Ingenieurbüro Lohmeyer GmbH & Co. KG

Immissionsschutz, Klima, Aerodynamik, Umweltsoftware

An der Roßweid 3, D-76229 Karlsruhe

Telefon: + 49 (0) 721 / 6 25 10 - 0
Telefax: + 49 (0) 721 / 6 25 10 30
E-Mail: info.ka@lohmeyer.de
URL: www.lohmeyer.de

Büroleiter: Dr.-Ing. Wolfgang Bächlin

Messstelle nach §§ 26, 28 BImSchG

PROKAS©

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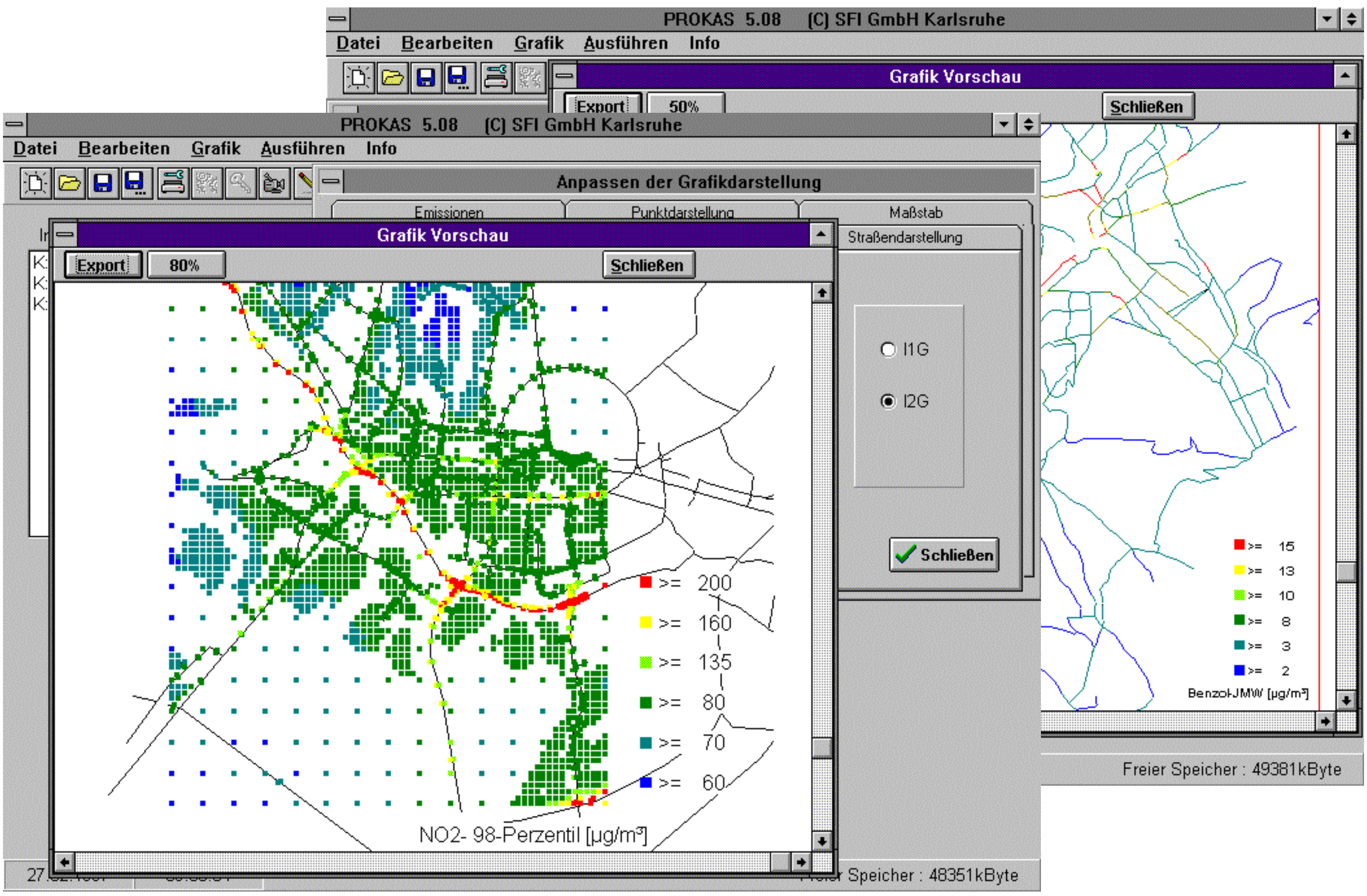
... Calculation method to determine traffic induced pollution levels



Content:

1. INTRODUCTION

The mathematical model PROKAS is designed to calculate the immission of an investigation point. It considers the influence of the surrounding road grid on the point of investigation up to a distance of several kilometers. It consists of the basis module PROKAS_V (Gaussian plume model). Besides this emission model the integrated building module PROKAS_B is used for calculating the immissions of densely developed roads.

