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QUALITY OF WEATHER FORECAST FOR MODELLING AIR POLLUTION DISPERSION FOR NUCLEAR EMERGENCY

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Abstract: Modelling the dispersion of pollution in the atmosphere immediately after a nuclear accident is key to taking the proper measures to protect the population. The IAEA MODARIA programme is researching the quality of dispersion modelling if weather forecasts in fine resolution are used instead of meteorological measurements when measurement networks are damaged or deficient. Using a weather forecast we can implement measures to protect the population beforehand, when developments at a nuclear power plant indicate that a nuclear accident will happen. The quality of a weather forecast is expected to be slightly lower than that of weather measurements. This article shows how much lower and how that affects the modelling of pollutant dispersion in the atmosphere. Since the meteorologically measured data at the time of the Chernobyl and Fukushima accidents are deficient, IAEA MODARIA is using the Šoštanj 1991 data set to validate the modelling (it was a well-measured industrial pollution experiment using a non-radioactive tracer; it was presented at Harmo16). The Šoštanj 1991 data set comprises a roughly three-week list of meteorological and dispersion events for a 15 km x 15 km area over highly complex terrain. We demonstrate the validation of a weather forecast using this data set. Weather forecasts were prepared with the WRF ARW model using historical marginal and initial conditions from the Climate Forecast System Reanalysis and ERA. How well the predicted wind fields matched the actual wind is evaluated graphically and statistically for 5 ground-level meteorological stations and for SODAR measurements at altitudes up to 1000 m above the basin floor. How well the temperature fields matched the actual temperatures is evaluated for 5 locations of ground-level meteorological stations, situated on the basin floor and on the peaks of nearby hills, comprising rural and urban locations. In the end we validate the pressure, precipitation and global solar radiation at a single ground-level meteorological station. The established deficiencies in weather forecasts for these meteorological variables are a main cause of errors in dispersion modelling. It is crucial that we are aware of them and able to quantitatively define them.

Key words: validation, weather forecast, air pollution dispersion, nuclear emergency, field data set

INTRODUCTION

Air pollution dispersion modelling in case of an accident in a nuclear facility with releases into the atmosphere is a key tool for the spatial mapping of actual radionuclide concentrations in the wider area of the facility. The spatial distribution data is used for designing protective actions, which is why it is important to be aware of the real quality of modelling results. For dispersion modelling we can apply either measured meteorological data (diagnosis) or weather forecasts (prognosis). Weather forecasts are used for two different reasons: one, if the measurements are not available, and two, if trying to visualize dispersion at a future point in time (e.g. a day or two in the future provided the events develop as predicted).

This article seeks to present the assessment of the quality of meteorological forecasts as the basis for dispersion modelling. It comes about as the result of the efforts of WG2 undertaken in the context of the MODARIA II Programme which takes place at IAEA in Vienna and covers this and similar topics. The prognosis testing was carried out on the data set Šoštanj 91 (Mlakar et al. 2014) whose key characteristics will be presented below.

METHODOLOGY

In order to assess the forecasting quality of atmospheric dispersion it's necessary to have ready a quality data set with measurements from real-life situations. Despite the data from two major nuclear accidents (Chernobyl and Fukushima), the applicable measured meteorological data for the immediate area around the facility covered in this study is insufficient. It is therefore not possible to make a reliable assessment of the modelling quality on those accidents' data sets. In light of this, the data set "Šoštanj 91" was chosen for the test, where the course of the dispersion was tracked via a chemical tracer. Below we present a brief description of the characteristics of the experiment with further details in the works cited (Mlakar et al. 2014).

The "Šoštanj 91" experiment

This is the name of the data set comprising the meteorological measurements and measurements of concentrations of SO2 in the atmosphere and in the emissions of the three chimneys of the Šoštanj Thermal Power Plant, Northeast Slovenia. The area is a closed valley surrounded by medium high complex hills with typically weak winds. The meteorological measurements and measurements of concentrations in the atmosphere were collected at 6 ground stations located across the bottom of the valley, on the slope and on hilltops. Available are wind profile measurements made with SODAR. In addition to SO2 concentrations, the measurements in chimneys also gave us flue gas flow rate and flue gas temperature values. All measurements were carried out automatically in 30-minute intervals. The full data range available pertains to a three-week period in the spring of 1991, and stands as an example of a high-quality controlled experiment. In this article we present the first part of that assignment; we will use the meteorological part of the measurements to test weather models, and follow-up with a test of the dispersion quality calculated from the entry data from such weather models. Weather models were tested retroactively in entry and boundary conditions that were subject to re-analyses. This method was used to actually test models primarily and to reduce the impact of possible errors in global entry (initial) and boundary conditions. The modelling and testing took place for the period spanning from 16 March 1991 to 7 April 1991 in 30-minute increments. The validation was performed for the close vicinity of the facility (15km x 15km) for which we have proper measurements of meteorological variables. Naturally, the weather model was set up in several nested domains to get as close as possible to the target area.

