NEW EVALUATION TOOLS FOR MEETING THE EU DIRECTIVE ON AIR POLLUTION LIMITS

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INTRODUCTION

The air quality in Sweden is strongly influenced by the geographic location and the climate in the northern part of Europe. During wintertime, the temperature is often below zero degree and rain and snow are common which cause slippery roads and needs for house heating. For anti-skid treatment, studded tyres and sand are frequently used which create a lot of road wear particles. Residential wood combustion is a common primary or supplementary space heating source. An increased use of small-scale biofuel is one of the alternatives considering the phasing out of fossil fuels. However, high emitting old wood stoves can give rise to negative impacts of air quality. Another source of air pollution is long range transport from emissions outside Sweden.

The EU directive on air pollution levels mirrored in the Swedish legislation has far reaching consequences for Swedish city administrations. Of special importance is the PM10 legislation, as the Swedish EPA estimates that around 80% of the cities will have to assess PM10 concentrations.

Health impact assessment for the Swedish population (Forsberg et al., 2005) has been estimated increased mortality related to long-range transport of particles to about 3500 deaths per year. The influence of local sources indicate about 1800 deaths per year, mostly due to local traffic emissions but also due to residential wood combustion, estimated to about 90-330 deaths per year.

To meet these problems two new Internet tools have been developed that can be used by all Swedish municipalities to assess air pollution levels and how they compare to the EU directive. The first is called SIMAIR road (Gidhagen et al., 2008) which is related to traffic emissions and the second is called SIMAIR rwc where rwc stands for residential wood combustion (Omstedt, 2007).

METHODS

SIMAIR road and SIMAIR rwc are using the same principles; coupled model system using different models on local, urban and regional geographical scales, best available emission data, but at the same time presented in a very simplified way. This is done by using a combination of pre-calculated concentrations from models of larger scale and outputs from fast computing local models. The main differences between the two Internet tools are the treatments of emissions and dispersion on local scale. An outline of models and databases used is given in Figure 1.

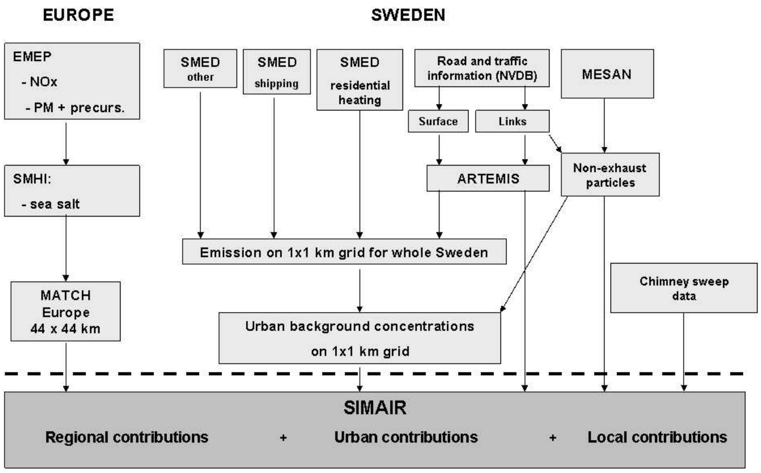

Figure 1. Databases and models used by the SIMAIR system. The dashed line illustrates the difference between stored data and pre-calculated concentrations from models of larger scale which is done on a Linux server (above the dashed line) and local models and user interface accessed from an ordinary Internet browser (below the dashed line).

Regional background concentrations

On the regional scale modelling is performed using the multi-scale atmospheric transport and chemistry model MATCH (Robertson et at., 1999; Andersson et al., 2007). The MATCH model is driven by the weather forecast model HIRLAM and uses a 44x44 km^2 grid over Europe. Emissions are taken from the EMEP 50x50 km^2 inventors (http://www.emep.int). Sea salt particles are included by a method developed by Foltescu et al. (2005). The MATCH model does not yet include secondary organic aerosols. Therefore, measurements of PM10 are also included using two dimensional variational data assimilation with PM10 data from some few regional stations in Scandinavia and background fields from the MATCH model.

