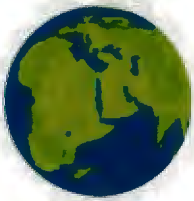

4th International Workshop on Uncertainty in Atmospheric Emissions

7-9 October 2015, Krakow, Poland

PROCEEDINGS

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About the Workshop

The assessment of greenhouse gases and air pollutants (indirect GHGs) emitted to and removed from the atmosphere is high on the political and scientific agendas. Building on the UN climate process, the international community strives to address the long-term challenge of climate change collectively and comprehensively, and to take concrete and timely action that proves sustainable and robust in the future. Under the umbrella of the UN Framework Convention on Climate Change, mainly developed country parties to the Convention have, since the mid-1990s, published annual or periodic inventories of emissions and removals, and continued to do so after the Kyoto Protocol to the Convention ceased in 2012. Policymakers use these inventories to develop strategies and policies for emission reductions and to track the progress of those strategies and policies. Where formal commitments to limit emissions exist, regulatory agencies and corporations rely on emission inventories to establish compliance records.

However, as increasing international concern and cooperation aim at policy-oriented solutions to the climate change problem, a number of issues circulating around uncertainty have come to the fore, which were undervalued or left unmentioned at the time of the Kyoto Protocol but require adequate recognition under a workable and legislated successor agreement. Accounting and verification of emissions in space and time, compliance with emission reduction commitments, risk of exceeding future temperature targets, evaluating effects of mitigation versus adaptation versus intensity of induced impacts at home and elsewhere, and accounting of traded emission permits are to name but a few.

The *4th International Workshop on Uncertainty in Atmospheric Emissions* is jointly organized by the *Systems Research Institute of the Polish Academy of Sciences*, the Austrian-based *International Institute for Applied Systems Analysis*, and the *Lviv Polytechnic National University*. The 4th Uncertainty Workshop follows up and expands on the scope of the earlier Uncertainty Workshops – the *1st Workshop* in 2004 in Warsaw, Poland; the *2nd Workshop* in 2007 in Laxenburg, Austria; and the *3rd Workshop* in 2010 in Lviv, Ukraine.

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On the uncertainty in modeling urban air quality under imprecise emission data

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Abstract

Air pollution dispersion models have recently been used for supporting decisions concerning air quality management and emission control. Emission inventory is the basic input dataset in air quality evaluation. To select the best strategy of emission reduction and to assess the possible environmental effects, there is a need to estimate the contribution of the respective emission sources to the resulting air pollution. This paper addresses the problem of uncertainty of air pollution models, related imprecision and uncertainty of the emission data. The problem is discussed in a case study for Warsaw agglomeration, where the main urban scale air pollutants: SO_2, NOx, PPM_{10}, $PPM_{2.5}$ are considered. CALMET/CALPUFF modeling system is used as the main forecasting tool which links the emission data with the resulting concentrations. Uncertainty analysis, based on a Monte Carlo algorithm, shows the main factors which decide on the resulting uncertainty of the model forecast.

Keywords: air pollution, emission inventory, computer model, uncertainty analysis

1. Air quality models in decision support systems

A direct application of air quality models is in forecasting dispersion of pollutants, analysis of ecological results of some specific meteorological episodes, or evaluation of the final environmental impact of emission sources. Recently developed Integrated Assessment Models (IAM) [2, 3, 9, 16] are used for supporting decisions concerning air quality management and emission control policy. The air quality model is a key module of such a system which enables to assess environmental, economic or health benefits of emission abatement, and to select the best strategy of emission reduction. In such applications, there is a need to estimate the contribution of emission sources to ambient concentrations with required accuracy. However, due to a very complex structure of such systems, there exist many sources of environmental effects of atmospheric pollution as well as in the resulting regulatory decisions.

The quantitative assessment of uncertainty brings the modeling prediction closer to reality. It increases decision maker's confidence in the modeling results and improves the quality of the final decisions. To assess the accuracy of modelling results and a connected decision support process, inaccuracy and uncertainty of the model should be evaluated. The main sources of results' variability (temporal or spatial) and uncertainty (imprecise information or lack of information about unknown quantity) should be identified and assessed [11, 15, 17].

It is a common view in the literature that emission field inventory is one of the main sources of uncertainty in modeling of air pollution dispersion. The problem is particularly significant in urban agglomerations [1, 4, 10, 12, 14]. Emission field in such cases comprises a variety of sources, point-, area- and line-, with different technological parameters, emission intensities, composition of polluting species, and also – with different uncertainty which is introduced to the system. This uncertainty must be taken into account in complex analysis, when the results are to be used in supporting regulatory decisions.

