MODELLING OF PRIMARY PM10 CONCENTRATIONS FOR THE CITY OF GRAZ, AUSTRIA

Dietmar Oettl

Government of Styria, Air Quality Department, Austria

Abstract: Within the frame of the European funded LIFE Project KAPA GS (2004-2008), a methodology for modeling the PM10 concentration with a very high resolution (10m x 10m) at the urban scale has been developed. After a first successful application for the city of Klagenfurt the method has now being applied to the city of Graz (~250.000 inhabitants) in Austria. Based on existing emission inventories for traffic including resuspension of road dust, domestic heating, and industry, simulations for the spatial distribution of PM10 have been performed using the Lagrangian particle model GRAL (Graz Lagrange Model), which is coupled with the mesoscale prognostic model GRAMM (Graz Mesoscale Model). The latter has been operated with a horizontal resolution of 300m x 300m, while the whole modeling domain was 27km x 39km.

GRAMM has been initialised using a simple statistics of 5 wind speed classes, 36 sectors of wind direction, and Pasquill-Gifford stability classes. The latter has been used to obtain the vertical profile of potential temperature. For each, out of several hundreds of such characterised dispersion conditions, a steady-state wind field and subsequently a steady-state concentration field has been computed.

16 meteorological stations have been used to compare simulated and observed wind direction frequencies as well as wind speeds. Apart from 12 permanent air quality monitoring stations (AQM) operated by our department, additional 9 particle counters for PM10, PM2.5 and PM1.0 (GRIMM) were available for comparison purposes.

It is shown that due to extremly bad dispersion conditions in the basin of Graz, PM10 levels can reach or even exceed that of megacities. A fairly well agreement between modelled and observed average PM10 concentrations could be achieved, although significant uncertainties arise for each step of the whole model chain (emission inventory, wind field-, and air quality simulations).

It came out that traffic is the most significant source of PM10 in the centre of Graz and nearby busy roads, while domestic heating may become the dominant source in suburban areas. Especially non-exhaust emissions are comparatively high, as became evident from road measurements in Graz and Klagenfurt, and additional chemical analyses of PM10 filters. There is also some observational evidence of local generated secondary PM (e.g. ammonium nitrate) at least in the city of Graz.

Key words: *Lagrangian dispersion model, GRAL, Urban scale, PM10*

1. INTRODUCTION

The city of Graz, capital of the federal state of Styria in Austria, faces the highest PM concentrations in Austria. Typically more than 100 days with daily mean PM_{10} concentrations above 50 µgm^{-3} are being observed at urban background air quality monitoring (AQM) stations. Although Graz with a population of 250.000 can be characterised as a relatively small town within Europe, PM_{10} concentrations are higher than in most European cities (Fig. 1). Almost only eastern European cities or regions observe even higher concentrations.

There were mainly two aims of this study, (i) to assess the major sources for the high PM_{10} concentrations, and (ii) to assess the influence of topography and meteorology on the PM_{10} levels.

