Informing you on ambient air quality in the Belgian Regions

Intergewestelijke Cel voor het Leefmilieu (IRCEL)
Cellule Interrégionale de l'Environnement (CELINE)
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# ANNUAL REPORT Air Quality in Belgium 2011

This report is the result of the collective effort of all the colleagues of the Belgian Interregional Environment Agency (IRCEL-CELINE) Air:

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# Acknowledgements
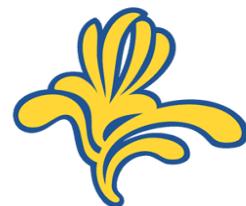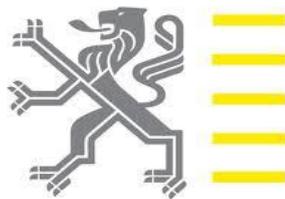
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# List of Abbreviations and Glossary

$PM_{10}$ — Particulate Matter with diameter less than 10 μm

$PM_{2.5}$ — Particulate Matter with diameter less than 2.5 μm

$NO_x$ — Generic term for a gas mixture consisting of nitrogen monoxide (NO) and nitrogen dioxide ($NO_2$)

$O_3$ — Ozone: highly reactive gas formed by the interaction of UV light and pollutants present in the air, especially on hot summer days.

NET60 — Number of Exceedances above a Threshold of 60 ppb (=120 μg/m³): Number of days where the daily maximum 8-hour mean ozone concentration exceeded 120 μg/m³

AOT60 — Accumulated Ozone Exposure above a Threshold of 60 ppb (=120 μg/m³): The difference between the daily maximum 8-hour mean concentration above 120 μg/m³ and 120 μg/m³, accumulated over a calendar year.

AOT40 vegetation

Accumulated Ozone Exposure above a Threshold of 40 ppb (=80 μg/m³): The difference between the hourly mean above 80 μg/m³ and 80 μg/m³ for all hourly values between 8 a.m. and 8 p.m. MET in the months of May, June and July (growth season). Indicator for the protection of crops and (semi-)natural vegetation.

AOT40 forests

Accumulated Ozone Exposure above a Threshold of 40 ppb (=80 μg/m³): The difference between the hourly mean above 80 μg/m³ and 80 μg/m³ for all hourly values between 8 a.m. and 8 p.m. MET in the months of April to September Indicator for the protection of forests.

$SO_2$ — Sulphur dioxide: a colourless gas with a characteristic irritating odour and taste at high concentrations.

RIO — Interpolation technique used in this report to generate a spatial map of the air quality in Belgium

AOD — Aerosol optical depth: a measure for the transparency of aerosols in the atmosphere

AEI — Average Exposure Index: national indicator which is calculated as the three-year running annual mean $PM_{2.5}$ concentration observed at urban background stations.

MTO — Medium-term objective

LTO — Long-term objective

WHO — World Health Organization

Temperature inversion

Phenomenon whereby the air temperature close to the ground is lower than in the higher atmospheric layers. This prevents air pollution from rising and dissipating, so that it remains trapped near the ground.

Smog    Condition of increased air pollution. In winter it is caused mainly by particulate matter, and in summer by ozone.

BC      Black Carbon or soot. This is a component of particulate matter and originates primarily from diesel vehicles and biomass burning.

VOCs    Volatile Organic Compounds: a mixture of gaseous compounds with carbon and oxygen as the main elements. They are a precursor of ozone.

# Summary

The table below gives an overview of the various air quality indicators for Belgium in 2011, using a colour code to compare to the minimum, maximum and mean values of the past 10 years: 2001-2010 (for $PM_{2.5}$ comparison with the period 2005-2010). The figures are based on calculations made with the RIO interpolation technique. The spatial resolution of RIO is 4x4 km². The figures are therefore representative for areas of 4x4km². As a result, the concentrations (or the number of exceedances) may locally be higher or lower.

**Table 1: Air quality indicators in Belgium, 2011.**

| Indicator | 2011 | | | European limit or target value | WHO guideline value |
|---|---|---|---|---|---|
| | min | mean | max | | |
| **$PM_{10}$** | | | | | |
| Annual mean (µg/m³) | 9 | 21 | 35 | 40 | 20 |
| Number of days > 50 µg/m³ | 1 | 19 | 59 | Max 35 days | Max 3 days |
| **$PM_{2,5}$\*** | | | | | |
| Annual mean (µg/m³) | 7 | 13.7 | 24 | 25 | 10 |
| **$O_3$** | | | | | |
| Number of days > information threshold 180 µg/m³ | | 2 | | | |
| Number of days > alert threshold 240 µg/m³ | | 0 | | | |
| Number of days with max. 8-h mean > 120 µg/m3 | 2 | 13 | 26 | MTO: 25 days, mean over 3 years, LTO: 0 days | 0 days with max. 8-h mean > 100 µg/m³ |
| Number of days with max. 8-h mean > 120 µg/m³ (mean 2009-2011) | 3 | 12 | 21 | MTT: 25 days, mean over 3 years, LTO: 0 days | 0 days with max. 8-h mean > 100 µg/m³ |
| AOT60 ((µg/m³).h) | 120 | 1581 | 3264 | 5800\*\* | |
| AOT40 vegetation ((µg/m³).h) | 1959 | 7554 | 14962 | MTO: 18000, mean over 5 years, LTO: 6000 | |
| AOT40 vegetation ((µg/m³).h) (mean 2007-2011) | 2479 | 8778 | 14934 | MTO: 18000, mean over 5 years, LTO: 6000 | |

| AOT40 forests ((µg/m³).h) | 4746 | 19857 | **24503** | Critical level: 10000** Reference level: 20000** | |

| NO$_2$ | | | | | |
|---|---|---|---|---|---|
| Annual mean (µg/m³) | 5 | 15.6 | **44** | 40 | 40 |
| 19th highest hourly mean (µg/m³) | 32 | 56 | 134 | 200 | highest hourly mean: 200 |

| SO$_2$ | | | | | |
|---|---|---|---|---|---|
| 25th highest hourly mean (µg/m³) | 4 | 7.4 | 56 | 350 | |
| 4th highest daily mean (µg/m³) | 3 | 5 | 33 | 125 | highest daily mean: 20 |

\* Comparison with period 2005-2010
\*\*Not in 2008/50/EC

Colour code:

| |
|---|
| **Value significantly lower than the past 10-year mean** |
| **Value comparable to the past 10-year mean** |
| **Value significantly higher than the past 10-year mean** |

*Red text colour indicates exceedance of the European limit value or target value.*

Compared with the past 10 years, 2011 was a favourable year for air quality. Only the daily exceedances for PM$_{10}$, the target value for the protection of public health from ozone, the AOT40 for forests and the 19th highest SO$_2$ hourly mean approach the 10-year mean over the period 2001-2010. This does not, however, mean that all European limit and target values are attained in 2011. This is also illustrated in Table 2, which shows the percentage of the population that is potentially exposed to values above the European limit or target value on the one hand, and above the guideline values of the World Health Organisation (WHO) on the other hand.

The European annual limit value for PM$_{10}$ is attained everywhere in Belgium. The number of days where the daily mean PM$_{10}$ concentration exceeded 50 µg/m³ is, however, still well above the permitted 35. The annual mean PM$_{2.5}$ concentrations in 2011 remained below the European target value which has been in force since 2010. A comparison with the WHO guideline values yields a less positive picture. Virtually the entire Belgian population was potentially exposed to PM$_{10}$ and PM$_{2.5}$ concentrations that exceed the WHO guideline values.

Compliance with the European annual limit for NO$_2$ remains problematic in the large agglomerations (Brussels and Antwerp) and the Port of Antwerp area. The European hourly limit value, by contrast, is attained everywhere.

The ozone medium-term objectives (MTO 2010) for the protection of health and vegetation are attained, but the long-term objective (LTO) for the protection of health is still exceeded everywhere, as is the LTO for vegetation. For forests, too, the situation is not favourable: more than half of the forests are exposed to ozone pollution above the critical level. The reference value is exceeded for almost the entire forest area in Belgium.

In conclusion, it can be said that the particulate matter ($PM_{2.5}$ and $PM_{10}$) and ozone concentrations are the most problematic in terms of health effects in 2011.

**Table 2: Percentage of population or vegetation area potentially exposed to values above the European limit or target value or WHO guideline value.**

| Indicator | European target or limit value | 2011 % of exposed population or % of area above the target value for vegetation (AOT40) | WHO guideline value | 2011 % of exposed population |
|---|---|---|---|---|
| **$PM_{10}$** | | | | |
| Annual mean (µg/m³) | 40 | 0% | 20 | 88% |
| Number of days >50 µg/m³ | Max 35 days | 18% | Max 3 days | 100% |
| **$PM_{2.5}$** | | | | |
| Annual mean (µg/m³) | 25 | 0% | 10 | 97% |
| **$NO_2$** | | | | |
| Annual mean (µg/m³) | 40 | 5% | 40 | 5% |
| Hourly mean > 200 µg/m³ | Max 18 hours | 0% | 0 hours | 0% |
| **$SO_2$** | | | | |
| Daily mean > 125 µg/m³ | Max 3 days | 0% | Daily mean > 20 µg/m³ | 1% |
| Hourly mean > 350 µg/m³ | Max 24 hours | 0% | | |
| **$O_3$** | | | | |
| Number of days with max. 8-h mean > 120 µg/m3 | LTO: 0 days | 100% | Daily max. 8-h mean > 100 µg/m³ | 100% |
| Number of days with max. 8-h mean > 120 µg/m³ (mean 2009-2011) | MTO: 25 days, mean over 3 years | 0% | | |
| AOT60 ((µg/m³).h) | 5800* | 0% | | |
| AOT40 vegetation ((µg/m³).h) | LTO: 6000 | 73% | | |
| AOT40 vegetation ((µg/m³).h) (mean 2007-2011) | MTO: 18000, mean over 5 years | 0% | | |

| AOT40 forests ((μg/m³).h) | Critical level: 10000* | 56% |
|---|---|---|
| AOT40 forests ((μg/m³).h) | Reference level: 20000* | 99% |

Colour code:

| 0% | 0 % - 50% | > 50% |
|---|---|---|

* not in 2008/50/EC

# Introduction

In Belgium, the air quality monitoring networks were, until 1994, operated by the Federal Institute of Hygiene and Epidemiology (IHE). Air quality assessments were also a federal responsibility. Responsibility for the monitoring and assessment of the air quality was transferred to the three Belgian Regions in 1994. The three Regions, however, decided to continue working together on a permanent basis. For this purpose the Belgian Interregional Environment Agency (IRCEL-CELINE) was established. One of IRCEL-CELINE's tasks is to report on air quality to citizens, media, and policymakers. This is achieved through efficient and close cooperation with the responsible agencies in the three Regions. As part of this cooperation agreement, IRCEL-CELINE is required to report each year on the air quality in the three Regions. This report presents an overview of the air quality situation in Belgium in 2011.

The concentrations of the various pollutants in the air are measured in the air quality monitoring networks of the three Regions. In Flanders these monitoring networks are operated by the Flemish Environment Agency (VMM) ([http://www.vmm.be](http://www.vmm.be)), in Wallonia by the Public Service Scientific Institute (ISSeP) ([http://www.issep.be](http://www.issep.be) ) and the Walloon Air and Climate Agency (AWAC) ( [http://airclimat.wallonie.be](http://airclimat.wallonie.be)) and in Brussels by the Brussels Environment Agency (IBGE-BIM) ([http://www.ibgebim.be](http://www.ibgebim.be)). The measured values are collected by IRCEL-CELINE and stored in the interregional database. In addition, the Regions have access to a meteorological monitoring network that measures various meteorological parameters. These parameters are used to interpret the measured air pollution concentrations. The following meteorological parameters are monitored: temperature, wind direction and speed, air pressure, precipitation and relative humidity.

This report describes the air quality situation in 2011 and the evolution of the air quality in Belgium over the last years. This report does not discuss the measurements at the various individual monitoring stations. For that purpose, reference is made to the individual annual reports on air quality of the Regions and the annual reporting by Belgium under European Directive 2008/50/EC. Figure 1 gives an overview of the regions, provinces and largest agglomerations in Belgium. The analyses in this report were conducted mainly using (spatial) interpolations of air quality measurements, the so-called RIO interpolation technique (see Box 1). The pollutants which will be discussed are $PM_{10}$, $PM_{2.5}$, $O_3$, $NO_2$ and $SO_2$, since the RIO interpolation technique was developed for these pollutants. For the results of other pollutants such as NO, CO, heavy metals, etc., reference is made to the regional annual reports.

*Note 1: exposure of the population as presented in this report is a 'static' exposure, calculated on the basis of the population numbers per RIO grid cell. This means that exposure is estimated on the basis of the residence of the population. Movements of the population are not taken into account. Moreover, the resolution of the RIO interpolation technique implies uncertainty on the actual exposed population. In a grid cell where for example an $NO_2$ annual mean of 41 µg/m³ is calculated, all people are assumed to have been exposed to this concentration above the annual limit value, whereas in reality a portion of the population will have been exposed to lower or higher concentrations. By contrast, in a grid cell where 40 µg/m is calculated, no one is assumed to have been exposed to above-limit value concentrations. The results should therefore be interpreted with some caution.* Figure 2 *shows the population density per RIO grid cell. This density is higher in the large agglomerations which are clearly visible on the map.*

Belgium: regions and provincial capitals
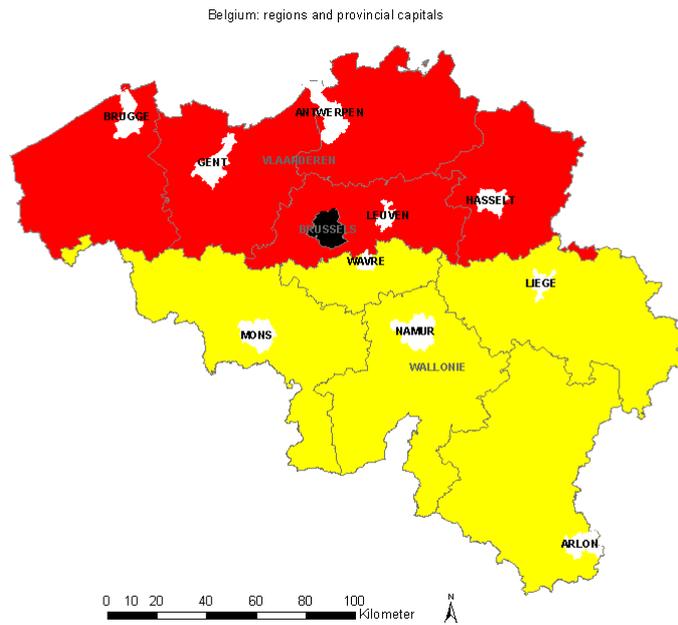
**Figure 1: Regions, provinces and large agglomerations in Belgium**



Population density
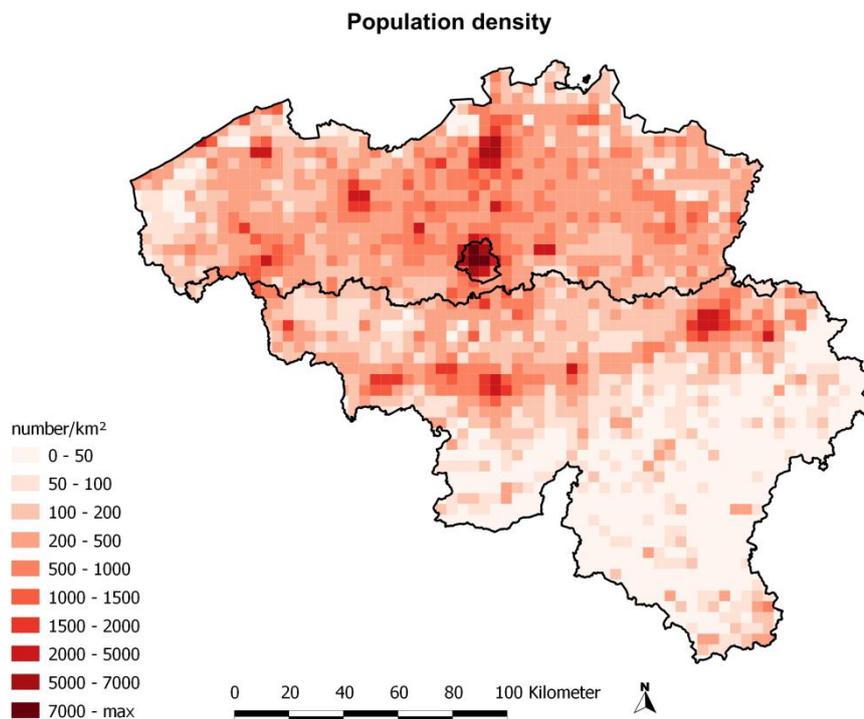
**Figure 2: Population density per RIO grid cell (Source: population figures Statistics Belgium)**

**BOX 1: RIO interpolation technique**

In this report, a spatial interpolation technique of air quality measurements, called RIO, is used. This technique also allows the exposure of the population to be estimated. Standard interpolation techniques such as Inverse Distance Weighting (IDW) and Ordinary Kriging (OK) require that each monitoring site is representative of the same spatial area. In practice, however, this does not apply in the case of air pollution. Concentrations measured close to a source of pollution will in many cases be representative only for a limited area around that source, whereas concentrations measured in a rural zone will generally be representative for a larger area. To cater for this, i.e. to take into account the local character of the air pollution, the RIO interpolation technique was developed (Hooybergs et al., 2006; Janssen et al., 2008). RIO is an intelligent interpolation technique where the influence of the locality of each monitoring station is removed first, so that a spatial homogeneous data set of air quality measurements can be generated. The measured values herewith obtained can subsequently be interpolated using Ordinary Kriging. In a final step, the local character of each of the interpolated monitoring sites is added again. The local character of a monitoring site is determined by a static analysis of long term time series of concentrations at the monitoring stations and the land use (Corine Land Cover) in the vicinity of those monitoring stations. This analysis reveals a strong correlation between land use and concentration levels. The correlation between concentrations and land use is summarised in trend functions. The land use is known for the whole of Belgium, so that the local character of each site where measurements are interpolated can be taken into account. For the interpretation of $PM_{2.5}$, not only the land use but also the aerosol optical depth (AOD) was used to determine the local character. Figure 3 shows the Belgian land-use map based on the Corine Land Cover 2006, aggregated for the 11 RIO Corine classes used within the RIO interpolation method. The clearly different land use in the three Regions will also be reflected in the air quality. The zone south of the Sambre and Meuse valley, for example, is clearly a more wooded zone, with fewer emission sources and therefore also less air pollution.

The spatial resolution of the RIO interpolation technique is 4x4 km. RIO allows the air quality to be calculated by the hour for all 4x4 km grid cells in Belgium. Missing measurement data at monitoring stations are filled by interpolation of the available measurement results of the other monitoring sites. This is very interesting for exceedance and excess indicators that accumulate concentrations over several hours or days. If these indicators are to be calculated per monitoring station, allowance should always be made for the fact that missing data may lead to incomplete results so that a correction will be required. The RIO interpolation method has been validated via the leaving-one-out method, meaning that an interpolation is made using the measurements of all but one monitoring station. The interpolated concentrations at the site of the omitted monitoring station can then be compared with the measured concentration at that station. RIO has also been validated with independent measurements, which demonstrated a low uncertainty (Janssen et al., 2008). Independent measurements are measurements that are not used at any stage during the RIO interpolation routine, including determining the trend functions. In addition, the uncertainty per grid cell for each pollutant is calculated. For these maps and a more detailed description of the determination of the model uncertainty, we refer to to Annex C.
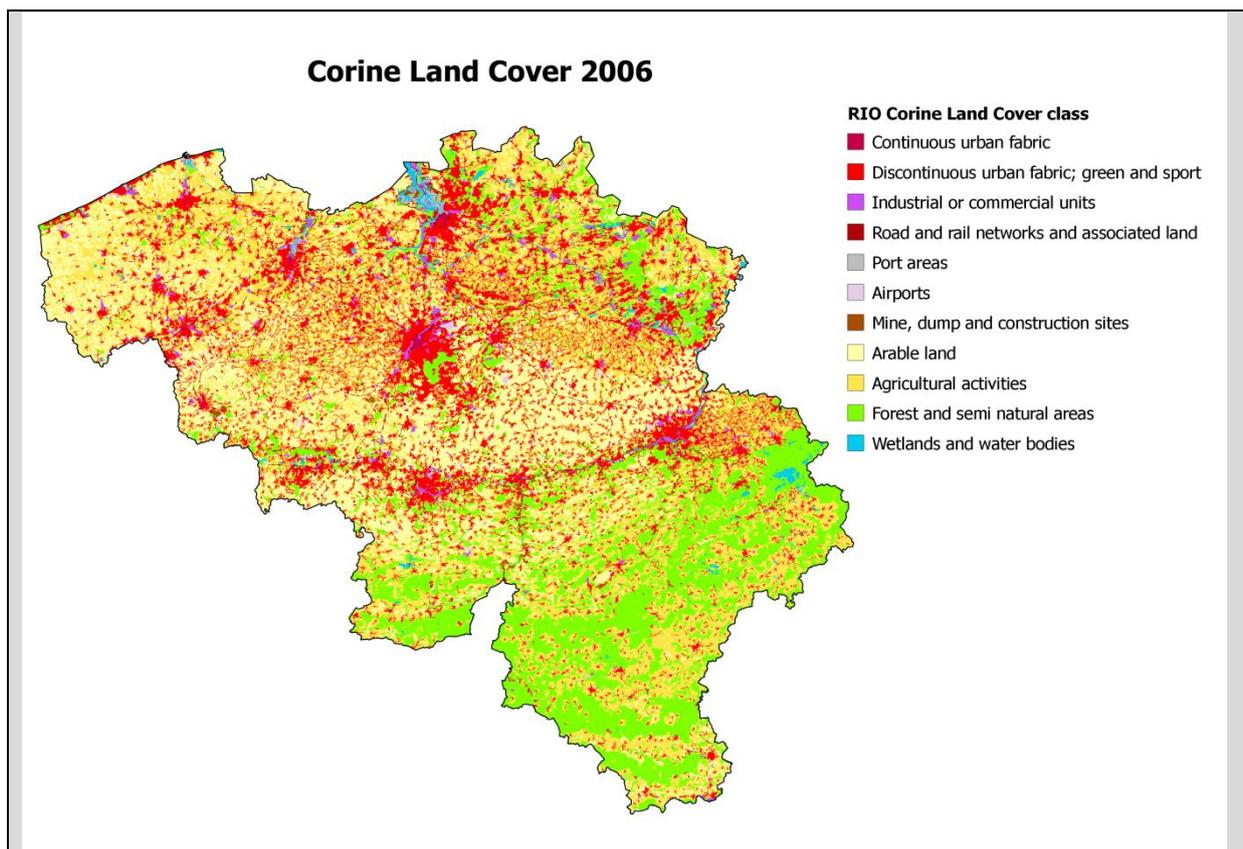
**Figure 3: Land use in Belgium, broken down into RIO-corine classes**

The RIO interpolation technique has been optimised for $PM_{10}$, $PM_{2.5}$, $O_3$ and $NO_2$ because these pollutants are found to be strongly correlated with land use (and AOD for $PM_{2.5}$). Due to the local character of $SO_2$, the technique, in its current form, appears less suitable for this pollutant, but is nevertheless used for the calculations. This is the reason why this report includes only the interpolation maps of $PM_{10}$, $PM_{2.5}$, $O_3$ and $NO_2$, although it also discusses the interpolation results for $SO_2$.

Apart from the various indicators for the year 2011, the RIO interpolation is used to calculate the trend in air concentrations for each pollutant and each 4x4 km² grid cell, from the beginning of the measurements up to 2011 (see Box 2). For this, it is important that reference is made to Note 2.

*Note 2: The trend in concentrations or indicators derived from concentrations is influenced by the different number of monitoring stations per year or any change of monitoring method. Ideally, only the measurements of stations that were operational throughout the monitoring period should be used in determining the trend. For most pollutants, the number of monitoring stations has increased significantly over the past 20 years, so that the spatially mean concentrations and the interpolation maps now have a smaller uncertainty. This means that the uncertainty on the values in years with few monitoring stations is greater than in years with more stations. The evolution graphs and maps should therefore be read bearing this in mind. The evolution in the number of stations for each pollutant is indicated at the beginning of each chapter.*

**BOX 2: Trend analysis**

To determine the slope and the statistical significance (p-value) of the trend (in µg/m³/year), the non-parametric Theil-Sen method is used (Theil, 1950; Sen, 1968). In the Theil-Sen method, the slope between all pairs of (x,y) points is determined. The Theil-Sen estimate of the slope is then the median of all these slopes. In a non-parametric method, in contrast to the more powerful parametric tests, it is not required that the data are normally distributed and that the condition of homoscedasticity, i.e. the constant variance of the air quality data over the different years, is satisfied. It is, however, still possible to calculate accurate confidence intervals. Moreover, the method is also resistant to outliers. These are observations that are relatively far removed from the other observations. The estimate of the trend parameters is subsequently made more robust by bootstrap resampling. This means that the original data set is regenerated an n number of times on the basis of a predefined distribution, and that also the trend analysis parameters are recalculated an n number of times.

Chapter 1 discusses the European air quality regulations with an overview of the applicable European standards. This is followed by an overview of the smog episodes in 2011 and possible explanations, such as the meteorological conditions, for the occurrence of these episodes. Next, we will, for each air pollution component, give a description of the pollutant, compare it against the European limit and target values and other relevant indicators, and analyse the long-term trend. Unless otherwise indicated, all maps and graphs published in this report have been compiled based on the results of the RIO interpolation technique. The table in Annex A lists the monitoring stations from the three regional monitoring networks that are used in the spatial interpolation maps, together with the pollutants that are measured there. Annex C shows the spatial distribution of the uncertainty on the interpolated concentrations for each pollutant. The calculation of the various indicators and the trend analyses were performed using the 'openair' package (Carslaw and Ropkins, 2012), developed for the statistical software program R (R Core Team, 2012). All maps in this annual report were created using QuantumGIS 1.7.4 (QuantumGIS Development Team, 2012).

# 1 European Regulations

The following chapter discusses the main characteristics of the European regulations. These regulations lay down requirements for the monitoring network in each country, as well as limit and target values for the various pollutants.

## 1.1 History

The Council [Directive 96/62/EC](#) of 27 September 1996 on ambient air quality assessment and management, was published on 21/11/96. This directive constitutes a milestone in the field of air quality regulations in the European Union (EU 1996). The new Framework Directive superseded the directives for $SO_2$ and particulate matter (80/779/EEC), Pb (82/884/EEC), $NO_2$ (85/203/EEC) and $O_3$ (92/72/EEC) which previously were in force within the European Union.

Together with a number of daughter directives, it formed the basis for a new air quality policy within the European Union. The purpose of the Framework Directive was to set forth the basic principles of a common strategy, whilst the daughter directives established air quality standards (limit and target values and in a number of cases alert thresholds) for 13 pollutants. The common strategy in the Framework Directive was aimed, on the one hand, at assessing air quality in a common manner and informing the population thereof via established measurement methods and criteria, and, on the other hand, establishing objectives for air quality designed to avoid, prevent or reduce harmful effects on human health and the environment. In the daughter directives, these air quality objectives were defined for each pollutant in the form of limit and target values, and also a date was set by which concentration levels below the limit values are to be attained. A margin of tolerance is set leading up to the deadline when the limit value is to be met. The member states are required to implement action plans when the limit values are exceeded. The Directives also set out for each pollutant the criteria and measurement methods to be used for monitoring the air quality and the information and alert thresholds at which the population must be informed. These thresholds have been defined for substances where short-term exposure above the threshold value can pose risks to public health. Alert thresholds have been defined for $NO_2$, $SO_2$ and $O_3$.

## 1.2 European Directive (2008)

In May 2008, Framework Directive 96/62/EC, the first three daughter directives and a directive on the exchange of information were superseded by new EU Directive 2008/50/EC. The limit and target values and the information and alert thresholds were retained, except for the second phase of the $PM_{10}$ limit value which was removed. Additionally, based on recent health research into the harmful effects of $PM_{2.5}$, monitoring requirements as well as limit and target values were established for this pollutant. On the basis of $PM_{2.5}$ measurements in urban background locations, an average exposure index (AEI) is calculated for the reference year 2010, based on the mean concentration in 2008, 2009 and 2010. This exposure index determines the reduction percentage which a member state is required to achieve by 2020. The new Directive also provides for additional flexibility for deducting natural sources when assessing the quality objectives and makes provisions for postponing the deadline for attaining the limit values for $NO_2$, $PM_{10}$ and benzene.

Where particulate matter exceedances are due, fully or partially, to natural sources, the relevant portion may be excluded. The contribution from winter-sanding and -salting may also be subtracted.

Table 3 gives an overview of the various limit and target values for each pollutant, and the dates by which they are to be met.

Table 4 lists the information and alert thresholds at which the population must be informed or alerted.

Also the criteria for aggregating data and calculating statistical parameters have largely been taken over from the old Framework Directives. One exception is the calculation of 24-hour values, for which, according to the new Directive, at least 75% of the hourly averages must be available.

The Directive also makes provisions that in zones or agglomerations where it is difficult to meet the defined limit values by the target date, the attainment deadline for the limit values may be postponed by a specified period (until 2011 for $PM_{10}$ and until 2015 for benzene and $NO_2$). For this, a detailed plan must be drawn up showing that attainment by the end of the revised period is guaranteed. This plan must be approved by the European Commission. In 2009 the request for postponing compliance with the 50 µg/m$^3$ daily limit value for $PM_{10}$ in various zones in Flanders, Brussels and Wallonia was not approved. Like many other European member states (22 of the 27), Flanders and Brussels failed to meet the European annual limit value of 40 µg/m$^3$ for nitrogen oxide ($NO_2$) in 2010. In early 2012 Flanders drew up an Air Quality Plan featuring a package of measures to meet the European limit value by 2015. For its zones in exceedance – the Antwerp agglomeration and the Port of Antwerp - the Flemish Region was granted permission by the European Commission to postpone compliance with the annual mean $NO_2$ limit value until 2015. Until that date, the limit value in those zones is 60 µg/m³. No postponement was granted to the Brussels-Capital Region. An overview of the requests for postponement and the related decisions of the European Commission can be found via the following website link: http://ec.europa.eu/environment/air/quality/legislation/time_extensions.htm

**Table 3: Overview of European limit and target values for the various pollutants according to EU Directive 2008/50/EC**

| Substance | Protection of | Averaging period | Value | Maximum allowable number of exceedances | Date by which the value is to be met |
|---|---|---|---|---|---|
| **Limit values** | | | | | |
| $SO_2$ | Human health | 1 hour | 350 μg/m$^3$ | 24 | 1 January 2005 |
| | | 1 day | 125 μg/m$^3$ | 3 | 1 January 2005 |
| | Vegetation | Year and winter | 20 μg/m$^3$ | | |
| $NO_2$ | Human health | 1 hour | 200 μg/m$^3$ | 18 | 01 January 2010 |
| | | year | 40 μg/m$^3$ | | 01 January 2010 |
| | Vegetation | year | 30 μg/m$^3$ | | |
| $PM_{10}$ | Human health | 1 day | 50 μg/m$^3$ | 35 | 01 January 2005 |
| | Human health | Year | 40 μg/m$^3$ | | 01 January 2005 |
| $PM_{2.5}$ | Human health | year | 25 μg/m$^3$ | | 1 January 2015 |
| | Human health | year | 20 μg/m$^3$ | | 1 January 2020 [1] |
| benzene | Human health | year | 5 μg/m$^3$ | | 01 January 2010 |
| CO | Human health | Daily max 8 hours [2] | 10 mg/m$^3$ | | 1 January 2005 |
| Pb | Human health | year | 0.5 μg/m$^3$ | | 1 January 2005 [3] |
| **Target values** | | | | | |
| $O_3$ | Human health | Daily max 8 hours | 120 μg/m$^3$ | MTO: 25 [4] LTO: 0 | 1 January 2010 |
| | Vegetation | AOT40: 8am-8pm CET in May to July | MTO: 18000 (μg/m³)·h [4] LTO: 6000 (μg/m³).h | | |
| $PM_{2.5}$ | Human health | year | 25 μg/m$^3$ | | 1 January 2010 |

(1) Indicative limit value which will be reviewed by the European Commission in 2013 in the light of further information on health and environmental effects, technical feasibility and experience of the target values in the various member states.

(2) The daily maximum 8-hour mean concentration is selected on the basis of the running 8-hour average, calculated from hourly data and updated each hour. Each calculated 8-hour mean is assigned to the day on which it ends.

(3) In the immediate vicinity of specific industrial sources situated on sites contaminated from decades of industrial activities, the limit value was to be met by 1 January 2010. Until this moment in time, a limit value of 1 μg/m$^3$ was in force in those areas.

