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Sulphur dioxide emissions modeling and monitoring, originating from a large combustion power plant

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Abstract. This paper presents the results of SO_2 dispersion modeling of emissions from a large combustion plant (LCP), between 1-30 September 2010, using ISC AERMOD View software/ ISCST3 model, specialized in modeling of gas dispersion. As input data, the software uses technical parameters of the pollution source, as emission rate, stack height, gas temperature; meteorological data, such as air temperature, atmospheric pressure, air humidity, wind speed and direction; and topographic data from the SRTM3 global digital elevation model. These simulations are used to observe the physical processes that affect air pollutants as they disperse in the atmosphere, and to observe and study the associated environmental impact. Also, the paper compares the simulation results with imission data from local monitoring stations of National Environmental Protection Agency. These data are measured with the HORIBA APSA 370 ambient sulfur dioxide monitor, based on ultraviolet fluorescence method as its operating principle, and they correspond to sulfur dioxide imission concentrations near the power plant.
Key Words: power plant, SO_2 emissions, monitoring, dispersion modeling.

Introduction. In the past few years the interest for monitoring and reduction of pollutants concentration and for the use of environmental friendly technologies increased. Atmospheric pollution has multiple and significant effects on all living organisms, some short-term and direct, like the impact of sulphur dioxide, of nitrogen oxides, of tropospheric ozone, heavy metals and particulate matter, and other long-term and indirect, like acid rain, destruction of the ozone layer and greenhouse effect (IPCC 2007).

On international and European level there is a growing preoccupation on strategies and optimal actions for reducing sulfur oxides responsible for acid rain, protection of the ozone layer and limitation of carbon oxides emissions. The European Parliament and Council Directive 2008/1/EC from 15 January 2008 concerning integrated pollution prevention and control is the main Directive which creates the legal framework for reduction of environmental pollution (IPPC Directive 2008).

Because large quantities of pollutant emissions are released in the atmosphere by combustion processes, especially from power plants, there was a necessity in adopting policies for emissions resulted from this type of industry. Because of this the 2001/80/EC Directive was adopted, with its main objective being the reduction of sulfur dioxide, nitrogen oxides emissions and particulate matters from large combustion power plants (LCP) (Ivanciu et al 2011; LCP Directive 2001; GEO 40 2010).

These pollutants are dispersed and carried over large distances and finally deposited on the ground, depending on different factors, such as: stack height, dimensional distribution of particulate matter, gas velocity at release, wind speed and direction etc. Deposition of pollutants is influenced by regional climatic conditions and topographic features (Triantafyllou 2003).

In order to establish the level of pollution at a certain location in a certain timeframe, as result of an activity that generates pollutant emissions, it is necessary to develop dispersion simulations using specialized programs. Atmospheric dispersion modeling is used as a tool in pollution control policies, offering the possibility to study the atmosphere from a mathematical and engineering point of view. Simulations offer the possibility to test the functionality and the dynamic behavior of the model (Ajtai et al 2012).

A major advantage of the dispersion modeling in air quality management and assessment is a better representation of pollutant concentration spatial distribution, on a regional and local scale. A complex simulation study requires different sets of data referring to source conditions, emissions, imissions, vulnerability, local meteorological conditions, terrain data etc (Buzatu 2010).

Most air dispersion simulation models were created to predict atmospheric pollutant concentration for short-term and medium-term. The quality of the results depends especially on versatility and quality of input data and the right choice of the model (Török et al 2011).

The case study focuses on sulphur dioxide analysis in a large combustion power plant (LCP) area, situated in south-eastern Transylvania on the left bank of the Mures river, with an installed power of 1285 MW generated by three large power groups. Its main method for generating energy is cogeneration, due to the ecological, economic advantages of the process. The analysis was made from the 1st to the 30th of September 2010, using the ISC AERMOD View program, for mathematical simulation of SO_2 impact on the environment, using as input data stack flue gas emissions, meteorological and topographical data of the area. Imissions were monitored at dedicated stations equipped with sulphur dioxide analyzers - HORIBA APSA 370.

Material and Method. This article presents a series of simulations for sulphur dioxide dispersion, using the ISC AERMOD View program - ISCST3 (Industrial Source Complex Short Term) model for the emissions associated with the LCP, and a series of in-situ concentration measurements using HORIBA APSA 370 sulphur dioxide gas analyzer. These two data sets are compared to see if there is a qualitative correlation between the concentrations resulted from these two types of analyses.

