The study presents the validation of the quality of the weather forecasts in the surroundings of the Nuclear Power Plant Krško in Slovenia, an area with highly complex terrain and the resulting complex meteorological characteristics. The forecast is available for a horizontal resolution of 2 km and half hour temporal interval and seven days in advance. The predicted meteorological parameters are validated using the measured meteorological parameters.

Keywords: validation, weather forecast, fine spatial and temporal resolution, complex terrain

Reference to this paper should be made as follows: Mlakar, P., Kokal, D., Grašič, B., Božnar, M. Z., Gradišar, D. and Kocijan, J. (xxxx) 'Validation of meteorological forecasts in fine spatial and temporal resolution produced as an input for dispersion models', *Int. J. xxxxxxxxxxx xxxxxxxxxxx*,

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Primož Mlakar received his PhD in 1996 from the University of Ljubljana,Slovenia. He started his research work at the Jozef Stefan Institute, Ljubljana in 1983 and continued at AMES d.o.o., where he was an Assistant Director. From 2007, he has worked in the research-oriented company (SME) MEIS as a leader of several projects and a research group, where he is also the coowner. He is the leader of the MEIS research unit.

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This paper is a revised and expanded version of a paper entitled "Validation of the performance of meteorological forecasts in fine spatial and temporal resolution designed as an input for dispersion models" presented at the 17th International conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes. Budapest, Hungary, May 9-12, 2016.

1 Introduction

In conditions of complex terrain, modelling of air pollutant dispersion is a very demanding task, which still has a number of scientific challenges. Ideally, appropriate meteorological data should be available for modelling, which should include the measurements of vertical profiles of wind and temperature, and not just ground-based meteorological information. Unfortunately, for many purposes, such as for example for studies of the impact of industrial plants on the surrounding atmosphere, where it is necessary to analyse the data for at least one year, there is no time to carry out suitable measuring campaigns.

Therefore, instead of measuring the profile and ground-level meteorological parameters, the results of prognostic weather forecasts (NWP models) are being widely used (Mircea et al., 2014, Moussafir, 2014). However, these models still have quite a few disadvantages when their results are used as input for dispersion models over complex terrain.

This paper dedicates special attention to a qualitative wind forecast, which is a basic parameter in pollution modelling. An additional parameter, which can lead to an incorrect assessment of the stability of the atmosphere with the wrong forecast, is the forecast of global solar radiation (Golder, 1972, Madronich and Flocke, 1999).

The aim of this paper is to demonstrate the quality of the forecast of meteorological parameters; which are important for modelling air pollutants' expansion; on an actual example of Slovenia, which is a country with a very complex terrain in the slipstream on the sunny side of the Alps.

Our final goal is that on harmonization initiative we should harmonize the criteria on how well should prognostic meteorology be prepared when it is used for air pollution dispersion modelling.

2 Methodology

When modelling the meteorological parameters above a complex terrain, we must be aware in the first place that the modelled meteorological description of the atmosphere must be a good match with the actual description in all three spatial dimensions, namely also vertically. Therefore, we are required to use an area where we dispose the quality measurements of meteorological parameters in the higher layers of the atmosphere in order to validate the modelled meteorological parameters.

Thus, we chose the area in Slovenia in the vicinity of the town of Krško because the Krško Nuclear Power Plant is located there, which takes exemplary care of its meteorological measuring system (Mlakar et al., 2014). This measuring system includes four ground level meteorological stations at the bottom of a half-open basin, and an additional SODAR station, which provides quality measurements of the wind directions and speed up to 500m above the ground. A MEIS weather forecast system (Mlakar et al., 2015), which gives the forecast for Slovenia for 7 days ahead in half-hour steps, and with a cell sized to 14 km, and subsequently it gives the forecast for seven days ahead in half-hour steps with the cell sized to 2 km horizontally for a narrower area in the vicinity of Krško is validated. The forecast has been compared to the forecast of the MEIS Kooreg model (Božnar et al., 2012, Mlakar et al., 2012), which gives the forecast for the entire

Slovenia for 2 days ahead with a cell sized to 4 km horizontally. The forecasts in all the examples is performed with the WRF model and global American input GFS data.

We focused on the first day of the forecast in the validation for all three modules. However, we are of course aware that in the event of the validation of the forecast for several days ahead, the quality of the forecast would diminish. According to our opinion, the forecast validation for the first day is also a solid assessment for the validation of reanalyses. Reanalyses in general may provide better results than the real forecasts, however, they are important because they are a traditional source of meteorological data for the events, when the atmospheric dispersion modelling is performed for a period that has already passed (and not in a continuous on-line mode, as is the case at the Krško Nuclear Power Plant).

