

Dispersion modelling

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1. Background

In many regions in Austria the topographical situation and the meteorological conditions result in high PM₁₀ concentration values. 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.

In order to elaborate and furthermore evaluate the effects of action plans before they are set into force the contributions of different sources has to be known. Therefore 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 PM₁₀ 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.

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.

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.

Emission inventory

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

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 Alpine basins like the Graz or the Klagenfurt basin.

The model system consists mainly of two modules:

- 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.
- 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).

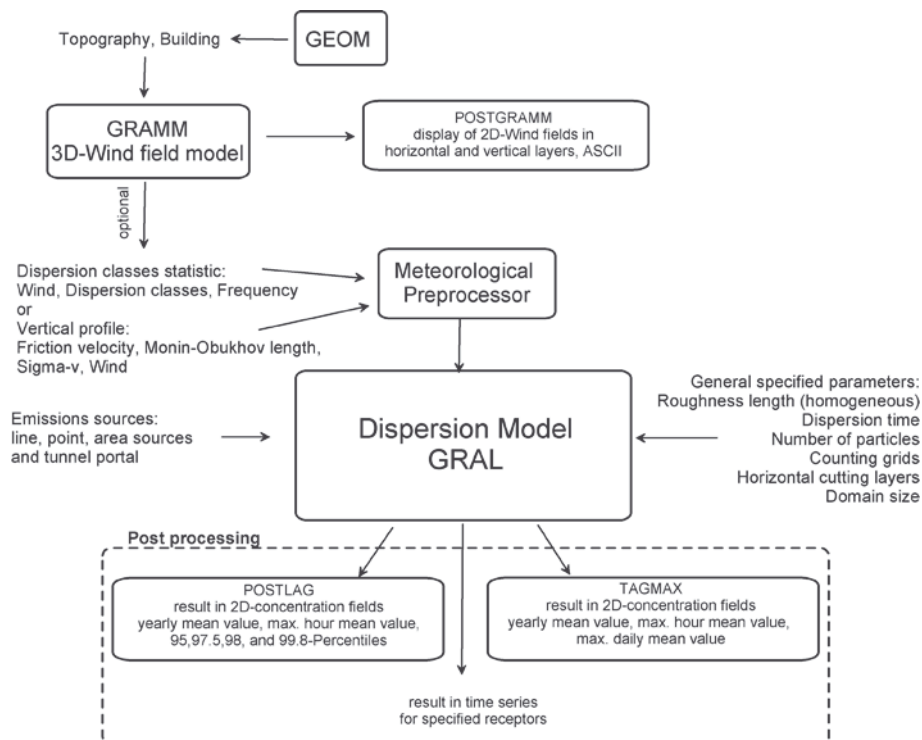


Figure 1: The model system.

Figure 1 depicts an overview of the models system. 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.

GRAMM

The analysis of wind fields with GRAMM (Almbauer et al. 2000, Oettl 2000) offers the advantage, in comparison to 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 topography influenced flows in the microscale (Schädler et al. 1996). 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 (Oettl et al. 2001a) 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 a special parameterisation of the

necessary turbulence parameters for low-wind situations is required. 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 (Oettl et al. 2001a). It considers the effect of stronger turbulences in low-wind weather situations, which was also found in tracer gas 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 van Dop (1993) 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 (Oettl 2000) and its performance has been evaluated by applying it in the MESOCOM (Thunis et al. 2003) and DATE-Graz projects (Almbauer et al. 2000).

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 (Oettl et al. 2001b, Oettl et al. 2003).

3. PM source contributions

3.1. Application to the city of Klagenfurt

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

In the framework of the EU-Life project KAPA-GS (Sturm et al. 2007) 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. Figure 2 shows the area under investigation. This area covers some 10 by 10 km.

Table 1: PM10 concentrations during the years 2000 to 2005.

Air quality monitoring station		max. daily mean value ($\mu\text{g}/\text{m}^3$)	No. of days > 50 ($\mu\text{g}/\text{m}^3$)	annual mean value ($\mu\text{g}/\text{m}^3$)
Koschatstrasse (urban background)	2005	86	31	26
	2004	84	34	27
Völkermarkterstrasse (hot spot location)	2005	123	84	39
	2004	116	80	38
	2003	99	74	38
	2002	127	58	37

Figure 2: Satellite image of the city of Klagenfurt (<http://www.klagenfurt.at/inhalt/873.htm>).

