PM_{10} and PM2.5 concentrations in Europe as assessed from monitoring data reported to AirBase

ETC/ACC contribution to the TFMM PM assessment report

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Steinar Larssen, NILU and Frank de Leeuw, MNP

1. PM_{10} concentrations in Europe, 1997-2005

The number of stations reporting PM_{10} data to AirBase has increased steadily for many years. 1997 was the first year with a fairly substantial number of stations reporting PM_{10} to AirBase, about 200 stations. In 2005, PM_{10} was reported from more than 2200 stations in 32 countries (Table 1). 1880 of these stations had a data coverage higher than 70% of the year. There were 235 stations in rural areas and 969 urban/suburban background stations. Of hot spot stations, there were 673 traffic stations (16 in rural areas) and 353 industrial stations (93 in rural areas). The rest of the stations were not properly classified.

In the following, summaries and overviews are presented of the PM_{10} data in AirBase. These overviews represent 2003, 2004 or 2005, as well as developments since 1997. 2003 and 2004 overviews taken from the Air Quality in Europe 1997-2004 report (EEA, 2007), while some 2005 overviews have been produced for this present contribution.

PM measured by automatic methods typically have to be corrected to give data corresponding to measurements with the reference method. This is to be doen using a correction factor, which is to be determined by comparison studies in each country. Chapter 3 gives an overview of the practices in the various countries to determine the CFs, and which CFs the countries as using. Many countries have station-specific CFs, and for some few stations even season-specific CFs are used. It is not completely clarified yet, however, how the CFs are implemented in the data that are contained in AirBase.

1.1 PM_{10} overview, 2004

Country-wise annual average PM_{10} concentrations measured at stations in 2004, reported to AirBase, are shown in Figure 1. There are separate bars for three types of stations: rural background, urban/suburban background, and street stations. The countries are placed in a sequence from North/West in Europe (Iceland, Norway, etc.), sweeping through the central and towards the South/East parts of Europe, and then towards the South/West ending up with Spain and Portugal. The Figure thus indicates the areas of Europe with higher/lower PM_{10} concentrations. The Figure shows elevated/high rural/urban levels in BeNeLux and East/South-East areas (from Poland and Czech republic and towards FYROM, Greece and Cyprus, and to a lesser extent in Mediterranean countries. Concentrations at street stations can be high in all countries.

Figure 2, representing 2004 data, shows number of stations and average PM_{10} concentration for three categories of stations (rural background, urban/suburban background and urban/suburban traffic/street), annual average and 36th highest day, according to three criteria: all stations, the stations which are above the limit value, and the station with highest concentration.

The PM_{10} concentrations in Europe in 2004, averaged over all stations of a certain category, were (number of stations with data in brackets):

- annual average:	at rural stations:	20.2 $\mu g/m^3$	(180)
	at urban background:	26.0 $\mu g/m^3$	(742)
	at street stations:	31.2 $\mu g/m^3$	(477)
- 36th highest day:	at rural stations:	34.4 $\mu g/m^3$	(176)
	at urban background:	43.3 $\mu g/m^3$	(717)
	at street stations:	51.4 $\mu g/m^3$	(459)

These numbers, as well as the visualisation in Figures 1 and 2, show clearly that the rural concentration level gives a large contribution to the concentration levels at urban locations, and even to the concentrations at street level stations.

The limit value for annual average was exceeded at 6, 69 and 81 rural, urban and street stations respectively. The short term limit value (represented by the 35th highest daily value) was exceeded at 17, 191 and 224 rural, urban and street stations respectively. The highest measured concentrations were up to and more than double the limit values.
Concentrations were higher and extent of exceedances was larger in 2003.

Concentrations at the industrial stations did not deviate much from the typical urban/traffic hot spot concentrations: they averaged 46.6 $\mu g/m^3$ (36th highest day), with a maximum station at 129 $\mu g/m^3$.

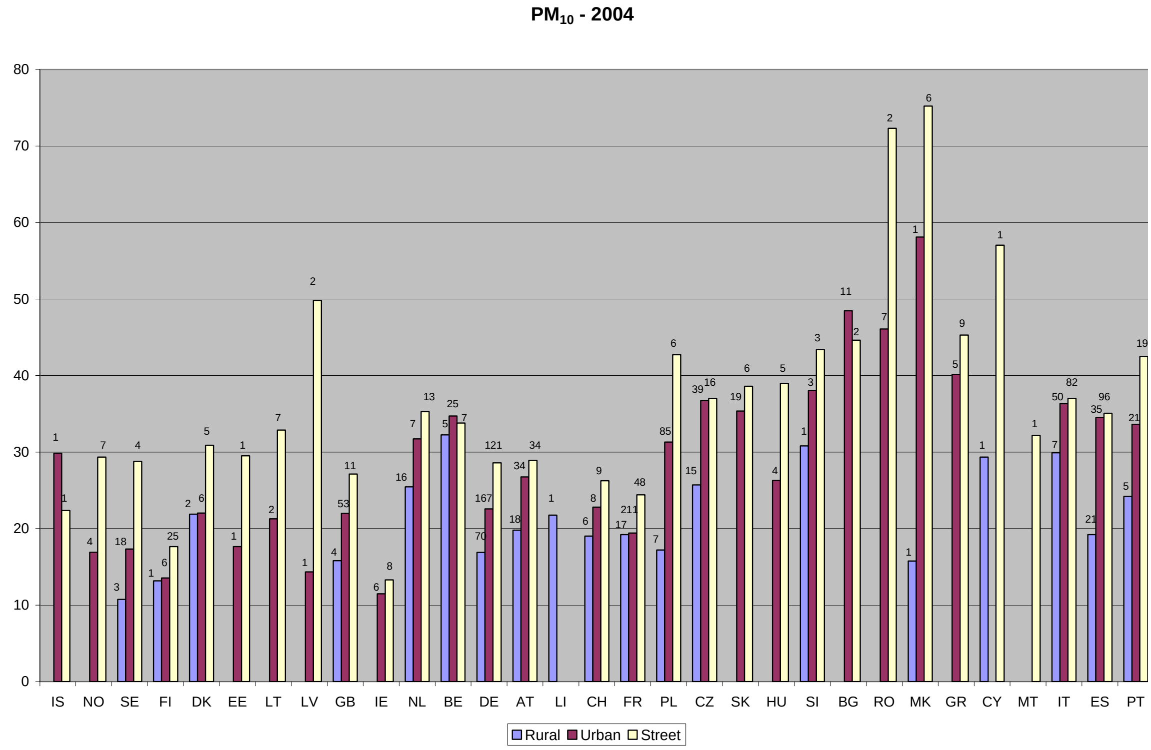


Figure 1: *Overview of PM_{10} data in AirBase, 2004: country-wise annual averages per station type. Number of stations on top of bars.*

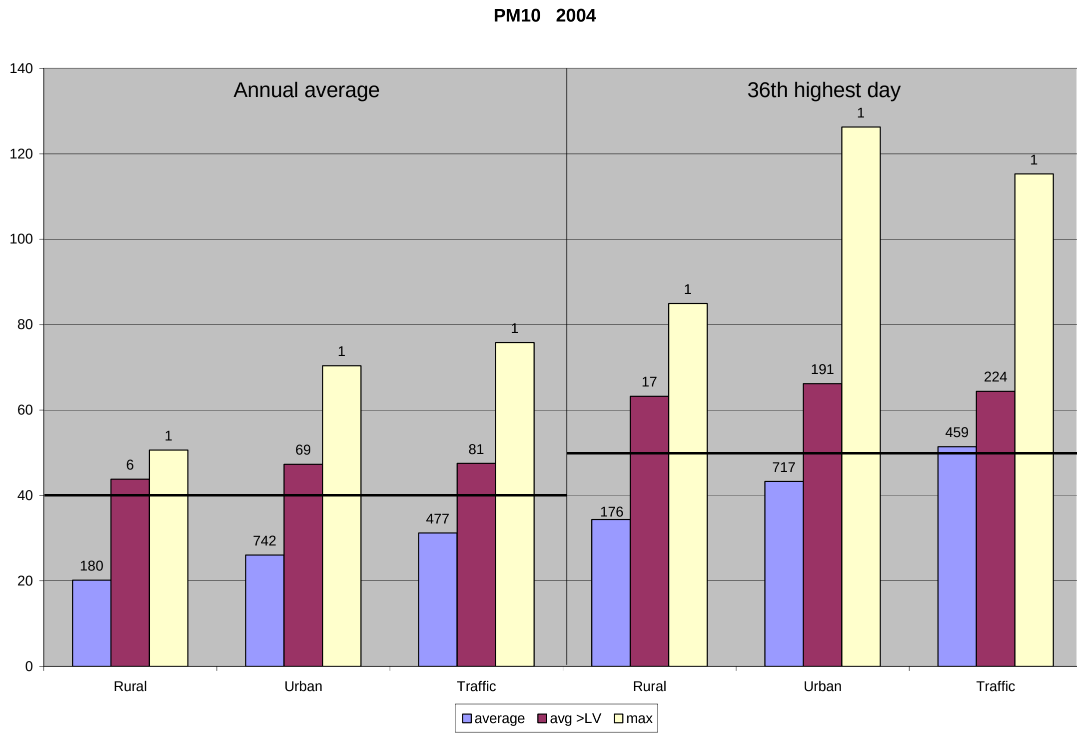


Figure 2: *Overview of PM_{10} data in AirBase, 2004: average concentrations, average at stations exceeding Limit Values, maximum concentrations, and number of stations in each category.*

