VALIDATION OF AIRGIS - A GIS-BASED AIR POLLUTION AND HUMAN EXPOSURE MODELLING SYSTEM

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Abstract: This study describes in brief the latest extensions of the AirGIS system used in Denmark for exposure modelling and gives results of a validation with measured air pollution data. The system shows a good performance for both long term averages (annual and monthly averages) as well as short term averages (hourly and daily).

Key words: *exposure Modelling, OSPM, street canyon, urban air pollution.*

1. INTRODUCTION

Modelling of air quality is complementary to measurements since information on air quality is ideally required at many locations and in high spatial and temporal resolution. Model estimates are useful e.g. for assessment of compliance with air quality standards, for validation and optimisation of emission reduction strategies, for estimation of the personal exposure of groups of individuals in air pollution epidemiological studies or for air pollution forecast and information of the public.

The AirGIS system was developed at NERI to be able to calculate ambient air quality and human exposures at high temporal (hourly) and spatial resolution (address) to support air pollution epidemiology and urban air quality assessment and management.

AirGIS has been extended several times and in this paper we will present a detailed validation of the air quality modelling system against several years of measurements from permanent monitoring stations as well as against measurements from 204 locations from an exposure study in the Greater Copenhagen Area in Denmark that represented a wide range of traffic levels and different street geometries as well as urban and rural conditions.

2. THE AirGIS SYSTEM

For a detailed description of the system see Jensen et al. (2001) or the internet page: http://AirGIS.dmu.dk. Here only the basic features of the system are described.

The AirGIS system integrates air quality models, digital maps, national and local data registers and a GIS. One of its unique features is its ability to automatically generate the necessary input data for air pollution models (e.g. source information, geometric data) based on GIS data that would otherwise be tedious and very time consuming to generate for a large number of locations. Traffic information and buildings are available or under construction for the entire country. In principle the system is able to calculate air pollution at any address point in Denmark.

AirGIS is presently focussing on traffic-related air pollution and estimates the contribution from general urban traffic sources and the contribution from individual streets. The considered compounds are NO_X, NO_2, O_3, CO, benzene, PM_{10} and $PM_{2.5}$. Vehicle emission factors and vehicle fleet composition were updated in February 2006 and used in this project. Historic emissions for NO_X and CO have been established to provide calculations back in time to about 1960.

The AirGIS modelling system operates at three different pollution levels as illustrated in Figure 1. The regional background is considered as spatially homogeneous on the city scale. Depending on its location the exposure point is additionally influenced by emissions from all urban sources (urban increment) and contribution from the major street near the address (street increment). The exposure point represents the geo-coded postal address location and concentration levels are modelled at a receptor point that represents a location at the facade of the building in question. The receptor height can be specified to take into account the different receptor heights of e.g. single family houses and multi-storey buildings.

- The regional background concentrations are obtained from either measurements at a regional background site or are modelled with a regional transport model (THOR system, Brandt et al., 2001).
- Urban emissions are represented in a 1x1 km^2 grid and dispersion is calculated with the Urban Background Model (UBM) (Berkowicz, 2000b) or with a simplified urban background (SUB) procedure that requires much less calculation time and gives comparable results to UBM (Berkowicz et al., 2008). If available also measured data might be used as urban background. Regional background concentrations are input to modelling of the urban background concentrations.

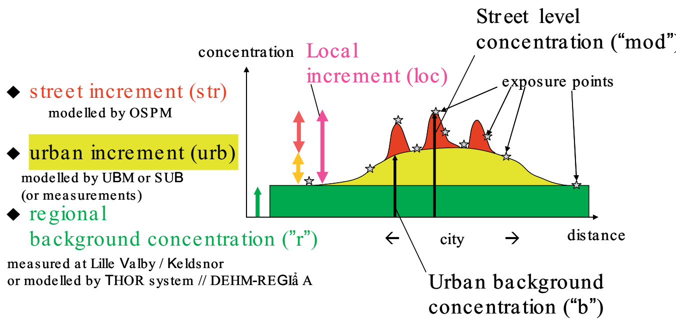

Figure 1. Illustration of the spatial variation of the three pollution levels in the vicinity of a city as considered in AirGIS and described in the text.

