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"ŠOŠTANJ" DATA SET FOR VALIDATION OF MODELS OVER VERY COMPLEX TERRAIN

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Abstract: In 1991 three institutions from Slovenia and Italy performed a measuring campaign to collect data for validation of models. The target was a local area around the Šoštanj thermal power plant (ŠTPP) in north-east of Slovenia. The measurements data set was intended for testing of the models capable of reproducing air pollution from point sources in complex meteorological and terrain situation that characterised Šoštanj area. At that time the database was elaborated and a written report was produced. The diskettes with data and the printed report have been delivered to several scientific institutions and libraries, but then after mostly forgotten. As one of the co-authors of the work we decided to renew the database and to produce nowadays needed information that will allow other researchers to use this experimental database for modern models testing. The measurements data set describes in details the following situation: Šoštanj thermal power plant at that time did not have desulphurisation plants therefore SO2 continuously emitted by its blocks was acting like a tracer in the environment (other sources of SO2 were negligible in comparison to ŠTPP). On-line automated measurements of SO2 were available at all stacks of the ŠTPP and at 6 ambient stations in the basin and on the surrounding hills that were measuring also ground level meteorology. The area is characterised by a very complex meteorological situations (characterized by low winds and thermal inversions). The air pollution patterns are even nowadays not so easy to reconstruct. Out of the three weeks of data there are two days very interesting for detail models performance testing (one in a neutral case and one in a very complex convective case). In the paper we will present a detailed description of the experiment (area description, site, terrain, measurements stations location, database and two most interesting cases suitable for a model validation (emission, ambient concentrations, meteorology). The available description and data offered will be sufficient for other modellers to use the validation set. In addition we will present examples of our validation of the AriaIndustry models Swift and Spray.

Key words: *air pollution dispersion modelling, database, validation, complex terrain, field dataset.*

INTRODUCTION

It is essential to realise with regard to the use of dispersion models for regulatory purposes how well models can illustrate what is actually happening in nature (Božnar, M. Z. et al., 2012). This was already a question two decades ago, when an initiative was launched in Europe to unify these models.

A group of researchers who worked at the Jožef Stefan Institute (IJS) (from Ljubljana), CISE and ENEL (from Milan) institutes at that time realised that the greatest problems with modelling arise when we wish to simulate processes taking place over highly complex terrain. In the spring of 1991, the three institutes thus conducted a measurement campaign in the surroundings of the Šoštanj Thermal Power Plant (ŠTPP) in north-eastern Slovenia (Elisei, G. et al., 1992, Božnar, M. Z. et al., 1994a, Božnar, M. Z. et al., 1994b). The goal of the measurement campaign was to obtain air pollution field dataset over complex terrain for the purposes of testing and validating dispersion models.

A modern automated measuring system for the measurement of meteorological parameters and SO2 concentrations was already operating at the time in the direct vicinity of the ŠTPP and emission measurements were automatically carried out in the stacks of the ŠTPP.

The key to the planning of this experiment was the fact that the ŠTPP was not yet equipped with a desulphurisation unit at the time and thus emitted very large quantities of SO2 into the atmosphere. The

SO2 emissions were so high due to the extremely high concentrations of sulphur in the local energy source used, i.e. lignite from the Velenje Coal Mine in the direct vicinity of the power plant. The presence of this source of lignite was the key reason for the construction of the power plant in Šoštanj.

There was no other comparable industrial or private source of air pollution in the wider area surrounding the ŠTPP that would emit sufficient quantities of SO2 into the atmosphere to have a significant effect (comparable to the SO2 emissions of the power plant) on SO2 concentrations in the area.

Given the above, the measurement campaign in Šoštanj could be said to have been an ideal example of a tracer experiment, wherein the tracer was the SO2 itself.

In this article, we explain in detail all the key aspects of the experiment and the database that enable modellers today to use these data to validate models over a complex terrain.