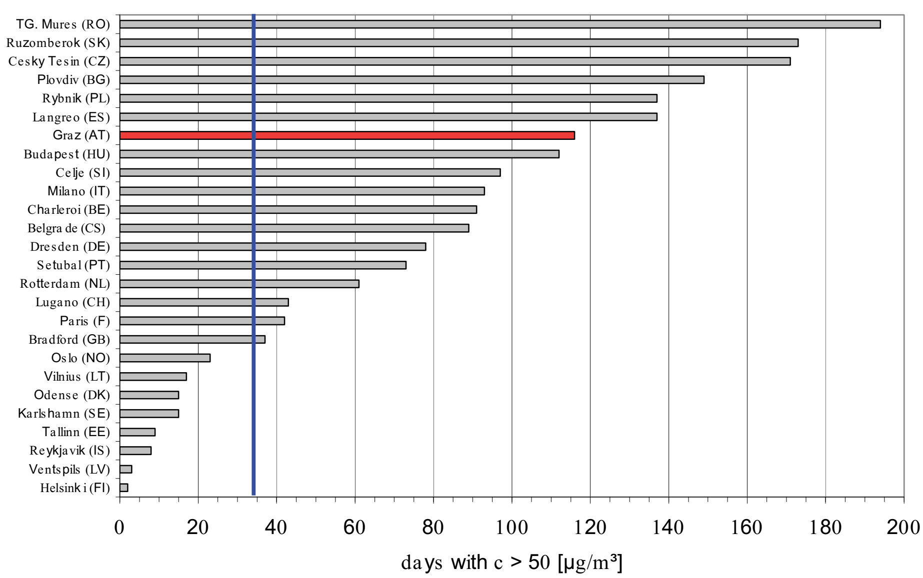

Figure 1. Comparison of PM_{10} concentrations observed at urban background sites in selected European cities and regions.

2. EMISSIONS

Exhaust emissions from traffic have been estimated using the **N**etwork **E**mission **Mo**del (NEMO) developed by the Graz University of Technology (Rexeis and Hausberger, 2005). The following input data for each road segment (~30.000) have been used for NEMO: annual average daily traffic, share of HDV, mean driving speed, characterisation of traffic situation.

There is a relative large uncertainty regarding non-exhaust emissions from traffic (re-suspension, road- and tire wear), as become evident from the wide range of values appearing in literature. To access non-exhaust emissions for Graz, PM_{10} and NO_x data from a traffic- and an urban background AQM station have been utilized. The method follows the one outlined in Ketzel et al. (2007). As can be seen from Figure 2 non-exhaust emissions have a typical seasonal variation with a maximum in late winter or spring and a minimum in summer time, which suggests an important influence of the winter service (mainly salting of streets). Note that for the mild winters in 2006/07 and 2007/08 much lower non-exhaust emissions have been estimated than in normal winters. In these two winters only about 20-25% of the normal salt amount was utilized in the winter service. Estimated non-exhaust emissions for Graz compare well with data from Klagenfurt (Austria), but are in general higher than in other European cities, except in Scandinavia (Gehrig et al., 2003, Ketzel et al., 2007). An average value of 0.12 gkm^{-1} has been estimated for the base year 2006 for the traffic emission calculations. For highways a much lower value according to Gehrig et al. (2003) has been applied.

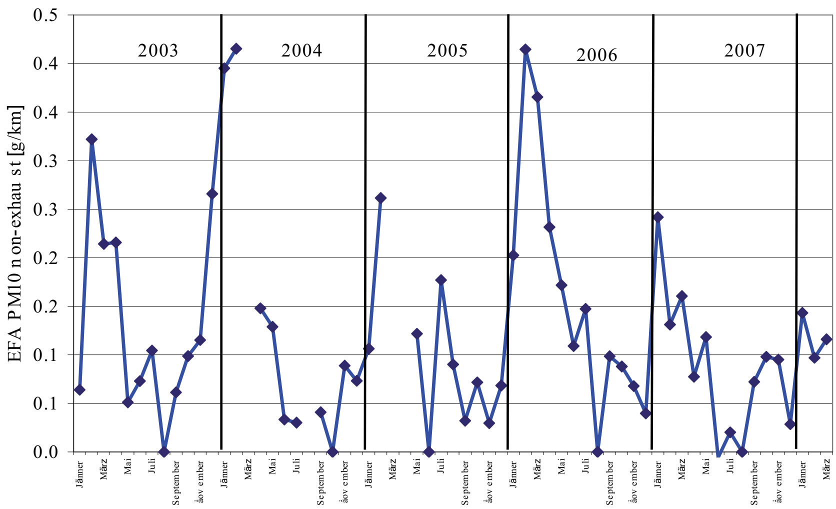

Figure 2. Monthly averaged estimated non-exhaust emission factors over the past years for one road site in Graz.

