Effects of PM_{10} emission abatement strategies on air quality in urban and rural areas

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Abstract

In many regions in Austria the topographical situation and the meteorological conditions result in high PM_{10} concentration values. Permanent violations of PM_{10} air quality (AQ) standards call for action plans to reduce the PM_{10} emissions. In cities like Graz (250.000 inhabitants) the threshold value for the daily average is exceeded for more than 120 day per year. Even in rural areas violations of the EU standard (35 allowed violations) occur. Austria adapted in its air quality standard a more stringent requirement. Currently only 30 exceedances per year are allowed. From 2010 on this limit will be reduced to 25 allowed violations.

In order to evaluate the effects of action plans before they are set into force a combined emission-dispersion tool has been developed and applied to certain regions in Austria. When looking on emission inventories very often it turns out that traffic, domestic heating and industry contribute equally to the PM_{10} problem. If dispersion is taken into account widely distributed low level sources like domestic heating become the major source. In countries like Austria with an intensive road service during wintertime due to de-icing and sanding, this winter service might also be a major source of air pollution.

If action plans are considered, they consist in most times of short and long term actions. Short term actions concern mainly road traffic, while long term actions shall change the emission situation in general. This concerns mostly domestic heating, vehicle fleet improvements and – especially in Austria – winter services for roads.

Several of these measures have been investigated in detail at different locations in Austria. The main results can be summarised as follows:

Traffic restrictions might become counterproductive as long as they are not accompanied by measures which ensure that vehicle usage is limited. In most cases traffic is only being diverted, which yields in general to a higher number of kilometres travelled and hence more pollution. Local improvements in air quality are superposed by an increase at other parts of the network.

Retrofitting of diesel cars with particle filters has a very limited effect as only a small share of vehicles is concerned and the efficiency of retrofitting systems is by far lower than expected.

Improvements in winter service of roads (e.g. changing from sanding to de-icing) reduces the kerbside concentrations to a remarkable extend. However, the positive effect is mostly restricted to regions close to roads.

If it is possible to improve the emission situation for domestic heating, by far the most positive effect on air quality can be expected.

However, it has to be remarked that even a combination of many of the listed measures will not help to avoid violations of the threshold for the PM_{10} daily mean value. In many of the cases violations will remain on more days than allowed.

Keywords: PM_{10}, abatement measures

1 Background

The EU directive 1999/30/EC defines the standards for air quality in the European Community. The Immissionsschutzgesetz Luft (IG-L) [1] is the transformation of the EU-directive into national law. In 2001 threshold values for PM10 were implemented. Austria implemented more stringent threshold values than given in the EU directive. While the threshold for the annual mean value (40 µg/m³) and the daily mean value (50 µg/m³) remains the same, the acceptable number of days with violations of the threshold for the daily mean value was reduced from 35 (EU) to 30 at the moment, and to 25 from 2010 on.

It turned out that throughout Austria the permissible number of days with threshold violations is exceeded by far. Unfavourable meteorological conditions at the south side of the Alps result in the fact that even in small agglomerations PM10 became a major problem in air pollution.

In the year 2005 the threshold value for the annual mean value was exceeded in Austria on two locations only. Both of them are in the City of Graz, one is very close to traffic, while the other one is located in the city centre. The picture looks quite different when the exceedances of the daily mean value are considered. On 58 out of 111 PM10 monitoring stations the 50 µg/m³ were exceeded more often than the allowed 30 times. Using the EU standard of 35 allowed violations still 54 locations did not meet the AQ criteria.

The ‘leading’ city is the city of Graz with up to 117 days with average mean values higher than 50 µg/m³. St. Pölten in Lower Austria and Klagenfurt in Carinthia are following with some 90 exceedances [2]. Figure 1 shows the location of the monitoring stations exceeding a daily mean value of 50 µg/m³. Most violations are in the south-east and south (Styria and Carinthia) followed by the east (Vienna and Burgenland). But not only urban areas are concerned, violations occur even in rural areas.

The reasons of the high PM10 burden are various. Local and regional emissions combined with unfavourable dispersion conditions are of importance in some regions, while in other the transboundary pollution, mainly from central Europe (east and south-east), is the decisive factor. In addition the basins in the central Alps as well as on the south side of the Alps suffer from unfavourable dispersion conditions with low winds, strong inversions during wintertime and little precipitation.

This high number of violations of the AQ standard calls for action plans with massive restrictions in order to achieve the limit values given in the AQ standards.

As PM10 emissions have various sources an abatement programme has to consider the impact of all these possible sources. But this implies that the sources are known, i.e. necessity of a good emission inventory and the impact can be determined, i.e. dispersion calculation.

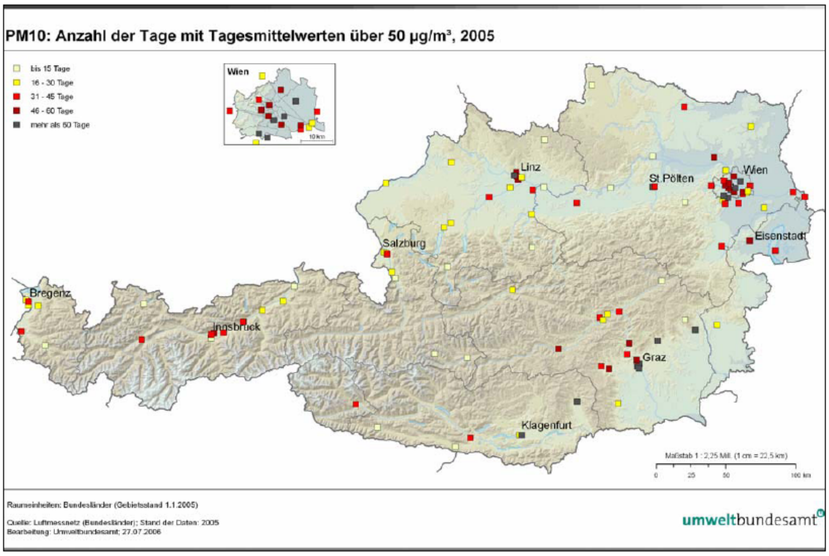

Figure 1: Locations with PM10 values (daily mean values) exceeding 50 µg/m³[2]

2 Methodological approach

The approach for evaluating the impact of different sources on the air quality as well as that of quantifying the effects of some abatement measures is based on the application of a high level emission inventory combined with a dispersion model.