ŠOŠTANJ AND ITS SURROUNDINGS – GEOGRAPHICAL AND METEOROLOGICAL FEATURES

Most of Slovenia has very complex terrain. This includes the region of north-east, where the ŠTPP is located. The micro-location of the ŠTPP is at the edge of the Velenje Basin, which is surrounded by hills. Figure 1 shows the terrain in an area of 15km × 15km centred around the ŠTPP. The wider surrounding area has similar characteristics. To the north and north-west, towards the border with Austria, lie the Karawanks, which are part of the Alps and constitute an even more prominent vertical barrier than the highlands immediately surrounding the basin. There are only a few narrow valleys between individual hills with rivers flowing along them, the most notable of which in the direct vicinity of the power plant is the River Paka, which winds its way south of the power plant through the hills.

Figure 1. Šoštanj TPP in centre of domain in size of 15 km x 15 km surrounded by 6 automatic environmental measuring stations (left) and location of the plant near the hills (right)

With its location south of the Karawanks and its highly complex terrain, the entire area under consideration, as well as the wider area of Slovenia, has very weak and variable winds. Stronger winds occur only rarely and are pronounced only at the tops of the hills, whereas they are relatively weaker in the valleys and at the bottom of the basin. The weak winds constitute the key reason for the area's high complexity in terms of air-pollution dispersion modelling throughout the year, even in the summer (Božnar, M. Z. et al., 2012, Grašič, B. et al., 2008). In winter in particular, there are additional circumstances that complicate matters even more, i.e. temperature inversions, which further impede the dilution of the air pollutants.

MEASURING SYSTEMS FOR METEOROLOGY, EMISSIONS AND AIR-POLLUTION CONCENTRATIONS

When the measurement campaign was carried out, there were already six fixed automatic measuring stations and one mobile automatic measuring station in operation in the vicinity of the ŠTPP (Elisei, G. et al., 1992).

The stations carried out ground-based real time meteorological measurements (at a 30-minute intervals). They measured the basic meteorological parameters with a standard set-up for horizontal wind measurement at 10m above the ground. The wind speed sensors were mechanical with a cup anemometer placed on magnetic bearings, which enabled accurate measurements of very weak winds with speeds of 0.3m/s and above. The measuring stations were also equipped with instruments for measuring ambient SO2 concentrations operating under controlled atmospheric conditions. The measuring instruments operated in their optimal range, as the concentrations sometimes exceeded $1mg/m^3$, which would be outrageously high today, considering the present situation and the regulatory requirements. The fact that the instruments operated in their optimal range also meant that measurement errors associated with an unstable zero point and the potential effect of other compounds on the measurement had a negligible impact on the targeted result, i.e. measurements of events with high SO_2 concentrations suitable for model validation. It is also important to note that an automatic daily SO_2 measurement quality control system was already in place at the time, wherein zero-air measurements and measurements of a stable predetermined SO_2 span concentration from an integrated permeation tube were carried out once per day (in one 30-minute period). These daily test procedures served to indicate the quality of the SO_2 measurements. In addition to the ŠTPP stations, a research group from Italy also contributed additional measuring equipment.

The first piece of equipment they brought in was a mobile measuring station for ground-based meteorological measurements and measurements of the atmospheric concentrations of gases, including SO_2. The mobile station was first tested at the location of one of the stationary stations in order to confirm that the measurements of Slovene and Italian systems were comparable, as measurement traceability was not so easily achievable at the time as it is today. The most important additional measuring instrument contributed by the Italian group was a very high-performance SODAR. The SODAR measured the vertical wind profile almost up to a height of 1,000 m under optimal conditions using a mechanical sound beam steering system. It was placed in an open location by the lake, away from the power plant towards the centre of the basin.

The emission measuring stations placed on the thermal power plant's stacks took real-time SO_2 concentration, temperature and stack gas flow rate measurements. A computer-based central unit at the thermal power plant collected all the measurement data in the ŠTPP Ecological Information System (EIS) and displayed the data numerically and graphically for the power plant operators. The measurement data provided by the Italian equipment were collected by a computerised data collection unit.

THE TIMELINE OF THE MEASUREMENT CAMPAIGN AND THE MOST RELEVANT DISPERSION CONDITIONS FOR MODEL TESTING

The measurement campaign was carried out between 15 March and 5 April 1991. The weather was very variable, ranging from sunny spring days to snowfall. Upon examining the high concentration measurements, we decided that the conditions of key importance for model validation were those that had occurred on 30 March and 2 April 1991 (Božnar, M. Z. et al., 1994a, Božnar, M. Z. et al., 1994b).