The ISCST3 model is a Gaussian plume dispersion model that predicts air concentrations around point or area sources up to a distance of about 50 kilometers, using technical parameters, meteorological conditions and topographic data as model inputs (Ajtai et al 2011). The required technical parameters are: release height of flue gas, calculated SO_2 emission rate, stack diameter, gas temperature at release and gas velocity at release (see Table 1).

Table 1

Source parameters

	Stack height [m]	*Calculated SO_2 average emission rate [g/s]*	*Gas temperature at release [℃]*	*Stack Diameter [m]*		*Gas velocity at release [m/s]*	*Flue gas flow [Nm^3/s]*
				at base	*at top*		
Stack 1	220	191.59	190	27.00	6.44	3.00	98.00
Stack 2	220	191.59	155	27.00	6.44	3.03	98.80
Stack 3	220	191.59	150	23.58	7.76	1.97	93.00

The meteorological data used in the dispersion model are ambient temperature and pressure, wind speed and direction, cloud cover and cloud height, obtained from the local meteorological station near the studied plant for a one month period (September 2010) and was inputed using Rammet View meteorological processor, which is part of the ISC AERMOD View software package. Based on this data, Rammet View estimates the atmospheric stability class and mixing layer height for every hour taken into study.

Topographical data was collected from SRTM3 digital elevation model (Figure 1), composed from global topographic data. Based on SRTM3 data, the software makes a terrain characterization, and generates grill receptors used in dispersion model (Mihăiescu et al 2011). The ISC AERMOD View outputs consist, in graphical form, of dispersion maps superimposed on topographic maps and text data obtained from the simulation report. The software can output only the first ten daily maximums simulated.

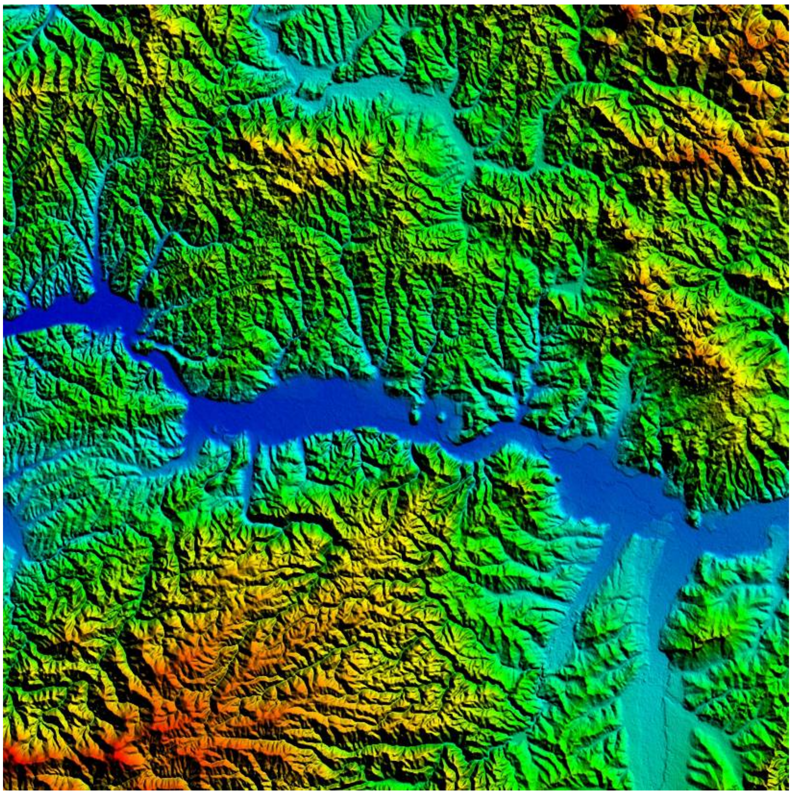

Figure 1. SRTM3 with location of the LCP (USGS 2012).

This article presents the first maximum hourly and daily average concentration maps and the first ten daily maximum averaged concentrations resulted in two selected receptor points. These receptor points (HD-1 and HD-2) were selected to match the coordinates of the HORIBA monitors. These monitors allow continuous measurements of SO_2 concentrations in the atmosphere (HORIBA Ltd 2009). Daily SO_2 concentrations can be obtained from hourly averages of measurements on the entire analysis period.

Results and Discussion. The objective of this study is to assess the impact of sulphur dioxide in the area of the LCP, in the 1-30 September 2010 time period. For this three different analyses were made:

- dispersion modeling, using ISCST3 dispersion model for SO_2 source emissions;
- data analysis of sulphur dioxide imission concentrations at air quality monitoring stations (HD-1 and HD-2) of the National Agency for Environmental Protection;
- comparative analysis of the ISCST3 dispersion simulation imission results with in-situ HORIBA measurements to establish a qualitative correlation between these two studies.

