Informing you on ambient air quality in the Belgian Regions

Intergewestelijke Cel voor het Leefmilieu (IRCEL)
Cellule Interrégionale de l'Environnement (CELINE)
Belgian Interregional Environment Agency (IRCEL-CELINE)

ANNUAL REPORT Air Quality in Belgium 2015

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

Frans Fierens
Charlotte Vanpoucke
Elke Trimpeneers
Olav Peeters
Stijn Quidé
Thierri de Vos
Philippe Maetz
Virginie Hutsemékers

Acknowledgements

This report is based on air quality and meteorological data collected from the monitoring networks in the three Regions. IRCEL-CELINE would therefore like to thank all staff of the Flemish Environment Agency (VMM), the Public Service Scientific Institute (ISSeP) and the Walloon Air and Climate Agency (AWAC) and of the Brussels Environment Agency (IBGE-BIM).

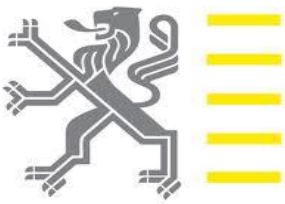


Table of Contents

List of Abbreviations and Glossary

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

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

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. CET in the months of April to September. Indicator for the protection of forests.

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. CET in the months of May, June and July (growth season). Indicator for the protection of crops and (semi-)natural vegetation.

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.

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

LTO — Long-term objective

MTO — Medium-term objective

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

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.

PAH — Polycyclic Aromatic Hydrocarbon. Atmospheric pollutants composed by several benzene rings; highly toxic.

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

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

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

Smog — Condition of increased air pollution. In winter it is caused mainly by particulate matter, while in summer the main cause is ozone.

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

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.

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

WHO World Health Organization

Summary

Table 1 below gives an overview of the various air quality indicators for Belgium in 2015, using a colour code to compare to the minimum, mean and maximum values of the past 10 years: 2005-2014. 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 be higher or lower locally.

Table 1: Air quality indicators in Belgium in 2015.

Indicator	2015			European limit or target value	WHO guideline value
	Min.	Mean	Max.		
PM_{10}					
Annual mean (µg/m³)	4	15	27	40	20
Number of days > 50 µg/m³	0	5	21	Max. 35 days	Max. 3 days
$PM_{2,5}$					
Annual mean (µg/m³)	6	10	16	25	10
O_3					
Number of days > information threshold 180 µg/m³	7				
Number of days > alert threshold 240 µg/m³	1				
Number of days with max. 8-h mean > 120 µg/m3	4	13	21	MTO: 25 days, averaged 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 2013-2015)	2	9	17	MTO: 25 days, averaged over 3 years, LTO: 0 days	0 days with max. 8-h mean > 100 µg/m³
AOT60 ((µg/m³).h)	520	2163	3880	5800**	
AOT40 vegetation ((µg/m³).h)	3140	9494*	15 625	MTO: 18 000, averaged over 5 years, LTO: 6000	
AOT40 vegetation ((µg/m³).h) (mean 2011-2015)	3233	8086*	13 372	MTO: 18 000, averaged over 5 years, LTO: 6000	

AOT40 forests ((µg/m³).h)	5175	18397 **	**24 618**	Critical level: 10000*** Reference level: 20000***	

NO_2					
Annual mean (µg/m³)	4	12	37	40	40
19th highest hourly mean (µg/m³)	26	44	107	200	Highest hourly mean: 200

SO_2					
25th highest hourly mean (µg/m³)	1	3	22	350	
4th highest daily mean (µg/m³)	1	2	13	125	Highest daily mean: 20

* Weighted mean of the vegetation area
** Weighted mean of the forested area
*** 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 exceedances of the European limit value or target value.*

The year 2015 appears to have been a favourable year regarding air quality. For PM_{10}, $PM_{2.5}$, NO_2 and SO_2, the majority of the indicators were significantly lower in the past year than the mean for the 10 years before. For ozone, most of the indicators in 2015 were comparable to those of the 10 year mean. The three-year mean of the number of days with a maximal 8-hour mean value exceeding 120 µg/m³, being an indicator for chronic exposure, is below the 10-year mean. Based on the RIO calculations, all European limit and target values are attained in 2015. 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. We can thus conclude, based on those calculations, no one in Belgium was exposed neither to more than 35 days with PM_{10} concentrations above 50 µg/m³, nor to annual mean concentrations of NO_2 above 40 µg/m³. The population exposure is estimated, based on RIO calculations that provide an image of the air quality at a resolution of 4x4 km² and the number of inhabitants at that resolution. This relatively low resolution explains that 0% of the population was exposed to concentrations above the thresholds as put by the European guidelines, while such exceedances were still measured in 2015.

The European annual limit value for PM_{10} is attained everywhere in Belgium. The annual mean $PM_{2.5}$ concentrations in 2015 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). The European hourly limit value, by contrast, is attained everywhere in Belgium.

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 almost everywhere, as is the LTO for vegetation. For forests, too, the situation is not favourable: almost the entire forest area (98%) is exposed to ozone pollution above the critical level. The reference value is exceeded for 30% of the forests in 2015.

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 2015.

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	2015 % of exposed population or % of area above the target value for vegetation (AOT40)	WHO guideline value	2015 % of exposed population
PM_{10}				
Annual mean (µg/m³)	40	0%	20	27%
Number of days > 50 µg/m³	Max. 35 days	0%	Max. 3 days	90%
$PM_{2.5}$				
Annual mean (µg/m³)	25	0%	10	87%
NO_2				
Annual mean (µg/m³)	40	0%	40	0%
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	0%
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 2013-2015)	MTO: 25 days, mean over 3 years	0%
AOT60 ((µg/m³).h)	5800*	0%
AOT40 vegetation ((µg/m³).h)	LTO: 6000	90%
AOT40 vegetation ((µg/m³).h) (mean 2011-2015)	MTO: 18000, mean over 5 years	0%
AOT40 forests ((µg/m³).h)	Critical level: 10000*	98%
AOT40 forests ((µg/m³).h)	Reference level: 20000*	30%

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 also were 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 co-operation with the responsible agencies in the three Regions. As part of this cooperation agreement, IRCEL-CELINE is required to report on the air quality in the three Regions each year. This report presents an overview of the air quality situation in Belgium in 2015.

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), in Wallonia by the Public Service Scientific Institute (ISSeP) **(**http://www.issep.be **)** and the Walloon Air and Climate Agency (AWAC) (http://airclimat.wallonie.be) and in Brussels by the Brussels Environment Agency (IBGE-BIM) (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 2015 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. **Error! Reference source not found.** gives an overview of the regions, provinces and largest agglomerations in Belgium.

The annual reports published by the Regions are available at the following locations:

- For Flanders: https://www.vmm.be/publicaties/luchtkwaliteit-in-het-vlaamse-gewest-2015
- For Wallonia : http://193.190.182.213/WebAirQuality/RapportAnnuel.aspx
- for Brussels: http://document.environnement.brussels/opac_css/

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 that will be discussed are PM_{10}, $PM_{2.5}$, BC, 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 based on 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 actually 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 40µg/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.

Error! Reference source not found. shows the population density per RIO grid cell. This density is higher in the large agglomerations, which are clearly visible on the map.

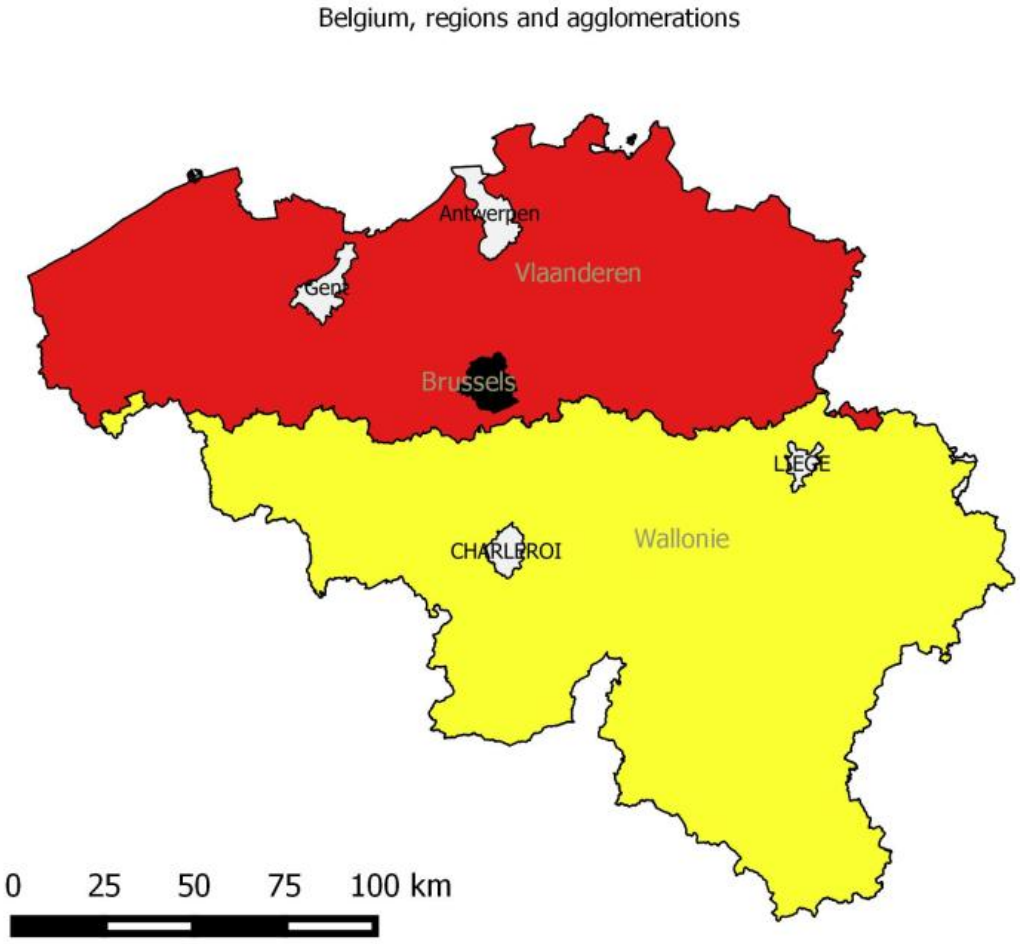


Figure 1: Regions, provinces and large agglomerations in Belgium

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 2 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 km². RIO allows the air quality to be calculated by the hour for all 4x4 km² 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 Annex C.

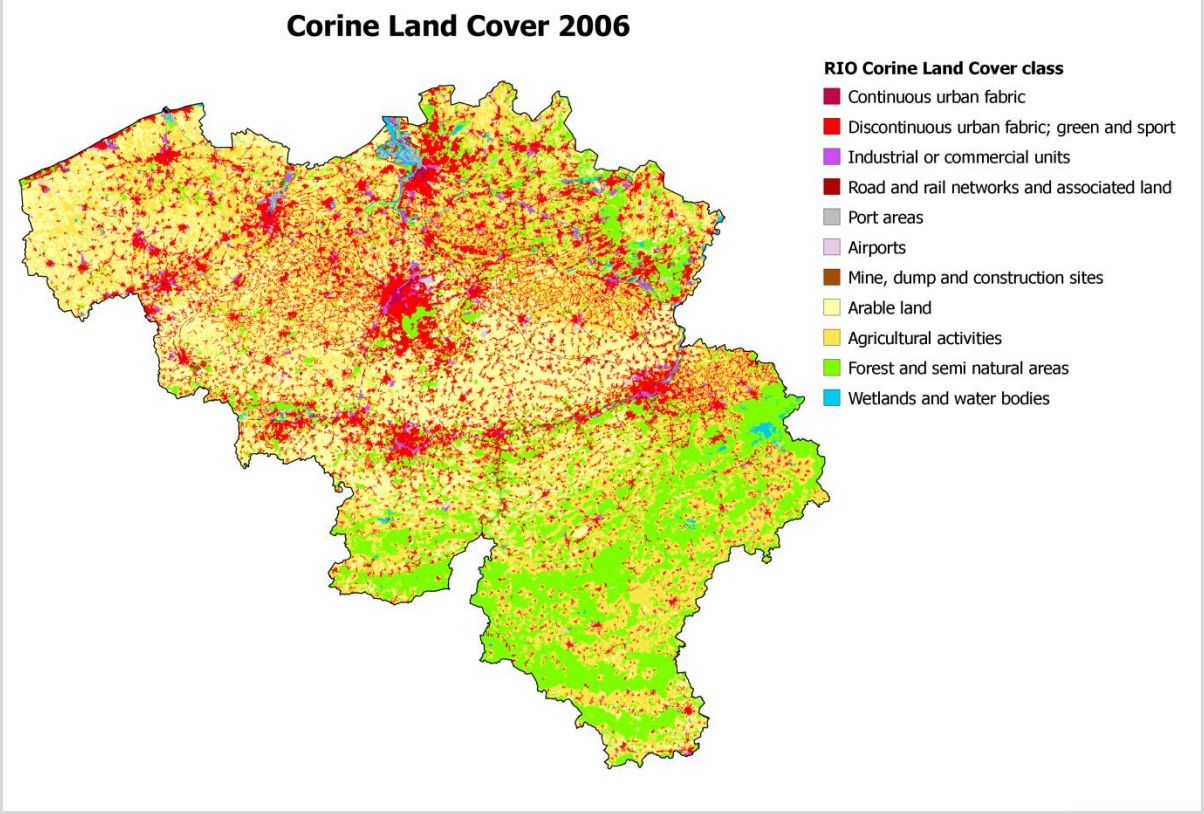


Figure 2: Land use in Belgium, divided into RIO-corine classes.

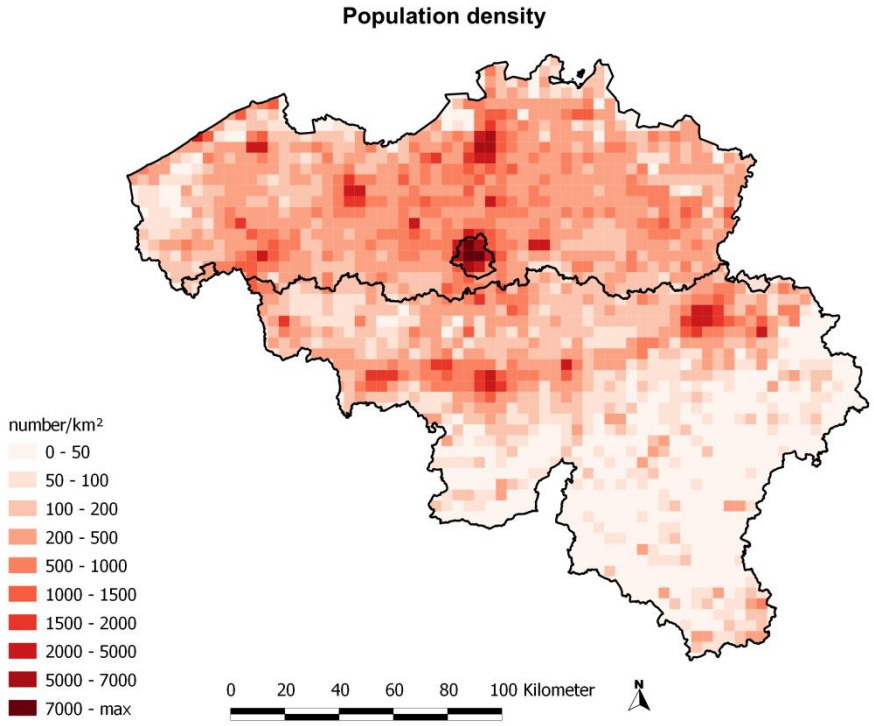


Figure 3: Population density per RIO grid cell (Source: population figures Statistics Belgium).

Apart from the various indicators for the year 2015, 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 (see Box 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 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 a certain number of times on the basis of a predefined distribution, and that also the trend analysis parameters are recalculated a certain 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 2015 (and possible explanations, such as the meteorological conditions, for the occurrence of these episodes) in Chapter 2. A detailed description of each air pollution component is given in Chapter 3 (Particulate matter), 4 (Nitrogen oxides), 5 (Ozone) and 6 (Sulphur dioxide). In these chapters, European limit and target values are compared to relevant indicators, and the long-term trend is analysed. 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 D 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 (QuantumGIS Development Team, 2015).

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, 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.

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/m³
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

On December 18th, 2013, the European Commission published a new package of measures to improve air quality in Europe. These measures are the result of an in-depth review of the policy framework in matters of air quality and involved experts from various member states, European institutions, industry, environmental action groups and stakeholders. This package of measures includes, on the one hand, a review of the « Thematic Strategy on Air Pollution and Clean Air for Europe (CAFE) » (2005), in which the Commission presents the objectives it wants to reach in terms of air quality, and on the other hand a proposal of review for the National Emission Ceilings (NEC) Directive (2001/81/EC) and the establishment of a new directive concerning the emissions of the Medium Combustion Plan (MCP Directive).

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, and counterbalances the reductions of emissions of the more recent car fleet. Furthermore, there is a gap between the emission standards which are established for each vehicle type and their actual emissions, and the planned renovation of the car fleet is taking place more slowly than expected (EU, 2011). All over Europe, there are several zones of exceedance of one or more standards of air quality. Since negative effects of air pollution on health and environment cannot be ignored and even after the implementation of the current policy, a negative impact will remain, the European Commission defined the goals to be achieved at short, medium and long term.

At a short term scale, no new legal framework will be introduced; the objective is to reach the complete implementation of the actual policy in all member states in 2020. To that end, the Commission proposed a financial support for the elaboration and implementation of plans for air quality improvement, and will pursue the efforts for the reduction of NO_x concentrations from traffic emissions, in particular for diesel vehicles, by means of Euro norms and the setting up of new test protocols to define more realistic thresholds in comparison with real emissions ("real driving emissions").

More recently, following the 'dieselgate' scandal, the European Commission has set both temporary, namely up to 2020-2021, and afterwards definitive factors of conformity, of respectively 2.1 and 1.5 for emissions of NO_2 under real driving conditions (2016/646/EU). De facto, this means a small reduction of the NO_x emissions in 2020.

At a medium term scale, the objective of the European Commission is to reduce the number of premature deaths due to high PM or O_3 concentrations and the surface of ecosystems in exceedance of critical values of 52% and 35 % respectively in 2030, in comparison with 2005. To reach these objectives, the Commission considers first to review the directive on National Emission Ceilings (NEC, 2001/81/EU), and second, the implementation of a new directive concerning the installation of medium combustion plant (1-50 MWh), in order to reduce the background concentrations. In the actual proposition of the NEC directive – still in discussion – new objectives of reduction are planned by comparison to 2005 ceilings. Apart from the ceilings already defined for NO_x, SO_2, NMVOC and NH_3, new ceilings are considered for CH_4 and $PM_{2.5}$. For 2020, the objectives are those from the Göteborg protocol (in the context of the international treaty LRTAP). For 2030, more stringent objectives should be applicable.

At a long term scale (by 2050), the objective is to adapt the European standards to meet the WHO guidelines. Nowadays, the European policies are less strict than the health advice values of the WHO and thus remain insufficient to reduce the impact of air pollution on health. In comparison with a

scenario without new legislation, the package for clean air is expected to prevent 58 000 early deaths in the EU and will significantly increase the area of protected ecosystems.