2.1 Emission inventory

The emission inventory is the basis for all the quantification activities. Hence, it I s imperative, that a high quality in source description is required. This high quality concerns quantification as well as temporal and special allocation.

2.2 Dispersion modelling

For dispersion modeling the model system GRAL, a Lagrange particle model, which has been developed at the Institute for Internal Combustion Engines and Thermodynamics, Graz University of Technology, is used. This model system accounts especially for calm wind conditions, which are dominant in basins like the Lavant or the Klagenfurt basin.

The model system consists mainly of two modules:

a) The non-hydrostatic prognostic wind field model GRAMM used for analysing stationary wind fields serving for the pollution dispersion in complex terrain or in build up areas.

b) The dispersion model GRAL developed for the specific dispersion situations both in calm wind conditions (the occurrence of large horizontal eddies) and from tunnel portals (effect of the jet streams).

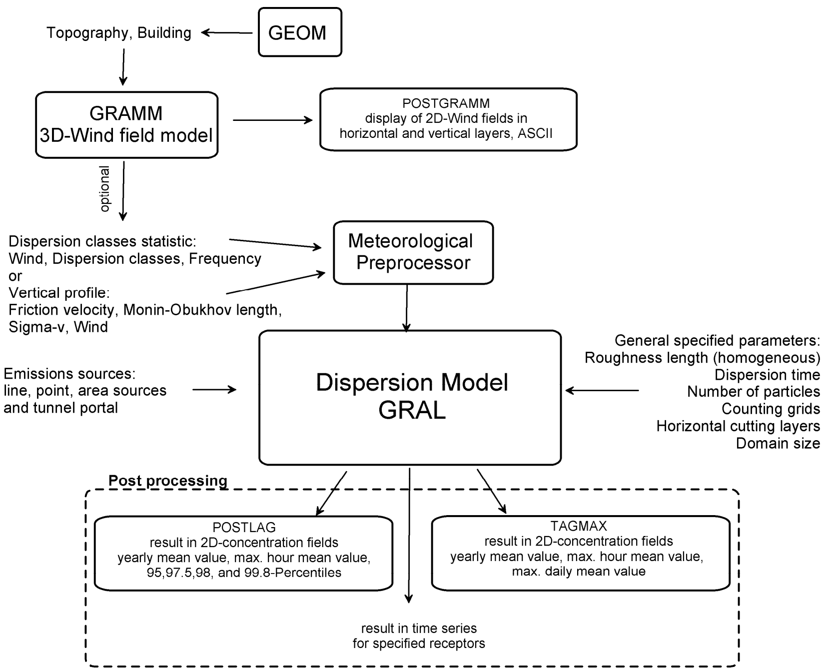

Figure 2 depicts an overview of the models system Graz. The module GEOM provides the terrain data for the wind field and for the dispersion simulations. GRAMM calculates the 3-dimensional wind fields. Turbulence parameters such as Monin-Obukhov length, friction velocity and so on are either provided by appropriate observations or are estimated by the meteorological pre-processor.

Figure 2: the model system GRAL

GRAMM

The analysis of wind fields with GRAMM offers the advantage, in comparison with diagnostic wind field models, to take into account dynamic effects (e.g. obstacle influenced flows). Therefore the model is initialized with a horizontally homogenous wind field and then the steady-state wind field is computed by solving the Navier-Stokes equations (RANS). This is the common way of computing building influenced flows in the microscale [6]. For the initialization the data from a local observation of wind speed, wind direction and a kind of atmospheric “stability” (e.g. radiation balance, cloud amount) are used. Due to this limited number of required input parameters it is possible to establish a simple classification of the meteorological conditions. The main disadvantage of this method is that often measurements, representative for the large scale wind (e.g. the mountain/valley breeze), are not available. In this study representative meteorological wind stations in both basins were available.

As locally observed wind directions and speeds are used as input to the model, the main characteristics of the pollutant advection is already captured (frequency distribution of wind speed, wind direction). The main assumption is that all other parameters in a mesoscale model are of minor importance once the large scale wind is used as input. The subsequent computation of a steady-state flow field for each classified meteorological condition using constant boundary conditions derived from the locally observed large scale wind aims mainly at the simulation of very local topographical influences on the large scale wind (e.g. development of eddies in the wake of mountains).

GRAL

Dispersion modelling is carried out using the model Lagrangian Particle Model GRAL which is initialized with the steady-state wind fields calculated by GRAMM. During low wind speed conditions large horizontal atmospheric motions develop (so called meandering), which influence the dispersion process significantly. Lagrangian models like GRAL are less affected by the problems of Gauss models, which produce unrealistic high results for very low wind speeds. Nevertheless there is no valid parametrisation of the necessary turbulence parameters for low-wind situations until now. When the parameters for higher wind speeds are used, it basically results in excessive pollution concentrations. The reason for this is that low-wind situations are frequently connected with considerable changes of the wind direction and a completely changed dynamics concerning the pollutant dispersion. This leads to faster dilution of air pollutants. The Lagrangian model used applies an algorithm created especially for this problem [8]. It considers the effect of stronger turbulences in low-wind weather situations, which was also found in tracergas experiments.

The input data from the emission inventory consists of different source types with different release characteristics. As a consequence it is necessary to simulate these different kinds of sources like line sources, point sources and tunnel portals, simultaneously. GRAL achieves for these requirements and the following parameters are taken into account for the individual source types:

- Point sources: location (3D): Source strength, exit velocity, temperature differences, and diameter.
- Line sources: location (3D, also bridges): Widths, source strengths, heights of noise barriers.
- Area sources: Same as line sources.
- Tunnel portals: Location (3D), source strengths, exit velocity, temperature differences, traffic influence on tunnel jet.