Testing – four modelling exercises

We created four modelling exercises to test weather forecasts. The key characteristics of all four exercises are noted in Table 1.Four partly different exercises were carried out in order to establish to what extent different model setups affect the quality of end results.First, it is important to determine which model and version are to be used. Currently, we have only used the WRF ARW model which was designed for modelling weather over the most difficult and complex terrain relief in spatial and temporal fine resolution. The relief around Šoštanj, in the bigger part of Slovenia and beyond, is very complex and constitutes one of the most challenging cases for modelling in fine-scale spatial and temporal resolution. Bearing in mind the difficulty of the target domain, the applied spatial resolutions fall below the limits of the positively validated applicability of the WRF model, therefore our work marks an important step forward.

Table 1. Key characteristics of four modelling exercises

Group /exercise no.	**Weather model**	**Inputs and boundary conditions** *Saha et al., 2010 **Dee et al., 2011	**Resolution**	**Domain 1 spatial and temporal resolution, grid**	**Domain 2 spatial and temporal resolution, grid**	**Domain 3 spatial and temporal resolution, grid**
MEIS-1	WRF ARW 3.9.1	NCEP climate forecast system reanalysis (CFSR)*	0.5˚ 6 h	25 km 3 h 80 x 80	5 km 0.5 h 86 x 86	1 km 0.5 h 101 x 101
MEIS-2	WRF ARW 3.9.1	ERA Interim (ECMWF)**	0.7˚ 6 h	25 km 3 h 80 x 80	5 km 0.5 h 86 x 86	1 km 0.5 h 101 x 101
CEA-1	WRF ARW 4.0	NCEP climate forecast system reanalysis (CFSR)*	0.5˚ 6 h	25 km 3 h 80 x 80	5 km 1 h 86 x 86	1 km 0.5 h 101 x 101
CEA-2	WRF ARW 4.0	ERA Interim (ECMWF)**	0.7˚ 6 h	25 km 3 h 80 x 80	5 km 1 h 86 x 86	1 km 0.5 h 101 x 101

RESULTS

This chapter provides the results for weather variables with the most profound impact on the modelling atmospheric pollution dispersion. The variables are: air temperature, wind speed (measurements on several sites), global solar irradiation and precipitation (measurements on one site). We were interested in the timeline and matching of 30-minute intervals, the statistical matching of daily cycles and daily error distribution, as well as in the numerical statistical matching estimators between recorded and forecast values. In all cases original measurements were analysed in 30-minute intervals. Forecasts were also analysed in 30-minute intervals. The following coefficients were used for statistical estimates: normalised mean square error NMSE, fractional bias FB, mean square error MSE, root mean square error RMSE, Pearson correlation coefficient R and coefficient of determination R^2 (Badescu et al. 2013; Kocijan et al. 2016). To analyse the matching of daily cycles between the measurements and the analysis of daily error distributions the sunflower plot was used (Božnar et al. 2015, Božnar et al. 2017).

We are unable to validate air temperature characteristics as a whole in the absence of RASS. However, we were able to validate individual ground level values at the sites of the stations. Because of the relatively long validation period, SODAR measurements and WRF forecasts of the vertical wind profile are provided only for three selected shorter periods. We have mapped the timeline of global solar irradiation and forecasts for one site where measurements were available. Detail graphical results are available in PDF version of poster presentation.

DISCUSSION

Air temperature

The air temperature in the period in question varied from warm spring weather to the ingress of cool air with snow, followed by a period of warming up. For this reason, this varied period is suitable for a temperature forecast test. The time charts of the measurements and forecasts indicate relatively good matching. Significant deviations are indicated in the night, seeing as the model suggests cooler temperatures than those actually arisen. The sunflower error analysis indicates this clearly. The error sunflower plot suggests that the station at Graška Gora has the biggest night-time deviations, with the model suggesting temperatures warmer by 5 degrees and up. Large deviations like this are less frequent in other stations. Interestingly enough, such deviations also occur in Graška Gora in daytime. The figures for the rest of the stations indicate significantly more accurate daytime forecasts (save for the Šoštanj station between 7 am and 8 am). Numerical estimators also confirm the acceptability of the forecast quality.