More information on the package for clean air in Europe can be found here: http://ec.europa.eu/environment/air/clean_air_policy.htm

2 Periods with increased air pollution (smog episodes) in 2015

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 such, concentrations can sometimes increase because of pollution imported from abroad. Pollutants can be formed or removed by various physicochemical 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. 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. Under these circumstances, the conditions for dispersion of the air pollution in the atmosphere are 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. These meteorological conditions are favourable for the natural, photochemical formation of ozone.

Smog periods can also be the result of the import of air pollution from nearby regions. This is generally accompanied by continental 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). A key component in this context is ammonia. High concentrations of secondary particulate matter 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 2015 is given in Annex B.

2.1 Winter and spring smog

Belgium suffered a period of increased concentrations of particulate matter between the 17th and the 20th of March 2015 (with a temporary decrease on March 19). As such, it is not really a typical winter smog episode, but rather a situation arising during spring time, on calm days. Characteristic of these spring smog episodes is the large spatial extent at which they occur. Particulate matter concentrations were not only elevated in Belgium, but very high concentrations were also measured in Holland, East-England and northern France. A meteorological situation with high air pressure, cold and humid nights, little wind and relatively mild temperatures is ideal for the formation of secondary particulate matter.

In addition to atmospheric conditions unfavourable for dispersion, ammonia emissions play an important role in particulate matter formation during this time of the year. Ammonia is released when farmers spread manure on their croplands. This compound can react with nitrogen oxides, mainly originating from traffic, forming ammonium nitrate. To a lesser extent it can also form ammonium sulphate due to reaction with SO_2 emitted by the industry. Ammonium nitrate is the main component of secondary (mineral) particulate matter. Particulate matter can thus be divided into a primary faction, originating directly from emissions (for example diesel soot), and a secondary faction that is not emitted directly, but is rather formed by complex physicochemical reactions in the atmosphere. Measurements of the composition of particulate matter have shown this secondary fraction may amount to up to 60% of the total mass of particulate matter.

The contribution of secondary particulate matter is not easy to forecast, mainly because the period of its prevalence varies from year to year, without prior knowledge. Forecast models need these data, in addition to other meteorological parameters in order to eventually result in a credible air quality forecast. As a result, forecasting spring smog is not easy.

The highest concentrations of particulate matter during the episode of the 17th to the 20th of March 2015 were observed on March 20 and varied between 52 and 119 µg/m³. $PM_{2.5}$, the fraction containing the majority of secondary minerals, represented more than 85% of the particulate matter measured.

During the whole period of March 17 to March 20, the smog alarm was not activated, as the activation norm (an exceedance of the daily mean of the 70 µg/m³ threshold during 2 subsequent days) was not surpassed.

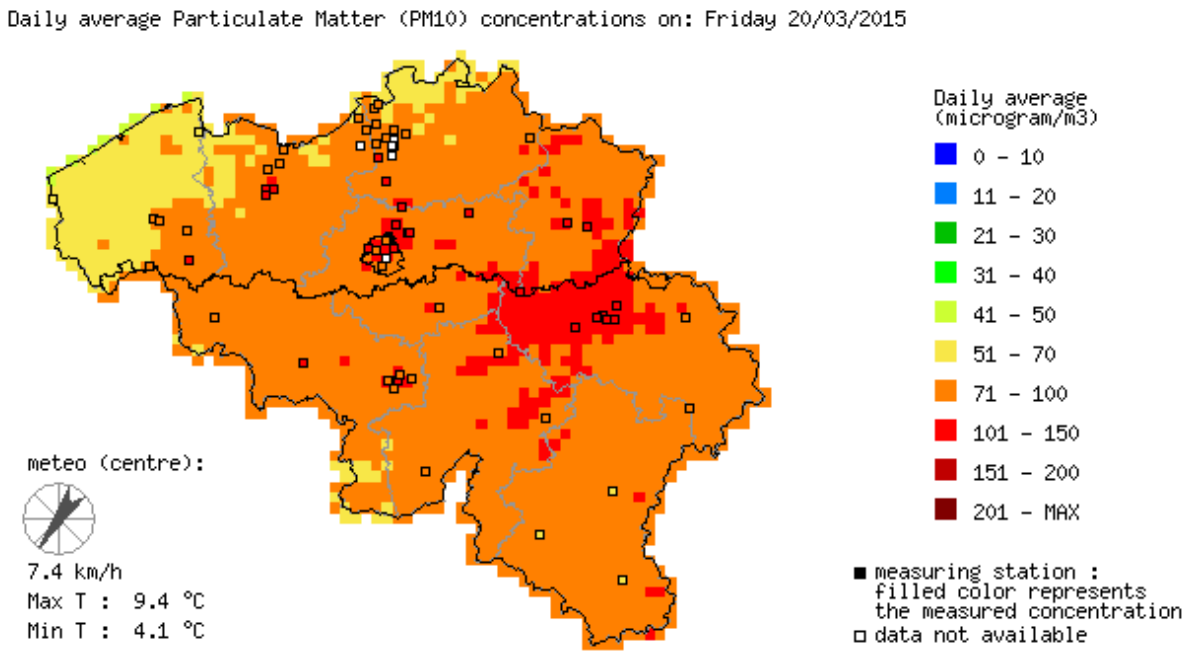


Figure 4: Daily mean particulate matter concentrations on March 20, 2015.

2.2 Summer smog

The summer of 2015 can be considered normal regarding temperatures and the amount of sunshine. The European information threshold for ozone of 180 µg/m³ was surpassed in at least one measuring station during 7 days between the end of June and mid August. The alert threshold of 240 µg/m³ was surpassed on 1 day during that period. The highest ozone concentrations were observed between the 30th of June and the 4th of July 2015, with a maximum on July 2. That day, the alert threshold was exceeded in 5 measuring stations, with a maximal value of 263 µg/m³ measured in Walshoutem. The largest number of exceedances was observed on July 3, when the information threshold was surpassed in 24 stations and increased ozone concentrations were registered all around Belgium, with the exception of the coast (see Figure 5). Exceedances of the information threshold were also observed on July 11 and August 13, 2015.

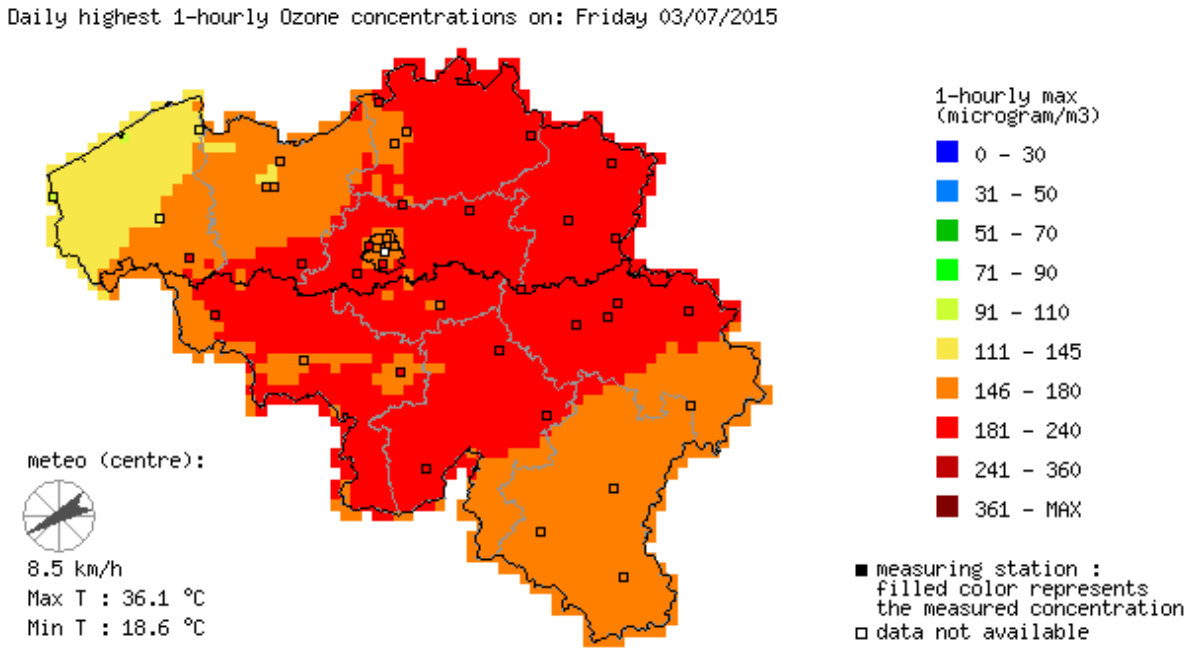


Figure 5: Highest ozone concentrations on July 3, 2015.

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), whereas $PM_{2.5}$ 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 that 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 heating of buildings. 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. It is estimated the mean life expectancy of the Belgian population is decreased by about 9 to 10 months due to the exposure to current $PM_{2.5}$ concentrations (Amann et al, 2005). In Flanders, particulate matter is responsible for approximately three quarters of the lost healthy years 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 a diameter smaller 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 is a carrier of various chemical, toxic substances. In 2012, diesel particles were

classified, by the IARC ("Agency for Research on Cancer", as part of the WHO), in group 1 of carcinogenic substances (WHO, 2012). Group 1 contains the substances that are indisputably carcinogenic for the population. In 2013, air pollution was qualified as carcinogenic for humans (group 1) as well (WHO, 2013).

In addition, particulate matter also 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) as a heating (Black Carbon) effect, and thus also plays an important role in climate change.

3.1 PM_{10}

3.1.1 PM_{10} monitoring stations

Figure 6 shows the evolution of the number of monitoring stations where PM_{10} is measured. 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 68 in 2015. Because the number of monitoring stations before 2004 is considerably less than in 2015, the uncertainty on the interpolated annual mean concentrations is greater in those initial years. For the Walloon region, this applies from 2008 onwards.

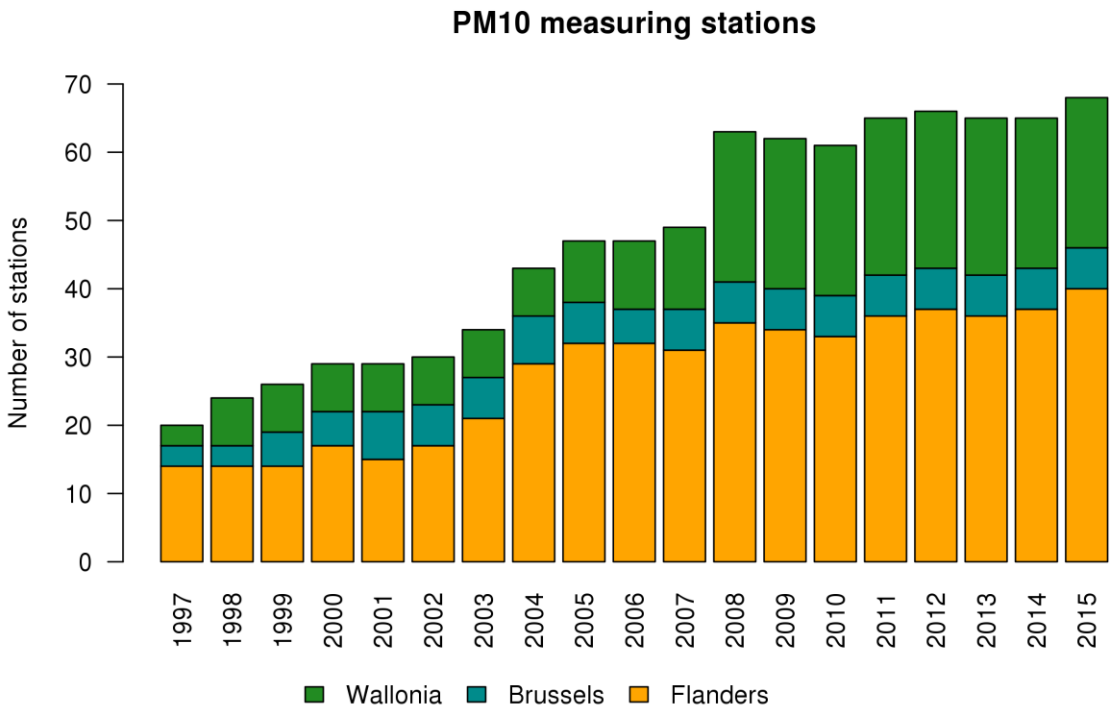


Figure 6: Evolution of the number of PM_{10} monitoring stations in Belgium

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 2015, the interpolated annual mean PM_{10} concentration across all RIO grid cells in Belgium was 15.4 µg/m³. The 40 µg/m³ limit value was not exceeded at any location (Figure 7). The highest annual mean PM_{10} concentrations, up to 26.8 µg/m³, were calculated around Ghent and Antwerp. In the rest of Flanders, Brussels and Northern Wallonia, the concentrations are situated around 16-20 µg/m³. The lowest annual mean PM_{10} concentrations, below 15 µg/m³, were recorded south of the 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.

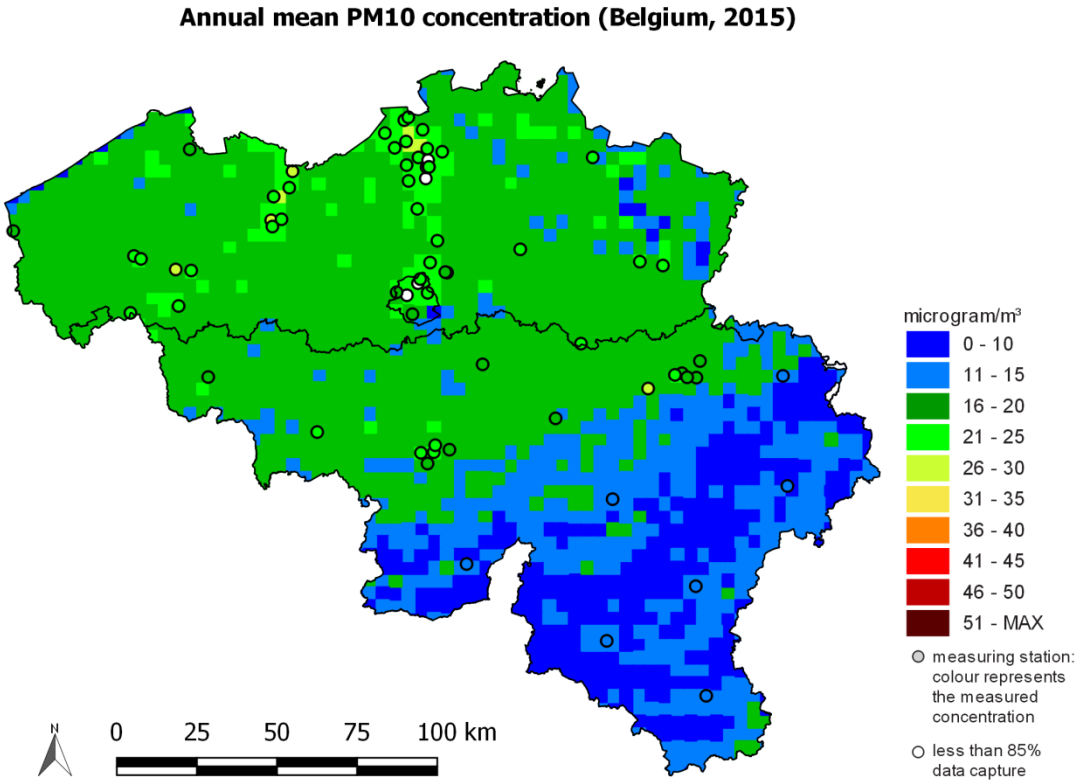


Figure 7: Spatial distribution of the annual mean PM_{10} concentration in Belgium in 2015. All data were calculated using the RIO interpolation technique.

Figure 8 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. Since 2007, the European limit value has been attained everywhere. The WHO guideline value of 20 µg/m³ is still being exceeded in 8% of the Belgian territory in 2015.

[1] P25 or the 25th percentile is the value at which 25% of all values are lower, and 75% of the values are higher.

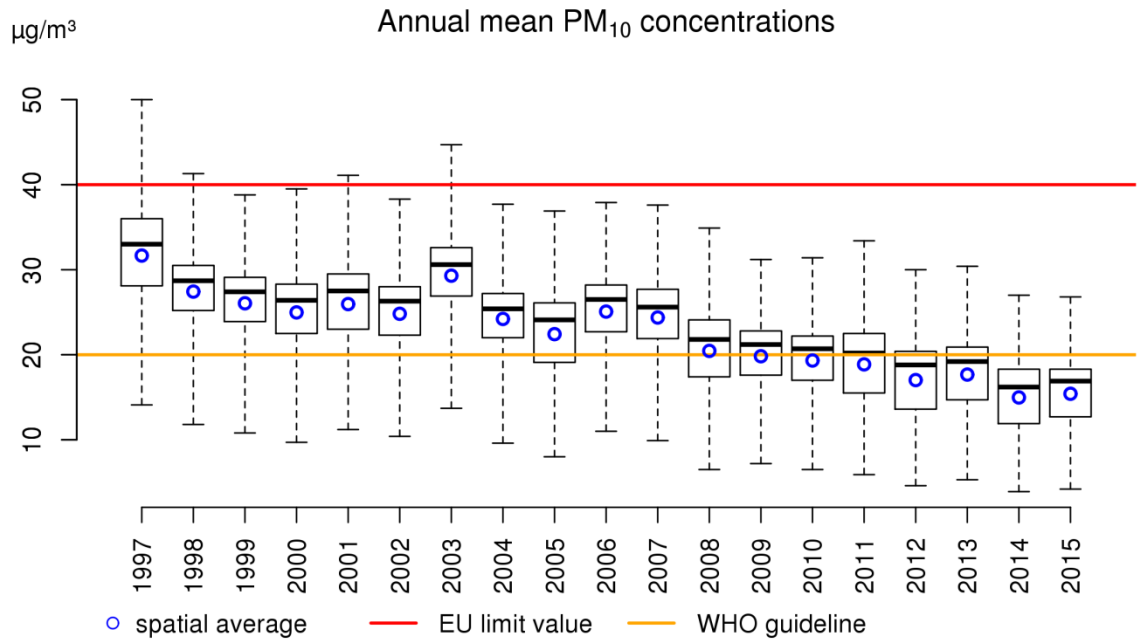


Figure 8: Box plot of the annual mean PM_{10} concentrations (µg/m³) over the period 1997-2015 in Belgium. The spatial average is represented by the blue circles. All data were calculated using the RIO interpolation technique.

The annual mean PM_{10} concentration in 2015 for Brussels, Flanders and Wallonia are 19.8, 18.1 and 13.3 µg/m³ respectively (Figure 9). 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 2015 it is 18.8 µg/m³).