1.2 Mapping of PM_{10} across Europe, 2003 and 2004

Figures 3-4 show assimilated maps of PM_{10} concentrations across Europe, where EMEP model results have been combined with data from the monitoring stations in rural and urban background areas, as well as with other parameters (ETC/ACC, 2005). Results are shown both for 2003 and 2004, indicating the situation in a year with high concentrations (2003) and with typical-to-low concentrations (2004) (see sections 1.4 and 1.5). Figure 3 shows annual average, and Figure 4 shows the 36^{th} highest daily value in a year.

Rural areas
As also indicated in Figure 1, rural PM_{10} concentrations are generally higher in some central, eastern and southern areas of Europe than in western parts of Europe. Spain and Portugal might experience elevated PM due to dry conditions and influence from Saharan dust, while BeNeLux and East England are possibly affected by transport from central Europe in addition to from local sources.

The PM_{10} limit value for annual average, 40 $\mu g/m^3$, is exceeded in various larger and small areas across Europe (Figure 3). The most pronounced of these areas are Silesia, North Bohemia, the Milan-Po Valley area and the southern tip of Spain. For 2005, the measurements gave that 5 rural stations in the Czech Republic, Italy and Spain had annual average above the limit value (Figure 6), and 15 stations were above 35 $\mu g/m^3$.

The PM_{10} short term limit value (max 35 days above 50 $\mu g/m^3$) is exceeded in rural areas to a larger extent that for the annual average (Figure 3 and 4). In 2003, with the high pollution levels, large areas in BeNeLux, northern Italy and eastern Europe as well as in Portugal were above this limit value. The same areas, although less extended, had high levels also in 2004. The southern tip of Spain had exceedances in 2004, presumably due to Saharan influence (?).

Urban background
Figures 3 and 4 show that the PM_{10} concentration is high at urban background locations in many cities across Europe. The 2004 summary in Figures 1 and 2 shows that exceedances of the annual average limit value were measured at 69 urban stations, and at 191 urban stations for the short-term limit value.

The highest urban background concentrations were measured in cities in central, eastern and southern countries (such in Bulgaria, Romania, Poland, Italy, Czech Republic, Slovakia, see Figure 7).

Traffic hot-spots
Figure 5 shows that concentrations at urban street stations are exceeding the PM_{10} short term limit value extensively in cities across all of Europe. The figure shows the situation in 2004. The annual average limit value was exceeded at 81 street stations,

and the short term limit value at 224 street stations (Figure 2), with the highest concentration measured about 2 the double of the limit values. Concentrations were even higher in 2003 (as indicated by Figure 9).

Similar to urban concentrations, the highest traffic related concentrations were measured in cities in central, eastern and southern countries (Macedonia, Poland, Italy, Spain, Romania, Czech Republic, Greece, see Figure 8). Sometimes special conditions are responsible for exceedances, such as suspended dust in Spain and studded winter tyres in Scandinavia.

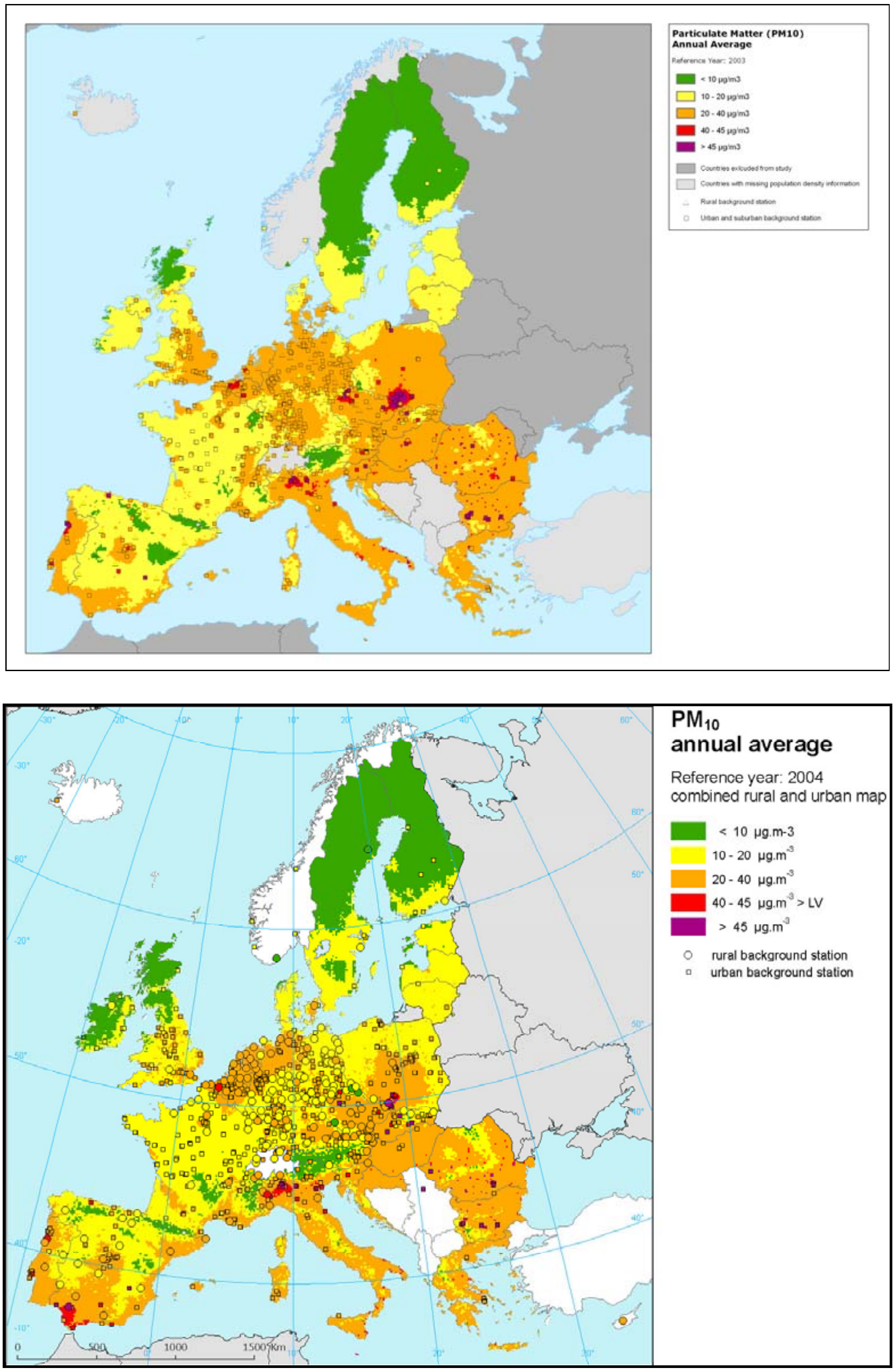
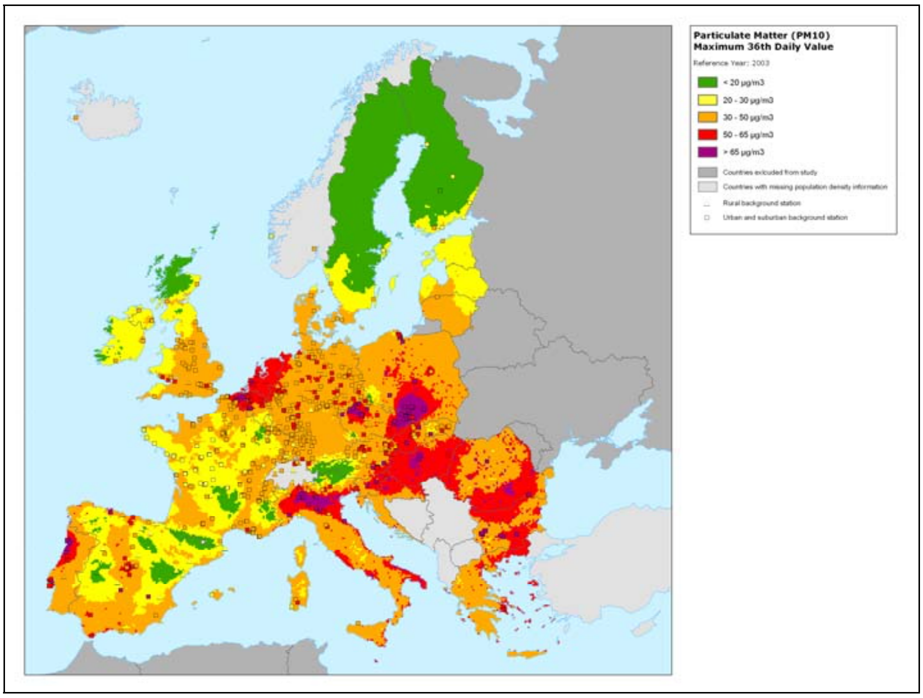


