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SHORT-TERM FINE RESOLUTION WRF FORECAST DATA VALIDATION IN COMPLEX TERRAIN IN SLOVENIA

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Abstract: Almost all industry in Slovenia lies in highly complex terrain characterized by low winds and thermal inversions. Existing major industrial facilities must obtain environmental permits under the IPPC that includes a detailed analysis of the facility's impact on the air. To model the impact of their emission to the ambient air they should measure one year of meteorology and ambient air pollution. It is recommended to measure meteorology using a standard ground level meteorological-station to obtain a time series of wind measurements and stability classes. Many articles show that one standard meteorological-station in highly complex terrain is not enough to be used to model air pollution with the desired precision. Around the plant in such terrain there should be a few ground level meteorological-stations, SODARs and RASSs. The configuration depends on the site. These are wishes that cannot usually be achieved. We tested a different solution: WRF's one day short-term forecasts at 4km and half hour resolution running every day to obtain 3D meteorological fields. We obtained over one year a data base of weather profiles from over the whole of Slovenia. We compared these data with the different ground meteorological-stations located in the basins, valleys and on the hills. The results show an unfavourable correlation with ground level meteorological stations, especially in basins and valleys, and a better correlation with stations situated at the top of hills. For the future we prepare comparison with radiosonde data and SODAR. At the end we will present some our experience on how to use these WRF data to improve the accuracy of the results of the air pollution model.

Based on this example a novel approach to the terrain complexity characterization of the area under examination is defined – "height and length of Topographic complexity, hlTc".

Key words: *meteorological forecast data validation, height and length of Topographic complexity hlTc, measurements, radiosonde, RASS, SODAR, WRF, short-term forecast*

INTRODUCTION – SLOVENE TOPOGRAPHY

We describe in this article a comparison of the prognosis of meteorological parameters important for the calculation of the dispersion of pollutants in the air using meteorological measurements.

Slovenia lies on complex terrain surrounded on the north west by the Alps and on the south by the Dinaric Alps. Most of the remaining terrain is covered with valleys and basins situated between hills of varying heights. There are few larger plains – enclosed basins – and only one wider plain on the north east, which opens into the Pannonian basin. Due to the complex terrain, gentle winds and temperature inversions are characteristic for most of the territory. These are also the main reasons for the slow dispersion of the concentration of emissions in the air, which causes, in unfavourable weather conditions, periods of significant air pollution.

We have established a regional system for air pollution diagnosis for one of the regions, Zasavje, which lies along the canyon through which the Sava river crosses the high hills in central Slovenia. The detailed characteristics of the system are described in the article on this conference (Mlakar, P., M. Z. Božnar, B. Grašič and G. Tinarelli, 2011). We require for the system a prognosis of the wind profile and temperatures in this domain at least for the higher layers of the atmosphere, as, unfortunately, SODAR or RASS measurements are not available at this time, but there are many ground-based meteorological stations available. The prognostic profile and ground-based meteorological stations are first combined as input data in the Swift 3D mass consistent modelling system, as this is required to achieve an adequate local resolution (200m) for calculating dispersion. As dispersion modelling can only be as accurate as the input meteorological data, our first step was to validate the prognosticated meteorological parameters (profile) obtained by applying the WRF model to the wider Slovenian area.

Validation is a necessary prerequisite for the reliable use of modelling results.

WRF is also validated above complex terrain (examples of such studies are Zarauz, J. and R. Pasken, 2010 and Koracin et al, 2007), but the meteorological characteristics are conditional upon the complex terrain in the central Sava valley and are different from the wider Slovenian area, justifying an independent analysis.

Our initial hypothesis is that the high complexity of the area under study constitutes a border area for the routine use of WRF for a small-scale fine-resolution application. In the continuation, we will present the validation of the prognosticated parameters by comparison to the measured meteorological parameters.

PURPOSE OF THE STUDY – A CASE ANALYSIS OF HOW WELL WRF REPRODUCES THE WEATHER PARAMETERS IMPORTANT FOR THE PREDICTION OF DISPERSION IN THE AIR

The final purpose of the study is to present the validation for a longer period in multiple seasons and in different meteorological situations, but the study has not yet been finished, and we are thus presenting the preliminary results for multiple cases selected in the last year of the system's operation. Although our main goal is to establish the quality of the representation of the meteorology parameters in the central Sava valley and in central Slovenia, we will also show some comparisons for other locations across Slovenia.

