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Re-evaluation of the Lagrangian particle modelling system on an experimental campaign in complex terrain

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Summary. — Slovenian legislation for industrial air pollution control requires efficient modelling systems for small domains over complex topography. To determine the performance and efficiency of the Lagrangian particle modelling system used for this purpose a study was made where a general purpose modelling system designed for local-scale areas was used. The main goal of the study was to evaluate a modelling system of this kind using an operational configuration of both input data and model parameters, choosing a testing period with very complex dispersion conditions. This severe check could help to better understand the general quality that a model can achieve in these conditions giving some idea on how to better evaluate and use some results that seem to be very negative simply looking at some statistical parameter. Data from a three-week experimental campaign performed around the Šoštanj thermal power plant during the spring of 1991 was used (analyzed) for evaluation. The database covers very high ambient concentrations (due to the absence of desulphurisation plants) over complex terrain. The simulation was performed for the full duration of the campaign and a particular situation during the 1st and the 2nd of April 1991 was used as an example to outline the model behaviour in complex conditions. During this selected sub-period measurements revealed that (measured) wind speeds were very low, wind changed course in all directions rapidly and consequently the plume spread in all directions. A comparison between measured and reconstructed SO_2 concentrations was made at the positions of several automatic air quality measuring stations located around the thermal power plant. Standard statistical indexes to evaluate model performances are instead computed at the same positions for the entire period of the experimental campaign. Overall the reconstructed SO_2 concentrations were underestimated relative to the measured ones, but all direct air pollution events were reconstructed. Some weaknesses of the model in the correct reconstruction of peak events are explained and a way to better describe them and to enhance statistical indexes is proposed.

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1. – Introduction

A Slovenian Government decree on the emission of substances into the atmosphere from stationary sources of pollution [1] came into force in April 2007 in accordance with the European Council Directive of 28 June 1984 on combating air pollution from industrial plants (84/360/EEC) [2]. Within the decree it is defined that performance of the modelling system used to reconstruct air pollution around stationary sources must meet the requirements of complex terrain. In complex terrain different atmospheric conditions can appear such as low wind-speed conditions, strong temperature inversions, flow over topography or the presence of terrain discontinuities such as land-sea or urban-rural. Among the currently available modelling techniques, the Lagrangian particle one fully satisfies all these requirements [3, 4].

To determine the performances and efficiency of Lagrangian particle modelling system a study was made using a general-purpose code designed for local-scale areas. A modern high-performance Lagrangian particle modelling system SPRAY was used in our study. The main goal of the study was to evaluate the modelling system in a typical complex terrain situation without any change (*ad hoc* adjustment) of its parameters. The exact description of selected modelling system structure, parameters and options are given in the papers by Tinarelli *et al.* [5, 6]. Complex terrain situation is very common in Slovenia and almost all air pollution facilities are located at the bottom of basins, valleys or river canyons. The evaluation was needed because the Lagrangian particle modelling system evolved in the past decade from research usage to usage for operational regulatory purposes [6-8].

The main purpose of this paper is an evaluation of the Lagrangian particle modelling system that is used for regulatory purposes over complex terrain, looking at its performances in severe conditions and trying to better understand and interpret some results. Many evaluations [9-12] of different modelling techniques used for regulatory purposes over flat terrain were performed using the well-established and documented *The Model Validation Kit* that has been used for a series of workshops and conferences on Harmonisation within Atmospheric Dispersion Modelling for Regulatory purposes [13]. The *Model Validation Kit* addresses the classic problem of a single stack emitting a non-reactive gas. It comprises data from the following four field experiments performed on flat terrain and controlled environment: Kincaid experiment (1980-81), Copenhagen experiment (1978-79), Lillestrøm experiment (1987) and the Indianapolis experiment (1985).

Some model evaluations for regulatory purposes were performed for complex terrain where emphasis was on descriptive evaluation rather than statistical analysis like: the evaluation of RIMPUFF model over complex terrain in Northern Spain by Thykier-Nielsen *et al.* [14], the evaluation of SCIPUFF model over complex terrain in New Mexico by Cox *et al.* [15] and the evaluation of the three models LASAT, ADMS and ONGAUSS plus over complex terrain of Zasavje region in Slovenia by Hirtl *et al.* [16].

For what concerns the SPRAY model, many validations in complex conditions have been performed both in controlled situations against wind tunnel data [5, 17], and in open atmosphere against tracer experiments data [18] or data from a local air quality network [19].

2. – Model, domain and experimental campaign selection

From the 1st of July 2006 until the 30th of June 2007 a campaign was performed around the Šoštanj thermal power plant to determine the impact of emissions from the three current stacks and emissions from two new stacks that are planned for the future. Their impact on the surrounding environment was determined according to new legislation [1] where the use of an advanced air pollution model for complex terrain is required. From the scientific point of view an idea occurred to evaluate modelling system on this type of operational conditions. The evaluation using recent dataset (2006-2007) can be difficult due to the presence of other sources of air pollution in region that can be confused with the small emissions from the thermal power plant.

To evaluate the performance of the selected modelling system, data from campaign performed in year 1991 over the same area was used. The data obtained during 1991 campaign can be used as a tracer experiment. The emissions from Šoštanj thermal power plant were 10 times higher than today's emissions because the thermal power plant that did not have desulphurization plants installed at that time. These emissions from the three stacks of power plant were so high that other local sources of emission can be neglected. Database from campaign performed during the spring 1991 was published and stored on floppy disks in order to be available for further processing and research. Contents of the floppy disks are available as part of the final report [20].

The modelling system was selected following the new legislation: in complex terrain situation it is required to use a Lagrangian particle model, combined with corresponding meteorological pre-processor able to reconstruct a three-dimensional diagnostic non-divergent wind field. In this research the Lagrangian particle modelling system termed SPRAY [21] was finally selected. SPRAY is a three-dimensional model designed to simulate airborne pollutant dispersion, and able to take into account the spatial and temporal non-homogeneities of both the mean flow and turbulence [6]. Concentration fields generated by point, area or volume sources can be easily simulated by this modelling system.

Another reason for selection of Lagrangian particle modelling system was the result produced during an evaluation of different modelling techniques [22, 23] that were achieved by SPRAY in a previous campaign during the spring of 1991 across the same area of interest. Result was produced on a powerful workstation computer that was available at that time. Only four hours of simulation could be performed at once. After the end of simulation the data that seem important to research team was printed and stored as report [20], while all data stored in digital format was erased to provide memory space for next simulation run. Results for simple situations with strong wind and unstable conditions were relatively very good for the computational resources that were available at that time and compared to other modelling techniques only the Lagrangian particle based modelling system was able to capture such occurrences in global which means that reconstructed concentrations peaks were correlated to measured ones, but peak values did not match. For complex situations with low-wind and stable conditions the results were according to authors only "promising" [22, 23]. The term "promising" was used to denote the results that could be improved to be correlated with measured ones if sufficient computational resources were available. In the last 15 years since this evaluation was performed, Lagrangian particle modelling systems were continuously improving and they became generally accepted as the most powerful tool for an air pollution reconstruction [3, 4]. On the other hand, also available computational resources significantly improved, especially on the field of personal computers that are nowadays very efficient also for computational demanding task. The modelling system was also redesigned to be used on a personal computer and not only on a workstations computer.