- The local street contribution is calculated with the Operational Street Pollution Model (WinOSPM) (Berkowicz, 2000a, http://ospm.dmu.dk). Urban background concentrations are input to modelling of the street concentrations.

All calculations in AirGIS are performed on an hourly basis. As far as available real measured meteorology and measured regional background data are used as input. This allows a calculation of short term averages and other statistics. Typically daily averages are used for correlation with health estimates as highest time resolution and averages over an exposure period, e.g. time a person was living at a certain address. AirGIS allows also the estimate of averages separated into working and non-working hours or other statistics, percentiles, running averages, highest daily average etc.

For historical calculations back to 1960 a standard meteorological input and synthetic background concentrations are used. For this type of estimates only long term averages (monthly, seasonal, annual) can be used for exposure estimates.

3. MEASURED DATA

Measurements at the following stations of the Danish Monitoring Network (http://www2.dmu.dk/1_Viden/2_miljoe-tilstand/3_luft/4_maalinger/default_en.asp) have been used for validation of modelled concentrations of NO_X, NO_2, CO and O_3:

- KELD – Keldsnor, South of the Island Langeland, Rural background
- HCOE – H.C. Ørsted Institute, Copenhagen, Urban background
- JGTV – Jagtvej, Copenhagen, Kerbside.

In the following figures and tables "*str*" denotes street contribution (i.e. subtracted background), "*b*" urban background, "*reg*" regional background, "*mod*" model results, and "*obs*" measurements.

4. VALIDATION RESULTS

Annual and Monthly Means

The performance of the modelling system in reproducing long term trends at street and background level is shown in Figure 2 for NO_2 and NO_X. When NO_2 is modelled the increasing share of direct NO_2 emissions has to be taken into account. In Figure 2 (left) is shown that a constant value of 5% direct NO_2 emissions leads to an underestimation of the annual NO_2 concentrations at Jagtvej while an increase of direct NO_2 emissions from 5% until 1998 to 12 % in 2005 reproduces the constant trend in NO_2 concentrations much better.

The performance of the two background models used in AirGIS is shown in Figure 2 (right) for NO_X using observed regional background. Both models reproduce the seasonal variation well with high correlation coefficient 0.84 and 0.79, for UBM and SUB respectively (Table 1). Also for other pollutants the background models show high correlations and reproduce both the averages and the variation in the data expressed as coefficient of variation (CoV= ratio of standard deviation and average). The present version of the THOR model performs well for O_3, while the CoV for NO_2 and NO_X is too small. Therefore we use observed regional background data as far as available and that only in case of missing data are substituted with modelled data. The variations in the urban background concentrations are influenced by the regional concentrations but also to a large extent by the meteorology. A large number of hours with wind speed below 2 ms^{-1} (plotted as well in Figure 2) causes typically a high urban concentration but can not explain all variation.

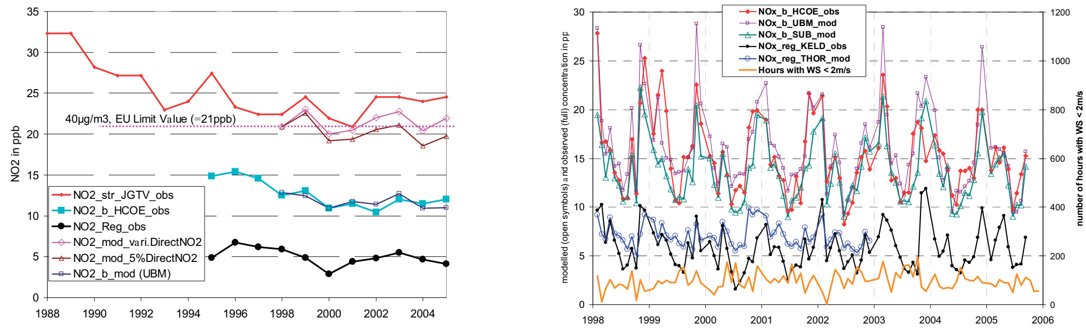

Figure 2. Annual trends for NO_2 1988-2005 (left) and monthly trends for NO_X 1998-2006.