Urban background concentrations

Urban background concentrations are simulated on a 1x1 km^2 grid using emission data from the Swedish Database for Emissions to the Environment (SMED; http://www.smed.se/). For the dispersion two different model approaches are used. For ground-level sources, e.g. traffic exhausts and small-scale wood combustion, an adjoint model approach is used similar to that presented by Berkowicz (2000a). The model is based on the determination of an influence area upwind a receptor point, within which all emissions are aggregated to the final concentration. Each of the cells within the urban 1x1 km^2 grid constitutes a receptor point. The dispersion of stack emissions is treated in a separate Gaussian point source model (Omstedt, 1988).

Road and traffic information

The Swedish National Road Database (NVDB) is a national road and vehicle database, containing up-to-date information about road-coordinates, functional road class, speed limit, number of lanes, road width, etc. A parallel database includes measured traffic volumes on state-owned roads, while traffic volumes on municipality roads have been simulated with a traffic demand model (for further details, see Gidhagen et al., 2008). Emission factors for the exhaust part of the PM10 emission are calculated by ARTEMIS (http://www.trl.co.uk/artemis/). For the non-exhaust part a semi-empirical model is used (Omstedt et al., 2005). For Nordic conditions, using studded tyres and sometimes sand as anti-skid treatment, the dominating part (80-88%) of the total PM10 emission originates from non-exhaust emissions (Ketzel et al., 2007).

Meteorological data

Meteorological data from the routine operating MESAN system (Häggmark et al., 2000) are used. It is based on the optimal interpolation technique. The background field is a six-hour forecast from the HIRLAM model with 22-km horizontal resolution. All available measurements from synoptic and automatic stations, radar and satellites are analyzed on 11x11 km^2 grid with 3 h resolution. SIMAIR uses the following meteorological parameters: wind speed and direction at 10m height, temperature and humidity at 2m height, cloudiness, global radiation and precipitation. Boundary layer parameter such as friction velocity, sensible heat flux and boundary layer height are calculated by methods from van Ulden and Holtslag (1985), Holtslag et al. (1995) and Zilitinkevich and Mironov (1996).

Data from Swedish Chimney sweep

Detailed local data for residential wood combustion are included on the users request for different cities. This is done in cooperation with the Swedish Association of Master Chimney Sweep.

Local scale models used by SIMAIR road

SIMAIR road uses two different dispersion models. If the road of interest is surrounded by buildings at one or both sides, the street canyon model OSPM (Berkowicz, 2000b) is used. If the road is not surrounded by buildings or obstacles (open road conditions) then a simplified Gaussian line source model for “infinite line sources” is used (Gidhagen et al., 2004).

Local scale models used by SIMAIR rwc

SIMAIR rwc uses two different local scale dispersion models, one for point sources and one for traffic sources. Both models are Gaussian. The point source model is based on the OML model (Berkowicz et al., 1986; Omstedt, 1988). The OML model has recently been used to investigate the influence of wood combustion on particle levels in a village residential area in Denmark (Glasius et al., 2008) with similar results as those obtained by SIMAIR rwc for Lycksele a small town in Sweden (Omstedt, 2007). The traffic model is a line source model for “finite line sources” similar to the model described by Venkatram and Horst (2006). In both models dispersion parameters are continuous functions of boundary-layer parameters, such as friction velocity, sensible heat flux and boundary layer height. Wind directions fluctuations are treated by empirical expressions using the method described by Hanna (1983).

An emission model for residential wood combustion, partly based on the work by Johansson et al. (2004), is connected to the local point source model. The following components are included: emission types, emission factors, start and running phases, storage tank and size. Input data are type of boilers and/or stoves, yearly energy consumption divided into share of oil, pellets, wood, wood chips or electricity, storage tank and size, chimney height etc. Time variations of emissions are described as function of social factors and/or as function of fuel consumption. For the later a method using heating degree-hours is used.