On 30 March, the Veliki Vrh station recorded direct air pollution in a predominantly neutral atmosphere when relatively strong winds blew the air directly from the stacks in the direction of the station. This event was relatively simple.

On 2 April, there was an SO_2 accumulation under an inversion layer during the night. During the sunny day that followed, convective mixing brought the accumulated pollutant from high in the atmosphere back down to the ground, causing multiple stations to record very high concentrations almost simultaneously. This event is very difficult to model.

THE PROCESSING OF MEASUREMENT AND OTHER DATA FOLLOWING THE CAMPAIGN
The detailed measurement data taken at half-hour intervals were organised, filtered and processed. The institutions issued a joint report on the entire measurement campaign (Elisei, G. et al., 1992). The report and the organised data were sent on diskettes in ASCII form to interested researchers around the globe.

MEIS has prepared an extract of the key measurement data in modern formats suitable for use today. Data on the digital height model, CORINE Land Cover data and the full geographical data on the domain locations of the ŠTPP measuring stations have also been added. In combination with data that are now accessible via modern GIS's (such as Google Maps), these data are suitable for use in model validation. For meteorological data in a wider context, we recommend researchers to use meteorological reanalysis data (**e.g. ECMWF data**), which has been verified to be available for the period during the period of the measurement campaign.

All that researchers need to know about the data (formats, labels, etc.) has been summarised in an informative PowerPoint presentation, which can be obtained together with the data by sending us an e-mail to info@meis.si. The presentation will also be available on the website of the Harmo Conference in Varna.

THE VALIDATION OF THE SPRAY MODEL
Below, we present our latest results for the two above-mentioned most relevant situations (30 March and 2 April 1991). The Spray Lagrangian particle model (part of the AriaIndustry package created by Arianet s.r.l.from Milan, Italy and Aria Technologies from Paris, France), the Minerve diagnostic mass-consistent wind field model and the SurfPro meteorological preprocessor were used for dispersion modelling (Tinarelli, G. et al., 2000, Finardi et al., 1998).

The results over time are presented for the locations of the measuring stations where significant pollution was measured. Due to the complexity of the situations which resulted in inconsistencies between the results of the model for the measuring station locations and the actual measurements, we also implemented a method that enabled an estimate to be made of inaccuracy in space and time. Based on this estimate, it is possible to assess whether a concentration cloud as predicted by the model only passed the station by a few cells or the model was entirely incorrect. It is also possible to check whether the model predicted peak concentrations too soon or too late or completely incorrectly. In simple terms, the results of the model are examined with regard to concentrations in a 3 × 3 or 5 × 5 matrix of ground cells around the cell containing the measuring station (**Figure 2**). The results for these cells are additionally examined 30 or 60 minutes before or after the actual measurement. Each model result for each individual cell is used only once. This method is detailed in the freely available paper by Grašič, B. et al. (2011).

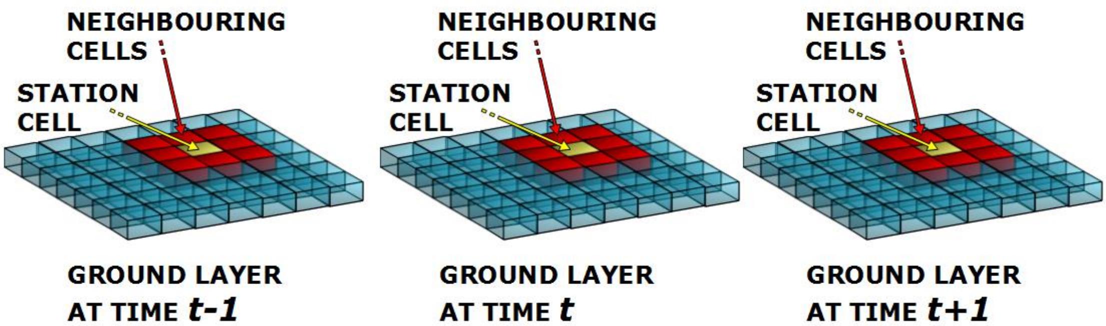

Figure 2. Examination of air-pollution concentrations in neighbouring cells to estimate model error in time and space

