EVALUATION OF THREE DISPERSION MODELS FOR THE TRBOVLJE POWER PLANT, SLOVENIA

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INTRODUCTION

Three up to date dispersion models (LASAT, ADMS, ONGAUSSplus) are evaluated in complex terrain with the data set from the power plant Trobovlje in Slovenia. The coal burning power plant is situated in the Save Valley between Celje and Ljubljana. The data set was provided by the Environmental Agency of the Republic of Slovenia (EARS). It includes time series of emissions, meteorological observations and air quality measurements (SO2) at four locations in the vicinity of the stack for a period of 2 years (1996 to 1997) on a 30 minute basis. The background concentrations were obtained during three months when the power plant was not in operation. Model runs using the meteorological input data of the four different locations were conducted to obtain time series of modelled concentrations.

LASAT is a Lagrangian particle model, ONGAUSSplus and ADMS 3 are based on a Gaussian approach. The models are run with different input data and resolutions. The calculated concentrations of the models are statistically analysed and compared with the observations.

APPLIED MODELS

ONGAUSSplus is based on the Austrian Standards Institute´s Gaussian model (*ÖNORM M 9440, 1996*). Different from most Gaussian models, the ONGAUSSplus diffusion parameters depend on the transport time of the plume to the receptor and not on the distance from the stack. The model was adapted to complex terrain by *Kolb, 1981,* using a simple approach: As soon as the plume intersects with topography, the effective source height is set to a minimum value of 10 m above gound in the case of strong wind (wind speed above 2 m/s) and 0 m above ground in the case of low wind speed (i.e., the plume flows over the hills) and the most stable stability classes 6 and 7 (*Turner, 1964*) are shifted to the less stable class 5. In the case of very low wind speed (below 0,8 m/s) the concentration, calculated for the wind speed of 1 m/s, is multiplied with a factor of 1,5 (*Pechinger, 1980*).

ADMS ROADS (*McHugh,1997*) is based on a Gaussian approach and includes the complex terrain model, FLOWSTAR, to calculate the flow and turbulence fields that are then used to enhance the calculation of dispersion. The model predicts a three-dimensional flow and turbulence field over the region of interest, dependent on both input values of terrain height and roughness, as well as the local meteorological conditions. In ADMS 3, the plume is subjected to these varying flow and turbulence fields, which results in ground level concentrations that may be higher or lower than the corresponding predictions for flat terrain. The model is run with two different resolutions of the terrain (ADMS: 32x32 grid points ADMS-fine: 64x64 grid points). For ADMS only average emission data was used. Afterwards the calculated concentrations were weighted with the actual SO_2 emission. Uncertainties in the effective source height are the consequence of this approach.

LASAT (*Janicke, 2003*) is a Lagrangian particle model and has a diagnostic windfield model integrated in the meteorological preprocessor that allows to consider modifications of the flow field by terrain and buildings. These can have various heights and complex geometry. For the calculations of the three dimensional wind fields, LASAT uses a diagnostic wind-field model that uses the meteorological conditions (wind, stability) at one location. Model runs using the diagnostic wind-field model TAMOSW (*Pechinger et al., 1996*) are conducted additionally. TAMOSW was developed at the ZAMG and can simultaneously use the input of several meteorological stations at different locations. LASAT was operated with an horizontal resolution of 100 m.

DESCRIPTION OF THE MODELLING SITE AND THE DATA SET

The Trbovlje power plant (Fig. 1) is situated in the Save Valley between Celje and Ljubljana, Slovenia. The stack with a height of 360 m is the highest in Europe. With an average SO2 emission in the considered period of 3,275 t/h and a maximum emission of 12,715 t/h the power plant is the most dominant source of SO2 in the region.

Fig. 1; The Trbovlje power plant, Slovenia.

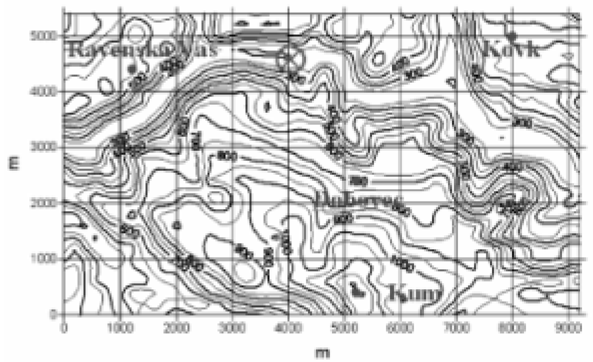

Fig 2; Locations of the Trbovlje power plant (x) and the air quality stations.