Wind

It arises from the visualized measured and forecast wind profiles that the forecast wind speeds are generally too high or roughly accurate at best (case 2 April). The directional forecast can be blatantly wrong in terrestrial layers. Wind roses indicate poor matching between the Šoštanj and Velenje station at the bottom of the valley and in Zavodnje, which is located at the slope, whereas Veliki Vrh and Graška Gora (located atop their respective hills) and both SODAR levels suggest solid to good matching.

Global solar irradiation

The time chart suggests good matching. The daily cycle in terms of measurements and forecasts separately clearly illustrates that the ratio of forecasts in the highest level for this period (in the range 500 and 800 W/m2) made by WRF is slightly too high. A more detailed daily cycle of the error distribution is shown by the deviation sunflower plot (forecast minus measurement), suggesting a higher ratio of errors over 200 W/m2, especially before noon and between 2 pm and 3 pm. Errors below 200 W/m2, which is an acceptable value, constitute a larger share through all intervals.

Precipitation

Precipitation is important for the assessment of wet deposition which is particularly relevant with regard to radionuclide pollution as it can be washed out by precipitation. The wet deposition can be quite high around the emission location, especially if there is heavy rainfall present. The temporal visualization of the measurements at one station, and the forecasts for the site of this station indicate surprisingly high matching.

Total assessment

Forecasts of variables for which a fine-scale spatial and temporal analysis was carried out match relatively high with the measurements.

Improvements will be necessary with regard to the wind speed, where the forecasts are too high as it pertains to the layers closer to the ground. In addition, there is room for improving directional matching. Statistical charts presented on Figure 1 show that the wind speed is usually overepredicted and the air temperatures are mostly only slightly underpredicted. Air temperature is pretty well estimated (FB < 0.5 and NMSE < 1 except for Šoštanj) even if model tends to underpredict the temperature. Same is with wind speed where models tends to overestimate the speed except for Zavodnje (-1 < FB > 1and NMSE < 1except for Zavodnje and Graška Gora).

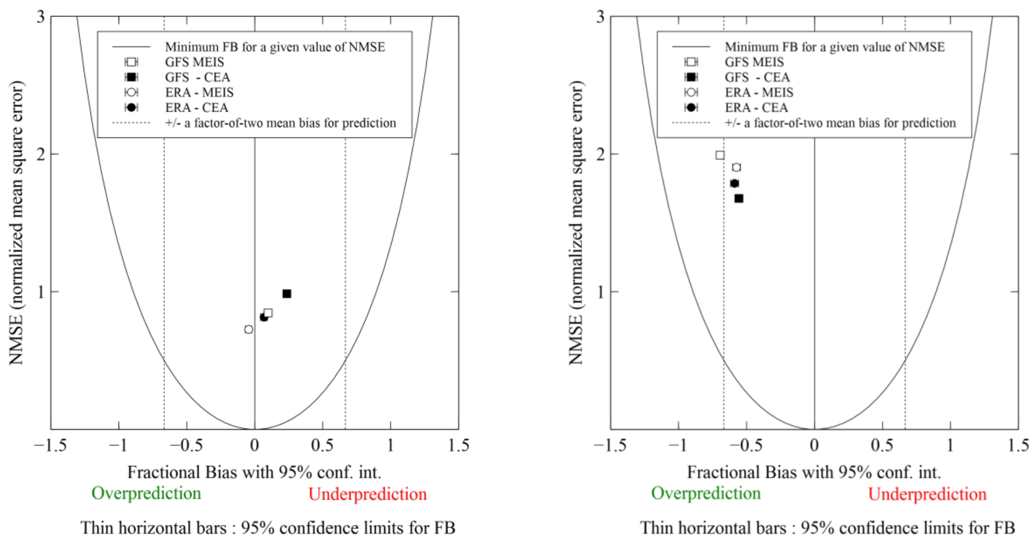

Figure 1. Statistical analysis on full data air temperature (left) and wind speed (right) from March 15th, 1991 (07:00) to April 5th, 1991(12:00)

CONCLUSIONS

Many countries use meteorological data forecasts in order to predict atmosphere dispersion and emergency rescue actions in the event of nuclear accidents. It is therefore important to analyse the quality of weather forecasts in terms of those variables that significantly influence atmospheric dispersion modelling.

The article presents the validation over a smaller area around Šoštanj, Slovenia, over complex terrain which makes the modelling of basic meteorology and atmospheric pollution dispersion extremely challenging.
The article presents a detailed graphical and numerical analysis of results and indicates which variables require improvements.

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