Table 1 shows the comparison between model and observations for different pollutants. The models show the best agreement for O_3, (R>0.9), followed by NO_X, NO_2 and CO.

Table 1. Validation for monthly means during 1998-2005, as shown e.g. in Figure 2 (right). Av= average, CoV= coefficient of variation, Corr (R) = correlation coefficient R between model and observed values.

Location	Method	NOx			NO2			O3			CO		
		Av	CoV	Corr(R)	Av	CoV	Corr(R)	Av	CoV	Corr(R)	Av	CoV	Corr(R)
Keldsnor	r_obs	5.7	0.38		4.8	0.41		30.2	0.26				
THOR	r_mod	7.1	0.17	0.71	6.3	0.17	0.60	26.0	0.27	0.92			
HCOE	u_obs	15.1	0.26		11.8	0.20		25.1	0.27		0.28	0.24	
HCOE	u_UBM (r_obs)	16.1	0.27	0.84	11.9	0.19	0.80	23.9	0.34	0.93	0.19	0.20	0.80
HCOE	u_SUB (r_obs)	13.6	0.23	0.79	10.8	0.19	0.75	24.8	0.32	0.92	0.28	0.16	0.82

Daily means

For correlation with some health indicators (e.g. daily hospital admission) the daily concentrations of pollutants at a specific address point are of interest. The plots given in Figure 3 give some examples of validation for NO_X at street level and background level. As for the monthly averages the averages and variation are well reproduced by the modelling system. E.g. the correlation coefficient is in the range 0.8-0.9 for the street level and 0.7-0.8 for the background level.

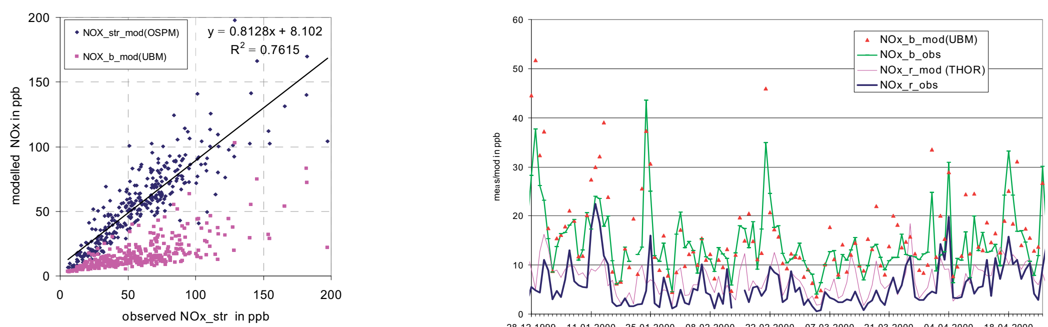

Figure 3. Validation of models for daily averages. Left: Scatter plot of daily street concentrations in 2003 modelled vs. observed for illustration also the modelled background concentration is plotted. Right: Time-series plot of modelled and measured daily NO_x concentrations in urban regional background.

Diurnal variation and Hourly averages

The modelling system has been successfully validated for average diurnal variations and hourly data as well. Results will be shown in an extended version of this paper.

Comparison at many street locations

The comparisons presented so far have been performed for a few permanent monitoring stations that are well studied in beforehand. A valuable validation data set with measurements at 204 address locations was obtained in the Copenhagen Childhood Cancer project and was used before for validation of the OSPM model, where input data (traffic volume, building configuration) were obtained with questionnaires sent to municipalities (Raaschou-Nielsen et al. 2000).