We used one year of forecasts and one year of measured data from the meteorological station at the location of the Krško Nuclear Power Plant, SODAR provided data only for six months within the chosen one-year-period interval due to its breakdown. Firstly, we validated the forecasts of the basic meteorological quantities for the bottom layer of the atmosphere. Validation of precipitation is a particular problem. Validation concluded with the validation of wind at higher altitudes. We use the traditional numeric estimators: RMSE (root-mean-square error), PCC (Pearson's correlation coefficient), MFB (mean fractional bias), FAC2 (The factor of the modelled values within a factor of two of the observations), NMSE (normalized mean-squared error) as defined in the papers by Kocijan et al. (2016) and Poli and Cirillo (1993) and R^2 (coefficient of determination) that was calculated as PCC^2.

3 Results

In tables 1–12, we firstly gathered the values for the basic meteorological parameters, predicted with three different configurations of the WRF model (the configurations are marked based on the horizontal size of the cells, and additionally with an internal code of the WRF configuration).

In figures 1–9 scatter plots (measurements vs. model results) of some selected parameters for all three different configurations of the WRF model are presented in order from best to the worst correlation.

For the parameters: **air temperature at 2m and 10m above the ground, relative air humidity at 2m**, air pressure and global solar radiation, which are relatively easy to predict, we can see that the WRF 2 km and WRF 4 km configurations are very similar, and that they both achieved extremely good values. There are major discrepancies with the WRF 14 km configuration, as a 14 km large cell in the horizontal direction is substantially a too homogeneous area at the ground, which does not see the proper characteristics of the atmosphere over highly complex terrain. The values of the estimator in the **precipitation analysis** are bad, but for a proper validation, we would have to analyse, for example, radar measurements and compare them with the forecast models. In our case, we validated the model by a spot metering of the precipitation at the location of the Krško Nuclear Power Plant. The problem with the precipitation is the extremely stochastic nature of storms, and additionally there is also some shift in space and time even between forecasts and the actual front passage. Due to averaging through a larger cell, the WRF 14 km configuration is better than the other two with precipitation. In the analysis of the ground wind for the wind speed at the location of the Krško Nuclear

Power Plant, the WRF 2 km and WRF 4 km configurations are again more successful, and they are exchanging the title as the best configuration based on the estimator. Thus, Figure 8 additionally also displays a scatter plot for all three configurations. It is evident from this chart that the WRF 2 km makes less exaggerations than the WRF 4 km. A forecast of a too strong ground wind over a complex terrain is a known issue of our NWP models. This issue is very disturbing for atmospheric dispersion modelling as a stronger wind means better dispersion in general. Therefore, the WRF 2 km is the best configuration for atmospheric dispersion modelling. We only took into consideration the values expressed in angle degrees for the verification of the wind direction, and we did not perform special analyses of the circular nature of the wind direction. The verification of the forecast of wind at higher altitudes of 220 m and 440 m respectively with the SODAR measurements (as shown in Figures 6 and 7) has shown that matching the forecasts of wind improves with height, which confirms the usefulness of forecasts of wind in the higher layers for the purpose of air pollution modelling. With the altitude, also the difference between the success of an individual WRF configuration decreases, where we are able to achieve good results even with the use of a lower spatial resolution.

4 Conclusions

This paper presents the validation of forecasting the basic meteorological parameters, used for atmospheric dispersion modelling. The validation has been carried out with the measured data at the location of the Krško Nuclear Power Plant in Slovenia with a very complex terrain, which makes the modelling much more difficult. Both ground measurements and also SODAR measurements of the vertical profile of the wind were used for the validation. The values for the first day of the forecast are subject to validation. We have shown that the forecasts are very good most of the time, we only have to be slightly more careful in the interpretation of the wind direction, and the speed of the ground wind, and also with the interpretation of precipitation, which is generally still a major challenge for the NWP models (Nasrollahi et al., 2012).

Acknowledgement

The authors acknowledge the projects (Development of the meteorological measurements based model for solar energy availability estimation in Slovenia, L1-4154, Development and implementation of a method for on-line modelling and forecasting of air pollution, L2-5475, Method for the forecasting of local radiological pollution of atmosphere using Gaussian process models, L2-8174, Assesment of natural and antropogenic processes in micrometeorology of Postojna cave system by numerical models and modern methods of data aquisition and transfer, L2-6762) were financially supported by the Slovenian Research Agency. We are grateful to the Nuclear Power Plant Krško for the meteorological data.