2. Urban scale uncertainty analysis

The computations performed in the framework of the study relate to the forecasts and analysis of air pollution dispersion in Warsaw agglomeration. The aim was to evaluate the environmental impact of the main categories of emission sources as well as to estimate the uncertainty of this forecast, which is related to the uncertainty of emission field inventory. The analysis covers a rectangular domain, approx. 30 x 40 km^2 of Warsaw Metropolitan Area shown in Fig. 1. The regional scale, Gaussian puff dispersion model CALPUFF [18, 19, 20] was used to simulate the air pollution transport and transformations within the domain.

Figure 1. The study domain and the receptor points ([8], due to CCA License)

In case of the discussed Warsaw study the total emission field was decomposed into four basic categories, mainly according to the emission parameters and the intrinsic uncertainty [7]. According to the previous remarks, assumed emission field was categorized into following four classes:

- 16 high point sources (power/heating plants – low uncertainty),
- 1002 low point sources (industry – medium uncertainty),
- 872 area sources (residential sector – high uncertainty),
- 1157 linear sources (transportation – high uncertainty).

For computational purposes, the domain is discretized with a regular square grid with the step size h = 1 km. The point sources are located according to the geographical coordinates, the area and linear sources are represented as one grid element, 1 km^2 (compare Fig. 1). Computations take into account temporal variability of the meteorological and emission input data with the assumed step-size of time resolution,

$\tau = 1$ h. The annual mean concentrations of the main polluting species are recorded at 563 fictitious receptor points, located in the center of grid elements shown in Fig. 1. The list of the main primary and secondary pollutants considered in this study encompasses sulfur oxides (SO_2), nitrogen oxides (NO_X), sulfate and nitrate aerosols, particulate matter (PM_{10} and $PM_{2.5}$) and Pb.

3. Uncertainty analysis

The uncertainty of the modeling results has been assessed using a Monte Carlo algorithm [6, 13] and the input uncertainties of the emission data. Applied to all the sources and pollutants, 2000 random sets of emission data were preprocessed within the assumed ranges of uncertainty. Each random set of the emission data encompasses a one-year time interval. As stated in [8], to avoid generating unrealistic emission episodes, a correlation between emission intensities of key individual pollutants from each emission source was established.

Table 1. The input uncertainty range depending on emission category (95 CI) ([8], due to CCA License).

Pollutant	Emission sources			
	High point	Low point	Area	Linear
SO_2	± 15%	± 20%	± 30%	± 30%
NOx	± 20%	± 30%	± 40%	± 40%
PPM_{10}	± 25%	± 40%	± 40%	± 40%
$PPM_{2.5}$	± 25%	± 40%	± 40%	± 40%
PPM_{10_R}	–	–	–	± 40%
$PPM_{2.5\_R}$	–	–	–	± 40%
Pb	± 30%	± 40%	± 50%	± 50%

Table 1 presents these ranges, assumed for 4 categories of emission sources, at the 95% confidence interval. The applied input uncertainties have been mainly based on expert opinions as presented in [8]. The normal distribution of the input emission data was assumed. The relative uncertainty range of the resulting pollution concentrations at a receptor point is calculated as a ratio: $(c_{97.5} - c_{2.5})/c_M$, where $c_{2.5}$ is the 2.5 and $c_{97.5}$ is the 97.5 percentile concentration value, and c_M is the mean value.

In the previous papers [7, 8] violation of air quality limits (EU 2008) by NO_X, PM_{10}, $PM_{2.5}$ concentrations, mainly in central districts, was indicated. The accuracy of the forecasts was confirmed by comparison of the results with measurements (FA2 index). Below the main factors which decide on the final uncertainty are discussed.

The first factor which determines the resulting uncertainty is the category of emission sources with the dominating share in polluting the receptor (see Table 1). For example, it is known that NO_X and Pb are typical traffic-related compounds for which the concentration maps are correlated with the topology of the arterial streets. The correlation is also seen on uncertainty maps. The mobile sources also contribute to PM_{10} pollution, but in the case of $PM_{2.5}$ and SO_2 there is a considerable share of the area sources (residential sector) and also of some point sources. The above correlations are reflected in the uncertainty maps.

An important factor influencing uncertainty is the relative share of emission categories which contribute to the selected receptor point. Exemplary maps shown below compare distributions of a typical traffic-related NOx pollution and the pollution of $PM_{2.5}$, which strongly depends on other emission categories, e.g. the area emission from the residential sector. Figure 2 contains two related pairs of maps, pollutant concentration and uncertainty, for NOx (top) and $PM_{2.5}$ (bottom), respectively.