VALIDATION RESULTS

SIMAIR road

Comparisons between measured and calculated concentrations of PM10 are made for six different streets in Sweden. Street and traffic information are shown in Table 1. The results are shown in Figure 2. SIMAIR road is able to account for the main features in the day-to-day mean PM10 variability, especially the peak in the PM10 concentrations in late winter and early spring that is commonly experienced in Nordic countries where studded tyres and the use of sand as anti-skid treatment are used. The scatter is rather large, however, with more detailed input data the correlation can be higher (Omstedt et al., 2005; Ketzel et al., 2007). By annual updates of the databases used in SIMAIR, input data will be improved.

Table 1. Street and traffic information for the six Swedish streets used in this study.

Street	Height of buildings (m) side 1/side 2	Width of the street (m)	Traffic intensity (vehicles/day)	Heavy duty vehicles (%)	Antiskid treatment	Share of studded tyres (%)
Sundsvall/Skolhusallen	10/1	20	20000	4	sand	90
Uppsala/Kungsgatan	20/0	18	18000	5	sand	76
Stockholm/Sveavägen	25/25	33	29100	4	salt	75
Stockholm/Norrlandsg	25/25	15	14800	4	salt	75
Stockholm/Hornsgatan	24/24	24	35000	5	salt	75
Malmö/Amiralsgatan	25/25	21	23000	10	salt	30