Author

Tables

Table 1. Temperature validation results at 2m

MODEL	PCC	RMSE	MFB	FAC2	NMSE	R^2
WRF 4 x 4	0.97	2.38	-0.047	0.87	0.042	0.94
WRF 2 x 2	0.97	2.52	-0.073	0.86	0.048	0.93
WRF 14x14	0.97	2.75	-0.127	0.85	0.060	0.94

Table 2. Temperature validation results at 10m

MODEL	PCC	RMSE	MFB	FAC2	NMSE	R^2
WRF 4 x 4	0.97	2.55	-0.042	0.87	0.048	0.94
WRF 2 x 2	0.96	2.77	-0.114	0.86	0.057	0.93
WRF 14x14	0.97	3.01	-0.198	0.84	0.071	0.93

Table 3. Relative air humidity validation results at 2m

MODEL	PCC	RMSE	MFB	FAC2	NMSE	R^2
WRF 4 x 4	0.68	15.9	-0.065	0.99	0.044	0.46
WRF 2 x 2	0.71	14.6	-0.034	0.99	0.036	0.50
WRF 14x14	0.72	13.9	-0.010	0.99	0.032	0.52

Table 4. Air pressure validation results

MODEL	PCC	RMSE	MFB	FAC2	NMSE	R^2
WRF 4 x 4	0.994	2.09	-0.002	1.00	4.4E-06	0.99
WRF 2 x 2	0.991	4.42	-0.004	1.00	2.0E-05	0.98
WRF 14x14	0.918	18.6	-0.019	1.00	3.5E-04	0.84

Table 5. Global solar radiation validation results

MODEL	PCC	RMSE	MFB	FAC2	NMSE	R^2
WRF 4 x 4	0.87	158	0.112	0.70	0.219	0.75
WRF 2 x 2	0.86	161	0.072	0.69	0.229	0.74
WRF 14x14	0.87	160	0.116	0.70	0.222	0.75

Table 6. Precipitation validation results

MODEL	PCC	RMSE	MFB	FAC2	NMSE	R^2
WRF 4 x 4	0.20	0.43	-0.017	0.30	74.5	0.04
WRF 2 x 2	0.18	0.44	-0.019	0.34	86.2	0.03
WRF 14x14	0.30	0.39	0.056	0.26	50.5	0.09

Table 7. Wind velocity validation results at the height of 10m

MODEL	PCC	RMSE	MFB	FAC2	NMSE	R^2
WRF 4 x 4	0.58	1.50	0.305	0.60	0.679	0.33
WRF 2 x 2	0.52	1.44	0.234	0.58	0.672	0.27
WRF 14x14	0.54	1.66	0.508	0.56	0.723	0.30

Table 8. Wind direction validation results at the height of 10m

MODEL	PCC	RMSE	MFB	FAC2	NMSE	R^2
WRF 4 x 4	0.45	105	-0.101	0.71	0.349	0.20
WRF 2 x 2	0.41	111	-0.056	0.71	0.362	0.17
WRF 14x14	0.41	115	-0.153	0.67	0.418	0.17

Table 9. Wind velocity validation results at the height of 220m (SODAR measurements)

MODEL	PCC	RMSE	MFB	FAC2	NMSE	R^2
WRF 4 x 4	0.65	3.99	0.507	0.57	0.685	0.42
WRF 2 x 2	0.64	4.76	0.628	0.49	0.858	0.40
WRF 14x14	0.65	3.89	0.476	0.57	0.667	0.43

Table 10. Wind direction validation results at the height of 220m (SODAR measurements)

MODEL	PCC	RMSE	MFB	FAC2	NMSE	R^2
WRF 4 x 4	0.62	89.4	-0.021	0.77	0.330	0.39
WRF 2 x 2	0.60	91.6	-0.006	0.78	0.349	0.36
WRF 14x14	0.60	91.4	-0.030	0.77	0.335	0.36

Table 11. Wind velocity validation results at the height of 440m (SODAR measurements)

MODEL	PCC	RMSE	MFB	FAC2	NMSE	R^2
WRF 4 x 4	0.65	4.78	0.303	0.71	0.422	0.42
WRF 2 x 2	0.70	4.94	0.371	0.68	0.428	0.49
WRF 14x14	0.71	4.36	0.287	0.72	0.359	0.51

Table 12. Wind direction validation results at the height of 440m (SODAR measurements)

MODEL	PCC	RMSE	MFB	FAC2	NMSE	R^2
WRF 4 x 4	0.71	80.9	-0.045	0.83	0.234	0.51
WRF 2 x 2	0.72	77.9	-0.026	0.83	0.220	0.52
WRF 14x14	0.71	78.9	-0.029	0.82	0.226	0.51

