Long-term Air Quality Projections for Prague and Central Bohemia Region: Application of the SUDPLAN Modelling Tool

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Abstract

Air quality projections of sulphur dioxide, nitrogen dioxide, PM_{10} and ground-level ozone for Prague and the Central Bohemia region till 2030 were developed using the SUDPLAN (Sustainable Urban Development Planner) modelling tool which enables simulation of the impact of emissions and climate change on the concentration of both primary and secondary pollutants in the atmosphere at both macroscopic and microscopic scales. Emission projections till 2030 were taken from the GAINS (Greenhouse Gas-Air Pollutants Interactions and Synergies) model. In addition, the impact on air quality was simulated for three typical situations: Substantial change in operation of a large combustion plant (close-down or doubled thermal input), completion of the Prague city highway bypass and hypothetic construction of three satellite settlements in the outskirts of Prague.

Introduction

Despite its significant improvement in the past 20 years, air quality remains one of the most serious environmental problems of the Czech Republic. Every year, there is a significant non-compliance with the limit values for suspended particles PM_{10} and target values for tropospheric ozone and benzo (a) pyrene. In addition, local non-compliance with limit values for certain other pollutants can be observed every year [1].

Air pollution is being monitored systematically by the State Air Quality Network operated by the Czech Hydrometeorological Institute (CHMI), which is supplemented by monitoring stations operated by other entities. All air quality data, compliant with the data quality requirements, are collected and evaluated within the Air Quality Information System (AQIS), operated by CHMI.

Based on the data from monitoring stations, fields of spatial distribution of concentrations in the Czech Republic are being developed. Obviously, the Gaussian dispersion model SYMOS 97 is applied, which does not include atmospheric chemistry and is therefore not able to simulate the concentrations of secondary pollutants - tropospheric ozone and secondary particles, which represent about 50% of the total load by PM_{10} particles [2, 3]. In the case of PM_{10}, CHMI uses an empirical model which combines models SYMOS'97, CAMx [4, 5], EMEP [6] and altitude and the measured concentrations at background stations using methods developed within the ETC / ACC [7].

Currently, advanced modelling tools are not available in the Czech Republic which would enable the development of long-term air quality projections for both primary and secondary pollutants taking into account not only emission projections but also the long-term impacts of climate change. As a

result, air quality projections are therefore not readily available. At the national level, the results of a comprehensive EU-wide GAINS model [8, 9] can be used, which generates emission and air quality projections, the impact of pollution on human health and vegetation and also allows the economic evaluation of the costs of reducing emissions, but it works with a resolution of 50 x 50 km and takes into account only the settlements with a population over 350,000. Overview of available models allowing the simulation of emission and air quality projections can be found in the monograph [10].

In addition to the evaluation of air pollution data at macro scale (at the level of the whole country or of the zones and agglomerations), modelling tools are being used at the micro scale in the process of Environmental Impact Assessment (EIA). Besides the aforementioned model SYMOS'97, the Gaussian dispersion model ATEM [11] is also being used, however it also does not simulate concentrations of secondary pollutants.

The objectives of the international project SUDPLAN (Sustainable Urban Development Planner for Climate Change Adaptation) [12], which provides advanced modelling tools to simulate the impact of climate change on air quality, was, in terms of the Czech Republic:

- at the macro scale: Simulation of air quality projections for the main primary (sulphur dioxide, nitrogen dioxide, primary particles PM_{10}) and secondary (secondary particles PM_{10} and tropospheric ozone) pollutants for Prague and Central Bohemia (area 100 x 100 km),

- at the micro scale: Verifying the usability of the tool for three typical situations: Significant change in the operation of a large combustion plant (closure or doubling performance), completion of the ring road by-pass of Prague and the emergence of three hypothetical satellite settlements in the northwest and southeast suburbs of Prague.

Methodology

The SUDPLAN model system consists of several related models; its basic scheme is shown in figure 1.