Figure 3: *Annual average PM_{10} concentrations in Europe 2003 and 2004, Figures constructed from combining measurements and model calculations. (ETC/ACC, 2005)*



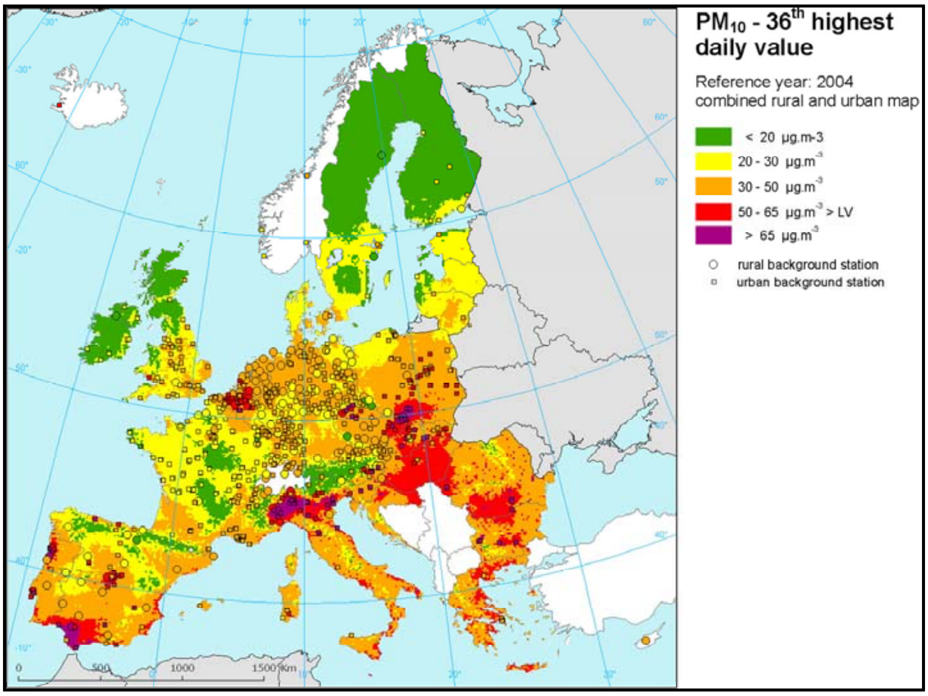


Figure 4: *PM_{10} concentrations in Europe 2004 and 2003, showing the 36th highest daily value. Figures constructed from combining measurements and model calculations. (ETC/ACC, 2005).*

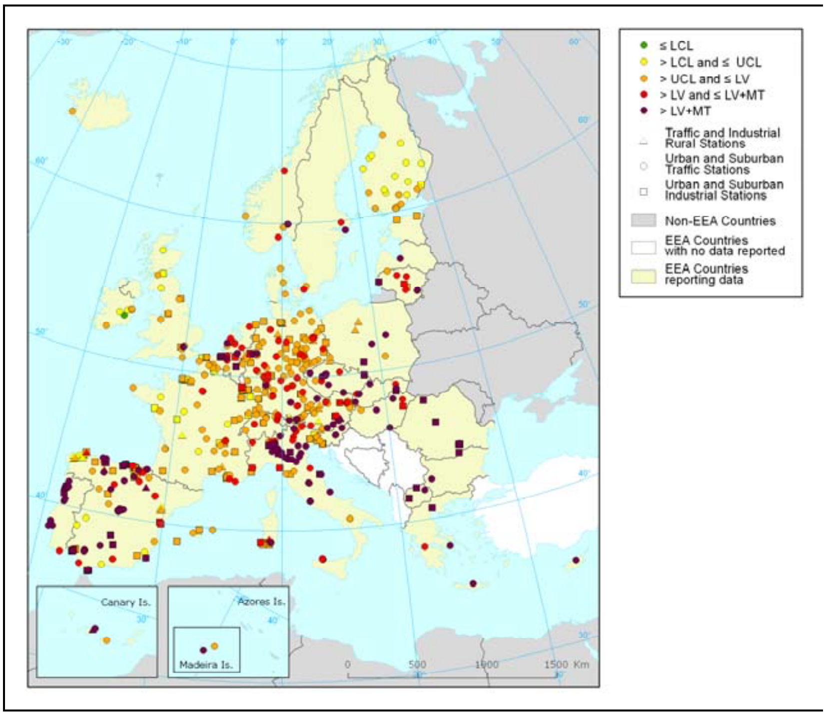


Figure 5: *PM_{10} concentrations at hot-spot stations, 2004*
36th highest daily value (EEA, 2007).

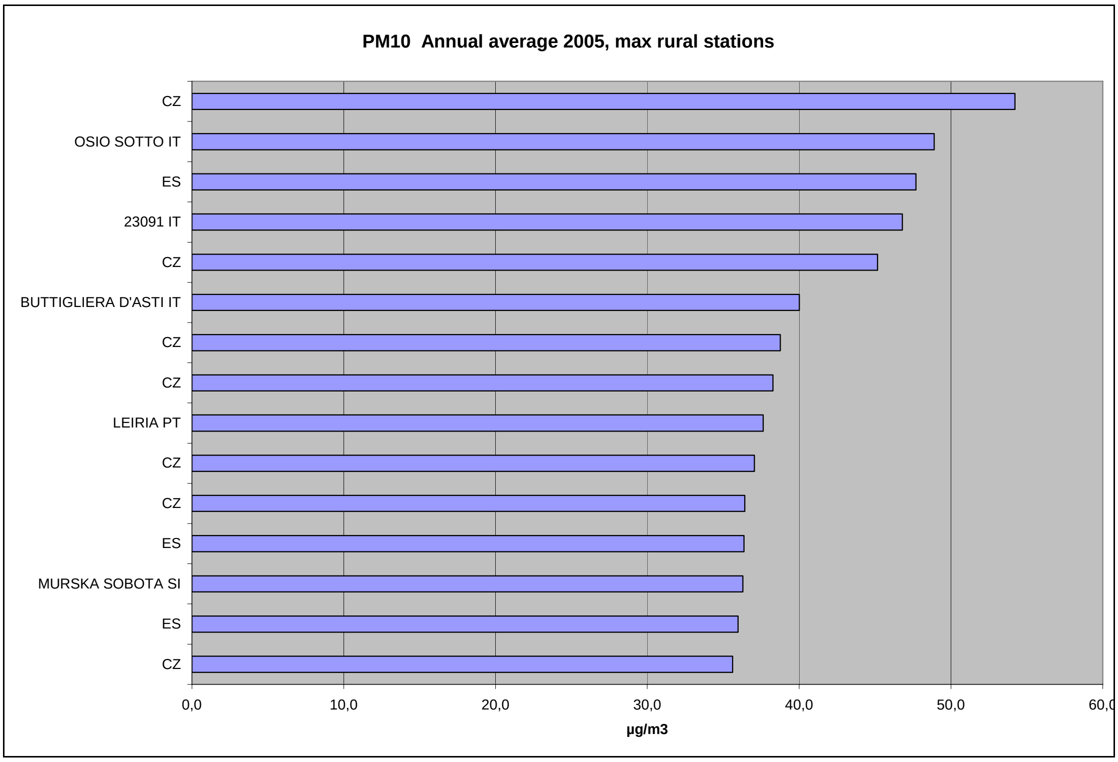


Figure 6: *PM_{10} annual average concentrations, 2005. Rural stations with the highest concentrations measured, reported to AirBase*