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 3 shows the calculated emissions for the city of Klagenfurt.

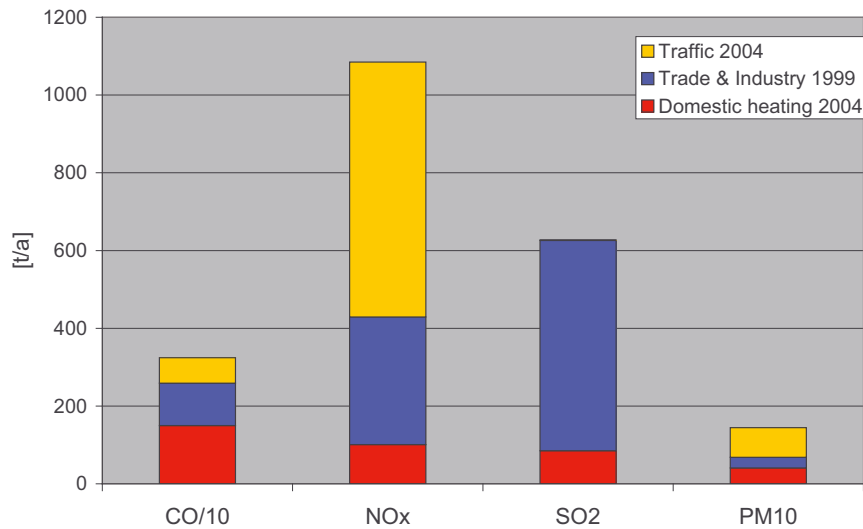


Figure 3: Emissions for the sectors 'traffic', 'trade & industry' and 'domestic heating'.

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 (Sturm et al. 2007).

Figure 4 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.

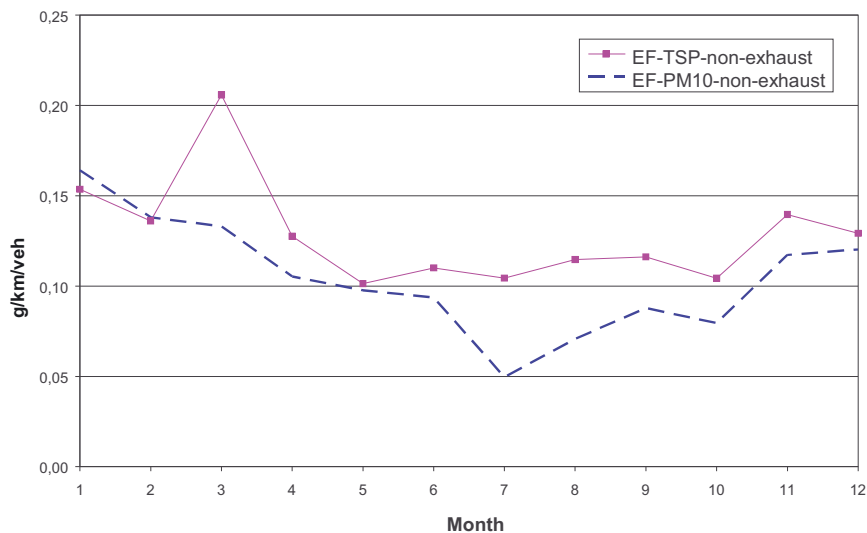


Figure 4: Emission factors for TSP and PM10 non-exhaust emissions.

Combining emissions with dispersion modelling resulted in source related figures concerning PM10 pollution. Figure 5 to Figure 8 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 $\mu\text{g}/\text{m}^3$ (annual mean value).