Author

Figures

Figure 1. Scatter plot for air pressure

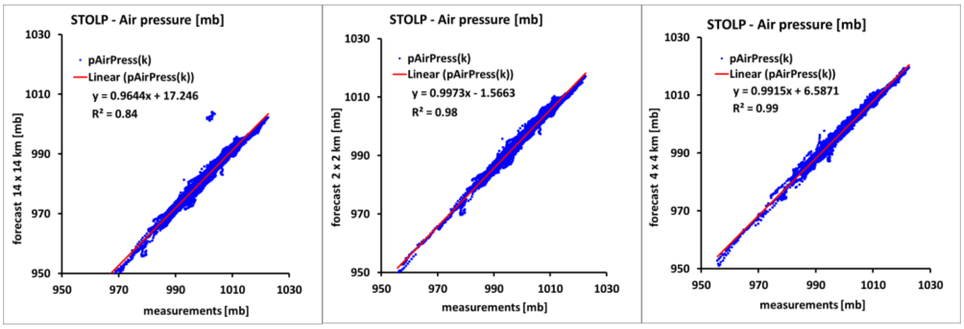

Figure 2. Scatter plot for air temperature at 2 m

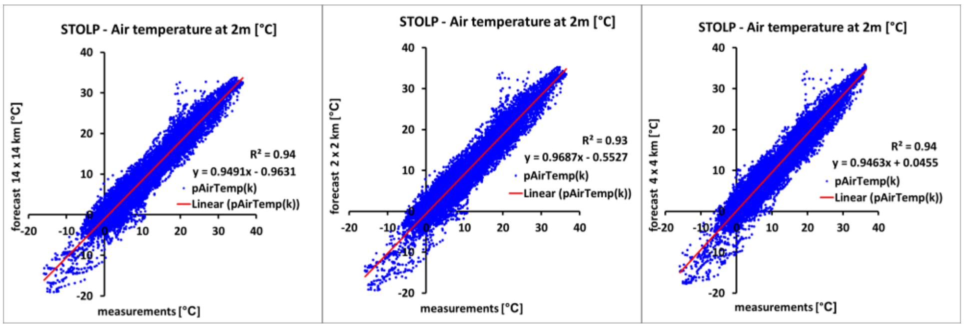

Figure 3. Scatter plot for air temperature at 10 m

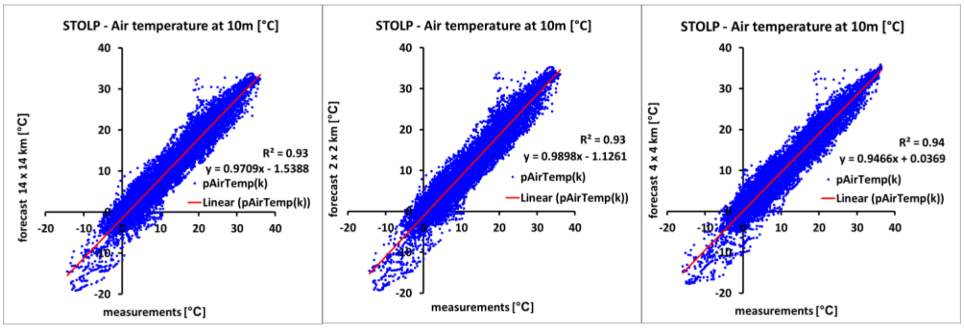

Figure 4. Scatter plot for global solar radiation

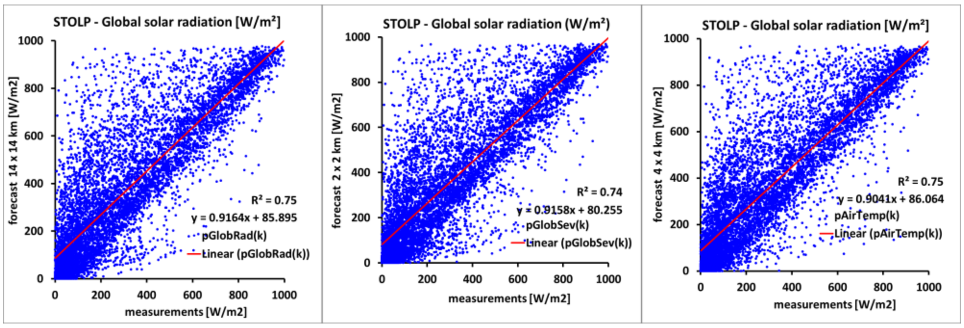

Figure 5. Scatter plot for relative air humidity at 2 m