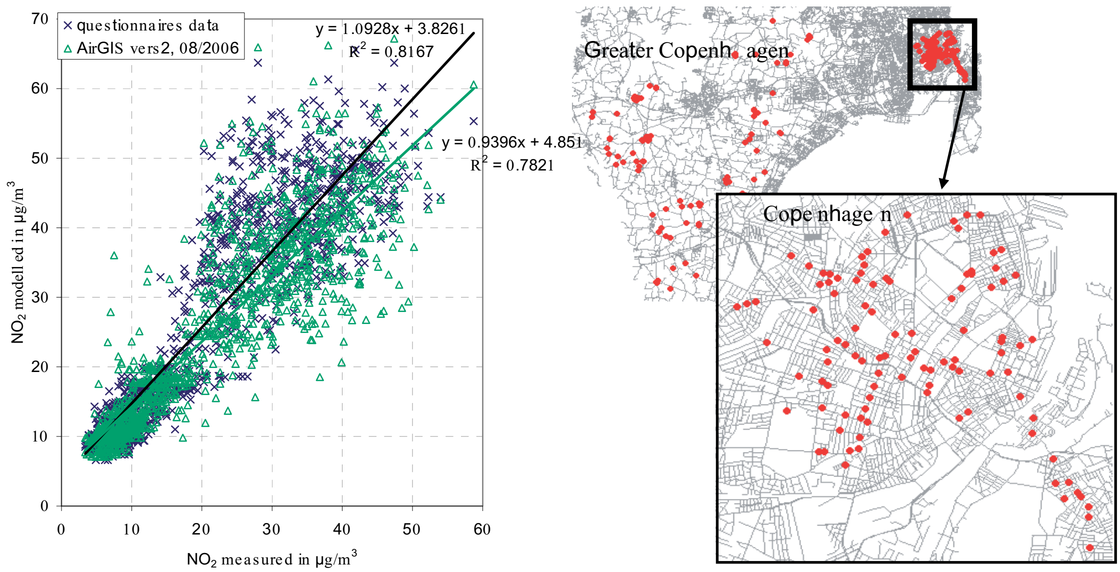

Figure 4. Left: Scatter plot for monthly averages of NO_2 modelled versus measured at the 204 addresses within the Childhood Cancer project (Raaschou-Nielsen et al. 2000). Shown are model results from 2000 based on input data from questionnaires as well as new calculations using the automated routines in AirGIS to create the input data. At each location 6 monthly periods are available. Locations were both inside Copenhagen and in surrounding rural areas (right).

In Figure 4 both the model results using input data based on the questionnaires and obtained with the AirGIS system are shown. This comparison will test the traffic data stored in the AirGIS data base and the routines to create the building configurations.

The comparison of modelled and observed data is slightly better (higher correlation coefficient) for the original data than with the automated procedure but the difference is small. The AirGIS system has the big advantage to be able to create the input data at virtually any location in much shorter time for many locations compared to the procedure by hand. A small loss in accuracy is observed. The reason for this is the higher number of outliers (points far away from the 1:1 line) in the AirGIS data. Main reasons for this are differences in the traffic data bases and the differences in selecting the location of the receptor point in situations where the location is close to a street intersection. The original traffic data base was established based on questionnaire information for the specific locations obtained from the municipalities whereas the new traffic data base was established based on data from a number of different sources (data from the Danish Road directorate for main roads, traffic model data for the Greater Copenhagen Area, traffic mapping data obtained from municipalities that had prepared a traffic and environmental action plan, etc.)

5. CONCLUSION

The Air Pollution and Human Exposure Modelling System AirGIS has been validated against observations at permanent monitoring locations and a measuring campaign on a large number of streets. The system shows a good performance for both long term averages (annual and monthly averages) and as well as short term averages (hourly and daily) and is therefore well suited for air pollution and exposure assessment.

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