Application of advanced and traditional diffusion models to an experimental campaign in complex terrain

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ABSTRACT

An experimental campaign was performed around the largest Slovenian Thermal Power Plant. EPA Gaussian and hybrid models for complex terrain (COMPLEX-1, RTDM and CTDMPLUS), a puff model (TRAMES) and a Lagrangian particle model (SPRAY) were applied to the data base obtained during an experimental campaign. The results of the intercomparison are presented.

INTRODUCTION

In 1991 an experimental campaign was performed near the Šoštanj Thermal Power Plant (ŠTPP) in the north of Slovenia. The aim of the campaign was to investigate the meteorological conditions that cause severe pollution episodes in the surrounding area, e.g. Elisei et al.[1].

The Šoštanj coal fired Thermal Power Plant is the major pollution source located in the Velenje basin in the northern Slovenia. It emits about 100,000 tons of SO_2 per year. Around the basin there are isolated hills to the south, and the hilly continuation of the Karavanke Alps to the west, north and east. The influence of complex orography causes very high SO_2 ground level concentrations. Serious damage to the surrounding forest has been detected during the past 10 years.

For data collection the Environmental Informational System of the ŠTPP, one mobile Doppler SODAR, DIAL and automatic mobile laboratories were used. The data base obtained from the 15th of March to the 5th of April 1991 was later used for model evaluation.

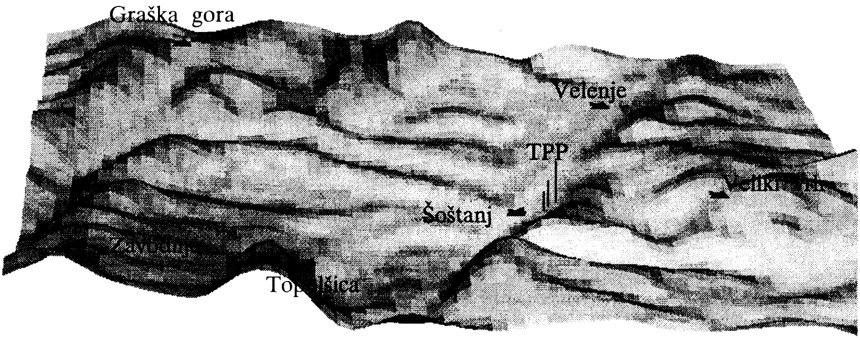

Figure 1: Šoštanj TPP with six automated measuring stations

POLLUTION SITUATIONS EXAMINED

The performances of different models were tested against experimental measurements of the atmospheric SO_2 concentrations obtained by the ground level monitoring network.

The EPA Gaussian models were tested over the whole campaign data base. For the evaluation of the puff and Lagrangian particle models, we chose two significant cases.

The first case concerned high level concentrations in the Veliki vrh area (200 m higher over the ŠTPP level), when a strong wind (up to 10m/s) was blowing directly from the TPP. The stability was neutral.

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The second case was characterised for a slight north wind in the morning increasing and rotating to SE in the afternoon. Different stations recorded high concentrations at different times.

DESCRIPTION OF MODELS USED

EPA Gaussian models

U.S. Environmental Protection Agency recommends COMPLEX-1, e.g. Gutfreund[2], RTDM, e.g. Paine[3] and CTDMPLUS, e.g. Perry[4] models for sites characterised by complex terrain.

ŠTPP has three stacks of different height (100m, 150m and 230m). For all three models we took wind velocity and direction from the 213m level of SODAR. These measurements were extrapolated to each stack height, supposing constant direction and computing the velocity by the power law profile.

The EPA Gaussian models were run using the following features: gradual plume rise (Briggs formula), stack-tip downwash effect and buoyancy induced dispersion.

COMPLEX-1 assumes that the pollutants are uniformly mixed in the crosswind direction in a 22.5° sector and zero outside. In the vertical plane it assumes a distribution described by Pasquill Gifford dispersion coefficients. The centre line height of the plume depends on orography, plume rise and stability class.

RTDM differs mainly from COMPLEX-1 by describing the orography effect on the plume in more detail. It introduces the critical height concept in the plume height calculation. RTDM uses a nonuniform dispersion in the horizontal plane for unstable and neutral classes, while for stable classes it behaves like COMPLEX-1.

CTDMPLUS is a Gaussian hybrid model. It can describe the vertical skewed distribution of turbulence in convective conditions by means of a two Gaussian probability function, e.g. Li5. The model needs special pre-processing of the orography. All the elevated orography should be treated as isolated hills. According to the critical height, the plume passes over and/or goes around the hill.