The area of interest was selected following the new legislation and some considerations about the local meteorological conditions to be simulated. In a complex terrain situation this area must extend over an area having a radius 50 times the height of the stack.

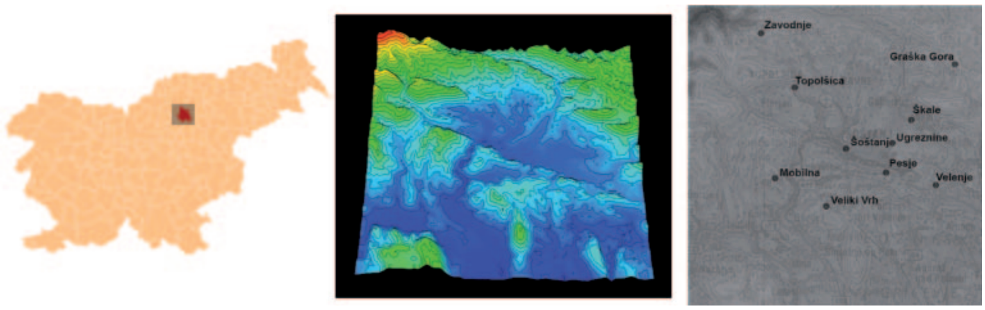

Fig. 1. – Šaleška valley: position in Slovenia, complex orography and positions of automatic measuring stations.

In our case, the highest stack being 230 m high, the area should be at least 23 km in diameter. According to complex terrain conditions with low wind that generate very high concentrations relatively close to source of emission and taking into consideration that local meteorological measurements are available only in a central area around the thermal power plant, a 15×15 km wide domain was finally selected. This extends across the complete Šaleška valley as presented in fig. 1 where the Šoštanj thermal power as source of air pollution is located in the centre of domain. The purpose of this paper is to point out the problems that could occur when legislation is strictly followed. A good illustration to problems that could be faced when reconstructing air pollution on complex terrain will be given to be used by authorities that are responsible to issue IPPC (Integrated Pollution Prevention and Control) licenses.

3. – Campaign description

In the northern region of Slovenia near the Šoštanj thermal power plant, an experimental campaign was organised during the spring of 1991. It was performed as a joint effort of three institutions: ENEL-CRAM and CISE from Milano in Italy and the Jozef Stefan Institute from Ljubljana in Slovenia [20]. The aim of the campaign was to investigate the environmental impact of pollutants emitted by the power plant with emphasis on the meteorological conditions that cause severe pollution episodes. The database obtained during the campaign was later used to evaluate traditional and advanced Gaussian models (COMPLEX-1 [24], RTDM [25] and CTDMPLUS [26]), a Gaussian puff model (TRAMES [27]) and a Lagrangian particle model (SPRAY [5,21]) [22,23]. The Gaussian models gave acceptable results in complex terrain within a global comparison. But when a comparison between measured and predicted values coupled in time and space was made, performances were very poor. The Gaussian puff model represents a link between Gaussian models and the more sophisticated 3D codes. It was determined that it can be used for quick analyses of simple pollution cases in complex terrain. Finally it was determined that the Lagrangian particle modelling system is the most effective tool for the reconstruction of pollution episodes in very complex terrain. The results obtained were declared as very promising [23].

The area of investigation extends across the Šaleška valley which is situated in the north-eastern part of Slovenia as presented in fig. 1. The central part of the Šaleška valley is a plain north of the river Paka, with an average altitude of three hundred metres above sea level. The basin is surrounded by isolated hills on the south, and by

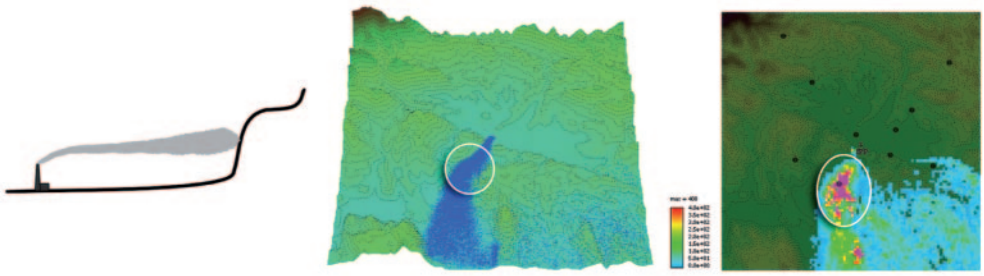

Fig. 2. – Plume impingement on high terrain.

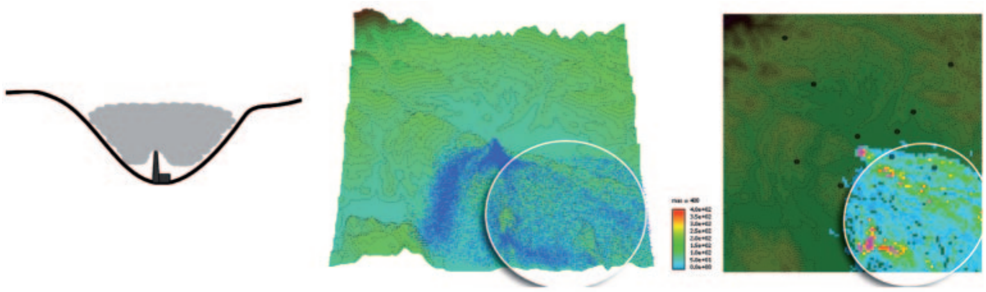

Fig. 3. – Pooling in valleys.

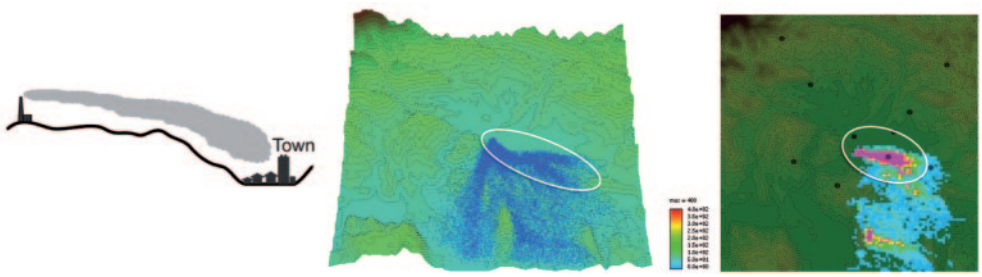

Fig. 4. – Drainage toward population centres.

