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AIR POLLUTION MODELLING IN SLOVENIA FOR THE REQUIREMENTS OF IPPC DIRECTIVE

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Abstract: The of the Republic of Slovenia (EARS) is presently finalizing the last IPPC permits for Slovenian industry with the exception that in the following two years the impact of IPPC plants to the ambient air should be modelled in details to evaluate if it is acceptable or if the emissions should be lowered. This is not a simple question as most of Slovenian industry that contribute to air pollution is placed in areas with very complex terrain, low winds and thermal inversions. Therefore determination of realistic ambient air pollution from such installations is still a scientific challenge. In the paper we will report how legislation on this particular issue of modelling was changing in the last two years and how it made air pollution assessment a very difficult task for modellers in addition to the natural complexity of our locations.
Firstly we will present the typical meteorological characteristics of the locations of Slovenia's biggest air polluting industry.
Then we will present the first variant of the legislation about modelling and its changing. We will critically evaluate the legislation with its comparison to the guidelines given by FAIRMODE and with its relations to scientific research modelling over such complex areas. As this regulatory modelling is not a finished work yet it is still appropriate to express scientifically based additional suggestions which may improve the quality of the future elaborations of IPPC plants. We will present our detailed opinion together with field examples for justification. Examples vary from very good practice to scientific pitfalls. In our opinion it is important to learn a lesson and not to repeat mistakes in usage of air pollution modelling for this and other European directives related to air quality in Slovenia or in other countries with similar problems.

Key words: *air pollution, IPPC directive, environmental impact assessment, Slovenian complex terrain, Lagrangian particle model, trans-boundary air pollution****,*** *validation*

INTRODUCTION
Slovenia is a country lying on the junction of the Alps and Dinarides mountains. Most of its territory is complex terrain that varies from Alpine valleys, to the very steep Sava river canyon, several basins and several types of mountains and hills. The majority of these shapes are characteristic for low winds and thermal inversions. All of these phenomena make local air pollution studies a very complex task.

Apart from this phenomena being a pearl for scientific research, it becomes very important within the frame of air pollution modelling for regulatory purposes.

Presently major industrial plants that emit pollutants into the atmosphere should assess their influence on the ambient concentrations in their surroundings in order to obtain IPPC permit. The assessment should be done based on one year of on-site meteorological measurements for the plants lying in complex terrain. For those few lying in flat or slightly rolling terrain requirements are simpler.

This modelling is a very important issue at several industrial sites, because local inhabitants in their vicinity require clean air (as required by directive on ambient air quality and cleaner air for Europe). The first step to achieve this is if industrial plants' influence is determined realistically in the process of applying for environmental permits and if only those plants that do not cause air pollution over the limit values can get the environmental permits.

In fact there are several sites in Slovenia where local associations actually fight with industry. As some cases are also in court it becomes important in addition that air pollution modelling results actually show the agreement in time and space with the real situation (measured by ambient stations). Such agreement is necessary for fair judgement about whose property is actually harmed or not harmed.

It is obvious that only "best available modelling techniques" can give satisfactory and more importantly fair answers to such complex cases.

If modelling techniques are used that are not in advance proven (validated) to give satisfactory results in such conditions it is at least an ethical responsibility (if not also legal) of the modeller.

In the following sections we will shortly explain the development of regulatory modelling in Slovenia in the last decades.

HISTORICAL DEVELOPMENT OF REGULATORY AIR POLLUTION MODELLING IN SLOVENIA
Thirty years ago there was no legislation for industrial plants. Absolutely most progressive was the air pollution modelling in the radiological field. In January 1984 Krško nuclear power plant started to operate made by a USA producer. Together with the technology we adopted also the USA regulation in this field. At that time it was using USA Regulatory Guides that among others prescribe also air pollution model for the safety measures. In particular RG 1.145 (1982) requires Gaussian model for the nearby vicinity, but already at that time the RG 1.111 (1976) required the use of models that give better results in the actual environment where Plant is operating.