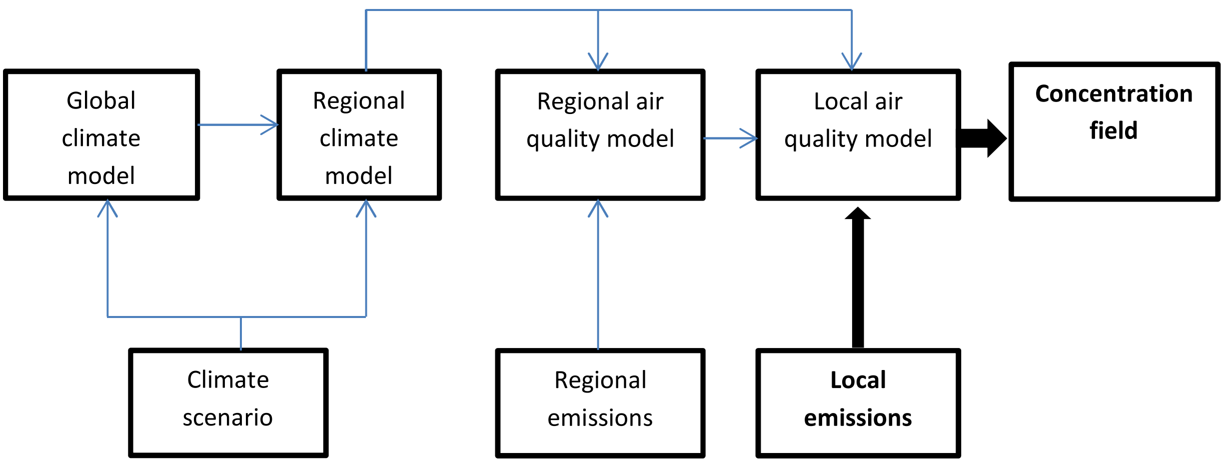

Figure 1: Basic scheme of the SUDPLAN model system

Global climate models (ECHAM5-r3 AIB and AIB ref HadCM3) using climate scenario AIB are entering the regional climate model RCA3, developed by the Rosby center. The chemical-transport model

MATCH [13, 18] is being used as the air quality modelling tool at regional and local levels. The emissions of pollutants at regional (pan-European) level are taken from the RCP4.5 model [14]. A detailed description of the methodology, including the local level is presented in [15], using simulation of air quality for Stockholm as an example. In the case of the Czech Republic the actual emissions at the local level were taken from the database REZZO, and emission projections at the local level have been estimated based on the GAINS model (see below). Simulations were performed by the Swedish Meteorological and Hydrological institute [16] where local emission data were entered into the model system via the AIRVIRO emission database [17].

Results

Area of interest was a square 100 x 100 km centred in Prague, covering the entire territory of the Central Bohemia region and small parts of adjacent regions[1].

Emission data

Existing emission data (2010) were taken from the national databases REZZO. The extra-large, large and medium sized stationary sources (REZZO 1 and 2) were entered into the model as points with geographical coordinates while the small sized sources (REZZO 3) were entered as fugitive emissions with a horizontal resolution of 5 x 5 km. Emission data for mobile sources (REZZO4) was calculated on the basis of traffic intensities and entered with a horizontal resolution of 0.5 x 0.5 km. Emission projections till 2030 were estimated using the GAINS model [8] for the EC4MACS Baseline scenario; the data in the NFR format (Nomenclature for Reporting) was transferred to the REZZO format (see Figure 2).

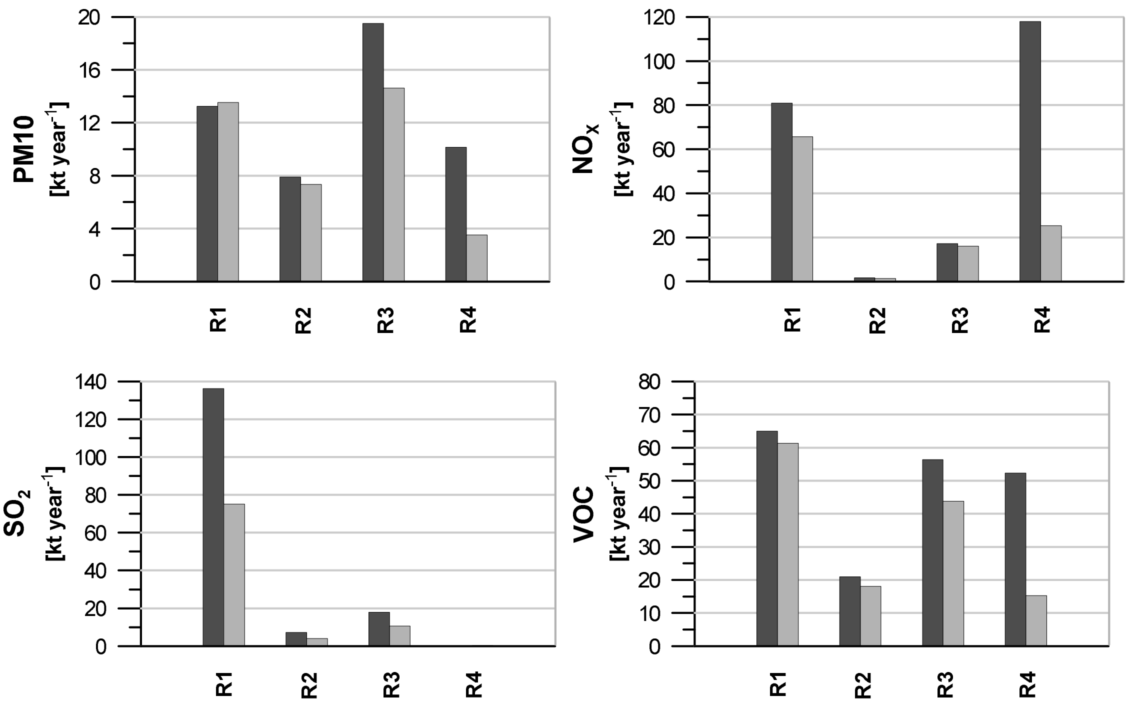

Figure 2: Emission data for 2010 (left dark columns) according to the REZZO database[2] and emission projections for 2030 (right light columns) by the GAINS model (scenario EC4MACS baseline).

[1] The Czech Republic is divided among 14 administrative regions, one of them being the Capital City of Prague.