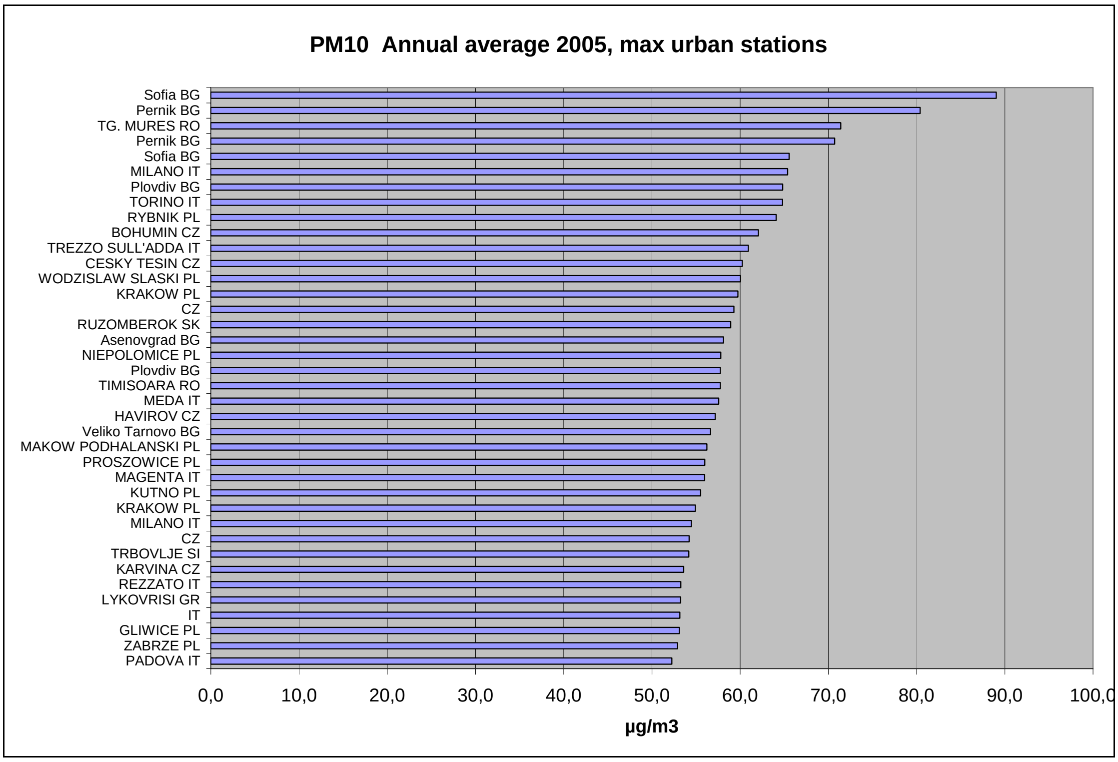


Figure 7: *PM_{10} annual average concentrations, 2005. Urban/suburban background stations with the highest concentrations measured, reported to AirBase*

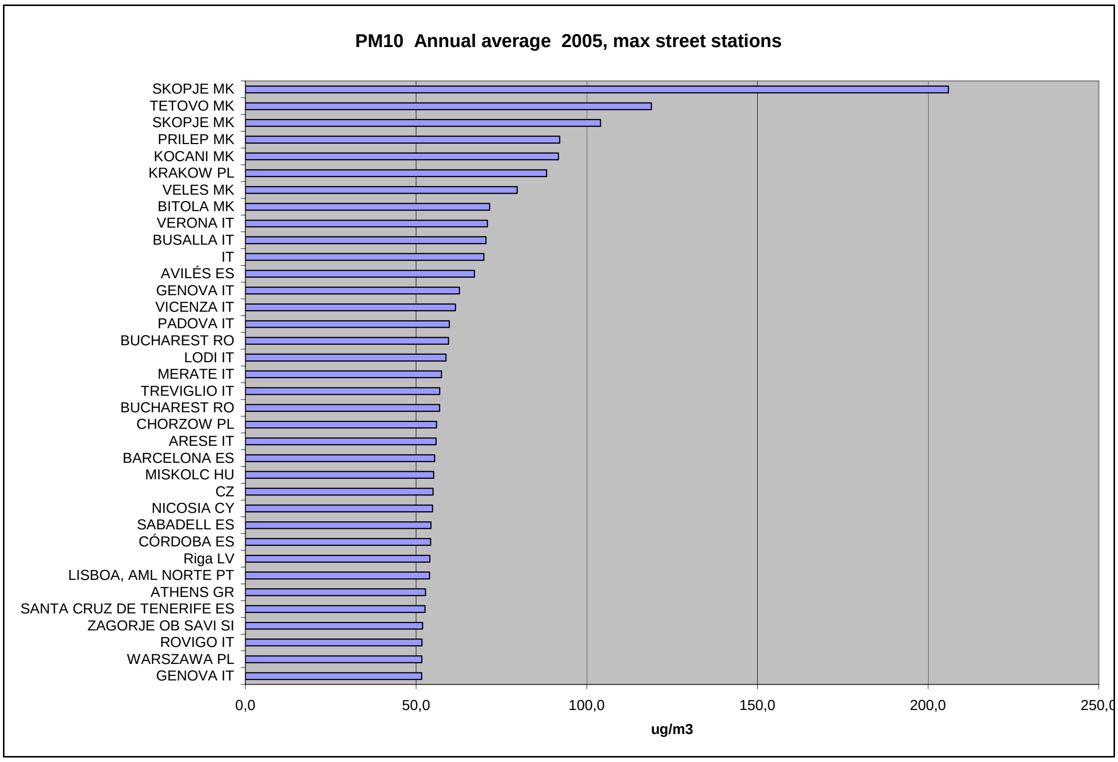


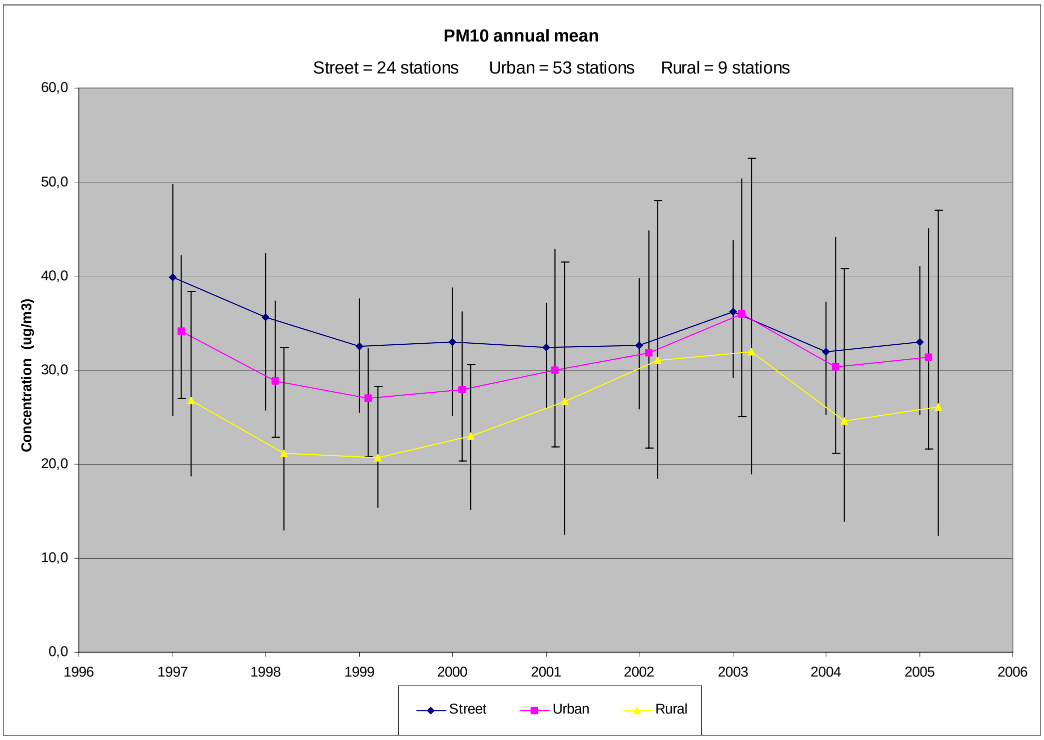
Figure 8: *PM_{10} annual average concentrations, 2005. Street stations with the highest concentrations measured, reported to AirBase*