WRF APPLICATION TO SLOVENE TERITORY – WEATHER PROGNOSIS, DATA EXPORT, DAILY FORECASTING

We applied the WRF Weather Research & Forecast model, which consists of two meso models ARW (Advanced Research WRF), maintained by NCAR, and the NMM (Non-hydrostatic Mesoscale Model), maintained by NOAA/NCEP. The model frame (data acquisition, data processing) is common; the difference is only in the dynamic core. Both models were tested in different resolutions and with different numbers of nesting on a four core computer (Dual Core Quattro) with a 64 bit system Open SUSE. Boundary and initial data are provided by a global meteorological model GFS (NCEP centre from America). For our project, after an initial comparison, we chose ARW, which is intended for research, whereas NMM is intended for more routine weather prediction – we, however, are interested in more specific meteorological features. Due to the abundance of data, we initially decided to only store vertical profiles of the wind, temperatures and humidity above 30 places of interest in Slovenia for the purpose of validation and additional use. The configuration of the ARW model which has been running on a daily basis is as follows:

- two domains,
- duration of prediction: 2 days and 3 hours,
- a larger domain (central Europe): 101 × 101 cells in a resolution of 12 km per hour;
- a smaller domain (Slovenia with surroundings): 76 × 76 cells in a resolution of 4 km per 30 min.
- The model is run at 5:00 UTC, the simulation runs for 3 to 4 hours, and it is run again at 17:00 UTC.

We use the GrADS programming tool for the presentation and validation of the results of the prognostic model.

THE ANSWERS WHICH MUST BE SUPPLIED BY VALIDATION – IMPLEMENTATION OF AN INDEX FOR THE HEIGHT AND LENGTH OF TOPOGRAPHIC COMPLEXITY

When authors refer to the validation of prognostic meteorological models, they usually give the following data: the local resolution in the horizontal plane, the temporal resolution of the established averages, the geographic location and the time interval of the validation data.

What this data lacks for a simpler comparison of different validations and for establishing what kinds of terrains and domains the model is successfully validated and can be reliably used for routine purposes is a description of the complexity of the terrain and weather situations in the subject domain. The description is usually concluded with a scanty statement that the terrain is flat, slightly rolling or very complex.

But in our opinion, this is not enough. The ratio between the local resolution of a model and the complexity of the terrain in a domain is of vital importance. To put it simply, there is an important difference between a model having a resolution of 500m where valleys are 3,000m wide or where a canyon is only 600m wide. There are also important differences in height between the bottoms of valleys and basins and the tops of the hills in a domain.

What we wish to describe is comparable to a Fourier Analysis of periodic signals, where we search for the basic components of signals in a complete system of sine functions and must, of course, determine the frequencies and amplitudes and phases of individual components. If we wish to describe a function of two independent variables (such as the height of the terrain in relation to the geographical width and length), we can use a “2D-FT” – two-dimensional Fourier transform (PlanetMath.org, 2011). Using this method, the terrain can be described in full and the resulting spectrum is thus mathematically consistent and constitutes an accurate description of the terrain’s complexity. But considering the desired purpose, such an approach is an overly complicated opposite extreme in comparison with the scanty simple description mentioned above. On the other hand, the Digital terrain modelling and terrain analysis theory (Huaxing, LU, 2008) dictates several complicated statistical indexes, which are also overly complex for our purpose. The Cost Action 710 document (Finardi, S., M. G. Morselli and P. Jeannet, 1997) defines 7 classes, from flat terrain to very complex terrain, which is a very good descriptive classification, but the terrain complexity classes lack a numerical dimension.

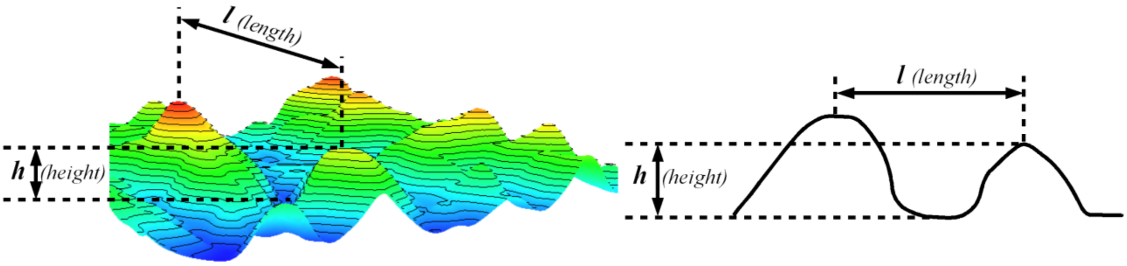

Figure 1. Illustration of the hlTc (height and length of Topographic complexity) index
(left: figure presents dimensions in 3D view of topography, right: figures presents dimensions in vertical cross-section).