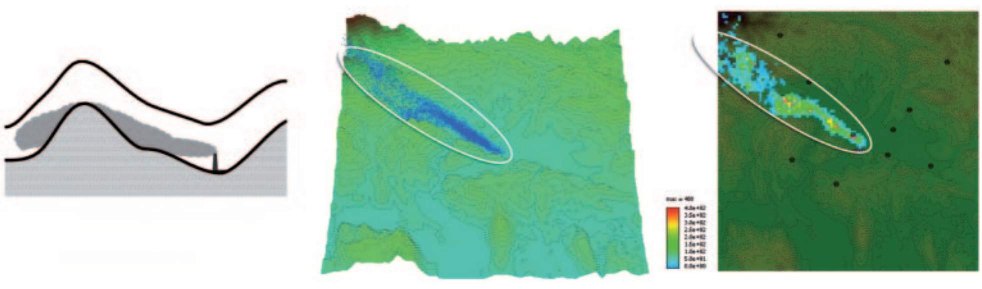

Fig. 5. – Persistence due to channelling.

the semi-mountainous continuation of the Karavanke Alps on the west, north and east. Two small towns are located in the basin: Šoštanj has approximately 3000 inhabitants, Velenje about 24000 and about 9000 people live in the villages around [20].

The main source of air pollution in the Šaleška valley is the Šoštanj thermal power plant located in the centre of domain. It has three stacks that are 100 m, 150 m and 230 m high. During the campaign the desulphurization facilities were not yet fully finished. It was estimated that emissions were about 100000 tons of SO_2 and 12400 tons of NO_X per year [20, 22]. Due to the complex orography and unfavourable climatic conditions (thermal inversion in the basin), very high concentrations of SO_2 occur, especially during the winter. The Šaleška valley represents a typical case of complex terrain [28]. There are certain air pollution situations that lead to increased concentrations in complex terrain: plume impingement on high terrain depicted in fig. 2, pooling in valleys depicted in fig. 3, drainage toward population centres depicted in fig. 4 and persistence due to channelling depicted in fig. 5. On the left side of presented figures the complex terrain phenomenon is illustrated, in the middle the three-dimensional presentation of phenomenon that occurred over the area is encircled and on the right side the impact of phenomenon on the ground level concentration is presented. Veliki Vrh hill located on the south of the power plant is the nearest high terrain obstacle. Plume impingement on the hill is encircled in the middle of fig. 2 and increased ground level concentrations caused by the phenomenon are shown on the right side. In fig. 3 pooling in valleys between isolated hills on the south of domain is presented where on the right side of figure the increased ground level concentration in the valley far from power plant is presented. Figure 4 represents the drainage of air pollution toward Velenje city, where on the right side of figure increased ground level concentration is present downwind from the power plant towards the city. Persistence of increased ground level concentration due to channelling caused by topography (chain of hills) on the west-south of the Šaleška valley is presented on the right side of fig. 5.

The experimental campaign was performed around the Šoštanj TPP from the 15th of March to the 5th of April 1991. A database was constructed from different measurement sources like the Environmental Informational System (EIS) of the Šoštanj TPP, one mobile Doppler SODAR, DIAL and an automatic mobile laboratory. EIS of Šoštanj TPP consists of six stationary stations and one mobile automated environmental measuring station located around the power plant as presented in fig. 1. On all the stations wind velocity and direction, air temperature, relative humidity and SO_2 concentrations were measured. On some of the stations also other parameters were measured such as global solar radiation, precipitation, air pressure and other pollutant concentrations (NO_X and O_3). Power plant pollutant emission data, smoke temperature and exit velocity were measured by the emission station [20].

4. – Model parameters and settings

Computational particles used by the SPRAY Lagrangian dispersion model are driven through three-dimensional fields generated by the meteorological pre-processor SWIFT/Miverve and SurfPro. SWIFT/Minerve [29] is a mass consistent wind and temperature diagnostic tool for reconstruction over complex terrain. Given a certain topography and local meteorological data, a mass consistent 3D wind field is generated. For the Šaleška valley simulations, meteorological fields are reconstructed at a 150 m horizontal resolution, the same used to describe the complex topography. Local meteorological data (air temperature, relative humidity, horizontal wind speed and direction, air pressure and global solar radiation) from six ground fixed stations (Zavodnje, Graška Gora, Topolšica, Šoštanj, Velenje and Veliki Vrh) and one mobile automated environmental measuring station (Škale) located around the power plant were available every half an hour at positions described in fig. 1. A mobile Doppler SODAR, located at the centre of the domain, was also present measuring vertical wind profiles at the same time frequency.

Turbulent fluctuation of wind components and the skewness of the distribution of vertical velocities, to be used by SPRAY to reconstruct the random motion of particles, are calculated by means of parameterization codes based on scaling variables derived by the SurfPro turbulence pre-processor, on the basis of the Monin-Obukhov similarity theory and surface energy budget evaluation [30], taking into account surface parameters derived from a land-use array and meteorological parameters given by SWIFT/Minerve. A Thomson's 1987 scheme with Gaussian random forcing [31] has been adopted to describe particle velocity fluctuations and to generate 1/2 hour average concentrations in the ground layer at the same horizontal resolution used by meteorological reconstructions. Emission data from three stacks of the Šoštanj thermal power plant were considered where each source of emission was described by static (stack position, stack1: 46.373N 15.052E, stack2: 46.372N 15.053E, stack3: 46.371N 15.055; stack height, stack1: 100 m, stack2: 150 m, stack3: 230 m; stack diameter, stack1: 6.50 m, stack2: 6.34 m, stack3: 6.20 m) and dynamic (exit temperature, stack1: from 155 °C to 171 °C, stack2: from 155 °C to 183 °C, stack3: from 172 °C to 202 °C; velocity of emitted gas, stack1: from 0.7 m/s to 2.9 m/s, stack2: from 8.8 m/s to 12.3 m/s, stack3: from 8.6 m/s to 12.7 m/s; emission rate, stack1: from 0.01 kg/s to 0.24 kg/s, stack2: from 0.87 kg/s to 2.05 kg/s, stack3: from 0.53 kg/s to 2.46 kg/s) parameters. The total number of emitted particles was defined in order to assure a minimum resolution for ground level concentrations less than $1\,\mu g/m^3$. The plume rise undergone by hot stack plumes option was simulated by means of Anfossi's formulation [32], taking into account horizontal and vertical variations of both mean wind and atmospheric stability.