2. CALCULATION OF IMMISSIONS WITH PROKAS_V

In the draft of the guideline VDI 3782, Sheet 8 “Ausbreitungsrechnung für Kfz-Emissionen”, PROKAS_V is designated as a dispersion model to analyze the concentration distribution both for calculating the pollution load in areas with or without loose development, and for calculating the background pollution concentration of densely developed areas.

The Gaussian approach within PROKAS_V corresponds to the “Ausbreitungsmodell für Luftreinhaltepläne” guideline VDI 3782 Sheet 1. The air pollutants of the exhaust plumes are moving with a typical transport velocity u_t, which results from a weighted averaging of the vertical wind profile over the concentration distribution in the exhaust plume. Because the vertical concentration profile changes with the distance to the source, u_t also becomes a function of the distance to the source. This assures that the continuity equation for the pollutants is valid for any distance from the road to be analyzed.

For calculations, the total road grid is divided into short line sources and the emission of each line source is distributed to several point sources. The distance between the point sources belonging to one line source is at most 1/10 of the distance of the point source to the investigation point. All together, the road grid is approximated by several 10.000 point sources depending on its density. Sensitivity investigations have proven that the calculation results are not affected by a further shortening of the distances between the point sources. For example, the division into single sources can also incorporate the case that emissions vary along a road, for instance if some parts are subject to speed limits. In this case, the point sources in the limited part will emit with a different intensity than those without limitation.

Thanks to the procedure mentioned above it is assured that each road segment can emit simultaneously, i.e. that the whole road grid always emits. This also allows for a realistic simulation of the conditions close to intersections, where emission points exist, which are polluted simultaneously by several roads at certain wind directions. In these cases, it is not correct to determine the 98-percentile value (concentrations which are not exceeded in 98 % of the time) by calculating the influence of each individual road and combining everything at a later stage.

Also the influence of a sound protection measures of a defined length can be considered in this way. This influence inferred in papers by Romberg et al. (1986) for the Bundesanstalt für Straßenwesen. The influence of the sound protection wall is interpreted as an initial dilution, where a value σ_{zo} is added as an additive term to the vertical dispersion parameter σ_z. The dispersion model is able to consider an individual value of σ_{zo} for each line source. The dispersion parameters σ_y, and σ_z of the guideline VDI 3782 Sheet 1 correspond to those of TA air (1986).

To correctly determine the 98-percentile value, it is important, to consider the traffic density dependent on the time of day. It also depends on the correct determination of the traffic and emission peaks. The model therefore allows the input of 5 different emission levels and their occurrence frequency.

With respect to the meteorology, PROKAS can calculate with 36 different wind direction classes, 9 different wind speed classes, and 6 different dispersion classes. The dispersion classes take into account that the dilution of exhaust gases for a given wind direction and a given wind speed also depends on the stability of the atmosphere. For instance, the dilution is lower for an “inversion” situation than for sunny, “normal” weather conditions. Altogether 36 x 9 x 6 = 1.944 weather conditions with the corresponding frequencies are considered.

Therefore for each investigation point, the calculated result consists of 1.944 weather conditions x 5 emission levels = 9.720 different concentration values along with the corresponding frequencies. This data shows how often the 9.720 concentration values occur per year. A frequency distribution is retrieved from this data. This distribution allows for the 98-percentile value to be determined. This is the 98-percentile value of the additional pollution concentration which we were looking for.

The immission parameters for the total pollution concentration are determined from the parameters of the background pollution concentration and the additional pollution concentration (due to the traffic emissions on the particular roads) according to the procedure given in the TA Luft (1986) Annex D.