We thus propose the introduction of a simple numerical index, the “height and length of Topographic complexity (hlTc)” index, defined as the pair of a characteristic combination of the width and height of the cross section of a basin, valley or canyon (the characteristic form of the terrain) for which we wish our model to accurately summarize the local meteorological characteristics important for dispersion (starting with wind and turbulence and temperature stratification).

The subject, the central Sava valley can thus be described as an example of very complex terrain (according to reference Finardi, S., M. G. Morselli and P. Jeannet, 1997) with an **hlTc = (0.4 km, 1.5 km).** This means that we want our modelling system to be able to describe the meteorological characteristics of the Sava canyon, where the differences in altitude between the bottom of the canyon and the tops of the hills are approximately 400m and the width of the canyon, measured from edge to edge, is approximately 1.5km. Of course, this cannot be achieved through the described application of WRF. This complexity can only be described using the Swift mass-consistent wind model, which uses WRF and the measurement results on the terrain of the central Sava valley. Using the application of WRF, we actually capture the hlTc indexes for the entire area of Slovenia, and we are interested in characteristics in the order of **hlTc = (0.5km, 20km), which we wish to represent through the application of WRF with a horizontal resolution of 4km, which, at first glance, is possible.** With this method of terrain description, **readers of the study will be able to quickly and unambiguously compare the model's resolution and terrain complexity and the consequential meteorological characteristics we wish to describe.** Of course, common sense dictates that the local resolution of the model must be at least several times greater than the length component of the hlTc index. The validation results show whether the ratio is large enough to provide good results.

VALIDATION RESULTS FOR THE CENTRAL SAVA VALLEY WITH THE REASONS FOR DEVIATIONS

The picture below presents the Zasavje region and its surroundings as seen by the WRF model (left) in 4km horizontal resolution and the inner domain of 20km by 20km as seen by the Swift model in 0.2km horizontal resolution. It is clear that WRF cannot cope with a complexity of inner domain characterized by **hlTc = (0.4km, 1.5km). The WRF application under validation can only cope with the complexity hlTc = (0.5km, 20km) of the outer domain. Therefore when using the profiles given by WRF for the Zasavje region we should not use the lower near- ground values but only the upper layers. The combination of such profile usage and ground measurements (when available) represent the optimal cost-effective modelling system for routine fine resolution modelling over the inner small domain.**

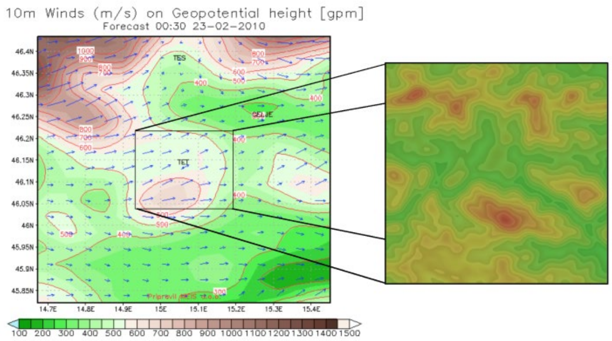

Figure 2. Zasavje region and its surroundings as seen by WRF model (left) in 4km horizontal resolution and the inner domain of 20 km by 20 km as seen by Swift model in 0.2 km horizontal resolution.

VALIDATION RESULTS FOR OTHER REGIONS OF SLOVENIA

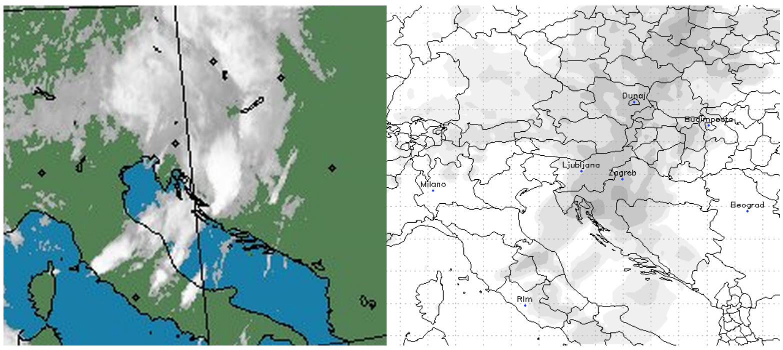

Figure 3. Excellent correlation between measured and forecasted clouds over central Europe for time interval 30.07.2010 at 09:00 hour (left: measured clouds from SEA Weather forecast and data, 2010, right: forecasted clouds by WRF)