1.3 Changes 1997-2005

Europe-wide developments

Figure 9 shows the tendencies in annual average PM_{10}, for 1997-2005 based upon a total of 86 stations in 8 countries with data for all years. There are separate lines for rural background, urban/suburban background and street stations. Figure 9 also shows the same for the period 2001-2005, based upon a much larger data set (528 stations in 19 countries). It should be noted that the stations of the different types do not necessarily represent the same areas (e.g. the rural stations are not necessarily in the same areas as the urban stations, and similar, the street stations are not necessarily or generally in cities where there are also urban background stations, although this is the case for many of the cities). Thus, the differences in concentrations in rural, urban and street locations shown in the figures are not fully representative of the ‘true’ difference between such locations in Europe.

The long time series, which is based upon a rather limited data set, does not show an overall tendency upwards or downwards since 1997. It has been shown that the development during the period 1997-2004 can largely be explained by inter-annual meteorological variability (see section 1.6). The shorter time series (2001-2005) based upon a much larger data set show similar variability as the shorter series, although less pronounced. Urban and rural background concentrations trends follow each other closely, the rural background concentration providing the dominating contribution to total urban background PM_{10}, and about 2/3 of the PM_{10} measured at street stations. The urban increment above the rural background, given by the total 2001-2005 data set is about 6 $\mu g/m^3$, and the street increment over the urban background is about 5 $\mu g/m^3$.



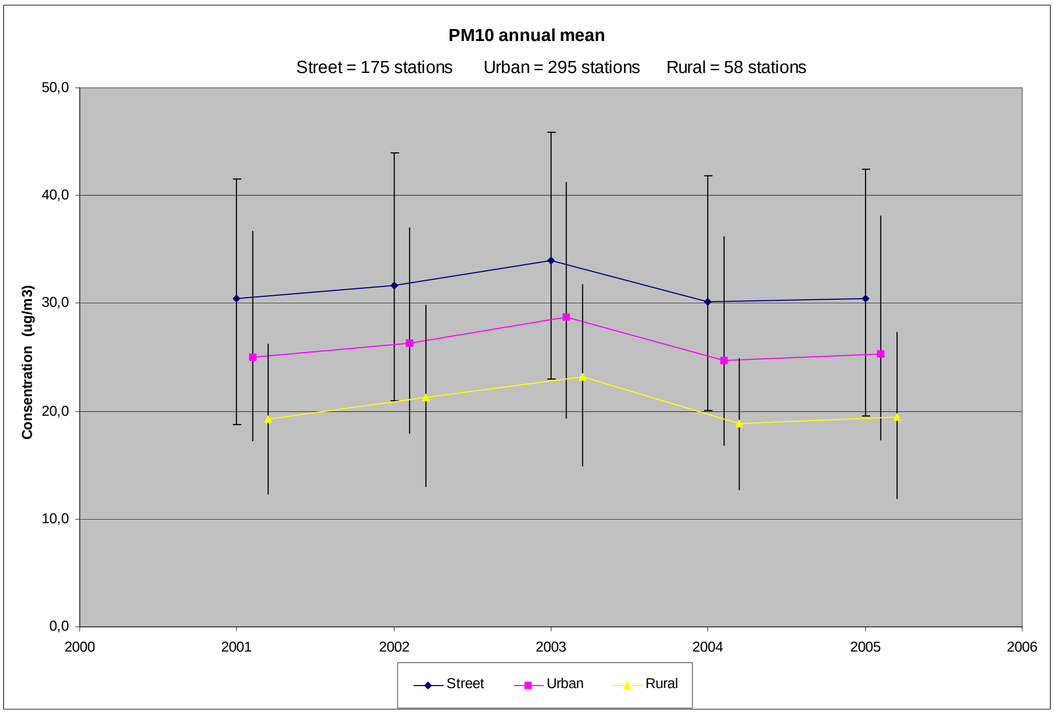


Figure 9: *PM_{10}, inter-annual variations, 1997–2005 and 2001-2005, annual average (µg/m^3). Vertical bars: 10th and 90th percentiles.*

1.4 Differences between countries, and tendencies in specific cities

Whilst the general background concentrations of PM as observed at rural background stations dominate developments, Figure 10 shows that its contribution does vary between countries, both in absolute and relative terms. Figure 10 shows the PM_{10} development in selected cities with long monitoring series.

In some areas, e.g. the Netherlands (as seen already in Figure 3), the existing rural background is very high, and the urban areas increase the concentrations only very little; in the Czech Republic the lower rural background there makes up about 75% of the urban concentration; and in the UK the lower rural background (as shown in Figure 3, although represented by only one station in Figure 9) contributes 'only' 50-60% of the total concentrations in urban areas. Street level contributions to total PM_{10} are limited on the average, but in streets with high traffic intensity the street contribution is more substantial. The street contribution to PM_{10} levels are due to both exhaust particles, abrasion particles from brake linings and tyres, as well as suspended street dust particles.

Factors behind these differences include the extent and scale of long-range atmospheric transport of PM_{10} to a country (dependent upon location and neighbour country emissions), importance of natural sources (e.g. sea salt, desert dust), size of cities/agglomerations, distance to neighbouring large cities as well as density of traffic in the area, main PM sources in the urban area in addition to road traffic (e.g. domestic heating), national PM control, and the creation of 'secondary' PM within a country by chemical reactions between gaseous pollutant emissions.

The ensemble of PM_{10} data in AirBase indicate two separate tendencies since 1999-2000:

- Increasing rural concentrations in central-Eastern areas (extending to Sweden, with an indication of additional increase in urban contributions). For instance, the Czech Republic has had a very substantial increase in background rural PM_{10} since 1999, a large urban contribution, and indications of an increase in that urban contribution. Upward tendencies are also seen in Germany, Switzerland, Poland, and Sweden.

- Decreasing or unchanging rural concentrations in the west to north-west (France, Belgium, Netherlands, UK); except an increase in all areas from 2002 to 2003. Urban contributions are very varied but have also been rather constant. Whilst urban and street contributions in the Netherlands are very small, in the UK the urban contribution is larger. Concentrations in Belgium and France with smaller station numbers are also flat with elevated 2002-3.

- The tendencies in most of the cities with long time series data do not deviate the overall European picture: decreasing concentrations towards 2000 and increasing thereafter with a drop in 2004 (Figure 10).

Station numbers elsewhere in Europe are too small, and time series too short for clear conclusions. Slight decreases in Spain and Slovakia are indicated, although limited data quantity makes its spatial representativeness and quality difficult to establish.