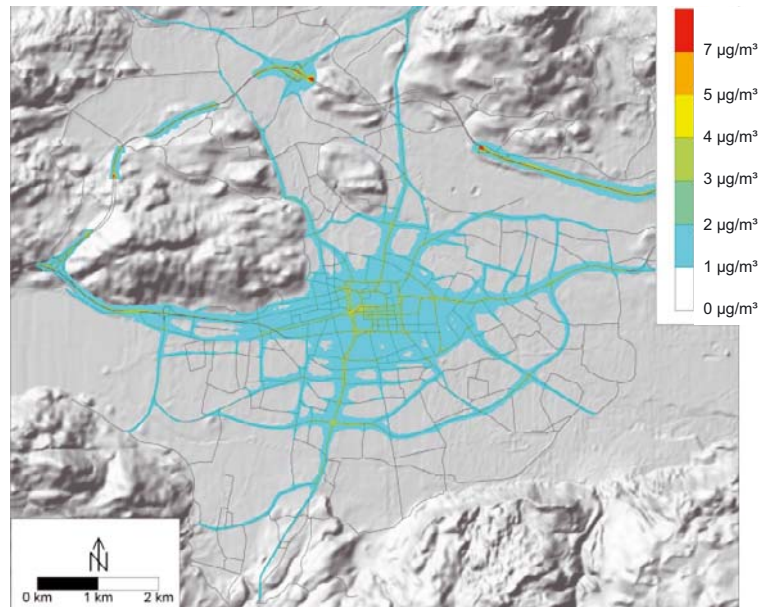


Figure 5: Contribution of traffic related exhaust emissions to the PM10 annual mean concentrations.

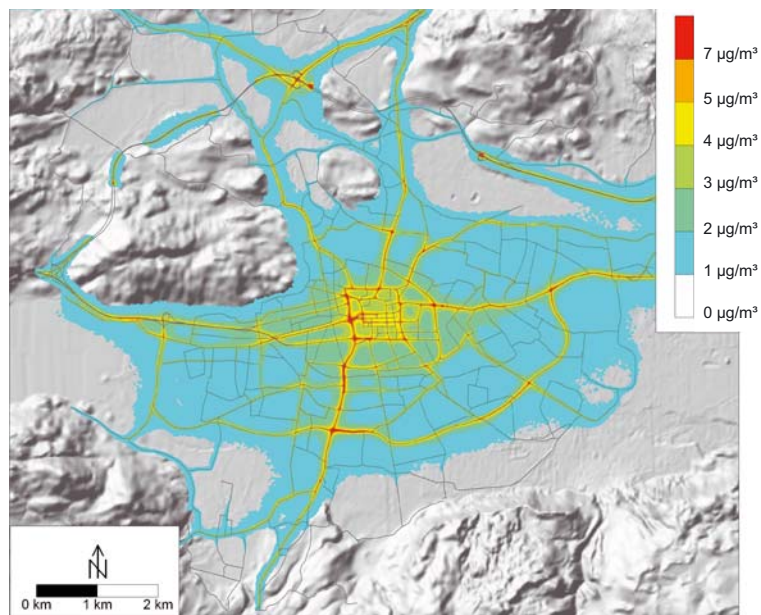


Figure 6: Contribution of traffic related non-exhaust emissions to the PM10 annual mean concentrations.

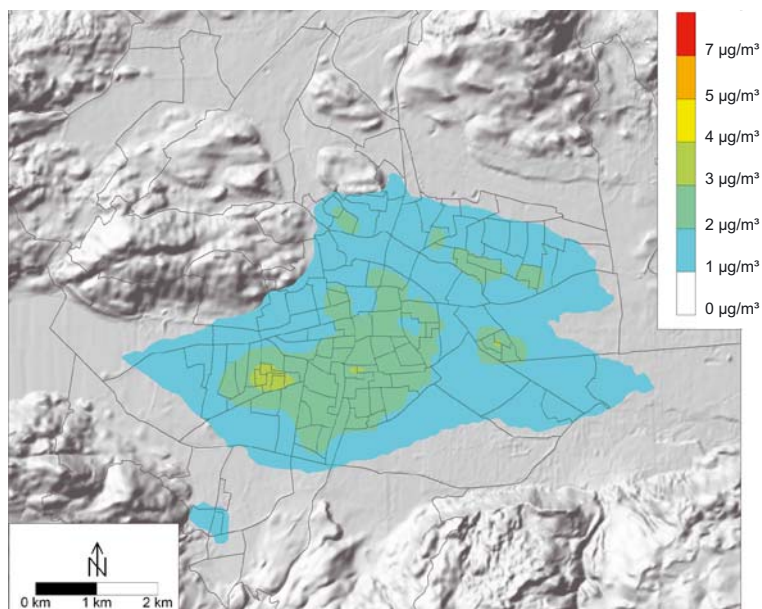


Figure 7: Contribution of 'trade & industry' emissions to the PM10 annual mean concentrations.