Model calibration

To calibrate the model system, the data from relevant 12 monitoring stations for the period 2009 – 2011 were used. The results of comparison of the annual average concentrations of nitrogen dioxide, sulphur dioxide, particulate matter PM_{10} and tropospheric ozone are listed in Table 1.

Table 1: Comparison of measured and simulated annual average concentrations

				real concentrations				simulated concentrations				ratio			
Station name	X	Y	Classification	NO2 annual aver.	SO2 annual aver.	PM10 annual aver.	O3 8hour aver	NO2 annual aver.	SO2 annual aver.	PM10 annual aver.	O3 8hour aver	NO2 annual aver.	SO2 annual aver.	PM10 annual aver.	O3 8hour aver
Kladno-střed města	4613968	3011598	B/U/R	21.57	5.30	22.15	50	8.44	3.86	11.1	53.5	**2.56**	**1.37**	**x**	**0.93**
Kosetice	4688058	2952644	B/R/AN-REG	9.37	2.43	19.10	62.6	4.24	1.43	10.3	62.3	**2.21**	**1.70**	**1.85**	**1.00**
Mlada Boleslav	4669879	3046888	B/U/R	18.30	5.30	29.77	51.1	7.91	2.4	11.2	54	**2.31**	**2.21**	**2.66**	**0.95**
Ondrejov	4664104	2989282	B/R/N-REG	10.70	3.93	x	63.3	8.11	1.95	11.3	53.6	**1.32**	**2.02**	**x**	**1.18**
Pha1-Nam-Republiky	4637784	3006875	B/U/C	37.17	x	27.53	36.2	19.5	2.49	14.8	42.4	**1.91**	**x**	**1.86**	**0.85**
Pha2-Riegrovy sady	4638768	3006265	B/U/NR	30.87	4.37	25.90	40.8	19.7	2.47	14.8	41.8	**1.57**	**1.77**	**1.75**	**0.98**
Pha4-Branik	4636867	3001723	B/S/R	31.87	4.75	24.57	x	17.3	2.31	13.7	44.9	**1.84**	**2.06**	**1.79**	**x**
Pha4-Libus	4639604	2997957	B/S/R	21.57	3.67	26.77	48.7	14.4	2.14	12.9	47.4	**1.50**	**1.71**	**2.07**	**1.03**
Pha5-Stodulky	4631077	3001804	B/U/R	25.13	4.63	24.67	47.8	15	2.2	12.9	47.6	**1.68**	**2.11**	**1.91**	**1.00**
Pha6-Suchdol	4634356	3010961	B/S/R	23.33	4.90	24.73	50.5	14.6	2.44	12.8	47.6	**1.60**	**2.01**	**1.93**	**1.06**
Pha6-Veleslavin	4632201	3007543	B/S/R	28.20	x	25.43	41.3	16.4	2.41	13.3	46.1	**1.72**	**x**	**1.91**	**0.90**
Pha8-Kobylisy	4640282	3010878	B/S/R	25.10	4.30	21.93	48.3	18.7	2.57	14.5	43.5	**1.34**	**1.67**	**1.51**	**1.11**
Average coefficient												**1.80**	**1.86**	**1.93**	**1.00**

The comparison of real and simulated concentrations shows that in the case of tropospheric ozone very good agreement was achieved (average ratio coefficient for all stations is equal to one) while in the case of other pollutants the simulated concentrations are significantly underestimated, with the average ratio between real and simulated data moving between 1.8 and 1.93. Given that the concentration ratios for both individual stations and their averages reach similar values (see statistical analysis in Table No. 2), it can be assumed that this is a systemic problem which can be caused by underestimation of local emission data from REZZO 3 (small stationary sources) and / or REZZO 4 (mobile sources), and especially by the undervaluation of background concentrations, which are calculated on the basis of emissions from a regional pan-European model, which works with a horizontal resolution of 50 x 50 km, and cannot therefore take into account local specifics (transport of pollution from neighbouring regions, such as the Ustecky region with high concentration of large combustion plants).

Table 2: Statistical analysis of deviations between measured and simulated data

	The ratio between real and simulated concentrations			
	Minimum value	Maximum value	Average	Median
NO_2	1,34	2,56	1,80	1,70
SO_2	1,37	2,21	1,86	1,89
PM_{10}	1,51	2,66	1,93	1,88
O_3	0,85	1,18	1,00	1,00

In order to correct the above-described systematically underestimated concentrations of nitrogen dioxide, sulphur dioxide and PM_{10}, the uniform correction factor of 1.8 was applied (by which the calculated concentration were multiplied). In a similar way, correction factors for the 98th percentile

[2] Database REZZO: R1-combustion plants with thermal output above 5MW and major technologies, R2-combustion plants with thermal output between 0.2 and 5 MW, medium-sized technologies, R3-small combustion plants, minor technologies, R4-mobile sources.

for nitrogen dioxide of 1.5 and for the 90th percentile for particulate matter PM_{10} of 2.2 were determined.

Air quality projections till 2030

Based on the emission projections presented above, air quality projections for 2030 for suspended particulates PM_{10}, nitrogen dioxide, sulphur dioxide and tropospheric ozone were calculated using the calibrated SUDPLAN model system. Results are shown in Figures No.3 to 6.