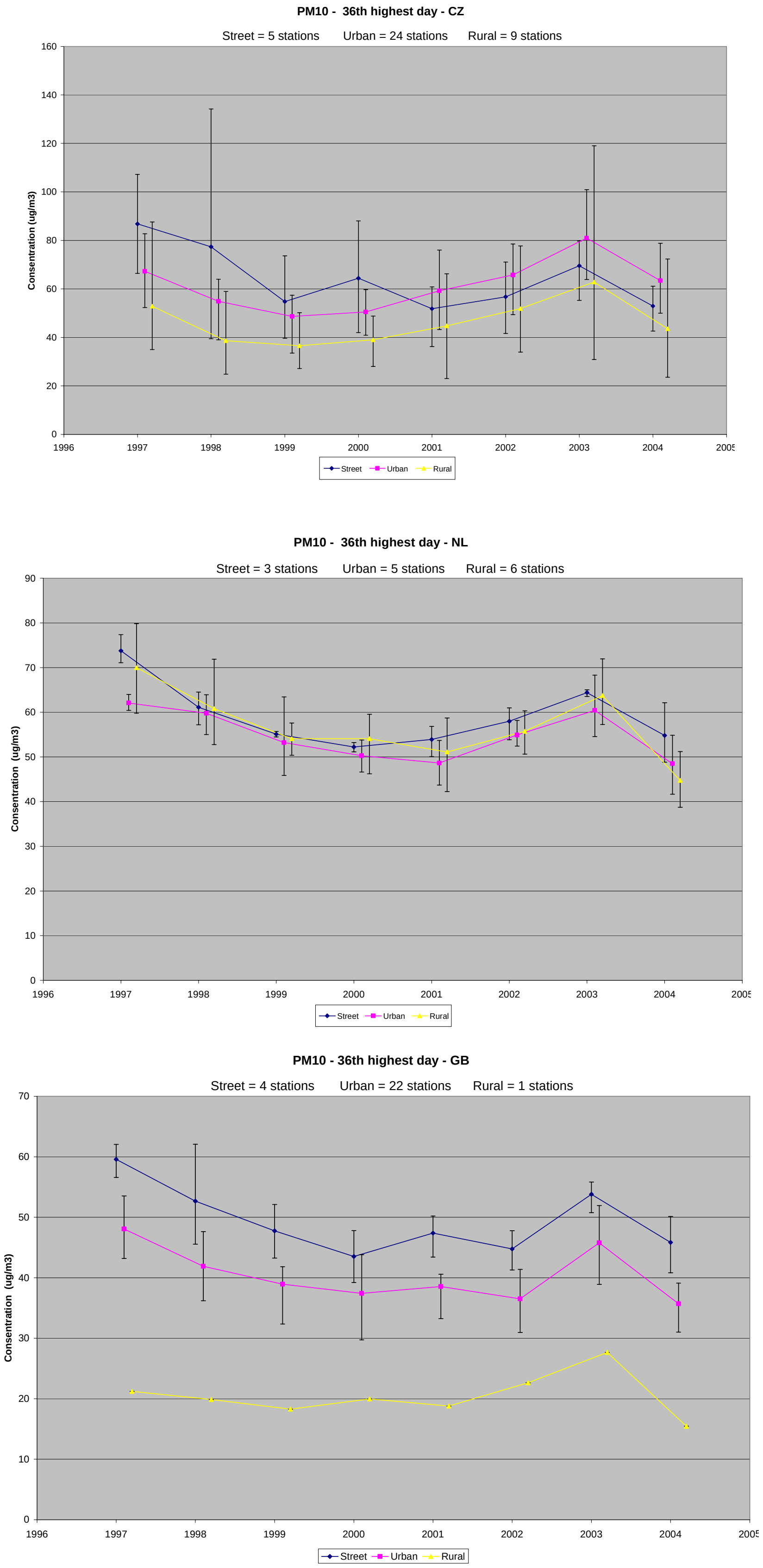


Figure 10: *Interannual variations of mean daily PM_{10} concentrations, 1997–2004, Example countries: Czech Republic, Netherlands, UK. Vertical bars: 10th/90th percentiles*

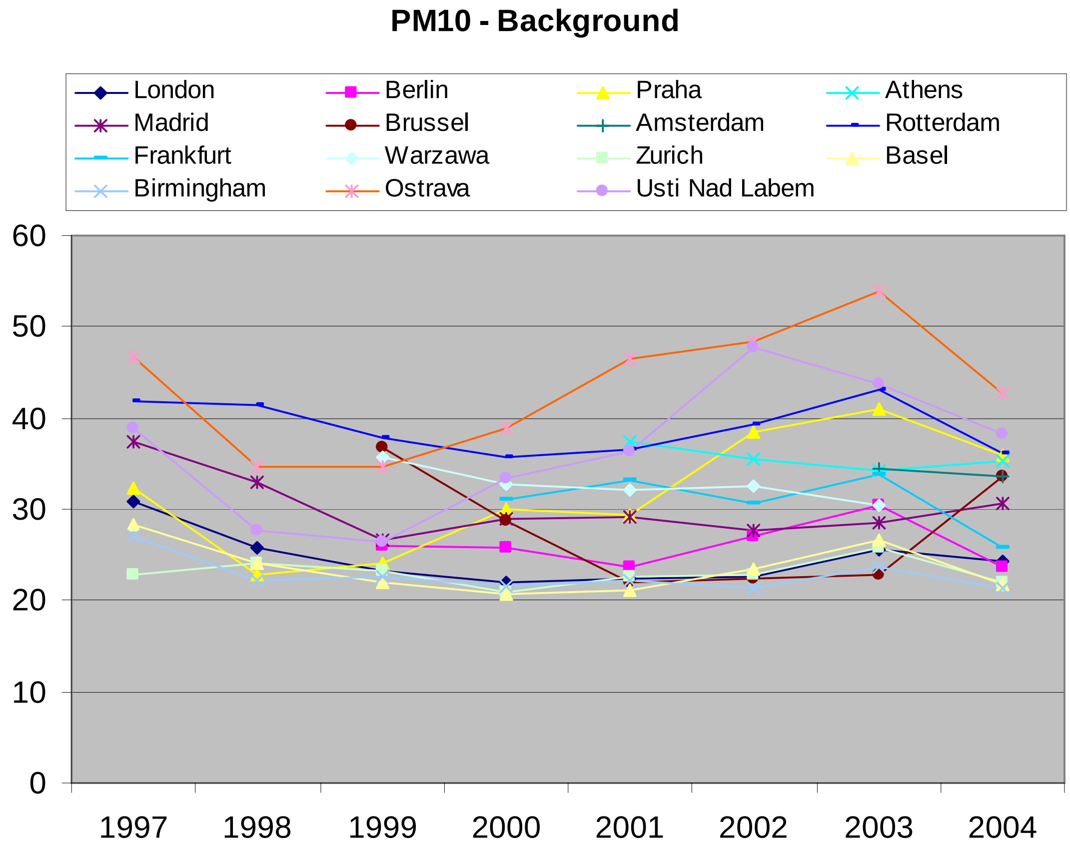


Figure 11: *PM_{10} annual average interannual variations, 1997–2004, selected cities. Urban Background. Cities with minimum 2 stations all years.*

1.5 Analysis of effect of meteorological variability on annual average PM_{10} concentrations.

Observed PM_{10} levels during 1997-2004 show decreasing level from 1997 towards 1999, then an increasing tendency towards 2003 with very high concentrations that year, and then decreasing tendency again (see section 1.3). Concentrations depend both on emissions and atmospheric factors, with inter-annual variations in meteorology affecting pollutant concentrations.

The effect on PM of meteorological variability can be estimated through computer modelling scenarios. In an exercise conducted for this report using the Unified EMEP model, emissions have been held constant for the years 1997-2004. Such comparative exercises can circumvent the problems of underestimation of absolute levels, while difficulties remain in representing urban/street concentrations below the 50km spatial model resolution.

Together with observed PM_{10} air concentrations, model estimates using both actual reported emissions and a scenario of constant emissions throughout the period are presented in Figure 12 for rural, urban background and street sites. The model reproduces the main signals in observations: a decrease towards 1999-2000, with subsequent increase in 2002 and 2003 regardless of emission changes. A decline is once again resumed n 2004. This strong signal suggests that higher observed concentrations 2002-3 may not have been due to increased emissions, but to meteorological conditions. Indeed, since the modelled rise in concentrations with emissions held constant was greater than observed, it suggests emissions have actually decreased in 2002-2003 in line with the emission estimates. On the other hand, observed concentrations have increased sharper than modelled with real, reported emissions. Possible meteorological explanations for the increased observed PM_{10} levels in 2002-3 include reduced precipitation with reduced washout of particulate material (thus higher air concentrations), warmer early-year temperatures in parts of Europe encouraging greater formation of secondary particulates, and relatively stable atmospheric conditions leading to reduced deposition, thus higher air concentrations.

The ratio between the maximum modelled yearly average concentrations in the two periods 2002-2003 and 1997-2001 (assuming constant emissions) is also mapped in Figure 12. The Figure indicates that in large areas in west and south-west Europe the PM_{10} levels have actually been reduced. The locations of AIRBASE stations often lie in areas with higher modelled PM_{10} concentrations in 2002-2003, which are found over large parts of Europe. , This suggests that observations may reflect the areas most subject to the meteorological influence, in particular for rural locations.