Puff model

3D puff model TRAMES described by Geai and Perdriel[6] developed by EDF, Paris, France was used.

The TRAMES model uses a 3D wind field obtained from the "mass consistent" code MINERVE, e.g. Geai, also developed by EDF, France. MINERVE utilises a SODAR vertical profile of the wind and the anemometer network around ŠTPP to build the wind field every half hour.

TRAMES splits emission into "puffs", that move along their own trajectories computed from the wind field and taking into account the plume rise effect. The lateral and vertical diffusion is obtained according to Gaussian formula. The concentration computed by the model is a sum of contributions from all the puffs in the domain.

Lagrangian particle model

The most sophisticated model we used was the Lagrangian particle model, SPRAY, e.g. Tinarelli et. al.[8], by EDF, Paris, France.

As input it uses:

- the 3D wind field from MINERVE code,
- the turbulence 3D field obtained from σ_θ and σ_w vertical profile measured by SODAR and Hanna[9] formula for Lagrangian time scale,
- emission data and
- the temperature profile.

The Lagrangian particle model SPRAY splits the total emission from the point source into multiplicity of particles. Each particle has its own mass, position, and velocity. Its behaviour is independent of the others. The velocity of the particle resulting in its position is compounded from three components: a mean wind field component, a stochastic component and a plume rise component. The stochastic part of the particle velocities are calculated so that their distribution is Gaussian in the horizontal direction and can be skewed in the vertical direction.

RESULTS

Statistical evaluation

The first results from the COMPLEX-1 model gave large overestimations in stable conditions (the plume goes directly to the hill) and a large number of zero values outside the 22.5° sector. According to the suggestion of Hanna and others[10] we changed the Plume Path Coefficient from 0 to 0.4 in E and F stability classes to allow the plume to climb over the hill. In this way we reduced the overestimation by a factor of two.

The RTDM results were better than the first results from COMPLEX-1 but worse than its modified version. In particular the maxima are overestimated.

The best results from the Gaussian models examined were given by CTDMPLUS. This is due to its treatment of the orography. In Table 1 we show a statistical comparison between these models: mean, max, and topten averages are calculated on the entire sample (about 6000 values) for standard COMPLEX, COMPLEX with plume path coefficient = 0.4 in stable conditions, RTDM and CTDMPLUS.

In Figure 2 the cumulative frequency distributions of measured and calculated SO_2 concentrations for the same four cases are shown, where only high concentrations (about 600 values higher than 100 $\mu g/m^3$) are considered in describing critical situations.

Table 1: Statistical comparison

	min	max ($\mu g/m^3$)	topten
Measurements	33.5	958	847
Standard COMPLEX	53.4	8132	5490
COMPLEX PPC=0.4	23.8	1750	1402
RTDM	35.1	4307	3183
CTDMPLUS	24.1	1820	893

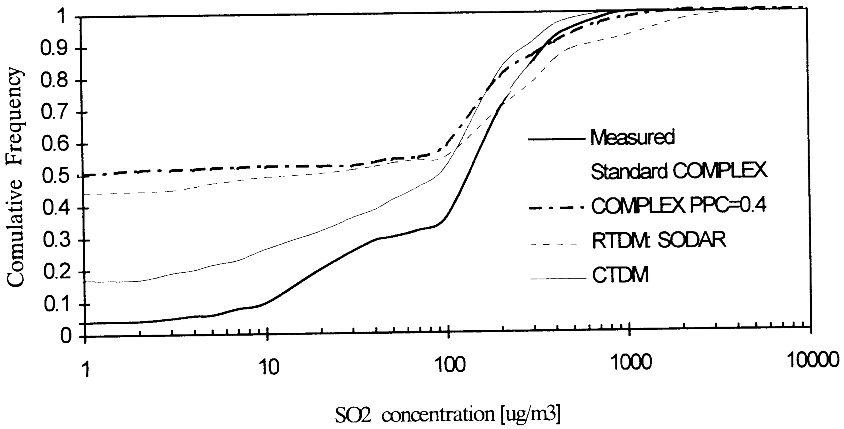

Figure 2. EPA models performance

Case of March 30

In Figure 3 the results obtained by all the considered models and the SO_2 ground level concentrations measured at Veliki vrh are shown. COMPLEX and RTDM fail completely because of their inability to consider the wind direction variations caused by the flow impact with the hill south of the ŠTPP. CTDMPLUS and TRAMES show over and underestimation, respectively, and also simulate the maximum values one hour before the measured one. On the other hand, the temporal evolution is followed quite well by SPRAY. TRAMES and SPRAY use the same wind fields, so the time shift in TRAMES simulation is caused by the different treatment of transport: TRAMES moves the puffs taking into account only the wind at the centre point of the trajectories, neglecting the wind at the puff edges; in SPRAY the plume splitting into independent particles make possible the simulation of the vertical wind structure.