5. – Simulated period and results

The simulation was performed for the full duration of the campaign that is from the 15th of March until the 5th of April 1991. A situation that lasted from the 1st of April 1991 at 20:00 until the 2nd of April 1991 at 20:00 will be outlined because of its complexity. This complexity makes it very difficult to reconstruct and represents the greatest challenge to all air pollution reconstruction modelling techniques.

SODAR measurements performed during the selected period and presented in fig. 6 reveal that wind speeds were very low and wind changed course in all directions very rapidly. The three-dimensional behaviour of the reconstructed plume presented in fig. 7 illustrates that the plume spread in all directions during a short period of time. This could also be supported by SODAR measurements that are at each presented reconstructed interval in fig. 7 consistent with measurements in fig. 6. The reconstructed intervals were chosen to present the spreading of air pollution in all possible directions.

During the selected period the phenomenon of air pollution accumulation also occurred. Due to the very stable meteorological situation mixing of the plume with air was very slow and the cloud of air pollution was moving very slowly with the average wind speed and direction. From the point of view of a measuring station the air pollution came from the direction of the source. When the main wind course changed direction the cloud began to move in the opposite direction. Suddenly from the point of view of

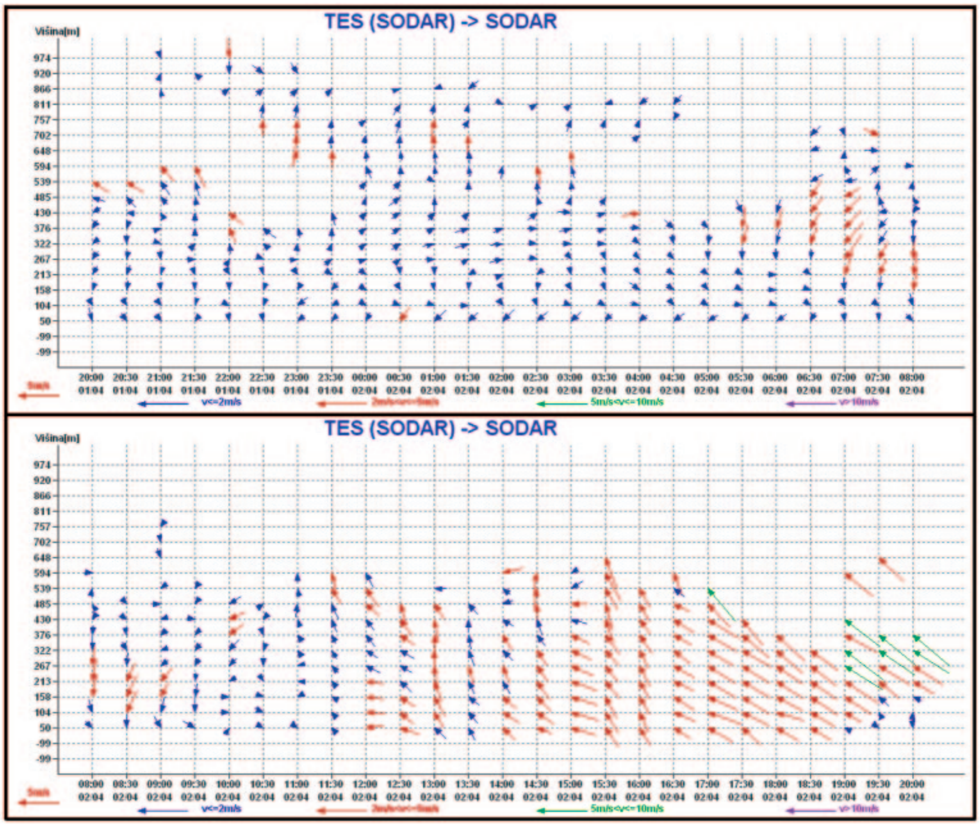

Fig. 6. – SODAR measurements.

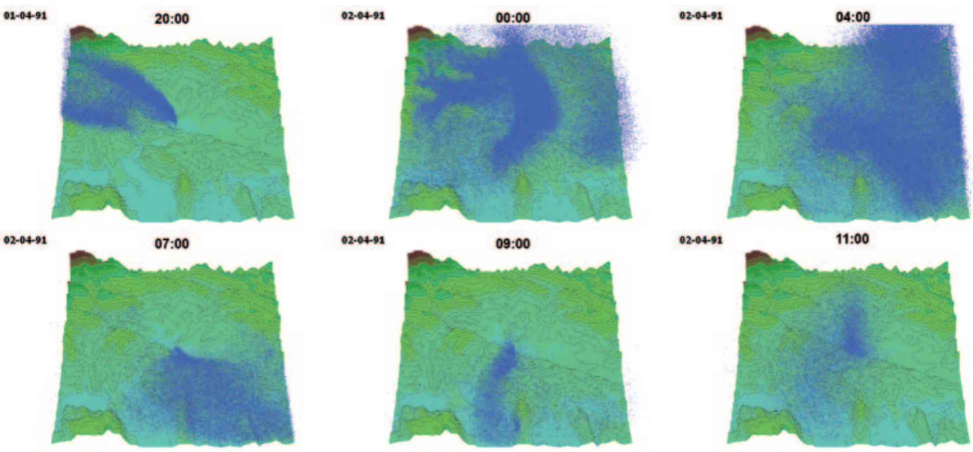

Fig. 7. – Plume spreading in all directions (selected pictures from 15 h interval).