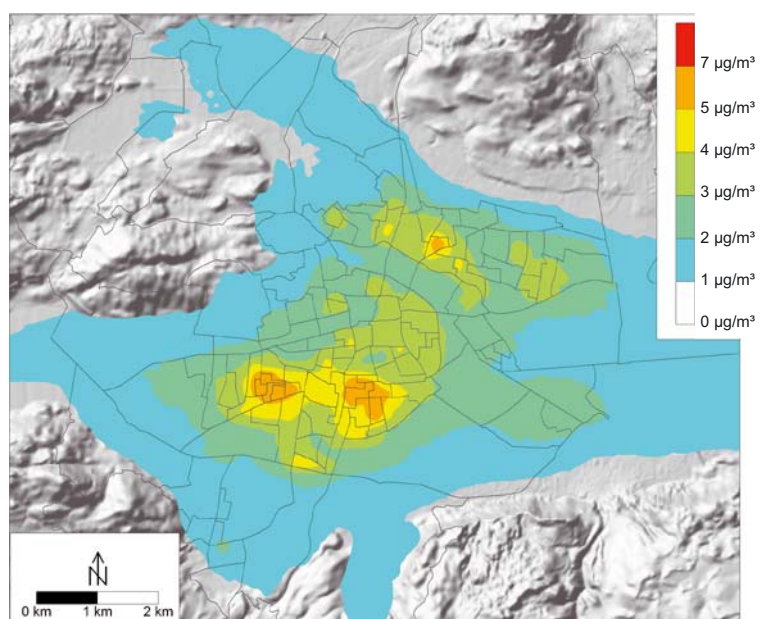


Figure 8: Contribution of 'domestic heating' emissions to the PM10 annual mean concentrations.

Figure 9 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.

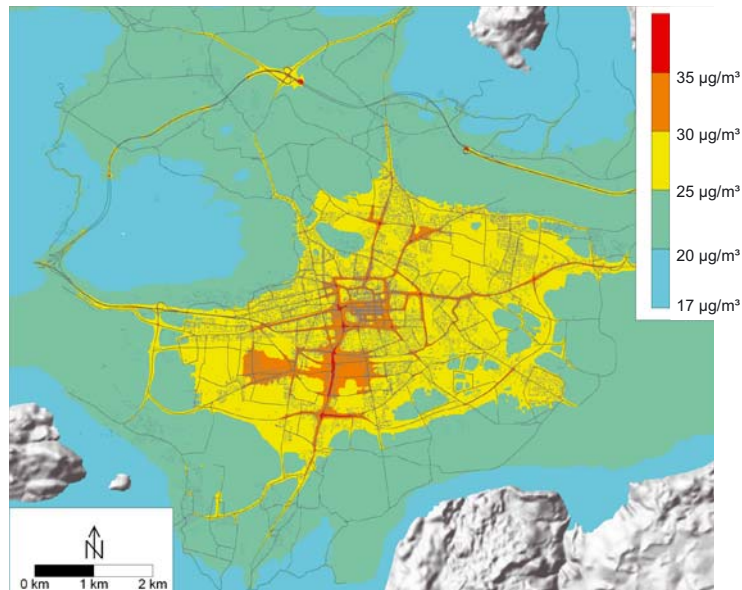


Figure 9: PM10 annual mean concentrations.

Figure 10 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.

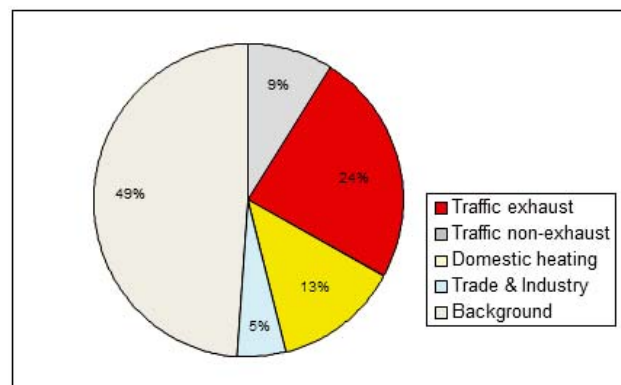


Figure 10: Calculated PM10 winter mean concentrations at the monitoring location 'Völkermarkter Straße', share of the different source types.

3.2. Application to the Lavanttal region

The Lavanttal region is a basin with an extension of some 30 times 20 km (see Figure 11). 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.

Current situation

Besides two big industrial facilities (pulp and paper mill and wood industry) this region is mainly dominated by small enterprises and agricultural activities.