The geometry of the road grid and the investigation points are digitalized or taken over from traffic pattern models, sound calculation programs, or databases. To control the correct input, the software produces a scaled graph with the road grid and the position of the investigation points, as well as a list with the distances (as calculated by the software) of the points to the line sources, and, in addition, the source strengths, the number of point sources and the length of each line source.

The results of the immission calculations (average yearly values and 98-percentile values of NO_2, and the average yearly values of two inert pollutants, e.g. benzene, soot, or PM10) are saved in a file for each investigation point in the form of a table. They can be graphically displayed either in the form of numerical values at the corresponding investigation points, or by colored symbols, with the color set according to the concentration.

3. CALCULATION OF IMMISIONS IN DENSELY DEVELOPED ROADS WITH PROKAS_B

Immissions cannot be calculated by PROKAS_V in the case of partially or completely closed developments (for instance a street canyons). The supplementary building module PROKAS_B is used instead. It is based on model calculations with the microscale dispersion model MISKAM of all typical types of development. The nondimensional exhaust gas concentration c* was determined for 20 different types of development and 36 flow directions in 1.5 m height and 1 m distance to the next building, respectively.

The different development types are street canyons with one- or two-sided development with a varying relation of the building height to the street canyon width and a varying percentage of gaps in the development. Gap density refers to the percentage of non-developed areas along the road with (one- or both-sided) developments. The width of the street canyons is defined as the double of the distance from the middle of the road to the development closest to the road. Tab. 3.1 describes the classification of the various types of developments. Road crossings are not considered due to insights from measurements (Kutzner et al., 1995) and model simulations. According to these studies, 10 % to 30 % lesser concentrations can be observed at crossings than at the neighboring street canyons.

The exhaust gas concentrations c are calculated via the nondimensional concentrations

$$c = \frac{c^* \cdot Q}{B \cdot u'}$$

whereby:

c = exhaust-gas concentration [µg/m³]

c* = nondimensional exhaust-gas concentration [-]

Q = emitted pollution source strength [µg/(m s)]

B = width of street canyons [m] alternatively the double distance from the middle of the road to the development

u' = wind speed in respect to traffic induced turbulences [m/s]

The contribution to the concentrations of PROKAS_V for the background pollution concentration and of PROKAS_B are combined for all individual situations, i.e. correlated by time.

Tab. 3.1: Types of road developments considered by PROKAS_B

Type	Development	Building height/ street canyon width	Percentage of gaps [%]
0*	loose	-	61 - 100
101	one-sided	1:3	0 - 20
102	"	1:3	21 - 60
103	"	1:2	0 - 20
104	"	1:2	21 - 60
105	"	1:1.5	0 - 20
106	"	1:1.5	21 - 60
107	"	1:1	0 - 20
108	"	1:1	21 - 60
109	"	1.5:1	0 - 20
110	"	1.5:1	21 - 60
201	both-sided	1:3	0 - 20
202	"	1:3	21 - 60
203	"	1:2	0 - 20
204	"	1:2	21 - 60
205	"	1:1.5	0 - 20
206	"	1:1.5	21 - 60
207	"	1:1	0 - 20
208	"	1:1	21 - 60
209	"	1.5:1	0 - 20
210	"	1.5:1	21 - 60

4. NITROGEN OXIDE CONVERSION

Vehicles mainly produce NO as nitrogen oxides and only a small portion of NO_2

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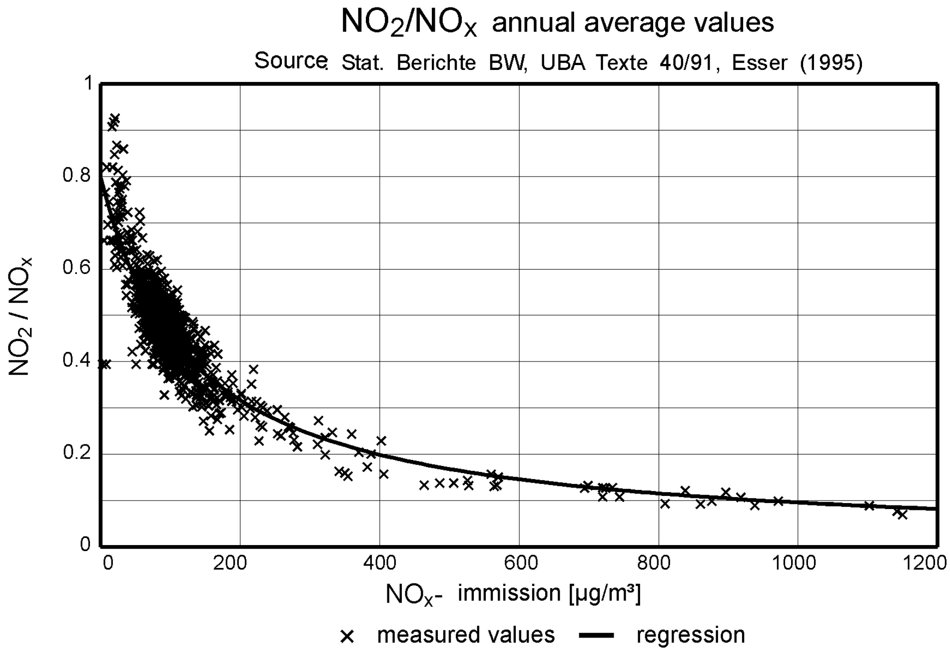