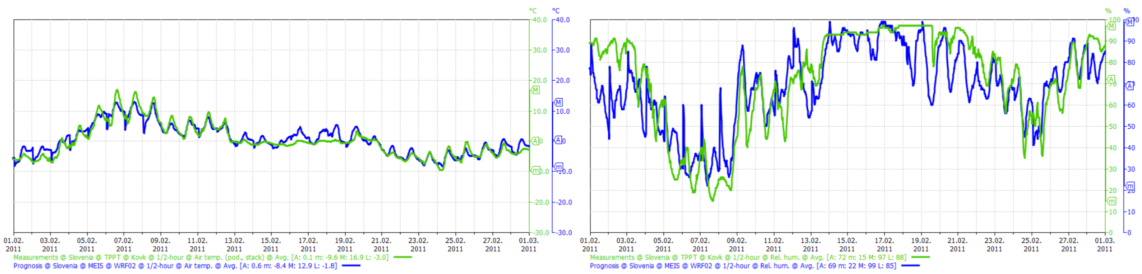

Figure 4. Very good correlation of temperature and relative humidity for Zasavje region for the February 2011 between measured temperature at station Kovk and forecasted temperature by WRF (measured data from SNSA Data portal, 2011).

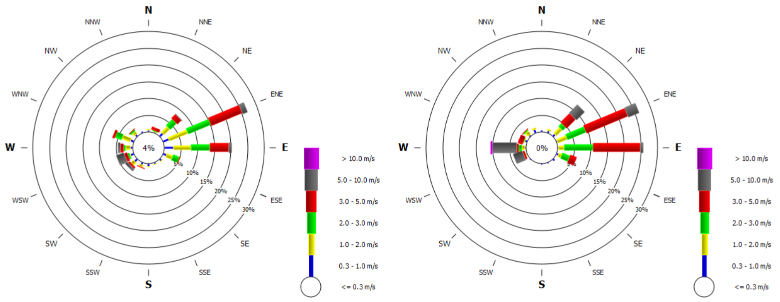

Figure 4. Excellent correlation between measured and forecasted wind in the Posavje region for the February 2011 (left: measured wind at meteorological tower on 70m near nuclear power plant, right: forecasted wind by WRF).

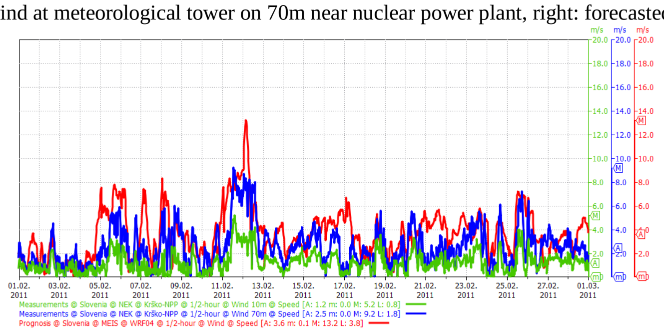

Figure 5. Wind for Posavje region is measured at the meteorological tower at heights 10 m, 40 m and 70 m. Comparison of wind speeds for the February 2011 as presented on the graph show that the correlation increases with the height. Comparison is made between measured wind at meteorological tower on two heights (10 m and 70 m) and forecasted wind by WRF (measured data from SNSA Data portal, 2011).

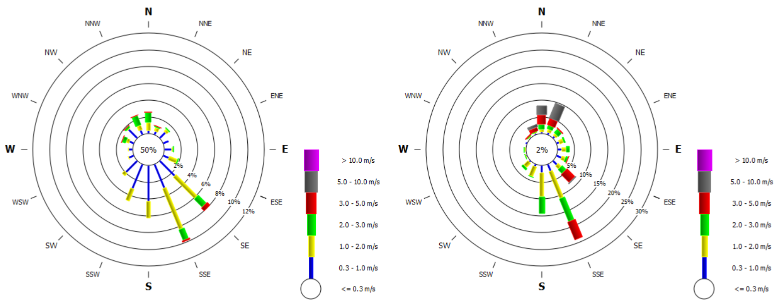

Figure 6. Relatively good correlation between measured and forecasted wind in the Šaleška region for the February 2011 (left: measured wind at 10 m station Ugreznine, right: forecasted wind by WRF).