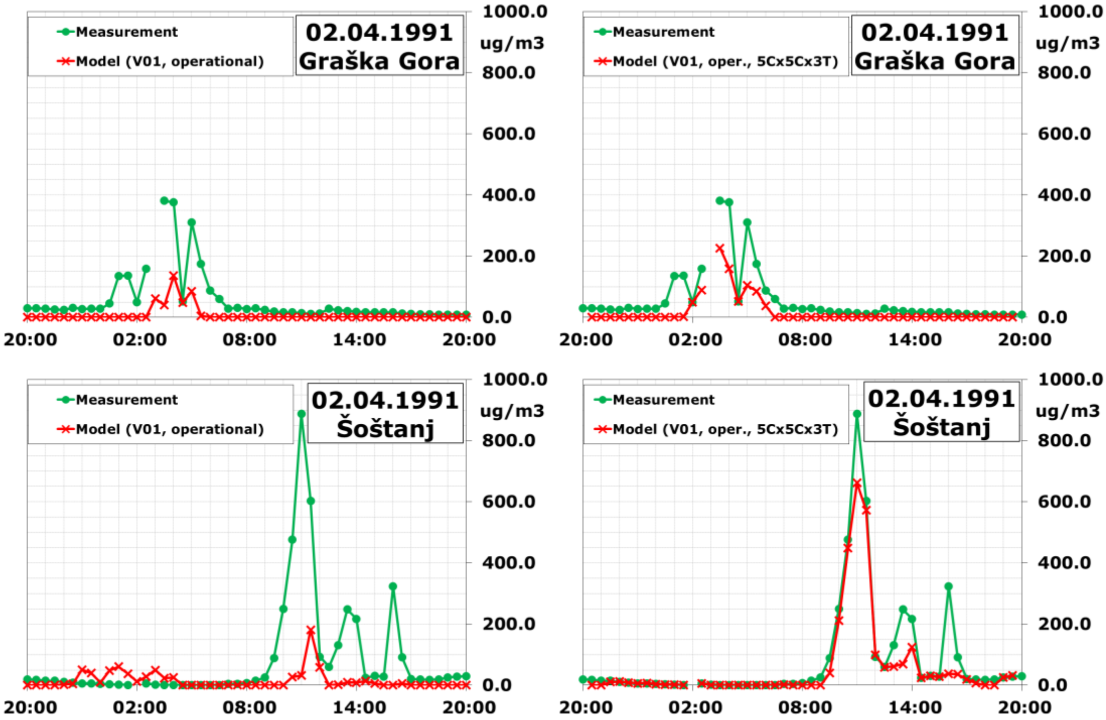

Figure 3. Validation results for two locations (Graška Gora at top and Šoštanj at bottom) (left operational model, right the same model but with method of neighbouring cells, 5 x 5 cells matrix and +/- half hour)

We would also like to mention at this point that the authors of this article have published quite a few papers on this topic in the past two decades, starting with those published at HARMO workshop (not yet a conference at that time) in Switzerland in 1993 (Božnar, M. Z. et al., 1994a, Božnar, M. Z. et al., 1994b).

CONCLUSION - THE VALIDATION RESULTS

Model's results are good, we are able to reproduce complex phenomena, but looking at details - the validation show that even with the highly sophisticated modelling tools of today, we are still not able to model all the details of the processes occurring over complex terrain such as that in the area surrounding Šoštanj and in quite a few other European regions. This applies, of course, to the results obtained by the authors of this article.

We hope that other researchers will also be able to use this complex measurement data set to validate models over very complex terrain and soon present new results.

Validation results (Figure 3) show that we still have some work to be done before we are able to achieve perfect consistency between models and actual measurements in the field of local dispersion modelling over complex terrain in urban as well as other areas. And good data sets will be very helpful for this purpose. Only when we have achieved this goal will we be able to say with certainty that we understand pollutant dispersion in such highly complex conditions.

Hiding behind statistical analysis methods that produce acceptable results constitutes hiding from the fact that science has not yet provided all the answers in this field.

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