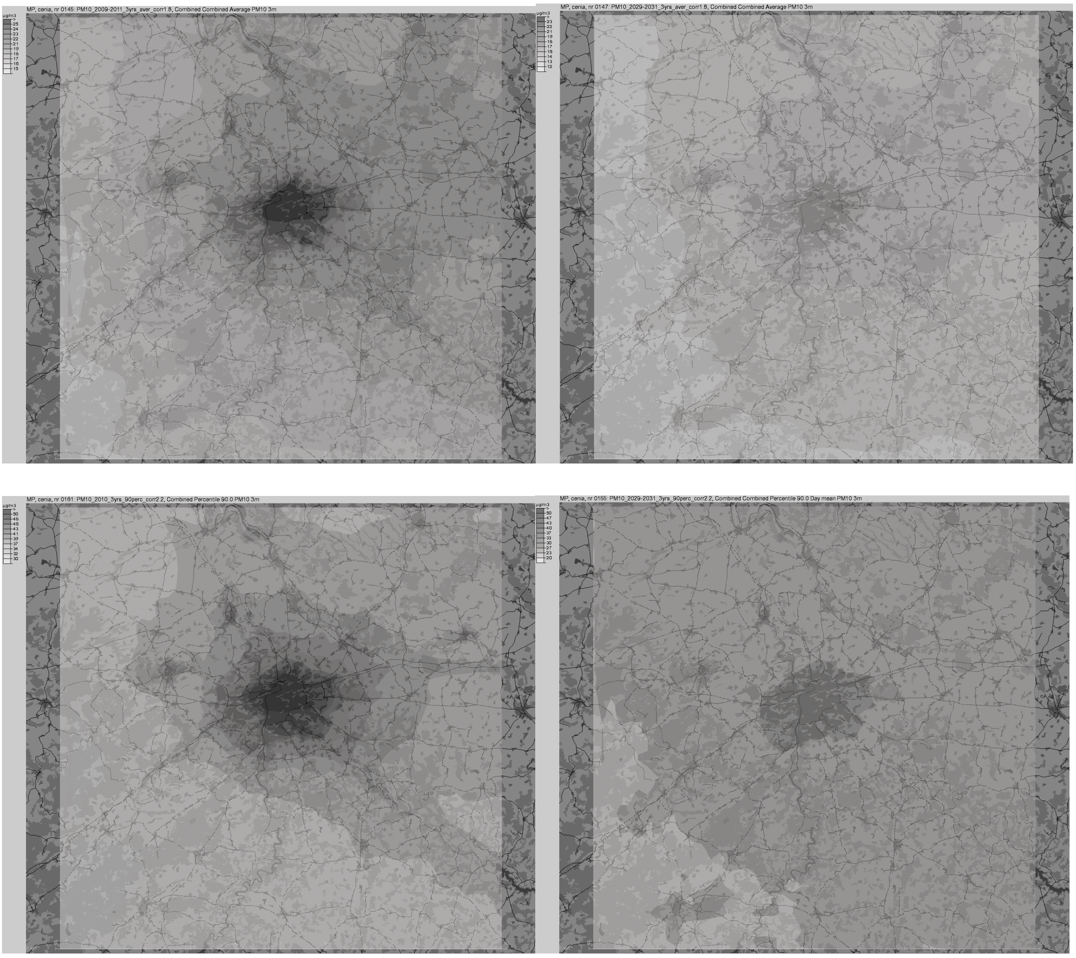

Figure 3: Annual average concentrations (upper pictures) and the 90th percentile of daily concentrations (lower pictures) of suspended particles PM_{10} in the area of interest for the year 2010 based on the average emissions for three years (pictures left) and for 2030 based on emission projections according to the GAINS model (pictures right).

The present results indicate that in 2030 the decrease of pollution by suspended particles PM_{10} can probably be expected. The highest decrease compared to 2010 should be seen in the centre of Prague, by about 36% in the case of an annual average basis and about 46% for the 90th percentile. In accordance with the emission projections, the decline in importance of large point sources and increase in importance of household heating and road transport (the improvement of quality of the vehicle fleet is only partly reflected as a significant proportion of emissions originate from the abrasion of brakes, tires and road surface) can be expected. Generally it can be said that

concentrations will be higher in the eastern and northern parts of the area influenced by the prevailing direction of the wind and by the topography of the terrain.