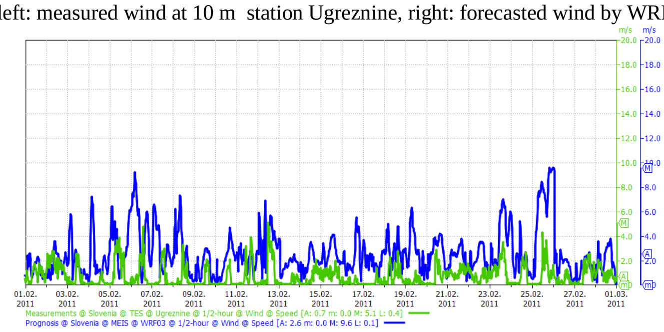

Figure 7. Comparison of wind speed for Šaleška region for the February 2011 between measured wind at 10m station Ugreznine and forecasted wind by WRF (measured data from SNSA Data portal, 2011).

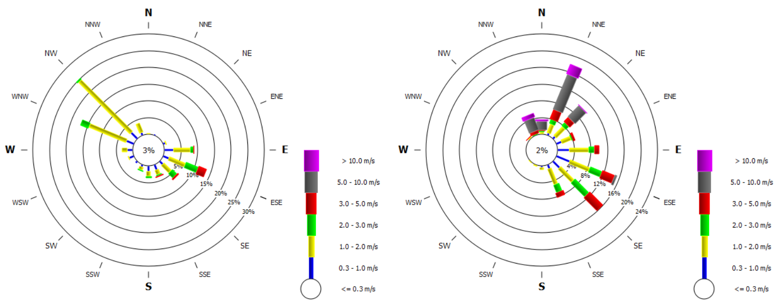

Figure 8. Relatively bad correlation between measured and forecasted wind for Jesenice region for the February 2011 (left: measured wind at 10m, station Kremšnita, right: forecasted wind by WRF)

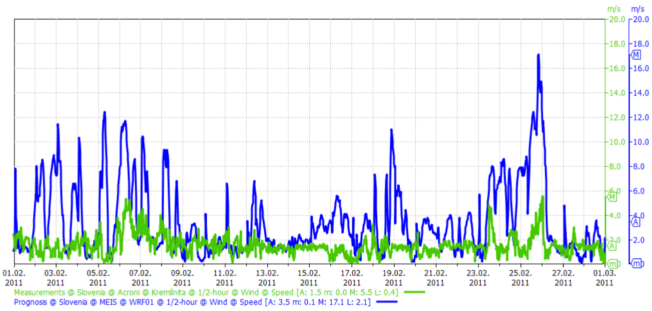

Figure 9. Comparison of wind speed for Jesenice region for the February 2011 between measured wind at 10m, station Kremšnita and forecasted wind by WRF

Results from the last location in Jesenice region (Figure 8 and 9) are not good because the station is located at the bottom of narrow alpine valley where hlTc length is smaller than the WRF resolution. When we compare prognostic profiles with ground measurements and profile measurements on the relatively open areas the results are satisfactory. But we obviously can not expect the WRF profiles to perform well in areas where area hlTc length is smaller than the WRF resolution.

PLANS FOR THE CONTINUATION OF THE STUDY

The above shown results are preliminary statistical results for one month only. We plan to extend this validation over one year period to obtain more statistically valid results. Currently we have started the validation of higher resolution WRF application in the Zasavje region in 1km horizontal resolution. The results are yet preliminary but already show that according to the given Zasavje complexity, problems are arising and at least for wind fields, additional successive modelling with a mass consistent model is needed.

CONCLUSIONS

In the study we have shown moderately successful validation of the WRF application in 4km and half hour resolution over Slovenia where the complexity of the Slovene terrain can be characterized as very complex with **hlTc = (0.5km, 20km).**

The hlTC is defined as **the pair of a characteristic combination of the height and length of the cross section of a basin, valley or canyon (the characteristic form of the terrain) for which we wish our model to accurately summarize the local meteorological characteristics important for dispersion.** The goal of introducing the new hlTc index is the numerical description of the consistency of the horizontal resolution of the applied model with the actual dimensions of terrain complexity. In our opinion, it is of vital importance in describing the characteristics of validation studies to stress in a numerical form the ratio between the resolution of the model and the dimension of the complexity of the terrain whose consequential complex meteorology we wish to represent using the model.

ACKNOWLEDGEMENT

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