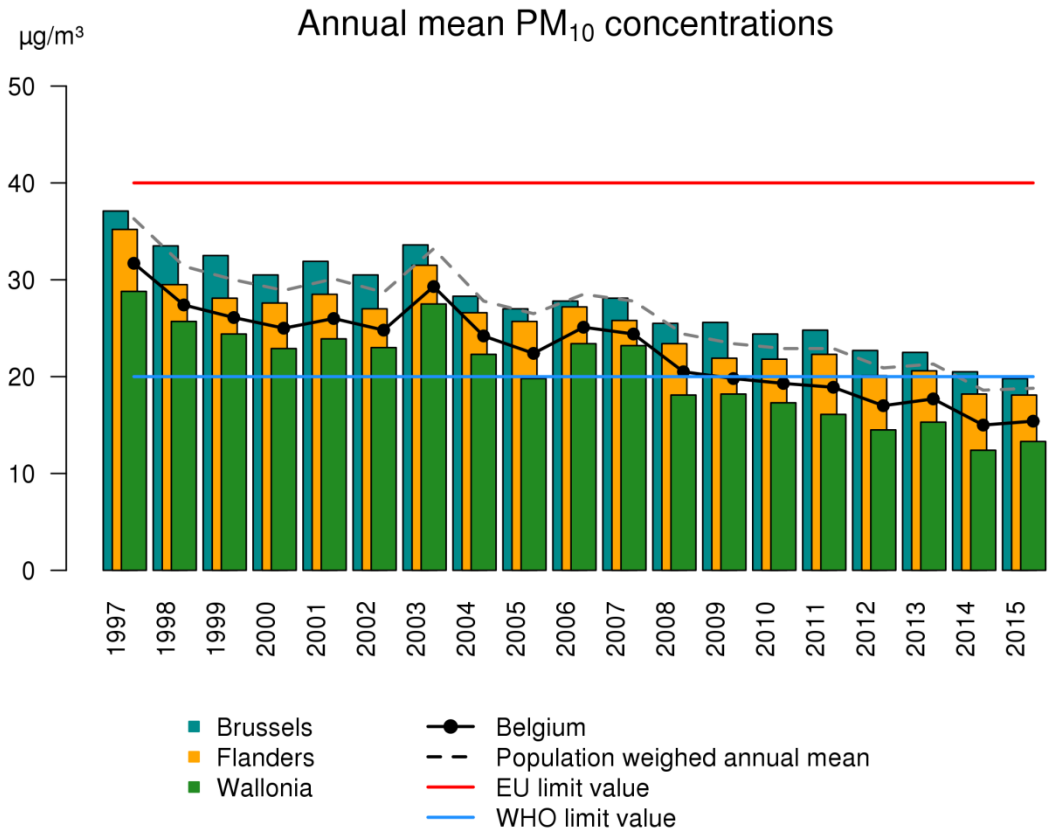


Figure 9: Evolution of the spatially distributed annual mean PM_{10} concentration in Belgium and the three Regions and the population-weighted mean concentration for Belgium. All data were calculated using the RIO interpolation technique.

The spatial trend between 2000 and 2015 shows that during this period, the PM_{10} annual mean concentrations have declined everywhere in Belgium (see Figure 10). This decline seems to be slightly greater in Wallonia, between -1.2 and -0.8 µg/m³/year, than in Flanders, between -1.0 and -0.6 µg/m³/year. Here, it should be noted (as already mentioned in Note 2) 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.

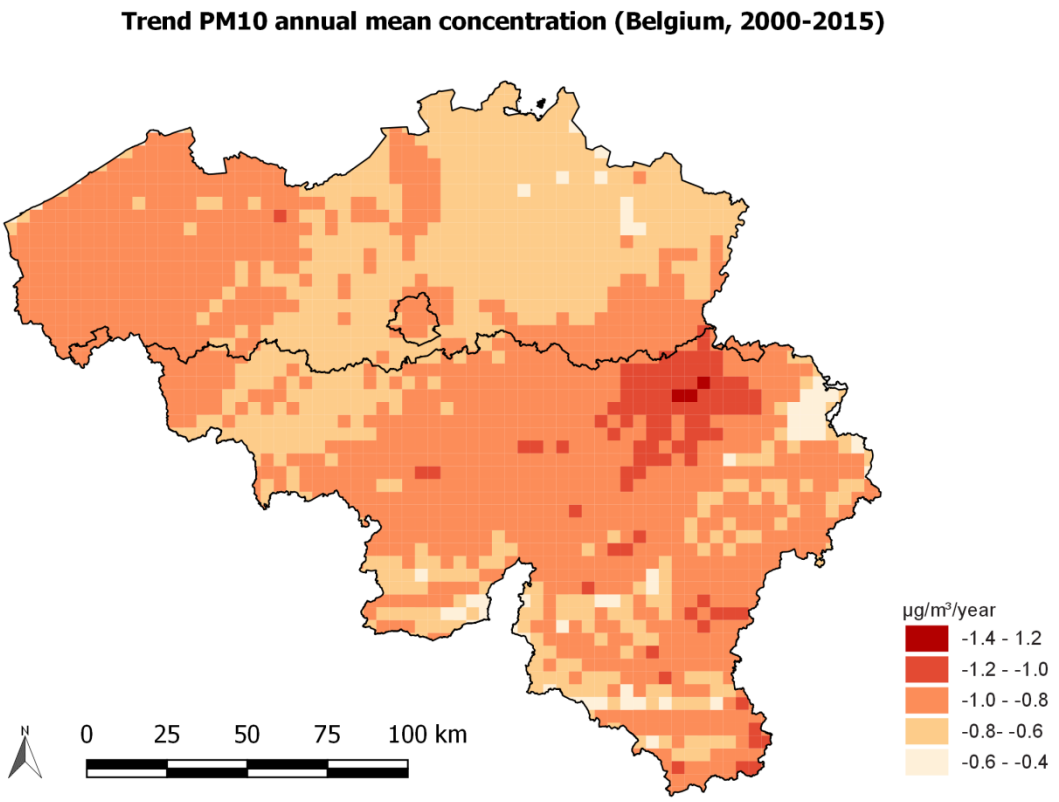


Figure 10: Spatial trend in annual mean PM_{10} concentrations (µg/m³/year). All data were calculated using the RIO interpolation technique.

In 2015, no one of the Belgian population was exposed to annual mean concentrations above the European limit value of 40 µg/m³ (Figure 11). 27% of the population was, however, still exposed to annual mean PM_{10} concentrations above the WHO guideline value of 20 µg/m³. The downward trend in population exposure of recent years continues. In 2015, 73% of the population was exposed to PM_{10} concentrations below the WHO guideline value (< 20 µg/m³), whereas in 2011 this was only 19% and in 2006 even 2%.

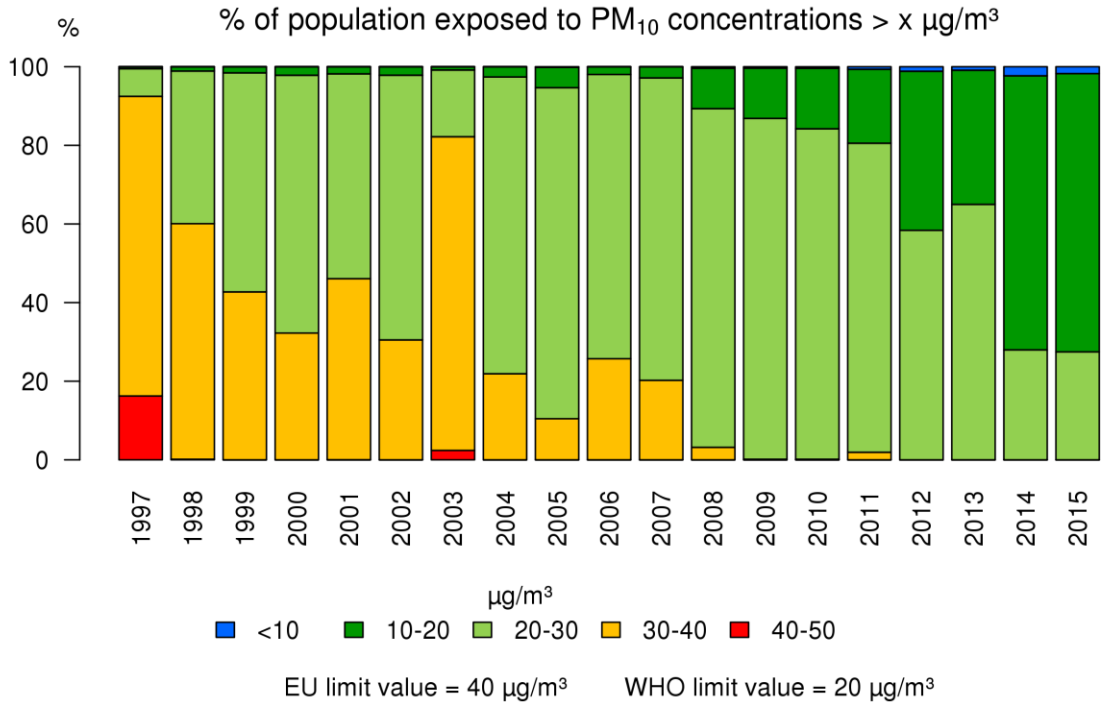


Figure 11: Evolution of the exposure of the population to annual mean PM_{10} concentrations on the basis of the RIO interpolation technique

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, which is not to be exceeded more than 35 times per year. In 2015 this threshold was exceeded nowhere (Figure 12). The air quality threshold for short-term exposure advised by the WHO, namely a maximum of 3 days on which the daily mean PM_{10} concentration exceeds 50 µg/m³, was only attained south of the Sambre and Meuse valley. Globally, 2015 was the best year since the start of the measurements in 1997 regarding the number of exceedances of the daily limit value for PM_{10}.

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

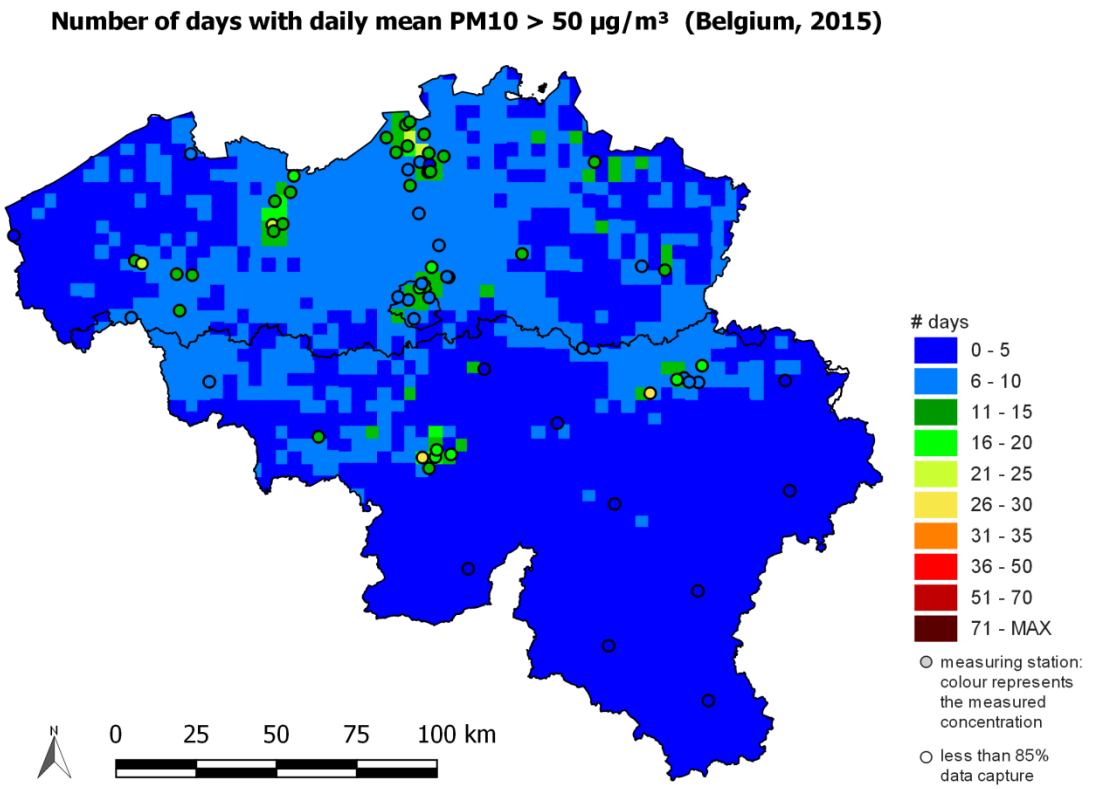


Figure 12: Spatial distribution of the number of days in 2015 where the daily mean PM_{10} concentration of 50 µg/m³ was exceeded in Belgium. All data were calculated using the RIO interpolation technique.

With 21 days, the maximum number of days where the daily mean PM_{10} concentration exceeded 50 µg/m³ (on a 4x4 km² resolution) in Belgium was the lowest observed since the beginning of the calculations in 1997 (Figure 13). 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 downward trend in the number of exceedance days since 1997 is observed for the three Regions (Figure 14). In 2015, the maximum number of days where the daily mean limit value was exceeded in the Flemish, Walloon and Brussels-Capital Regions amounted to 21, 17 and 12 respectively.

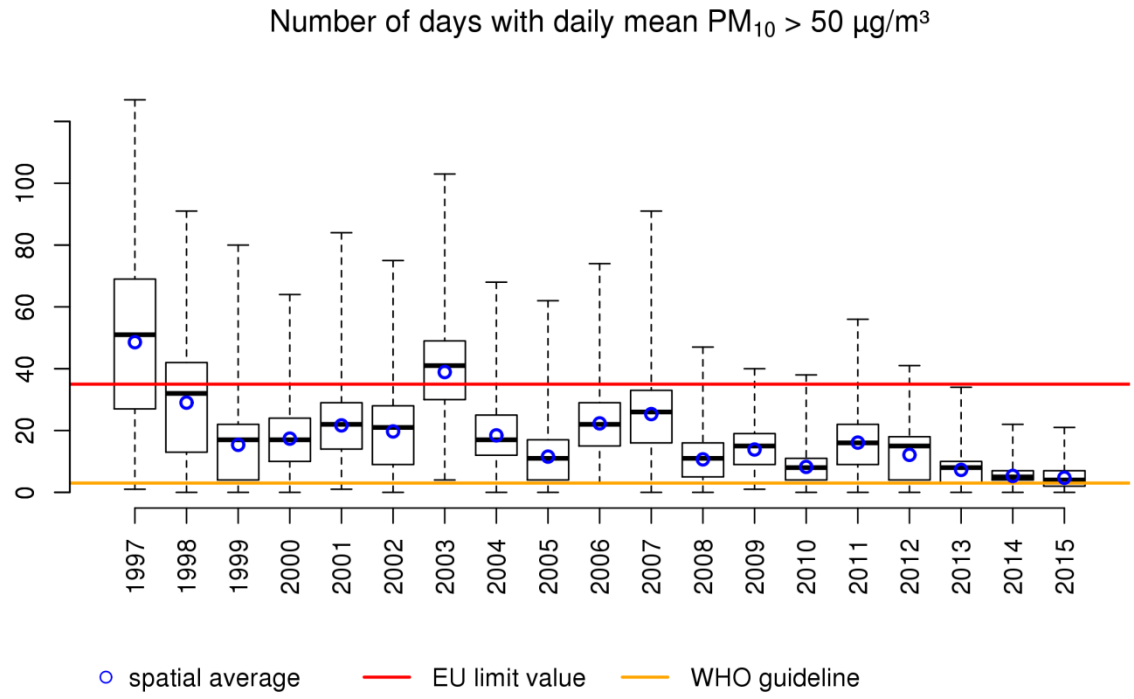


Figure 13: Box plot of the number of days per year where the daily mean PM_{10} concentrations exceeded 50 µg/m³. The spatial average is represented by the blue circles. All data were calculated using the RIO interpolation technique.

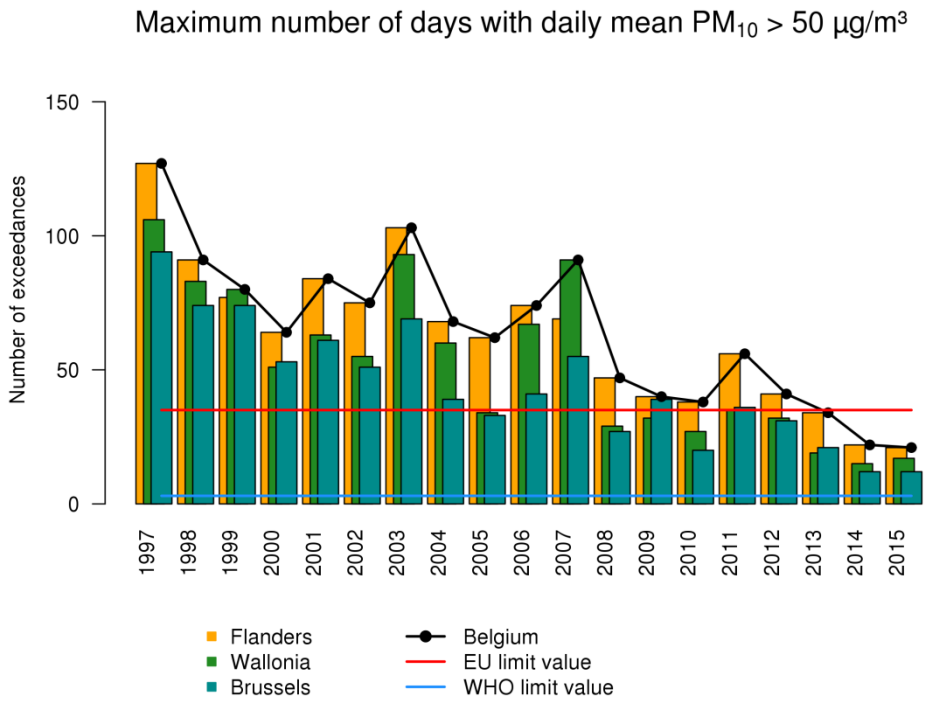


Figure 14: Evolution of the <u>maximum</u> number of days per year where the daily mean PM_{10} concentration exceeded 50 µg/m³ in Belgium and the three Regions. All data were calculated using the RIO interpolation technique.

Figure 15 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 2000-2015.

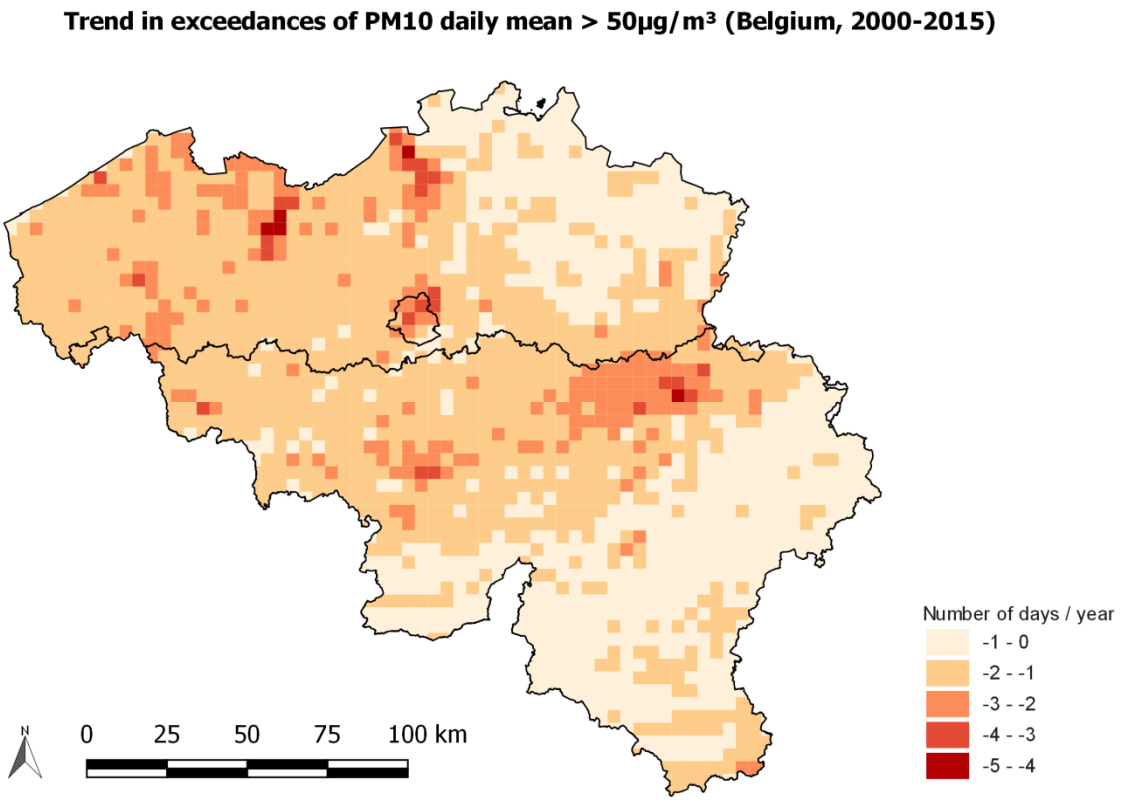


Figure 15: Spatial trend of the number of days with daily mean > 50µg/m³ over the period 2000-2015 (number of days/year). All data were calculated using the RIO interpolation technique.