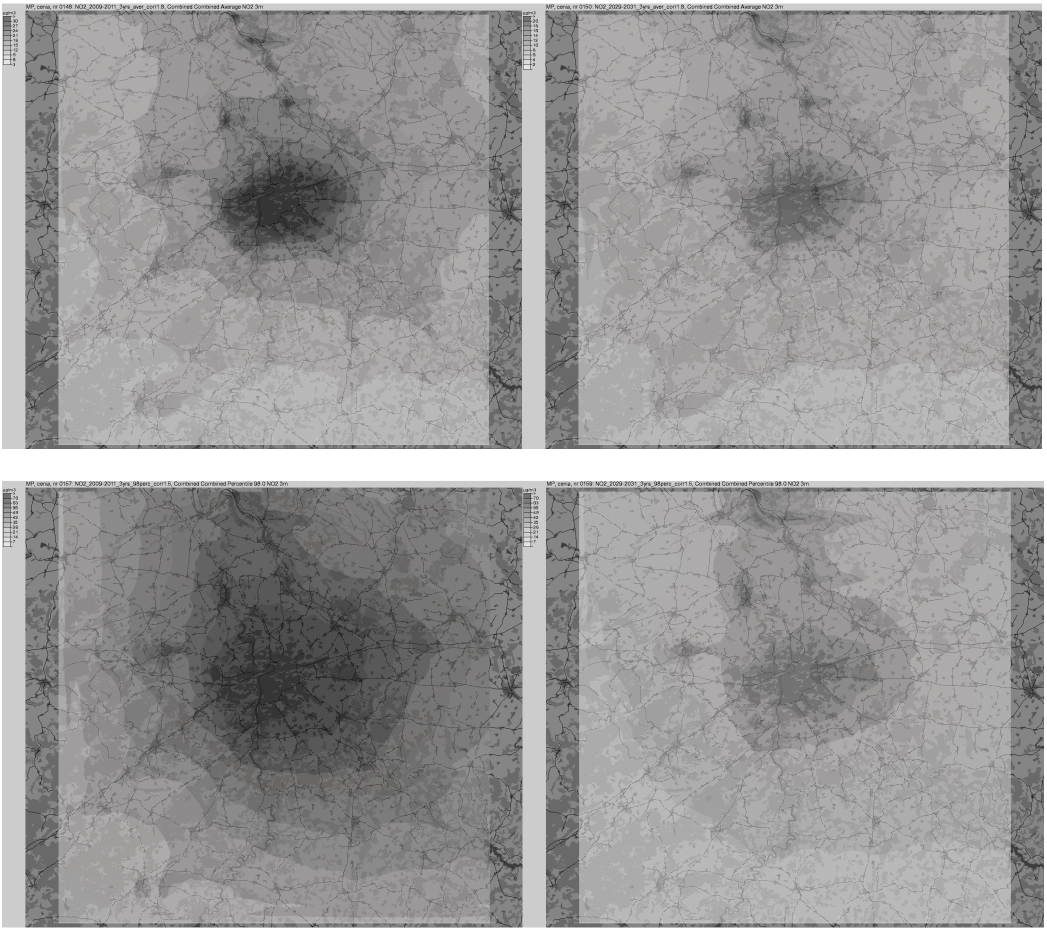

Figure 4: Annual average concentrations (upper images) and the 98th percentile of hourly concentrations (lower pictures) of nitrogen dioxide in the area of interest for the year 2010 based on the average emissions for three years (pictures left) and for 2030 based on emission projections according to the GAINS model (pictures right).

The results for 2030 show a significant decrease in the annual average concentrations of nitrogen dioxide, by 50 to 70 %, with the highest decrease expected in the areas adjacent to the centre of Prague and the lowest decrease in the southern part of the area. Generally, it can be said that the relative decline in emissions is more even across the area than it was in the case of suspended particles. In the next period the decrease of the importance of road transport (particularly in the context of improving the quality of the fleet) and the increasing importance of large point sources can be expected concerning air pollution by NO_2

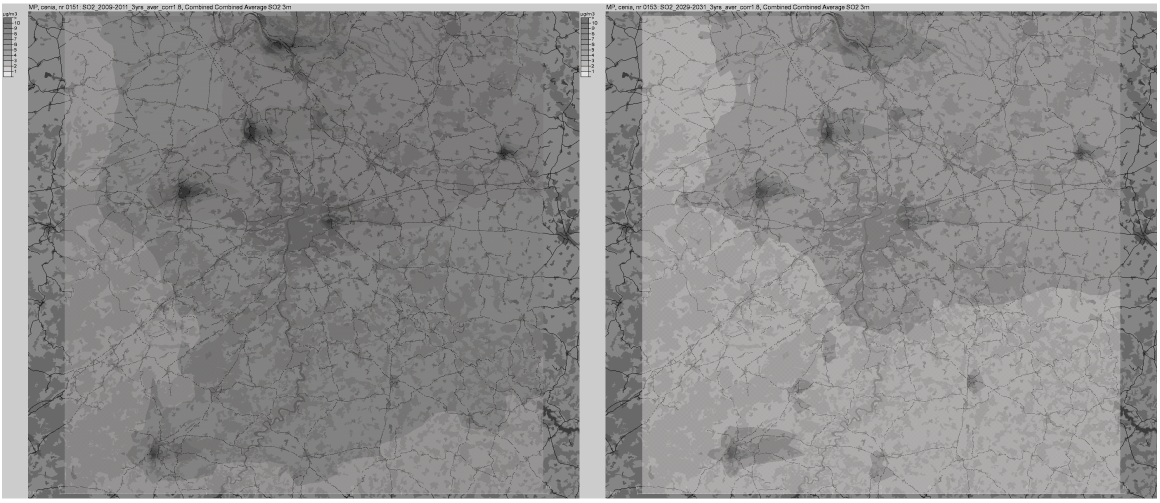

Figure 5: Annual average concentrations of sulphur dioxide in the area of interest for the year 2010 based on the average emissions for three years (left) and for 2030 based on emission projections according to the GAINS model (right).