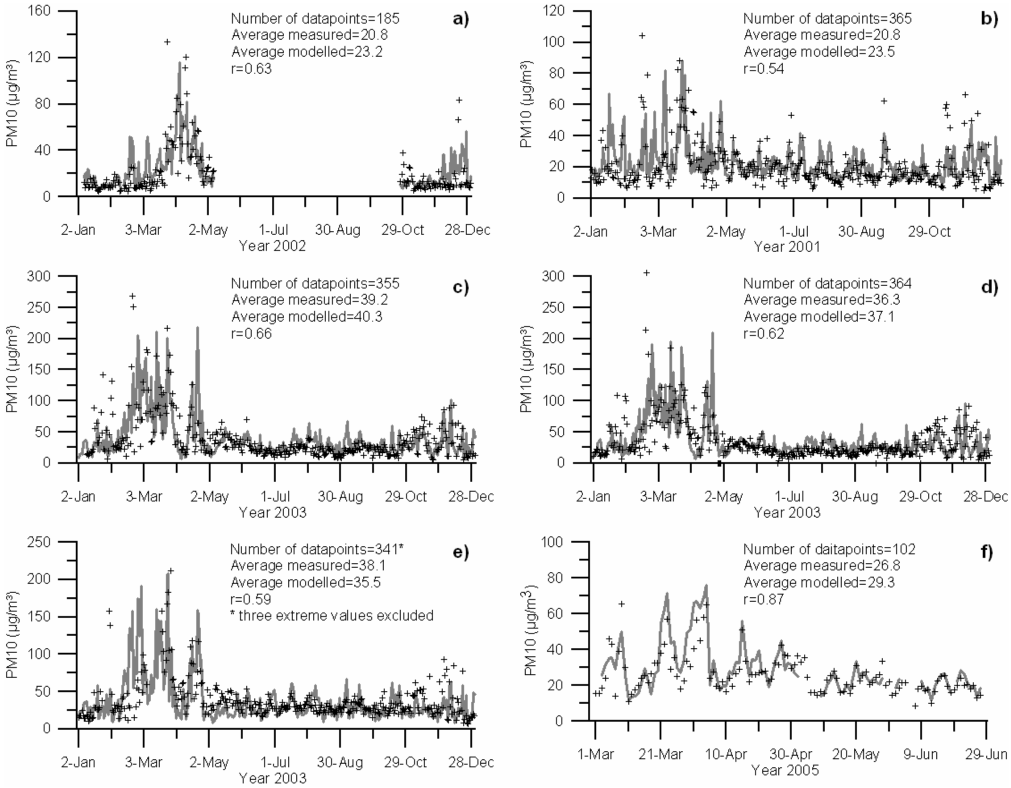

Figure 2. Comparison of measured (+) and modelled (grey solid line) daily mean concentrations of PM10 (µg/m^3) at six different streets in Sweden: (a) Skolhusallen in Sundsvall for six month during the year 2002, (b) Kungsgatan in Uppsala for the year 2001, (c) Sveavägen (d) Norrlandsgatan and (e) Hornsgatan in Stockholm for the year 2003, (f) Amiralsgatan in Malmö for about four month during the year 2005. r is the correlation coefficient. The results from (b) - (e) are also presented and discussed by Gidhagen et al. (2008).

SIMAIR rwc

Comparison of measured and calculated concentrations of PM10 is made in Lycksele, a small town with about 9000 inhabitants situated in the inland of northern Sweden (N64.6, E18.7). The results are shown in Figure 3. Measurements have been made during two winter periods. Both periods show strong variations of PM10 concentrations due to temperature, with high local concentrations during cold weather conditions and low local concentrations during warm conditions, which reflect variations in emissions due to the demand of energy needed for house heating. Other important meteorological parameters are wind speed, wind direction and stability, discussed in more details by Krecl et al. (2008). SIMAIR rwc describes the main features in the day-to-day mean PM10 variability rather well.

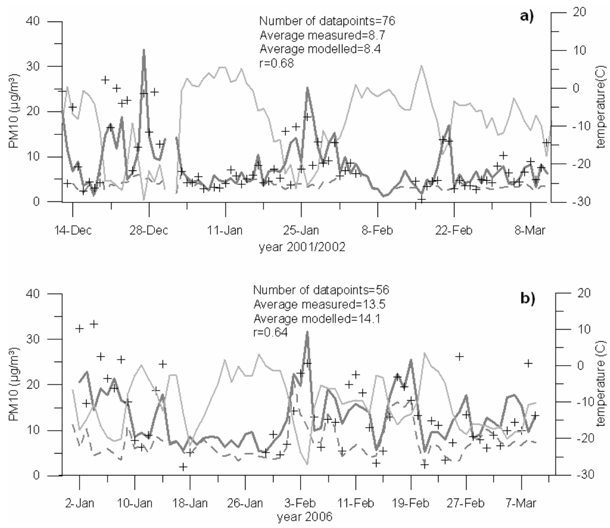

Figure 3. Comparison of measured (+) and modelled (grey solid line) daily mean concentrations of PM10 (µg/m^3) at Lycksele/Sweden for two different time periods. Grey broken line is background concentrations and thin grey solid line is daily mean temperature. (a) Time period 20011214-20020310, (b) Time period 20060101-20060310.

Comparison with EU directive on air quality

According to EU directives on ambient air quality, the uncertainty for modelling estimation is defined as the maximum deviation of the measured and calculated concentration levels, over the period considered and at the limit value in consideration, without taking into account the timing of the events. Modelling uncertainty for PM10 is defined for annual average to ±50%. For daily average it is not yet defined, but we use the same percentages also for the comparison of measured and calculated limit values such as 90- and 98-percentiles and number of days exceeding 50 µg/m^3. In Figure 4 and Table 2 these standards are compared with the modelling results given above. The comparison for SIMAIR rwc is made only for time periods of about 2-3 months and therefore more uncertain. As shown in the figure, SIMAIR road and SIMAIR rwc are able to calculate statistics of mean values, 90-percentile and 98-percentile daily mean values that are well within the ±50% that EU requires for model estimates of yearly mean values for PM10. In the comparison all values except one are within ±25%, which is the quality objective for fixed measurements according to the EU directive. For SIMAIR road statistics of number of days exceeding the limit value are included in the comparison. For SIMAIR rwc this is not included due to the relative small time periods used.