(4) MTO: Medium-term objective (2010). LTO: long-term objective. The MTO is calculated as the average over three (protection of human health) or five years (protection of vegetation). If not enough successive annual averages are available, the minimum requirement for compliance with the target values is valid data from one or three consecutive years for protection of human health or vegetation respectively.

**Table 4 Overview of average hourly information and alert thresholds according to EU Directive 2008/50/EC**

| Pollutant | Information threshold | Alert threshold |
|---|---|---|
| (*) $SO_2$ | | 500 µg/m$^3$ |
| (*) $NO_2$ | | 400 µg/m$^3$ |
| (**) $O_3$ | 180 µg/m$^3$ | 240 µg/m$^3$ |

(*) *Measurement for three successive hours at locations that are representative of the air quality above at least 100 km$^2$ or above a complete zone or agglomeration if the latter covers a smaller area.*

(**) *For the application of short-term measures, exceedance of the threshold value must be measured or predicted for three consecutive hours.*

The air quality guideline values of the WHO (World Health Organisation) are more stringent than the limit and target values imposed by the European Union, see Table 5. The purpose of the EU limit and target values is to identify how the best possible air quality offering maximum protection to the population in all EU-27 member states can be achieved in the most cost-effective way. To achieve these objectives, Europe takes into account not only health reasons but also economic feasibility. The guideline values proposed by the WHO are therefore an acceptable and feasible objective to minimise health effects within local capabilities and constraints and public health priorities. For particulate matter, for example, the WHO did not establish a lower limit below which no harmful health effects occur.

**Table 5: Overview of air quality guideline values of the World Health Organisation**

| Pollutant | Averaging period | Maximum allowable number of exceedances | Value |
|---|---|---|---|
| $PM_{10}$ | 1 day | 3 | 50 µg/m$^3$ |
| | year | | 20 µg/m$^3$ |
| $PM_{2.5}$ | 1 day | 3 | 25 µg/m$^3$ |
| | year | | 10 µg/m$^3$ |
| $NO_2$ | 1 hour | 0 | 200 µg/m$^3$ |
| | year | | 40 µg/m$^3$ |
| $O_3$ | 8 hour | 0 | 100 µg/m$^3$ |
| $SO_2$ | 10 minutes | | 500 µg/m$^3$ |
| | 1 day | 0 | 20 µg/m$^3$ |

Source: WHO, 2006

## 1.3 Review of European Directive 2008/50/EC

The current policy at European and national level has not yet produced the expected results. There are various reasons for this. In traffic, for example, the transport volume has increased, there is a gap between the emission standards established for each vehicle type and the actual emissions, and the planned renovation of the car fleet is taking place more slowly than expected (EU, 2011). This is why the European Commission is currently working on an in-depth review of EU Directive 2008/50/EC, building further on the policy framework set out in the "Thematic Strategy on Air Pollution and Clean Air for Europe (CAFE)" of 2005. The review process includes a public and expert-oriented survey and the creation of an interest group made up of experts from the various member states, European institutions, industry, environmental action groups, etc. In addition, a number of workshops are organised where research institutes can make their contributions and the European Commission is entering into a dialogue with international organisations such as WHO, UNECE and other relevant forums active in the field of air quality. The review is expected to be finalised by the end of 2013. At the same time, the National Emission Ceilings (NEC) Directive (2001/81/EC) will be reviewed, resulting in new emission ceilings being imposed on the various member states.

## 2    Periods of increased air pollution – smog episodes - in 2011

The concentrations of air pollutants in the ambient air vary from day to day (and even from hour to hour). This has various causes. First of all, the concentrations depend on the pollution that is emitted by human and natural sources. Major sources of pollution include industry, traffic, agriculture, and households. These emissions are emitted locally, but can also travel long distances in the atmosphere. As a result, concentrations can sometimes increase due to the import of pollutants from abroad. Pollutants can be formed or removed by various physico-chemical reactions in the atmosphere and can be removed from the air by deposition. A very important factor that determines the concentration levels in the air, is the weather. Parameters such as pressure, temperature, wind direction and speed, turbulence, etc. all affect the processes that occur in the atmosphere or the extent to which air pollution can be diluted.

When the concentrations in the air become too high, smog is formed. The main substances that can cause smog are particulate matter, ozone, nitrogen dioxide and sulphur dioxide.

Increased air pollution due to particulate matter, nitrogen dioxide and sulphur dioxide during the winter (winter smog) usually occurs under stable weather conditions with little wind and in the presence of a temperature inversion. The conditions for dispersion of the air pollution in the atmosphere are then unfavourable. A temperature inversion at low altitude causes the polluted air to remain trapped close to the ground surface with a layer of warmer air above it.  When such a situation persists for several days, the polluted air can accumulate and the concentrations of air pollutants will gradually rise.

Ozone smog episodes (summer smog) occur especially on hot summer days (>25°C) with few clouds and little wind.

Smog periods can also be the result of the import of air pollution from nearby regions. This is generally accompanied by local air currents allowing the air pollution to accumulate during the long distance transport.

Increased particulate matter concentrations can also be the result of a sudden increase in secondary particulate matter. In contrast with directly emitted or primary particulate matter, secondary particulate matter is formed by chemical reactions in the atmosphere. Chemical analyses of particulate matter show that "secondary inorganic" salts account for 30 to 40% of the total mass of particulate matter (VMM, 2009; 2010). An important component in this context is ammonia. High secondary particulate matter concentrations often occur in spring, when farmers clean the stables and spread out manure, resulting in high ammonia emissions.

However, a smog episode is rarely attributable to a single cause. High concentrations in the air are nearly always the result of a combination of the above factors (emissions, weather, import, secondary reactions), with one cause predominating over the others, depending on the situation.

An overview of the daily mean particulate matter concentrations, the daily maximum concentrations of ozone, nitrogen dioxide and sulphur dioxide in 2011 is given in Annex B.

## 2.1 Particulate matter

Two particulate matter smog episodes occurred during the winter of 2011. The first episode ran from January 29th to February 1st. At the beginning of this period, the high particulate matter concentrations were caused primarily by the import of air pollution from abroad. Figure 4 shows the origin of the air masses that arrived in Belgium on January 30th. The air pollution was initially transported from Poland over Germany and the Netherlands to our country. The last two days of this smog period were characterised by very unfavourable dilution conditions, as a result of which the already present air pollution, together with local emissions, led to measured daily mean particulate matter concentrations fluctuating around 75 µg/m³, locally reaching values as high as 140 µg/m³, see Figure 5.
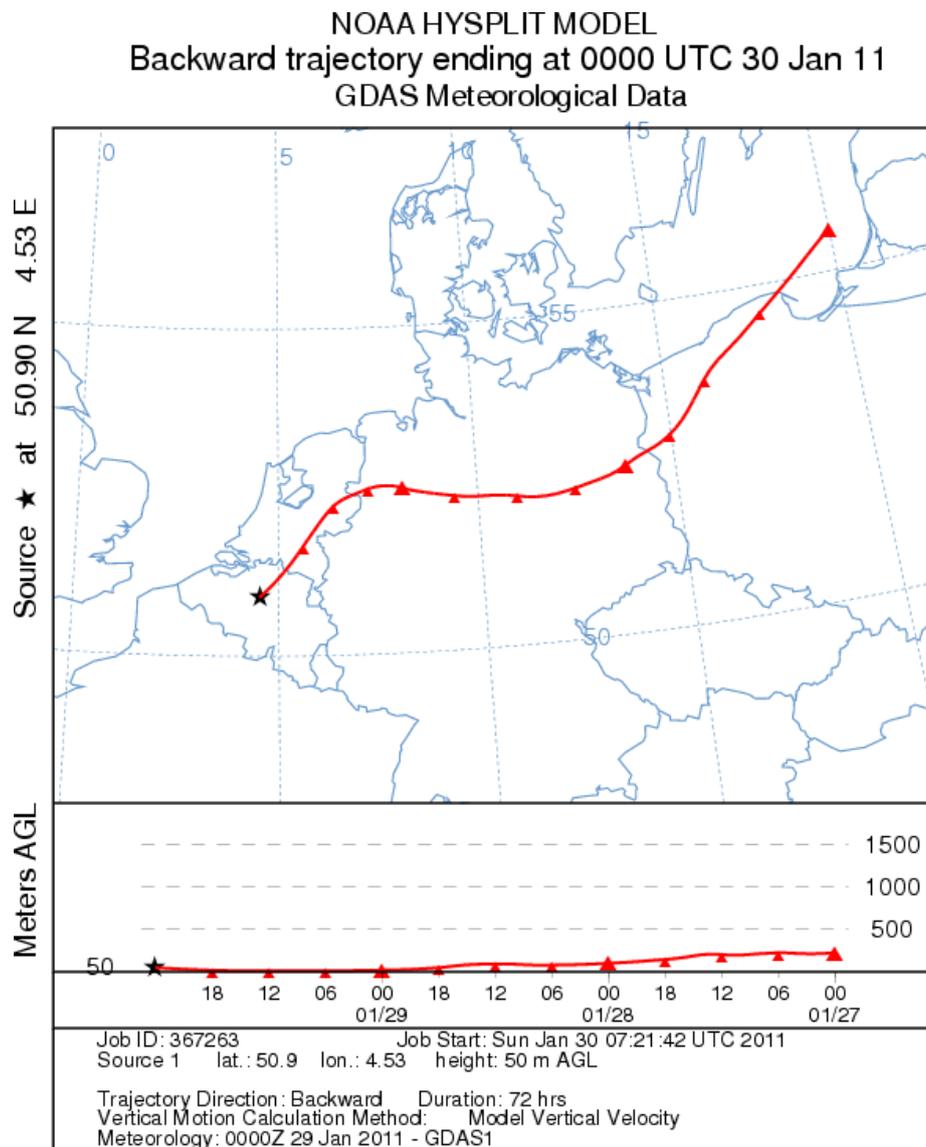


**Figure 4: Trajectory of the air mass that reached Belgium on 30/1/2011**
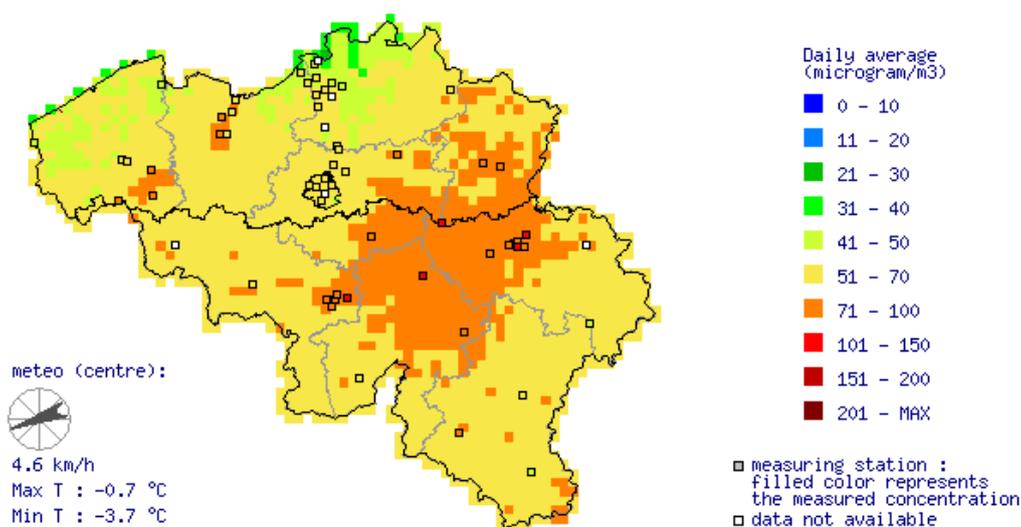
**Figure 5: Daily mean particulate matter concentration on 31/1/2011**

The second particulate matter episode occurred in the first week of March. On February 28th, particulate matter concentrations increased by around 50 µg/m³ in a couple of hours. This increase was caused by the import of polluted air which was transported from Poland over the north of Germany and via the Netherlands to our country. At the same time, a temperature inversion was present at 500m altitude. During that week, daily mean $PM_{10}$ concentrations of up to 80-90 µg/m³ were measured in Belgium, despite the moderate wind. Not only high $PM_{10}$ concentrations, but also high $PM_{2.5}$ and BC concentrations were measured.

The period from mid-February to mid-April was characterised by dry, stable weather, often with continental air currents. This dry weather caused an increase in wind-blown dust and in the month of April the formation of secondary particulate matter probably also played an important role. This highly unfavourable weather period was responsible for the fact that more exceedance days (= days with daily mean > 50 µg/m³) were recorded in the first 4 months of 2011 compared to the same period in previous years.

The period from 14 to 23 November was again characterised by poor dilution conditions due to the presence of a strong high pressure area which led to a so-called subsidence inversion and low wind speeds. The daily mean particulate matter concentrations in that period reached values of 50 to 70 µg/m³. The alert threshold for implementation of a smog alarm together with traffic reduction measures, was not reached. This alert threshold is 70 µg/m³ (average in a region) and must be forecast for two consecutive days.

## 2.2 Ozone

The spring of 2011 was exceptionally warm and very sunny, which resulted in increased ozone concentrations in the second half of April and in May. The summer months of 2011, with the exception of a few summer days at the end of June, were characterised mainly by the inflow of clean maritime air and many days with precipitation. Due to the bleak summer there were no long periods of ozone pollution. At the end of September and during the first days of October, the weather was extremely mild, with still a number of summer-temperature days, which were also accompanied by high ozone concentrations.

The information threshold of 180 µg/m³ was exceeded on one day only, notably on June 28th, in a number of locations, see Figure 6. An exceedance was measured at one measuring station on October 2nd. The alert threshold of 240 µg/m³ was not exceeded in 2011.
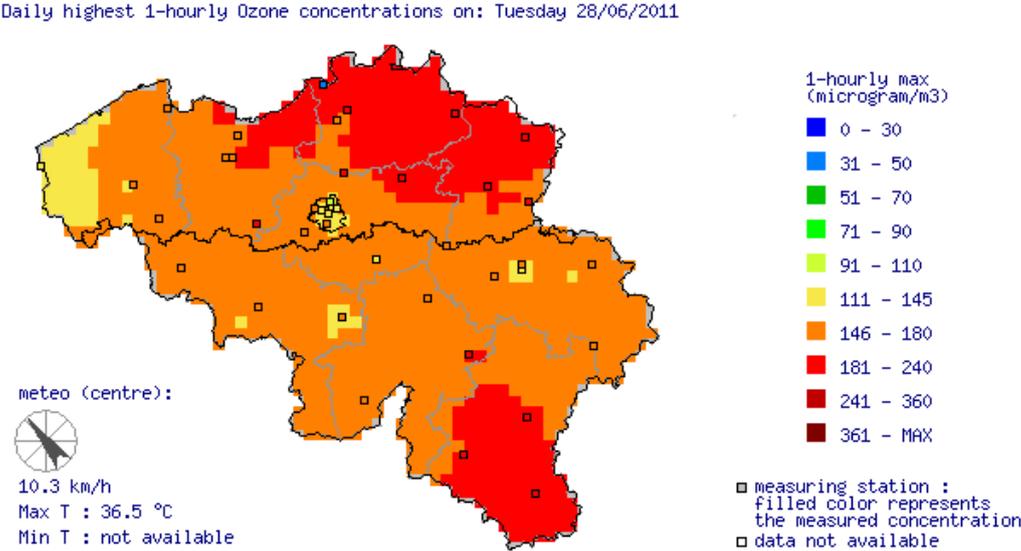


**Figure 6: Peak ozone concentrations on 28 June 2011**

# 3 Particulate matter

Particulate matter denotes all small solid and liquid particles that float around in the atmosphere. They can reside there for hours to months depending on their properties (e.g. particle size) and on meteorological conditions. A particle floating around in a gas is called an aerosol. The behaviour of particles in an aerosol is determined by the properties of the particles (dimensions, form, density) and those of the gas (velocity, turbulence, composition). The term "aerodynamic diameter" has been developed to describe the behaviour of particles. This behaviour is determined by the dimensions of the particles, but also by their form and density. The aerodynamic diameter is defined as the diameter of a spherical particle whose behaviour in ambient air is identical to that of the particle under consideration, hereby assuming that the spherical particle has the same density as water. The $PM_{10}$ particle fraction has an aerodynamic diameter less than 10 micrometer (µm), $PM_{2.5}$ has a diameter of less than 2.5 µm.

The particles can end up in the atmosphere through a natural cause (natural aerosol) or through human activities (anthropogenic aerosol). In both cases, they can be categorised as primary and secondary particles in terms of the way in which they are formed. Primary particles are emitted directly into the atmosphere or formed by mechanical fragmentation of coarser material (e.g. heavy metals in metal processing). The main emissions caused by humans originate from transport, industry, agriculture and building heating. Major natural sources of primary particulate matter are sea salt aerosol and wind-blown soil dust. Secondary particles are formed in the atmosphere by oxidation and transformation from gaseous components such as $NH_3$, $SO_2$, $NO_x$ or from organic compounds such as volatile organic compounds (VOCs).

The composition of secondary particles is highly complex. They are formed from the gaseous phase, and by condensation, where substances with the lowest vapour pressure condense faster than those with a higher vapour pressure. Fine particles can therefore exhibit a complex, layered structure. This is amplified by the fact that the available surface of all particulate matter in the atmosphere is delivered mainly by the small particles. Substances that are emitted in gaseous form (including dioxins) will therefore be deposited almost exclusively on the small particles. Heavy metals from foundries and traffic, PAHs, dioxin and soot are therefore present in the fine fraction.

Epidemiological studies show that the most severe health effects caused by air pollution are due to particulate matter, and to a lesser extent, to ozone. Inhalation of particulate matter causes irritation or damage to the pulmonary tissue. Particulate matter can cause both short and long-term health effects. According to the World Health Organisation (WHO), there is no safe threshold value below which no harmful effects occur. While short-term exposure to particulate matter complicates existing health problems such as respiratory infections and asthma, the health effects of long-term or chronic exposure are significantly more severe. Chronic exposure increases the risk of cardiovascular and pulmonary diseases and of lung cancer. Exposure to the current $PM_{2.5}$ concentrations is estimated to reduce average life expectancy of the Belgian population by approximately nine to ten months (Amann et al., 2005). In the Flemish Region, particulate matter accounts for approximately three-quarters of lost years of healthy life due to environmental factors (MIRA, 2012). The $PM_{2.5}$ fraction was found to have the strongest link with health effects, but effects were also demonstrated for the finer UFP fraction (UltraFine Particles; particulate matter with diameter less than 0.1 µm) and the coarser 2.5-10 µm fraction (Brunekreef et al, 2005). Particulate matter includes Black Carbon (BC or diesel soot) and other combustion-related material, which in itself is not the most toxic component of the smaller PM particles, but it is a carrier of various chemical, toxic substances.

In addition, particulate matter has adverse effects on climate change and ecosystems. It contributes to the degradation of treated surfaces which therefore need to be cleaned more often (the so-called soiling effect) and has, depending on the composition, a corrosive effect on material and cultural heritage. Particulate matter has both a cooling (sulphate aerosols) and warming (black carbon) effect, and therefore also plays a role in climate change.

## 3.1 $PM_{10}$

### 3.1.1 $PM_{10}$ monitoring stations

Figure 7 shows the evolution of the number of monitoring stations where $PM_{10}$ is measured and which are shown on the RIO interpolation maps in this report. They include both the telemetric stations and the stations used in specific studies. The number of $PM_{10}$ monitoring stations in Belgium has risen from 20 in 1997 to 65 in 2011. Because the number of monitoring stations for 2004 is considerably less than in 2011, the uncertainty on the interpolated annual mean concentrations is greater in those initial years. For the Walloon region, this applies from 2008 onwards.
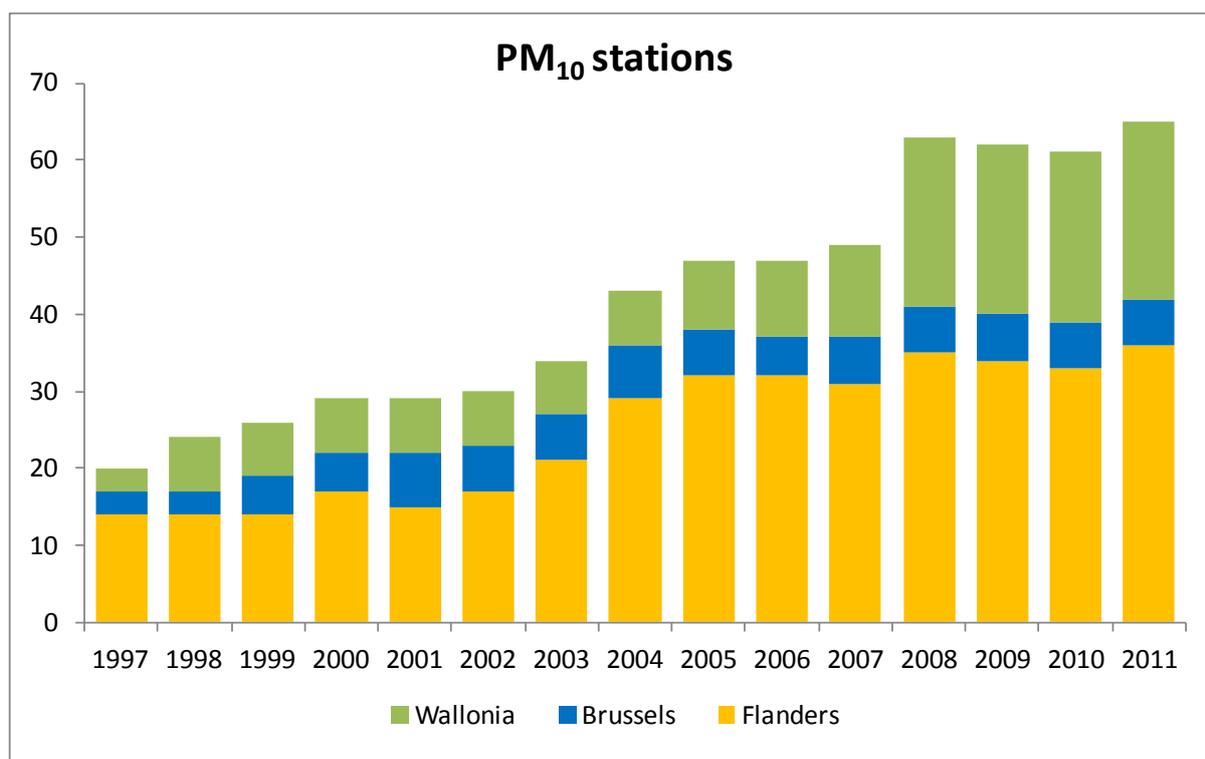


**Figure 7: Evolution of the number of $PM_{10}$ monitoring stations in Belgium**

### 3.1.2 $PM_{10}$ annual mean concentration

The European limit value for protection of human health from long-term exposure to $PM_{10}$ is 40 µg/m³ as the annual mean concentration. In 2011 the interpolated annual mean $PM_{10}$ concentration across all RIO grid cells in Belgium was 20.6 µg/m³. The 40 µg/m³ limit value was not exceeded at any location (Figure 8). The highest annual mean $PM_{10}$ concentrations were calculated in East and West Flanders, northwestern Flemish Brabant and around Antwerp. In general, the concentrations in this region are between 26-30 µg/m³, whereas concentrations of 31-35 µg/m³ are reached around Ghent, Antwerp,

Ostend, Bruges and Kortrijk. The lowest annual mean $PM_{10}$ concentrations, between 0-15 µg/m³, were recorded south of Sambre and Meuse rivers.

The uncertainty on the annual mean concentration map is given in Annex D, which also contains a map showing the probability of exceedance of the European annual limit value.
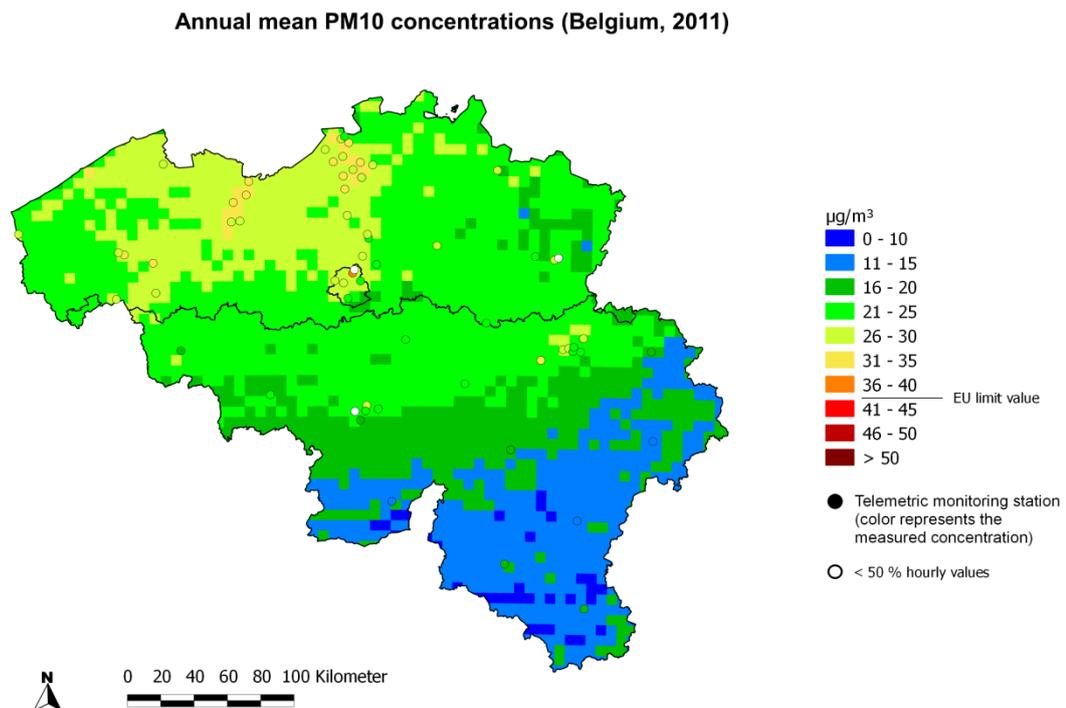


**Figure 8: Spatial distribution of the annual mean $PM_{10}$ concentration in Belgium in 2011. All data were calculated using the RIO interpolation technique.**

Figure 9 uses box plots to show the evolution of the minimum, the 25th percentile (P25)[1], the 50th percentile (P50), the 75th percentile (P75) and the maximum annual mean $PM_{10}$ concentrations in Belgium (see also Annex C for details on the interpretation of the box plots). It also shows the spatial average across Belgium. All these parameters show a similar trend. The distribution is more or less equal over the entire period. The annual mean $PM_{10}$ concentrations show a downward trend from 2003, which has levelled out in the past few years. Since 2007, the European limit value has been attained everywhere. The WHO guideline value of 20 µg/m³, however, is still being exceeded in over 25% of the Belgian territory.

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[1] P25 or the 25th percentile is the value at which 25% of all values are lower, and 75% of the values are higher.
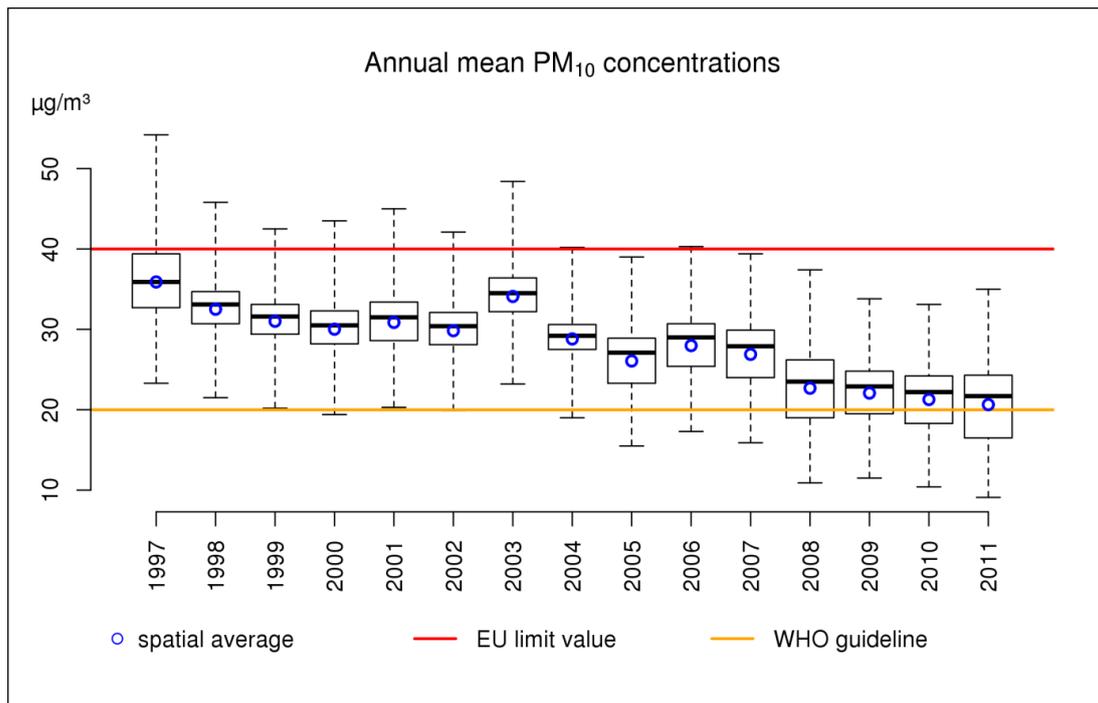
**Figure 9: Box plot of the annual mean PM$_{10}$ concentrations (µg/m³) over the period 1997-2011 in Belgium. The spatial average is represented by the blue circles. All data were calculated using the RIO interpolation technique.**

The annual mean PM$_{10}$ concentration in 2011 for Brussels, Flanders and Wallonia are 25.4, 24.4 and17.6 µg/m³ respectively (Figure 10). The population-weighted concentration, for which grid cells with a higher population density are given more weight in calculating the spatial average, is invariably higher than the Belgian annual mean PM$_{10}$ concentration and for 2011 it is more or less equal to the annual mean PM$_{10}$ concentration in Flanders (24.5 µg/m³).

The spatial trend between 2000 and 2011 shows that during this period the PM$_{10}$ annual mean concentrations have declined everywhere in Belgium, see Figure 11. This decline seems to be slightly greater in Wallonia, between -1.6 and -2.0 µg/m³/year, than in Flanders, between -0.4 and -0.8 µg/m³/year. Here it should be noted (as already mentioned in Note 2 on p. 10) that prior to 2008 only a limited number of PM$_{10}$ monitoring stations were operational in Wallonia, which moreover were located mainly in industrial areas. This may give rise to an overestimation of the PM$_{10}$ concentrations across the Walloon Region at the beginning of the period, so that the decline probably appears bigger than it actually is.