With the development of computers that enable complex numerical modelling on PCs in real time the Krško Nuclear Power Plant decided to place a SODAR (end of nineties) at its site in complex terrain in addition to three existing meteorological ground level stations and one with high tower. After successful validation of Lagrangian particle model Spray coupled with 3D diagnostic mass consistent wind field model in local scale high resolution at Šoštanj Thermal Power Plant (Elisei, 1992, Božnar *et al.*, 1993, 1994) that operates in similarly complex terrain in north Slovenia, the Krško NPP decided to use this model. The modelling system described has operated in Krško since 2002 in on-line mode. Every half hour (365 days) results in the form of dilution coefficients are available automatically to be used for dose calculation in case of release into the atmosphere. Even after so many years the modelling principles (and models themself) used there still represent the "best available modelling techniques" as there are no other techniques that would prove in scientific validation to give better results in such a complex terrain within domain of 25km x 25km as should be observed there (Grašič *et al.*, 2008).

The modelling system in the Krško NPP was assessed also by international OSART inspectors and it received excellent marks and was given as "example of good practice" to other NPPs over Europe located in complex terrain. (OSART, 2003).

Stack height determination of other industrial plants was mainly based on "nomograms" with pre-calculated charts for estimation of stack height or using Gaussian screen models.

In spite of good practice in Krško (since 2002, Breznik *et al.* 2004) several pitfalls were made in some other industrial cases that actually have consequences for the near-by living inhabitants. In the socialistic era at least very high stacks were built that allow initial significant dilution in most cases before the plume reached the populated areas.

Unfortunately there are (at least) two cases where after year 2000 stack height for plants in complex terrain were calculated based on Gaussian models without taking into account actual complex terrain. The first one resulted in a stack that is actually lower than the location of houses lying on the nearby hill. And the second one resulted in a stack almost as low as the industrial plants and shopping centre in the vicinity.

It is clear that better techniques were available already at that time that could have prevented this.

FIRST GUIDELINES FOR POSSIBLE REGULATORY REQUIREMENTS

At the 5th Harmonisation conference on Rhodes in 1998 possible guidelines were presented (Božnar *et al.*, 1998) for further development of Slovenian regulatory requirements.

The basic idea for modelling of local influence of industrial sites was to distinguish plants operating in the area of flat or slightly rolling terrain from those operating in areas over complex orography.

For both, on-site meteorological measurements would have been required, but their duration, number of locations and availability of wind profile measurements would be different.

In addition also the required complexity of meteorological model and air pollution dispersion model would be different. For complex cases numerical Lagrangian particle model based on 3D mass consistent diagnostic wind field model would have been required.

EXAMPLES OF GOOD PRACTICE IN INDUSTRY BEFORE OFFICIAL REGULATORY REQUIREMENTS CAME INTO FORCE

In spite of the lack of formal regulation some major industrial and power plants used modern air pollution modelling techniques for assessment of their existing and possible future new units influence on the air pollution.

The good practice of Krško Nuclear Power Plant is explained in previous paragraphs.

The same modelling system (numerical Lagrangian particle model Spray (Tinarelli *et al.*, 2000) coupled with 3D mass consistent wind field model) was also successfully used at Šoštanj and Trbovlje Thermal Power Plants and Lafarge Cement Factory Trbovlje. (Božnar *et al.*, 1993, 1994, 2006, 2008, 2008, Mlakar *et al.*, 2008).

In all cases one year of meteorological measurements data from several ground level stations (from 6 to 10) and one SODAR profiler were taken into account. Cell horizontal size was 200m in case of Trbovlje Sava river Canyon and 150m in case of Šoštanj basin.

Šoštanj Thermal Power Plant supported research validation over two decades (Božnar *et al.*, 1993, Božnar *et al.*, 1994, Grašič *et al.*, 2007). Recently new investments for additional block of the TPP were elaborated in detail and the model was extensively validated before (Grašič *et al.*, 2008).

Trbovlje Thermal Power Plant and Lafarge Cement Factory Trbovlje started detail evaluation of their impact in 2005.

Fortunately these Power Plants and Industrial plant were wise enough to choose modelling techniques that can give reliable results with agreement in time and space (when compared to actual measurements of several environmental automatic stations in their surroundings).

These all are good examples of industry being responsible for their environmental impact in the segment of air pollution.