Figure 11: Topographical map of the Lavanttal basin.

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 basis of the available data only emissions from land cultivation (e.g. ploughing, harrowing) were taken into consideration, emissions from life stock were excluded. Figure 12 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 remarkable 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 13 to Figure 16 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 17 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 $17 \mu\text{g}/\text{m}^3$. 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 $50 \mu\text{g}/\text{m}^3$ for the daily mean value. This correlation can be defined according to the following equation.

$$\text{Number of days exceeding } 50 \mu\text{g}/\text{m}^3 = 4 \text{ times annual mean value} - 77$$

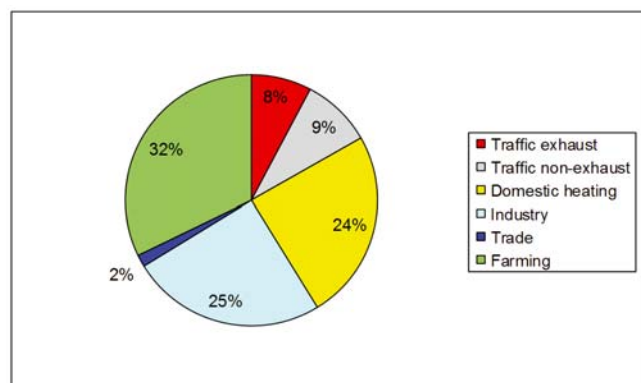


Figure 12: Contribution of the different sources to the PM emissions in the region under consideration.

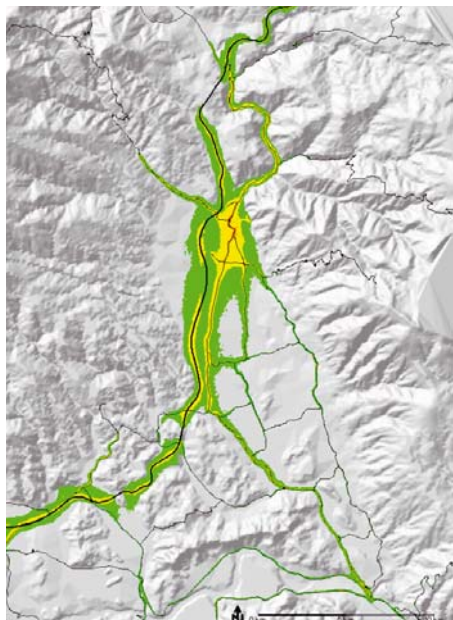


Figure 13: Road traffic related PM10 concentrations.

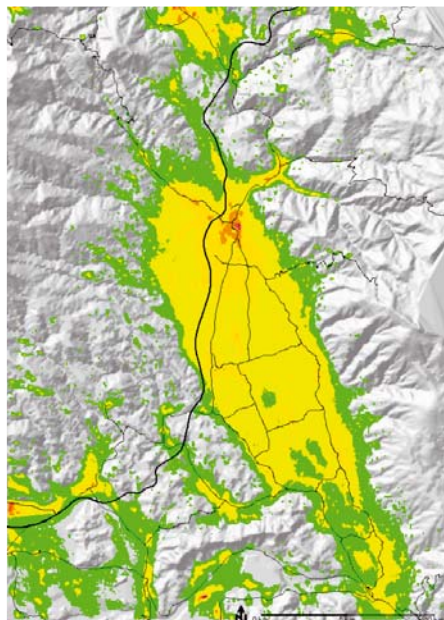


Figure 14: Domestic heating related PM10 concentrations.

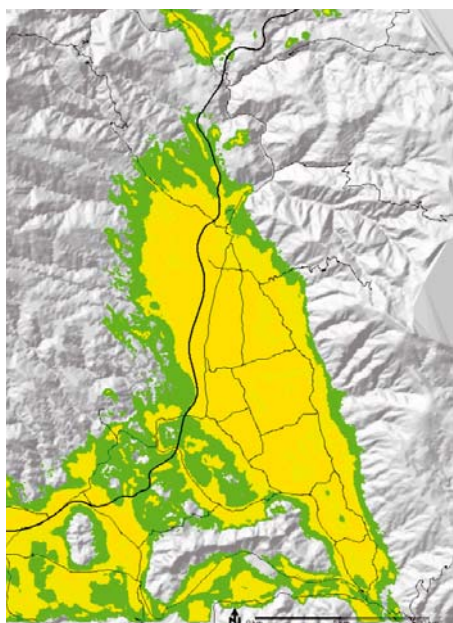


Figure 15: Farming related PM10 concentrations.