Furthermore, it should be mentioned that a European reference method exists for measuring particulate matter. Particulate matter monitoring techniques other than this European reference method may be used if they can be demonstrated to be equivalent to this European reference method. If necessary, a calibration is performed (PM$_{cal}$ = A x PM$_{measured}$ + B). This calibration depends on the measuring method used and can evolve over time. All measurement results used for the RIO interpolation technique are calibrated measurement results which have been demonstrated to be equivalent to the European reference method.
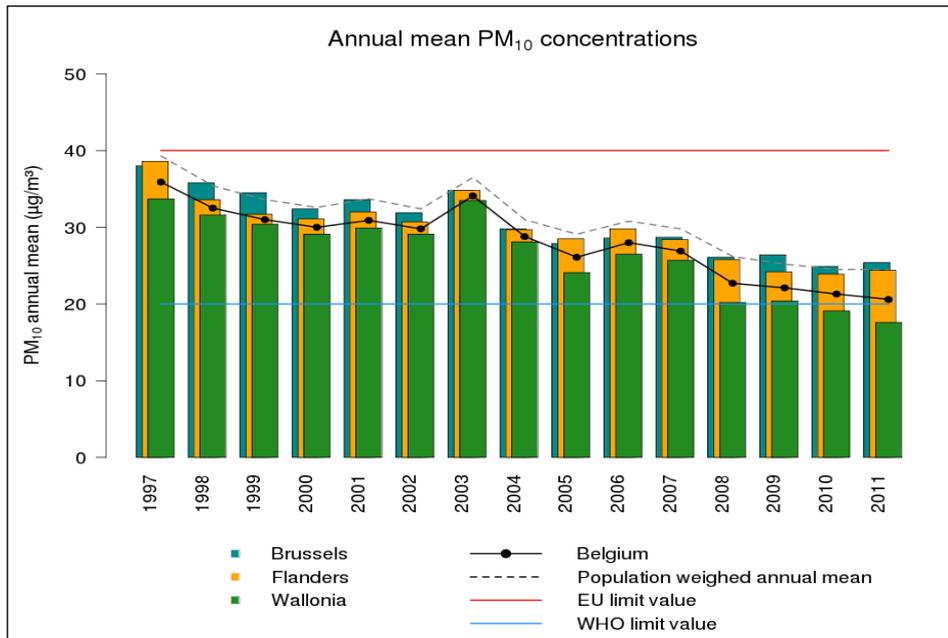
**Figure 10: Evolution of the spatially distributed annual mean PM$_{10}$ concentration in Belgium and the three Regions and the population-weighted mean concentration for Belgium. All data were calculated using the RIO interpolation technique.**
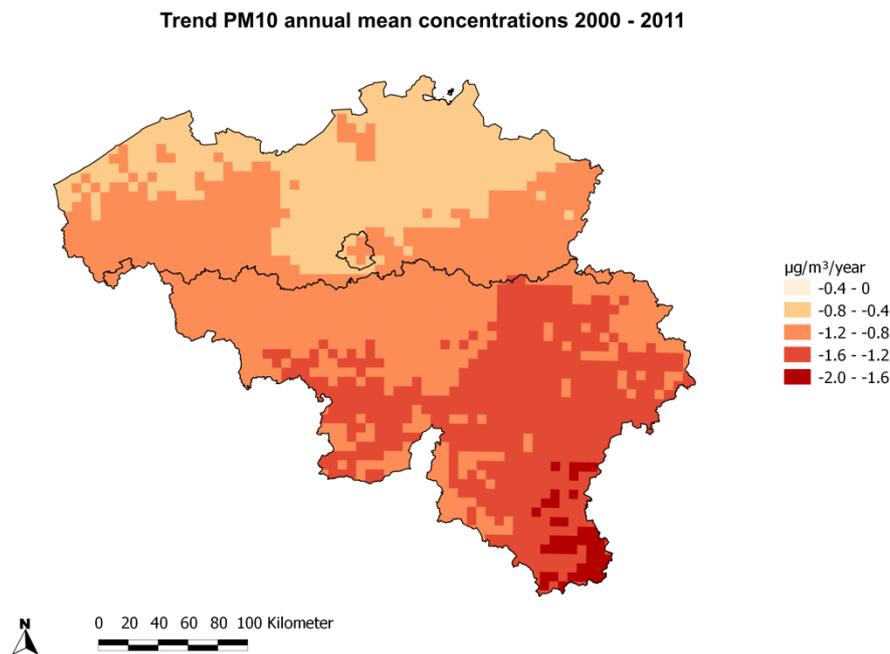


**Figure 11: Spatial trend in annual mean PM$_{10}$ concentrations (μg/m³/year). All data were calculated using the RIO interpolation technique.**

In 2011 the Belgian population was not exposed to annual mean concentrations above the European limit value of 40 μg/m³ (Figure 12). 89% of the population was, however, still exposed to annual mean

PM$_{10}$ concentrations above the guideline value of 20 µg/m³. The downward trend in population exposure of recent years continues. In 2011, 11% of the population was exposed to PM$_{10}$ concentrations lower than the WHO guideline value (< 20 µg/m³), whereas in 2010 this was only 8% and in 2006 even 0%.
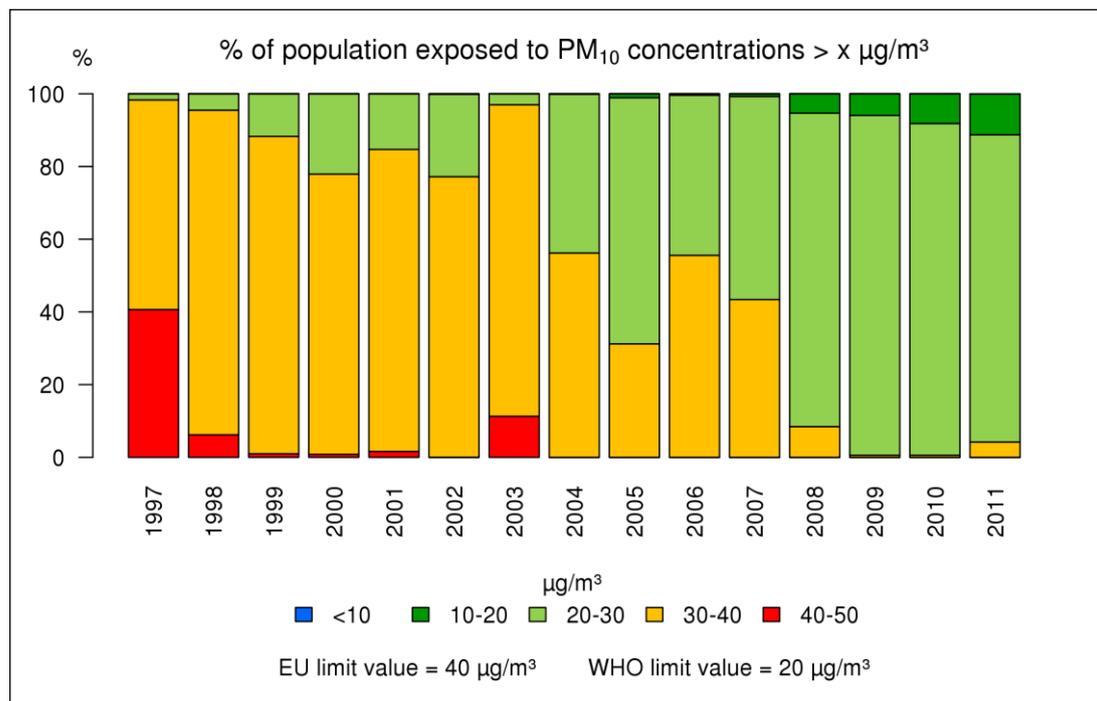


**Figure 12: Evolution of the exposure of the population to annual mean PM$_{10}$ concentrations on the basis of the RIO interpolation technique**

### 3.1.3 PM$_{10}$ daily mean concentration

The EU limit value for protection of human health from short-term exposure to PM$_{10}$ is a daily mean PM$_{10}$ concentration of 50 µg/m³ that is not to be exceeded more than 35 times per year. In 2011 this threshold was exceeded at several locations in the Flemish, Walloon and Brussels-Capital Regions, including almost the entire province of West Flanders, the northwestern part of the province of East Flanders, the Port of Antwerp area, the northern part of the Brussels-Capital Region and at various locations in the Sambre and Meuse valley (Figure 13). At a number of locations in the areas around the Ports of Ghent and Antwerp, the daily mean concentration of 50 µg/m³ was even exceeded more than 50 times. In 2011, the maximum, minimum and average exceedance days in Belgium amounted to 59, 0 and 19 respectively. The WHO air quality guidance value for short-term exposure, i.e. no more than 3 days where the daily mean PM$_{10}$ concentration exceeds 50 µg/m³, was attained only at a few locations south of Sambre and Meuse rivers.

A map showing the calculated probability of exceedance of the European daily limit value is included in Annex D.

**Number of days with daily mean PM10 > 50 µg/³ (Belgium, 2011)**
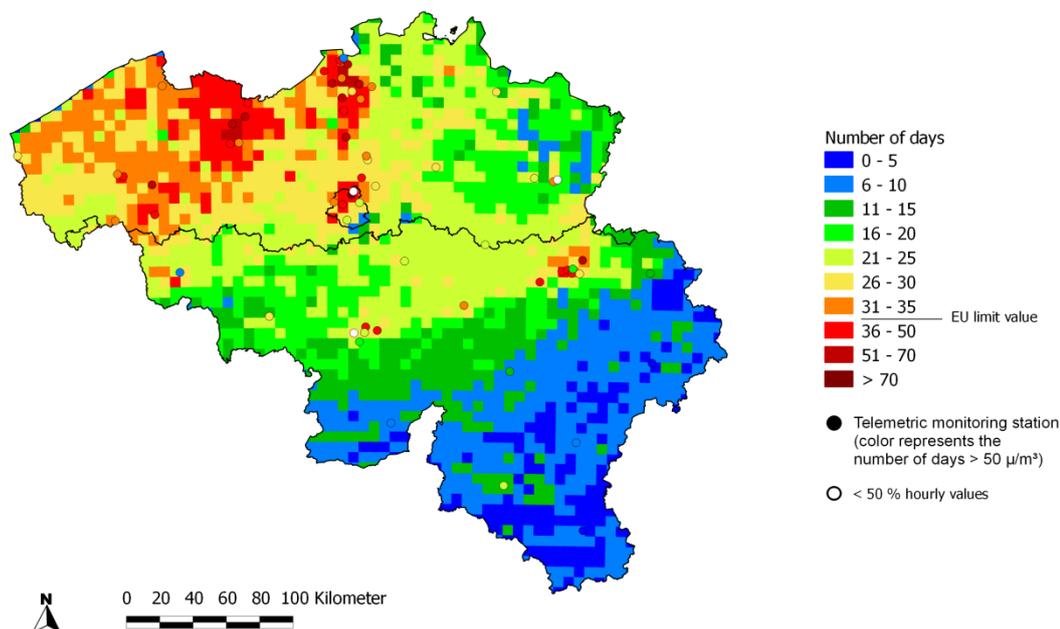
**Figure 13: Spatial distribution of the number of days in 2011 where the daily mean PM$_{10}$ concentration of 50 µg/m³ was exceeded in Belgium. All data were calculated using the RIO interpolation technique.**

With 59 days, the maximum number of days where the daily mean PM$_{10}$ concentration exceeded 50 µg/m³ in Belgium increased by 40% compared to 2010, when a maximum of 42 exceedance days were recorded, see Figure 14. Fluctuations between years may be driven by meteorological conditions. Nevertheless, a downward trend can be observed in the number of exceedance days in Belgium since 1997, which indicates that also the measured decline in emissions of primary particulate matter and particulate matter precursors has a positive effect on the number of exceedance days. The spatial variation has also decreased in Belgium since 1997. The European limit value of 35 days which should already have been attained by 2005 was still being exceeded at various locations in 2011. The WHO guideline value of 3 exceedance days was almost nowhere attained. Consequently, in 2011, 99.8% of the total Belgian population was exposed to daily mean PM$_{10}$concentrations above the WHO guidance value.
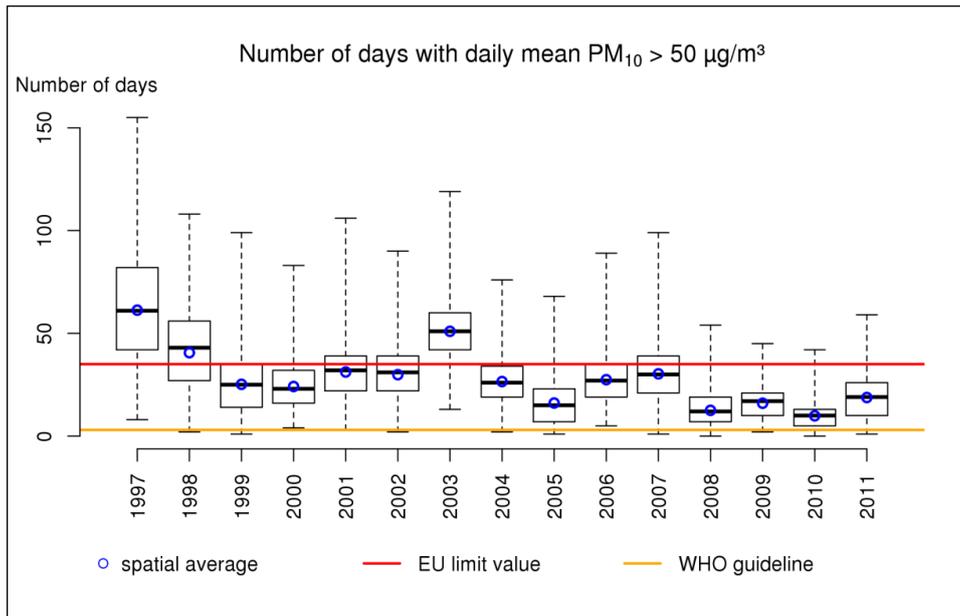
**Figure 14: Box plot of the number of days per year where the daily mean PM$_{10}$ concentrations exceeded 50 µg/m³. The spatial average is represented by the blue circles. All data were calculated using the RIO interpolation technique.**

The downward trend in the number of exceedance days since 1997 is observed for the three Regions (Figure 15). In 2011, the maximum number of days where the daily mean limit value was exceeded in the Flemish, Walloon and Brussels-Capital Regions amounted to 59, 38 and 39 respectively.
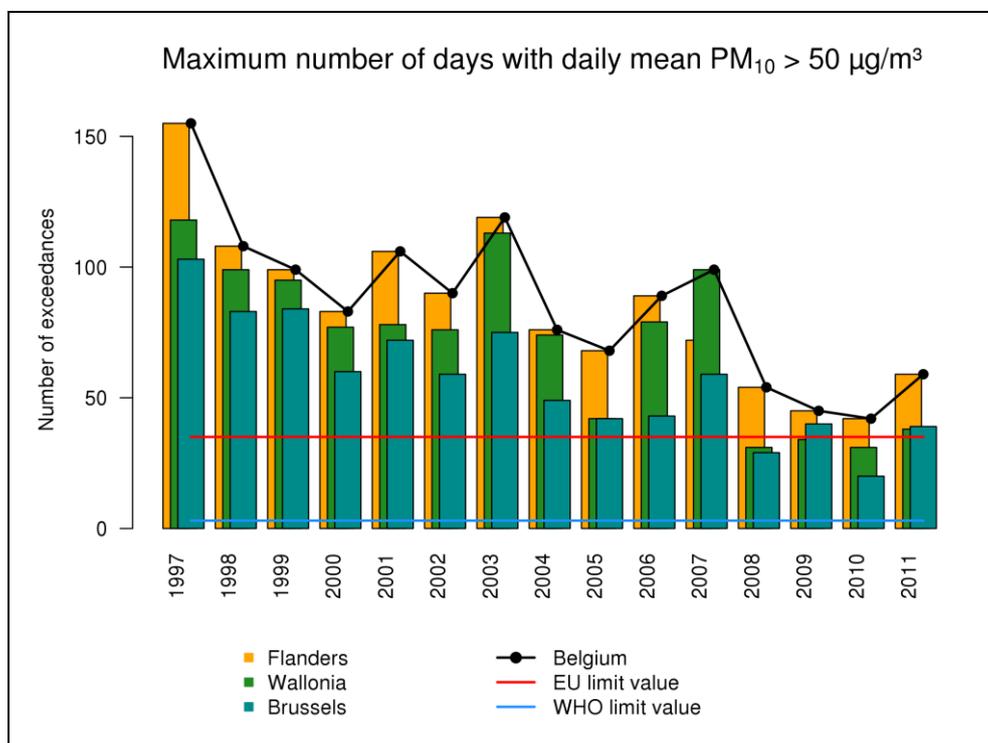


**Figure 15: Evolution of the <u>maximum</u> number of days per year where the daily mean PM$_{10}$ concentration exceeded 50 µg/m³ in Belgium and the three Regions. All data were calculated using the RIO interpolation technique.**

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Figure 16 shows the spatial distribution of the trend in the number of days with daily mean $PM_{10}$ concentrations above 50 μg/m³ over the period 2000-2011. The largest decrease (2 to 5 exceedance days per year) occurs in the large agglomerations of Ghent, Antwerp, Brussels, Charleroi and in the area around Liege. On average, the decrease in the number of exceedance days has been rather limited during the past 12 years.

**Trend in number of days with daily mean PM10 > 50 μg/m³**
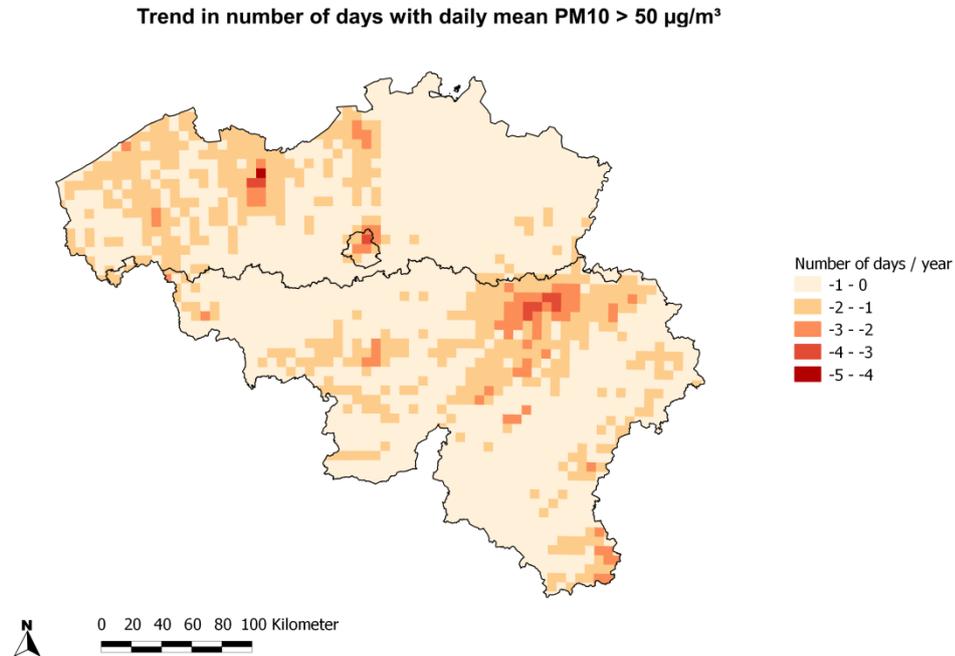


**Figure 16: Spatial trend of the number of days with daily mean > 50μg/m³ over the period 2000-2011 (number of days/year). All data were calculated using the RIO interpolation technique.**

The significantly higher number of exceedance days in 2011 compared with 2010 means that also a higher population percentage was exposed to more than 35 exceedance days (Figure 17), namely 18% of the Belgian population. 1% of the population was even exposed to more than 50 exceedance days of the European daily limit value of 50 μg/m³. As such, the situation in 2011 is clearly worse than in past three years, but better than in 2007 and previous years, with the exception of 2005.

29
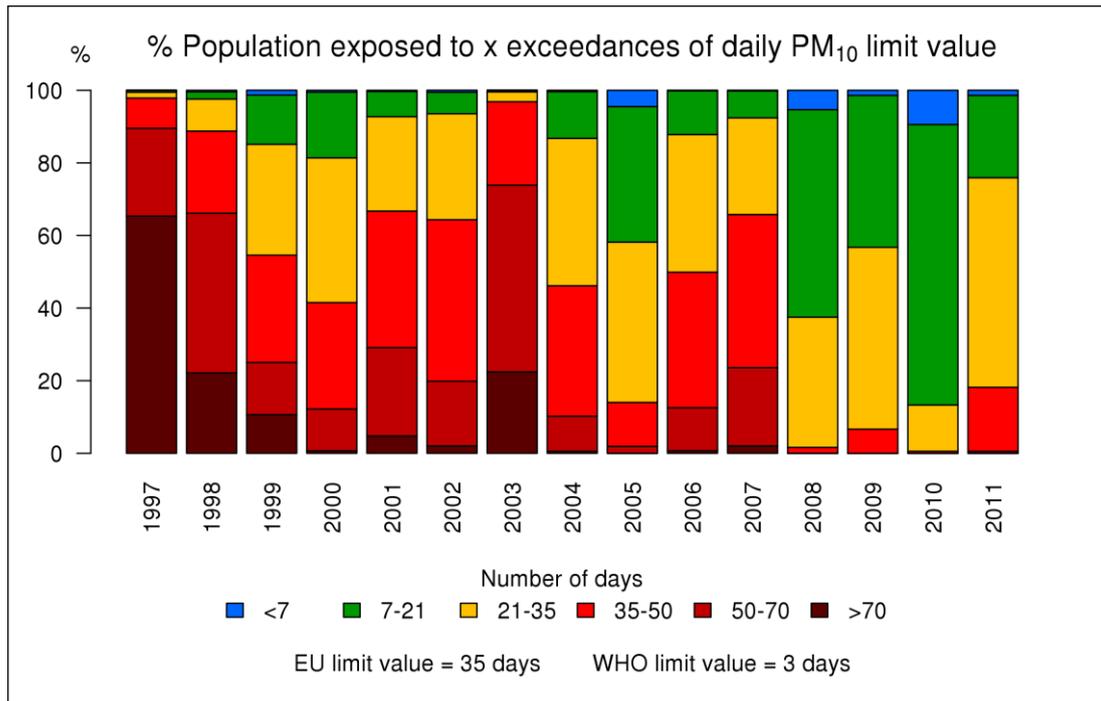
**Figure 17: Evolution of the population exposure to days where the daily mean PM$_{10}$ concentration exceeded 50 μg/m³ . All data were calculated using the RIO interpolation technique.**

Figure 18 shows how the maximum number of exceedance days per region is distributed over the various months, both for 2011 and averaged for the three previous years. In 2011, exceedances were observed mainly during the first half of the year, from January to April, and also in November. March was the worst month with 13, 16 and 13 exceedance days for Brussels, Flanders and Wallonia respectively. For Flanders, an additional exceedance was observed in May and in October. This distribution is similar to that of the past three years, where the majority of exceedances was also recorded in the period from January to April. There is one difference in that in 2008-2010 several exceedances were observed in the month of December, whereas in 2011 not a single exceedance occurred in December. Also in June, July and September, a number of exceedances were occasionally observed in the previous three years, which was not the case in 2011.
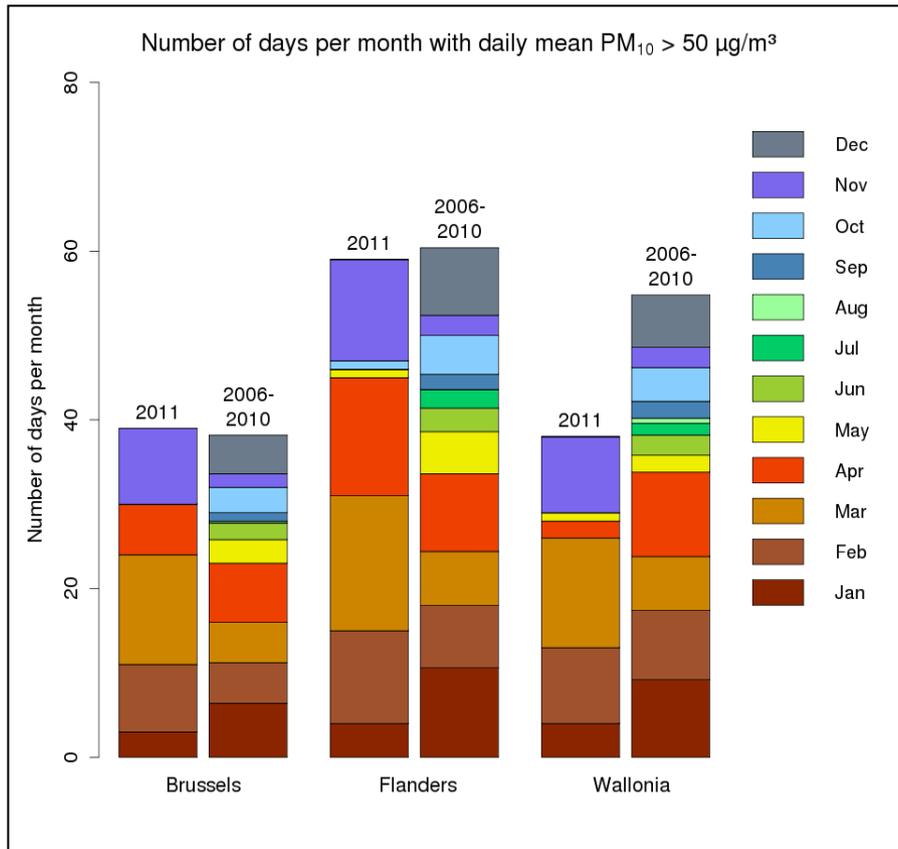
**Figure 18: Highest number of days per month where somewhere in the Brussels-Capital, Flemish and Walloon Regions the daily mean PM$_{10}$ limit value of 50 μg/m³ was exceeded in 2011 and the three previous years. All data were calculated using the RIO interpolation technique.**

## 3.2 PM$_{2.5}$

### 3.2.1 PM$_{2.5}$ monitoring stations

Figure 19 shows the evolution of the number of monitoring stations where PM$_{2.5}$ is measured and which are shown on the RIO interpolation maps in this report. They include both the telemetric stations and the stations used in the specific studies. The number of PM$_{2.5}$ monitoring stations has risen significantly from 5 in 2000 to 37 in 2011. Because the number of monitoring stations for 2008 is substantially less than in 2011, the uncertainty on the annual mean values is greater in these initial years. This is especially true for Wallonia where no PM$_{2.5}$ was measured before 2008.

31
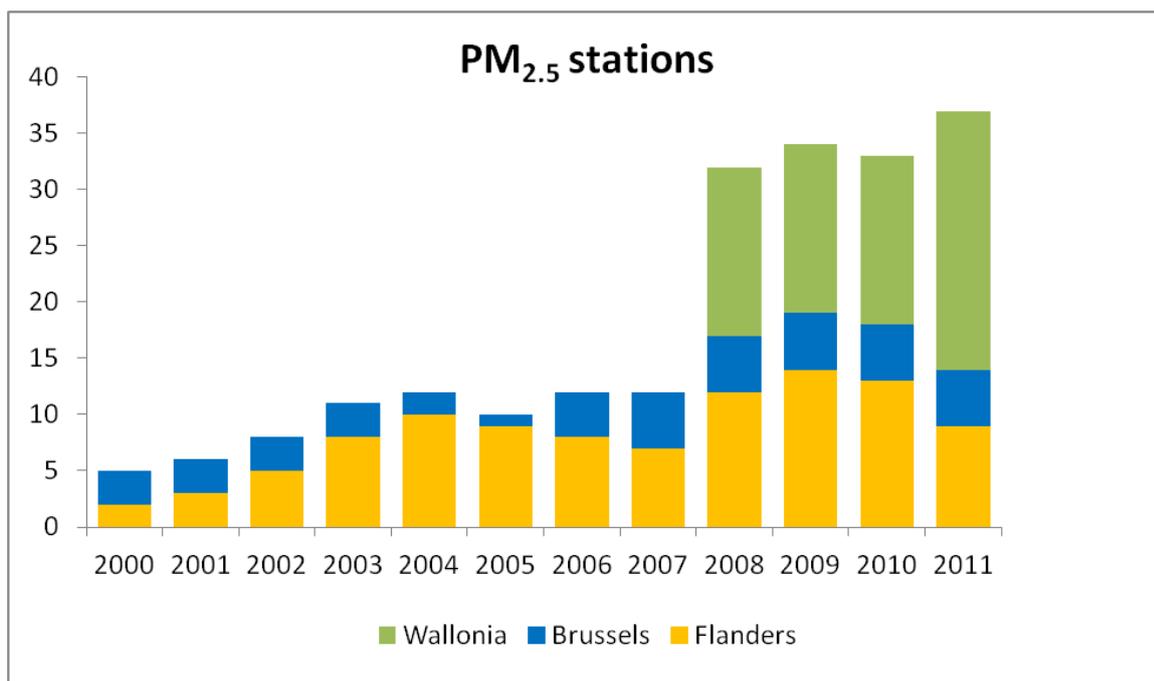
**Figure 19: Evolution of the number of PM$_{2.5}$ monitoring stations in Belgium**

### 3.2.2 *PM$_{2.5}$ annual mean concentration*

The European limit value for protection of human health from long-term exposure to PM$_{2.5}$ was set at 25 μg/m³ as the annual mean concentration. However, compliance by the various member states with this limit value is not required until 2015. Until then, the 25 μg/m³ limit is used as target value. In 2011, the annual mean PM$_{2.5}$ concentration was less than 25 μg/m³ everywhere in Belgium. The spatially average PM$_{2.5}$ concentration across Belgium was 13.7 μg/m³. The maximum concentration of 23.5 μg/m³ was calculated in the Brussels-Capital Region. Concentrations above 20 μg/m³, which is the European indicative limit value in 2020, also occurred in the areas of the Ghent, Antwerp and Ostend ports. The lowest concentrations, below the WHO guideline value of 10 μg/m³, were recorded south of the Sambre and Meuse valley.

The uncertainty on the calculated annual mean PM$_{2.5}$ map is given in Annex D.

The spatially averaged PM$_{2.5}$ concentrations as well as the lowest percentiles have shown a downward trend since 2006 (Figure 21). The maximum annual mean concentration has levelled out over the last few years, but is below the European limit value of 25 μg/m³. In 2011, annual mean PM$_{2.5}$ concentrations above the WHO guideline value of 10 μg/m³ were, however, still recorded in over 75% of Belgium.

The spatially averaged annual concentrations for Flanders, Wallonia and Brussels were 16.7, 11.3 and 19.3 μg/m³ respectively in 2011. Since 2006, the PM$_{2.5}$ concentrations have decreased in all Regions, although for Brussels an increase by 1 μg/m³ as compared to 2010 was observed in 2011 (Figure 22). Based on spatial interpolation in 4x4 km grid cells, people have not been exposed to PM$_{2.5}$ concentrations above 25 μg/m³ since 2008. However, in 2011 11.8% of the Belgian population was exposed to PM$_{2.5}$ concentrations between 20 and 25 μg/m³, which is comparable with 2009 and 2010. Population exposure to concentrations less than 10 and between 10 and 15 μg/m³ has, however, increased in the past few years (Figure 23).