2015 was one of the better years since the start of the measurements, in terms of air quality. Consequentially, no one in Belgium was exposed to more than 35 exceedance days (Figure 16). 37% of the population was exposed to less than 7 exceedance days, while 63% had to deal with 7 to 21 exceedance days. In spite of this, 90% of the population still was exposed to over 3 exceedance days, which is the WHO guideline. Again, it is important to keep in mind the spatial resolution of the RIO interpolation technique.

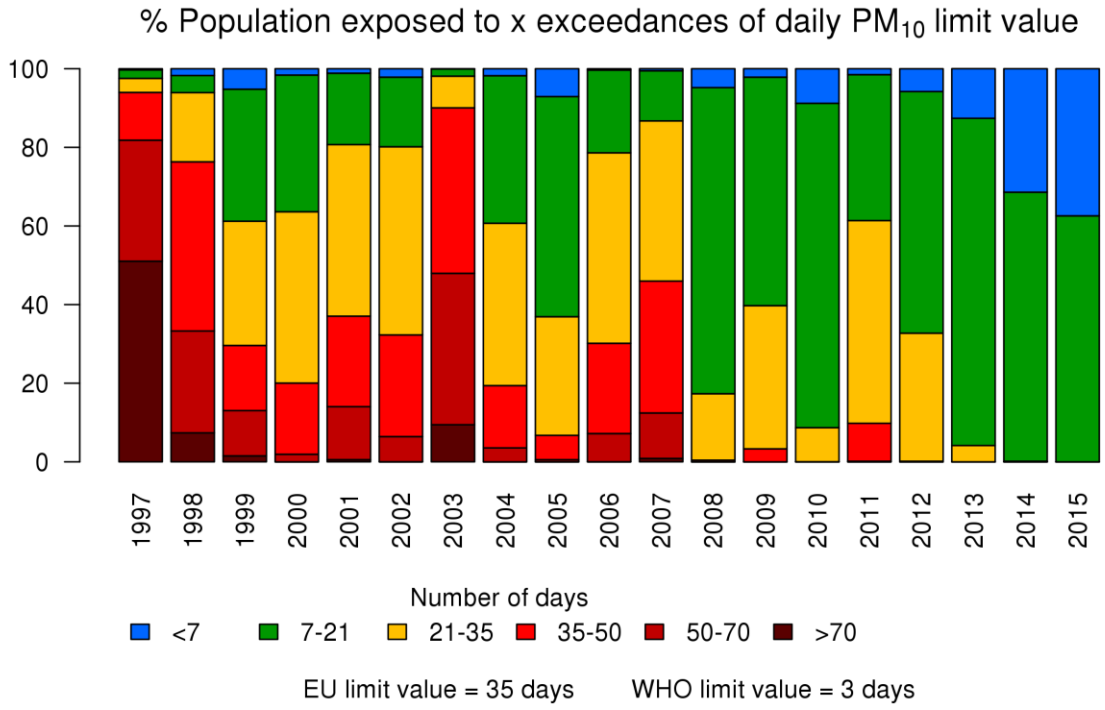


Figure 16: Evolution of the population exposure to days where the daily mean PM_{10} concentration exceeded 50 µg/m³. All data were calculated using the RIO interpolation technique.

Figure 17 shows how the maximum number of exceedance days per region is distributed over the various months, both for 2015 and averaged for the five previous years. In 2015, exceedances were observed mainly between January and April.

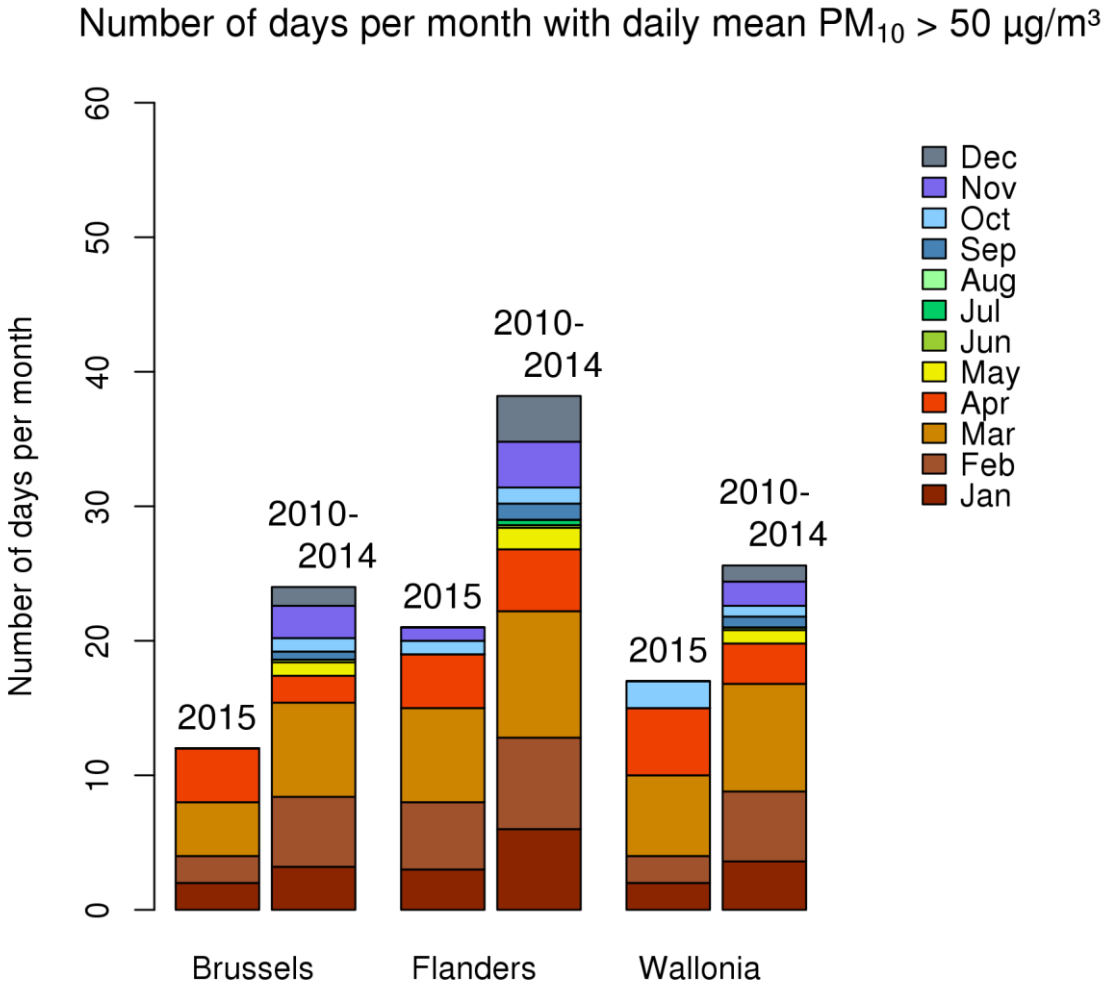


Figure 17: Highest number of days per month on which somewhere in the Brussels-Capital, Flemish and Walloon Regions the daily mean PM_{10} limit value of 50 µg/m³ was exceeded in 2015 and the five previous years. All data were calculated using the RIO interpolation technique.

3.2 $PM_{2.5}$

3.2.1 $PM_{2.5}$ monitoring stations

Figure 18 shows the evolution of the number of monitoring stations where $PM_{2.5}$ is measured. 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 67 in 2015. Because the number of monitoring stations for 2008 was substantially lower, the uncertainty on the annual mean values is greater in these initial years. This is especially true for Wallonia where $PM_{2.5}$ was not measured before 2008.

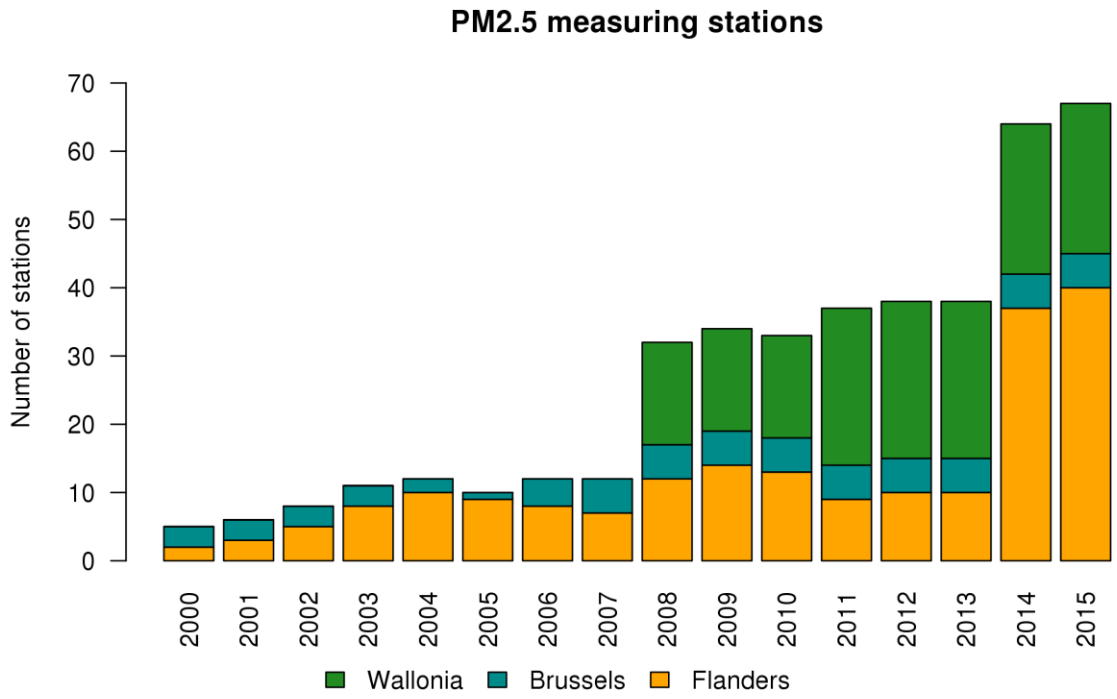


Figure 18: Evolution of the number of $PM_{2.5}$ monitoring stations in Belgium

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 and is in force as of 2015. In 2015, the annual mean $PM_{2.5}$ concentration was below 25 µg/m³ everywhere in Belgium. The spatial average $PM_{2.5}$ concentration across Belgium was 10.3 µg/m³. The maximum concentration of 16.2 µg/m³ was calculated in the Flemish Region. 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 slight downward trend between 2006 and 2014 (Figure 20). The values obtained for 2015 are comparable to those of 2014, the only exception being the maximum, which has decreased further. The spatially averaged annual concentrations for Flanders, Wallonia and Brussels were 12, 8.9 and 13.6 µg/m³ respectively in 2015. Since 2006, the $PM_{2.5}$ concentrations have decreased in all Regions, although a stabilisation is observed since 2014 (Figure 21). In 2015, the Belgian population was not exposed to

$PM_{2.5}$ concentrations above 20 µg/m³. However, population exposure to concentrations higher than the WHO guideline of 10 µg/m³ reached 87% in 2015, which is an increase in comparison to 2014 (Figure 22).

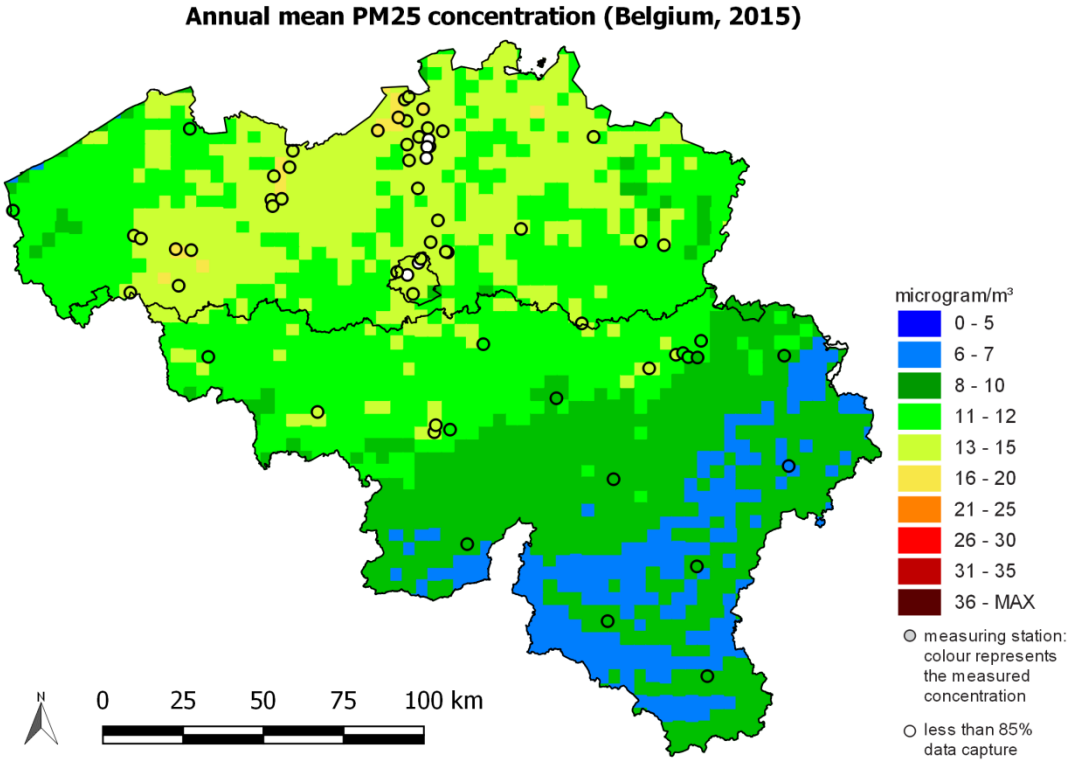


Figure 19: Spatial distribution of the annual mean $PM_{2.5}$ concentration in Belgium in 2015. All data were calculated using the RIO interpolation technique.

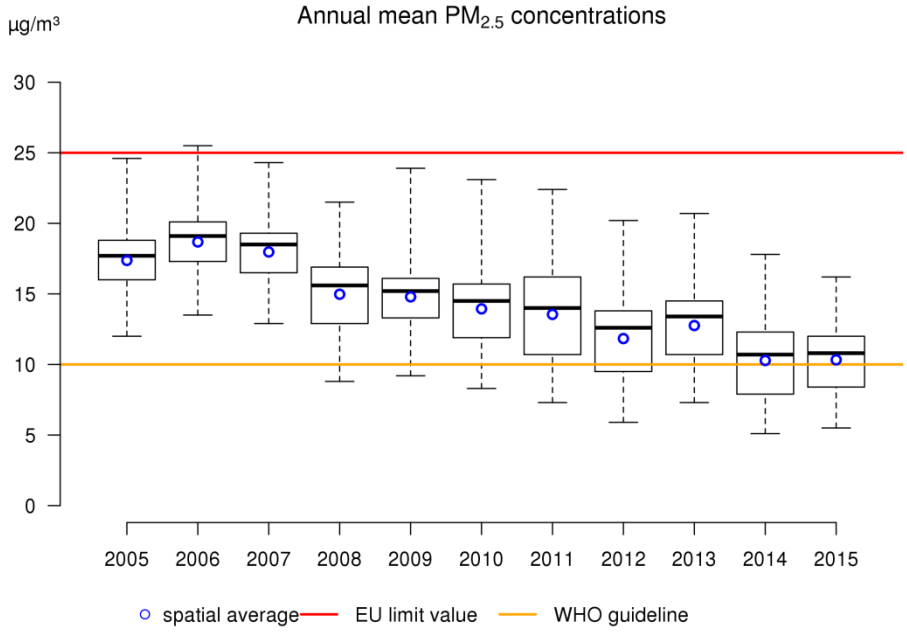


Figure 20: Box plot of annual mean $PM_{2.5}$ concentrations (µg/m³) over the period 2005-2015. The spatial average is represented by the blue circles. All data were calculated using the RIO interpolation technique.

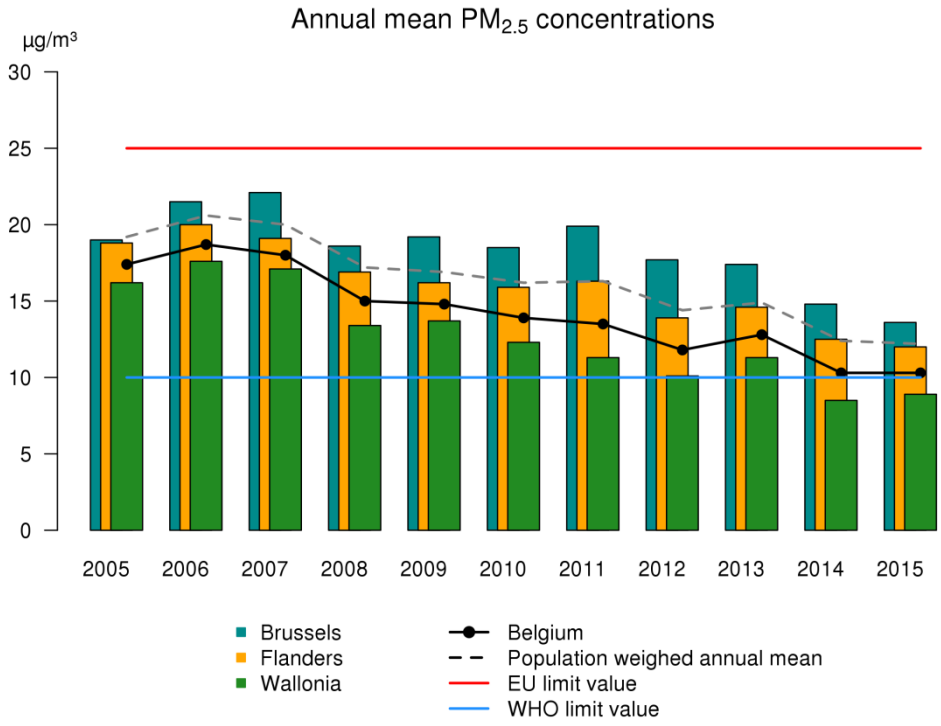


Figure 21: Evolution of the spatially averaged annually mean $PM_{2.5}$ concentrations for the three Regions and Belgium, and of the population-weighted annual mean concentration for Belgium. All data were calculated using the RIO interpolation technique.