The dispersion of pollutants from longitudinal ventilated tunnels is considered to differ significantly from those of other sources, such as line or point sources. In order to take all the peculiarities of the dispersion from tunnel portals into account a special software module (GRAL TM 3.5) has been developed.

Near the tunnel portal differences in temperature and velocity between the tunnel air and the ambient air occur. For vertical dispersion a modified method according to [11] for point sources is utilized, which is able to account for buoyant plumes (i.e. when there exist positive temperature differences).

The impact of the tunnel jet stream on dispersion is caused by two main forces:

- Turbulent friction due to differences in the velocity of the ambient wind parallel to the jet stream and the jet stream which causes it to slow down.
- A pressure force caused by the ambient wind perpendicular to the jet stream which bends the jet stream towards the ambient wind direction.

The module accounts for wind direction fluctuations, which cause the tunnel jet also to vary in space.

GRAL TM 3.5 has been tested against five data sets from different tunnel portals in complex and flat terrain with different meteorological conditions (high/low wind velocities, stable/unstable atmospheric conditions).

Quality assurance

The wind field model GRAMM has been validated [7] and its performance has been evaluated by applying it in the MESOCOM [12] and DATE-Graz projects [13].

The quality assurance of the modelling system GRAL is mainly based on the comparison of observed and modelled concentrations for certain field experiments. Currently 18 different data sets for tunnel portals, point sources, line sources and built-up area are used for the model evaluation, such as Prairie Grass, Indianapolis, INEL, Elimaeki, Goettingerstrasse, Hornsgatan,etc. Many of the modelling results have been published in peer-reviewed journals [9], [10].

3 Abatement measures

3.1 Application to the city of Klagenfurt

In the framework of the EU-Life project KAPA-GS [4] an intensive study was carried out to determine the share of different PM10 emission sources. Measurements were combined with numerical simulations and chemical analyses.

On one hand the numerical simulations - based on emission inventories and dispersion calculations - allow for a clear distinction between the different sources. On the other hand the chemical analyses of PM10 samples allow for a source profile on the measurement side and for a validation of the model chain. This approach has been applied to the city of Klagenfurt, which is a city of 90.000 inhabitants and some 150.000 including the suburbs and commuters. Its location in a basin on the south side of the Alps result in wintertime in long periods with strong inversions combined with calm winds. These unfavourable dispersion conditions lead to a relatively high PM10 burden. The annual mean values are met on all air quality monitoring locations, but the threshold value for PM10 as daily mean

Figure 3: View of the city of Klagenfurt [3]

value is exceeded frequently. In 2005 85 violations were registered at one of the monitoring stations (see Table 1).

Table 1: PM10 concentrations during the years 2000 to 2005

Air quality monitoring station		max. daily mean value [µg/m³]	No. of days > 50 µg/m³ [ ]	annual mean value [µg/m³]
Koschatstrasse	2005	86	31	26
	2004	84	34	27
Völkermarkterstrasse	2005	123	84	39
	2004	116	80	38
	2003	99	74	38
	2002	127	58	37

3.1.1 Current situation

The emission situation is given on bases of an emission inventory, which is updated on an irregularly bases. The latest update was made in 2004 and covered the sectors 'traffic' and 'domestic heating'. Emissions for the sector 'trade and industry' are currently available only on basis of 1999 data. Figure 4 shows the calculated emissions for the city of Klagenfurt.

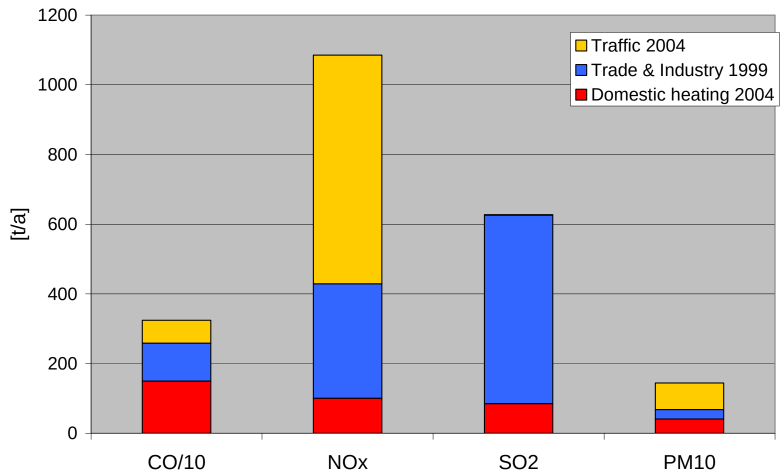

Figure 4: Emissions for the sectors 'traffic', 'trade & industry' and 'domestic heating'

Traffic emissions were calculated as line sources (hot exhaust emissions and resuspension of road dust), using traffic data on road by road basis, and as area sources (cold start emissions), based on demographical data. Domestic heating emissions were calculated on basis of statistical data given for special demographical areas using data on fuel usage, heating systems and building structure. Data for trade and industry is based on single inquiries (big point sources) and statistical data using either fuel usage or production information.

When considering road traffic, strong emphasis was put on the influence of winter service. During wintertime road sanding or de-icing (salt) is a major source of PM10 pollution. Detailed investigations led to the development of site-specific emission factors for resuspension of road dust [4]. Figure 5 show the emission factors derived from roadside measurements over one year. The peak value for TSP in March was due to intensive road cleaning during that time. However, the peak was monitored for TSP but not for the PM10 fraction.