**Annual mean PM2.5 concentrations (Belgium, 2011)**
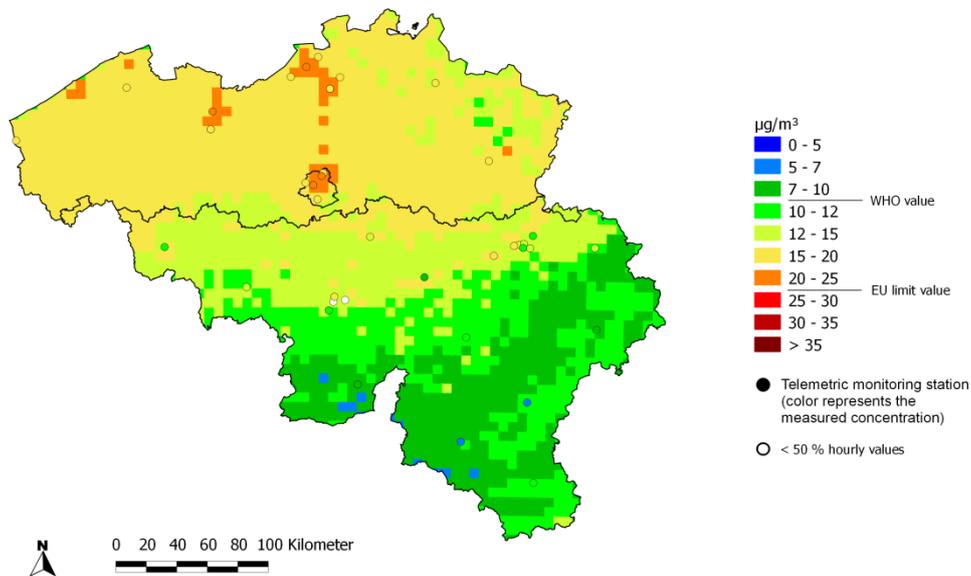
**Figure 20: Spatial distribution of the annual mean PM$_{2.5}$ concentration in Belgium in 2011. All data were calculated using the RIO interpolation technique.**
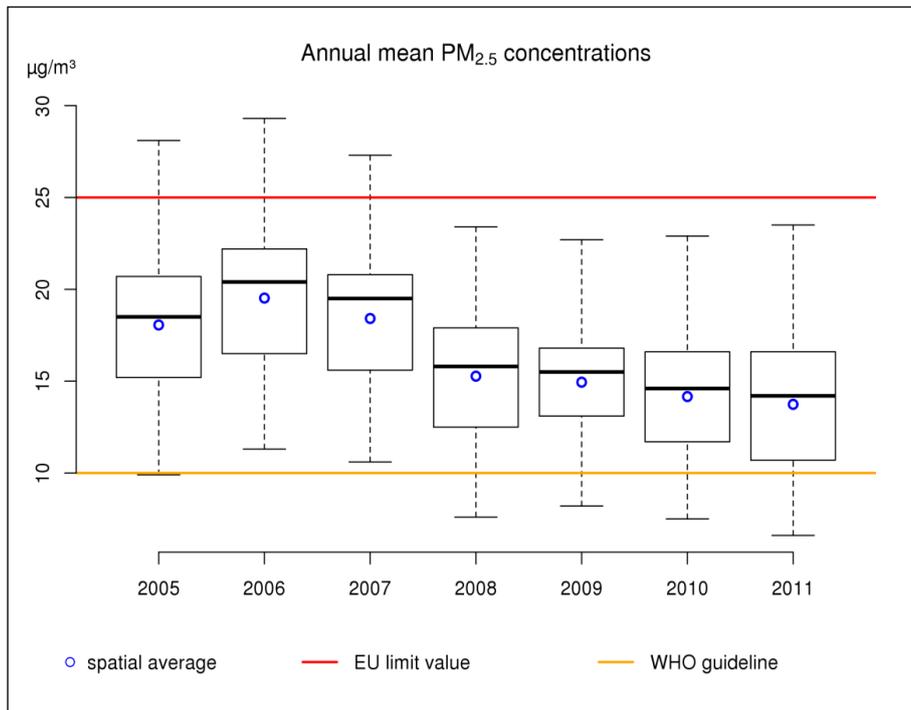


**Figure 21 Box plot of annual mean PM$_{2.5}$ concentrations (μg/m³) over the period 2005-2011. The spatial average is represented by the blue circles. All data were calculated using the RIO interpolation technique.**
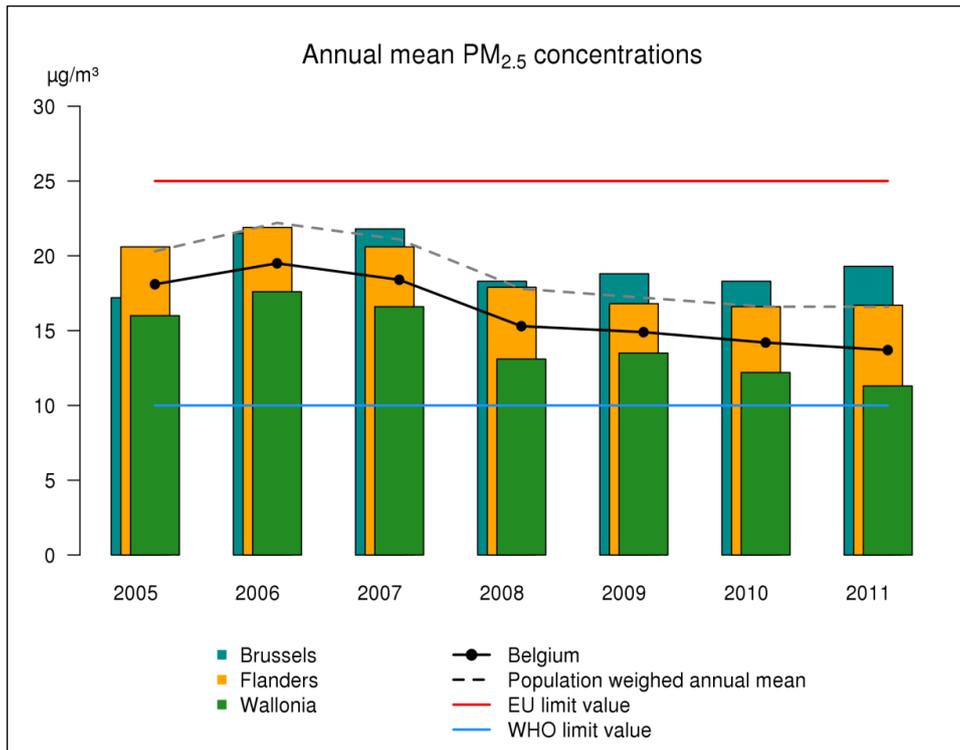
**Figure 22: Evolution of the spatially averaged annually mean PM$_{2.5}$ concentrations for the three Regions and Belgium, and of the population-weighted annual mean concentration for Belgium. All data were calculated using the RIO interpolation technique.**
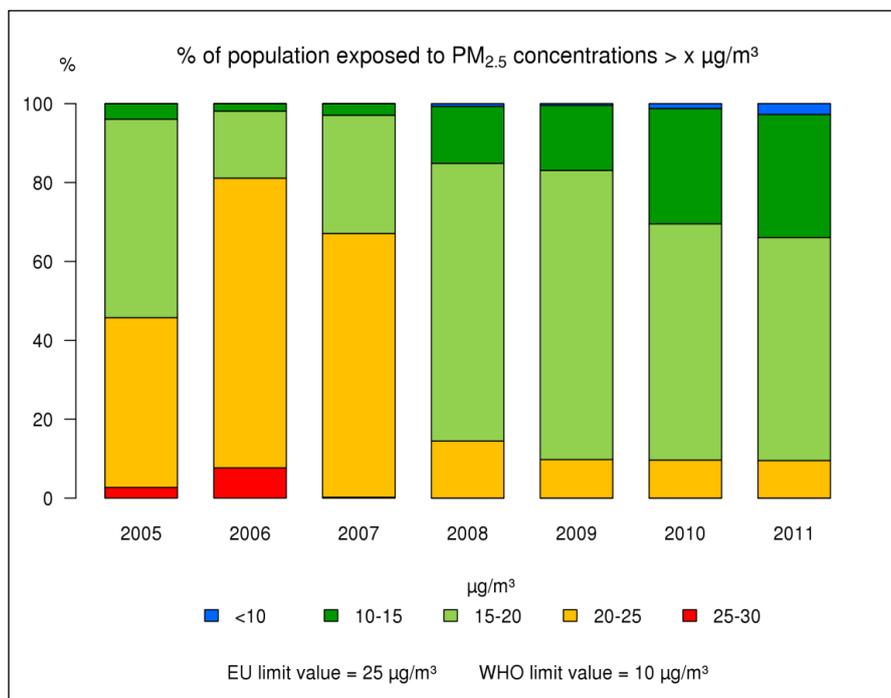


**Figure 23: Evolution of population exposure to annual mean PM$_{2.5}$ concentrations based on the RIO interpolation technique**

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Based on the PM$_{2.5}$ concentrations in the 4x4 km grid cells and the known population number per grid cell, a relationship can be established between the PM$_{2.5}$ concentration and the population density (number of inhabitants per km²) above a specified value (Figure 24). This relationship shows that people living in areas with a high population density are exposed to the highest annual mean PM$_{2.5}$ concentrations. In areas with more than 3750 inhabitants/km², annual mean PM$_{2.5}$ concentrations higher than 20 µg/m³ were recorded in 2011, just as during the period 2008-2010.
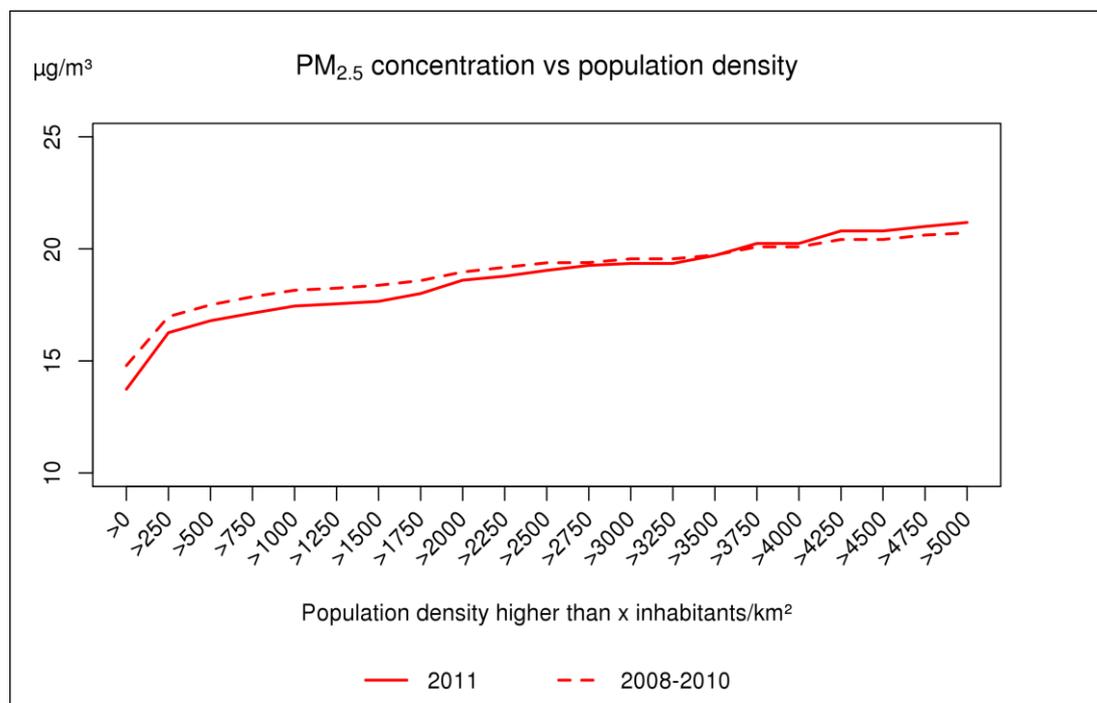


**Figure 24: Relationship between the interpolated annual mean PM$_{2.5}$ concentrations and the population density (inhabitants/km²) above a specified value. All data were calculated using the RIO interpolation technique.**

### 3.2.3   Average Exposure Index (AEI)

The "average exposure index" (AEI) is included as an additional provision in European Directive 2008/50/EC in order to reduce the exposure of the population to PM$_{2.5}$. The AEI is a national target value and is calculated as the three-year average of the PM$_{2.5}$ concentrations measured in urban background stations. For this AEI, a limit value of 20 µg/m³ and a reduction percentage to be attained by 2015 and 2020 respectively, have been established. For Belgium, this reduction percentage[2] is determined by the AEI which has been calculated based on the years 2009, 2010 and 2011, and is to be attained by 2020 based on the AEI for the years 2018, 2019 and 2020.

For the calculation of the AEI, only those stations that have met the data quality objectives, i.e. for which at least 90% validated data are available, are taken into account. Table 6 gives an overview of the urban background monitoring stations selected by the three Regions for the calculation of the AEI, together with the eventually calculated (national) AEI. The rounding of the calculation complies with the Commission Implementing Decision of 12 December 2011 (2011/850/EU) (Implementing

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[2] In accordance with Annex XIV of European Directive 2008/50/EC on ambient air quality and cleaner air for Europe.

Provisions for Reporting - IPR), i.e. the rounding should be the final step of the calculation and should be performed only once. For Belgium this results in an AEI of 19.0 μg/m³. In accordance with Annex XIV of Directive 2008/50/EC, this AEI falls into category "=18 -> 22 μg/m³", meaning that Belgium is required to reduce the AEI by 20% by 2020. This would yield an AEI of 15.2 μg/m³. The final assessment will be made on the basis of the measurements (in the same urban background monitoring stations) in the period 2018, 2019 and 2020.

**Table 6: Overview of the PM$_{2.5}$ concentrations for 2009, 2010 and 2011 per urban background station to be included in the calculation of the average exposure index or AEI**

| Station name | 2009 | 2010 | 2011 |
|---|---|---|---|
| SINT JANS MOLENBEEK | 21.81 | 22.44 | 25.05 |
| UKKEL | 18.63 | 18.45 | 18.77 |
| LIEGE | 16.41 | 14.54 | 14.66 |
| CHARLEROI | 16.45 | * | 14.17 |
| BRUGES | * | 18.91 | 18.64 |
| GHENT | 19.95 | 20.75 | 20.24 |
| ANTWERP | 20.16 | 20.16 | 19.55 |
| SCHOTEN | 19.20 | 19.27 | 18.96 |
| average per year | **18.94** | **19.22** | **18.75** |
| average 2009 2010 2011 | | **18.97** | |
| AEI | | **19.0** | |

*do not meet the data quality objectives specifying that at least 90% validated data must be available.*

# 4 Nitrogen oxides

Nitrogen oxide ($NO_x$) is the generic name for a mixture consisting mainly of nitrogen monoxide (NO) and nitrogen dioxide ($NO_2$). Nitrogen oxides are primarily emitted by human activities during high-temperature combustion processes in which dinitrogen ($N_2$) is oxidized. The major sources of $NO_x$ are (road) transport, energy production and industry (including refineries) and building heating. In Belgium, almost half of $NO_x$ emissions come from road transport. $NO_2$ is therefore a good proxy for the complex mixture of transport-related air pollution. $NO_x$ is mainly emitted as NO and to a lesser extent as $NO_2$ (except in the case of diesel vehicles, where the $NO_2/NO_x$ ratio can total 60%) (Grice et al. 2009). However, NO has a very short lifetime (a few minutes). NO undergoes photochemical reactions with other substances, including ozone and volatile organic compounds (VOCs), to form $NO_2$ which has a longer atmospheric life time (a few hours to days). Apart from anthropogenic emissions, $NO_x$ is also emitted into the atmosphere via biochemical processes in the soil, by lightning and forest fires.

Nitrogen oxides also play an important role in the formation of ozone and aerosols. On hot summer days with strong solar radiation, the UV light of the sun causes $NO_2$ to dissociate into NO and a free oxygen radical ($O^-$). The latter will subsequently react with an oxygen atom to form ozone ($O_3$). Ozone is a very reactive gas with harmful effects for the population and ecosystems. Nitrogen oxides also play a role in the formation of aerosols. Via chemical reactions in the atmosphere, $NO_x$ is responsible for the formation of nitrate ions ($NO_3^-$), a secondary component of particulate matter. The longer lifetime of $NO_2$, allows this pollutant to be transported over greater distances, so that damage is also caused in more remote areas where fewer or no sources of air pollution are present.

Nitrogen oxides also cause acidification and eutrophication of the environment (MIRA, 2011; MIRA, 2006). $NO_2$ is converted in the atmosphere to nitric acid ($HNO_3$). Dry or wet deposition of nitric acid causes acidification of soil and water, thereby leading to the degradation of ecosystems. Acidification is defined as the combined effects of air pollutants that are imported via the atmosphere and from which acids (such as $HNO_3$) can be formed (MIRA, 2006). Eutrophication denotes the accumulation or enrichment of soil or groundwater with nutrients (including N). High nutrient concentrations have a disruptive effect on ecosystems (MIRA, 2011).

Exposure to very high $NO_2$ concentrations can cause immediate adverse health effects due to the toxicity of the gas. The effect of long-term exposure to current $NO_2$ concentrations is difficult to isolate in epidemiological studies. It is, however, clear that adverse health effects are associated with transport emissions and $NO_2$ is strongly correlated with the mixture of transport-related air pollution. For that reason, and also because $NO_2$ is indirectly harmful to people and the environment, limit values have been set by the European Commission and the World Health Organisation.

## 4.1 NO$_2$ monitoring stations

Figure 25 shows the evolution of the number of monitoring stations where NO$_2$ is measured and which are shown on the RIO interpolation maps in this report. They include both the telemetric stations, stations used in specific studies and stations that are managed by the electricity producers and the Belgian Petroleum Federation in cooperation with the regional environmental administrations. The number of NO$_2$ monitoring stations has risen from 26 in 1990 to 89 in 2011. Since the number of monitoring stations before 1997 is considerably less than in 2011, the uncertainty on the annual mean concentrations is greater in those initial years.
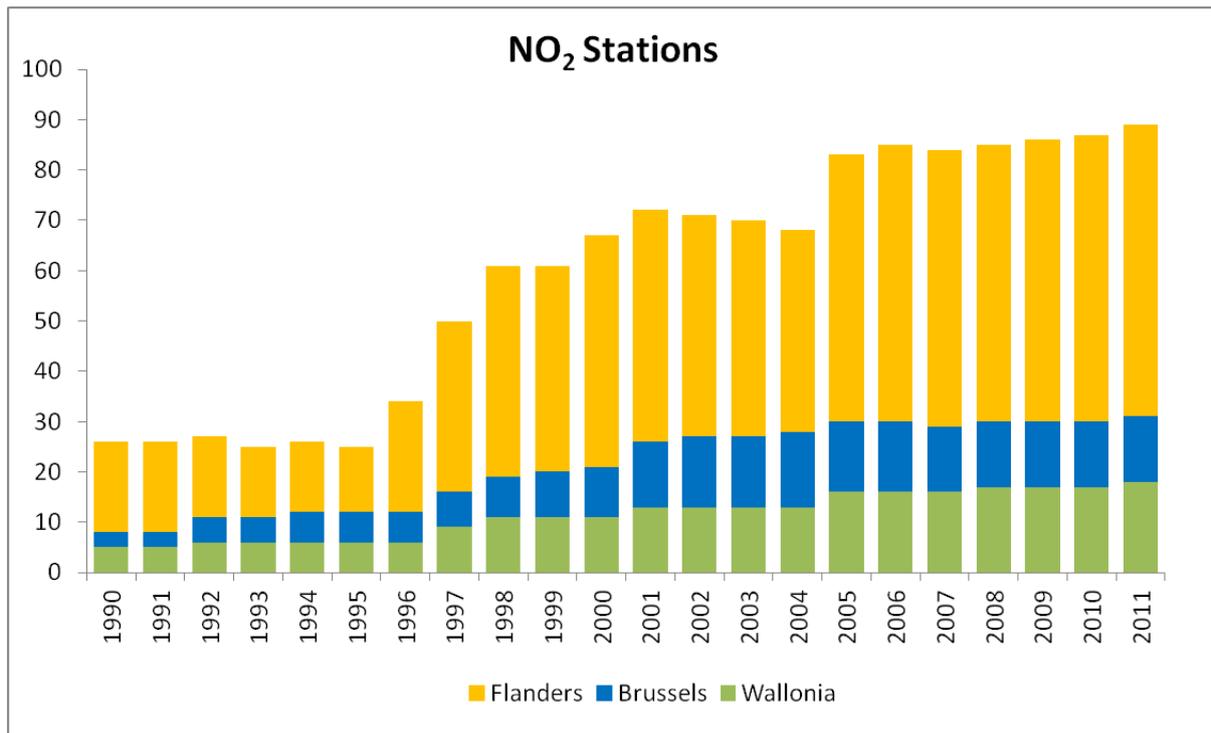


**Figure 25: Evolution of the number of NO$_2$ monitoring stations in Belgium**

## 4.2 NO$_2$ annual mean

The European annual limit value for protection of human health is 40 µg/m³. This limit value applies as from 2010. Only the Port of Antwerp and Antwerp Agglomeration zones have been granted postponement until 2015 for compliance with this limit value (see also 1.2). Until then, a limit value of 60 µg/m³, based on the limit value of 40 µg/m³ with a 50% margin of tolerance, applies in these two zones. To be granted this postponement, a detailed plan was drawn up showing that the limit value of 40 µg/m³ will be attained as from 2015. Figure 26 clearly shows that the highest annual means are measured in the urban areas. This is not surprising due to the highly transport-related character of NO$_2$. Annual mean concentrations above 40 µg/m³ were measured at sites in Antwerp and Brussels. The highest NO$_2$ annual mean of all Belgian grid cells is 44 µg/m³. The average annual mean concentration across Flanders, Brussels and Wallonia is 19 µg/m³, 32 µg/m³ and 13 µg/m³ respectively. The average across Belgium, taking account of the number of inhabitants per grid cell (population-weighted average) is 23 µg/m³. This value clearly exceeds the non-population-weighted average across Belgium (16 µg/m³), which indicates that the grid cells with the highest population

numbers are also those with higher $NO_2$ annual mean concentrations, namely the urban areas. This is also illustrated by Figure 27, which represents the relationship between annual mean $NO_2$ concentration and the accumulated population density. From a population number of 2500 inhabitants/km², the annual mean $NO_2$ concentration exceeds 35µg/m³ in 2011. For the period 2006-2010 this value was even slightly higher and annual mean concentrations above 40 µg/m³ were calculated for grid cells with more than 5000 inhabitants/km². In 2011 this value fell below the European limit value.

The uncertainty on the calculated annual mean $NO_2$ concentrations is given in Annex D, together with the probability of exceedance of the annual limit value.

**Annual mean NO2 concentrations (Belgium, 2011)**
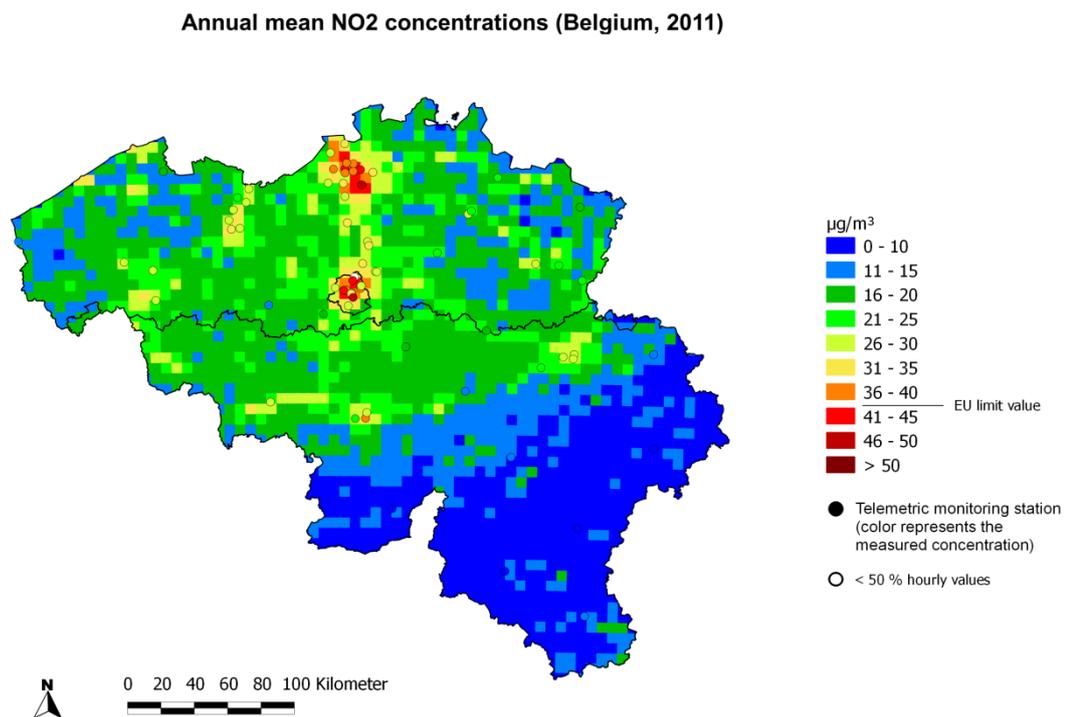


**Figure 26: Spatial distribution of the NO$_2$ annual mean concentration in 2011. All data were calculated using the RIO interpolation technique.**

The evolution of the minimum, 25th percentile (P25)[3], 50th percentile (P50), 75th percentile (P75) and maximum $NO_2$ annual mean concentration in Belgium is shown in Figure 28. It also shows the spatial average across Belgium. This figure, too, shows that the European annual limit value is still not being met everywhere.

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[3] P25 or the 25th percentile is the value where 25% of all values are lower than P25, and 75% of the values are higher.
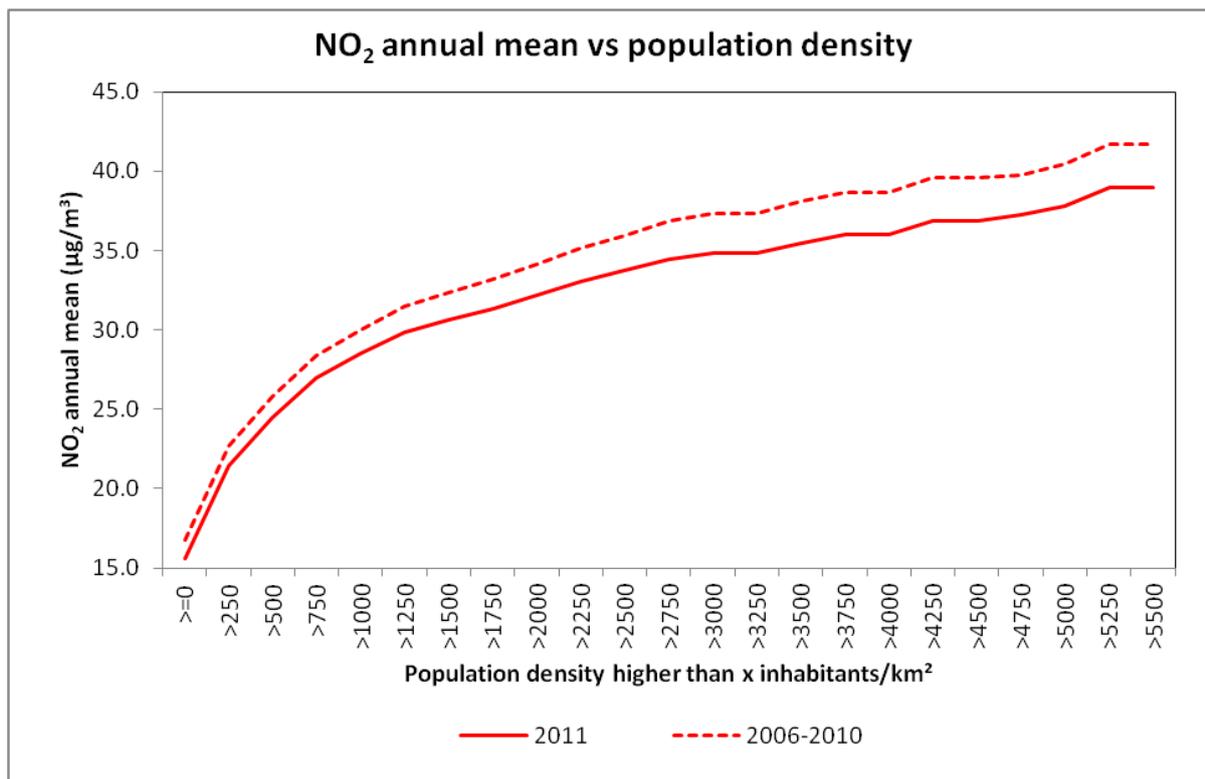
**Figure 27: Relationship between the interpolated annual mean NO$_2$ concentrations and the population density (inhabitants/km²) above a specified value. All data were calculated using the RIO interpolation technique.**
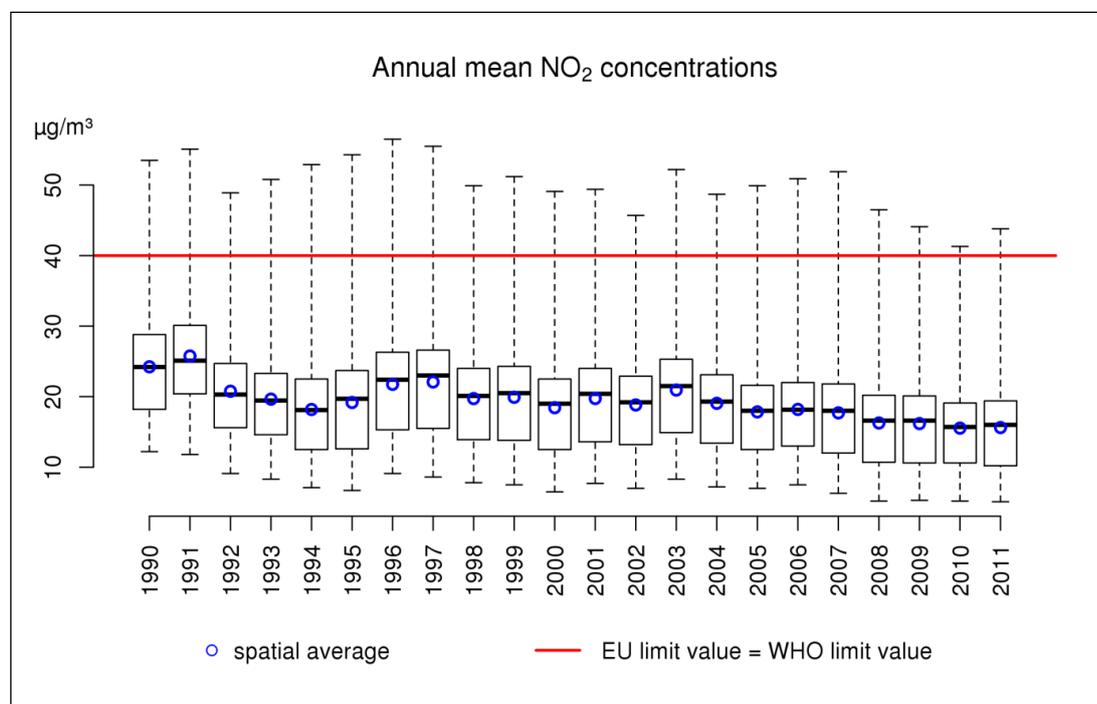


**Figure 28: Box plots of the annual mean NO$_2$ concentrations (µg/m³) for the period 1990-2011. The spatial average is represented by the blue circles. All data were calculated using the RIO interpolation technique.**

Figure 29 shows the evolution of the annual mean NO$_2$ concentrations in Belgium and per region. Here, too, the higher annual mean concentrations in the city of Brussels are clearly visible. No clear

trend is visible in the annual mean $NO_2$ concentrations at regional or Belgian level, all the more so because of the greater uncertainty in the years before 1997 due to the smaller number of monitoring stations.
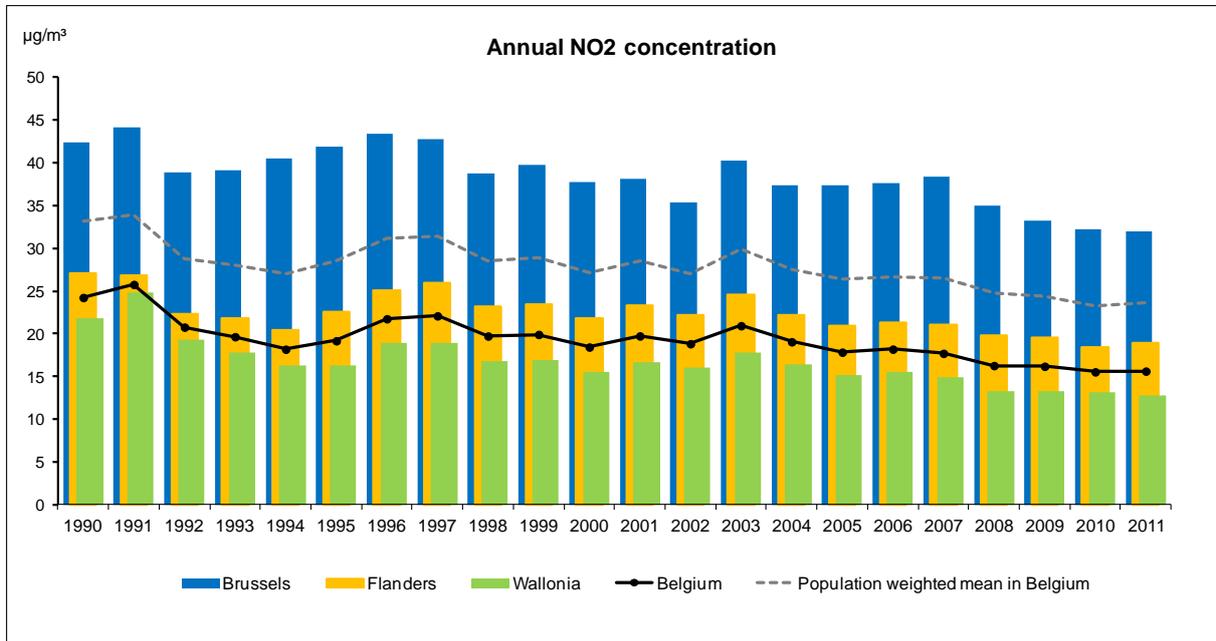


**Figure 29: Evolution of the $NO_2$ annual mean in Belgium based on the RIO interpolation technique**

The decrease in the annual mean $NO_2$ concentrations in Belgium over the period 1990-2011 is rather limited (Figure 30). The largest decreases - between 0.6 and 0.75 µg/m³/year - occur in the region around Charleroi, Brussels and the southwestern part of the province of Flemish Brabant.