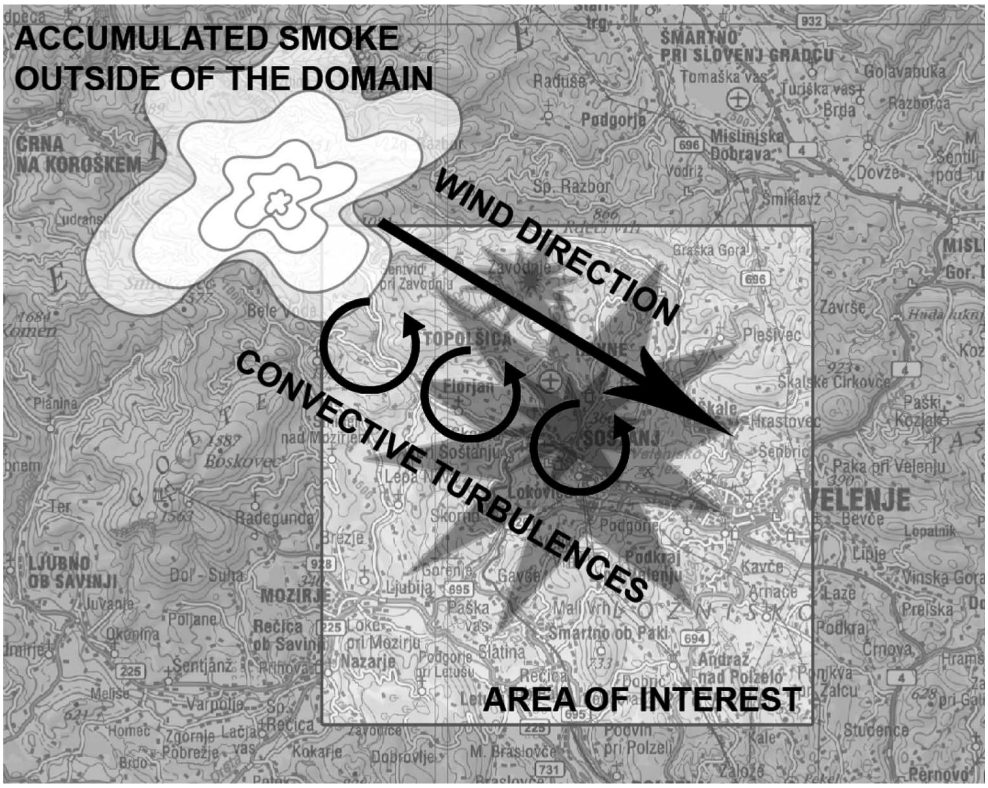

Fig. 8. – Air pollution accumulation effect.

the measuring station it appeared that the air pollution came from a virtual source of emission located on the other side. The Lagrangian particle modelling system is capable of reproducing this kind of phenomenon only when the area of interest in wide enough. Sometimes when the selected area of interest is not wide enough, the cloud of air pollution is lost from the computational domain and when the wind reverses its direction the air pollution accumulation phenomenon is partially lost. Such a situation is depicted in fig. 8.

6. – Comparison of measured and reconstructed values

A comparison between measured and reconstructed SO_2 concentrations was made at the positions of four automatic air quality measuring stations located in different directions around the thermal power plant. The results of this comparison are presented in figs. 9, 10, 11 and 12 where a rotation over the domain of the air pollution plume from power plant is clear. At the beginning of the selected period the wind in higher layers at a height of approximately from 200 m to 250 m changed its direction from NW to SE. As a consequence of this event, the SO_2 concentration on Graška Gora increased as depicted in fig. 9, where it can also be seen that the reconstructed SO_2 concentrations agree well with the measured ones. After that, the wind changed its direction toward the S causing an increase of SO_2 concentrations at the Šoštanj and Veliki Vrh stations.

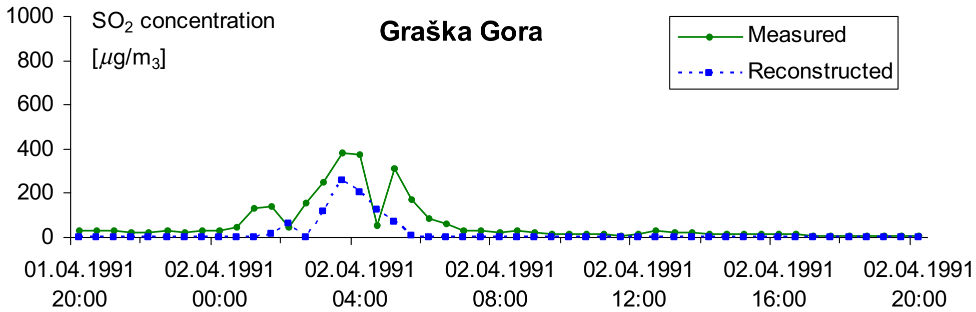

Fig. 9. – Graška Gora.

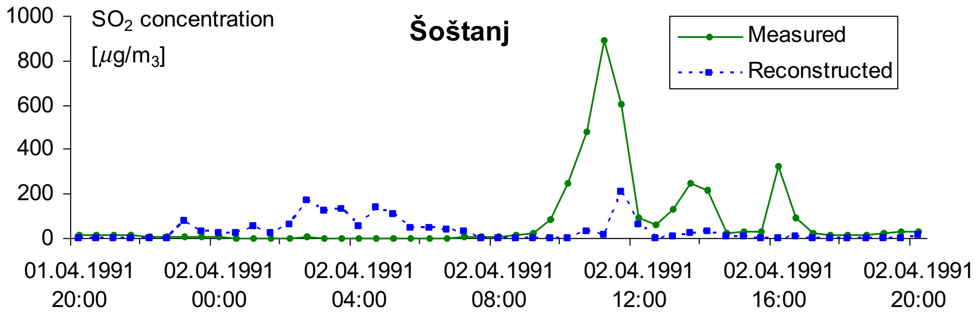

Fig. 10. – Šoštanj.

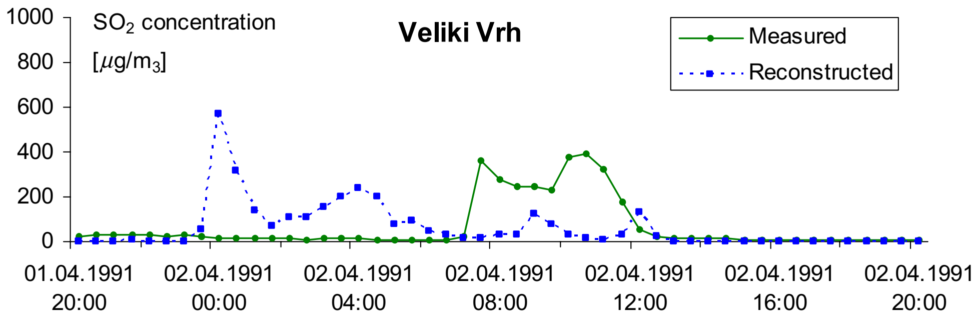

Fig. 11. – Veliki Vrh.

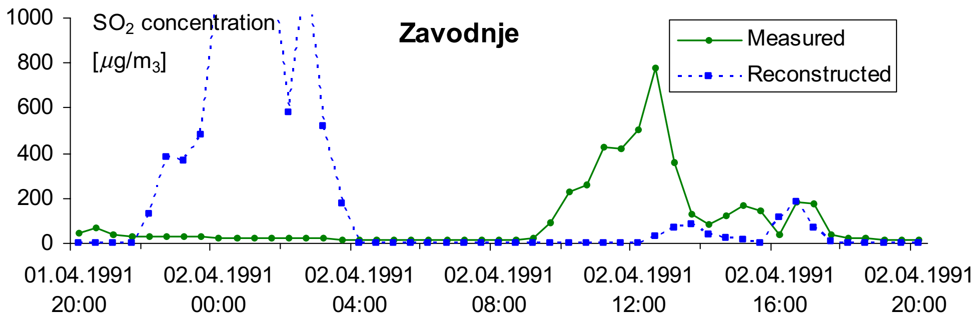

Fig. 12. – Zavodnje.