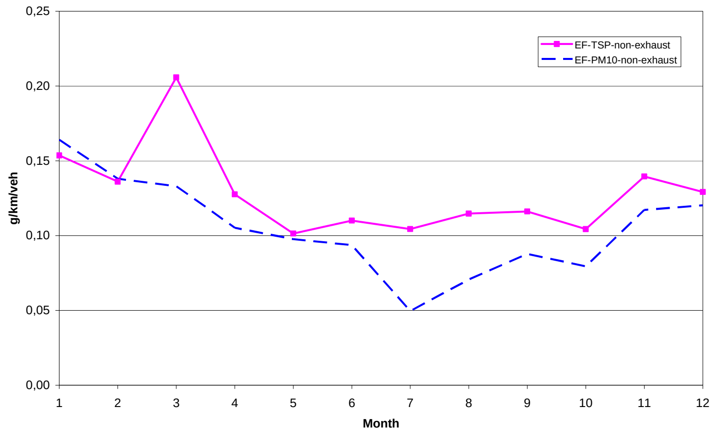

Figure 5: Emission factors for TSP and PM10 non-exhaust emissions

Combining emissions with dispersion modelling resulted in source related figures concerning PM10 pollution. Figure 6 to Figure 9 show the results for various sources. While PM10 from traffic exhaust follows strongly the roads with heavy traffic, traffic non-exhaust PM10 emissions have a broader dispersion band. This is mainly due to the higher quantity of non-exhaust PM10 and due to different emission factors for de-icing (salting) on the main routes and sanding in the secondary road network.

Domestic heating has the biggest extension in terms of covered area. The highest local contributions result from traffic and domestic heating.

However, taking all these sources into account only some 50% of the measured values can be attributed to contribution of the modelled sources. I.e., a big share of the total PM10 burden is missing. This has two reasons. One of them is the share of secondary formed particles, the other one is the part of the background concentration, i.e. that pollution which is transported into the calculation domain.

The calculated concentrations were compared to the values derived from the both monitoring stations ‘Völkermarkter Straße’ (kerbside location) and ‘Koschatstraße’ (urban background location). Based on these calculations, background and secondary formed PM10 pollution account for some 15 to 20 µg/m³ (annual mean value).

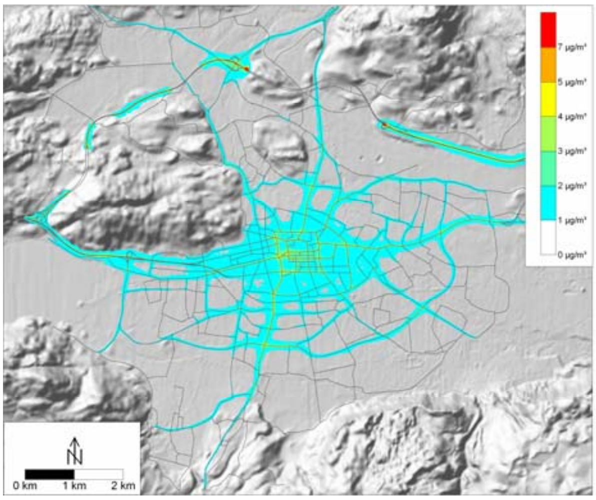

Figure 6: Contribution of traffic related exhaust emissions to the PM10 annual mean concentrations

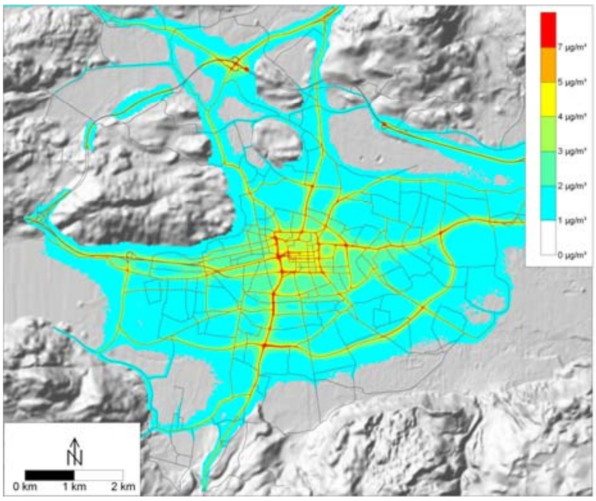

Figure 7: Contribution of traffic related non-exhaust emissions to the PM10 annual mean concentrations

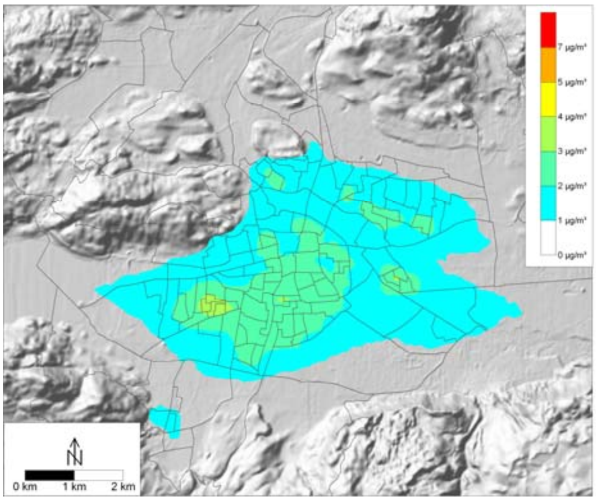

Figure 8: Contribution of 'trade & industry' emissions to the PM10 annual mean concentrations

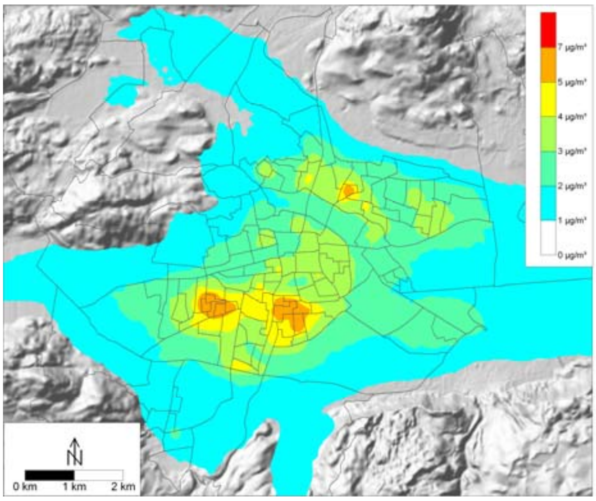

Figure 9: Contribution of 'domestic heating' emissions to the PM10 annual mean concentrations

Figure 10 shows the total PM10 concentrations (annual mean value). The main roads and the city centre are the most polluted parts. In addition one region with a high share of solid fuels (wood and coal burning) is clearly depicted in the south and south west of the region.