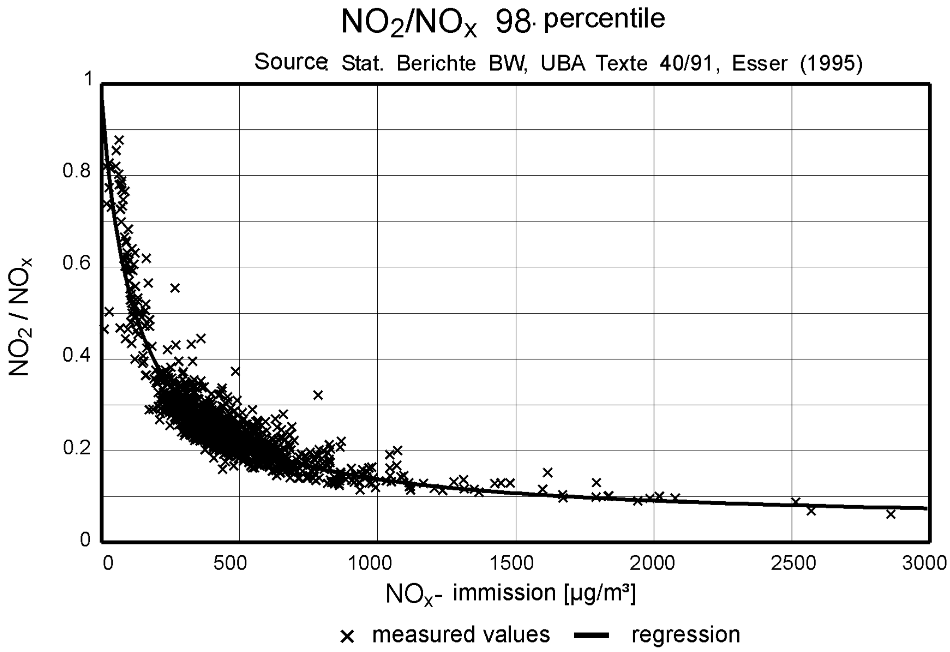

Fig.1: NO2/NOx-proportion (conversion rate) depending on the NOx-immission for annual average and 98-percentile

NO is converted to NO_2 on its dispersion path. The conversion rate is concentration dependent. With an increasing distance to the road, proportionally more and more NO is converted to NO_2.

The nitrogen oxide conversion is dealt with accord to the draft of the guideline VDI 3782 Sheet 8. This procedure is briefly explained in the following passage.

The conversion rate is parameterized through a ratio of NO_2/NO_x by a high number of measurements of the nitrogen oxides NO and NO_2 at measurement stations in Germany (Romberg et al., 1996, see Fig. 1). NO_x is the sum of NO and NO_2, identified as NO_2, which means each mol (also of NO) is calculated with a mass of 46 g. Among the measurement stations, some heavily influenced by traffic, as for instance Frankfurt City or Cologne-Neumarkt, some are in remote areas, as for instance Villingen-Schwenningen in the Black Forest. The measurement values are published by the Umweltbundesamt in Berlin (UBA, 1991), the Statistische Landesamt Baden-Württemberg in Stuttgart (Statistische Berichte BW, 1985 until 1991), the Landesanstalt für Immissionsschutz, Nordrhein-Westfalen (LIS, 1985 until 1991), and the Bundesanstalt für Straßenwesen (Esser, 1992 and 1993). All are yearly values for the years 1985 through 1989, or 1990.