FINAL REMARKS

Many cities in Sweden have problems meeting the EU directive on air pollution levels, especially the PM10 legislation. The responsibility to secure good air quality in a city in Sweden is the local city administration. To help them in their work, two new models which can be used by Internet in a user friendly environment have been developed. Comparing them with measurements show that the models yield results that lead to the same conclusions as measurements, in term of air quality statistics. Thus the models can also to some extent replace costly measurements. They will be used and tested in a lot of different practical applications.

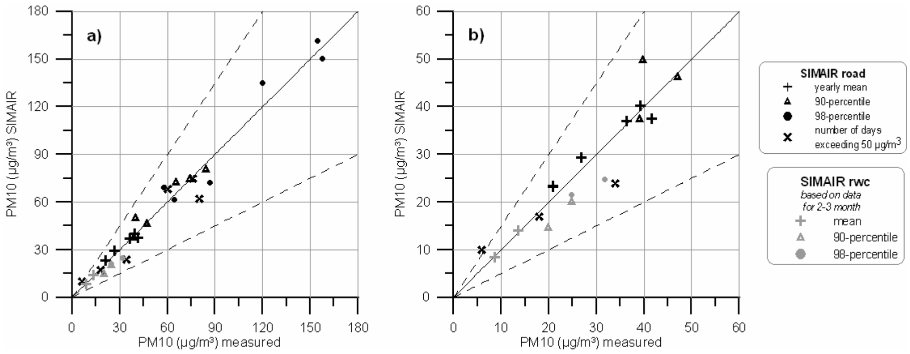

Figure 4. Comparison of measured and modelled concentrations of PM10 (µg/m^3) expressed in terms of air quality levels defined by the Swedish legislation and the EU directive on air pollution levels for PM10. Broken line shows the modelling uncertainty of ±50% defined for annual averages of PM10. (a) All data, (b) data below 60 µg/m^3. The figures present the same results as given in Table 2.

Table 2. Comparison of measured (meas) and modelled (mod) concentrations of PM10 (µg/m^3) expressed in terms of air quality levels defined by the Swedish legislation and the EU directive on air pollution levels for PM10 (see also Figure 4).

	Yearly mean		90-percentile		Number of days exceeding 50 µg/m^3		98-percentile	
	meas	mod	meas	mod	meas	mod	meas	mod
Stockholm Sveavägen year 2003	39.2	40.3	84.4	80.3	76	75	154.5	161.4
Stockholm Norrlandsgatan year 2003	36.3	37.1	74.2	74.2	80	62	120.1	134.9
Stockholm Hornsgatan year 2003	41.6	37.6	65.5	72.3	60	68	157.4	150.3
Uppsala Kungsgatan year 2001	20.8	23.5	39.0	37.4	34	24	64.1	61.6
Sundsvall Skolhusallen year 2002	20.8	23.2	47.0	46.3	18	17	86.5	72.2
Malmö Amiralsgatan year 2005	26.8	29.3	39.7	49.7	6	10	57.9	69.2
Lycksele year 2001/2002*[1]	8.7	8.4	19.9	14.5			24.8	21.5
Lycksele year 2006*[2]	13.5	14.1	24.7	20.1			31.8	24.7

*[1] only for a timeperiod of about three months *[2] only for a timeperiod of about two months

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REFERENCES

Andersson, C., Langner J. and Bergström, R., 2007. Interannual variation and trends in air pollution over Europe due to climate variability during 1958-2001 simulated with a regional CTM coupled to the ERA40 reanalysis. *Tellus B* **59**, 77-98.

Berkowicz, R., Olesen, H.R. and Torp, U., 1986. The Danish Gaussian air pollution model (OML). *Air Pollution Modeling and its Application*. Plenum Press, New York.

Berkowicz, R., 2000a. A simple model for urban background pollution. *Environment Monitoring and Assessement* **65**, 259-267.

Berkowicz, R., 2000b. OSPM – a parameterised street pollution model. *Environment Monitoring and Assessement* **65**, 323-331.