Figure 11 depicts the shares of the different source types at the kerbside monitoring location 'Völkermarkter Straße'. Shown is the average over the winter months November to March. As to be expected the non-exhaust part is dominating (winter service). But even at that location domestic heating contribute more to the pollution than traffic exhaust emissions.

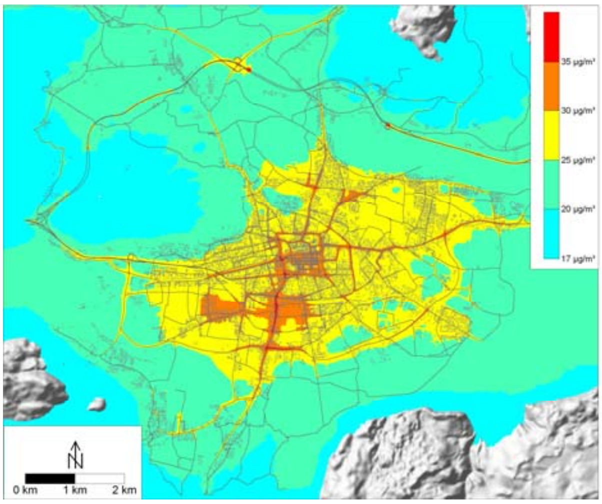

Figure 10: PM10 annual mean concentrations

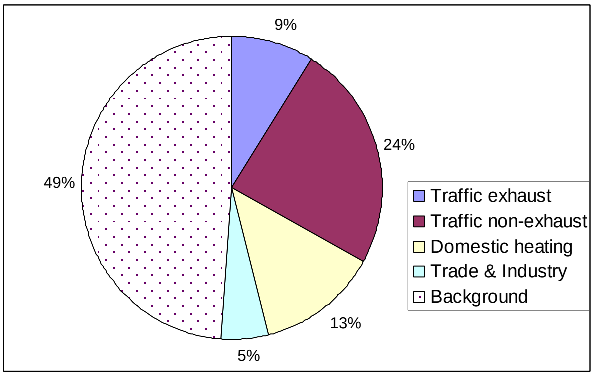

Figure 11: Calculated PM10 winter mean concentrations at the monitoring location 'Völkermarkter Straße', share of the different source types

3.1.2 Abatement measures

Having the impact of different sources in mind, it turns out that domestic heating and resuspension of road dust (mainly winter service) are the main sources of the existing PM 10 problem.

Based on these findings different abatement strategies were defined. The action plan which was set into force already in the wintertime 2005/06, contained short term measures as well as long term measures.

3.1.2.1 Short term measures

The short term measures are based on traffic restrictions which will be implied as soon as 50 µg/m³ (daily mean value for PM10) are exceeded for more than 5 consequent days. In this case one of the main streets into the city will be closed for traffic. If the high PM10 pollution remains for more than 10 days the main inner city ring (and all roads inside this ring) will be closed too. A lift of this traffic restriction happens as soon as PM10 decreases below 50µg/m³ as daily mean value. Accompanying measures like P+R facilities with shuttle bus service free of charge are planned. Unfortunately the acceptance rate by the car users is very limited. The result will be more into the direction of deviating traffic than restricting traffic. Figure 12 shows the results of the simulation. As one main street from the east is closed, car users will take a different route either than using public transport. This results in a reduction of pollution on this specific route (green part of Figure 12), while on other streets PM10 concentrations will increase. In total the mileage will increase as well as the overall PM10 emission. As a clear result of the simulation it came out that much more effective accompanying actions have to be set. Otherwise such a single measure will contradict its intention.

Figure 12: Impact of the closure of one main street on the PM10 concentration (daily mean value)

3.1.2.2 Long term measures

Long term measures are based on actions which should result in long term changes of the emission situations. Long term actions concern typically changes in fuel usage for domestic heating or changes in winter service for roads. While the first one might take years to become effective, the latter one could be applied quicker. As an example the effects of upgrading of old heating facilities on the PM10 concentrations are shown. In the near future some 600 households which use currently mainly wood, coal and oil shall be connected to the district heating system. In total some 3.5 GWh/a on energy consumption shall be replaced. This concerns only $1.4 * 10^{-4}$ percent of the energy consumption needed for room heating in the city of Klagenfurt. Although the share of the concerned energy consumption is very small, this is not the case concerning emissions. Using the standard emission factors for the concerned heating fuels and facilities, the following emission quantities can be reduced:

PM10 1500 kg/a; SO2 1460 kg/a; NOx 1265 kg/a; CO 42030 kg/a

Using the emission data and the geographical allocation, the impact of these emissions on the air quality situation can be demonstrated. On a mean level for the winter time some 1 to 3 µg/m³ on PM10 can be reduced due upgrading of old heating systems. For the maximum daily mean value a reduction potential up to 8 µg/m³ has been calculated. This shows clearly, that the elimination of old heating systems has a great effect on air quality improvement.

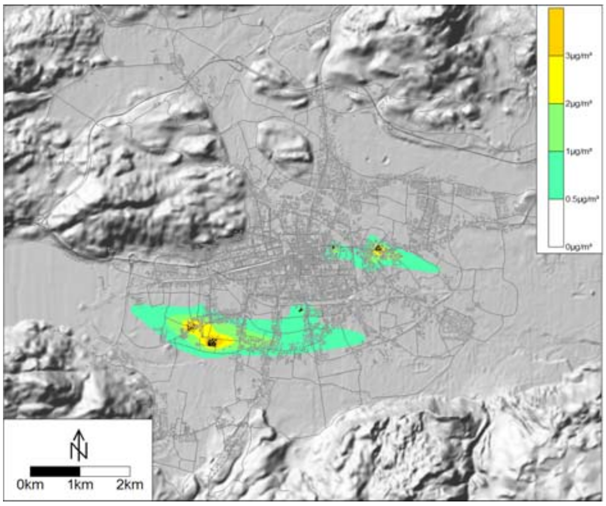

Figure 13: Impact of local upgrading of domestic hearing systems on PM10 wintertime mean value [µg/m³]