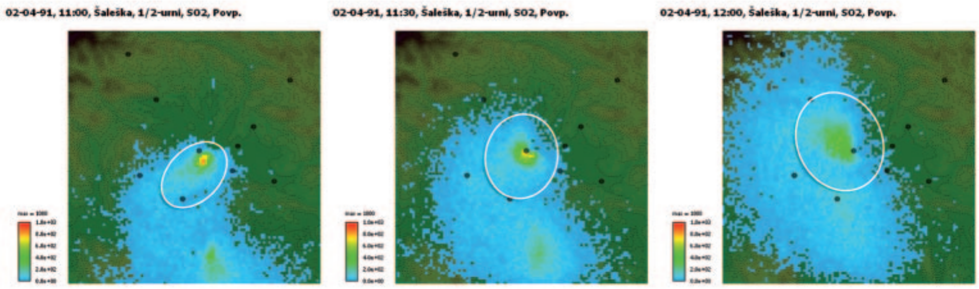

Fig. 13. – Reconstructed ground SO_2 concentrations for three subsequent time intervals with emphasis on the first peak near the Šoštanj station.

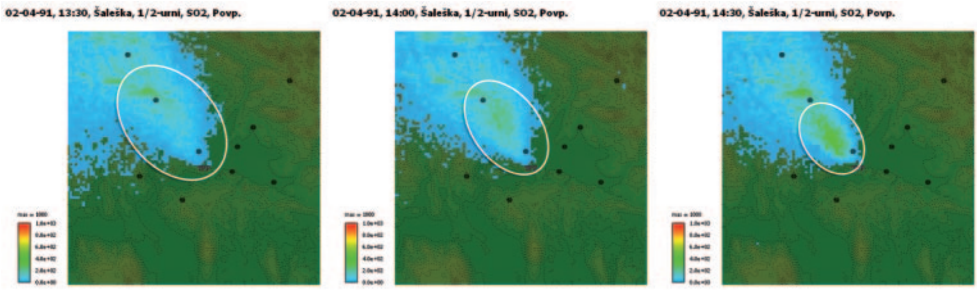

Fig. 14. – Reconstructed ground SO_2 concentrations for three subsequent time intervals with emphasis on the second peak near the Šoštanj station.

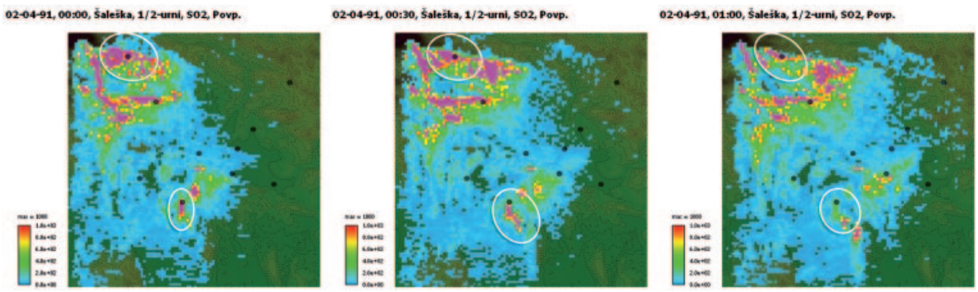

Fig. 15. – Reconstructed ground SO_2 concentrations for three subsequent time intervals with emphasis on the first peak near the Veliki Vrh and Zavodnje stations.

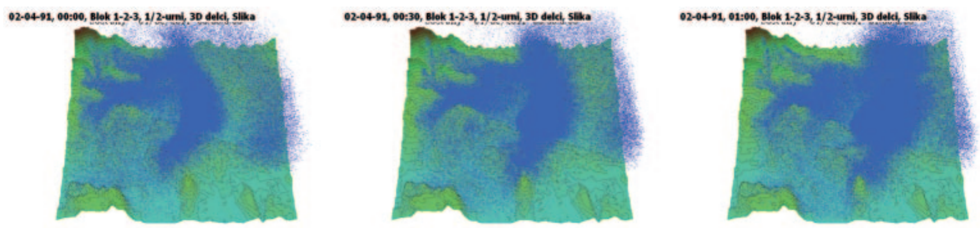

Fig. 16. – Reconstructed three-dimensional figures of particles for three subsequent time intervals with emphasis on drainage of air pollution during the night.

SO_2 concentrations at the Šoštanj station are depicted in fig. 10 where it can be seen that the reconstructed values are underestimated. The first reconstructed peak at 11:30 is underestimated compared to the measured ones, mainly due to inaccuracy in the position of the reconstructed peak. It is highlighted in fig. 13 that a peak of the correct high concentration was reconstructed just two cells away from the station. Ground SO_2 concentration reconstruction for the second measured peak at 14:00 hour is depicted in fig. 14 where it is shown for three subsequent time intervals. The second reconstructed peak is underestimated according to the measured ones mainly due to the short distance between the station and the power plant which is approximately 500 m. Due to the short distance two effects are not expressed strongly enough: the stack tip down-wash effect, and the effect of a low-wind speed directed towards the station in combination with convective turbulences.

In fig. 11 SO_2 concentrations at the Veliki Vrh station are depicted. The comparison shows that two peaks of air pollution were reconstructed lasting from 00:00 to 04:00 and from 06:00 to 12:00, respectively. The first reconstructed peak is again a consequence of inaccuracy in the position of the reconstructed peak. A peak with a sharp edge was reconstructed at the position of the monitoring station as highlighted in fig. 15 where the ground SO_2 concentrations for three subsequent time intervals are presented. In the real situation this peak could be created just few hundred metres from the station without being measured.

A similar process occurred at the Zavodnje station where the phenomenon of inaccuracy in the position of the reconstructed peak is also very obvious. This caused the appearance of the first measured peak in the simulation that lasted from 00:00 to 04:00. Again a peak with a sharp edge was reconstructed just at the position of the Zavodnje station which is highlighted in fig. 15 where the ground SO_2 concentrations for three subsequent time intervals are presented. The cause of this first peak was drainage of air pollution during the night as presented in fig. 16 where three-dimensional figures of particles for three subsequent intervals are depicted. The second measured peak at 13:30 was underestimated due to the phenomenon of air pollution accumulation that was lost in the simulation due to the insufficient size of the area of interest (see fig. 8). It occurred at the conclusion of the selected period when the wind changed its direction from south to its initial north-west direction.