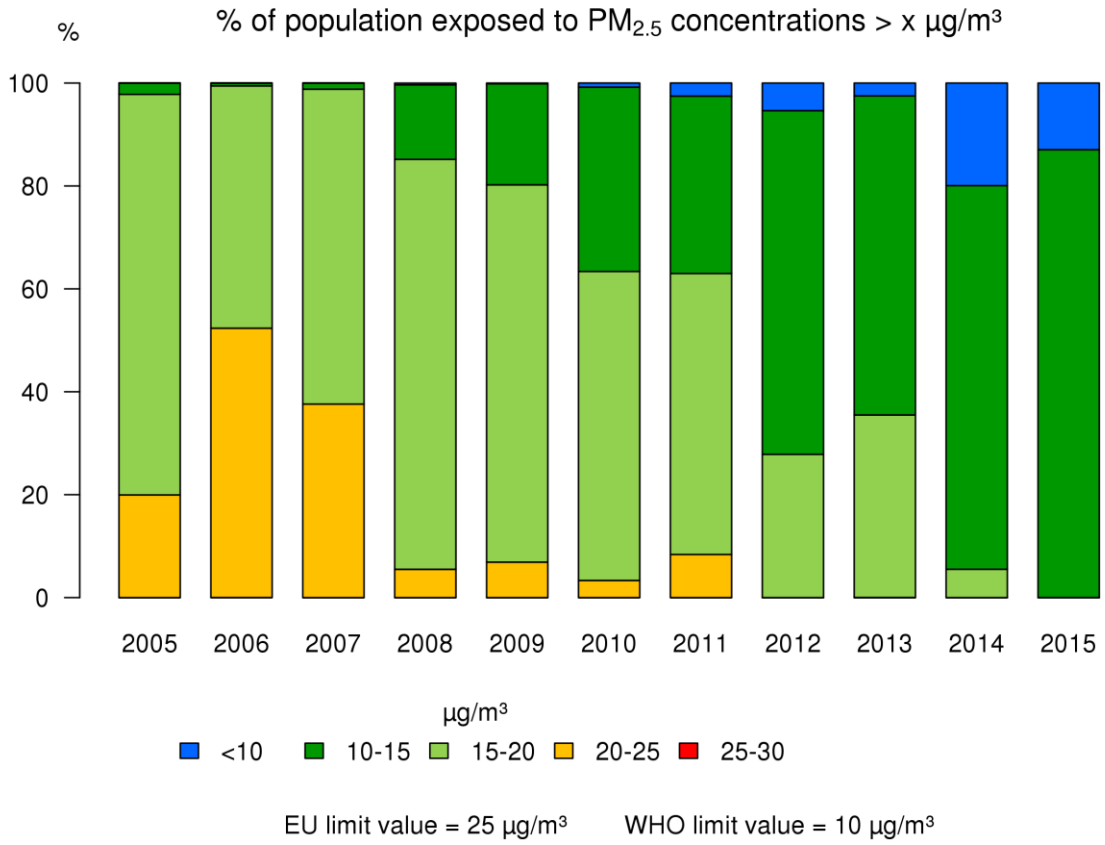


Figure 22: Evolution of population exposure to annual mean $PM_{2.5}$ concentrations based on the RIO interpolation technique.

Based on the $PM_{2.5}$ concentrations in the 4x4 km² 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 23). This relationship shows that people living in areas with a high population density are exposed to the highest annual mean $PM_{2.5}$ concentrations.

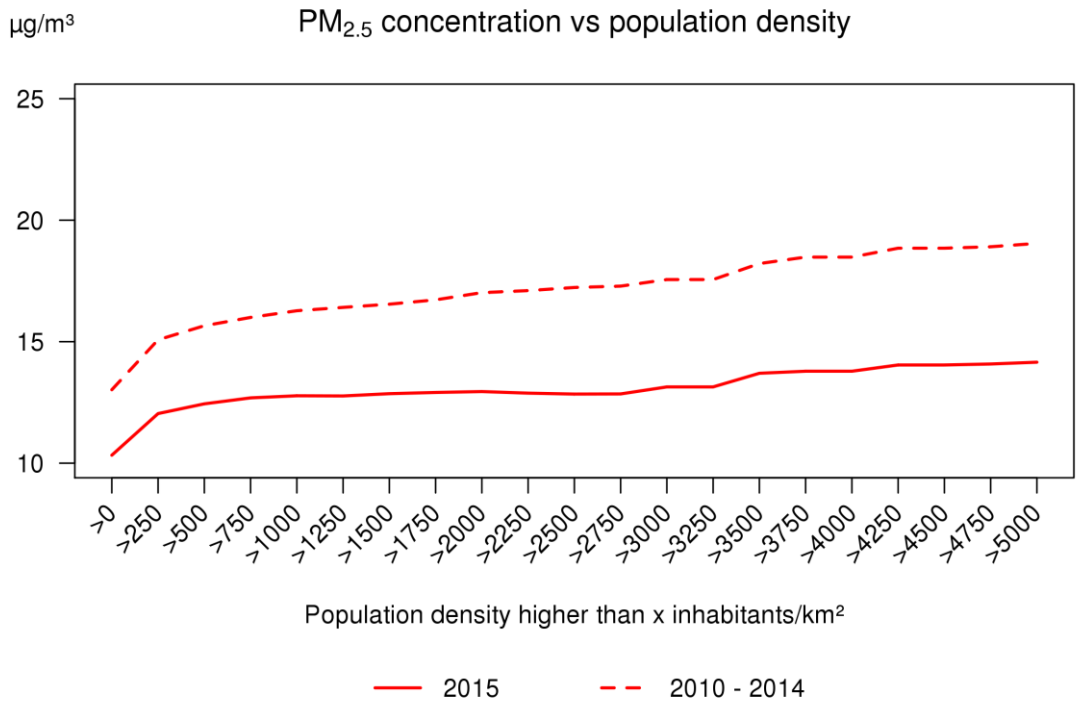


Figure 23: Relationship between the interpolated annual mean $PM_{2.5}$ concentrations and the population density (inhabitants/km²) above a specified value. All data were calculated using the RIO interpolation technique.

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 85% 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 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

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

assessment will be made on the basis of the measurements (in the same urban background monitoring stations) in the period 2018, 2019 and 2020.

The AEI calculated for the years 2013, 2014 and 2015 reached 15.4 µg/m³ (Table 7) and thus is situated close to the goal for 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 2009-2011		**18.97**	
AEI		**19.00**	

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

Table 7: Overview of the PM2.5 concentrations for 2013, 2014 and 2015 per urban background station to be included in the calculation of the average exposure index or AEI

Station name	2013	2014	2015
SINT JANS MOLENBEEK	20.38	16.67	*
UKKEL	19.29	17.00	14.42
LIEGE	14.80	10.92	10.30
CHARLEROI	15.59	11.79	12.84
BRUGES	16.67	15.19	12.94
GHENT	18.87	15.70	14.64
ANTWERP	17.83	16.06	14.81
SCHOTEN	16.51	14.56	13.72
average per year	**17.49**	**14.74**	**14.11**
average 2013-2015		**15.45**	
AEI		**15.40**	

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

3.3 Black Carbon (BC)

3.3.1 BC monitoring stations

BC measures started in the telemetric stations in 2007 in Flanders, 2009 in Brussels and 2011 in Wallonia (Figure 24). The number of stations has increased to 27 in 2015, including 19 in Flanders, 5 in Brussels and 3 in Wallonia.

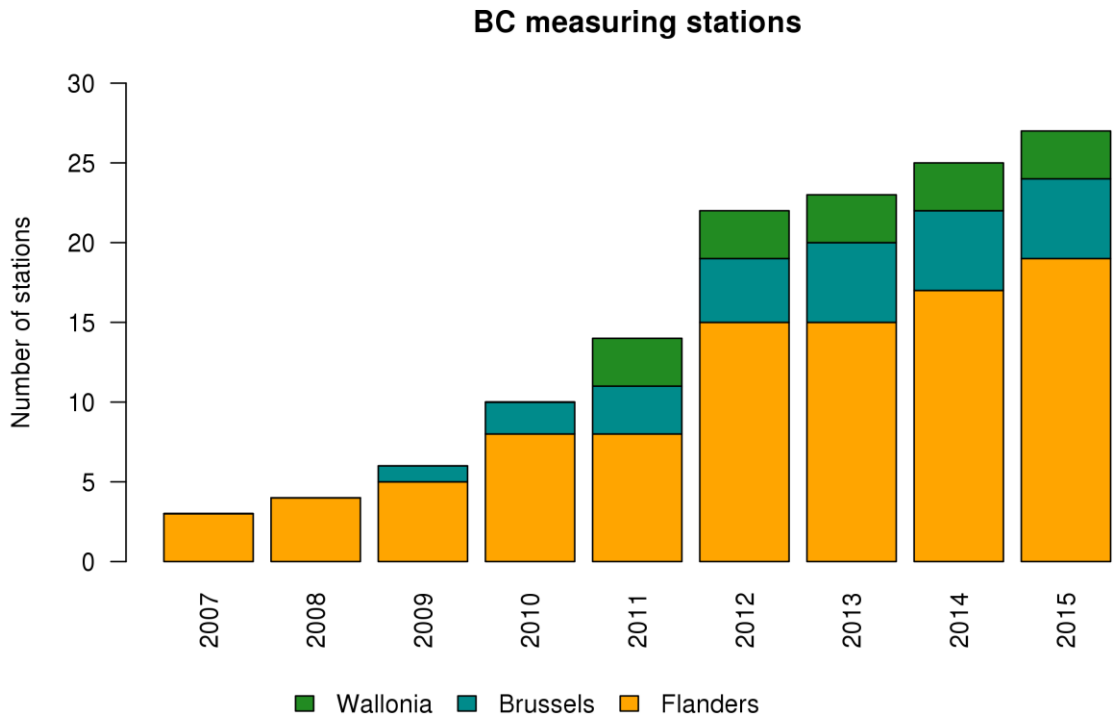


Figure 24: Evolution of the number of BC monitoring stations in Belgium.

3.3.2 BC annual concentrations

Black Carbon is a pollutant related to the combustion of fossil fuels, biofuels or biomass. As a result, the highest BC concentrations are generally observed in traffic-rich areas and in locations were biomass is burned. For the moment, there are no limit or guideline values to which the interpolated values can be compared.

Figure 25 shows the spatial distribution of the BC annual mean in Belgium for 2015. It has to be noted that, on the one hand, the number of BC monitoring stations is currently very low in comparison to the surface area to cover in Belgium (in particular in Wallonia) and in addition they are spread in a heterogeneous way. On the other hand, the BC concentrations decrease rapidly when moving away from the sources. The map of concentrations presented in Figure 25 is therefore provided just for information.

The evaluation of uncertainty related to the map of BC annual means is given in Annex D.

Since the time period of measures is limited (the measures having started in 2007), a trend analysis is currently not yet available.

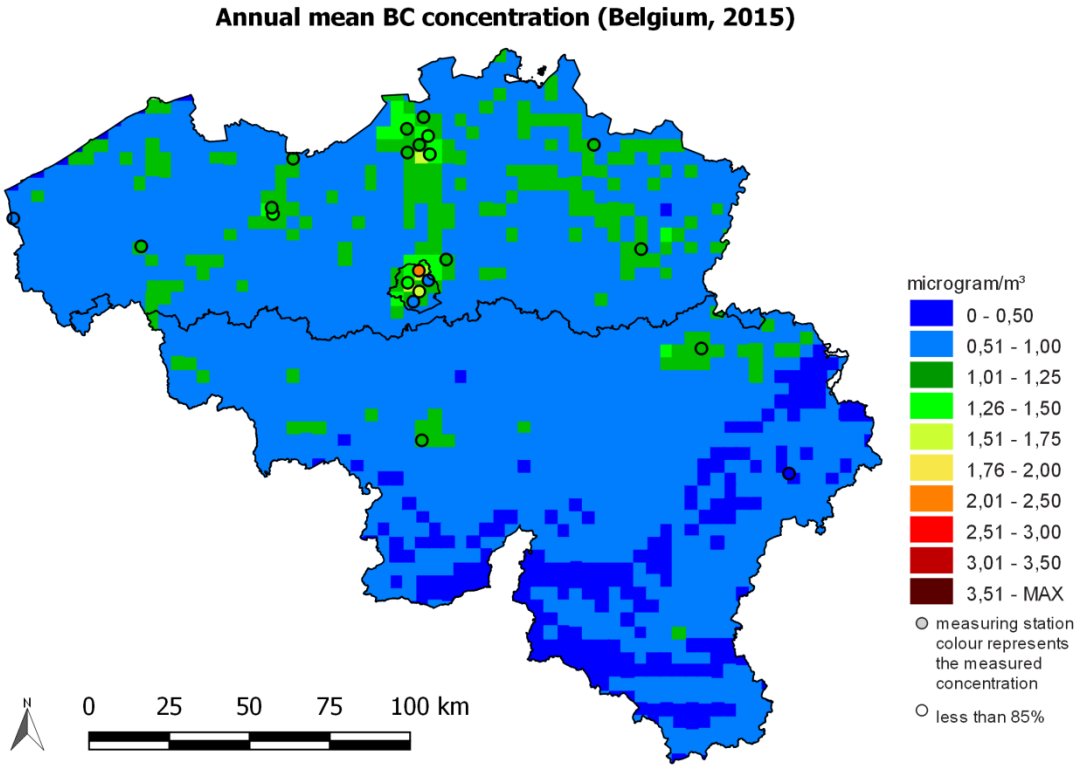


Figure 25: Spatial distribution of the annual mean BC concentration in Belgium in 2015. All data were calculated based on the RIO interpolation technique.

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 originate 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. Based on the REVIHAAP study (WHO, 2013), more and more clues appear to indicate that NO2 is also harmful itself, mainly related to short term exposure. Regarding chronic, long term exposure, the conclusions are less unambiguous.

4.1 NO_2 monitoring stations

Figure 26 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 93 in 2013. In 2015, 91 stations were used. Since the number of monitoring stations before 1997 is considerably less than in 2015, the uncertainty on the annual mean concentrations is greater in those initial years.

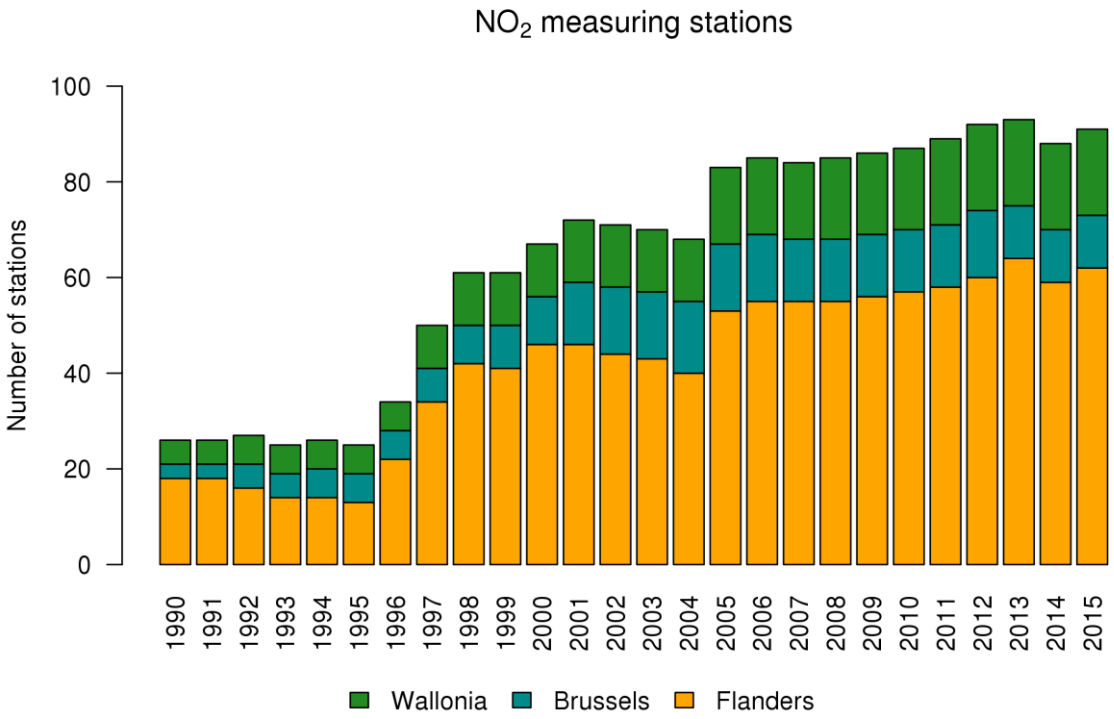


Figure 26: Evolution of the number of NO_2 monitoring stations in Belgium.

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 the Antwerp Agglomeration zones had been granted postponement until 1/1/2015 for compliance with this limit value. Until then, a limit value of 60 µg/m³, based on the limit value of 40 µg/m³ with a 50% margin of tolerance, applied 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. From 2015 onwards, the limit value of 40 µg/m³ applies for the whole Belgian territory.

Figure 27 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. Because of the restricted spatial resolution

(4x4 km²) of the RIO interpolation technique, local exceedances of the NO_2 limit value may not always be visible on the interpolation maps.

The highest NO_2 annual mean of all Belgian grid cells is 37.2 µg/m³. The average annual mean concentrations across Flanders, Brussels and Wallonia are 14 µg/m³, 28 µg/m³ and 10 µg/m³ respectively. The average across Belgium, taking account of the number of inhabitants per grid cell (population-weighted average) is 19 µg/m³. This value clearly exceeds the non-population-weighted average across Belgium (12 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 28, which represents the relationship between annual mean NO_2 concentration and the accumulated population density. From a population number of 4750 inhabitants/km² onwards, the annual mean NO_2 concentration in 2015 exceeded 30 µg/m³. For the period 2009-2014, this was still slightly higher.

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.