In the first case, simulation results revealed a high concentration of pollutant in the surrounding area of the power plant. In some cases, concentration values exceeded limit values for atmospheric SO_2 imissions (350 µg/m^3 - hourly limit, and 125 µg/m^3 - daily limit for human health protection) (Law 104 2011).

The simulation results show dispersion over distances in excess of 15-20 kilometers from the source, because of the high altitude of the stack (220 m) and the high release temperature.

Hourly and daily maximum concentrations obtained using ISCST3. In the following section, the maximum SO_2 concentrations resulted from modeling and simulation are presented. The program outputs impact maps based on emission input data and technical parameters, necessary to the calculations.

Two types of dispersion maps are presented: one with hourly averaged maximum SO_2 concentrations and one with daily averaged maximum SO_2 concentrations.

On the hourly impact map (Figure 2) it can observed that the resulted maximum SO_2 concentration surpasses hourly limit values of 350 μg/m^3, especially in the south of the power plant, on the high hills in that area (450-600 m). It can be observed a low concentration of SO_2 in the Mureş river corridor due to frequent winds and high concentration of pollutant at higher altitudes. The hills can obstruct the pollutant cloud causing lower dispersion in these areas. From the daily impact map (Figure 3) it can be observed that the daily limit value of 125 μg/m^3 is surpassed, especially in the south of the power plant.

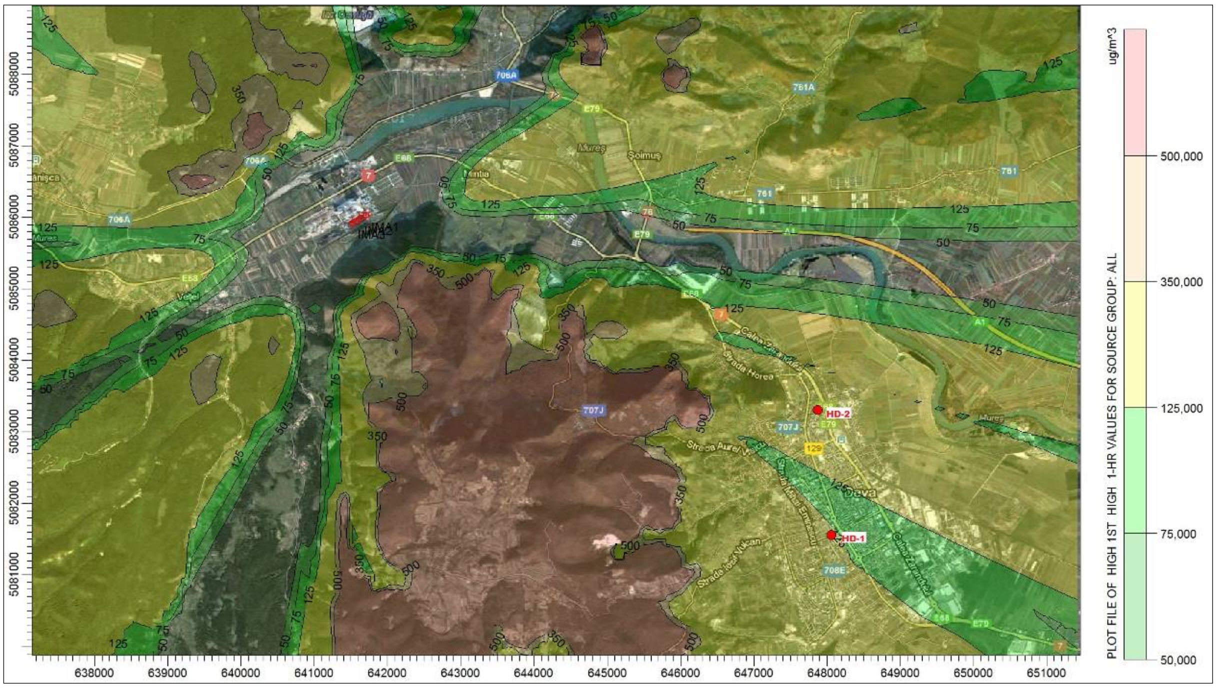

Figure 2. Impact map representing first maximum hourly average SO_2 concentrations.