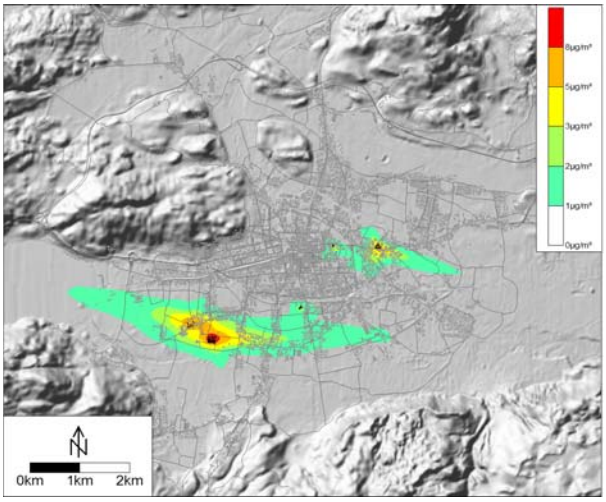

Figure 14: Impact of local upgrading of domestic hearing systems on PM10 maximum daily mean value [µg/m³]

3.2 Application to the Lavanttal region

The Lavanttal region is a basin with an extension of some 30 times 20 km (see Figure 15). The mountains in the east, north and west reaches altitudes between 1800 and 2200 m asl., while the basin is at an altitude of 400 m asl. The hills in the south reach up to some 800 m asl. Major emitters in that region are a paper and pulp mill, the small town of Wolfsberg and agricultural activities. Traffic is dominated by a highway and some minor roads.

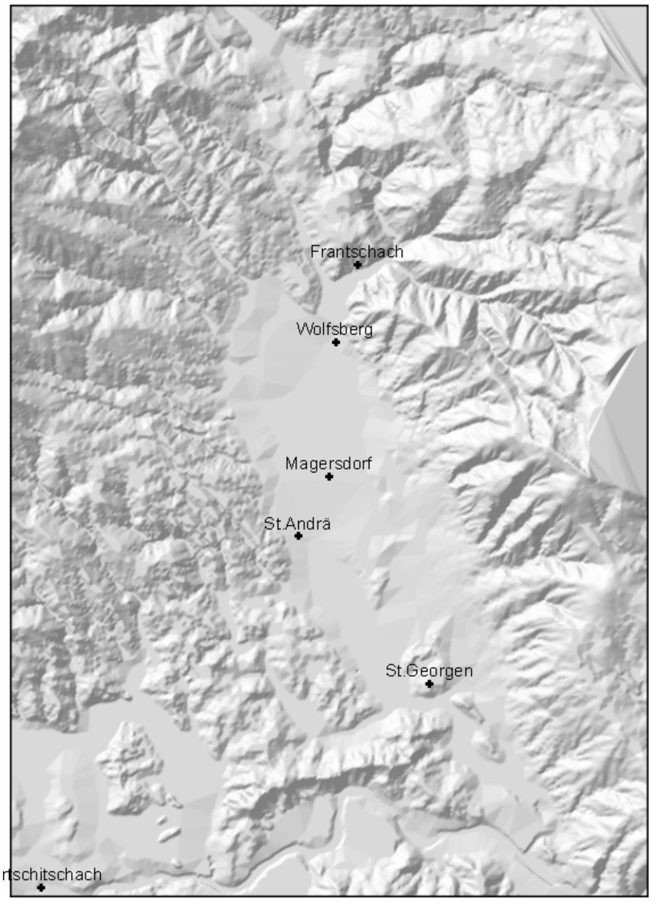

Figure 15: Topographical map of the Lavanttal basin

3.2.1 Current situation

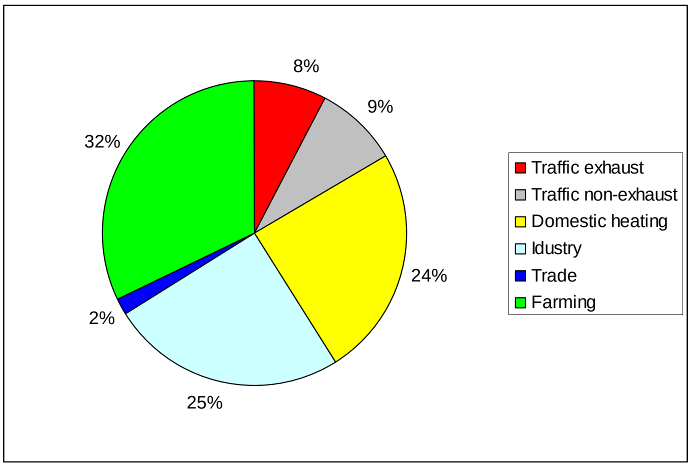

Figure 16: Contribution of the different sources to the PM10 emissions in the region under consideration

Besides two big industrial facilities (pulp and paper mill and wood industry) this region is mainly dominated by small enterprises and agricultural activities. Nevertheless, PM10 is a problem. While there is no problem in meeting the AQ standard for the annual mean value, the 50 µg/m³ threshold for the daily mean value is violated throughout the whole basin between 35 and 68 days per year. Due to this, a detailed emission analyses was performed. Contrary to urban locations in this case emissions from farming play an important role. On bases of the available data only emissions from land cultivation (e.g. ploughing, harrowing) were taken into consideration, emissions from life stock were excluded. Figure 16 shows the contributions of the different source categories. Farming is dominating, although it has to be considered that these emissions occur mostly during the 'low pollution season' spring to autumn. Industry has also a remarkably share. However, those emissions are discharged with high stacks and hence contribute only little to the low level concentrations. Domestic heating has a relatively high share as in the rural areas wood is still a major energy source. In future this wood burning might become even more popular due to its positive effects on greenhouse gas emissions. Concerning road traffic, exhaust and non-exhaust PM emissions are in the same order of magnitude. During wintertime traffic non-exhaust is by a factor of three to four more important than traffic exhaust.