With the help of this parameterization, the average yearly immission of NO_2 and the 98-percentile value for NO_2 immission is known for each NO_x immission. The NO_x immission is obtained at the investigation points according to the previously described method. The correlation between NO_2 and the NO_x total pollution concentration is obtained via a regression curve of the conversion rate NO_2/NO_x. (Fig. 1). The most likely value of the NO_2 total pollution concentration is obtained via this regression curve.

5. COMPARISON OF THE MODEL RESULTS WITH MEASUREMENTS (VALIDATION)

To compare the calculation values with measurement values the following datasets were used:

- Measurements of the Bundesanstalt für Straßenwesen (BASt) at the A 4 at Bergisch Gladbach (Esser, 1995)

- Measurements of the UMEG, Karlsruhe, in the context of the permanent measuring stations of the Land Baden-Württemberg in Karlsruhe and Stuttgart (UMEG, 1995a and 1995b)
- Sample measurements of the Landesamt für Umwelt und Geologie Sachsen, of the UMEG, and of the Amt für Umweltschutz der Stadt Dresden in Dresden (1994/95).

The measuring stations were situated in loosely developed as well as in densely developed areas. The total pollution of loosely developed areas was calculated with PROKAS_V, the background pollution concentration from the surrounding road grid in densely developed areas using PROKAS_V with additional pollution calculations coming from PROKAS_B.

The comparison is displayed in Fig. 2 and Fig. 3. In total, a satisfying conformity is observable between measurements and calculations. The comparison of the datasets indicates the expected deviations in Tab 5.1.

Tab. 5.1: Relative deviation of the calculated results with PROKAS_V (in street canyons with background pollution with PROKAS_V and additional pollution with PROKAS_B) in comparison to measured values at the investigation points in Karlsruhe, Stuttgart, and Dresden, and at the A 4. See also Fig. 2 and Fig. 3.

Statistical parameter	Relative deviation
NO_2-yearly average	- 20 % to + 20 %
NO_2-98-percentile value	- 20 % to + 50 %
Benzene yearly average	- 20 % to + 20 %
Soot yearly average	- 40 % to + 10 %

The deviations between the measured and calculated values do not only result from the modeling of the pollution dispersion, but also from uncertainties in the used input data, which are not based on ideal but on real natural conditions. That means, that parameters such as exact traffic numbers, weekly vehicles loads, meteorology, and so on, are mostly not exactly known. In addition it has to be questioned in which time span and with which frequency the single measurements were combined to yield statistical parameters.

For instance, the measured NO_2 98-percentile values in Dresden are generally higher than the calculated ones (Fig. 2). One reason is surely the sample character of this measurement, which results in more uncertainties in this dataset than in other datasets. Without these sample measurements, the deviations for the NO_2 98-percentile value is closer to $\pm$ 20 % for the investigated cases.

Higher relative deviations are also noticeable for soot. The reason for this is on one hand, that the comparison measurement vs. calculation was performed only in 4 cases. On the other hand, there are uncertainties in the soot emission determination as well as in the soot immission measurement. Because benzene and soot both disperse equally as inert, non-sedimenting air pollutants (soot particle diameter < 10 µm), the dispersion calculation of benzene and soot are of the same quality. Differences in the calculation results are therefore not based on the dispersion calculation, but are due to uncertainties in the emission determination, in the immission measurement technology, and in the determination of the background pollution concentrations due to explicitly not considered sources.

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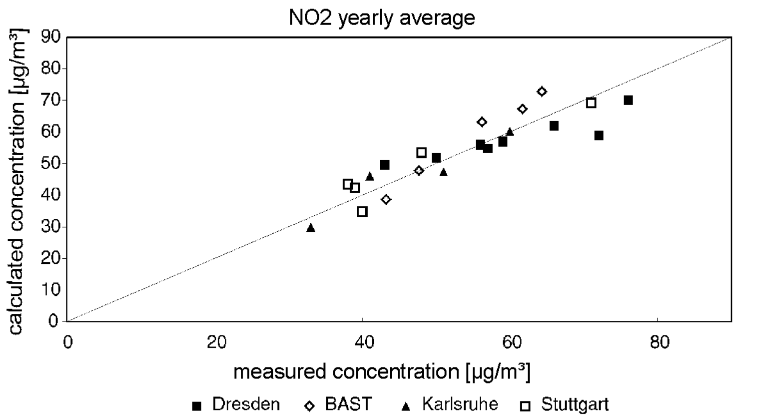