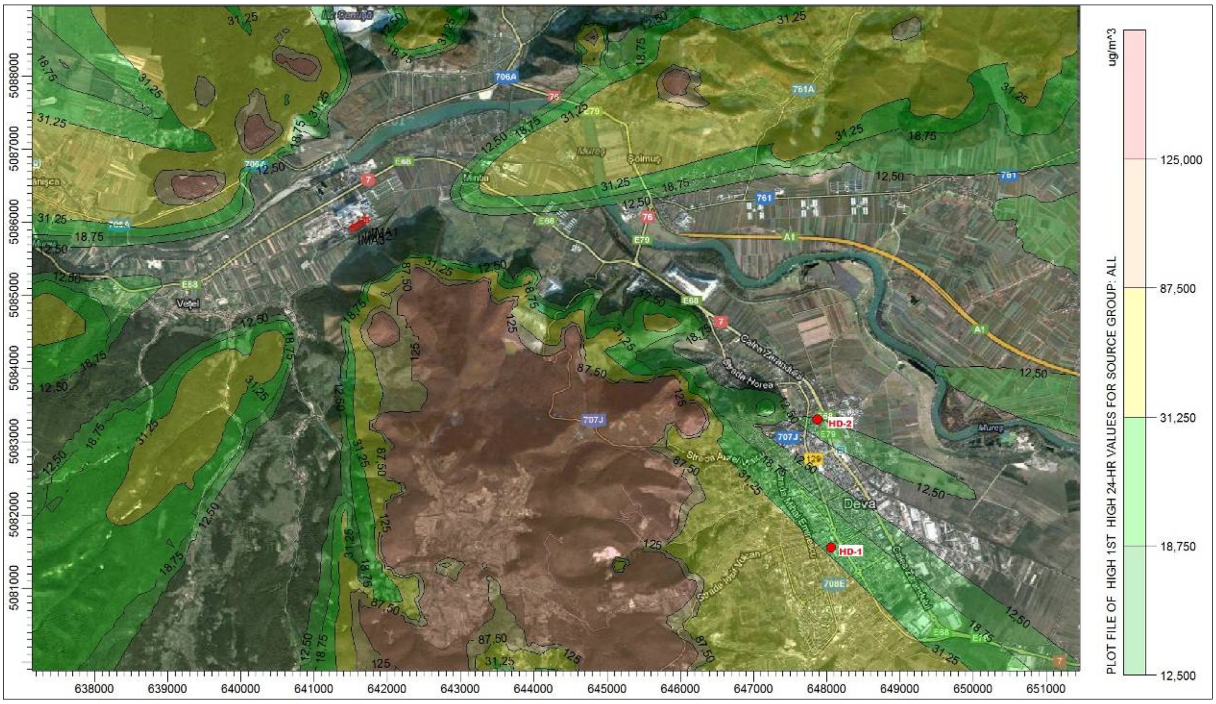

Figure 3. Impact map representing first maximum daily SO_2 concentration.

Maximum concentrations simulated for receptors (HD-1 and HD-2). In the SO_2 dispersion simulation two virtual receptors were generated, located at the coordinates of air quality stations (HD-1 and HD-2) of the National Agency for Environmental Protection. Table 2 presents the first three maximum hourly and daily average concentrations resulted from simulations.

Table 2

First three maximum SO_2 concentrations in the receptor points obtained by simulation

	Maximum hourly SO_2 concentration [µg/m^3]	*Date 2010.09 DD.HH*	*Maximum daily SO_2 concentration [µg/m^3]*	*Date 2010.09 DD*
First	127.9 (HD-1)	05.10	28.7 (HD-1)	05
maximum	138.0 (HD-2)	28.10	8.0 (HD-2)	28
Second	102.8 (HD-1)	08.11	15.0 (HD-1)	08
maximum	110.9 (HD-2)	17.11	6.8 (HD-2)	17
Third	102.4 (HD-1)	07.12	11.0 (HD-1)	16
maximum	8.3 (HD-2)	05.10	1.1 (HD-2)	05

Comparison between simulation and monitoring results in receptors. Using data from HD-1 and HD-2 monitoring stations and the ten maximum daily concentrations obtained from dispersion simulation a comparative graph can be plotted (Figure 4).