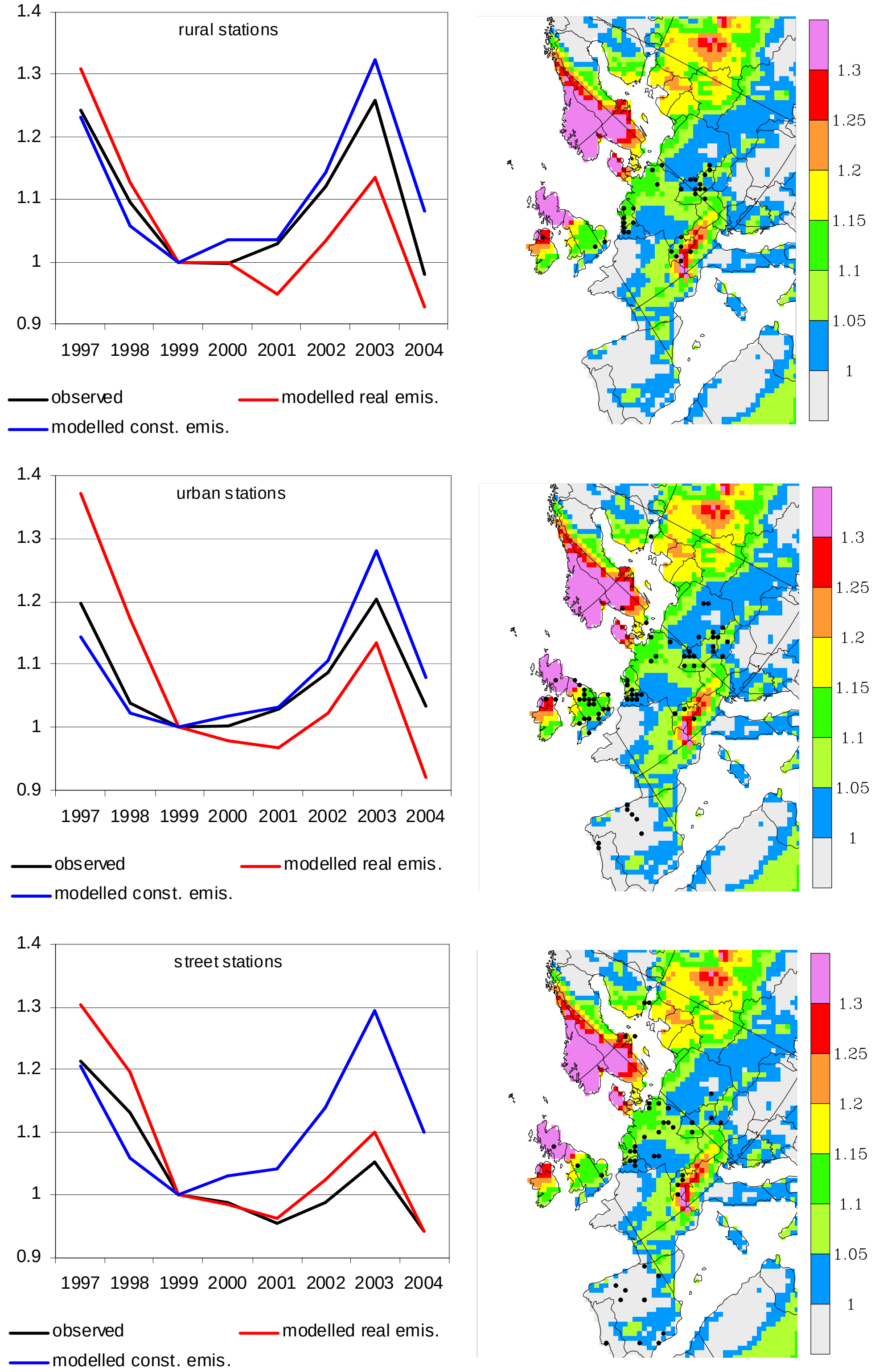


Figure 12: *Left panels: observed and modelled PM_{10} concentrations relative to 1999.*
Right panels: ratio of the max. modelled yearly concentrations for 2002-2003 to 1997-2001.
Dots indicate the measurement sites.

2. $PM_{2.5}$ concentrations in Europe

The routine monitoring of PM2.5 is still in a starting phase. Whereas in 2004 a total of 195 stations reported PM2.5 concentration to AirBase, this number increased to 268 in 2005. However, the PM2.5 equipment seems to be less reliable than PM10 instruments: the data coverage is much lower than for PM10: in 2004 25% of the PM2.5 stations failed to have a coverage of 75% or more; in 2005 this was even 35%. For PM10 19% (18% has a data coverage of less than 75% in 2004 (2005).

In Figure 13, concentrations (annual average) are shown in classes, for the stations with >70% data coverage in 2005. Stations with annual average above the proposed cap value (25 µg/m^3) exist in many countries, many of them in the Czech Republic and Silesia.

There is still only very few stations with a time series covering a number of years. Figure 14 is based on nine stations reporting data during the full 5-year period 2001-2005. These nine stations include one traffic station (London), five (sub)urban background stations (Three stations in France, one in Finland and one in the UK) and three rural background stations (one in Austria and two in the UK). Obviously, Figure 14 cannot be said to representative of the PM2.5 concentration development in Europe in general, although it bears some resemblance with the similar figure for PM_{10} (Figure 9), as far as urban and rural concentrations go, with relatively high concentrations in 2003.

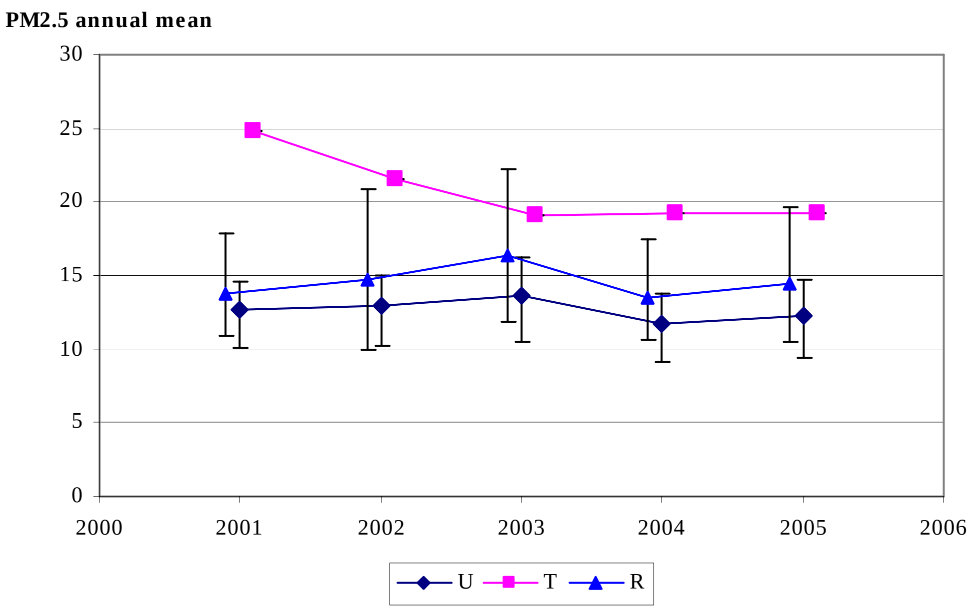


Figure 14: Annual variability of PM2.5 annual mean concentrations.