Since 2003, an increasing number of people have been exposed to lower annual mean $NO_2$ concentrations (Figure 31). From 1998, the percentage of the Belgian population that is potentially exposed to annual mean concentrations above the EU limit value fluctuates around 10%. In 2010, this percentage had dropped to 3% and in 2011 it slightly went up again to 5%.
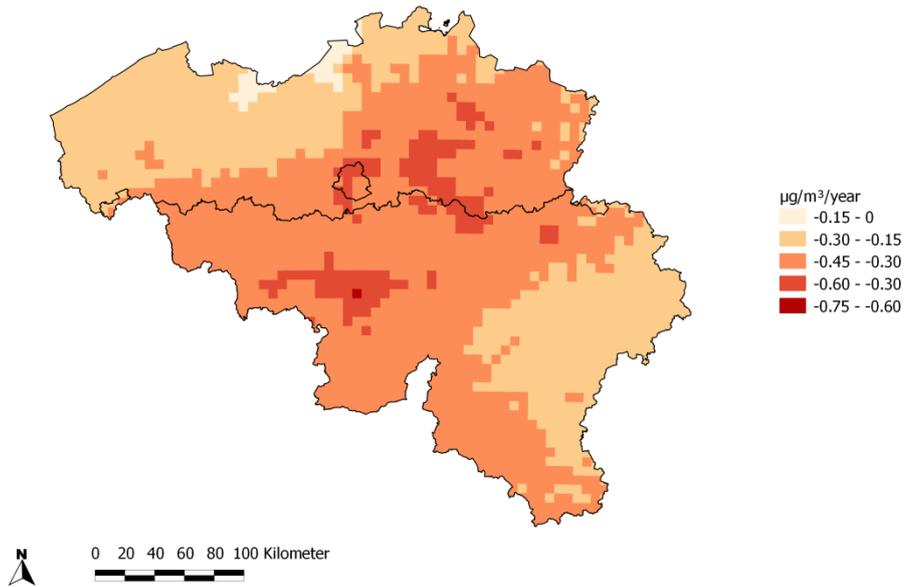
**Figure 30: Trend (µg/m³/year) of the annual mean NO$_2$ concentrations in the period 1990-2011. All data were calculated using the RIO interpolation technique.**
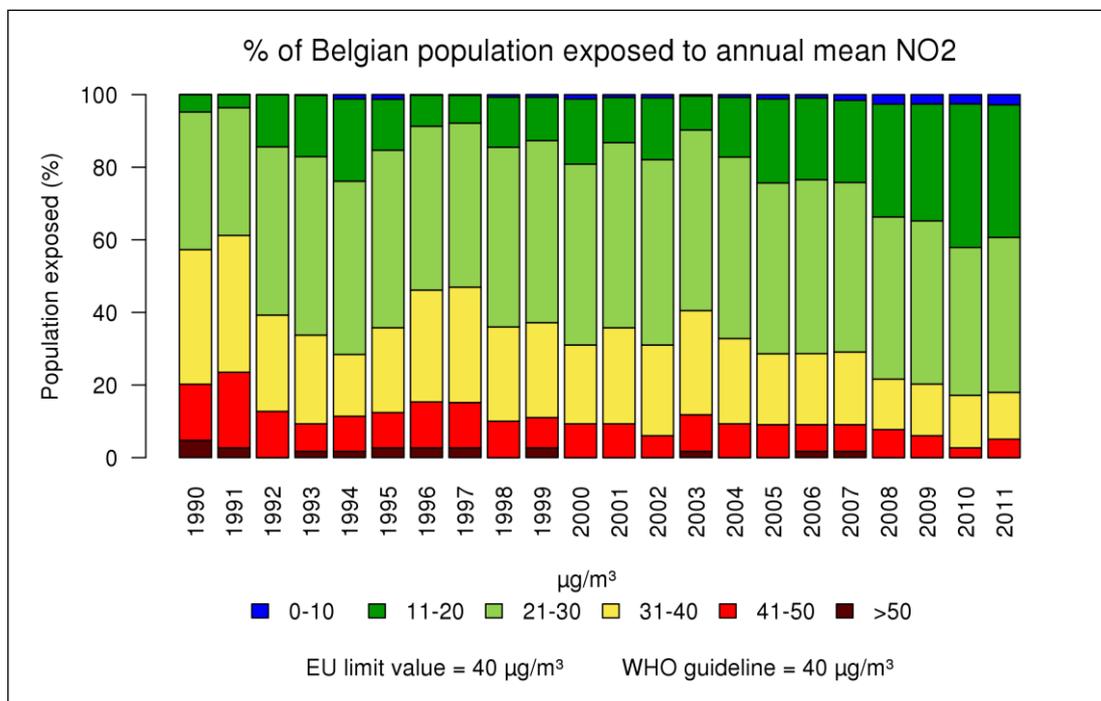


**Figure 31: Percentage of the Belgian population exposed to annual mean NO$_2$ concentrations. All data were calculated using the RIO interpolation technique.**

For the protection of vegetation and natural ecosystems, the European Directive also sets a critical level at an annual mean of 30 µg/m³. This limit value is to be attained at monitoring stations that are representative of an area of at least 1000 km², and are located at least 20 km from an agglomeration and at least 5 km from a busy roadway, built-up area, industry, etc. Belgium has no locations that meet these criteria, so this limit value does not apply.

## 4.3  NO$_2$ hourly values

For the protection of human health from short-term NO$_2$ peak concentrations, the European legislation imposes an hourly limit value of 200 µg/m³. This hourly limit is to be exceeded no more than 18 times (hours) per year. In Belgium, this hourly limit value is easily attained. Very locally, in busy traffic streets, the 200 µg/m³ limit may be exceeded a few times per year, but the 18-hour limit is never reached in any of the monitoring stations. Local exceedances are not visible due to the resolution of the RIO interpolation technique. The 19th highest hourly value in Belgium in 2011 is represented in Figure 32 (this corresponds to the 99.8[th] percentile of all hourly mean concentrations in one year). The maximum of the 19th highest hourly value in Belgium, representative at 4x4 km², is 134 µg/m³, which is well below the European limit of 200 µg/m³, and is measured in Brussels. The average 19th highest NO$_2$ hourly value in Flanders, Wallonia and Brussels is 63 µg/m³, 50 µg/m³ and 105 µg/m³ respectively. The highest values occur only in large agglomerations such as Brussels and Antwerp. The WHO guideline value is also 200 µg/m³, but is not to be exceeded at any time. This value, too, is attained everywhere in Belgium. The maximum hourly mean NO$_2$ concentration, representative of an area of 4x4 km², was 174 µg/m³.

Since 1990 there has been little variation in the spatially averaged, minimum and maximum of the 19th highest NO$_2$ hourly value (Figure 33). This means that the peak NO$_2$ concentrations have not or have hardly decreased in the Flemish, Brussels-Capital and Walloon Regions in the last 20 years (Figure 34). One exception was the year 1997, when very high concentrations were measured in the stations of the Belgian Petroleum Federation in Antwerp in the month of January.

**19th highest hourly NO2 concentration (Belgium, 2011)**
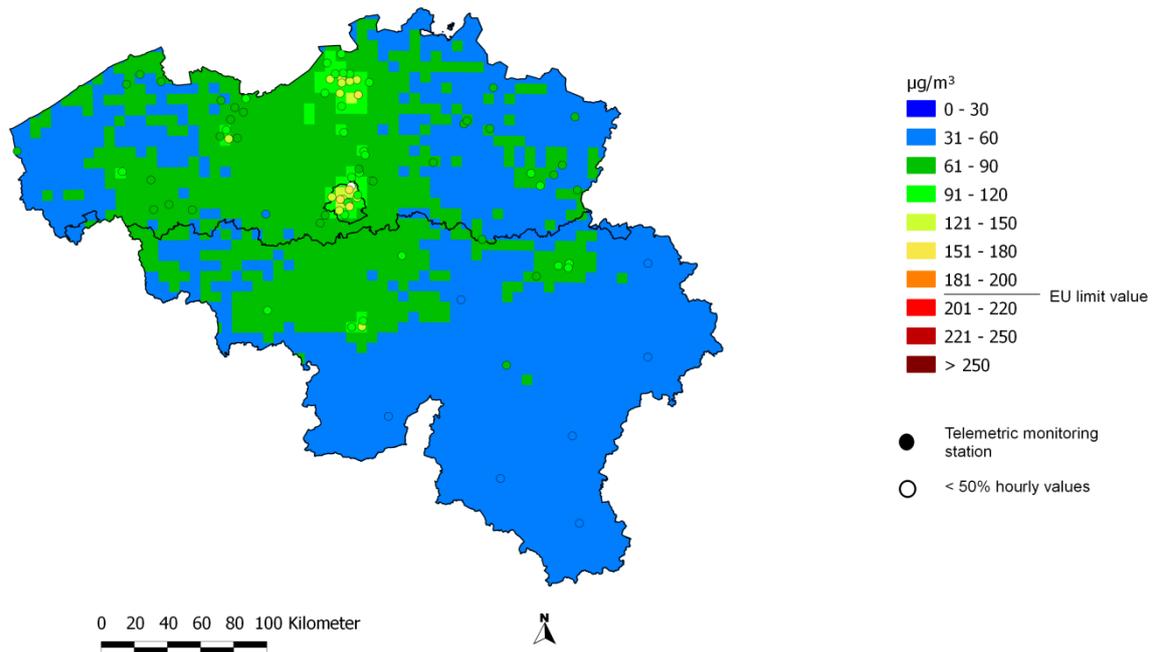
**Figure 32: Spatial distribution of the 19th highest hourly mean NO$_2$ concentration in Belgium, 2011. All data were calculated using the RIO interpolation technique.**
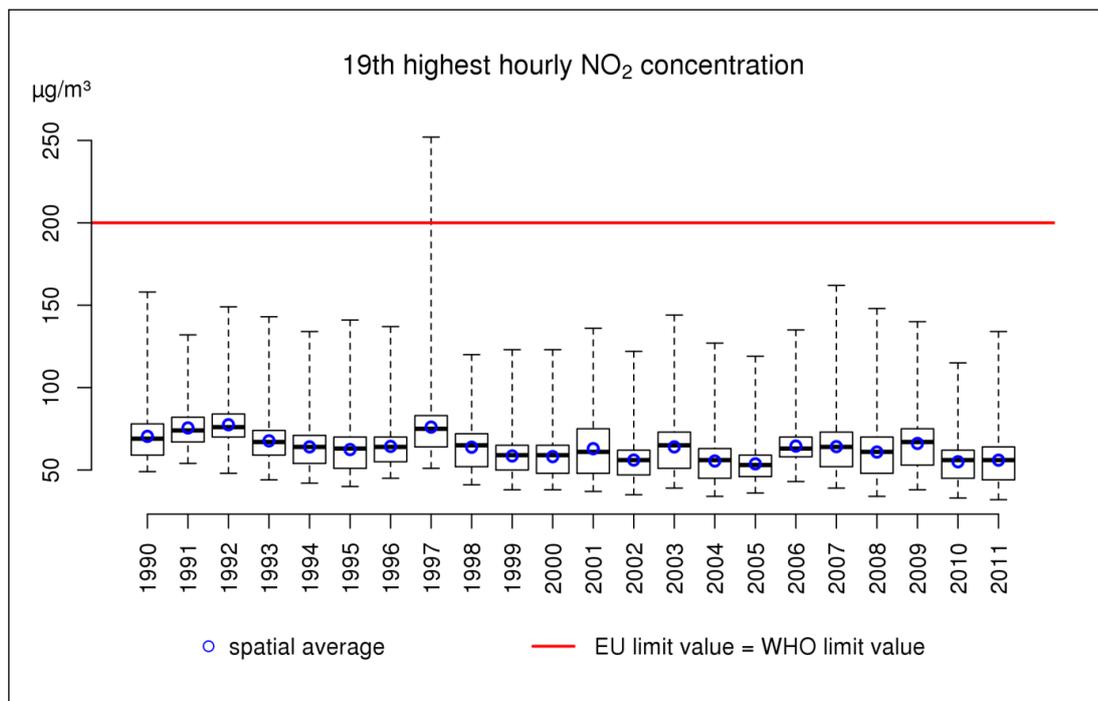


**Figure 33: Box plot of the 19th highest hourly mean NO2 concentration (µg/m³) over the period 1990-2011. The spatial average is represented by the blue circles. All data were calculated using the RIO interpolation technique.**

**19th highest hourly NO2 concentration (max per region)**
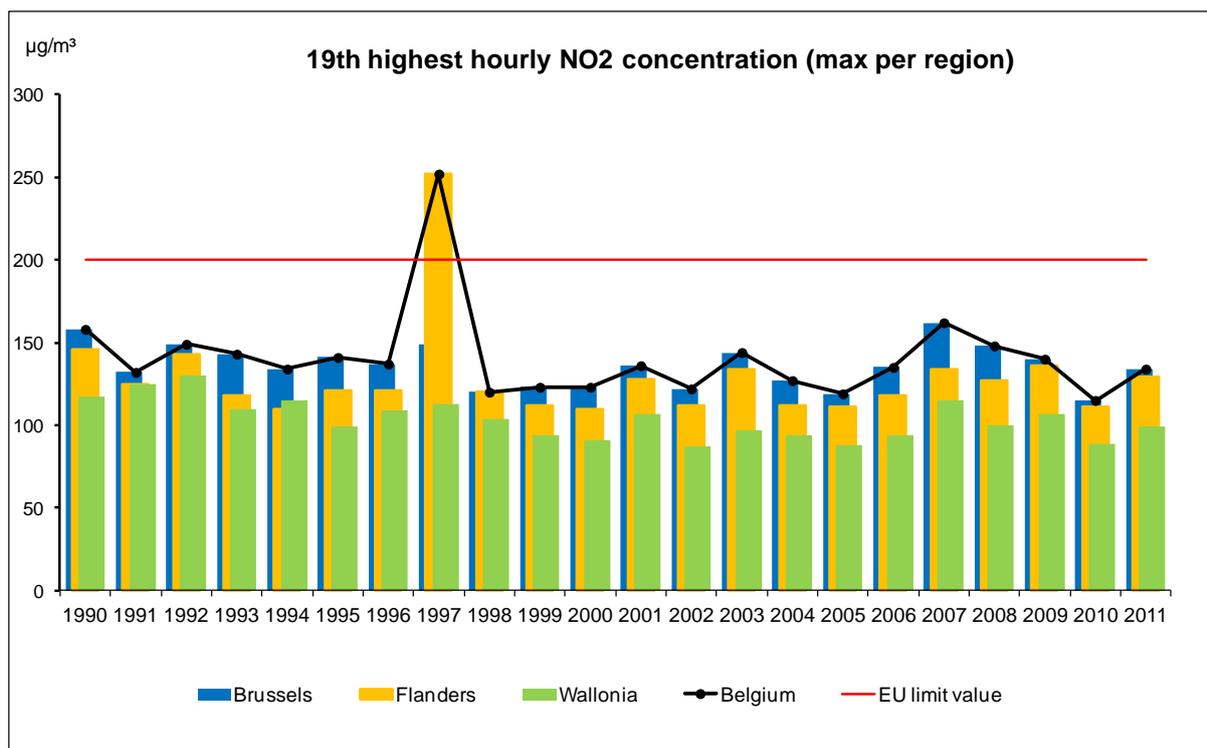
**Figure 34 Evolution of the maximum of the 19h highest NO$_2$ hourly value in the three Regions and Belgium based on the RIO interpolation technique**

# 5   Ozone

Ozone ($O_3$) is a very reactive gas that is formed in the atmosphere by various photochemical reactions. Ozone is a secondary pollutant and is therefore not emitted directly into the air. Ground-level ozone is formed through the effect of UV light on air pollutants on hot summer days. The ozone precursors are $NO_x$, VOC and CO. In Belgium, about half of the $NO_x$ emissions come from transport. Other major sources of $NO_x$ are building heating and industry. VOCs are emitted mainly by transport and use of solvents (paints, cleaning products, etc.) in industry but also in households. Apart from the ozone that is produced on hot days, a global background concentration is present at all times.

$NO_x$ (=NO + $NO_2$) emissions have a double effect on ozone. On the one hand, NO breaks down $O_3$, thereby forming $NO_2$, and, on the other hand, $NO_2$ aids the formation of $O_3$. In the atmosphere, these pollutants are always in chemical equilibrium. NO has a short lifetime in the atmosphere, so that ozone is mainly broken down in places where much NO is emitted. During this reaction $NO_2$ is formed, which has a longer lifetime in the atmosphere. This ozone-forming substance can be transported over greater distances, and contribute to the formation of ozone in more distant places. This is why ozone concentrations are generally higher in rural areas than in an urban environment with many sources of $NO_x$.

Because of its strong oxidising power, ozone can cause harmful effects to humans, animals, plants and materials. Exposure to high ozone concentrations can cause acute health problems such as irritation to eyes, nose and throat, irritant cough and oversensitivity of the lungs. When high ozone levels are present, everyone (including healthy individuals!) engaging in outdoor physical activity experiences reduced lung function and is at risk of inflammatory reactions in the airways. The effect of ozone varies greatly from one person to another and also people without airways diseases may be extremely sensitive to ozone. This sensitive group, people with lung problems and people engaging in prolonged outdoor physical activity may be most affected, but people with lung diseases are at the greatest risk due to the reduced lung function. Health complaints can be avoided or reduced by refraining from any sporting or heavy physical activity outdoors between noon and 10 p.m. or by staying indoors. Ozone concentrations indoors are on average 50% lower than outdoors.

The effect of long-term exposure to low ozone concentrations is less well known. One study has, however, demonstrated the causal relationship between chronic exposure to ozone pollution and fatality caused by lung disease (Jerret M. et al, 2009).

Ozone also causes damage to plants. Visible effects are mottling or bleaching of the leaves. Invisible effects are reduced resistance and damage to the cells. As a result, more energy goes towards the restoring plant tissue, at the expense of growth. For crops this leads to reduced yields, for forests to less biomass production and reduction in biodiversity. Chronic exposure to lower ozone concentrations has a greater impact on vegetation than acute exposure to high concentrations. Long-term exposure to ozone also results in erosion of materials such as rubber and plastics.

The impact of ozone is not limited to harmful effects to public health, vegetation or materials. Ozone is, after carbon dioxide and methane, the third major anthropogenic greenhouse gas. Indirectly, ozone contributes even more to the greenhouse effect since damage to vegetation will lead to reduced absorption of $CO_2$.

The ozone issue is a global issue that requires a global approach. Short-term measures such as speed restrictions during periods of ozone smog have no effect in our region since a drop in $NO_x$ emissions will initially lead to a decrease in ozone breakdown, which will actually result in higher ozone

concentrations. An effective decrease in ozone concentrations can only be achieved by sustainable measures at European and even global level which drastically reduce VOC, $NO_x$ and methane emissions (more stringent emissions standards, cleaner fuels, less traffic, etc.).

## 5.1   Ozone monitoring stations

Figure 35 shows the evolution of the number of monitoring stations where ozone is measured and which are shown on the RIO interpolation maps in this report. They include both the telemetric stations and the stations used in specific studies. The number of ozone monitoring stations has risen from 12 in 1990 to 41 in 2011. Since the number of monitoring stations in 1997 is substantially lower than in 2011, the uncertainty on the interpolated annual mean concentrations is larger in those initial years.
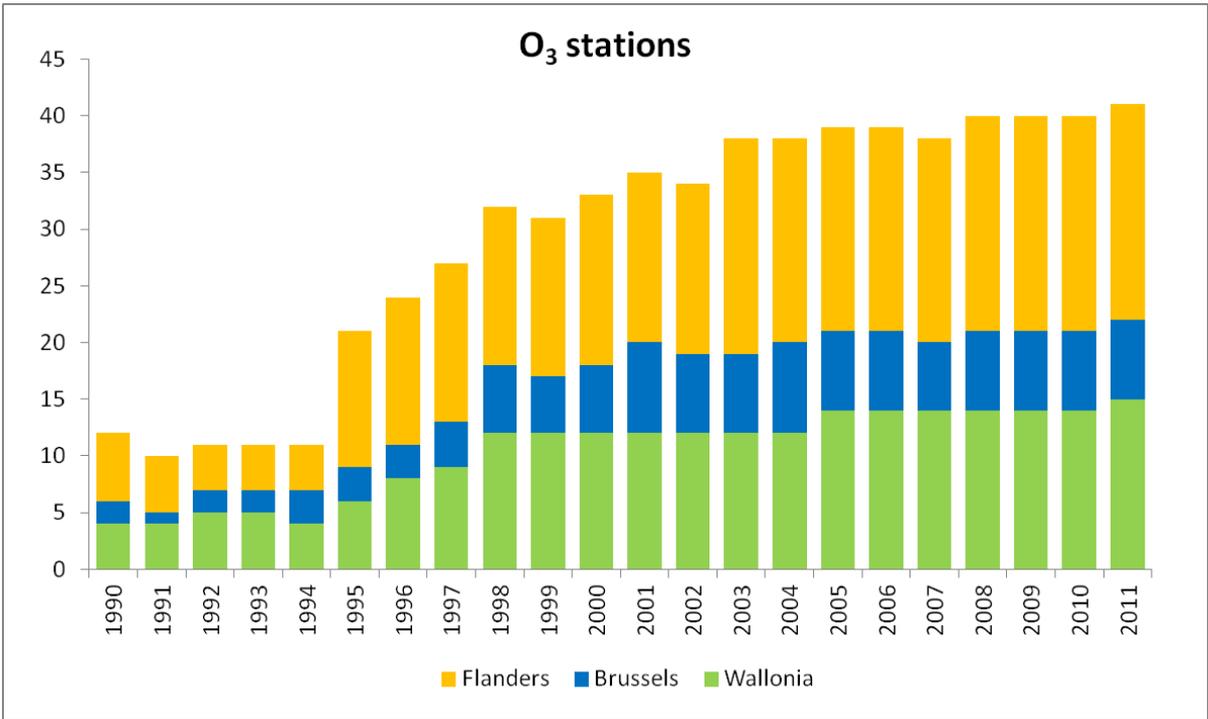


**Figure 35: Evolution of the number of O$_3$ monitoring stations in Belgium**

## 5.2 Ozone and population

### 5.2.1 NET60

The European target value for the protection of human health is based on the daily maximum 8-hour mean ozone concentration. Averaged over 3 years, this daily maximum 8-hour mean should not exceed 120 µg/m³ more than 25 times a year. This European target value is a medium-term objective (MTO) and applies since 2010 (average 2010-2012). The long-term objective (LTO) is not a single day with maximum 8-hour means above 120 µg/m³. This indicator is expressed as the NET60 indicator[4].

In 2011, the maximum number of days with a maximum 8-hour mean concentration above 120 µg/m³ reached anywhere in Belgium, was 26 days. This occurred in the far east of Wallonia (see Figure 36). In Flanders and Brussels, the NET60 remained below 25 days. Due to the favourable meteorological years 2009 and 2010 in which not a single exceedance of the NET60 was recorded, the 3-year average used for the assessment according to the European target value, also remained below 25 days. The long-term objective, i.e. not a single exceedance, was not attained anywhere in Belgium.
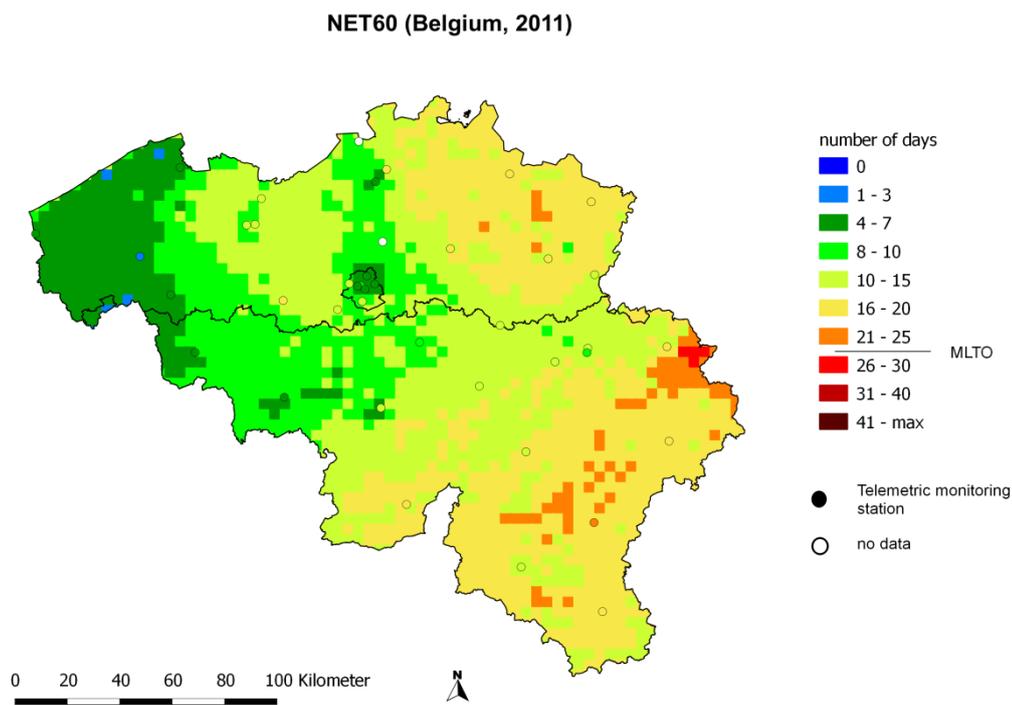


**Figure 36: Spatial distribution of the number of days with maximum 8-hour mean ozone concentration > 120 µg/m³, 2011. "No data" means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique.**

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[4] NET60: Number of Exceedances above a Threshold of 60 ppb (=120µg/m³).

**NET60 (Belgium, 2009 - 2011)**
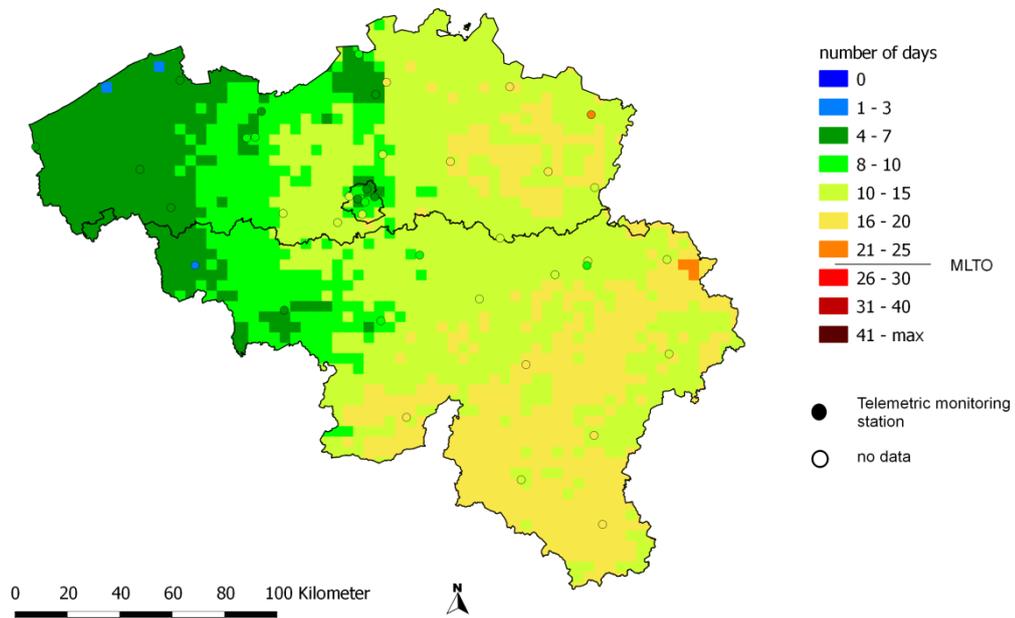
**Figure 37: Spatial distribution of number of days with maximum 8-hour mean > 120 µg/m³, averaged over 2009, 2010 and 2011. "No data" means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique.**

Figure 36 and Figure 37 show the spatial distribution of the number of exceedance days, respectively in 2011 and averaged over 2009, 2010 and 2011. An east-west and north-south gradient is clearly visible. The maximum values were recorded in the Campines and in the region south of the Sambre and Meuse valley. The maximum of 21 days averaged over three years is found in the far east of the country. The minimum exceedance days occur in the urban environments and in West Flanders. Spatially averaged across Belgium, the NET60 (averaged over 2009-2011) amounts to 11 days.

The evolution of the number of days with the maximum 8-hour mean ozone concentration above 120 µg/m³ shows a strong variation from year to year, depending on the quality of the summer (see Figure 38). No clear trend is apparent in the spatial average. The most unfavourable ozone year since 1990 is 2003 with a maximum of 65 exceedances somewhere in Belgium. Since 2007, we have had relatively favourable ozone years, which explains why in recent years the 3-year average has remained below the European target value of 25 days.

Figure 39 geographically represents the trend of the number of days with maximum 8-hour mean ozone concentration >120µg/m³ during the period 1990-2011. In this period, there is a decrease of maximum 1 day/year in the west of the country to an increase by 0.2 days/year in the northeast of the country.

49
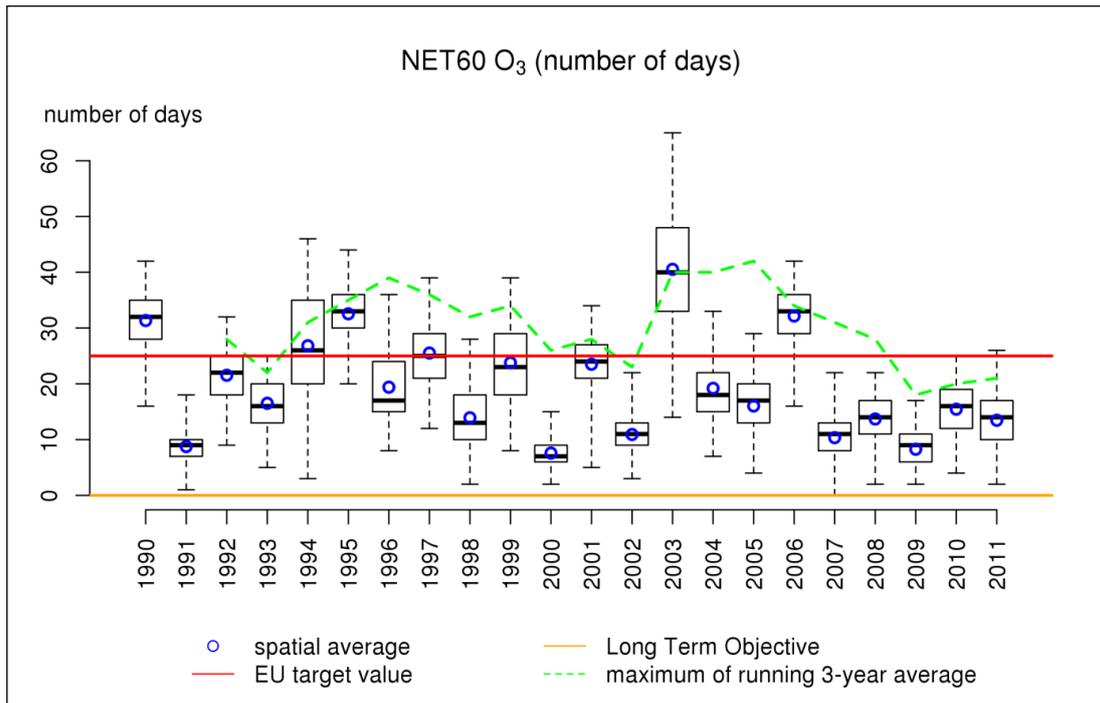
**Figure 38: Box plots of number of days with maximum 8-hour mean ozone concentrations > 120 µg/m³ in Belgium over the period 1990-2011. The spatial average is represented by the blue circles. The green dotted line indicates the maximum of the 3-year averaged number of exceedance days in Belgium. All data were calculated using the RIO interpolation technique.**
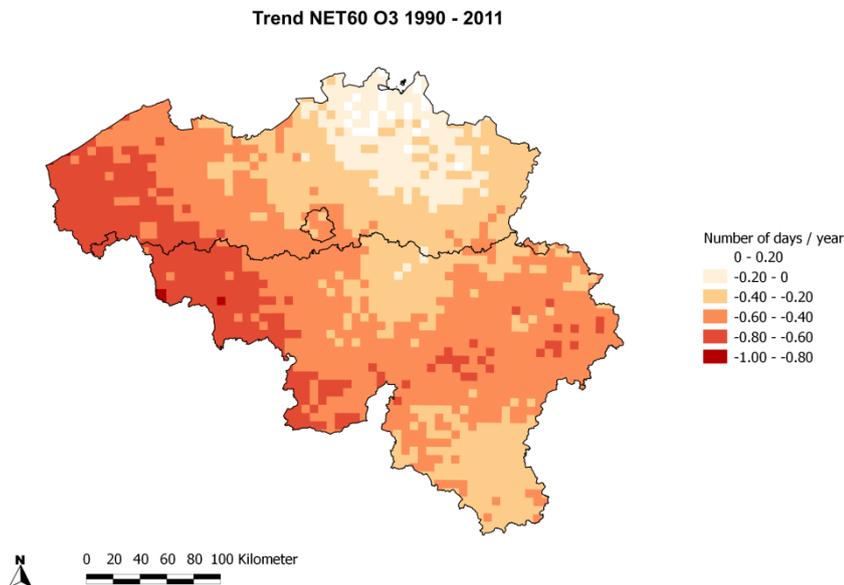


**Figure 39: Trend (number of days/year) of the number of days with maximum 8-hour mean ozone concentration above 120 µg/m³ (NET60) over the period 1990-2011. All data were calculated using the RIO interpolation technique.**

The evolution of the percentage of the population that is exposed to daily maximum 8-hour mean ozone concentrations above 120 µg/m³ shows that the last five years were favourable ozone years (see Figure 40). In the last five years, no one has been exposed to maximum 8-hour mean ozone concentrations > 120 µg/m³ on more than 25 days. In 2011, half of the population was exposed to maximum 8-hour mean ozone concentrations > 120 µg/m³ on 10 or fewer days. Only a small percentage (0.3%) was exposed on more than 20 days. By contrast, 1990, 1995, 2003 and 2006 were very unfavourable in terms of population exposure to high ozone concentrations. In those years, the major part of the population was exposed to maximum 8-hour mean concentrations > 120 µg/m³ on more than 25 days.
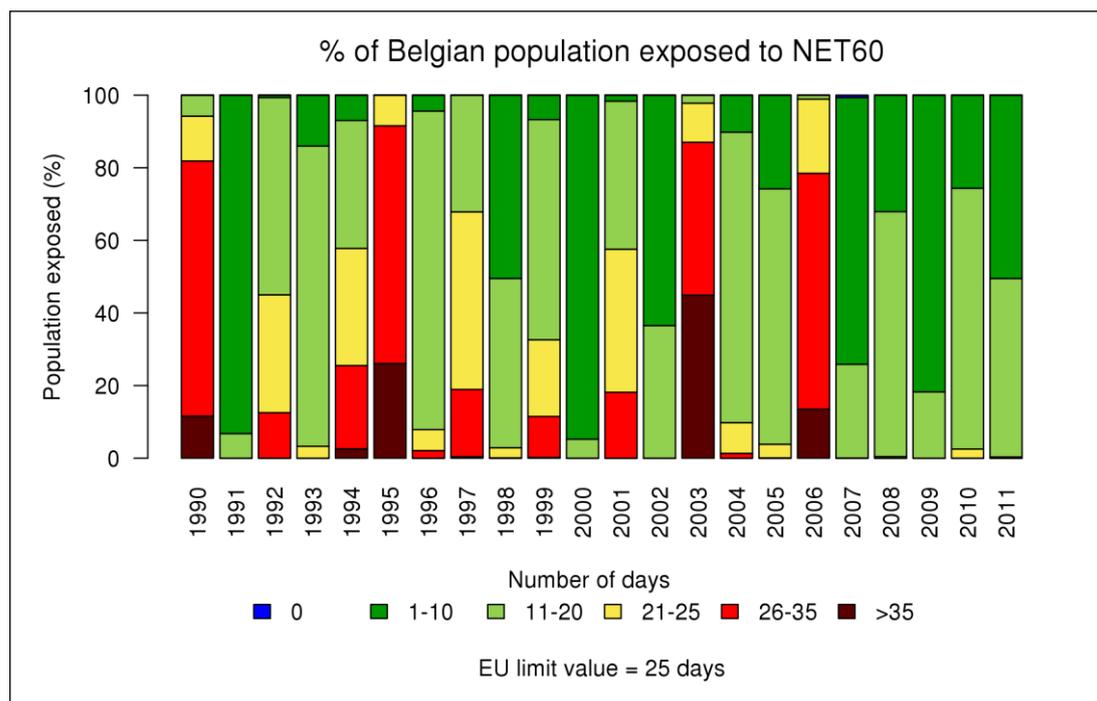


**Figure 40: Evolution of population exposure to the number of days with maximum daily 8-hour mean ozone concentrations > 120 µg/m³. All data were calculated based on the RIO interpolation technique.**

The WHO uses a threshold of 100 µg/m³ as the maximum 8-hour mean ozone concentration of one day, below which no significant health effects occur,. Since the WHO guideline value is more stringent than the European long-term objective and the latter was not met anywhere in Belgium, the WHO guideline value was also (largely) exceeded everywhere in Belgium.