Applying the dispersion calculations the contributions from the different source types to the overall PM10 concentrations can be determined. Figure 17 to Figure 20 contain now the contributions from the different source types to the PM10 concentrations (annual mean value). Farming and domestic heating has the greatest impact in terms of area coverage. As stated above, the farming contributions are mainly during spring to autumn, while domestic heating is typically a winter time problem.

Figure 21 contains all source contributions including background concentrations. As in all other investigations, background account for almost 50% of the measured PM concentrations. This background consists again of secondary formed PM and primary PM transported into the calculation domain. In this case background was determined by measurements taken from a monitoring station within the calculation domain, but at a higher altitude location. The annual mean value at that station amounts to 17 µg/m³. Adding this value to the calculated ones results in a good agreement between calculation and measurement at the remaining three monitoring locations.

There is a strong correlation between annual mean values and days of violations of the 50 µg/m³ for the daily mean value. This correlation can be defined according to the following equation.

Number of days exceeding 50 µg/m³ = 4 times annual mean value - 77

The area inside the thick blue line in Figure 21 depicts the region in which the Austrian PM10 standard for 2010 (25 days with exceedances) will be violated. Such areas have to be declared as PM10 non-attainment zones. In such zones abatement measures have to be set by law.

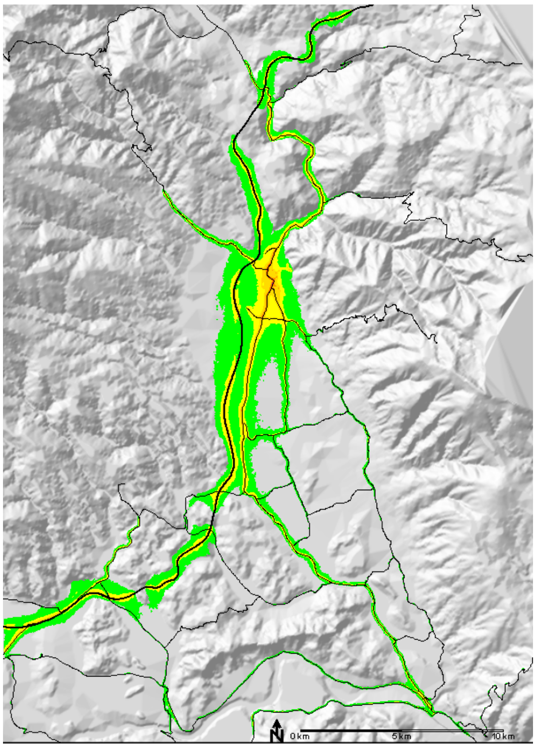

Figure 17: Road traffic related PM10 concentrations

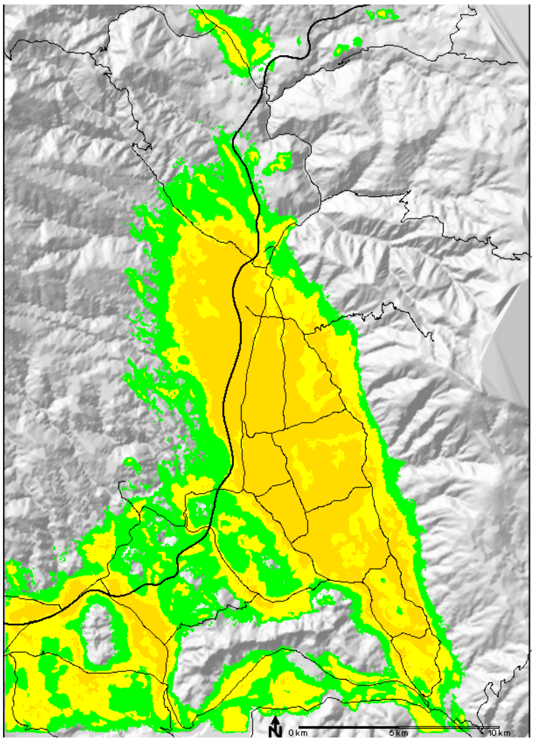

Figure 19: Farming related PM10 concentrations

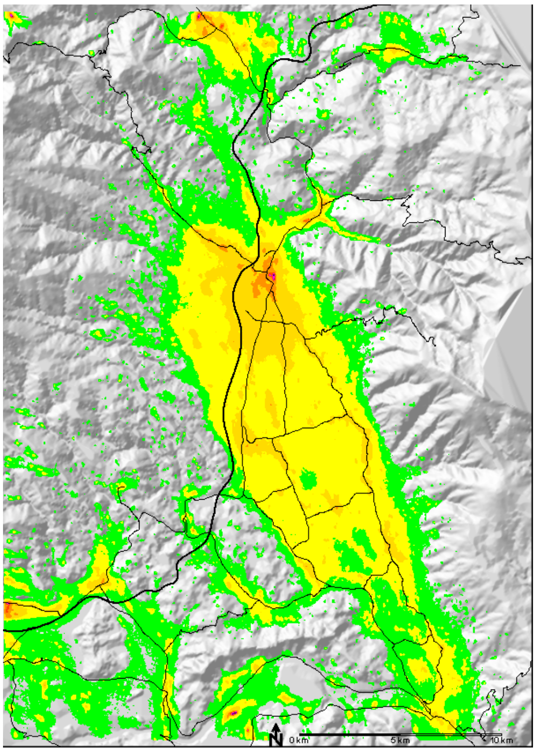

Figure 18: Domestic heating related PM10 concentrations

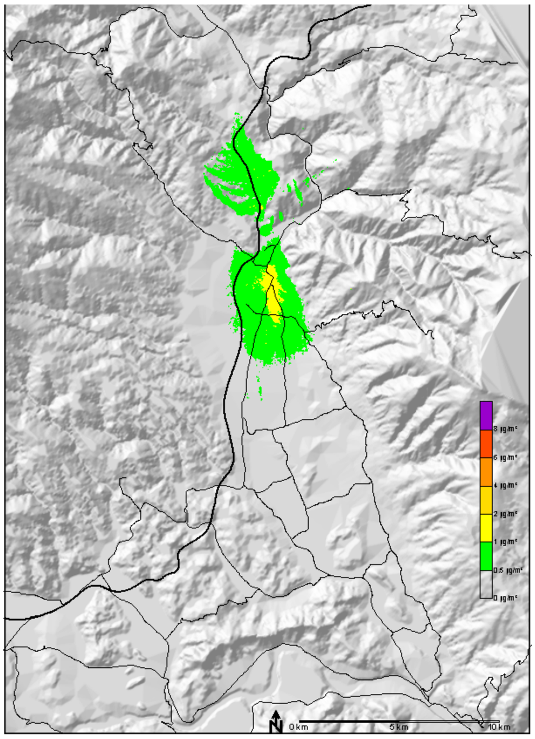

Figure 20: Trade and industry related PM10 concentrations

3.2.2 Abatement measures

The potential of several measures for reduction of the PM10 concentrations was investigated. These measures were defined as follows:

- Improvements in winter service due to enforcement of de-icing instead of sanding (scenario 1)
- Reduction of domestic heating emissions by 50% due to usage of district heating (scenario 2)
- Retrofitting of all diesel cars with PM filters with an efficiency of 90% (scenario 3)

These measures were considered as feasible by the local authorities.

An improvement in winter service (scenario 1) helps to reduce the PM emissions by more than 10 tons per year. However, the area with threshold violations would be reduced by 5% only.

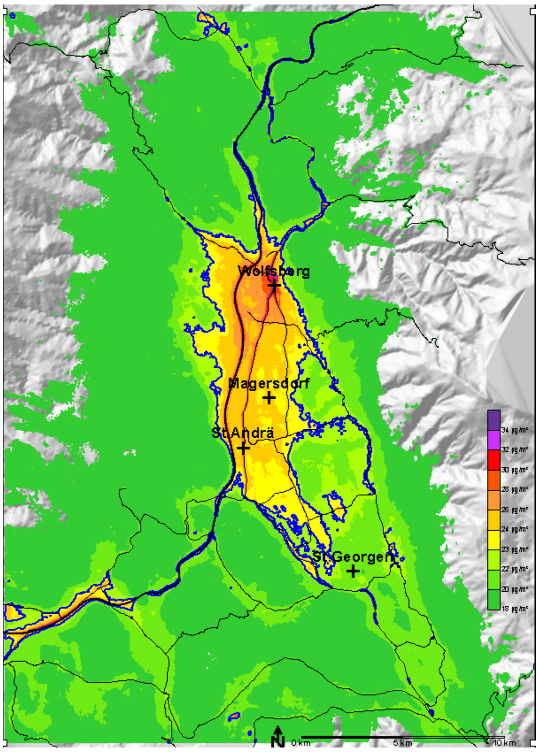

Figure 21: PM10 concentrations, all sources, annual mean

A reduction in domestic heating emissions (scenario 2) by 50% (i.e. by almost 47 tons) would result in a reduction of concerned area of almost 43%. The retrofitting of diesel cars with PM filters would minimise the PM emissions be some 6 tons per year. However, the effect on the area concerned is almost negligible.

It has to be mentioned, that even with a combination of possible measures (reduction in emissions from domestic heating and winter service) would not ensure that the air quality goals can be met.

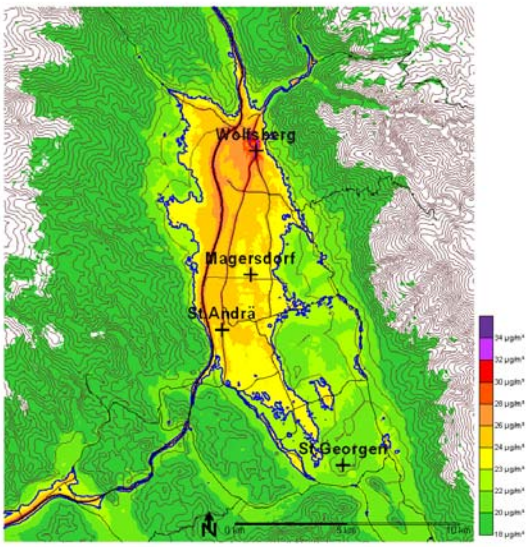

Figure 22: PM10 concentrations and area of threshold violations, improved winter service (scenario 1)

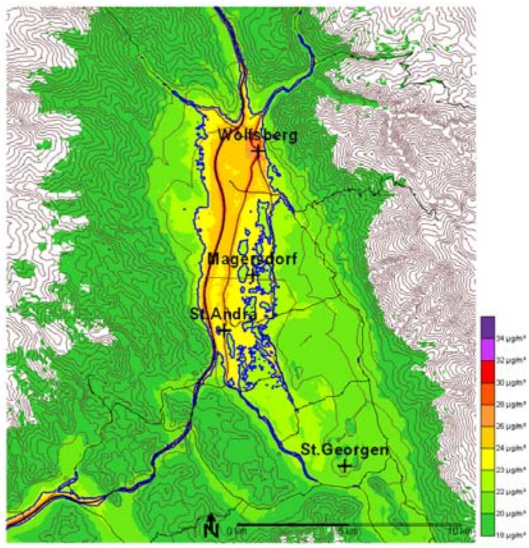

Figure 23: PM10 concentrations and area of threshold violations, improved domestic heating (Scenario 2)

4 Summary

PM10 remains to be a major problem in air quality. At most monitoring locations the annual mean value can be met without problems, but the threshold for the daily mean value is exceeded frequently. In most cases it is a combination of local emissions, background emissions and unfavourable dispersion conditions which might result even in small agglomerations in threshold violations. As a result of this many regions in Austria had to be assigned as non-attainment regions, even in small agglomerations. In those regions action plans have to be implemented in order to archive the air quality goals.

Short term measures like traffic abatement on certain days have a very limited effect. If they are not accompanied by other massive measures in order to reduce the numbed of travels, they mostly yield in traffic rerouting and hence in more emissions.

Concerning long term measures it turned out that measures related to domestic heating have the broadest impact, but it takes some time to change heating facilities and improve the emissions.

But it has to be remarked that even when implementing currently achievable measures concerning road traffic, domestic heating and other sources it will not be possible to meet the air quality target for PM10.

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