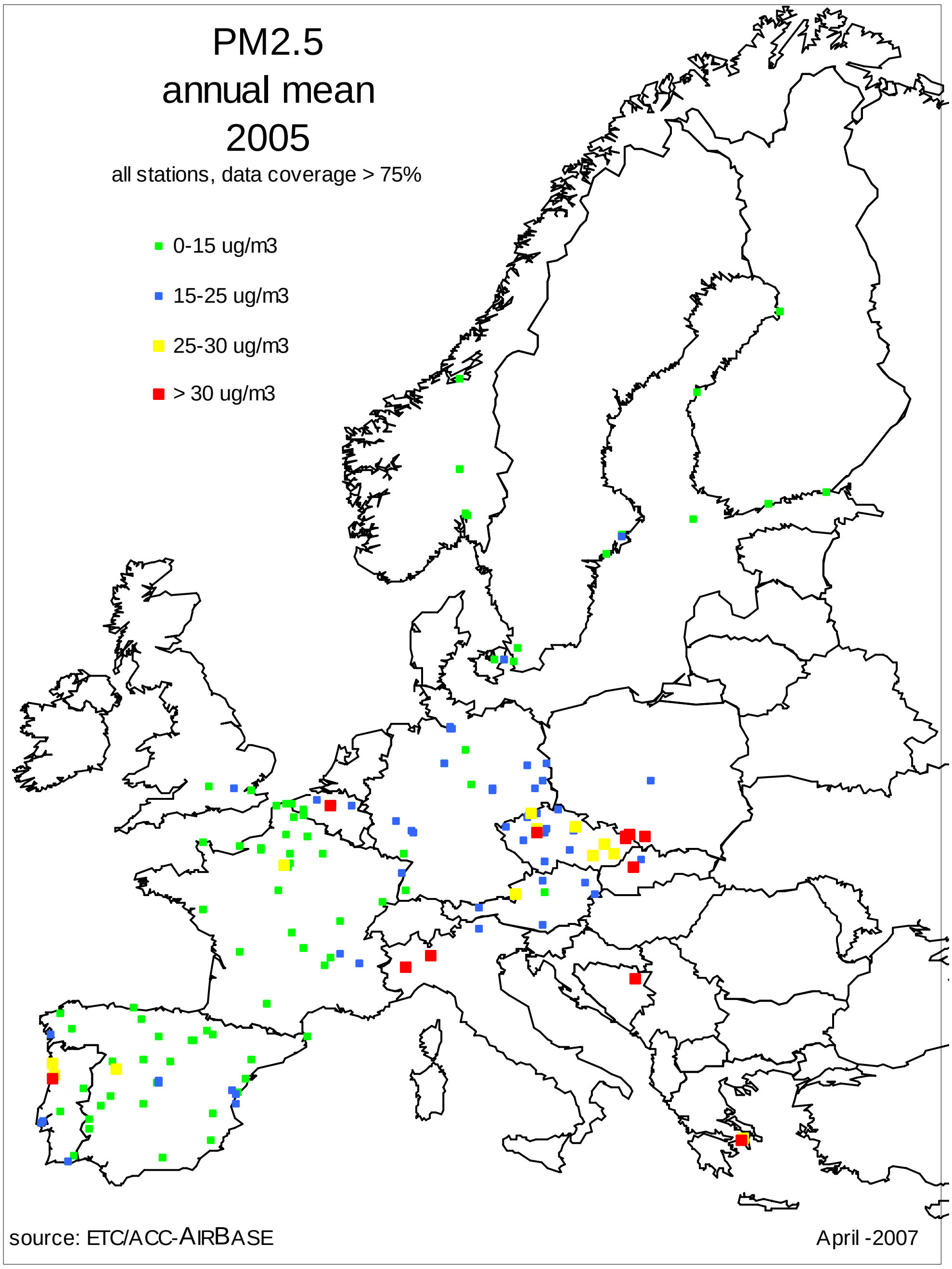


Figure 13: PM2.5 concentrations (annual mean) all stations with a data coverage of more than 75% are included.

3. Methodological aspects of PM mass measurement, and correction factors

PM mass is measured with different methods and instrument across Europe. The prevailing methods are:

- Gravimetry (sampling on filters with subsequent filter weighing in the laboratory), according to, or similar to, the CEN reference method.
- Automatic instruments using the beta ray absorption method (referred to as BAM method)
- Automatic instruments using the tapered element oscillating method (referred to as the TEOM method).

All methods require that acceptable QA/QC procedures are applied by the operating institution to provide quality data according to the requirements to accuracy set in the EU AQ Directive.

It is also established that the automatic instrumental methods needs to be compared with the reference sampling method in order to provide quality controlled results, and that in most areas in Europe, results from the automatic methods need to be corrected to provide correct PM data.

Tables 1 and 2 show the mix of methods used for PM_{10} and $PM_{2.5}$ monitoring respectively in the various countries reporting to AirBase.

For both PM_{10} and $PM_{2.5}$, the gravimetric methods, for PM_{10} presumably conforming to the reference method, are used at about 20% of the stations reporting data to AirBase. The beta attenuation method (BAM) is the most widely used method for PM_{10}, used at 950 (42%) of the 2272 stations, while TEOM is most prominent at the $PM_{2.5}$ stations, used at 83 (31%) of the 268 stations. The method is not reported for some of the stations.

Most countries have been or are investigating the correction factors (CF) to use for their PM mass measurements, according to the CEN 12341 standard methodology. The full knowledge of their respective CFs has not yet penetrated into AirBase, although many countries have installed their CFs into the AirBase database. Table gives an overview of the CFs in AirBase as of ….. . 17 out of the 32 EEA Member Countries have reported CFs, and 14 of them have CFs different from 1.0. The CFs vary largely between 1.0 and 1.3. Many countries have station-specific CFs. The TEOM CFs are typically somewhat larger than the BAM CFs. Belgium are using the largest CFs.

Although a reference method has not yet been set for $PM_{2.5}$, some countries have reported CFs for some of their $PM_{2.5}$ stations to AirBase. This concerns Germany, Spain, Hungary and Slovenia, and they are typically using the same CFs for $PM_{2.5}$ as they use for PM_{10}.

The work to clarify the status of setting and implementing CFs for data in AirBase is not yet completed. We don't have the full view yet of which countries have or have not implemented CFs for all years of data in AirBase. This work is in progress.

Country	Gravimetry	BAM	TEOM	Unknown	Total
AT	34	34	39		107
BE		20	27		47
BG	14	14			28
CH	17		4	1	22
CS		1			1
CY			2		2
CZ	35	84			119
DE	66	227	77	58	428
DK	9		3		12
EE		4			4
ES	54	114	167	50	385
FI		14	18		32
FR		66	287	5	358
GB	7	1	63		71
GR		10			10
HU		18	1		19
IE	11		3		14
IS		2			2
IT	39	173	17	6	235
LI		2			2
LT		12			12
LV		3			3
MK		14			14
MT		1	1		2
NL		38			38
NO	1	5	13		19
PL	85	38	28	1	152
PT	4	50			54
RO	15				15
SE	15		12		27
SI			10		10
SK	1	5	22		28
Total	**407**	**950**	**794**	**121**	**2272**

BAM: Beta attenuation method
TEOM: Tapered element oscillation method

Table xx: PM_{10} mass measurement methods per country, for stations reported to AirBase

Country	Gravimetry	BAM	TEOM	Unknown	Total
AT	7				7
BA		2			2
BE	1		8		9
CZ	7	24			31
DE	8	7	5	4	24
DK			3		3
ES	18	19	5	28	70
FI	1	4	1		6
FR			56	3	59
GB			4		4
GR		2			2
IS		2			2
IT	3	8	1		12
NO			8		8
PL	2				2
PT	4	13			17
SE			7		7
SK		2	1		3
Total	51	83	99	35	268

Table 2: $PM_{2.5}$ mass measurement methods per country, for stations reported to AirBase

Country	BAM	TEOM	Unknown
AT	1.3 Seasonally variable at 7 stations	1.0-1.3	
BE	1.37 1.08 at 1 station	1.47	
DE	1.1-1.3	1.2-1.26	
DK		1.23-1.36	
EE	1.15		
ES	0.84-1.2 ~0.7*b at some stations	1.0-1.3	1.0-1.56
FI	1.0	1.0	
FR	1.0	1.0	
HU	1.0-1.31	1.0	
IT	-	- 1.3 at 1 station	
LV	1.0		
MT	1.3	1.3	
NL	1.3		
PT	1.11-1-18	1.1-1.2	
SI		1.12-1.3	
SK	1.3	1.3-1.3+	
UK		1.3	

Table 3: Correction factors for PM_{10} reported to AirBase

4. References

ETC/ACC (2005) Horalec, Jan et. al.,Interpolation and assimilation methods for European scale air quality assessment and mapping - Part II: Development and testing new methodologies. ETC/ACC Technical Paper 2005/8

EEA (2007) Larssen, S. et.al., Air Quality in Europe 1997-2004. In press.

To be completed