OTHER EXAMPLES APART FROM GAUSSIAN MODELLING

Not many other examples exist. However there is another example of modelling step Zasavje Sava river Canyon and its vicinity – Trbovlje region – done by ENERGIS (B. Cerkvenik, R. Žabkar *et al.* 2007). In this study Žabkar did modelling of an approximately 130km x 90km wide area from west to east of Slovenia in a horizontal resolution of 1.0km. Out of this whole area only results for Trbovlje region were presented for approximately 60km x 40 km. It is important to mention that the Sava river canyon that directs the local air pollution dispersion is in some parts only 600m wide.

The study was done using non-hydrostatic prognostic model WRF and WRF Chem Eulerian model (without chemical reactions). The study was done only for one winter day and for one summer day.

The results of meteorological fields modelling and the results of air pollution modelling were not compared or validated against measurements although there are 9 ambient air pollution and meteorological stations in the region continuously operating, some of them for more than 15 years, and major industrial plants have on-line emission measurements.

FIRST OFFICIAL REGULATORY REQUIREMENTS FOR MODELLING OF INDUSTRIAL PLANTS AND THEIR TIME CHANGES

In 2007 the first official regulatory requirements were issued:

Year 2007

For plants operating in flat or slightly rolling terrain it was allowed to use models that prove to be according to German model (VDI 3945, September 2000, in practice AUSTAL). Elaboration should be done on time series of one year meteorological data. Three months should be measurements on-site with ground level meteorological stations, for the rest of the one-year period measurements from near-by meteorological station with similar wind characteristics can be used.

For plants operating in complex terrain situation a more powerful Lagrangian particle model suitable for complex terrain was required. It should be coupled with 3D mass consistent diagnostic wind field.

Several requirements (in terms of proper "reproduction" of meteorological and air pollution phenomena) were given for such a model in order to enable adequate modelling of dilution situations that cause the most severe air pollution cases in Slovenia. Examples of these requirements:

- Horizontal cell size at most 300m. (We have canyons less than 1000m wide where heavy industry is located).
- Model should take into account digital model of the relief and land use in the same grid.
- Model should allow particles accumulation in order to simulate thermal inversion phenomena (that is a very important phenomena for Slovene air pollution cases).
- Model should calculate plume rise dynamically as the plume moves over hills and valleys of complex terrain.
- 3D turbulence field should be calculated based on Monin-Obukhow theory. (This is basic because complex terrain causes different turbulences generation due to terrain and surface roughness length, different solar insulation, different albedo and bowen ratio.)
- Model should be able to take into account calm conditions (no wind situation can be up to 30% of all time in basins).

Elaboration should be done on one year time series of meteorological measurements. Measurements should include several (at least two) ground level stations; number should reflect the complexity of the investigated domain. In addition SODAR measurements of wind profile was required.

The requirements were strict enough to ensure modelling with basic characteristics good enough for realistic results in complex situations where Slovenian industry is located.

Year 2008

Unfortunately in year 2008 the requirement for wind profile measurements with SODAR was removed. Unfortunately no other guidelines were given that would require any kind of sufficient determination of vertical wind profile.

And the requirement for at least two ground level stations was removed too. Only general requirement that a number of meteorological measurements sites should reflect the area complexity remained.

31st July 2009 - Deadline for modelling plans official submission

In 2009 the 31st of July was the deadline for the industry to officially submit their plans for how to measure meteorology and how to model air pollution caused by their emission. Approximately twenty industrial plants have this obligation. The Environmental Agency of the Republic of Slovenia is the authority responsible for this official procedure that should result in plant's environmental permits until 31st December 2011. On the deadlines date the requirements for the modelling were as explained above.

August 1st 2009 – Changes of legislation on the day after submissions of plans

One day after this deadline, on August 1st 2009 the new legislation came into force and it was published only one day before in the official gazette of Republic of Slovenia.

The new requirements for the flat or slightly rolling terrain remain the same as explained above.

But the requirements for complex terrain cases were drastically changed.

The most important change was that only very general formulations were used that do not specify the quality level of the modelling enough in our opinion. Official requirements for regulatory modelling should be specific enough that also a third party modelling expert can determine if an adequate modelling tool is used in an adequate way in case a dispute should arise between the industrial plant, competent agency (of the Republic of Slovenia) and eventual land or property owners in the effected area. Such a dispute can have serious legal consequences.