## 5.2.2   AOT60

Another indicator to assess the effects of ozone for the population is the AOT60[5]. The AOT60 sums the difference between the concentrations above 120 µg/m³ and 120µg/m³ of the daily maximum 8-hour mean concentrations. In contrast to the NET60 indicator, the AOT60 considers the size and duration of the exceedance. In the draft version of the first ozone directive (2002/3/EC) and the National Emissions Ceilings Directive, 5800 (µg/m³).hours was proposed as the medium-term

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[5]AOT60: Accumulated Ozone Exposure above a Threshold of 60 ppb (=120µg/m³) by the maximum daily 8-hour mean.

objective (MTO) for 2010, which corresponds to a NET60 equal to 25 days. The long-term objective is 0 (µg/m³).hours. The AOT60 was not incorporated into the current European Ambient Air Quality Directive, but is a better indicator to quantify the excess burden on public health. This indicator was also incorporated into the Flemish MINA-4 plan (2011-2015) to illustrate the plan objectives.

Figure 41 shows the spatial distribution across Belgium of the ozone excess in 2011. It is clear that the ozone excess burden was limited in Belgium during 2011. The maximum value is 3264 (µg/m³).h and was reached in the far east of Wallonia. The average AOT60 across Belgium was 1581 (µg/m³).h. West Flanders showed the lowest AOT60 with a minimum value of 120 (µg/m³).h. However, the long-term objective of 0 (µg/m³).h was not attained anywhere in Belgium.

The spatial distribution of the trend in AOT60 over the period 1990 – 2011 shows the same pattern as before the NET60, with a decrease of up to -200 (µg/m³).u/year for the west of the country, and a decrease of between 0 and 40 (µg/m³).u/year for the northeast.



**AOT60 (Belgium, 2011)**
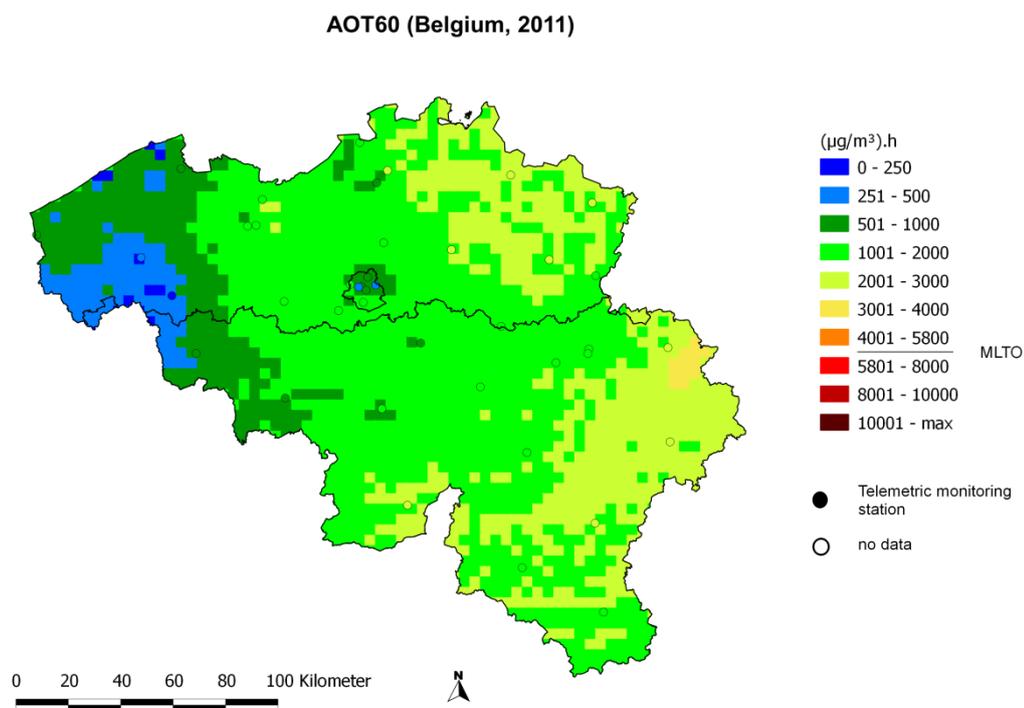
**Figure 41: Spatial distribution of the ozone excess (AOT60) in 2011. "No data" means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique.**

## 5.3 Ozone and vegetation

For vegetation, long-term exposure to ozone is more relevant than acute exposure. It is difficult to quantify the potential damage to plants caused by ozone pollution. In fact, ozone causes the most damage when it is taken up by the plant. The ozone concentrations in the atmosphere are, however, not a direct measure of ozone uptake in the plant. Many other parameters play a role: humidity level, soil condition, plant growth phase, etc. The European Union has defined an excess indicator for the protection of vegetation. The AOT40 for vegetation is the accumulated excess of hourly ozone concentrations above 80 µg/m³ between 8:00 and 20:00 CET (Central European Time = Universal Time (UT) + 1) in the months of May, June, July (=growth season). This indicator is designed for the protection of crops and (semi)natural vegetation. Additionally, an excess indicator for the protection of forests has been defined. The AOT40 for forests is calculated in the same way, but runs over the period April-September. These indicators quantify only ozone exposure, i.e. not the effective ozone uptake by (and therefore damage caused to) vegetation.

### 5.3.1 AOT40 for vegetation

In 2011, the AOT40 for vegetation was well below the European target value of 18000 (µg/m³).h. The vegetation-weighted[6] average across Belgium was 7554 (µg/m³).h. The maximum value of 14962 (µg/m³).h was calculated in the far east of the country. Vegetation in West Flanders showed the lowest AOT40. In 2011, 27% of the area with vegetation cover (excl. forests) remained below the long-term objective of 6000 (µg/m³).h.

Figure 42 and Figure 43 show the spatial distribution of AOT40 for vegetation in 2011 and the 5-year average over the period 2007-2011. The map shows only the areas with vegetation cover (excluding forests). The spatial distribution is similar to that for the AOT40 for human health. The maximum AOT40 was measured in the area south of the Sambre and Meuse valley and the High Fens. In Flanders, the maximum AOT40 is found in Limburg. West Flanders shows the lowest AOT40 for vegetation. The European target value of 18000 (µg/m³).h averaged over 5 years was met everywhere in Belgium. The maximum value was 15029 (µg/m³).h.

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[6]        The AOT40_vegetation value per grid cell is weighted with the fraction of the vegetation present in that grid cell. In this way, more weight is given in the average to grid cells with more vegetation.

AOT40 vegetation (Belgium, 2011)
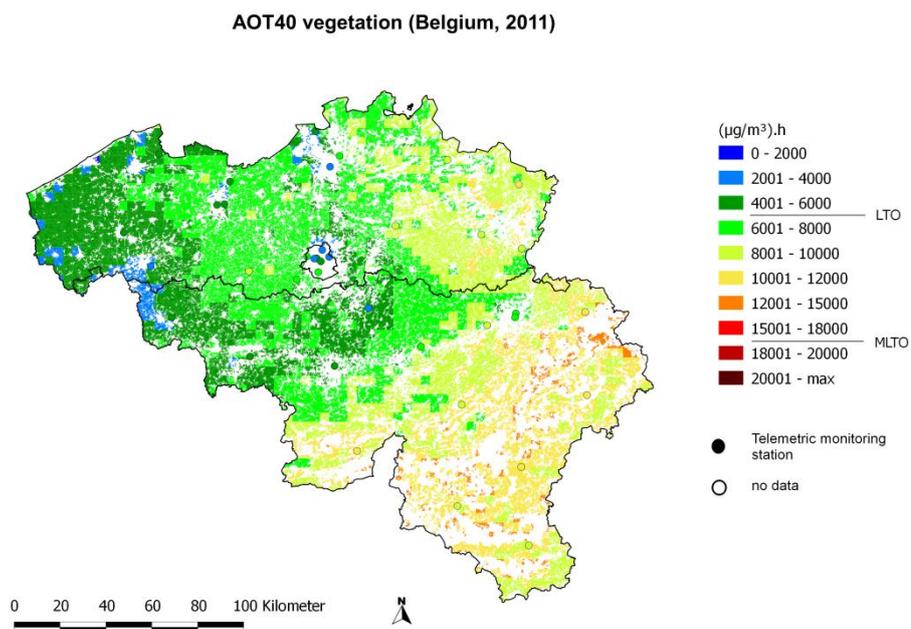
**Figure 42: Spatial distribution of the ozone excess for vegetation (AOT40 for vegetation), 2011. "No data" means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique.**



AOT40 vegetation (Belgium, 2007 - 2011)
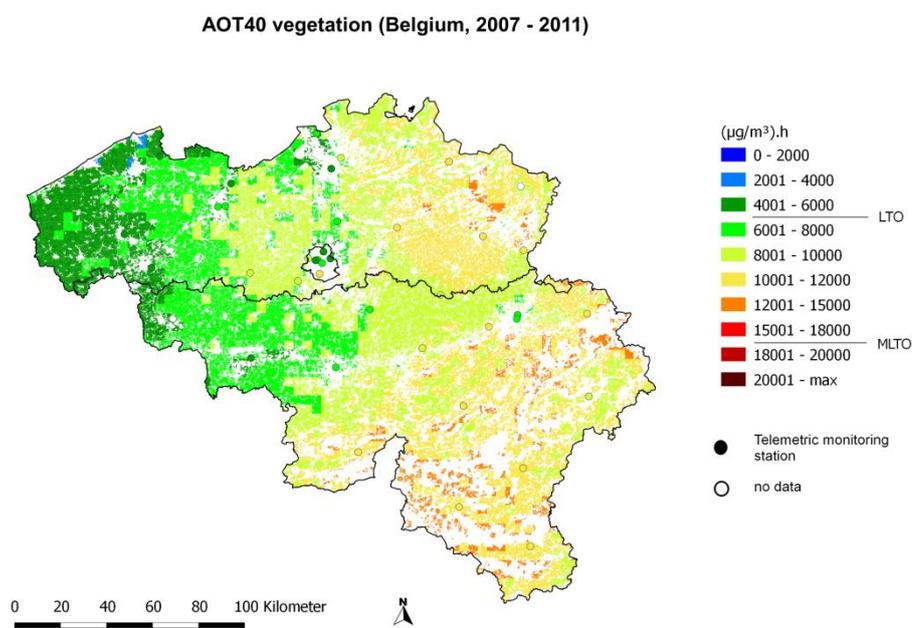
**Figure 43: Spatial distribution of the ozone excess for vegetation (AOT40 for vegetation), 5-year average 2007-2011. "No data" means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique.**
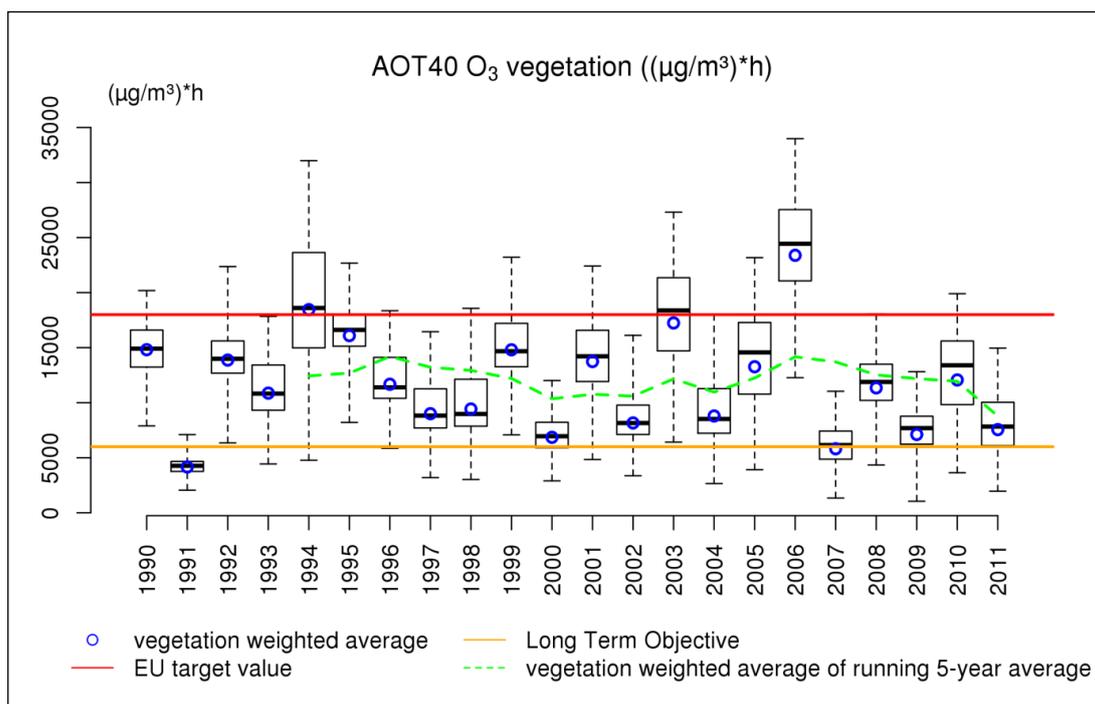
**Figure 44: Box plots of the ozone excess for vegetation (AOT40 for vegetation) in Belgium (1990-2011). The vegetation-weighted averages for Belgium are indicated by the blue circles. The green dotted line indicates the vegetation-weighted average of the 5-year averaged AOT40. All data were calculated using the RIO interpolation technique.**

Figure 44 shows the evolution of the AOT40 for vegetation in Belgium since 1990. The years 1994 and 2006 are clearly shown to be unfavourable ozone years for vegetation. The last 5 years are relatively favourable; the maximum excess in Belgium never exceeds the European target value of 18000 ($\mu g/m^3$).h, except for a slight exceedance in 2008 and 2010. The 5-year averaged AOT40 for vegetation in Belgium remains at all times below the European target value of 18000 ($\mu g/m^3$).h. The long-term objective of 6000 ($\mu g/m^3$).h is, however, each year exceeded somewhere in Belgium.

### 5.3.2 AOT40 for forests

The ozone excess for forests is calculated in the same way as for vegetation, the only difference being that a longer period is taken into account, namely from April to September. The current Air Quality Directive does not include any objectives for the ozone excess for forests. In the previous ozone daughter directive, a reference value of 20000 ($\mu g/m^3$).h was specified. This reference value is more stringent than the target value of 18000 ($\mu g/m^3$).h for the protection of vegetation. The last Mapping Manual of the UNECE also specified a critical value of 10000 ($\mu g/m^3$).h. This is a level above which direct unfavourable effects can be observed.

Just as for the other ozone indicators, the largest AOT40 for forests was to be found in the southern part of the country, where also most forest resources are situated. The largest AOT40 was recorded in particular in the area below the Sambre and Meuse valley. The maximum in 2011 totalled 24503 (µg/m³).h. 56% of Belgian forests were exposed to an AOT40 above the reference value of 20000 (µg/m³).h. In virtually all forest resources (99%) the AOT40 exceeded the critical UNECE level of 10000 (µg/m³).h.
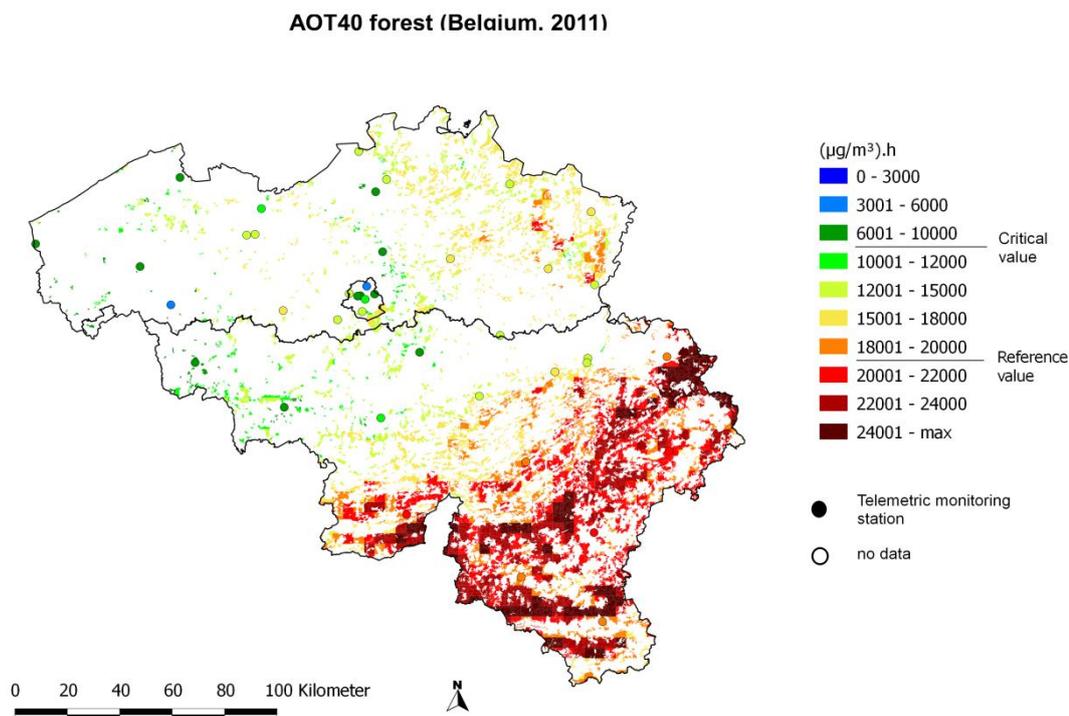


**Figure 45: Spatial distribution of the ozone excess for forests (AOT40 for forests) in 2011. "No data" means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique.**

**AOT40 forest (Belgium, 2007 - 2011)**
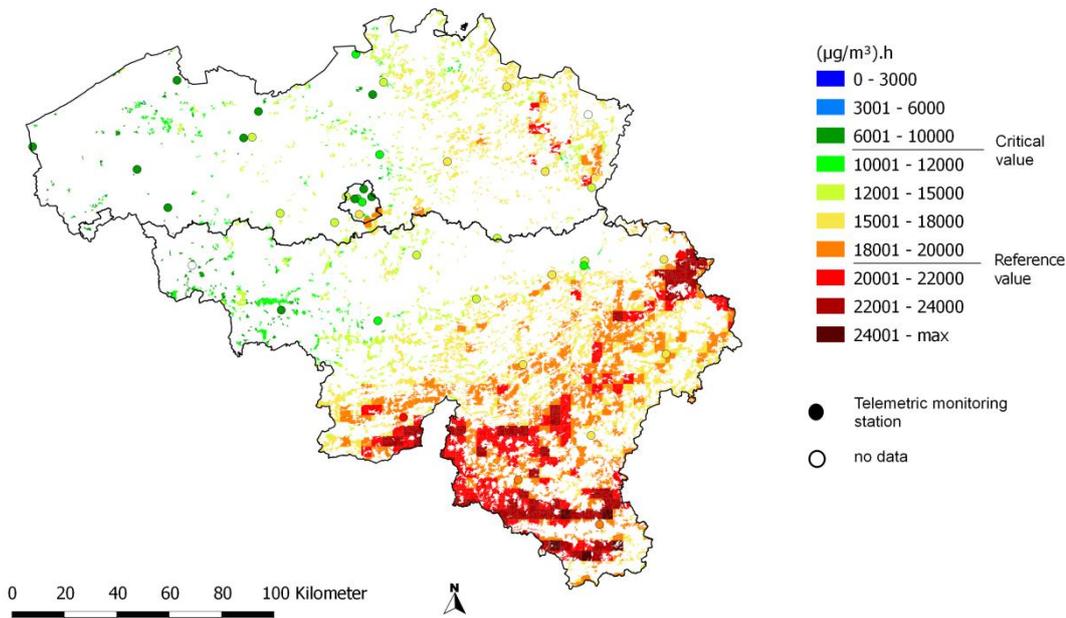
**Figure 46: Spatial distribution of the ozone excess for forests (AOT40_forests), 5-year average 2007 – 2011 . "No data" means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique.**

## 5.4   O$_3$ annual mean

The annual mean ozone concentration is a measure of the background concentration in Belgium. Figure 47 shows the spatial distribution of the annual mean ozone concentrations in 2011. For the uncertainty on this map, reference is made to Annex D. It is clear that the ozone values will, in general, be higher in rural Wallonia than in Flanders and urban Brussels. The reason for this is that more ozone is broken down by NO because of the higher NO$_x$ emissions. By contrast, further downwind of the NO$_x$ emissions less ozone is broken down. The relationship between the annual mean ozone concentrations and the population density is inverse to that for PM or NO$_2$. In grid cells with the highest population density, the lowest annual mean ozone concentrations are recorded. A comparison between 2011 and the period 2006-2010 reveals hardly any difference in this relationship.

In 2011, the annual mean concentrations for Brussels, Flanders and Wallonia were 39 µg/m³, 44 µg/m³ and 49 µg/m³ respectively. The average across Belgium is 47 µg/m³. The population-weighted annual mean ozone concentration in Belgium lies between the Flemish and Brussels average and amounts to 42 µg/m³.

**Annual mean (Belgium, 2011)**
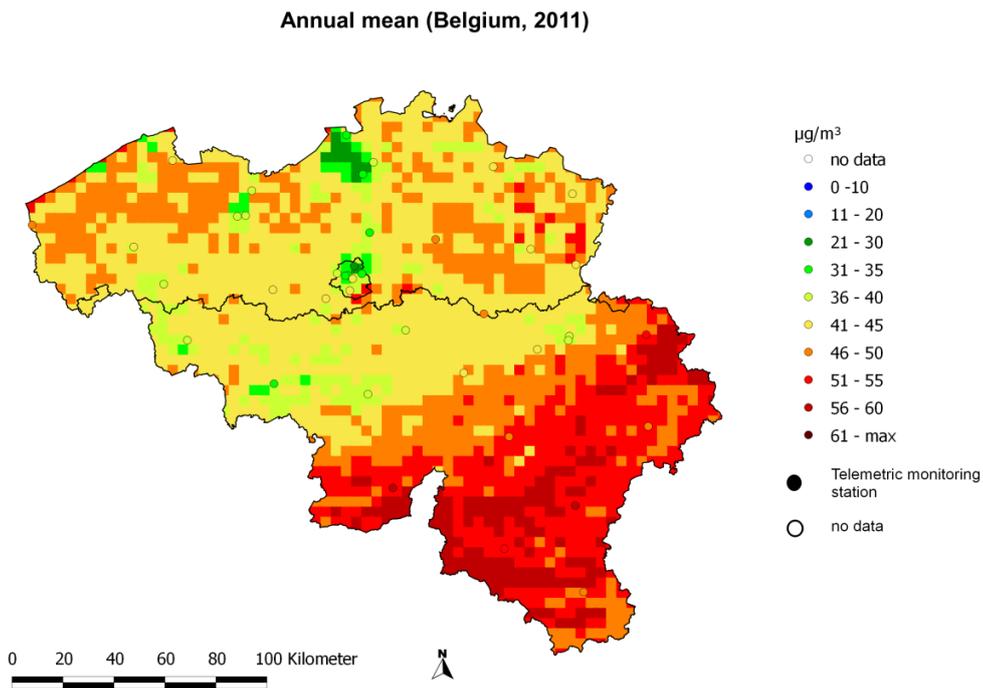


**Figure 47: Spatial distribution of the O₃ annual mean concentrations in Belgium, 2011. . "No data" means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique.**
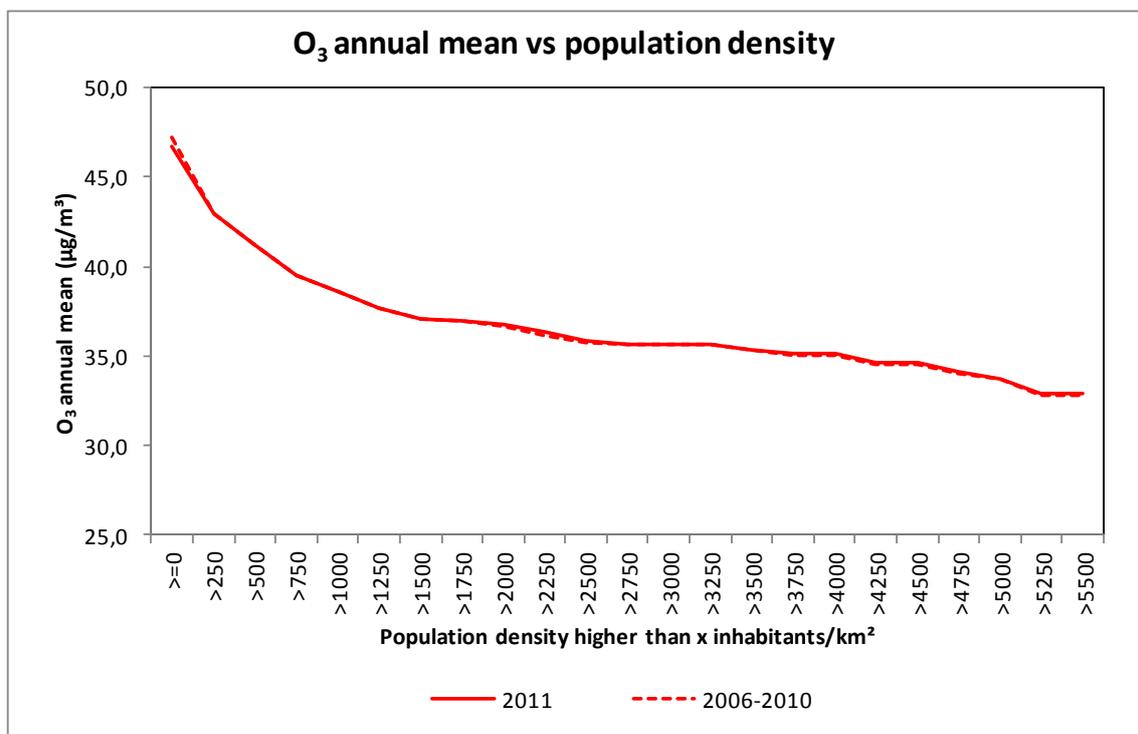


**Figure 48: Relationship between the interpolated annual mean O₃ concentrations based on the RIO interpolation technique and the population density (inhabitants/km²).**
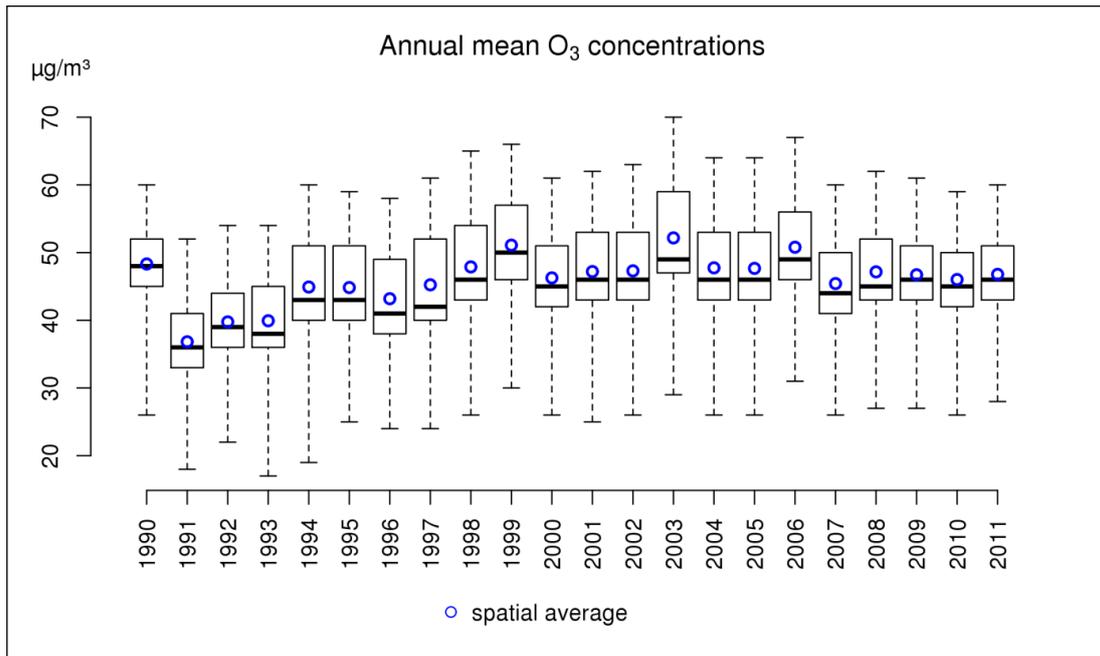
**Figure 49: Box plot of annual mean O3 concentrations over the period 1990-2011. The spatial average is represented by the blue circles. All data were calculated using the RIO interpolation technique.**

Figure 50 shows the evolution of the annual mean concentrations for Belgium and the three individual regions. Between 1990 and 2000, the annual mean ozone concentrations show an upward trend. From 2000 the curve remains fairly constant with values around 40 μg/m³, 45 μg/m³ and 50 μg/m³ in Brussels, Flanders and Wallonia respectively.
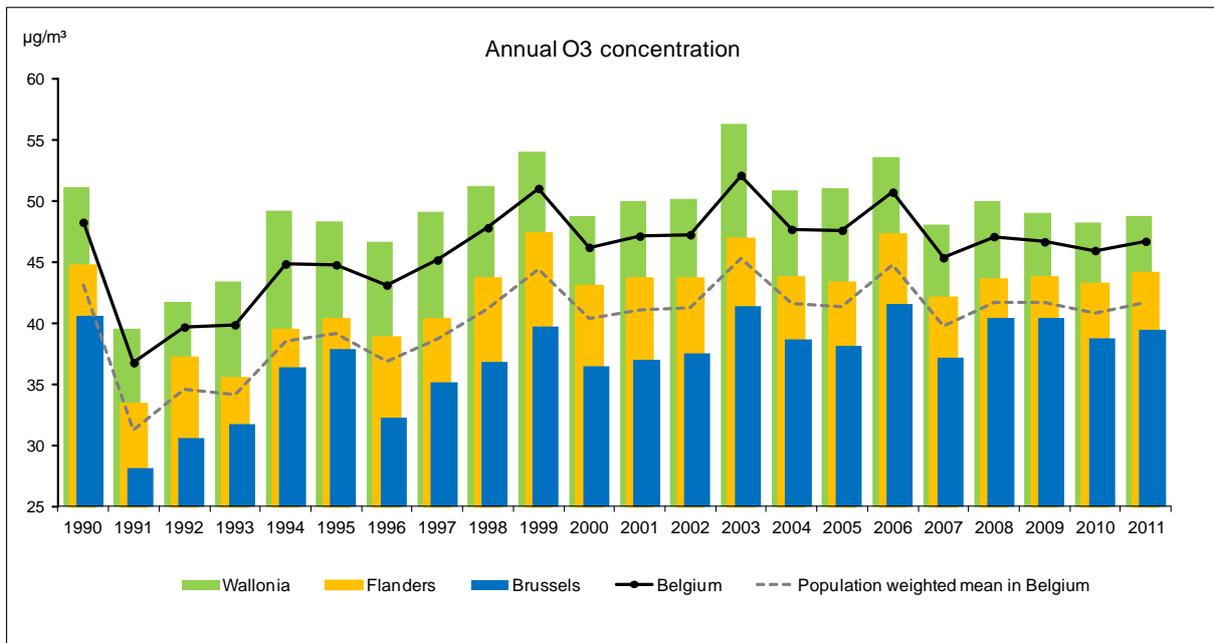


**Figure 50: Evolution of the annual mean concentration in Belgium and the three Regions based on the RIO interpolation technique**

The spatial distribution of the increase in the $O_3$ annual mean over the period 1990-2011 is shown in Figure 51. The highest increases, between 0.3 and 0.5 µg/m³/year, occur in Flanders and Brussels.