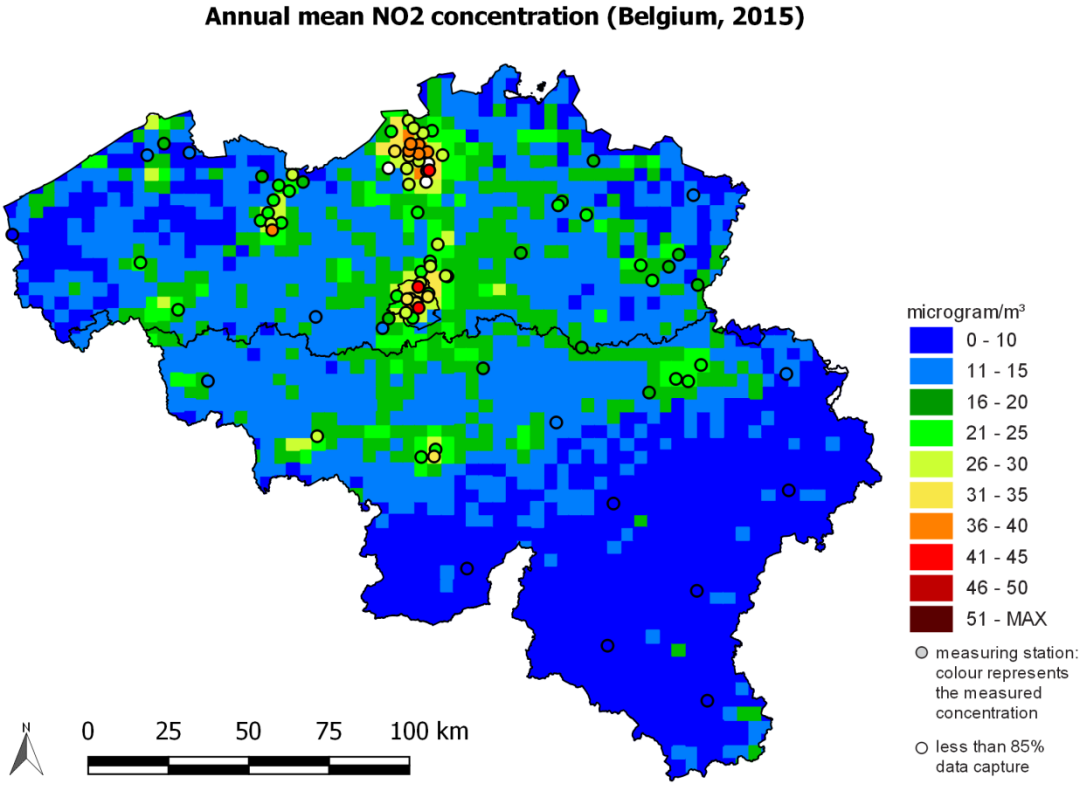


Figure 27: Spatial distribution of the NO_2 annual mean concentration in 2015. All data were calculated using the RIO interpolation technique.

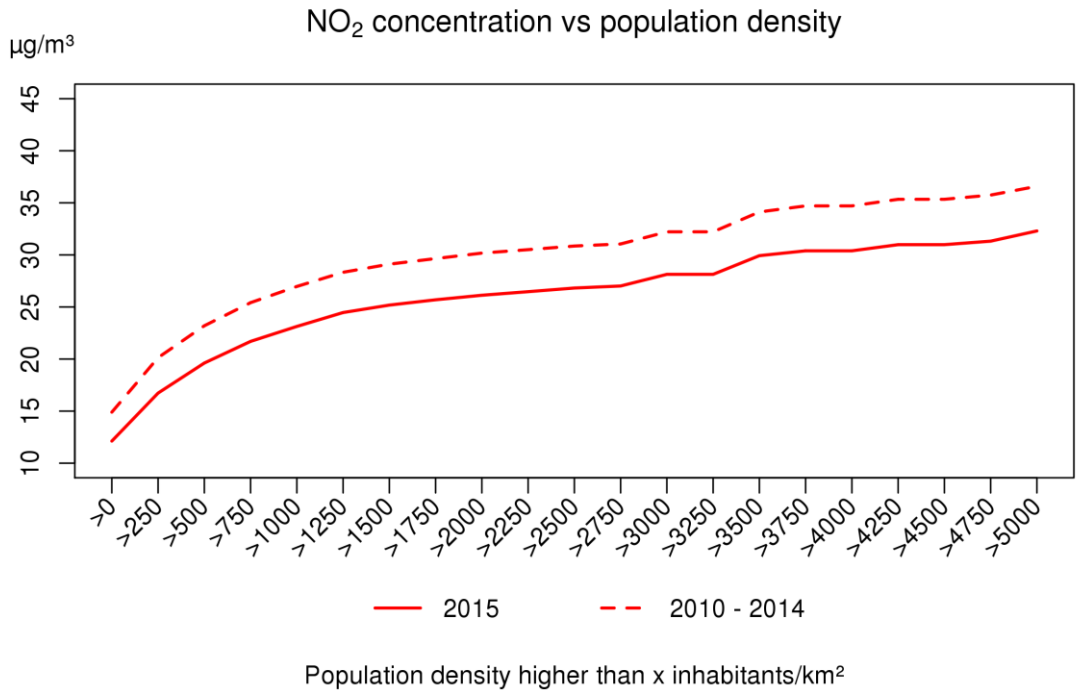


Figure 28: Relationship between the interpolated annual mean NO_2 concentrations and the population density (inhabitants/km²) above a specified value. All data were calculated using the RIO interpolation technique.

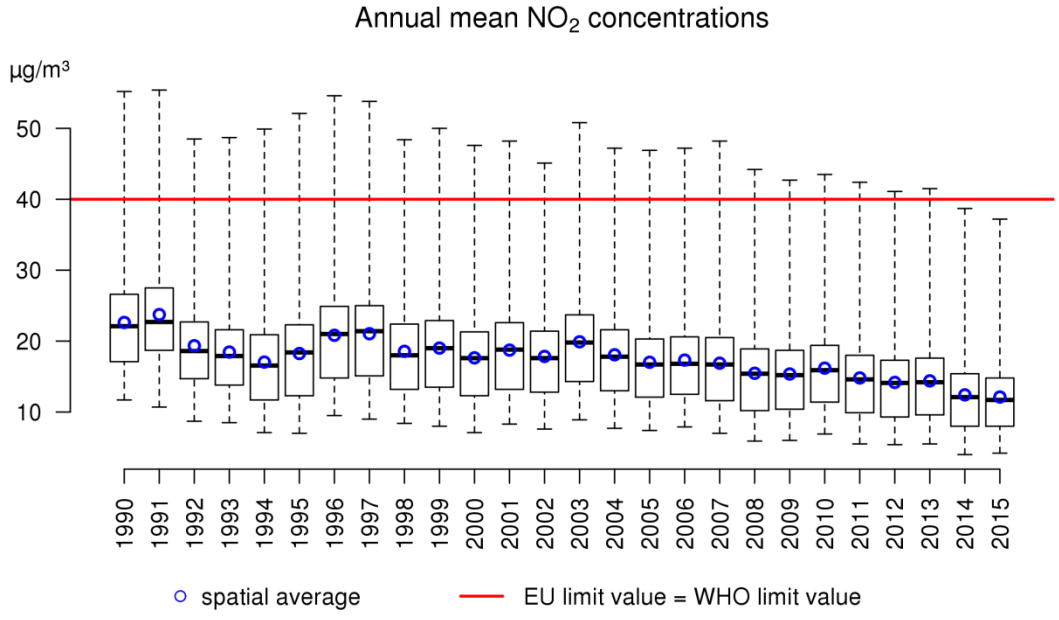


Figure 29: Box plots of the annual mean NO_2 concentrations (µg/m³) for the period 1990-2015. The spatial average is represented by the blue circles. All data were calculated using the RIO interpolation technique.

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 **Error! Reference source not found.**. It also shows the spatial average across Belgium. This figure, too, shows that the European annual limit value is still not met everywhere.

Error! Reference source not found. 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. From 2007, the annual mean NO_2 concentrations slightly decrease in the three Regions. Before 1997, the uncertainty on the calculation of the annual means is greater due to the smaller number of monitoring stations.

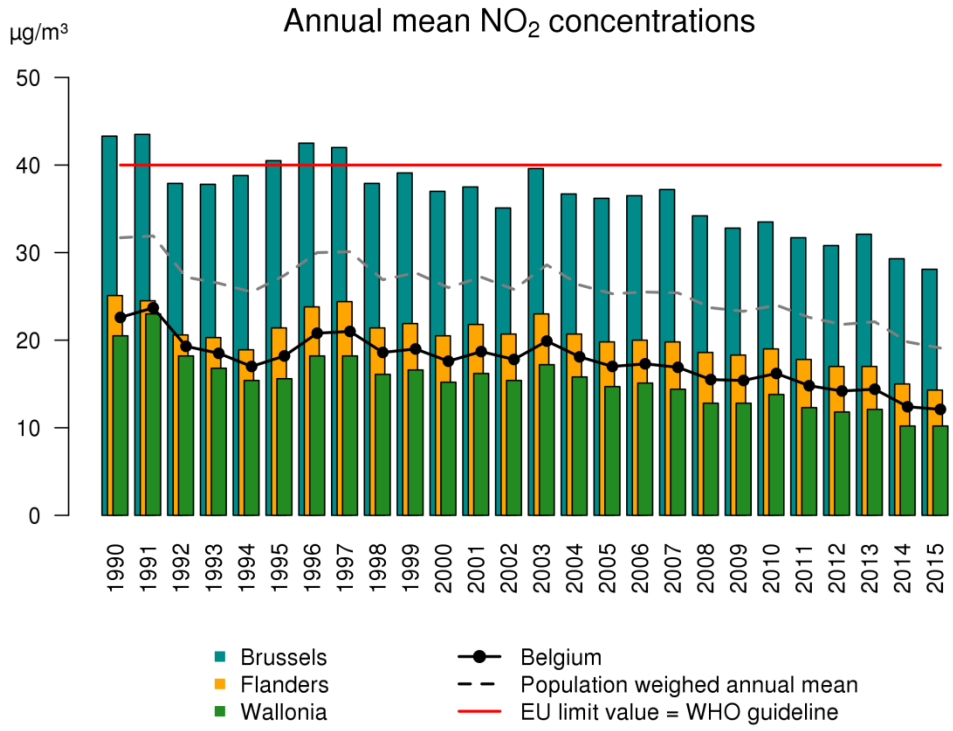


Figure 30: Evolution of the NO_2 annual mean in Belgium based on the RIO interpolation technique.

The decrease in the annual mean NO_2 concentrations in Belgium over the period 1990-2015 is rather limited (**Error! Reference source not found.**). The largest decreases - between -0.7 and -0.5 µg/m³/year - occur in the centre of the country.

[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.

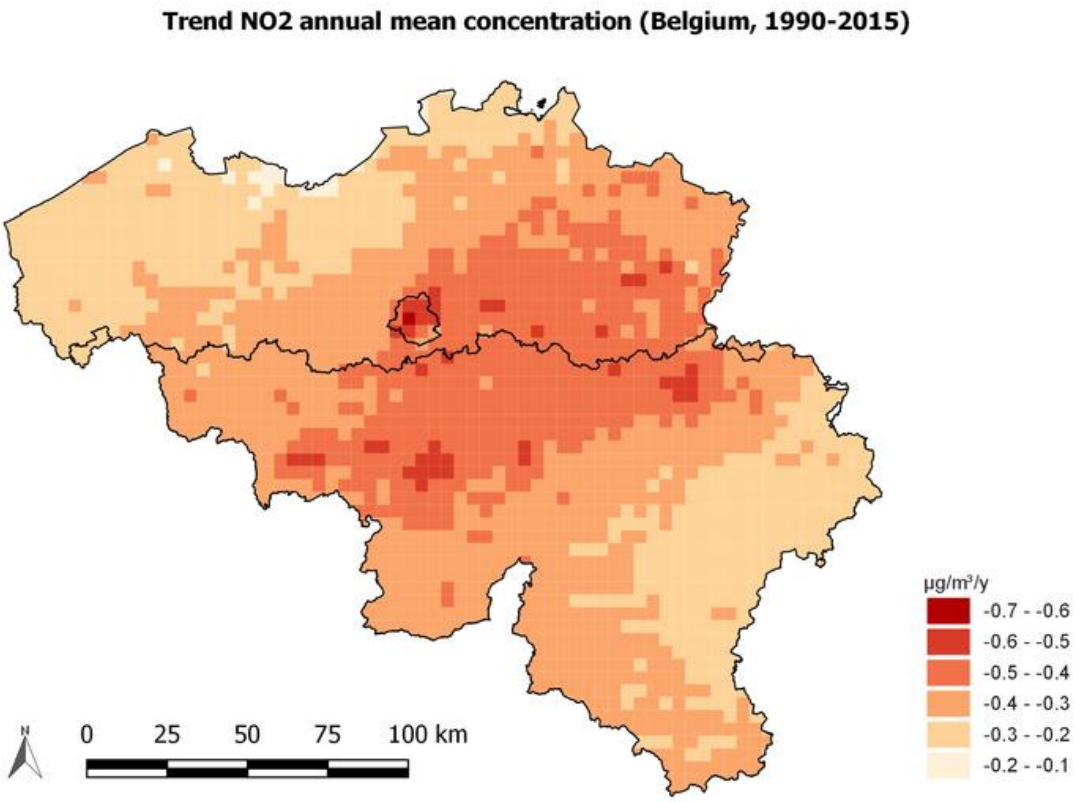


Figure 31: Trend (µg/m³/year) of the annual mean NO_2 concentrations in the period 1990-2015. All data were calculated using the RIO interpolation technique.

Since 2003, an increasing number of people have been exposed to lower annual mean NO_2 concentrations (**Error! Reference source not found.**). Since 1998, the percentage of the Belgian population that is potentially exposed to annual mean concentrations above the EU limit value fluctuated around 10%. In 2013, this percentage had dropped to 3% and in 2014 and 2015, according to the calculations, no one was exposed to annual mean concentrations above the EU limit value. The results however have to be interpreted with caution. Population exposure is estimated based on a spatial interpolation of measurements and the number of inhabitants per 4x4 km² grid cell. As stated previously, concentrations above or below the RIO-interpolated concentrations (which apply for 4x4 km²) can be measured locally. It is because of this, while Figure 32 show no exposure to increased concentrations (> 40 µg/m³), parts of the population were exposed to concentrations above 40 µg/m³ at locally. This happens mainly in the direct vicinity of measuring stations were exceedances were registered.

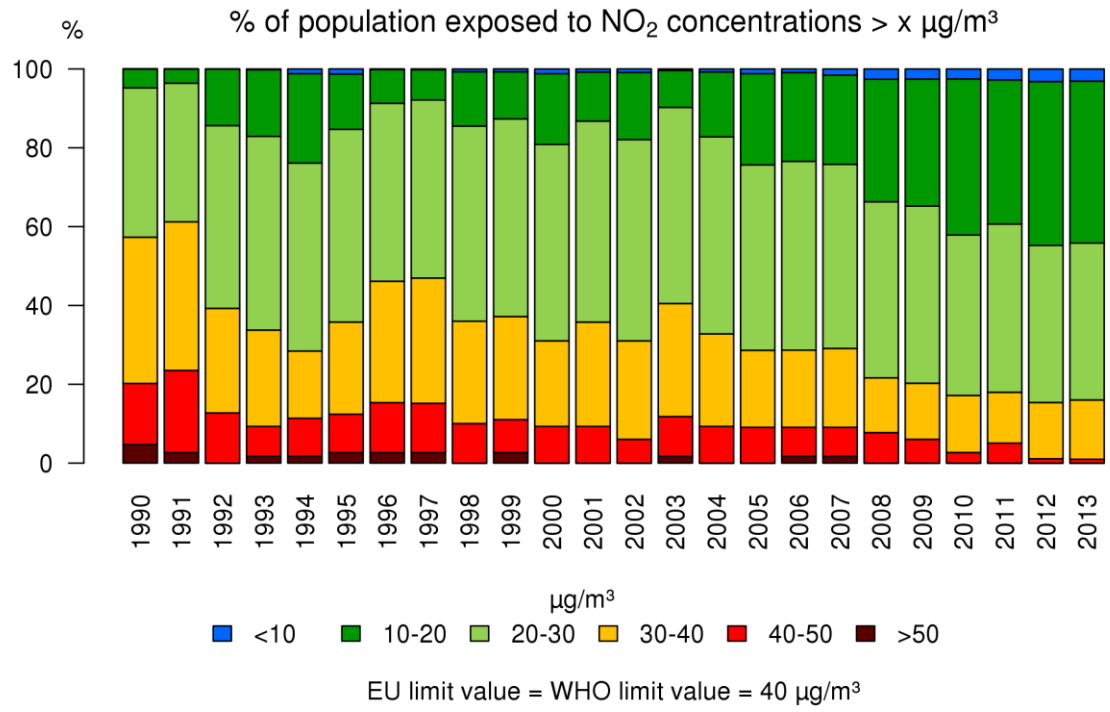


Figure 32: Percentage of the Belgian population exposed to annual mean NO_2 concentrations. All data were calculated using the RIO interpolation technique.

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 that 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. However, in the stations that resemble such stations most closely, no exceedances of this limit were observed during the last 5 years.

4.3 NO_2 hourly values

For the protection of human health against 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 limited resolution of the RIO interpolation technique. The 19th highest hourly value in Belgium in 2015 is represented in Figure 33 (this corresponds to the 99.8th percentile of all hourly mean concentrations in one year). The maximum of the 19th highest hourly value in Belgium, representative at 4x4 km², is 107 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 50 µg/m³, 40 µg/m³ and 85 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 125 µg/m³ in 2015.

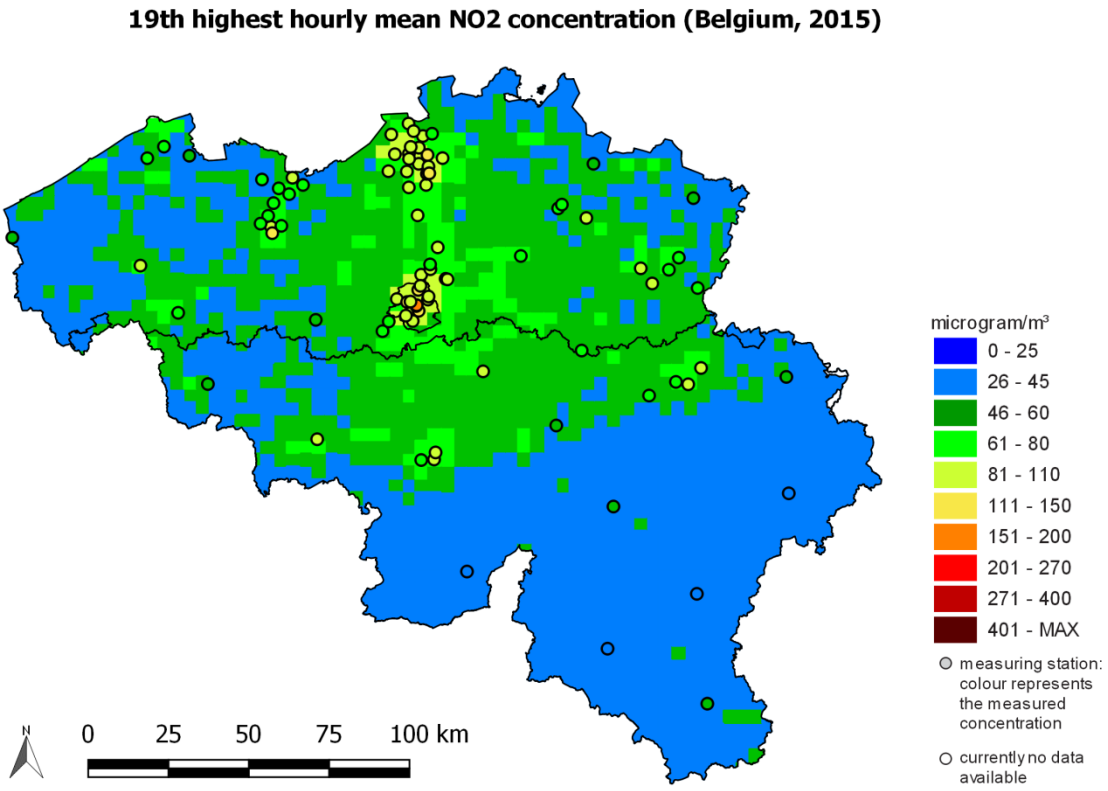


Figure 33: Spatial distribution of the 19th highest hourly mean NO_2 concentration in Belgium, 2013. All data were calculated using the RIO interpolation technique.