Foltescu, V.L., Pryor, S.C. and Bennet, C., 2005. Sea salt generation, dispersion and removal on the regional scale. *Atmospheric Environment* **39**, 2123-2133.

Forsberg, B., Hansson, H.C., Johansson, C., Areskoug, H., Persson, K. and Järvholm, B., 2005. Comparative health assessment of local and regional particutate air pollutions in Scandinavia. *Ambio* Vol. **34**, No. 1, 11-19.

Gidhagen L., Johansson, C., Omstedt, G., Langner, J. and Olivares, G., 2004. Model simulations of NOx and ultrafine particles close to a Swedish highway. Environ*. Sci. Technol.* **38**, 6730-6740.

Gidhagen, L., Johansson, H. and Omstedt, G., 2008. SIMAIR-Evaluation tool for meeting the EU directive on air pollution limits. *Atmospheric Environment*, doi:10.1016/j.atmosenv.2008.01.056.

Glasius, M., Ketzel, M., Wåhlin, P., Bossi, R., Stubkjaer, J., Hertel, O., Palmgren, F., 2008. Characterization of particles from residential wood combustion and modelling of spatial variation in a low-strength emission area. Atmospheric Environment, doi:10.1016/j.atmosenv.2008.04.037

Hanna, S.R., 1983. Lateral turbulence intensity and plume meandering during stable conditions. *Journal of Climate and Applied Meteorology* **22**, 1424-1430.

Holtslag, A.A.M., Meijgaard, E. van and De Rooy, W.C., 1995. A comparison of boundary layer diffusion schemes in unstable conditions over land. *Boundary-Layer Met*. **76**, 69-95.

Häggmark, L., Ivarsson, K.I., Gollvik, S. and Olofsson, P.O., 2000. Mesan, an operational mesoscale analysis system. *Tellus* **52A**, 1-20.

Johansson, L. S., Leckner, B., Gustavsson, L., Cooper, D., Tullin, C. and Potter, A., 2004. Emission characteristics of modern and old-type residential boilers fired with wood logs and wood pellets. *Atmospheric Environment* **38**, 4183-4195.

Ketzel, M., Omstedt, G., Johansson, C., During, I., Pohjola, M., Dieterman,O., Gidhagen, L., Wåhlin,P., Lohmeyer, A., Haakana, M. and Berkowicz, R., 2007. Estimation and validation of PM2.5/PM10 exhausted and non-exhausted emission factors for practical street pollution modelling. *Atmospheric Environment* **41**, 9370-9385.

Krecl, P., Ström, J., Johansson, C., 2008. Diurnal variation of atmospheric aerosol during the wood combustion season in Nothern Sweden. *Atmospheric Environment* **42,** 4113-4125**.**

Omstedt, G., 1988. An operational air pollution model. SMHI report RMK nr 57, 35 pp (available from kundtjanst@smhi.se).

Omstedt, G., Bringfelt, B. and Johansson, C., 2005. A model for vehicle-induced non-tailpipe emissions of particles along Swedish roads. *Atmospheric Environment* **39**, 6088-6097.

Omstedt, G., 2007. VEDAIR ett internetverktyg för bedömning av luftkvalitet vid småskalig biobränsleeldning. SMHI report nr 123 (available from kundtjanst@smhi.se).

Robertson, L., Langner, J. and Engardt, M., 1999. An Eularian limited-area atmospheric transport model. *Journal of Applied Meteorology* **38**, 190-210.

Van Ulden, A.P. and Holtslag, A.A.M., 1985. Estimation of atmospheric boundary layer parameters for diffusion applications. *J. Climate Appl. Met.* **24**, 1196-1207.

Venkatram, A. and Horst, T.W., 2006. Approximating dispersion from a finite line source. *Atmospheric Environment* **40**, 2401-2408.

Zilitinkevich, S. and Moronov, D.V., 1996. A multi-limit formulation for the equilibrium depth of a stably stratified boundary layer. Max-Plank-Institut for Meteorology, Report No. 185, ISSN 0397-1060, 30 pp.