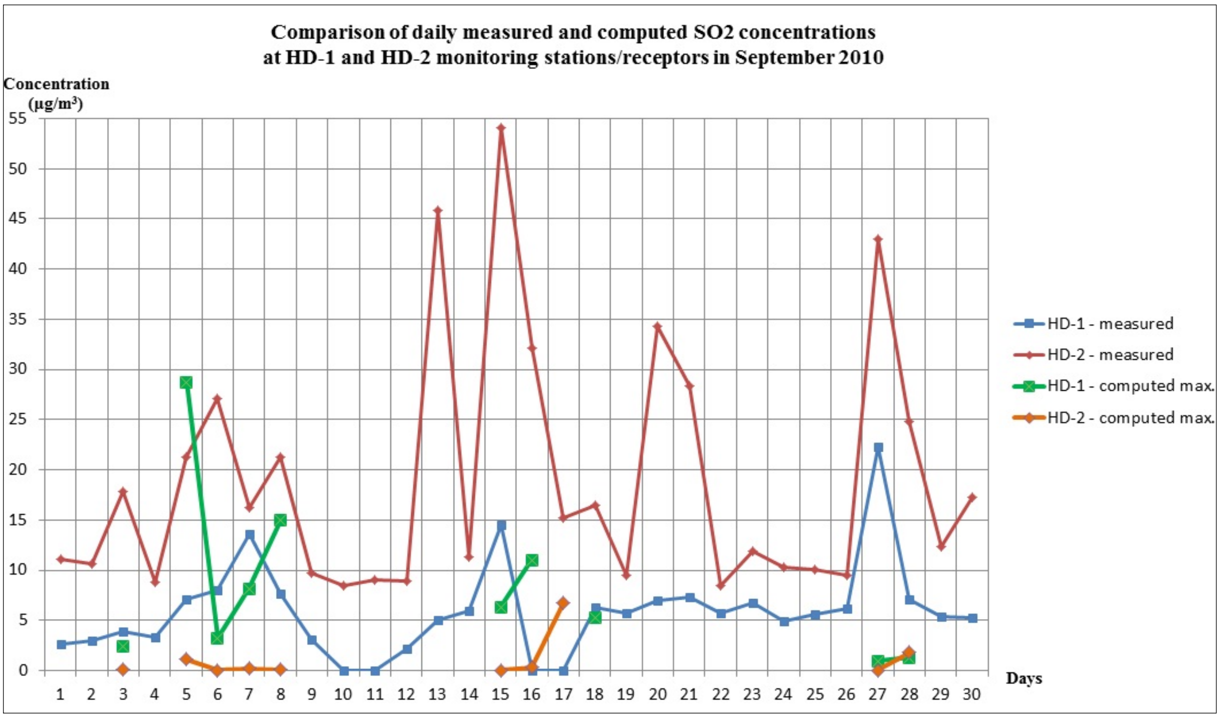

Figure 4. Comparison of daily measured and computed SO_2 concentrations.

Geographically, HD-2 monitoring station is closer to the LCP than HD-1 monitoring station. At HD-1 station, the analyzer detected three daily maximums, and at HD-2 there are 5 maximums detected. At both locations, these maximum values are within the daily limit value for human health protection (125 µg/m^3) (Figure 4).

At both stations (HD-1 and HD-2) measured concentrations are dependent on some physical, meteorological factors, such as precipitation, solar radiation, air temperature, atmospheric pressure, wind speed and direction, responsible for different values and different days with maximum concentration resulted from data analysis.

A qualitative correlation can be made between the two types of analyses, but only for daily maximums, due to the fact that in situ measurements are daily averaged.

This comparative graph (Figure 4) shows a good qualitative correlation of SO_2 maximum concentrations between the two monitoring stations.

Regarding the inter-comparison between these data and simulation results, only HD-1 data series shows some degree of correlation with in-situ measurements, the concentration values having the same size factor.

Uncertainties may be due to several factors:

- monthly averaged emission data computed for the LCP;
- ISCST3 model limitations;
- uncertainty in meteorological data, use of daily averaged data instead of hourly averaged;
- undetermined external influences upon SO_2 analysis at the HD-1 and HD-2 stations.

Conclusions. Given the fact that there are no individual hourly emissions data for each stack to use as input data to run the simulations an average emission rate was introduced. This can induce significant errors in simulation results.

These shortcomings generated by the inaccurate estimation of the emission rate can be overcome by using advanced 3D Optoelectronic systems like high-performance IR and UV cameras for optical determination of gaseous particle emissions in the atmosphere. These terrestrial UV and IR cameras have been used to monitor industrial and anthropogenic gas emissions (SO_2, particulates), volcanic cloud and visual range (Kern et al 2010; Nisulescu et al 2010).

Digital cameras, sensitive to a specific area of spectrum UV (ultraviolet), were used to quantify the emissions of sulfur dioxide (SO_2) in recent years (Stebel et al 2012).

Due to the adverse effects associated with these emissions, such studies are necessary in order to better assess the impact of SO_2 on the surrounding environment and to provide decision makers and policy makers additional information for the flue gas desulphurization implementation procedures.

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