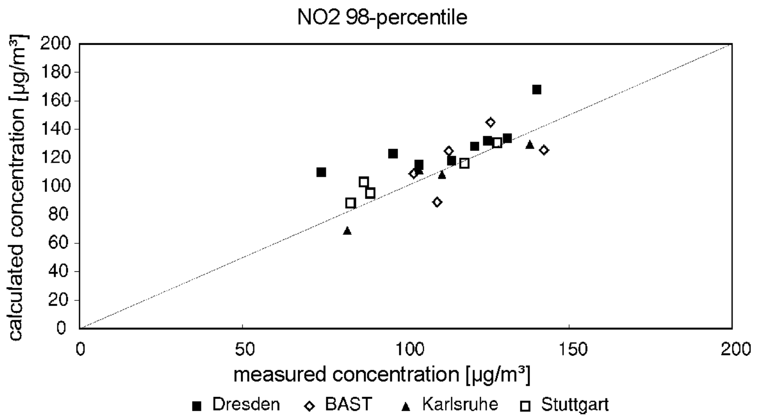

Fig. 3: Comparison of calculated (PROKAS with developed roads, based on MISKAM calculations for typical types of development) NO2 concentrations with measurements in Stuttgart, Dresden, and at the A 4

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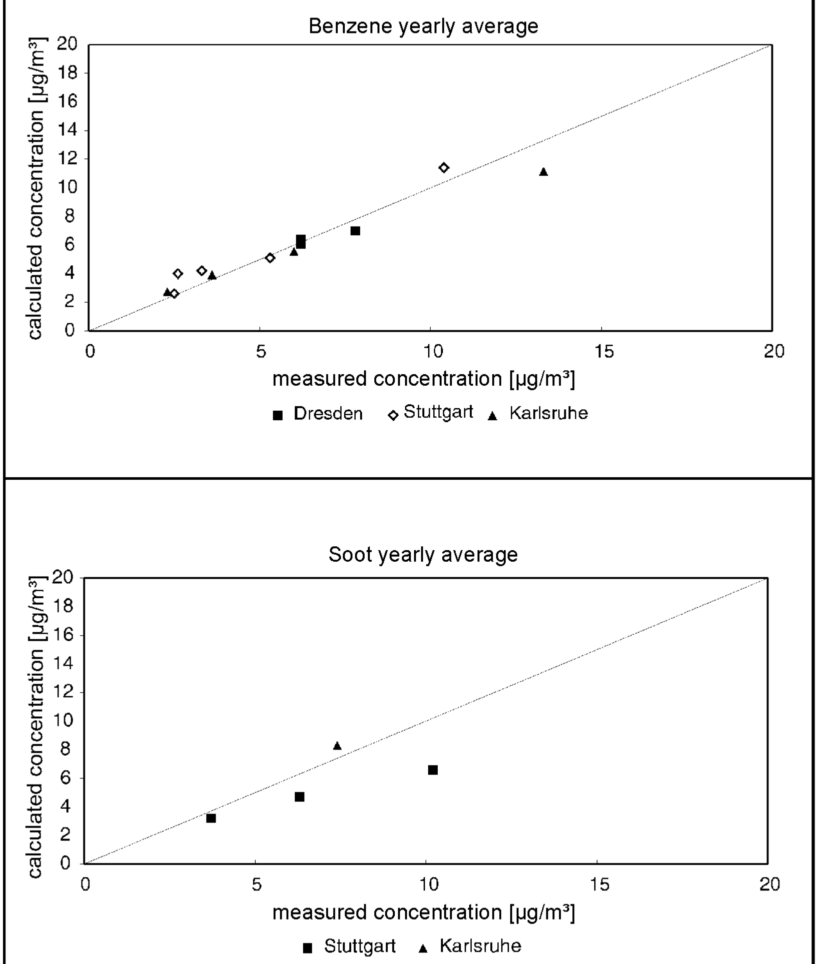

Fig. 4: Comparison of calculated (PROKAS with developed roads, based on MISKAM calculations for typical types of development) benzene and soot concentrations with measurements in Stuttgart, Dresden, and at the A 4

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