**Trend O3 jaargemiddelde concentraties 1990 - 2011**
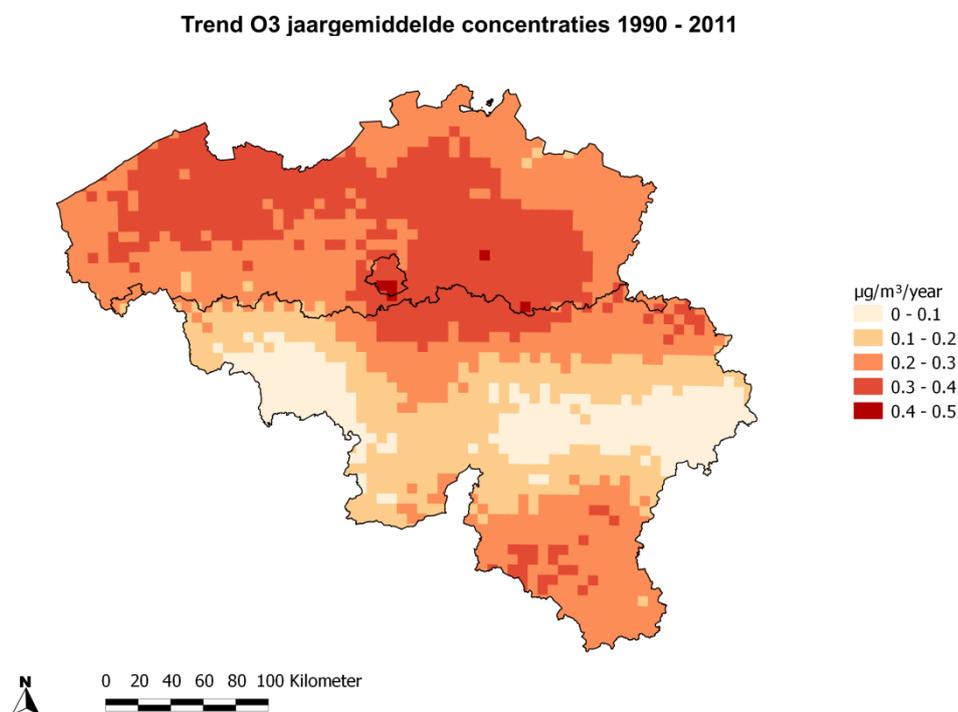


**Figure 51: Spatial trend in annual mean $O_3$ concentration (µg/m³/year) over the period 1990-2011. The data for the trend analysis were generated based on the RIO interpolation technique.**

## 5.5 Evolution of trend in $O_3$ concentration classes

To analyse the long-term trend in ozone concentrations, it is important to distinguish the various concentration classes or percentile values. In Belgium, concentration classes around 40-50 µg/m³, which roughly correspond to the 50th percentile, are representative of the ozone background concentration, whilst peak concentrations (represented by the 99.9th percentile) are concentrations above 180 µg/m³. The evolution of both can be completely different.

To analyse the long-term trend, the 1st, 10th, 50th, 90th, 95th, 99th and 99.9th percentile were calculated for each RIO grid cell for the periods 1990-2000 and 2001-2011, and subsequently the difference in the percentiles between these two periods was calculated. Figure 52 shows this variation as a function of the percentiles over the period 2001-2011. This clearly shows that the ozone background concentrations, represented by the 50th and 90th percentiles, have slightly increased over the period 2001-2011 as compared to the period 1990-2000 with a maximum of 8 µg/m³. However, the higher ozone concentrations, represented by the 99th and 99.9th percentiles have decreased in many places, even by as much as -24 µg/m³. There are, however, still a number of places where the ozone peak concentrations show an increase by up to 6 µg/m³. These trends are comparable to those observed in the network of the European Monitoring and Evaluation Programme (EMEP; Torseth et al., 2012).
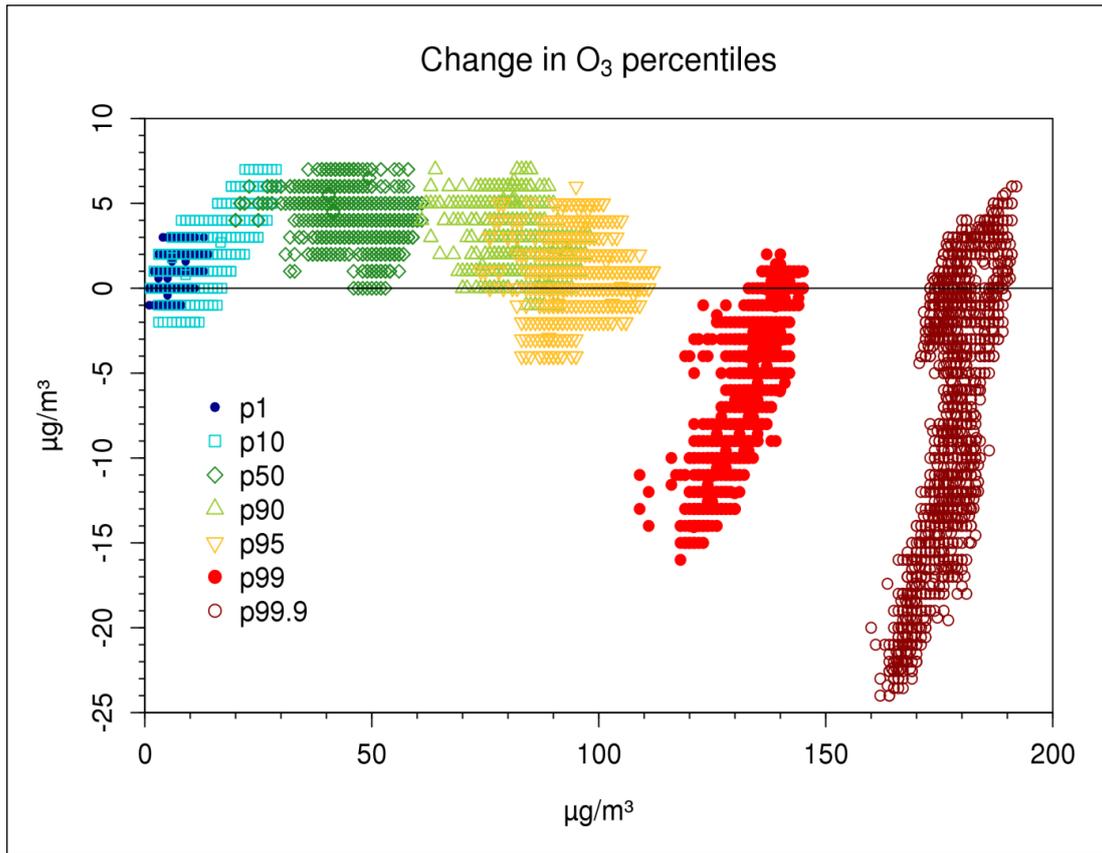
**Figure 52 Variation in O₃ percentiles between the periods 1990-2000 and 2001-2011 in relation to the percentile values in the period 2001-2011 for all RIO grid cells. The data were generated based on the RIO interpolation technique. The different colours indicate the different percentile values.**

# 6 Sulphur oxide

Sulphur oxide ($SO_2$) is a colourless gas with a characteristic irritating odour and taste at high concentrations (from 1000 µg/m³). $SO_2$ is mainly emitted into the air from the combustion of sulphur-containing fossil fuels such as coal and petroleum. Major sources of $SO_2$ are industry and refineries followed by building heating and transport. Volcanic eruptions are a natural source of $SO_2$.

$SO_2$ is harmful to humans, animals and plants. Inhalation of $SO_2$ concentrations can cause irritation of the respiratory tract, even at low concentrations. Short-term exposure to high concentrations leads to reduced lung function and breathing problems, especially for asthma patients and people with lung diseases.

$SO_2$ is highly water soluble, which easily leads to the formation of sulphuric acid ($H_2SO_4$). Dry or wet deposition of this sulphuric acid causes acidification of soil and water, resulting in degradation of ecosystems (MIRA, 2006). In addition, $SO_2$ plays a key role in the accelerated erosion of historic buildings (and stone in general) and metal corrosion.

$SO_2$ is also a precursor for the formation of aerosols. Via chemical reactions in the atmosphere, $SO_2$ is responsible for the formation of sulphate ions ($SO_4^{2-}$), a secondary component of particulate matter.

$SO_2$ can be transported over great distances so that damage is also caused in more remote areas.

## 6.1 $SO_2$ monitoring stations

Figure 53 shows the evolution of the number of monitoring stations where $SO_2$ is measured and which are shown on the RIO interpolation maps in this report. They include both the telemetric stations, stations used in specific studies and stations that are managed by the electricity producers and the Belgian Petroleum Federation in cooperation with the regional environmental administrations. The number of $SO_2$ monitoring stations has dropped from 81 in 1990 to 58 in 2011. In the years where there are fewer monitoring stations, the interpolated values have a larger uncertainty.

## 6.2 $SO_2$ hourly mean values

The European Air Quality Directive imposes a limit value of 350 µg/m³ for the hourly mean $SO_2$ concentration. This hourly limit value is not to be exceeded more than 24 times a year.

Considering the highly source-oriented character of $SO_2$ pollution, this report does not as yet include RIO interpolation maps based on the relationship between land use and measured $SO_2$ concentrations. It can, however, be said that the hourly limit value is amply met in Belgium (Figure 54 and Figure 55). The highest values are recorded in the vicinity of $SO_2$ sources (in industrial areas). Local exceedances are not visible due to the resolution of the RIO interpolation technique. The maximum of the 25th highest hourly value in Belgium in 2011, representative of an area of 4x4 km², is 56 µg/m³, which is well below the European limit value of 350 µg/m³.

The evolution graph of the 25th highest hourly mean concentration clearly shows a downward trend. Since 1997, the $SO_2$ peak concentrations have decreased systematically and significantly.
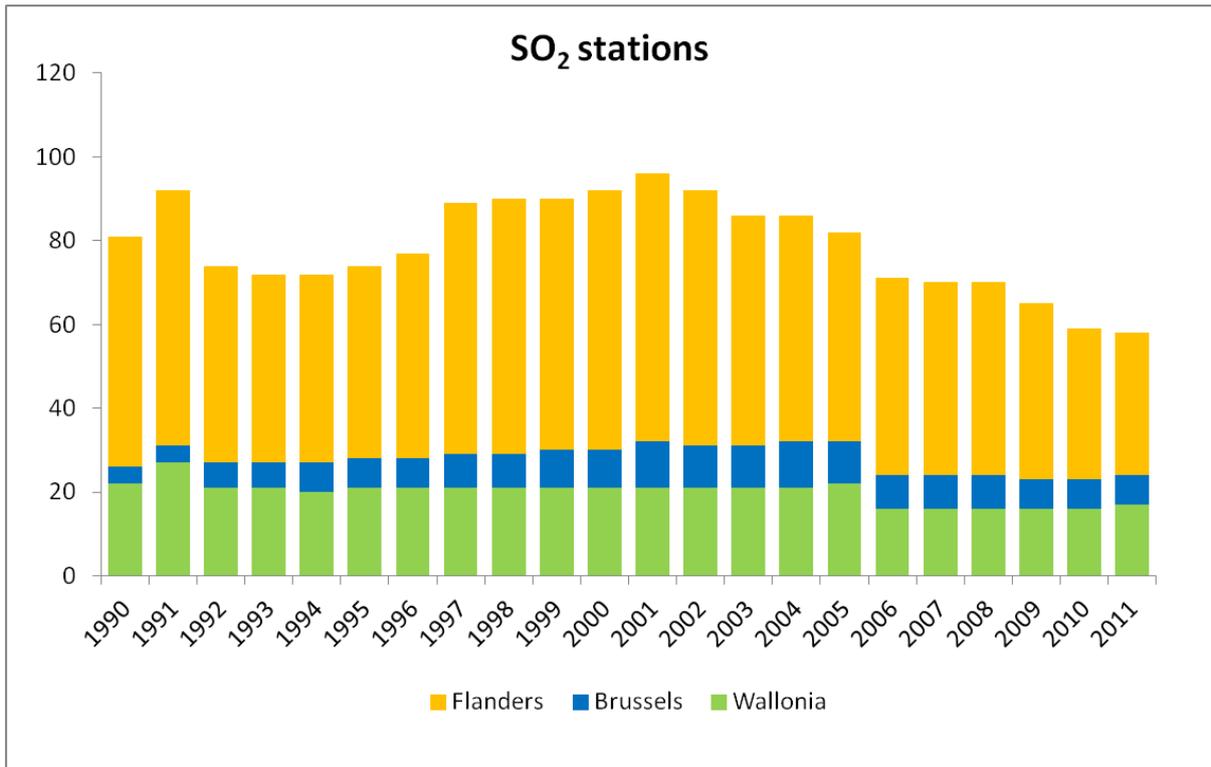
**Figure 53: Evolution of the number of SO₂ monitoring stations in Belgium**
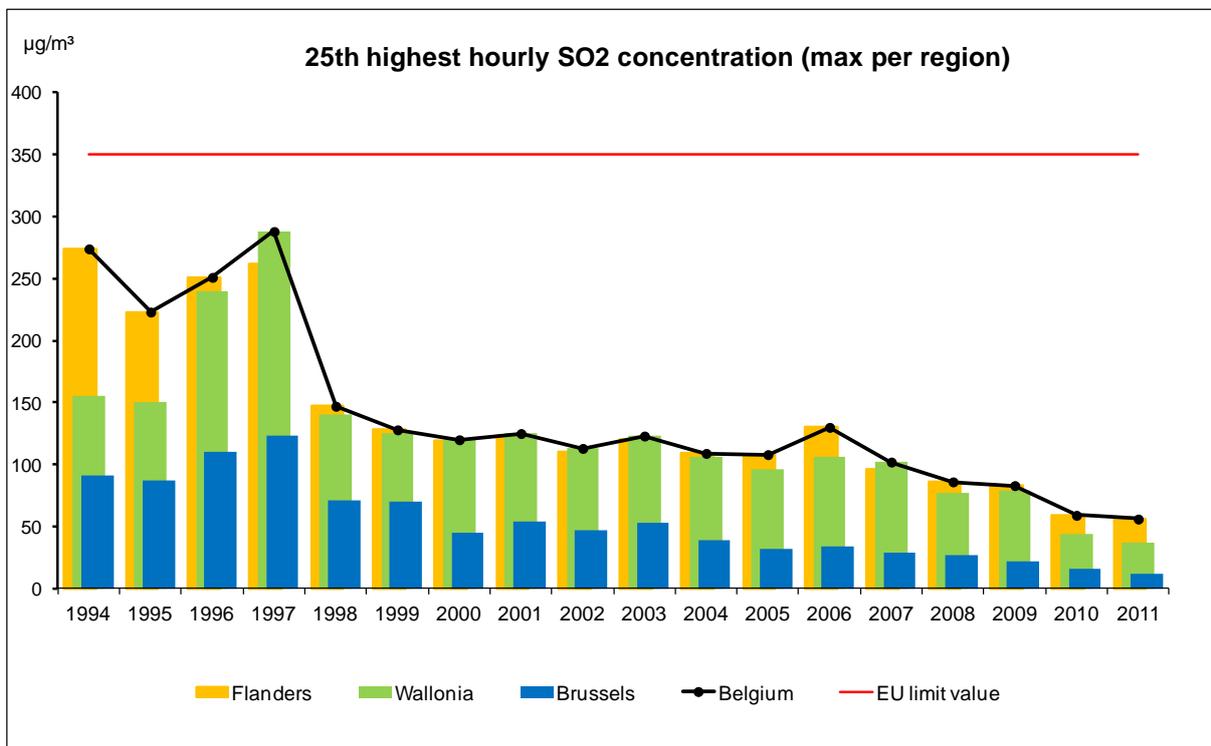


**Figure 54 Evolution of the maximum 25th highest hourly mean SO₂ concentration per Region and Belgium based on the RIO interpolation technique**
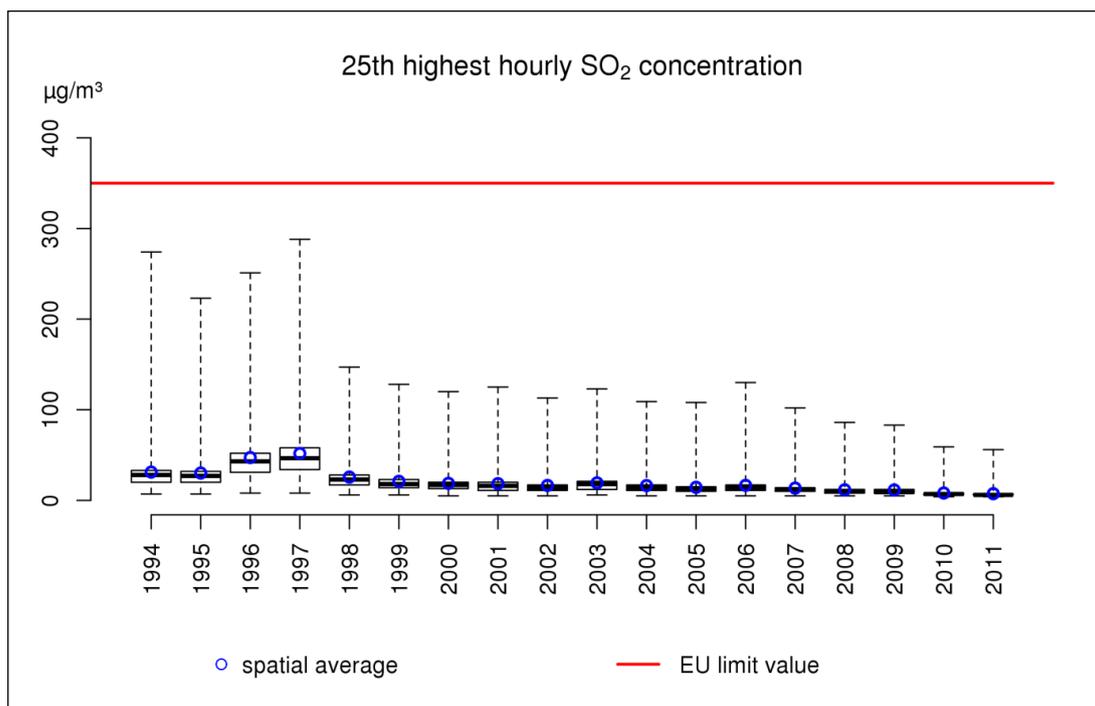
**Figure 55: Box plot of the 25th highest hourly mean SO$_2$ concentration over the period 1994-2011 in Belgium based on the RIO interpolation technique**

## 6.3 SO$_2$ daily mean values

For the protection of human health from the short-term effects of SO$_2$, the European Directive also imposes a limit value for the daily mean SO$_2$ concentration. The daily limit value of 125 µg/m³ is to be exceeded no more than 3 times a year. The WHO guideline value has been tightened to 20 µg/m³ since 2006. The EU limit value is amply met everywhere in Belgium. The WHO guideline value is, however, still exceeded in industrial zones.

Just as for the SO$_2$ hourly mean values, the evolution of the 4th highest daily mean values shows a continuously downward trend (Figure 56 and Figure 57).

## 6.4 SO2 annual mean values

For the protection of vegetation and natural ecosystems, the European Directive also imposes a critical level of 20 µg/m³ as the annual mean concentration and an average over the winter season. This limit value is to be attained at monitoring stations that are representative of an area of at least 1000 km², located at least 20 km from an agglomeration and at least 5 km from a busy roadway, built-up area, industry, etc. Belgium has no locations that meet these criteria, so this limit value does not apply.
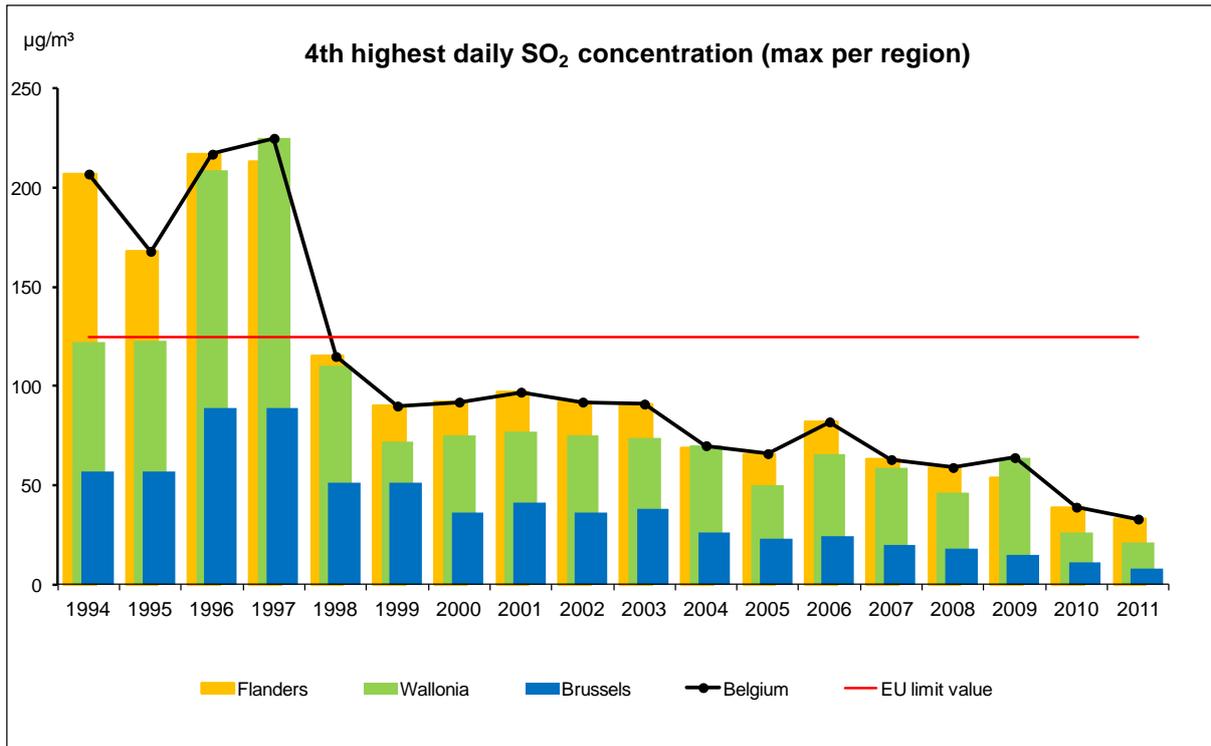
**Figure 56 Evolution of the maximum 4th highest daily mean SO$_2$ concentration per Region and in Belgium based on the RIO interpolation technique**
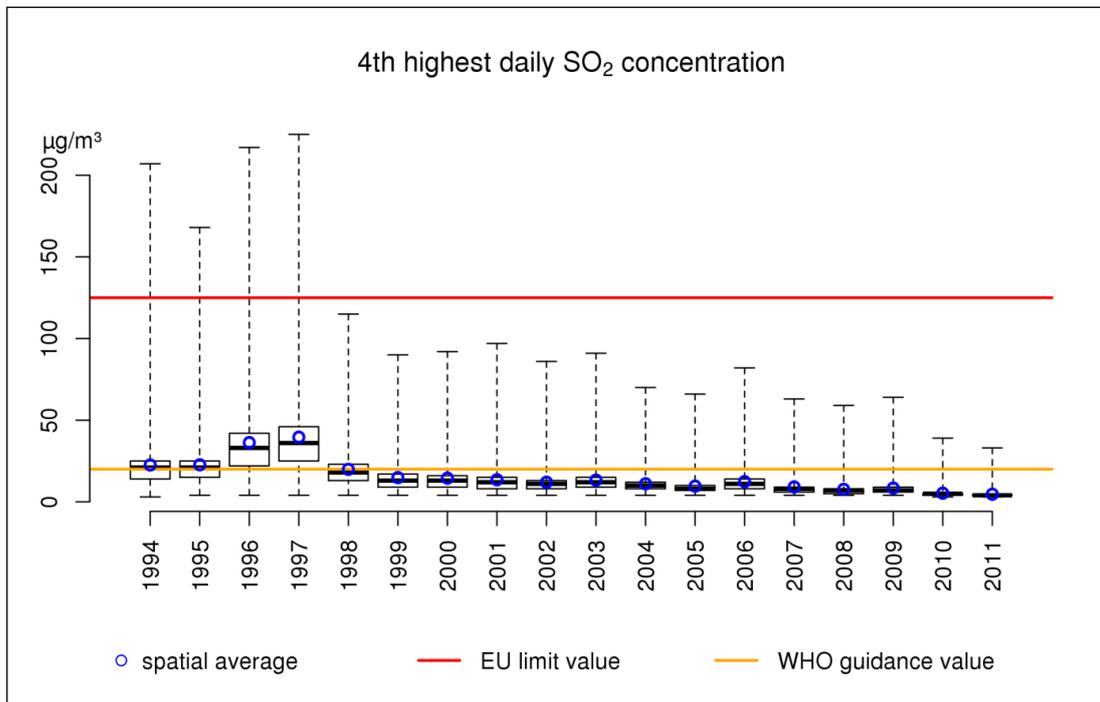


**Figure 57: Box plot of the 4th highest daily mean SO$_2$ concentration over the period 1994-2011 across Belgium based on the RIO interpolation technique**

# Prospect: improvement of the RIO interpolation technique

To improve the spatial resolution, IRCEL-CELINE is currently working on the installation of the RIO-IDFM model (Lefebvre et al., 2013), which is a combination of the current RIO interpolation technique with the IFDM model. IFDM is a bi-Gaussian plume model that models the distribution of emissions based on emission sources and meteorological parameters. The IFDM model uses the emissions of all major motorways and regional roads and point sources to calculate concentrations at a much higher resolution (up to 10 x10 m). An example of a RIO-IFDM map of Belgium for the daily mean $NO_2$ concentrations on 22/11/2011 is shown in Figure 58. Such models will make it possible in the future to monitor also the air quality and the exposure of the population with a higher level of spatial accuracy.
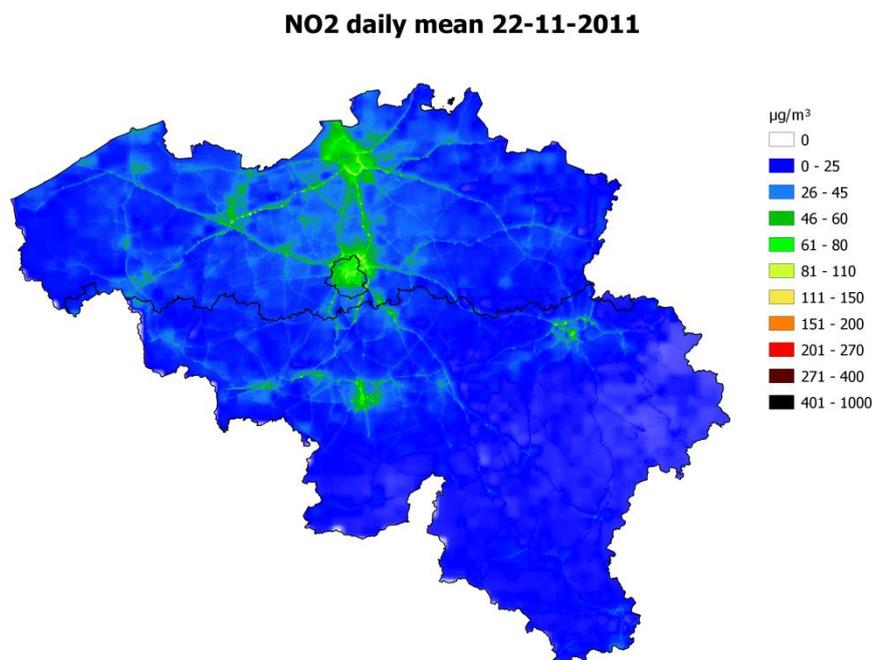


**Figure 58  RIO-IFDM map of Belgium for the daily mean $NO_2$ concentrations on 22-11-2011**

# Conclusion

This annual report gives an overview of the spatial distribution of the air quality in Belgium in the year 2011 for the four major pollutants, PM, $NO_2$, $O_3$ and $SO_2$, and also discusses the evolution of the various indicators over time. As can also be seen in Tables 1 and 2 in the summary, the downward trend over time of the minimum, average and maximum of nearly all indicators is continued in 2011. A number of indicators show a stagnating trend. However, Belgium still exceeds the European limit or target value for the number of exceedances of the $PM_{10}$ daily limit value, the number of days with maximum 8-hour mean ozone concentration > 120 μg/m³ (and the accumulated excess or AOT60), the ozone AOT40 for forests, and the annual mean $NO_2$ concentration. When we compare the values with the more stringent and health-related WHO guideline values, we find that almost all pollutants (and associated indicators) exceed the said values.

Based on this annual report, it can therefore be concluded that air quality in Belgium has significantly improved over the last decades, but that a high percentage of the Belgian population is still exposed to excessive concentrations of the 4 most important air pollutants. In this respect, it should be stressed that the results presented in this report are based on calculations made with the RIO interpolation technique. This technique has a spatial resolution of 4x4 km², so that the results in this report are representative of areas with a surface area of 4x4 km². The concentrations may be higher in the vicinity of major emission sources (highways, industrial zones, etc.).