Pollution by sulphur dioxide as compared to the 1990s is not a problem now. However, sulphur dioxide plays an important role in the formation of secondary particles, which may represent about 50% of the total mass of PM_{10} particles [2, 3]. In 2030 we can expect another approx. 50% drop in already low concentrations, which will be seen throughout the whole area of interest except the areas close to large stationary sources, where it will drop only moderately.

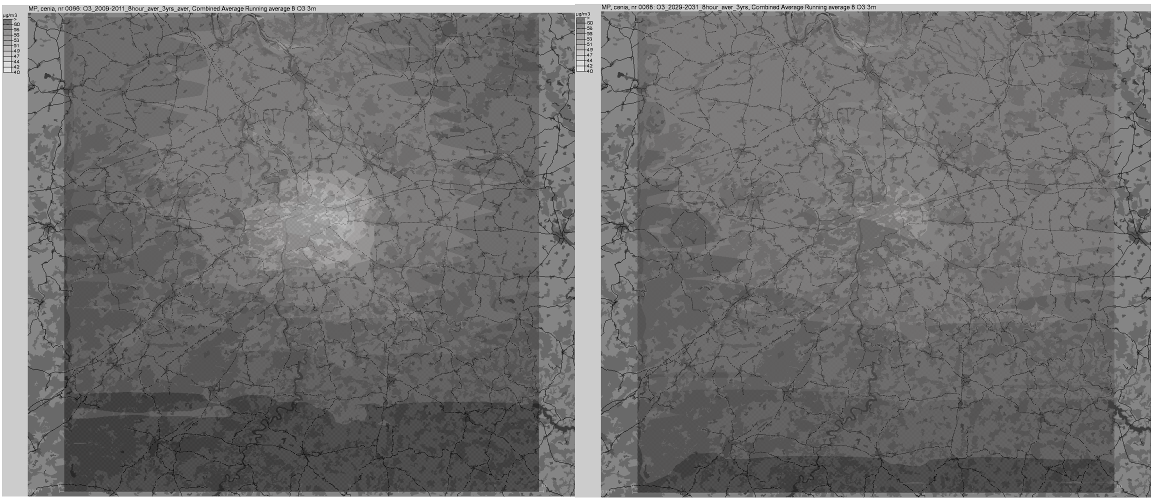

Figure 6: Annual average concentrations of tropospheric ozone in the area of interest for the year 2010 based on the average emissions of precursors for 3 years (left) and for 2030 based on emission projections according to the GAINS model (right).

The highest concentrations of ozone can generally be expected in the mountainous southern part of the area, the lowest ones in the city centre which can be attributed to the impact of nitrogen dioxide. However, in the centre of Prague about 10% increase in ozone concentrations can be expected due to lower concentrations of nitrogen dioxide. In the areas outside Prague 2-6% decrease in concentrations can be expected, especially in the southern part of the area.

Case studies

Due to the expected use of the SUDPLAN model system in regional and spatial planning, **three typical situations** were simulated which can significantly affect air quality: A significant change in the operation of a large combustion plant, construction of major transport infrastructure and finally suburbanization (transfer of residence of the population from Prague to newly constructed suburban settlements).

The subject of the **first case study** was the **estimation of the impact of either close-down of the large combustion plant (Melnik Power Station) or doubling its thermal input on air quality in the area of interest**. Horizontal resolution is 2 x 2 km. The simulation results are shown in Figures No. 7 - 10.

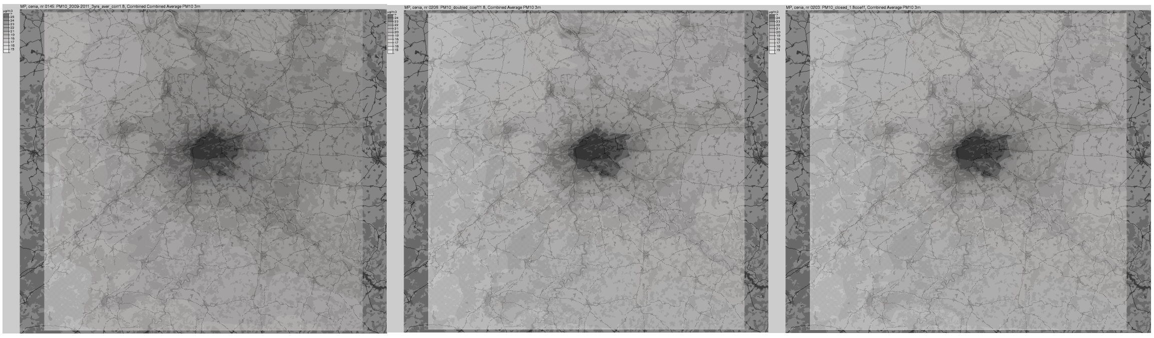

Figure 7: Effect of significant changes in operation of a large combustion plant to annual average PM_{10} concentrations in the area of interest: Left picture - the current state, middle picture – doubled thermal input, right picture – close down.