Case of April 2

In Figure 4 a visualisation of the temporal sequence of SPRAY 3D particle plumes is presented. Two stacks (100m and 230m high) are working. It is possible to see that the generally expected behaviour of the plumes (rotation, trapping of the higher plume below the growing convective PBL) are reproduced.

CONCLUSIONS

EPA Gaussian models give acceptable results in complex terrain as a global comparison. But when we want to compare measured and predicted values coupled in time and space, the performance becomes worse.

The puff model is a link between Gaussian models and more sophisticated 3D models. It can be used for quick analyses of simple pollution cases in complex terrain.

Lagrangian 3D models seems to be useful tool for the reconstruction of pollution episodes in very complex terrain. The results we obtained are very promising.

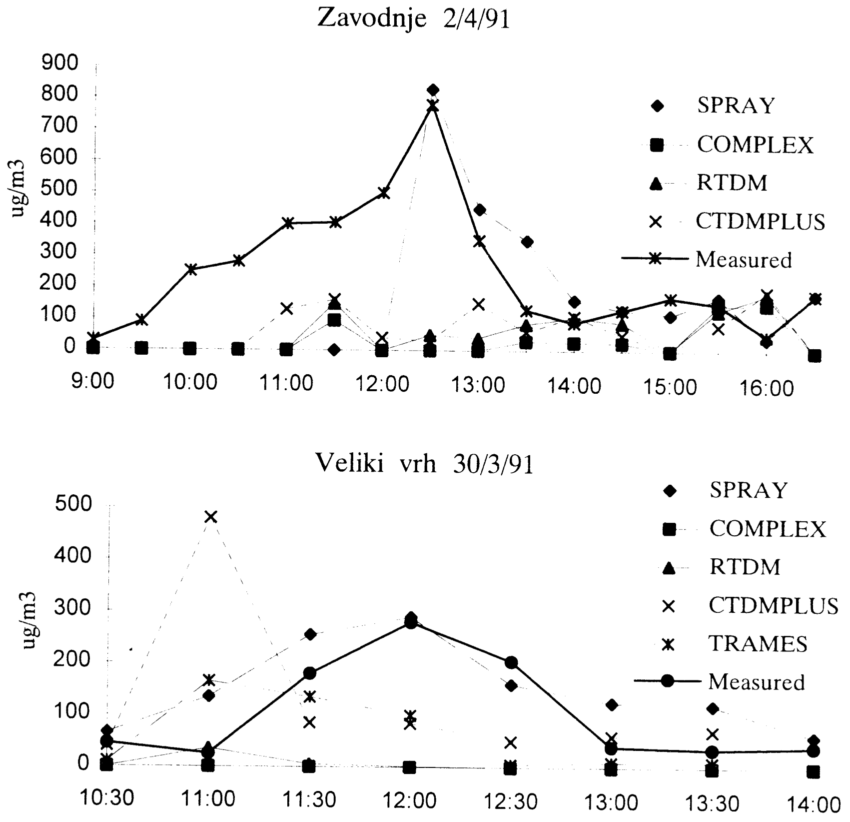

Figure 3: Comparison of models for two different cases.

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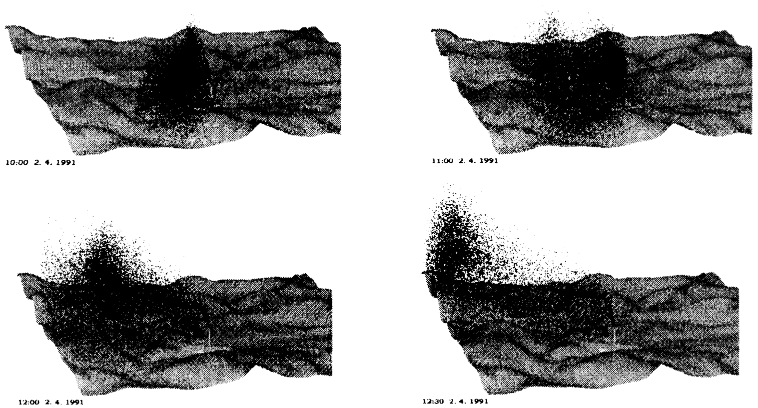

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Figure 4: Time evolution - SPRAY model - Šoštanj 2. 4. 1991