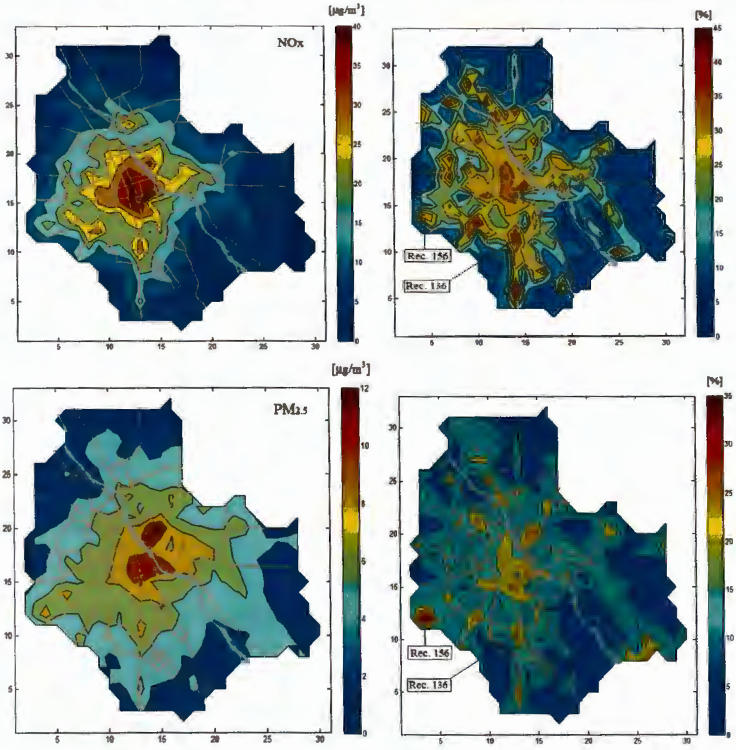

Figure 2. The spatial maps of concentration (left) and uncertainty (right): NO_X – top and $PM_{2.5}$ – bottom ([8],due to CCA License)

It can be observed that the maximum concentrations (left maps) occur in the central districts of the city, but the spatial variability of uncertainty (right map) is much more evident is not strictly correlated with the concentration map. For NO_X the maximum uncertainties are obtained near the main crossroads (similar properties represent the other traffic dependent pollutants, such as PM_{10} or Pb), while the global uncertainty maximum for $PM_{2.5}$ represents the residential sector (individual housing area).

In these cases, high uncertainties correlate to some extent with the concentration values, but in fact they depend also on the location of the receptors. The location determines the relative share of the contributing emission categories and the quantity of the individual emission sources which affect a given receptor point. A specific coincidence of these factors leads to extreme values of the overall uncertainty at some locations. The quantity of individual sources that substantially contribute to a spot strongly influence the uncertainty. Due to the averaging effect, the rising number of such emission sources leads to the lower aggregate level of the relative uncertainty, while a low number of the unbalanced sources mean high uncertainty. This fact is illustrated by the data for pollutions NO_X and $PM_{2.5}$ recorded at receptors #136 (crossroad) and #156 (housing), presented in Table 2 and in Table 3, respectively.

Table 2. Uncertainty of NO_X concentration depending on the receptor location

	Receptor #136 uncertainty range 45%			Receptor #156 uncertainty range 28%		
Sources	Concentration [ug/m^3]	Share [%]	Dominating sources	Concentration [ug/m^3]	Share [%]	Dominating sources
LINEAR	29,8	94,3	4	15,94	80,1	9
AREA	1,0	3,1		2,86	14,4	2
LOW	0,7	2,2		0,4	3,5	
HIGH	0,1	0,3		0,7	2	
Total	31,6		4	19,9		11

Table 3. Uncertainty of $PM_{2.5}$ concentration depending on the receptor location

	Receptor #136 – uncertainty range 23%			Receptor #156 – uncertainty range 33%		
Sources	Concentration [ug/m^3]	Share [%]	Dominating sources	Concentration [ug/m^3]	Share [%]	Dominating sources
LINE	6,4	74,5	5	3,1	33,7	1
AREA	1,9	22	1	5,8	60	3
LOW	0,2	2,0		0,2	2,2	
HIGH	0,08	0,9		0,1	1,1	
Total	8,58		6	5,97		4

So, the fewer sources contribute to the pollution level, the higher level of the relative uncertainty may be expected. At the same time, an unbalanced contribution of the individual generally increases the aggregate level uncertainty for the forecasted pollution. This general conclusion is illustrated in the two selected receptor points, namely receptor #136 (crossroad) where the high level of uncertainty occurs for traffic-related pollutants (NOx), and receptor #156 (residential area) in a peripheral district where fine particulates $PM_{2.5}$ predominate in the emission field and induce a high level of uncertainty. On the other hand, in such cases, the impact of the input emission uncertainty assumed in Table 3 becomes less important.

4. Summary

The paper addresses the problem of uncertainty of urban scale air pollution models under uncertainty of emission data. The case study discussed deals with Warsaw agglomeration where Monte Carlo algorithm is used. and sources contribute to the pollution level, the higher level of the relative uncertainty may be expected. Exemplary results illustrate the spatial distribution of uncertainty in the domain. The main factors are indicated which decide on resulting uncertainty of the forecast. It relates to the receptor's location, but also depends on the share of emission classes that affect the receptor site and on the number of the individual emission sources contributing to the overall concentration.

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