The requirements for complex terrain cases as they have been valid since August 1st 2009
In the following paragraph is direct translation of presently valid requirements for modelling in complex terrain.

"Modelling methods should be used that are internationally recognized and validated, they should be comprised of adequate dispersion model, that is capable of calculating concentrations field above complex terrain, and meteorological model that is capable of 3D wind field calculation over such terrain based on measured wind data.

Meteorological data that should be taken into account as basis for modelling:

Modelling should be done on meteorological data for one year with averaging intervals of at most one hour.

According to modelling domain complexity (due to terrain and meteorological features) enough representative meteorological data should be taken into account.

For complex terrain cases it is required to measure meteorological parameters at least one year on suitable locations in the modelling domain. The number of measuring sites should be suitable to the complexity of meteorological situation in the modelling domain."

FAIRMODE BASIC REQUIREMENTS
FAIRMODE (FAIRMODE, 2009) basic requirements should also be taken into account. Some of the most relevant guidelines for industrial sources modelling can be summarised as follows:

- modelling should be done by expert modellers,
- modelling should be done with models that are validated before their regulatory use,
- modelling system should be fit to the purpose,
- modelling domain cell size for industrial sources modelling should not be bigger than 250m.

CONCLUSIONS
Most of the Slovenian territory where major industrial and power plants are installed is a very complex terrain. The complexity is represented by terrain consisting of several small valleys, basins, hills and mountains. In addition most of the area is characterised by low winds and often thermal inversions. Therefore the most advance models are needed to get reliable environmental impact assessment for existing and for new industrial and power plants with emission of pollutants into the atmosphere.

The crucial impact in such conditions is always in the close vicinity of the plant. Therefore the models are needed that give reliable results in fine resolution (below 200m) when evaluating point sources. Lagrangian particle model coupled with 3D diagnostic mass consistent wind field model is a possible solution that proved to be a successful combination that gives results that show agreement with measurements in time and space which is very important for the local inhabitants.

For these studies to be reliable it is very important that the set of models (meteorological and air pollution dispersion) was used that was previously successfully validated in similar conditions. It is mandatory that the models are fit for the purpose and that validation is always made before regulatory usage of the model and that validation is made on similar conditions (in terms of domain size, grid, time step, terrain similarities and especially similar meteorological conditions).

REFERENCES
Breznik, B., Božnar, M., Mlakar, P., Tinarelli, G. Dose projection using dispersion models: [presented at 8th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, 14-17 October 2002, Sofia, Bulgaria]. *Int. j. environ. pollut.*, 2004, vol. 20,

Božnar M., Brusasca G., Cavicchoioli C., Faggian P., Finardi S., Minella M., Mlakar M., Morselli M. G., Sozzi R., 1994: Model Evaluation and Application of Advanced and Traditional Gaussian Models on the Experimental Šoštanj (Slovenia, 1991) Campaign. Workshop on Intercomparison of Advanced Practial Short-Range Atmospheric Dispersion Model, Manno, 1993, Proceedings of the Workshop, editor C. Cuvelier, European Commission: 112-121

Božnar M., Brusasca G., Cavicchoioli C., Faggian P., Finardi S., Mlakar M., Morselli M. G., Sozzi R., Tinarelli G., 1994: Application of advanced and tradicional diffusion models to an experimental campaign in complex terrain. 2nd International Conference on Air Pollution, Barcelona, 1994, Air Pollution II, Vol. 1, Computer Simulation, editors J. M. Baldsano *et al.*, Southampton, Boston, Computational Mechanics Publ.: 159-166

Božnar, M., Mlakar, P., Planinšek, T.. Regulatory modelling in Slovenia. V: BARTZIS, J.G. (ur.), KONTE, K... (ur.). International Conference on Harmonisation Within Atmospheric Modelling for Regulatory Purposes, 18-21 May, Rhodes, Greece, 1998. *Preprints*. [S.l.]: INTRP/Environmental research laboratory, 1998

Božnar, M, Grašič, B, Tinarelli, G. Thermal power plant Trbovlje air pollution impact modelling in complex terrain. V: *Sixth Annual Meeting of the European Meteorological Society (EMS)[and] Sixth European Conference on Applied Climatography (ECAC): Ljubljana, Slovenia, 4-8 September 2006*, (EMS annual meeting abstracts, volume 3). Ljubljana: European Meteorological Society: Agencija RS za okolje, 2006