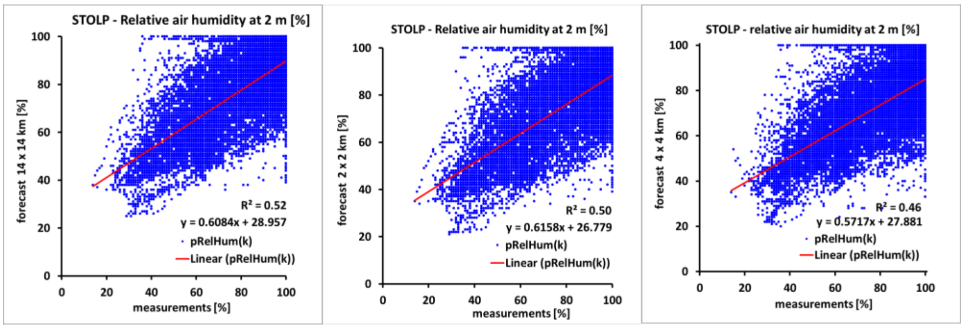

Figure 6. Scatter plot for wind speed at 220 m (SODAR measurements)

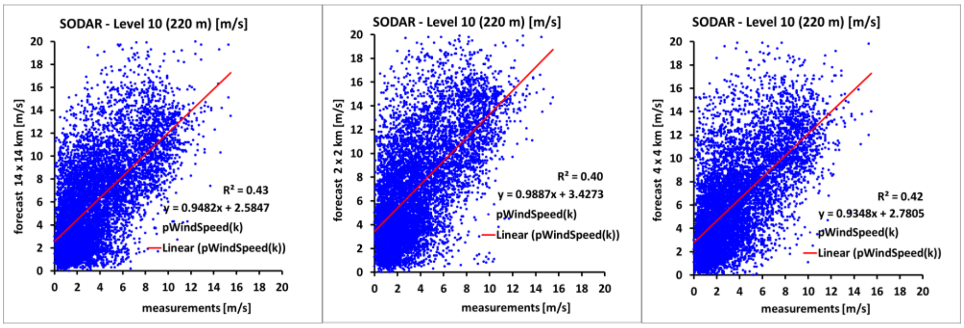

Figure 7. Scatter plot for wind speed at 440 m (SODAR measurements)

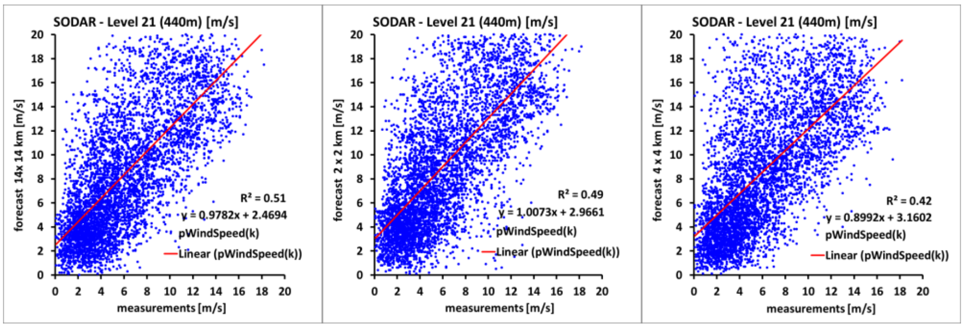

Figure 8. Scatter plot for ground wind speed at 10 m

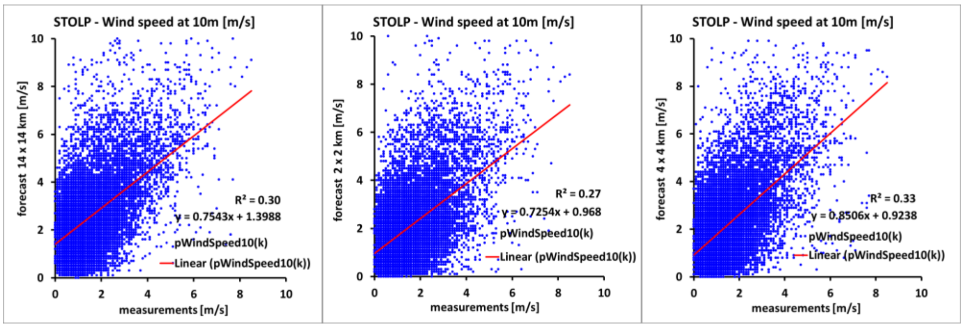

Figure 9. Scatter plot for precipitations