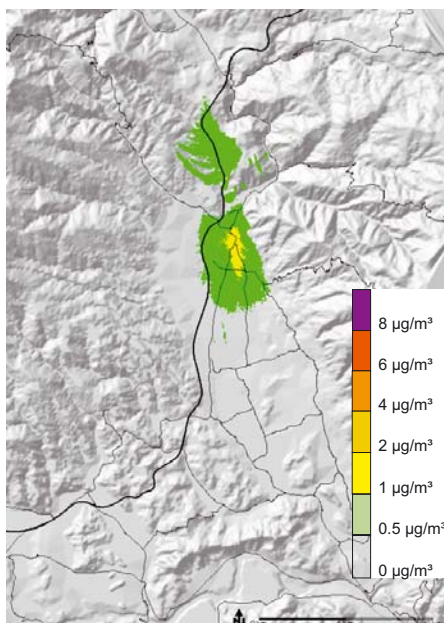


Figure 16: Trade and industry related PM10 concentrations.

The area inside the thick blue line in Figure 17 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.

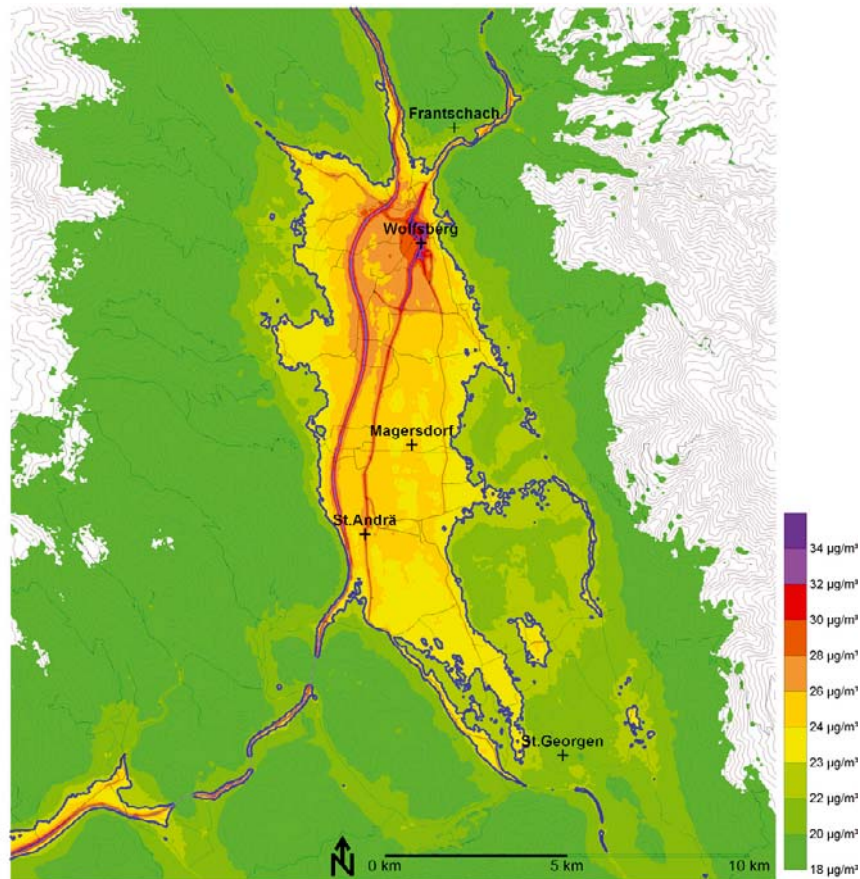


Figure 17: PM10 concentrations, all sources, annual mean.

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.

The combination of emission inventories with dispersion tools allows for a detailed analysis of the causes of PM 10 problems. Moreover the definition and evaluation of PM10 abatement plans is strongly related to such tools.

However, it has to be kept in mind, that the regional background concentrations as well as the formation of secondary aerosols (nitrates and sulphates) play a major role in the PM10 problem. The contribution of both these "fractions" can only be taken into account as background contribution.

The methodology described here has already been applied to many cities and regions of Austria and abroad and is basis for defining and evaluation of abatement plans.

5. References

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