Emissions from heating (including warm water) of private households and of industry/business were available for defined areas at sub-community level (Oettl, 2008a; Heiden et al., 2008). The base year for these emission inventories is 2001, because for this particular year the latest statistical data regarding heating systems, fuels, and building sizes were available in Austria. Emissions from agriculture, construction works, offroad vehicles, and fugitive dust emissions from industry were not available and should thus lead to an underestimation of computed concentrations with the dispersion model. Table 1 lists the estimated emissions for Graz. The major sources are non-exhaust emissions from passenger cars (PC) and room heating (incl. warm water) of private houses.

Table 1. Calculated emissions for traffic and room heating for Graz in [ta^{-1}].

PC exhaust	PC non-exhaust	HDV exhaust	HDV non-exhaust	Private households	Heating of business buildings
37	85	20	38	70	44

3. DISPERSION CALCULATIONS

To take into account topography, in a first step 3D wind fields were computed with the Graz Mesoscale Model (GRAMM, Oettl, 2000). GRAMM solves the conservation equations for mass, potential temperature, and momentum using an implicit time integration scheme following the SIMPLER algorithm described in Patanker (1980). Turbulence closure is performed either with a k-l scheme, or purely diagnostic using the Richardson number in stable conditions and the vertical heat flux in convective conditions (e.g. Schluenzen, 1996). GRAMM also calculates the surface energy balance by taking into account soil moisture content, soil heat capacity, heat transfer coefficient, parameterised on the basis of CORINE land use categories. In the simulations a horizontal resolution of 300 x 300 m² and a vertical cell height at the bottom of 10 m has been used. The grid is terrain following and consists of special hexahedrons (Almbauer, 1995). In the vertical direction the height of the grid cells increase from the bottom to the top. 15 vertical layers have been defined. Instead of nesting GRAMM within an European wide model, GRAMM has been initialised and driven by one single local wind station, which is in a first step extrapolated to the whole model domain using a simple vertical logarithmic wind profile. A first guess vertical temperature profile has been estimated from the stability class, determined according to U.S. EPA (2000). Based on the quantities wind speed, -direction, and stability class, a classification of meteorological situations for the year 2006 has been undertaken resulting in about 500 different situations with different frequencies of occurrence. For each situation, a quasi steady-state wind field has been computed. Figure 3 shows the simulated annual average wind speeds. In the main basin, wind speeds are rather low between 0.7 ms^{-1} and 1.2 ms^{-1} in the north. The values agree very well with observations.

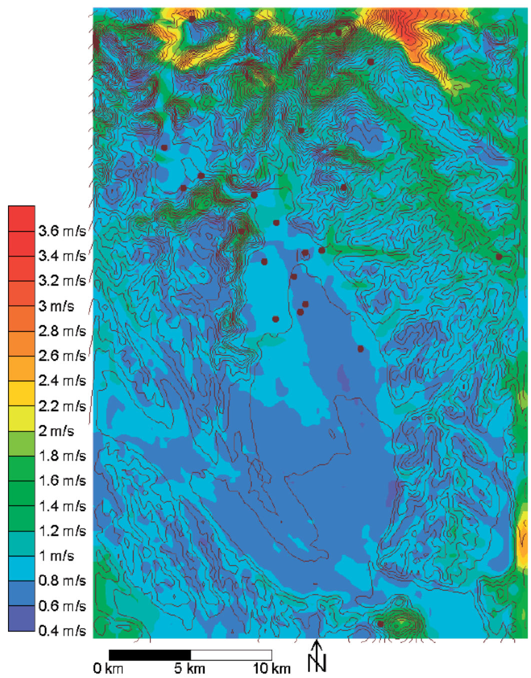

Figure 3. Simulated annual average wind speeds 15 m above ground level with GRAMM.