COMPARISON A: results of simulation that was performed for the full duration of the campaign, that is from the 15th of March until the 5th of April 1991, were also compared to measured data to quantitatively evaluate the model performances. Comparison was again performed at positions of four automatic air quality measuring stations where measured SO_2 concentrations were available: Graška Gora, Šoštanj, Veliki Vrh and Zavodnje. Evaluation was performed by statistical analysis of data where the following three performance indices had been determined:

– the correlation coefficient

$$CORR = \frac{\frac{1}{N}\sum_{i=1}^{N}(Cm_i - \hat{C}m)(Cr_i - \hat{C}r)}{\sigma_{Cm}\sigma_{Cr}}, \tag{1}$$

– the normalized mean square error

$$NMSE = \frac{\frac{1}{N}\sum_{i=1}^{N}(Cm_i - Cr_i)^2}{\hat{C}m \cdot \hat{C}r}, \tag{2}$$

TABLE I. – *COMPARISON A: statistical comparison of measured and reconstructed ground* SO_2 *concentrations at original positions of stations for the time period from the 15th of March until the 5th of April 1991.*

Station	CORR	FB	NMSE	AVAILABLE PATTERNS
Graška Gora	0,34	1,60	40,42	884
Veliki Vrh	0,13	0,09	8,70	881
Šoštanj	0,02	0,37	17,32	839
Zavodnje	-0,004	0,10	38,35	858

– and fractional bias

(3) $$FB = 2\frac{\hat{C}m - \hat{C}r}{\hat{C}m + \hat{C}r}\,,$$

where

Cm_i ... i-th measured concentration,

Cr_i ... i-th reconstructed concentration,

$\hat{C}$ ... average concentration,

σ_C ... concentration standard deviation,

N ... number of evaluated patterns.

Table I shows the statistical indexes resulting from a point-to-point comparison. Results appears to be quite bad at a first view. Only the correlation at Graška Gora seems to reach a satisfactory value higher than 0.30, as suggested by many authors [9-11, 13] that were participating in model evaluation framework *Model evaluation toolkit* established and maintained by Olesen [13]. Olesen also presented in his paper [13] difficulties that appear in model evaluation process. In his paper he explains that inherent uncertainties should be emphasized. In his statement residual between measured and reconstructed concentrations is defined to consist of measurement error, inherent uncertainty, input uncertainty and model formulation error.

The phenomenon of inaccuracy in the position and time was presented in the analysis of a complex situation that lasted from the 1st of April 1991 at 20:00 until the 2nd of April 1991 at 20:00. The phenomenon of inaccuracy in the position and the phenomenon of inaccuracy in the time are a consequence of model's sensitivity to measured wind directions and measured wind velocities, due to the presence of complex terrain.

COMPARISON B: to minimize the effect of inaccuracy of position on the statistical analysis another comparison was performed where also the ground level concentrations of neighbouring cells were used. That means that ground level concentrations of cells in the radius of 300 m (2 grid cells) around the position of station were compared to measured concentrations at station. The best correlated ground level cell concentrations for each station are presented in table II where also the offset of the position where best correlation was found is presented. The obtained results show significant improvement at stations Veliki Vrh and Šoštanj, while correlation at Zavodnje station is still under expectations. Results stay uncorrelated due to long distance from Zavodnje station to sources of emission where the phenomenon of inaccuracy in the time is present because high concentrations arise in low-wind situations where inaccuracies of wind measurements are high.

TABLE II. – *COMPARISON B: statistical comparison of measured and reconstructed ground* SO_2 *concentrations at adjusted positions of stations for the time period from the 15th of March until the 5th of April 1991.*

Station	CORR	FB	NMSE	AVAILABLE PATTERNS	BEST X OFFSET	BEST Y OFFSET
Graška Gora	0,36	1,59	39,61	884	-150 m	150 m
Veliki Vrh	0,34	0,44	6,39	881	150 m	-300 m
Šoštanj	0,10	0,39	16,74	839	150 m	-300 m
Zavodnje	0,04	0,08	13,21	858	-150 m	300 m

COMPARISON C: to avoid both effects of inaccuracy of position and time final statistical analysis was performed where ground level concentration at certain station measured was compared to most similar reconstructed ground level concentration around the position of station in radius of 150 m and in time frame from $-1/2$ hour to $+1/2$ hour. The most similar reconstructed concentration for a particular station was determined from the set of 27 combinations (3×3 cells around position of the station combined with 3 time shifts for time reconstructions of $-1/2$ h, 0 h, $+1/2$ h). The selection was done for each particular $1/2$ h measured valued for selected station. In this way we took into account positional and time inaccuracy of the model in the same statistical measure. The results of comparison are presented in table III where all correlations between measured and reconstructed values significantly improved, especially for Zavodnje station. Values of fractional bias are generally increased because several of overestimated reconstructed concentrations were reduced which also resulted in the decrease of the mean value of reconstructed concentrations. To achieve better performances of the model in complex terrain both inaccuracies should be reduced. The solution to perform this is still under research, where one of the possibilities is the usage of presented methods in this paper.

A comparison between measured and in time and space adjusted reconstructed SO_2 concentrations was repeated at the positions of four automatic air quality measuring stations located in different directions around the thermal power plant for the selected situation that lasted from the 1st of April 1991 at 20:00 until the 2nd of April 1991 at 20:00. The results of this comparison are presented in figs. 17, 18, 19 and 20. At the beginning of the selected period the SO_2 concentration on Graška Gora increased as depicted in fig. 17, where it can also be seen that the reconstructed SO_2 concentrations agree well with the measured ones. SO_2 concentrations at the Šoštanj station are de-

TABLE III. – *COMPARISON C: statistical comparison of measured and most similar reconstructed ground* SO_2 *concentrations around the position of each station in maximum radius of 150 m and in variable time frame from* $-1/2$ *hour to* $+1/2$ *hour for the time period from the 15th of March until the 5th of April 1991.*

Station	CORR	FB	NMSE	AVAILABLE PATTERNS
Graška Gora	0,69	1,14	10,38	881
Veliki Vrh	0,74	0,61	3,26	878
Šoštanj	0,36	0,95	20,64	836
Zavodnje	0,37	0,79	6,30	855

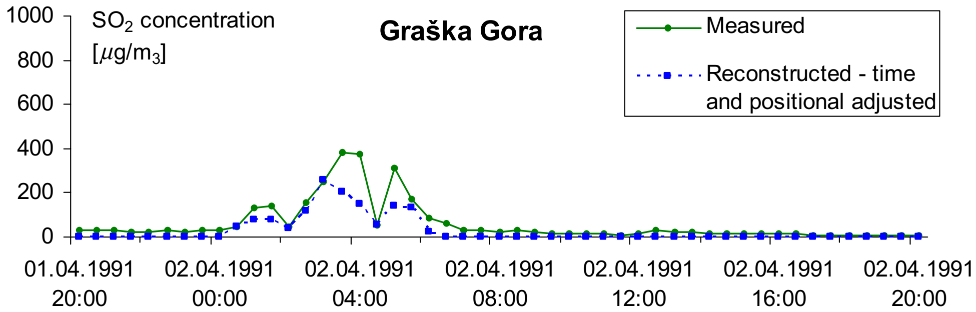

Fig. 17. – Graška Gora—time and positional adjustment.