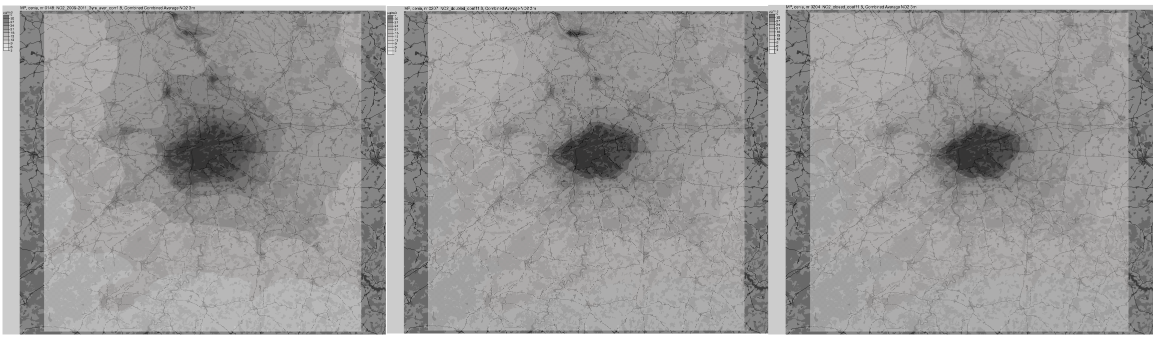

Figure 8: Effect of significant changes in operation of a large combustion plant to annual average nitrogen dioxide concentrations in the area of interest: Left picture - the current state, middle picture – doubled thermal input, right picture – close down.

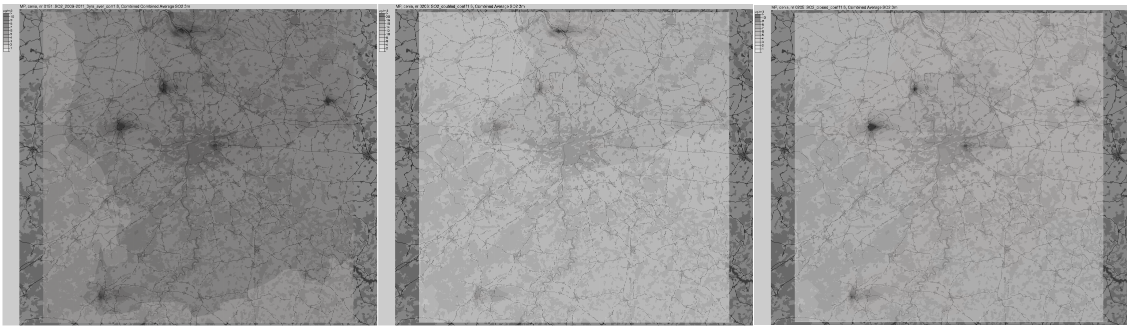

Figure 9: Effect of significant changes in operation of a large combustion plant to annual average sulphur dioxide concentrations in the area of interest: Left picture - the current state, middle picture – doubled thermal input, right picture – close down.

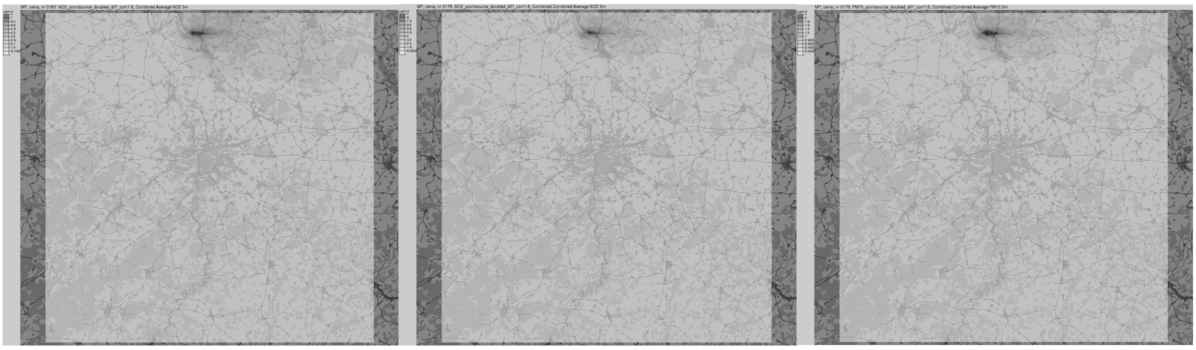

Figure No.10: Differences in annual mean concentrations of nitrogen dioxide, sulphur dioxide and PM_{10} in the area of interest between the current state and the estimation of the situation after doubling the thermal input.

The present results indicate that the effect of doubling the thermal input of the source is reflected in its immediate vicinity by increasing concentrations of PM_{10} and tropospheric ozone by about 10% and in the case of nitrogen dioxide by 40%; an increase in concentrations can be seen up to a distance of 40 km. In the case of sulphur dioxide the increase up to 70% can be seen in vicinity of the plant while partially increased concentrations can be seen up to a distance of 50 km.

Subject of **the second case study** was **the estimation of the impact of the completion of the Prague ring road on the air quality in the area of interest**. Emission data were estimated on the basis of traffic intensity, the horizontal resolution is 1 x 1 km. Results are shown in Figure No. 11.