The locations of the power plant and of the four measurement sites are shown in Fig. 2. The Save Valley runs from east to west. The stations are situated at the nearby slopes: Ravenska Vas in the west in a distance of 3,5 km from the stack and 378 m above valley floor, Kovk in the east (distance: 3,5 km, 398 m above valley floor), Dobovec (2,8 km, 498 m above valley floor) and Kum (4 km, 1008 m above valley floor) in the south. The annual means of the measured SO2 concentration range from 32,5 µg/m3 at Kum to 87,9 µg/m3 at Ravenska Vas, the maximum half hour means from 2843 µg/m3 (Ravenska Vas) to 7067 µg/m3 (Dobovec).

The measurement stations are part of the Slovenian air quality network and are not designed for model evaluation. The SO2 data incorporate some uncertainties, especially in the case of low concentration, and some background concentration. From April to June 1996 the power plant was out of work. The SO2 concentrations during this period average between 26 µg/m3 at Dobovec and at Kum and 31,7 µg/m3 at Ravenska Vas and give some estimation of the average magnitude of the background SO2 concentration. But neither continuous monitoring nor some information about the annual variation of the background concentration are available.

The wind statistics show different characteristics at each station: Ravenska Vas is shadowed from wind from the west by forest; Dobovec is influenced from down valley wind from south west. Near Kovk, the valley turns to southeast and is open to the north, thus winds from north and south are relatively frequent. At the highest situated station Kum wind from southwest and northwest prevail. However, there are no obstacles between the stations and the stack. Wind speed generally is low except at Kum. The frequency of calm ranges between 4% at

Dobovec and Kum and 18% at Kovk, wind speed below 0,8 m/s (calm excluded) between 3% at Kum and 35% to 50% at the other sites. For a more detailed description see *Kaiser et al, 2005*.

The model calculations are based on the wind data from the respective station, except the LASAT simulations with the diagnostic windfield-model TAMOSW and the LASAT run for Dobovec where it was not possible to calculate appropriate wind fields (the wind from Kum was used in this case). With the wind-model TAMOSW the wind data from all four stations together are used. Stability classes for ONGAUSSplus have been calculated using the vertical temperature gradient, derived from the measurements at Kum and Ravenska Vas, and the wind speed from the respective station. The stability classes for ADMS and LASAT are based on cloudiness data from Ljubljana. Uncertainties in the case of ADMS and LASAT may result from the deduction of the stability classes with the cloudiness data from Ljubljana: The data may not always be representative for the site and the method is valid for flat terrain and near ground layers, whereas the effective source height ranges between 370 m and 520 m above ground.

Due to the uncertainties in the SO2 and meteorological data we made the following restrictions: Different from common practise we added the mean background concentration to the calculated concentration and compared that with the measured data; otherwise we would have obtained a lot of extremely small or even negative measurement data. We assume that that does not adulterate the results too much because the concentration values caused by the power plant are much higher than the background concentration. However, this assumption has no effect on the model comparison. We did not run the models in calm situations and we only considered situations when the models calculated a contribution from the power plant and the measured concentration was above the average background concentration at the particular station, i.e., situations, when model and measurement indicate a transport of the plume towards the station. Concentrations are also normalised by emission rates.

EVALUATION RESULTS AND DISCUSSION

The model evaluation software BOOT (Chang and Hanna, 2004) is used to calculate and visualise the normalised mean square error (NMSE) and the fractional bias (FB). The NMSE gives the average squared differences between observed and modelled concentrations normalised by the average product of these values.

The NMSE is a measure for the overall deviations between predicted and measured concentrations. As the absolute deviations between hourly values are summed, the NMSE reveals the point by point agreement between two data-sets. If the comparison of model and observations renders a low NMSE, the model is performing well both in space and time. On the other hand, high NMSE values do not necessarily mean that a model is completely wrong.

$$NMSE = \frac{\overline{\left(C_{obs} - C_{\mathrm{mod}}\right)^2}}{\overline{C_{obs} \cdot C_{\mathrm{mod}}}} \qquad (1)$$

The FB indicates whether the model on average over-predicts (negative FB) or under-predicts (positive FB) the measurements. In the case of exact agreement between observations and model results in magnitude and time, NMSE as well as FB are zero.

$$\mathrm{FB} = \frac{1}{0{,}5} \cdot \frac{\left(\overline{C_{obs}} - \overline{C_{\mathrm{mod}}}\right)}{\left(\overline{C_{obs}} + \overline{C_{\mathrm{mod}}}\right)} \qquad (2)$$

Additionally it is reasonable to investigate whether modelled time-series reproduce the observed number of exceedances of a threshold limit per year and different magnitudes of concentrations. For this purpose, the observed and the calculated hourly concentrations are ordered by magnitude and compared in so-called quantile plots. The diagonal line in these plots indicates the best agreement between two values.