The dispersion of PM is calculated with the Lagrangian dispersion model GRAL (Graz Lagrangian model). A comprehensive description of the model and its validation is given in Oettl (2008b). The advantage of using a Lagrangian dispersion model is that the sources can be resolved very accurate and that concentrations can be computed with a very high resolution, which allows for a comparison with observations even close to roads. The horizontal resolution used in GRAL was 10 x 10 m². the 3D wind fields of GRAMM together with the stability class was used as input. A meteorological pre-processor computes all further necessary turbulent quantities, such as friction velocity, Monin-Obukhov length, boundary layer height, etc. Steady-state concentration fields have been computed and stored on a PC. A simple post-processing routine calculated the annual mean, the maximum daily mean, etc. concentrations by considering the half-hourly classified weather situation, and the seasonal and daily variation of emissions, which can be different for the various sources considered in this study. For instance, the seasonal variation of non-exhaust traffic emissions has a peak in February. Note that only primary PM emissions have been taken into account. Local formation of secondary aerosols (ammonium nitrate, ammonium sulfate) was roughly estimated on a monthly average basis from chemical analysis at two AQM sites within Graz and at a mountain site above 1.000 m in Switzerland (Hueglin et al., 2005). Further, long range transport of PM_{10} to Graz has been set equal to observed concentrations at a mountain site 1.100 m above sea level in Styria. This AQM site shows a clear dependence of PM_{10} on the wind direction. Highest concentrations are typically found when air masses come from east European countries. In 2006 the average PM_{10} concentration, which is attributed to long range transport from these countries was 16 μgm^{-3}.

Figure 5 depicts the annual average PM_{10} concentration. On the left hand side, simulations were made with GRAL taking into account meteorological data from Graz and the real topography. On the right hand side, results are shown for flat terrain and with meteorological data from Vienna. Note that the annual average wind speed in Vienna is about 4.0 ms^{-1}, while in Graz it is below 1.0 ms^{-1}. A comparison of modelled concentrations with observed ones gave evidence that the annual mean PM_{10} concentrations could be simulated within +/-15% at all AQM stations. The major contributors are non-exhaust emissions followed by domestic heating. As an example the source apportionment is shown for the AQM station Graz-Don Bosco, which is the highest polluted site in Austria (Figure 6). Measures like particle filters, which are currently being implemented in modern European diesel PC, will by far not solve the problem of the PM_{10} burden in Graz. In fact, emissions from domestic heating of private houses plus the entire traffic emissions (exhaust and non-exhaust) need to be zero to meet the EU PM_{10} standards.

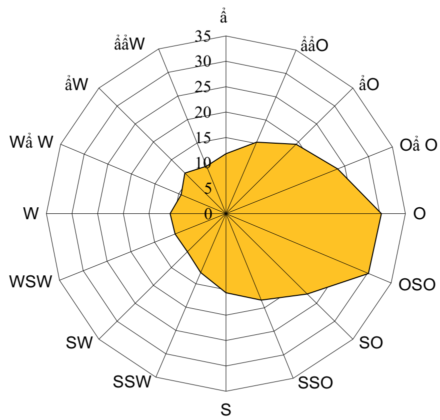

Figure 4. Observed average PM_{10} concentrations [µgm^{-3}] in dependence on wind direction at a mountain site at 1.1000 m a.s.l. in Styria, Austria.

Only a few small areas within the city do not meet the EU standards, if Graz would be in flat terrain with the same dispersion conditions in Vienna (Austria). The simulations with GRAL suggest that emissions near the ground in Graz cause about 3-4 times higher air pollution levels than in Vienna due to the worse dispersion conditions. Thus, the EU air quality directives lead to strong disadvantages in regions with bad dispersion conditions and high background concentrations regarding e.g. licensing procedures for new businesses or in terms of financial burdens for communities to take measures for reducing pollutant levels.