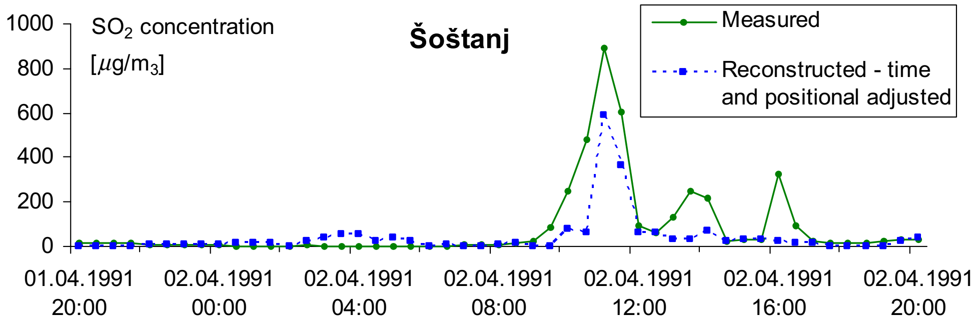

Fig. 18. – Šoštanj—time and positional adjustment.

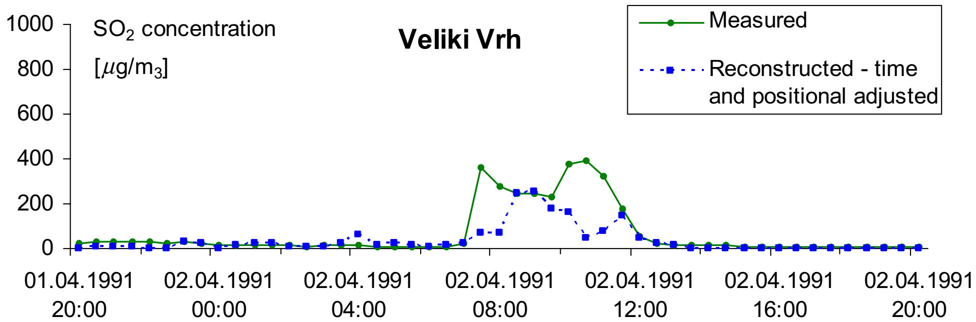

Fig. 19. – Veliki Vrh—time and positional adjustment.

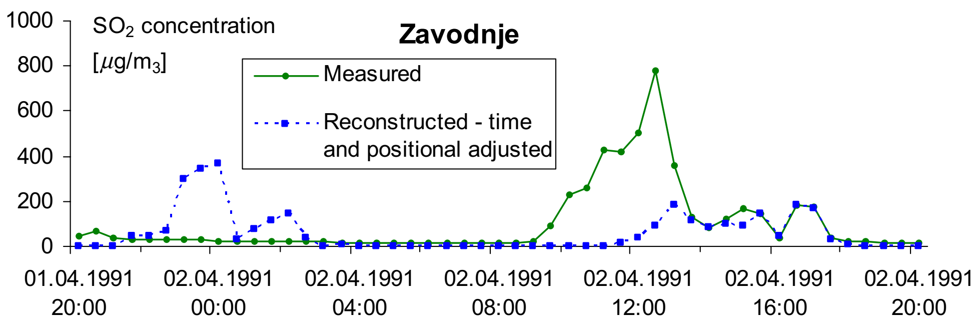

Fig. 20. – Zavodnje—time and positional adjustment.

picted in fig. 18 where it can be seen that the reconstructed values are now only slightly underestimated. In fig. 19 SO_2 concentrations at the Veliki Vrh station are depicted. The comparison shows that two reconstructed peaks of air pollution are very well correlated with measured ones. At Zavodnje station comparison presented in fig. 20 the phenomenon of inaccuracy in the position of the reconstructed peak is strongly reduced, but the lack of phenomenon of air pollution accumulation is still present.

7. – Conclusions

The performance and efficiency of the general-purpose Lagrangian particle modelling system SPRAY designed for local-scale area was evaluated in this study. A Lagrangian particle modelling system was used because it satisfies the requirements of the complex terrain situation which is common in Slovenia. Another reason was the requirements in the new Slovenian legislation that requires usage of advanced modelling techniques.

Using the selected modelling system, a simulation was performed to reconstruct the air pollution situation during an experimental campaign around the Šoštanj power plant. The campaign was organised during the spring of 1991. The situation of the 2nd of April 1991 was illustrated because of its complexity that makes it very difficult to reconstruct. During the selected period also the phenomenon of air pollution accumulation occurred. Because the selected area of interest was not wide enough, the cloud of air pollution moved out of the area and when the wind changed its course the air pollution accumulation phenomenon could not be reproduced. This problem could be avoided by using a larger computational domain, but this was beyond the scope of the work in which we wanted to check the reliability of the model in a typical configuration. In addition, almost all automatic meteorological measurements were available around the centre of the domain and enlargement of the domain could worsen the results of the meteorological pre-processor and consequently also the reconstructed air pollution dispersion.

A comparison between measured and reconstructed SO_2 concentrations was made at the positions of four surrounding automatic air quality measuring stations located in different directions around the thermal power plant in a critical situation, where the plume was spreading in all directions during a short period of time. This was supported by measured and reconstructed concentrations of SO_2 at the positions of the automatic air quality measuring stations. The reconstructed SO_2 concentrations were underestimated relative to the measured ones. But all direct air pollution events were correctly reconstructed except the air pollution accumulation phenomenon. The inherent inaccuracy in the position of the reconstructed peak is usually few cells wide. This occurs due to statistical reconstruction of turbulence. So far we are not able to reconstruct turbulences at the exact positions where they occur in the atmosphere. Among the reasons is the fact that measurements are performed only at some selected point-like positions where the turbulences are determined based on statistical processing of the measurements. Statistically processed data are used in the meteorological model for the wind field reconstruction where the inaccuracy in the positions of turbulences occurs.

To minimize the effect of inaccuracy of position and time new statistical analysis was defined and performed where ground level measured concentration at certain station measured was compared to most similar reconstructed ground level concentration around the position of station in radius of 150 m and in time frame from $-1/2$ hour to $+1/2$ hour. Significant improvement shown by this analysis pointed out the sensitivity of the model to input parameters especially to measured wind speed and direction which could be improved in future.

The illustrated problems that occurred during the evaluation are presented to challenge other researchers on this research field to improve air pollution reconstruction techniques for regulatory purposes and to point out that air pollution reconstruction techniques for use on complex terrain are still not completely satisfactory.

* * *

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