Since 1990 there has been little variation in the spatially averaged, minimum and maximum of the 19th highest NO_2 hourly value (Figure 34). 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 35). 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.

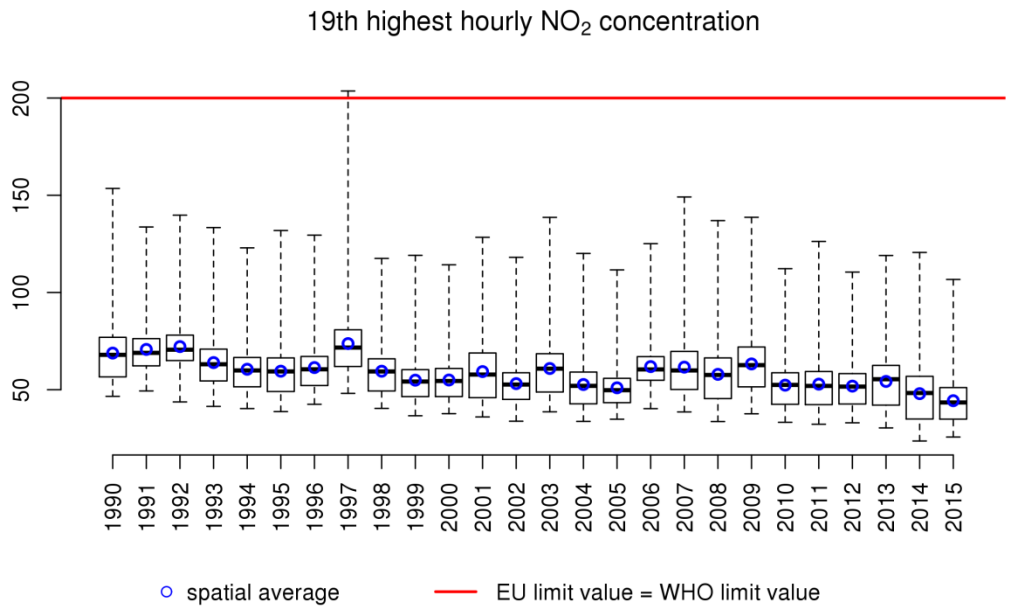


Figure 34: Box plot of the 19th highest hourly mean NO2 concentration (µg/m³) over the period 1990-2015. The spatial average is represented by the blue circles. All data were calculated using the RIO interpolation technique.

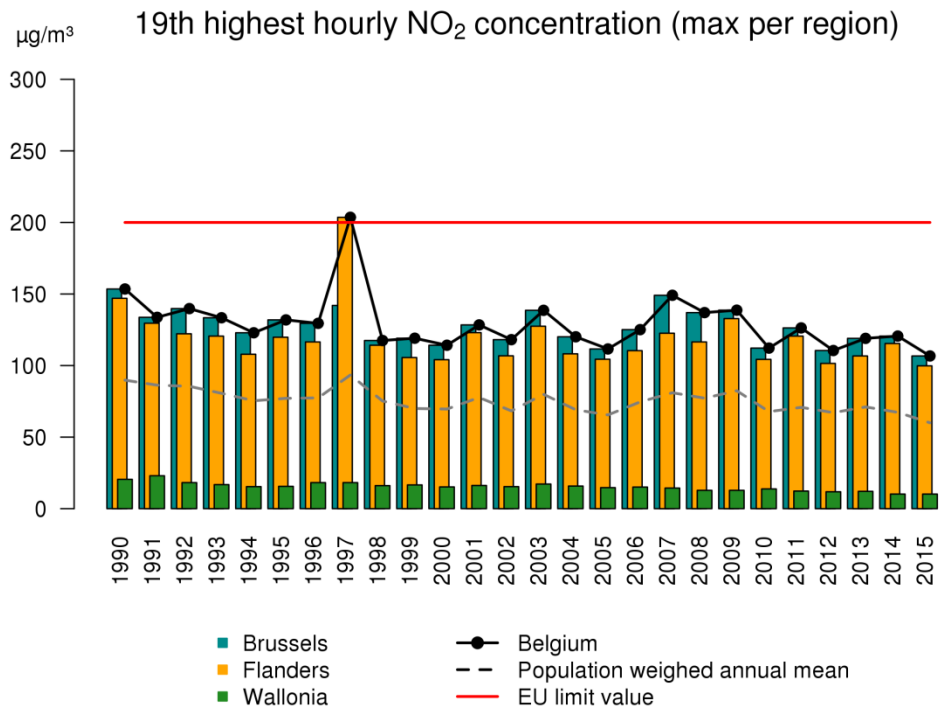


Figure 35: Evolution of the maximum of the 19h highest NO_2 hourly value in the three Regions and Belgium based on the RIO interpolation technique.

5 Ozone

Ozone (O_3) is a very reactive gas that is formed in the atmosphere (troposphere) by various photochemical reactions. Ozone is not emitted directly into the air and is therefore a secondary pollutant. 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 originate 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 oxidizing 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 coughing 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 respiratory 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 restoring the 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 the third major anthropogenic greenhouse gas, after carbon dioxide and methane. 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 36 shows the evolution of the number of monitoring stations where ozone is measured. 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 and did not evolve since then. Since the number of monitoring stations in 1997 is substantially lower than in 2015, the uncertainty on the interpolated annual mean concentrations is larger in those initial years.

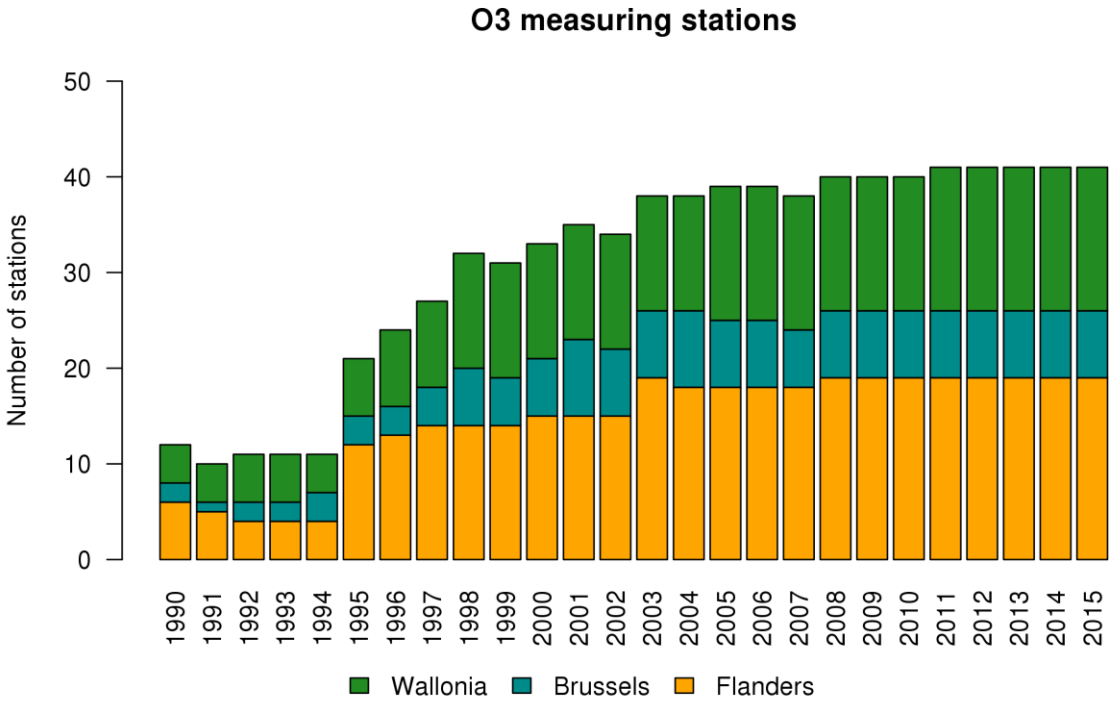


Figure 36: Evolution of the number of O_3 monitoring stations in Belgium.

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 2015 in Belgium, the NET60 maximum was 21 and occurred in the northeast part of Belgium, in Flanders (see Figure 37). Due to the favourable ozone years 2013 and 2014 (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 (see Figure 38). In contrast, the long-term objective, i.e. not a single exceedance, was not attained anywhere in Belgium.

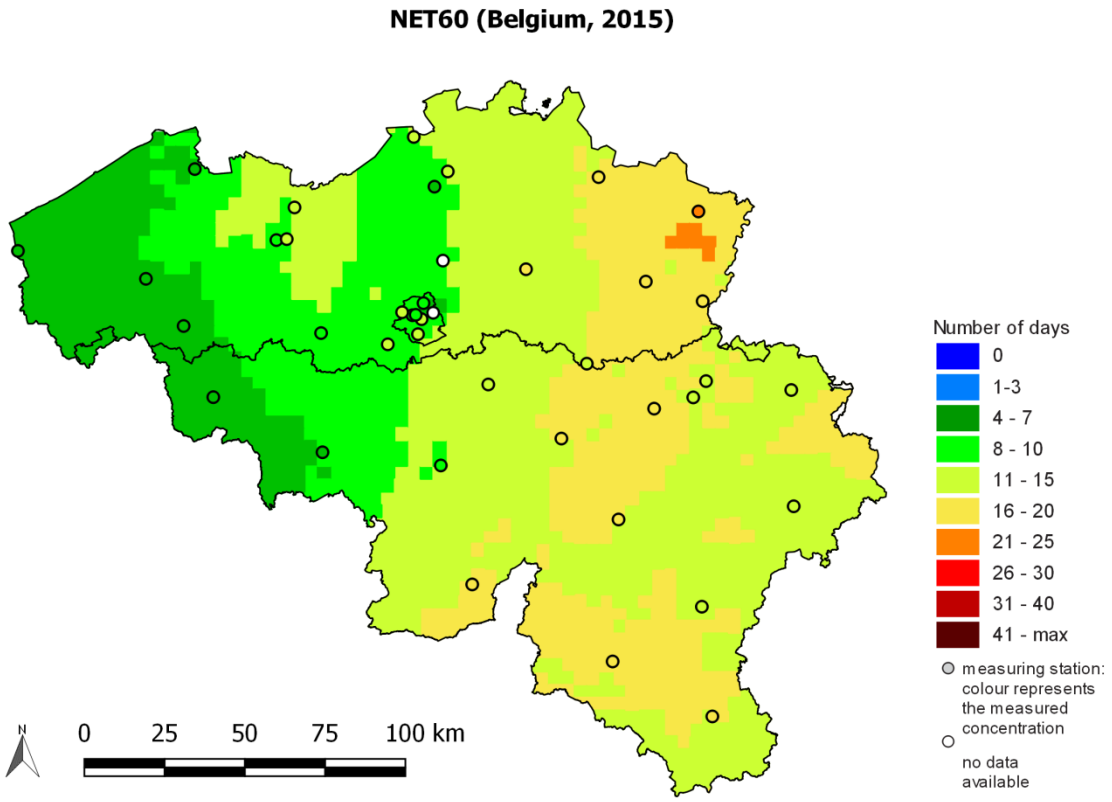


Figure 37: Spatial distribution of the number of days with maximum 8-hour mean ozone concentration > 120 µg/m³ in 2015. 'No data available' means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique.

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

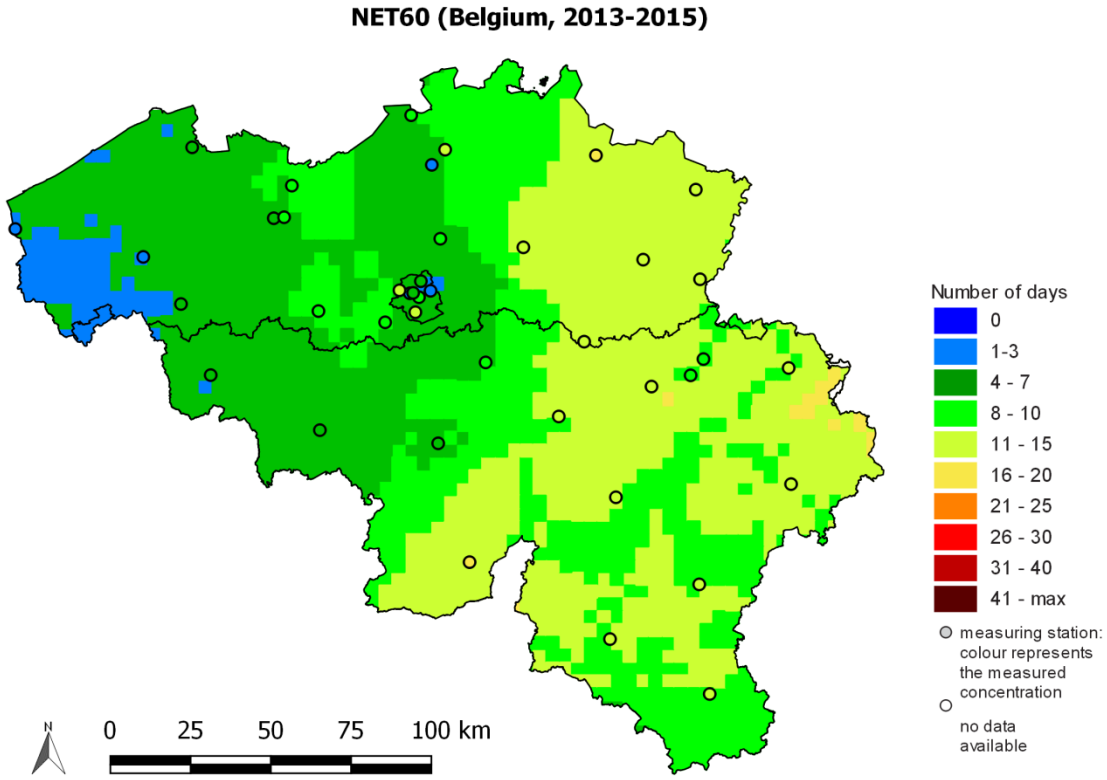


Figure 38: Spatial distribution of number of days with maximum 8-hour mean > 120 µg/m³, averaged over 2013, 2014 and 2015. 'No data available' means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique.

Figure 37 and Figure 38 show the spatial distribution of the number of exceedance days, respectively in 2015 and averaged over 2013, 2014 and 2015. An east-west gradient is clearly visible. The maximum values were recorded in the Campines, the far east of Wallonia and in the region south of the Sambre and Meuse valley. The maximum of 17 days, averaged over three years, is found in the far east of the country. The minimum number of exceedance days occurs in the urban environments and in West Flanders. Spatially averaged across Belgium, the NET60 (averaged over 2013-2015) amounts to 9 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 meteorological conditions during summer (see Figure 39**Error! Reference source not found.**). No clear trend is apparent for the spatial average. The most unfavourable ozone year since 1990 was 2003 with a maximum of 60 exceedances in Belgium. Since 2007, we have had relatively favourable ozone years, because of which, in recent years, the 3-year average has remained below the European target value of 25 days.

Figure 40 geographically represents the trend of the number of days with maximum 8-hour mean ozone concentration >120µg/m³ during the period 1990-2015. In this period, there is a decrease of maximally 1 day/year in the west and south of the country and a status quo in the northeast of the country.

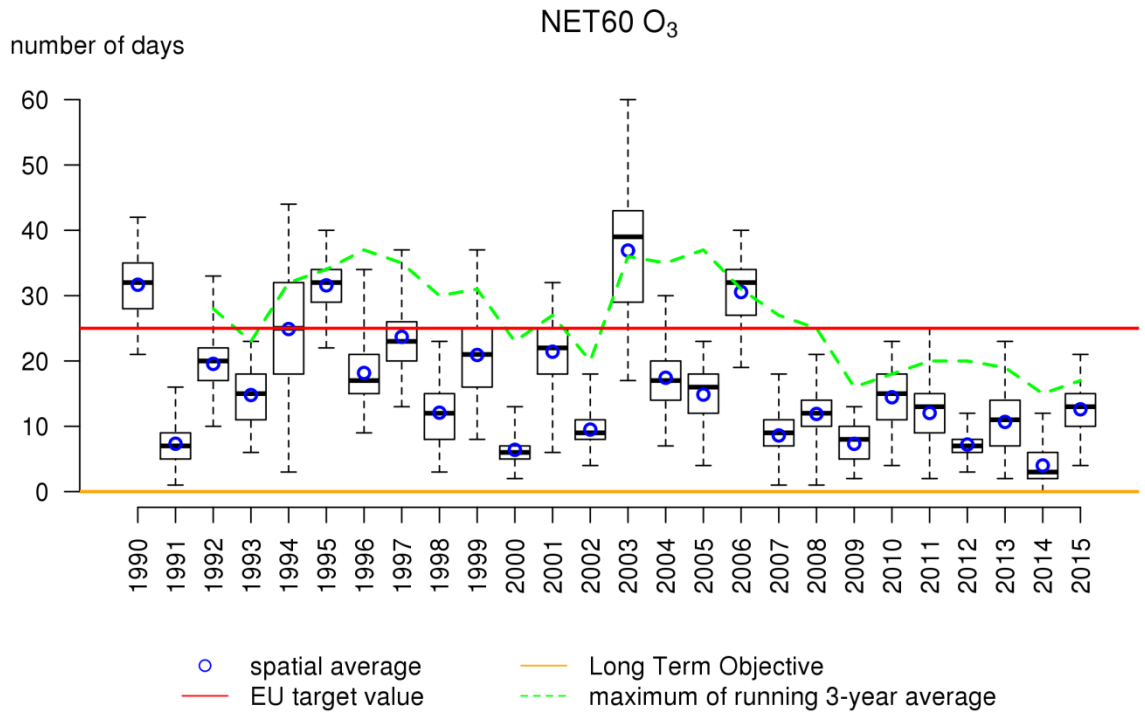


Figure 39: Box plots of number of days with maximum 8-hour mean ozone concentrations > 120 µg/m³ in Belgium over the period 1990-2015. The spatial average is represented by the blue circles. The green dotted line indicates the maximum of the 3-year averaged number of exceedance days in Belgium. All data were calculated using the RIO interpolation technique.