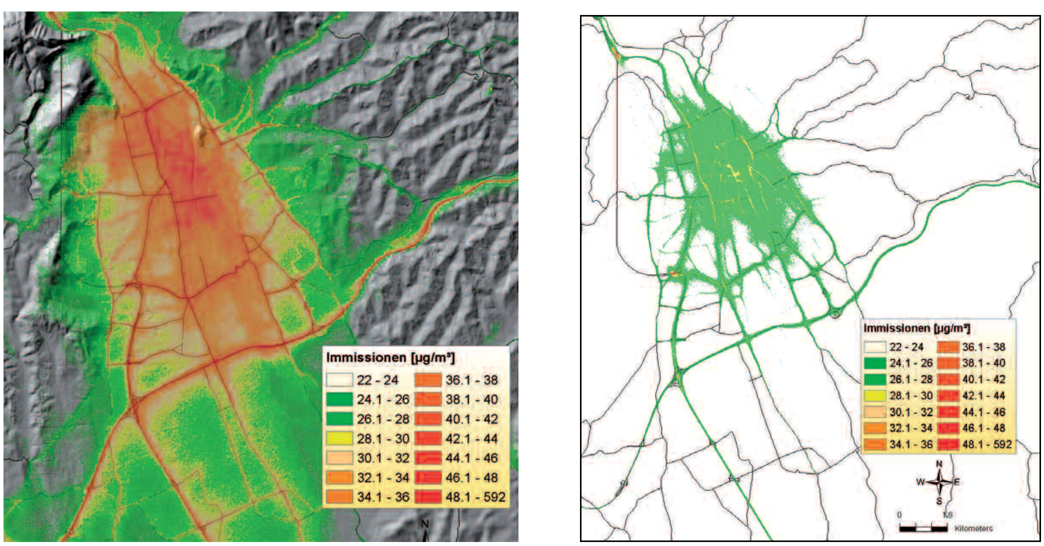

Figure 5. Simulated annual average PM_{10} concentrations for Graz for the base year 2006 in [µgm^{-3}] (left: real conditions; right: meteorology from Vienna, flat terrain).

4. CONCLUSIONS

In this study it is shown that high resolution dispersion simulations with GRAL provide valuable insights in the possible causes of very high PM_{10} levels observed in Graz, Austria. The major sources for PM_{10} are non-exhaust emissions from traffic, possibly mainly caused by salting and sanding of roads in winter time, and emissions from heating of private households and businesses. Thus, there is a strong pressure to reduce traffic within Graz and to force heating systems with lower PM_{10} emissions. However, due to the extremely bad dispersion conditions in the Graz basin, the limit values for PM_{10} set up by the EU can not be met in Graz everywhere. A matter of further research is the formation of locally formed secondary aerosols from the precursors NO_2, NH_3, and SO_2, as they seem to be very important too. It is desirable to get more financial support from the EU for communities like Graz to set up strong measures (forcing of public transport, etc.), as such have to spend much more money to reduce pollutant levels than cities with better dispersion conditions.

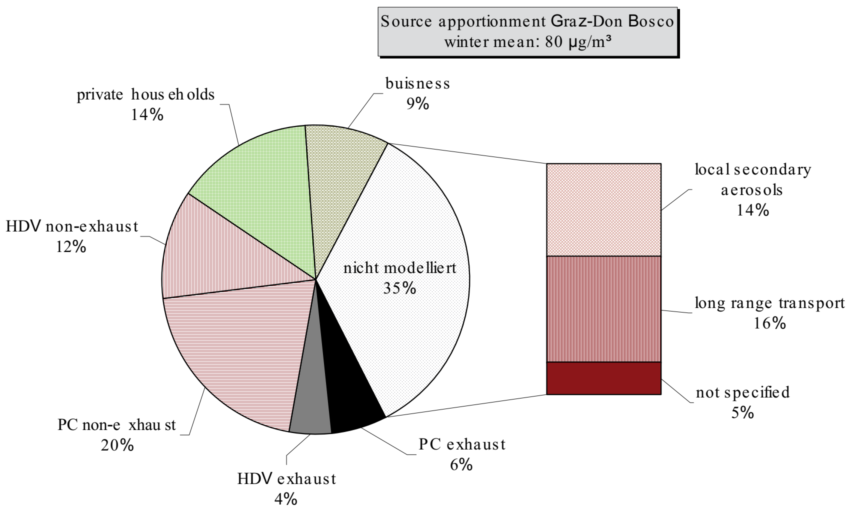

Figure 6. Example of a source apportionment based on the simulations with GRAL for the AQM station Graz-Don Bosco for the winter months in 2006 (Jan-Feb, Dec).

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