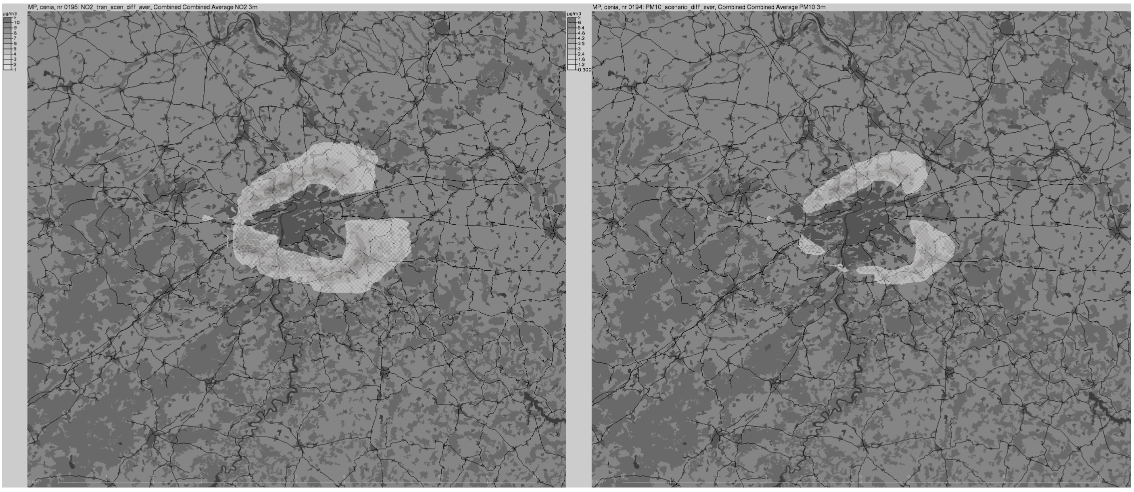

Figure 11: Influence of the completion of the Prague ring road on the average annual concentration of nitrogen dioxide in the area of interest: Left picture - the current state, middle picture - situation after the completion, right picture - difference in concentrations.

The presented results indicate that the completion of the Prague ring road could lead to lower concentrations of nitrogen dioxide and PM_{10} in the city centre by about 7%, while the concentration of these substances in the vicinity of newly constructed roads would increase by 10 to 15%. Influence on the most of the area of interest can be considered negligible. The decrease of air pollution in the city centre does not include additional transport measures e.g. green zones which are planned to be implemented. In this case, the decrease of concentrations in the city centre will be more significant.

Subject of the third case study is **the simulation of the hypothetical construction of three new satellite settlements in the north-western and south-eastern outskirts of Prague**. Around 2,500 new houses, 10,000 passengers travelling daily to Prague for employment and other activities and about 6,000 cars are expected in total. The simulation results are shown in Figure No. 12.

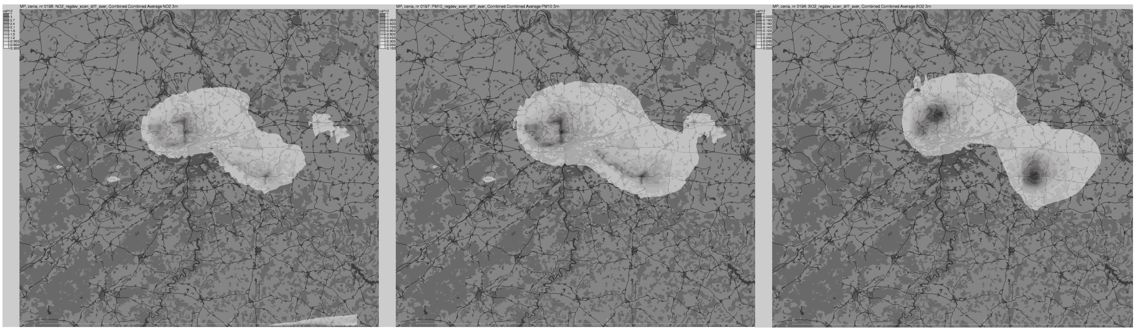

Figure 12: Influence of the hypothetical construction of satellite settlements on the average annual concentration of PM_{10} in the area of interest: Left picture - the current state, middle picture - situation after the completion, right picture - difference in concentrations.

The results indicate that the construction of new settlements would lead in respective locations to the increased concentrations of nitrogen dioxide (by 10-15%, approx. 2 ug/m^3), with higher relative increase in south eastern locality. Moreover, the increase of NO_2 concentrations would take place near to the main roads connecting newly built settlements and Prague city centre, reaching between 5-10 %. Regarding suspended particles PM_{10} and sulphur dioxide the expected increases of

concentrations are somewhat lower between 2-5 %, with the highest increase in the settlements and their vicinity and lower close to the main roads. . In the case of tropospheric ozone a slight (2%) decrease can be expected in the localities described above.

Conclusions

The present results indicate that the SUDPLAN model system is usable both at the macroscopic scale to simulate air quality projections for both primary and secondary pollutants, as well as at the microscopic scale for assessing the impact of constructions and or substantial changes in operation of large stationary sources on air quality.

The detailed results of model calculations presented in this work can be found at the website http://geoportal.gov.cz/sudplan.

Acknowledgements

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