Table 1 shows the calculated annual averages as well as the respective maximum hourly means for the different model runs. The values are compared to the measurements at the different locations.

Table 1. Calculated annual means / maximum hourly means compared to the observations. Background concentrations are added to the calculations.

[SO_2]=µg/m3	Dobovec	Kovk	Kum	Ravenska vas
Observation	**76 / 6072**	**87 / 3000**	**32 / 3640**	**88 / 2578**
ONGAUSSplus	73 / 4759	133 / 3180	46 / 1648	64 / 1943
ADMS	27 / 344	51 / 170	29 / 148	34 / 186
ADMS (fine)	27 / 1430	53 / 1270	30 / 674	34 / 213
LASAT	36 / 2146	57 / 3313	37 / 2926	64 / 11462
LASAT/TAMOSW	32 / 2667	48 / 2595	30 / 2228	39 / 2186

ADMS and LASAT seem to underestimate the observations in general. In all cases ONGAUSSplus results in higher annual means than the other two models. Considering ADMS the resolution of the topography has only a small influence on the annual means. The finer topography leads to higher hourly means but the calculations are still lower than the measurements. Using the wind information at all four stations (LASAT/TAMOSW) leads to lower concentrations compared to the runs conducted with LASAT using only one wind-information.

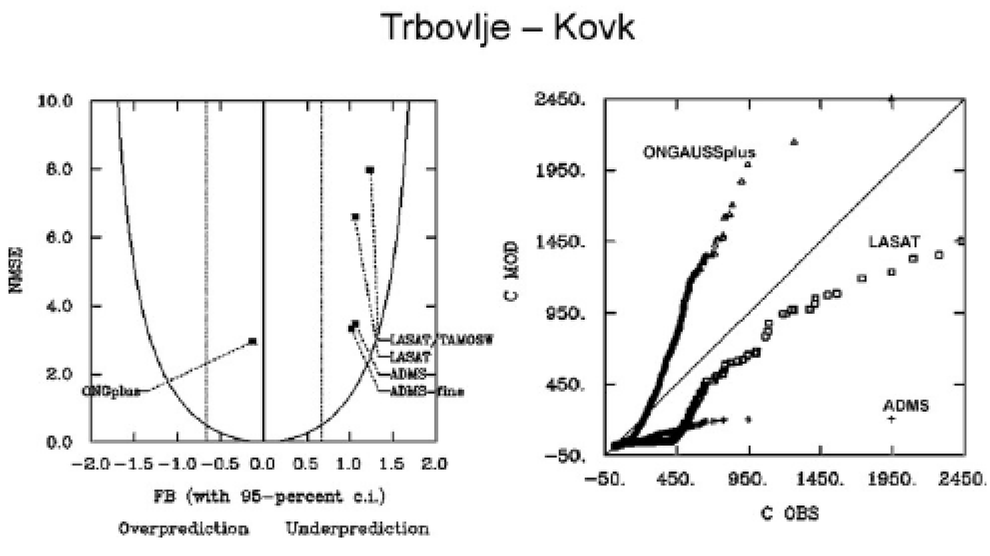

Fig. 3; Fractional bias (FB) and normalised mean square error (NMSE) (left) and quantile—plot (right) between observed and modelled SO_2 concentrations (normalised) at the station Kovk.

Figure 3 shows the FB-NMSE and quantile plots for the selected station Kovk. ONGAUSSplus achieves the best results for this station with a very low fractional bias and a

NMSE around 3. The quantile plot shows that the high concentrations are overestimated by ONGAUSSplus. The NMSE for ADMS is slightly higher but the model under-predicts the measurements which can be seen in the high FB as well as in the quantile plot. LASAT also under-predicts the observations but performs better than ADMS to predict maximum values. For the average values the FB shows that the results of ADMS and LASAT are comparable.

CONCLUSIONS

Depending on the location of the measurement station each of the models is able to reproduce average or maximum concentrations. ADMS and LASAT in general under-predict the observed concentrations. Different resolutions for the terrain with the model ADMS do only lead to minor changes in the results. Larger differences occur for the two different model runs conducted with LASAT. For all cases the LASAT/TAMOSW approach leads to smaller concentrations than the model runs using only one wind information. This study shows that complex dispersion modelling requires a careful choice of the meteorological input and spatial resolution of terrain data.

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