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## Annex A: Monitoring stations

The following table gives an overview of the monitoring stations of which the measurements are shown on the geographical maps in this report. The bold check marks indicate, for each pollutant, the stations that were used in the calculations made with the RIO interpolation technique.

| Station code | Location | PM10 | PM2.5 | O3 | NO2 |
|---|---|---|---|---|---|
| 40AB01 | ANTWERP (BOUDEWIJN SLUICE) | **x** | | | |
| 40AB02 | BERENDRECHT | **x** | | | |
| 40AL01 | ANTWERP-LEFT BANK | **x** | | | |
| 40AL02 | DOEL (ENGELSESTEENWEG) | x | | | |
| 40AL03 | BEVEREN | | **x** | | |
| 40AL04 | BEVEREN | | **x** | | |
| 40AL05 | KALLO (SLUICE KALLO) | x | | | |
| 40BE06 | BEERSE | | | | |
| 40GK06 | DIEPENBEEK | **x** | | | |
| 40GK09 | GENK | **x** | | | |
| 40HB23 | HOBOKEN | **x** | | | **x** |
| 40LD01 | LAAKDAL-GEEL | | | | **x** |
| 40LD02 | LAAKDAL - GEEL | | | | **x** |
| 40ML01 | MECHELEN | **x** | | | **x** |
| 40MN01 | MENEN | **x** | | | |
| 40OB01 | OOSTROZEBEKE | **x** | | | **x** |
| 40RL01 | ROESELARE (BRUGSESTEENWEG) | **x** | | | |
| 40SZ01 | STEENOKKERZEEL | | | | **x** |
| 40SZ02 | STEENOKKERZEEL | **x** | | | **x** |
| 40TS21 | TESSENDERLO | | | | |
| 40WZ02 | MOL (WEZEL) | | | | |
| 41B004 | BRUSSELS (SINT-KATELIJNE) | | | **x** | **x** |
| 41B005 | BRUSSELS | | | | **x** |
| 41B006 | BRUSSELS (EU PARLIAMENT) | | | **x** | **x** |
| 41B011 | SINT-AGATHA-BERCHEM | **x** | **x** | **x** | **x** |
| 41MEU1 | SINT-LAMBRECHTS-WOLUWE | **x** | **x** | | **x** |
| 41N043 | HAREN | **x** | **x** | **x** | **x** |
| 41R001 | SINT-JANS-MOLENBEEK | **x** | **x** | **x** | **x** |
| 41R002 | ELSENE | | | | **x** |
| 41R012 | UKKEL | **x** | **x** | **x** | **x** |
| 41WOL1 | SINT-LAMBRECHTS-WOLUWE | **x** | | **x** | **x** |
| 42M802 | ANTWERP LUCHTBAL | **x** | | | **x** |
| 42N016 | DESSEL | **x** | | **x** | **x** |
| 42N027 | BREE | | | x | x |
| 42N035 | AARSCHOT | **x** | | **x** | **x** |
| 42N040 | SINT-PIETERS-LEEUW | | | **x** | **x** |
| 42N045 | HASSELT | **x** | **x** | **x** | **x** |
| 42N046 | GELLIK | | | **x** | **x** |
| 42N054 | LANDEN | **x** | | **x** | **x** |
| 42R010 | SINT-STEVENS-WOLUWE | | | | **x** |

| Station code | Location | PM10 | PM2.5 | O3 | NO2 |
|---|---|---|---|---|---|
| 42R020 | VILVOORDE | x | | | x |
| 42R801 | ANTWERP | x | x | x | x |
| 42R802 | ANTWERP | x | x | | x |
| 42R811 | SCHOTEN | x | | x | x |
| 42R815 | ZWIJNDRECHT | x | | | x |
| 42R820 | KAPELLEN | | | | |
| 42R821 | BEVEREN-WAAS | | | | x |
| 42R822 | ANTWERP | | | | x |
| 42R830 | DOEL | | | | x |
| 42R831 | BERENDRECHT | x | | x | x |
| 42R832 | RUISBROEK | x | | | x |
| 42R833 | STABROEK | x | x | | |
| 42R841 | MECHELEN | x | | x | x |
| 42R891 | ANTWERP | | | | x |
| 42R892 | KALLO | | | | x |
| 42R893 | ANTWERP | | | | x |
| 42R894 | ANTWERP | | | | x |
| 42R897 | ANTWERP | | | | x |
| 43H201 | SAINT NICOLAS | x | x | | |
| 43M204 | ANGLEUR | x | x | | |
| 43N060 | HAVINNES | x | x | x | x |
| 43N063 | CORROY LE GRAND | x | x | x | x |
| 43N066 | EUPEN | | | x | x |
| 43N067 | MEMBACH | x | x | | |
| 43N070 | MONS | x | x | x | x |
| 43N073 | VEZIN | x | x | x | x |
| 43N085 | VIELSALM | x | x | x | x |
| 43N093 | SINSIN | x | x | x | x |
| 43N100 | DOURBES | x | x | x | x |
| 43N113 | SAINT-ODE | x | x | x | x |
| 43N121 | OFFAGNE | x | x | x | x |
| 43N132 | HABAY-LA-NEUVE | x | x | x | x |
| 43R201 | LIEGE | x | x | x | x |
| 43R221 | LIEGE | x | x | | |
| 43R222 | LIEGE | x | x | x | x |
| 43R223 | JEMEPPE | x | x | | x |
| 43R240 | ENGIS | x | x | x | x |
| 44M702 | ERTVELDE | | | | x |
| 44M705 | ROESELARE | x | | x | x |
| 44N012 | MOERKERKE | x | | x | x |
| 44N029 | HOUTEM | x | x | x | x |
| 44N051 | IDEGEM | | | x | x |
| 44N052 | ZWEVEGEM | x | | x | x |
| 44R701 | GHENT | x | x | x | x |
| 44R710 | DESTELBERGEN | x | | x | x |

| Station code | Location | PM10 | PM2.5 | O3 | NO2 |
|---|---|---|---|---|---|
| 44R721 | WONDELGEM | | | | x |
| 44R731 | EVERGEM | x | x | | x |
| 44R740 | SINT-KRUIS-WINKEL | x | | x | x |
| 44R750 | ZELZATE | x | | | x |
| 45R501 | CHARLEROI | x | x | | x |
| 45R502 | LODELINSART | x | x | x | x |
| 45R510 | CHATELINEAU | x | x | | |
| 45R511 | MARCINELLE | x | x | | |
| 45R512 | MARCHIENNE AU PONT | x | x | | x |
| 47E007 | SINT-PIETERS-LEEUW | | | | x |
| 47E008 | GRIMBERGEN | | | | x |
| 47E009 | ZEMST | | | | x |
| 47E013 | VORST | | | | x |
| 47E701 | VICHTE | | | | x |
| 47E702 | ELSEGEM | | | | x |
| 47E703 | OOSTEEKLO | | | | x |
| 47E714 | DUDZELE | | | | x |
| 47E715 | ZUIENKERKE | | | | x |
| 47E716 | MARIAKERKE | | | | x |
| 47E804 | MOL | | | | x |
| 47E805 | BORNEM | | | | x |
| 47E806 | HEMIKSEM | | | | x |
| 47E811 | DIEPENBEEK | | | | x |
| 47E812 | GENK | | | | x |
| 47E813 | HAM | | | | x |

# Annex B: Annual overview of air quality pollutants

## Mean daily PM$_{10}$ concentrations in 2011
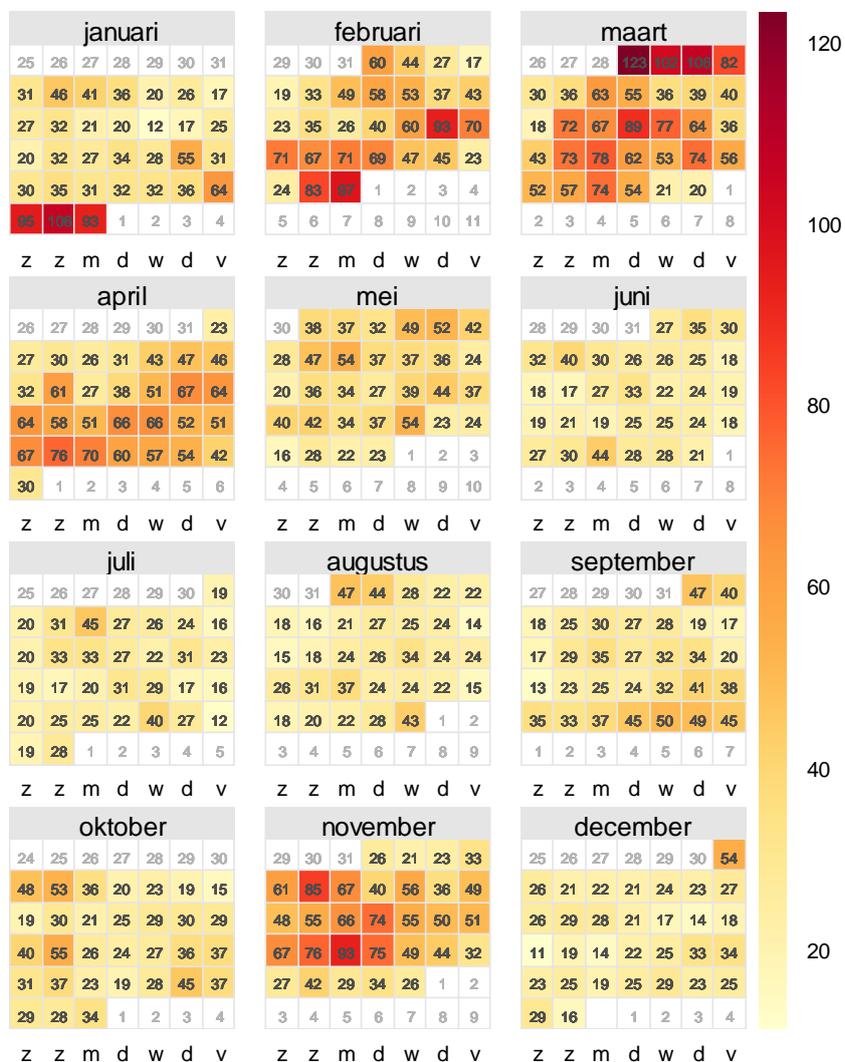


**Mean daily PM$_{10}$ concentrations in 2011**

# Maximum daily O$_3$ concentrations in 2011
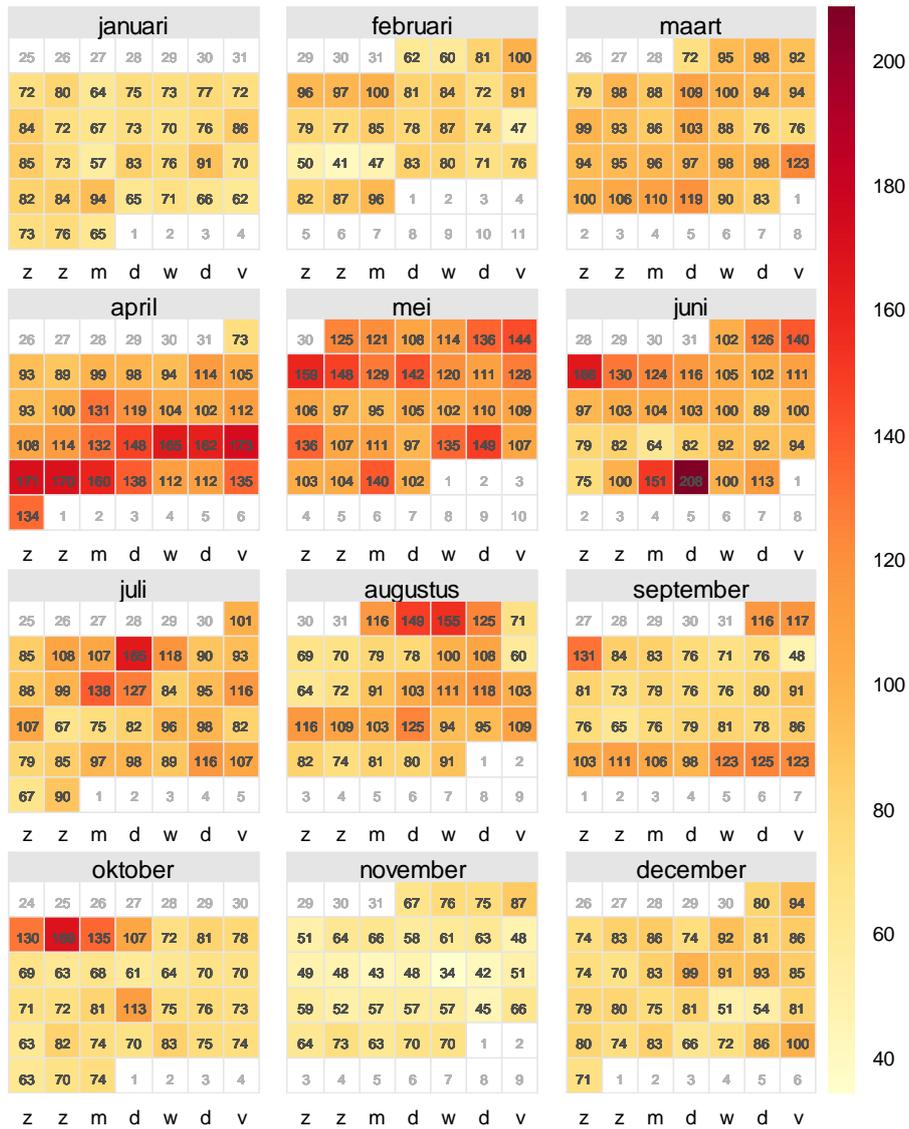


**Maximum hourly O$_3$ concentrations per day in 2011**

Maximum hourly NO$_2$ concentrations in 2011

**januari**

| z | z | m | d | w | d | v |
|---|---|---|---|---|---|---|
| 25 | 26 | 27 | 28 | 29 | 30 | 31 |
| 76 | 87 | 77 | 79 | 67 | 83 | 48 |
| 79 | 106 | 75 | 80 | 51 | 50 | 39 |
| 66 | 70 | 80 | 83 | 102 | 92 | 67 |
| 58 | 90 | 77 | 98 | 69 | 81 | 73 |
| 62 | 71 | 85 | 1 | 2 | 3 | 4 |

**februari**

| z | z | m | d | w | d | v |
|---|---|---|---|---|---|---|
| 29 | 30 | 31 | 81 | 91 | 59 | 31 |
| 38 | 63 | 127 | 122 | 77 | 103 | 89 |
| 52 | 106 | 92 | 114 | 117 | 72 | 73 |
| 53 | 72 | 101 | 103 | 100 | 76 | 52 |
| 54 | 77 | 61 | 1 | 2 | 3 | 4 |
| 5 | 6 | 7 | 8 | 9 | 10 | 11 |

**maart**

| z | z | m | d | w | d | v |
|---|---|---|---|---|---|---|
| 26 | 27 | 28 | 74 | 79 | 108 | 86 |
| 65 | 91 | 104 | 77 | 52 | 90 | 80 |
| 66 | 82 | 91 | 65 | 54 | 78 | 92 |
| 125 | 148 | 174 | 93 | 93 | 111 | 59 |
| 72 | 104 | 129 | 126 | 61 | 59 | 1 |
| 2 | 3 | 4 | 5 | 6 | 7 | 8 |

**april**

| z | z | m | d | w | d | v |
|---|---|---|---|---|---|---|
| 26 | 27 | 28 | 29 | 30 | 31 | 76 |
| 60 | 60 | 86 | 92 | 86 | 94 | 76 |
| 76 | 135 | 69 | 86 | 96 | 99 | 93 |
| 88 | 110 | 117 | 148 | 163 | 119 | 96 |
| 81 | 62 | 114 | 61 | 88 | 82 | 44 |
| 36 | 1 | 2 | 3 | 4 | 5 | 6 |

**mei**

| z | z | m | d | w | d | v |
|---|---|---|---|---|---|---|
| 30 | 51 | 56 | 89 | 103 | 153 | 99 |
| 50 | 90 | 87 | 85 | 63 | 79 | 80 |
| 36 | 53 | 53 | 62 | 74 | 83 | 96 |
| 93 | 61 | 66 | 88 | 85 | 64 | 41 |
| 60 | 69 | 52 | 75 | 1 | 2 | 3 |
| 4 | 5 | 6 | 7 | 8 | 9 | 10 |

**juni**

| z | z | m | d | w | d | v |
|---|---|---|---|---|---|---|
| 28 | 29 | 30 | 31 | 52 | 46 | 44 |
| 52 | 73 | 61 | 58 | 67 | 90 | 53 |
| 48 | 30 | 70 | 93 | 63 | 63 | 28 |
| 34 | 60 | 54 | 69 | 51 | 60 | 39 |
| 46 | 102 | 91 | 55 | 72 | 69 | 1 |
| 2 | 3 | 4 | 5 | 6 | 7 | 8 |

**juli**

| z | z | m | d | w | d | v |
|---|---|---|---|---|---|---|
| 25 | 26 | 27 | 28 | 29 | 30 | 43 |
| 45 | 60 | 85 | 66 | 61 | 48 | 65 |
| 138 | 83 | 61 | 45 | 50 | 80 | 72 |
| 23 | 33 | 66 | 70 | 52 | 52 | 47 |
| 69 | 66 | 58 | 59 | 72 | 43 | 31 |
| 63 | 82 | 1 | 2 | 3 | 4 | 5 |

**augustus**

| z | z | m | d | w | d | v |
|---|---|---|---|---|---|---|
| 30 | 31 | 87 | 99 | 68 | 59 | 50 |
| 53 | 41 | 51 | 66 | 43 | 50 | 43 |
| 40 | 79 | 82 | 60 | 90 | 87 | 74 |
| 77 | 72 | 76 | 61 | 76 | 69 | 46 |
| 40 | 51 | 72 | 78 | 61 | 1 | 2 |
| 3 | 4 | 5 | 6 | 7 | 8 | 9 |

**september**

| z | z | m | d | w | d | v |
|---|---|---|---|---|---|---|
| 27 | 28 | 29 | 30 | 31 | 102 | 80 |
| 49 | 48 | 46 | 46 | 51 | 54 | 51 |
| 33 | 45 | 52 | 58 | 91 | 83 | 38 |
| 47 | 75 | 54 | 77 | 73 | 93 | 110 |
| 104 | 97 | 93 | 98 | 120 | 155 | 158 |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |

**oktober**

| z | z | m | d | w | d | v |
|---|---|---|---|---|---|---|
| 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| 149 | 118 | 66 | 49 | 46 | 59 | 62 |
| 44 | 35 | 40 | 57 | 75 | 87 | 83 |
| 93 | 71 | 68 | 78 | 95 | 95 | 71 |
| 80 | 73 | 72 | 78 | 112 | 96 | 66 |
| 47 | 87 | 53 | 1 | 2 | 3 | 4 |

**november**

| z | z | m | d | w | d | v |
|---|---|---|---|---|---|---|
| 29 | 30 | 31 | 77 | 73 | 103 | 98 |
| 59 | 60 | 67 | 91 | 103 | 53 | 86 |
| 61 | 103 | 105 | 112 | 79 | 86 | 122 |
| 95 | 136 | 145 | 86 | 68 | 65 | 49 |
| 85 | 120 | 69 | 94 | 56 | 1 | 2 |
| 3 | 4 | 5 | 6 | 7 | 8 | 9 |

**december**

| z | z | m | d | w | d | v |
|---|---|---|---|---|---|---|
| 25 | 26 | 27 | 28 | 29 | 30 | 78 |
| 91 | 70 | 52 | 66 | 74 | 57 | 85 |
| 78 | 83 | 61 | 66 | 52 | 66 | 57 |
| 65 | 72 | 60 | 94 | 77 | 75 | 79 |
| 59 | 51 | 30 | 46 | 72 | 48 | 47 |
| 83 | 44 | 1 | 1 | 2 | 3 | 4 |

**Maximum hourly NO$_2$ concentrations per day in 2011**

75

Maximum hourly SO$_2$ concentrations in 2011

**Maximum hourly SO$_2$ concentrations per day in 2011**

# Annex C: Interpreting box plots

A box plot is an effective graphical representation of the distribution of a set of data. It shows the quartiles (or the 25th and 75th percentiles), the median (the 50th percentile) and the maximum and minimum of the set. The nth percentile is the value at which n% of all values is below and 100-n% of the values above the nth percentile.



Maximum →

$75^{ste}$ percentile →

$50^{ste}$ percentile →

$25^{ste}$ percentile →

Minimum →

Spatial average
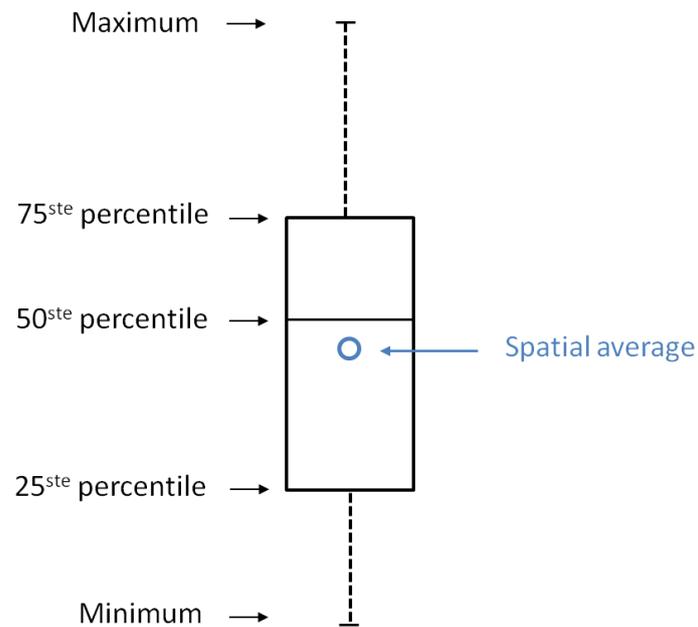
**Representation of a box plot**

# Annex D: Uncertainty maps

The RIO interpolated value is not an absolutely correct value, but is subject to a certain degree of uncertainty. In addition to the uncertainty on hourly or daily mean interpolated concentrations, their aggregation to annual mean concentrations or daily exceedances is an additional source of uncertainty.

In the RIO interpolation technique, a number of aspects contribute to the uncertainty on the interpolated concentrations:

1. Error on measured values: this error is taken indirectly into account because the variogram used in the Kriging (i.e. a component of the RIO interpolation technique) exhibits a "nugget" effect (i.e. at distance 0 between monitoring stations, not the same measured concentration is assumed).

2. Clustering of monitoring stations: more stations grouped close together yield a smaller interpolation uncertainty.

3. Distance from the monitoring stations: the farther a location is from the monitoring station, the greater the interpolation uncertainty.

4. Variation of the actual measurements: if the measurements exhibit a great variation for monitoring sites that are located close to each other, the interpolation uncertainty will also be greater.

5. Error due to re- and de-trending (for both trend averages and standard deviation).


After the uncertainty on the hourly or daily mean interpolated concentrations has been determined, the following must be taken into account for the aggregation:

1. Autocorrelation due to the fact that overall less information will be available, e.g. because the concentrations of today are dependent on those of yesterday.

2. Covariance between the various grid cells which at all times exhibit a fixed spatial pattern over time.

Based on the above sources of uncertainty, an uncertainty (1 sigma) is calculated for the RIO-interpolated concentrations (see maps below) assuming that the measurements are normally distributed. An error of 1 sigma means that for a value x and an error of 5.0 µg/m³, there is a 68% probability that the actual value lies between (x-5.0) and (x+ 5.0) µg/m³. Based on the interpolated concentration, the calculated uncertainty and the limit value, a probability of exceedance of the European limit values can then be calculated.

**PM10**



Error on PM10 annual mean (Belgium, 2011)
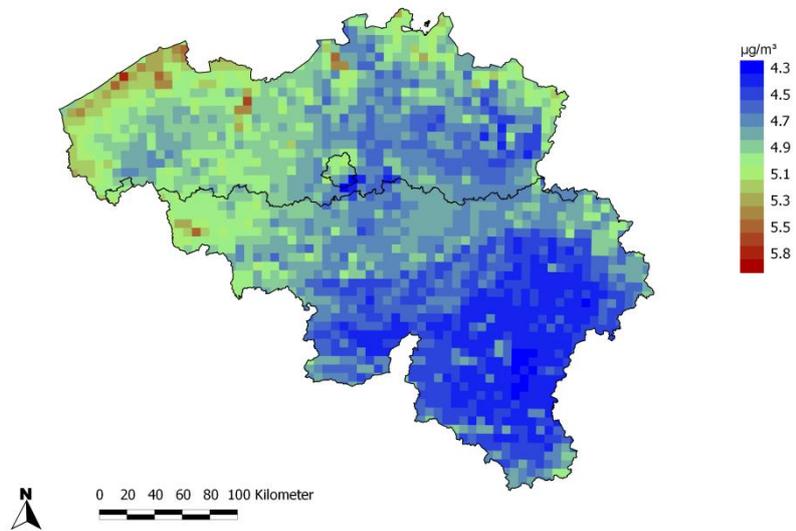
**Spatial distribution of the absolute error (µg/m³) on the annual mean PM$_{10}$ concentration.**



Probability of exceedance of PM10 annual limit value (Belgium, 2011)
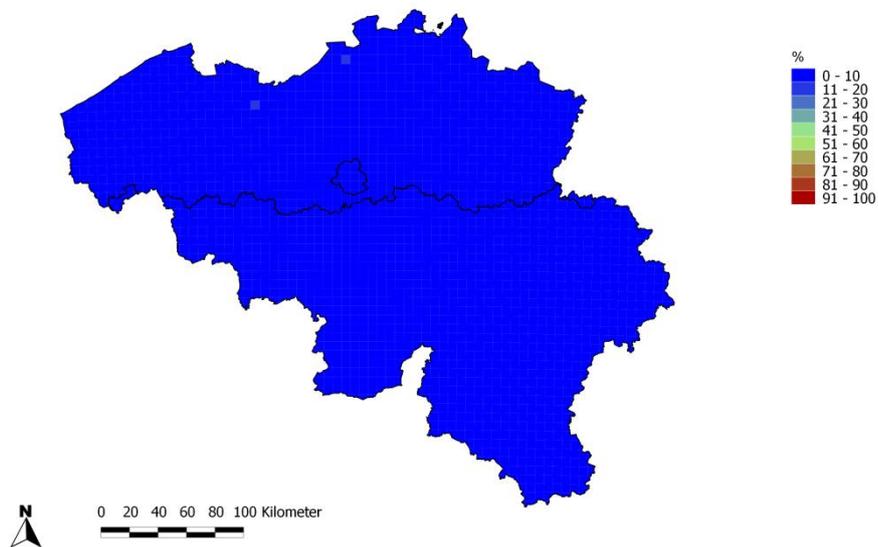
**Probability (%) that the annual mean PM$_{10}$ concentration exceeds the European limit value of 40 µg/m³.**

**Probability of exceedance of PM10 daily limit value (Belgium, 2011)**



%
0 - 10
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100

0 20 40 60 80 100 Kilometer

N
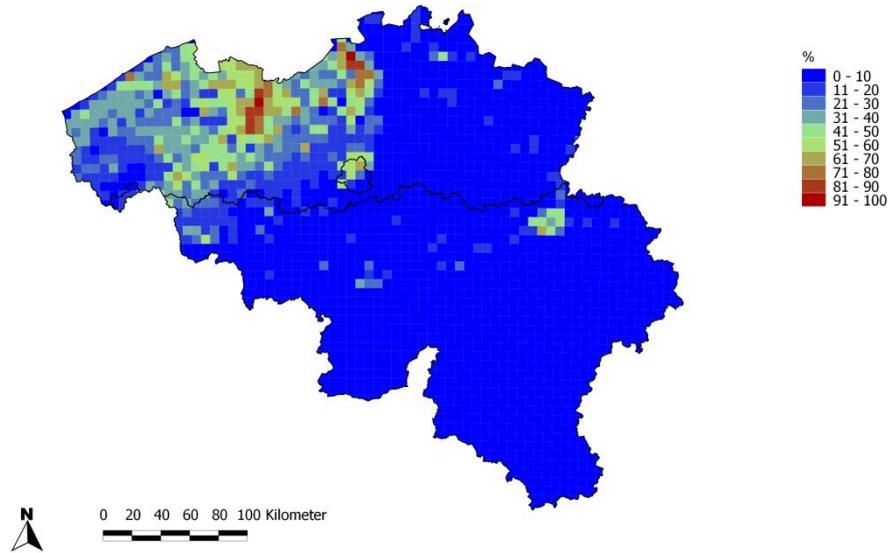
**Probability (%) that the PM$_{10}$ daily limit value of 50 µg/m³ is exceeded on more than 35 days.**

**PM2.5**

**Error on PM2.5 annual mean (Belgium, 2011)**



µg/m³
2.6
2.8
3
3.2
3.4
3.6
3.8
4
4.1

0 20 40 60 80 100 Kilometer

N
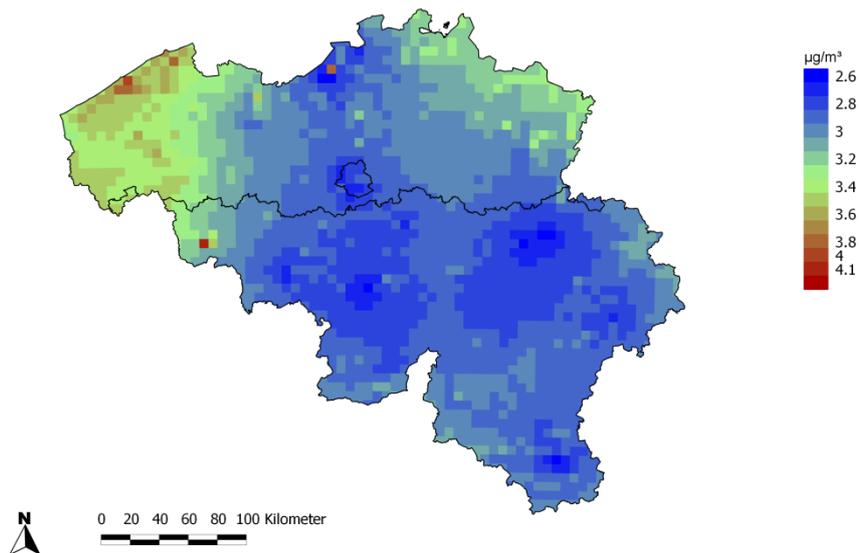
**Spatial distribution of the absolute error (µg/m³) on the annual mean PM$_{2.5}$ concentration**

**NO2**

Error on NO2 annual mean (Belgium, 2011)
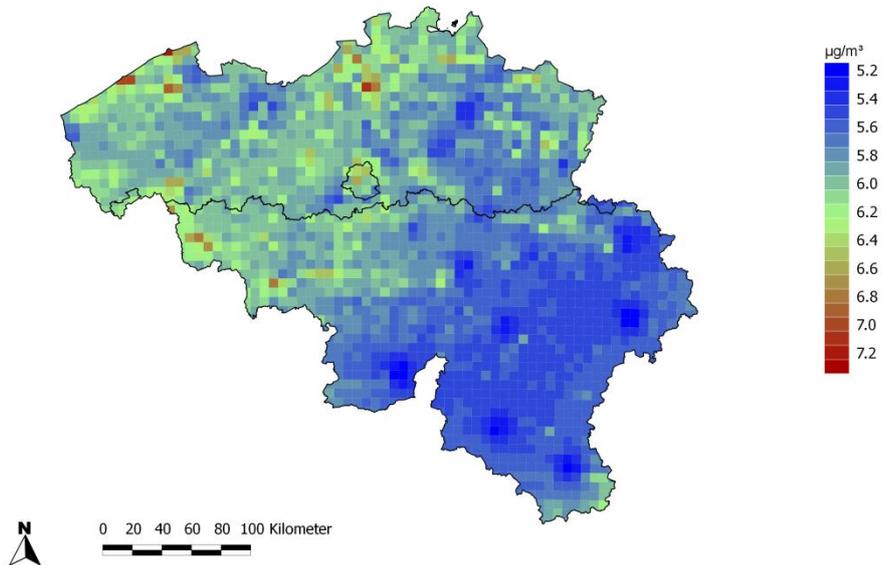


**Spatial distribution of the absolute error (µg/m³) on the annual mean NO₂ concentration**

Probability of exceedance of NO2 annual limit value (Belgium, 2011)
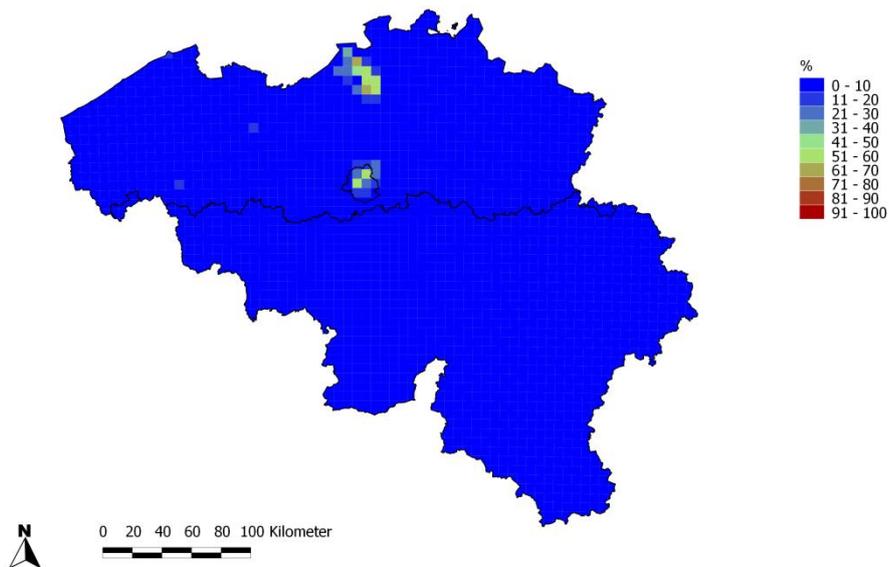


**Probability (%) that the annual mean NO₂ concentration exceeds the European limit value of 40 µg/m³.**

**O3**

Error on O3 annual mean (Belgium, 2011)



**Spatial distribution of the absolute error (μg/m³) on the annual mean O₃ concentration**