Božnar, M., Mlakar, P., Grašič, B., Tinarelli, G. Air pollution reconstruction around Thermal power plant Trbovlje in complex terrain for model evaluation and regulatory planning. V: CEGNAR, Tanja (ur.), AVSEC, Stanislav. *Responding to environmental change: from words to deeds, Poster abstracts*. Ljubljana: of the Republic of Slovenia, cop. 2008

Božnar, M., Mlakar, P., Grašič, B. Air pollution dispersion modelling around Thermal power plant Trbovlje in complex terrain : model verification and regulatory planning. V: BORREGO, C. (ur.), MIRANDA, Ana Isabel (ur.). *Air pollution modeling and its application XIX : [proceedings of the 29th NATO/OCCMS International Technical Meeting on Air Pollution Modelling and its Application, Aveiro, Portugal, 24-28 September 2007]*, (NATO science for peace and security series, Series C, Environmental security). Dordrecht: Springer, cop. 2008,

Elisei G., Bistacchi S., Bocchiola G., Brusasca G., Marcacci P., Marzorati A., Morselli M. G., Tinarelli G., Catenacci G., Corio V., Daino G., Era A., Finardi S., Foggi G., Negri A., Piazza G., Villa R., Lesjak M., Božnar M., Mlakar P., Slavic F, 1992. Experimental Campaign for the Environmental Impact Evaluation of Šoštanj Thermal Power Plant, Progress report. CISE Technologie innovative, Milano, Italia, ENEL S.p.A, CRAM-Servizio Ambiente, Milano, Italy, C.I.S.E. Tecnologie Innovative S.p.A, Milano, Italy, Institute Jozef Stefan, Ljubljana

Cerkvenik B, Žabkar R., Podboj A., Persovšek N., Delež velikih nepremičnih virov emisij pri obremenjevanju zraka v zasavju ter njihov vpliv na kakovost zraka v zasavju, ENERGIS, Ljubljana, Slovenia, October 2007

FAIRMODE, 2009: Guidance on the use of models for the European Air Quality Directive, FAIRMODE - Forum for Air Quality Modelling in Europe, ETC/ACC report, Version 5.1, http://fairmode.ew.eea.europa.eu/fol404948/guidance-document/Model_guidance_document_v5_1.pdf/download

Grašič B., Božnar M. Z., Mlakar P., 2007: Re-evaluation of the Lagrangian particle modelling system on an experimental campaign in complex terrain. Il Nuovo Cimento C, Vol. 30, No. 6: 557-575

Grašič B., Mlakar P., Božnar M. Z., Tinarelli G., 2008: Enhanced evaluation of a Lagrangian-particle air pollution model based on a Šaleška region field data set, V: BREBBIA, Carlos Alberto (ur.), LONGHURST, James W. S. (ur.). Air pollution XVI: [reviewed papers accepted for the Sixteenth International Conference on Modelling, Monitoring and Management of Air Pollution held in Skiathos, Greece, September 2008], (WIT transactions on ecology and the environment, vol. 116). Southampton: WIT, cop. 2008: 39-48.

Mlakar, P., Božnar, M., Grašič, B., Tinarelli, G. Evaluation of the Lagrangian particle modelling system over complex terrain based on field data set from Šaleška region. V: CEGNAR, Tanja (ur.), AVSEC, Stanislav. *Responding to environmental change: from words to deeds, Poster abstracts*. Ljubljana: of the Republic of Slovenia, cop. 2008

OSART, Draft Report Of The Osart (Operational Safety Review Team) Mission To The Krško Nuclear Power Plant, 2003, http://www.ursjv.gov.si/fileadmin/ujv.gov.si/pageuploads/si/Porocila/PorocilaEU/KrskoMissionReportSLO9011.doc

Tinarelli G., D.Anfossi, M. Bider, E.Ferrero, S. Trini Castelli, 2000: A new high performance version of the Lagrangian particle dispersion model SPRAY, some case studies. Air Pollution Modelling and its Applications XIII, S.E. Gryning and E. Batchvarova eds., Kluwer Academic / Plenum Press, New York