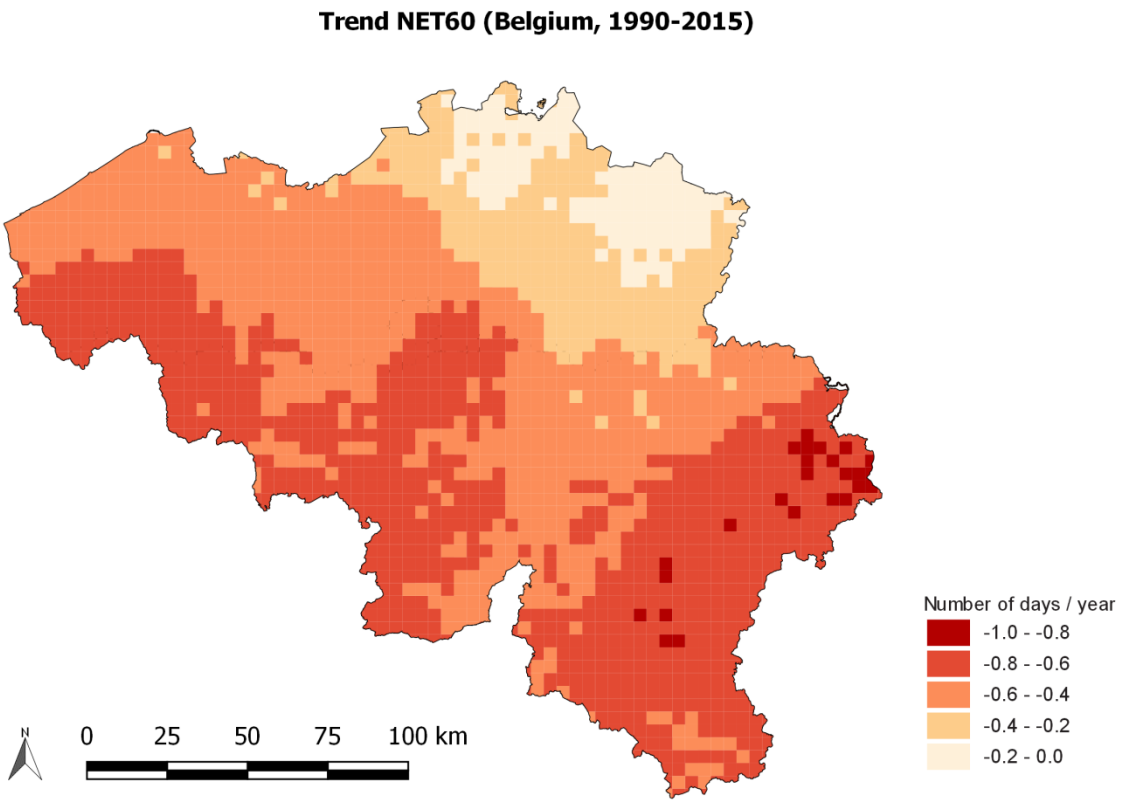


Figure 40: Trend (number of days/year) of the number of days with maximum 8-hour mean ozone concentration above 120 µg/m³ (NET60) over the period 1990-2015. All data were calculated using the RIO interpolation technique.

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 9 years were favourable ozone years (see Figure 41). In this periods, no one has been exposed to maximum 8-hour mean ozone concentrations above 120 µg/m³ on more than 25 days. In 2015, 51% of the population was exposed to maximum 8-hour mean ozone concentrations > 120 µg/m³ on 10 or fewer days. By contrast, 1990, 1995, 2003 and 2006 were very unfavourable in terms of population exposure to high ozone concentrations. In those years, the majority of the population (above 80%) was exposed to maximum 8-hour mean concentrations above 120 µg/m³ on more than 25 days.

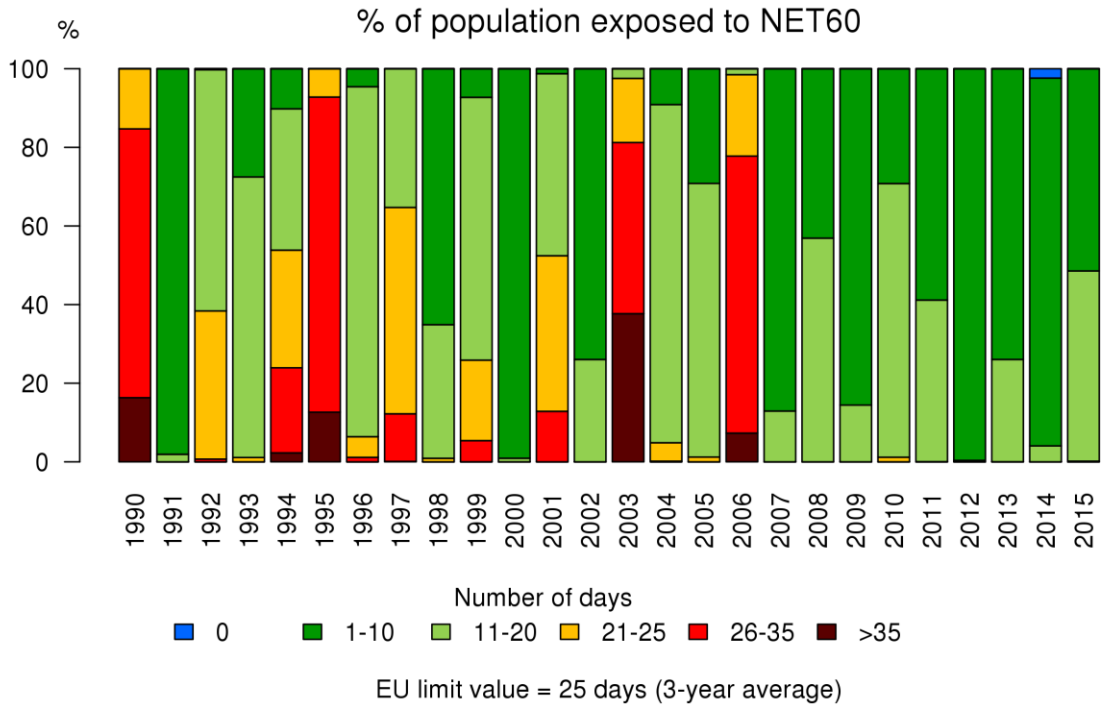


Figure 41: Evolution of population exposure to the number of days with maximum daily 8-hour mean ozone concentrations > 120 µg/m³.

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 in 2015, the WHO guideline value was also 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 exceedances and can thus be seen as a sort of "overdose" of ozone. 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 objective (MTO) for 2010, which corresponds to a NET60 equal to 25 days. The long-term objective is 0 (µg/m³).hours. The AOT60 indicator was not incorporated in 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.

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

Figure 42 shows the spatial distribution across Belgium of the ozone excess in 2015. It is clear that the ozone excess burden was limited in Belgium during 2015. The maximum value is 3880 (µg/m³).h and was reached in Limburg. The average AOT60 across Belgium was 2163 (µg/m³).h. However, the long-term objective of 0 (µg/m³).h was not attained anywhere in Belgium.

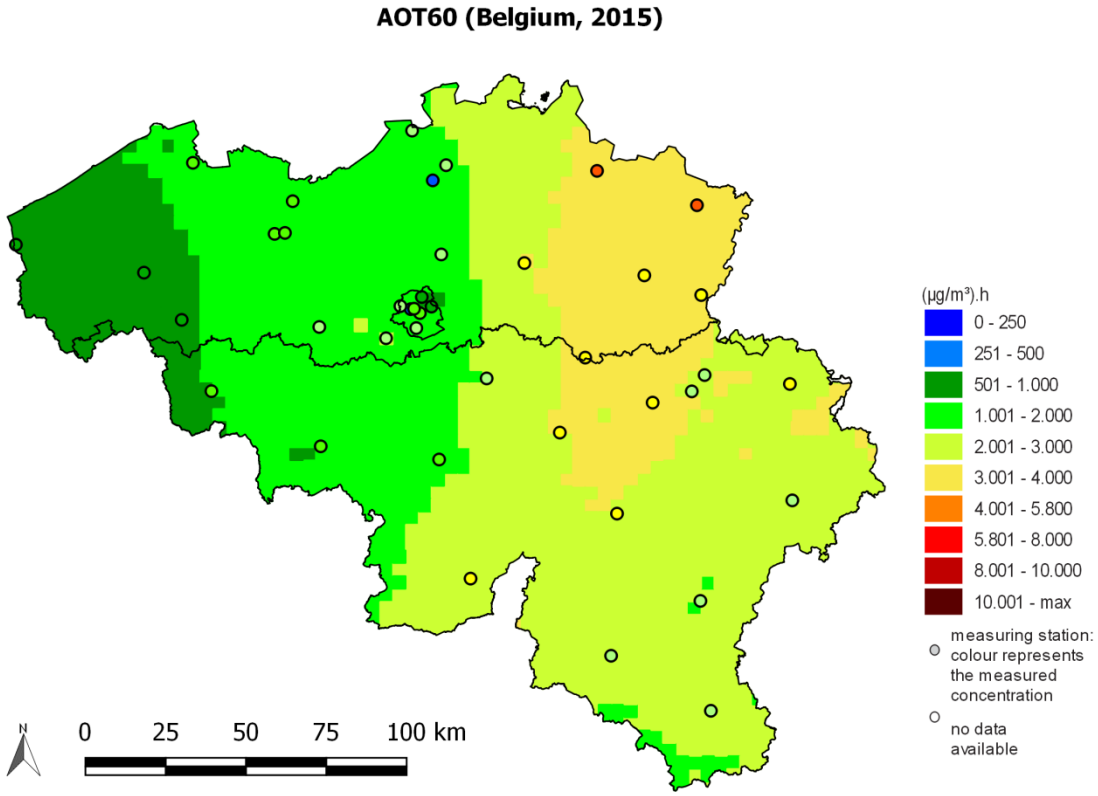


Figure 42: Spatial distribution of the ozone excess (AOT60) in 2015. 'No data available' means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique.

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 2015, the AOT40 for vegetation was well below the European target value of 18 000 (µg/m³).h. The vegetation-weighted[6] average across Belgium was 9494 (µg/m³).h. The maximum value of 15 625 (µg/m³).h was calculated in the far east of the country. Vegetation in West Flanders and Hainaut showed the lowest AOT40. In 2015, only 10% of the area with vegetation cover (excl. forests) remained below the long-term objective of 6000 (µg/m³).h.

Figure 43 and Figure 44 show the spatial distribution of AOT40 for vegetation, respectively in 2015 and the 5-year average over the period 2011-2015. 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 based on the 5-year average (13 372 (µg/m³).h) was measured in the east of the country. The European target value of 18 000 (µg/m³).h averaged over 5 years was met everywhere in Belgium.

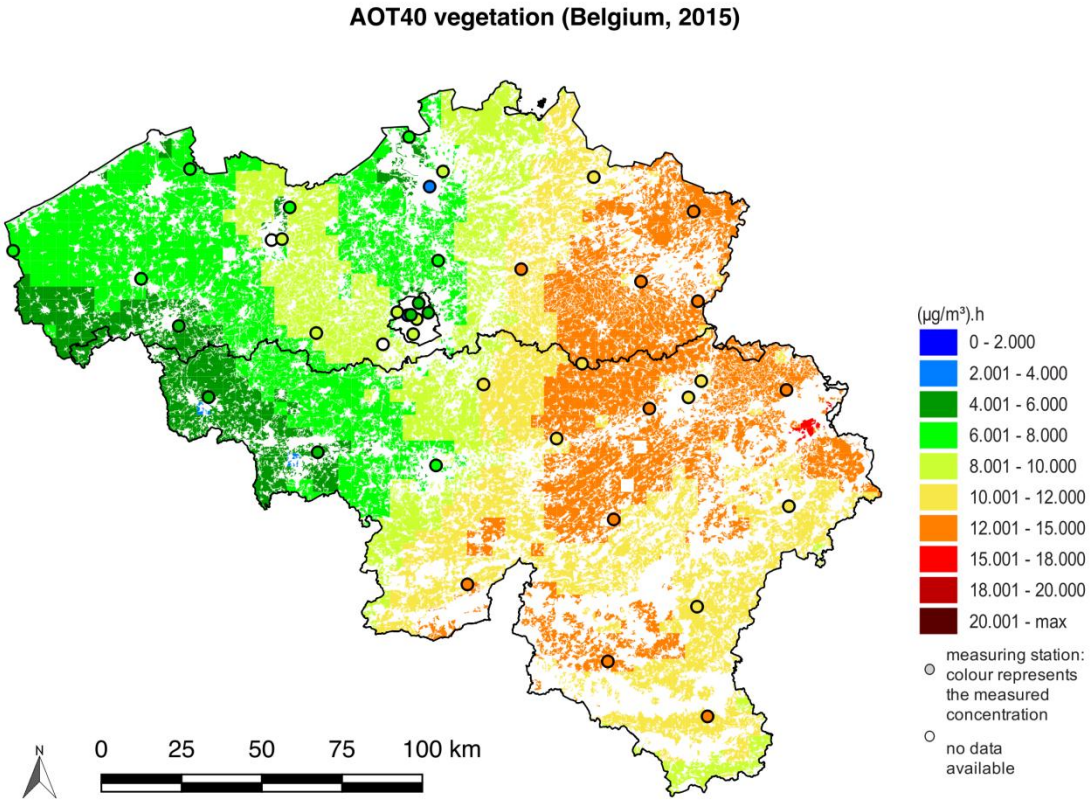


Figure 43: Spatial distribution of the ozone excess for vegetation (AOT40 for vegetation), 2015. 'No data available' means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique

[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.

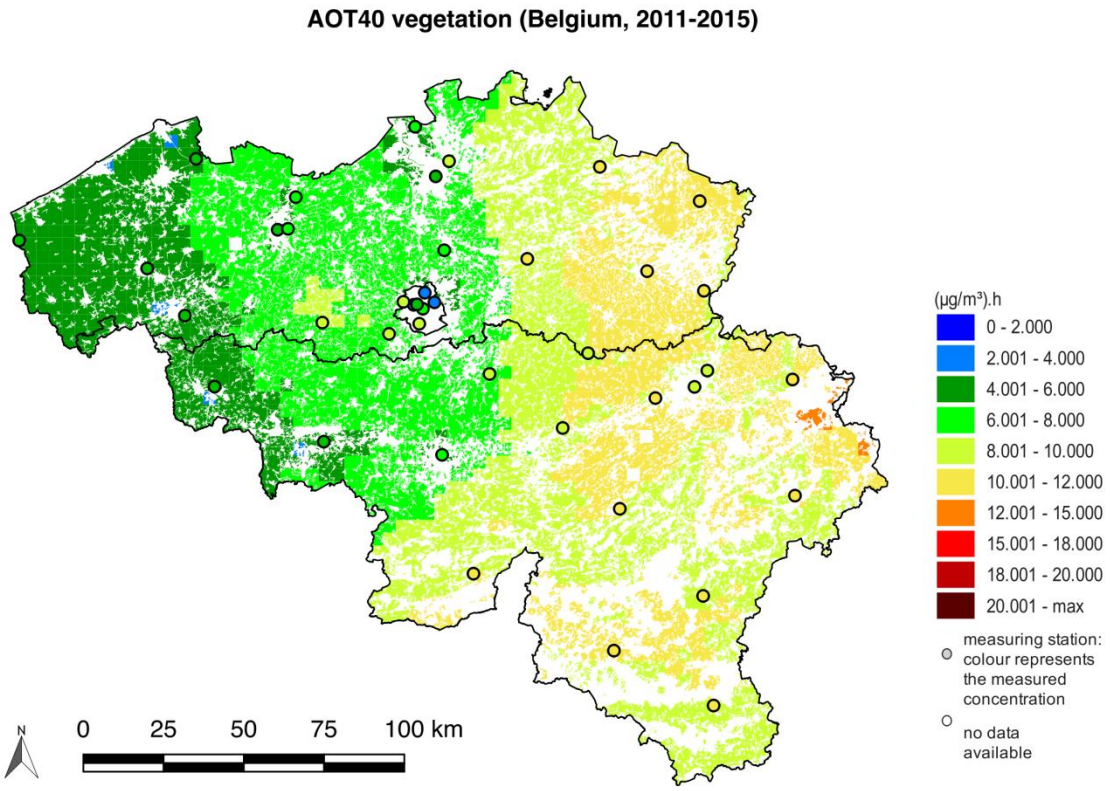


Figure 44: Spatial distribution of the ozone excess for vegetation (AOT40 for vegetation), 5-year average 2011-2015. 'No data available' means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique.

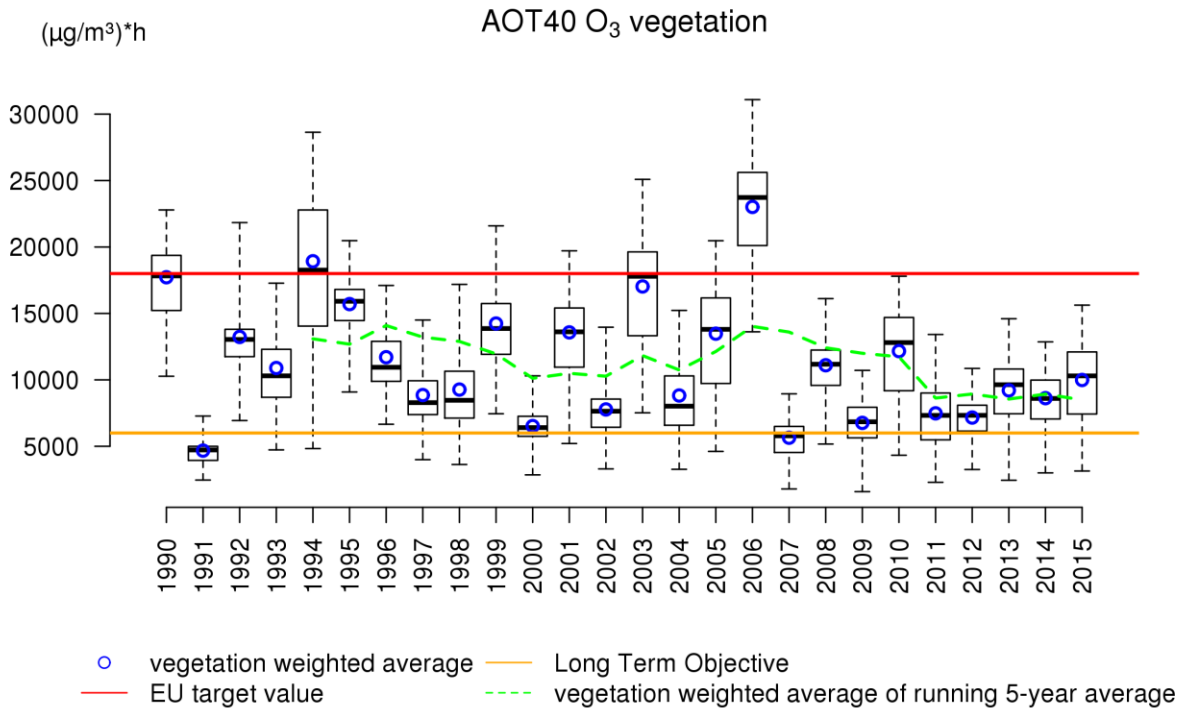


Figure 45: Box plots of the ozone excess for vegetation (AOT40 for vegetation) in Belgium (1990-2015). The vegetation-weighted averages for Belgium are indicated by the blue circles. The green dotted line indicates the vegetation-weighted average of the 5-year averaged AOT40. All data were calculated using the RIO interpolation technique.

Figure 45 shows the evolution of the AOT40 for vegetation in Belgium since 1990. The years 1994 and 2006 clearly were unfavourable ozone years for vegetation. The last 5 years have been relatively favourable; the maximum excess in Belgium never exceeded the European target value of 18 000 (µg/m³).h. The 5-year averaged AOT40 for vegetation in Belgium remained below the European target value of 18 000 (µg/m³).h at all times. The long-term objective of 6000 (µg/m³).h is, however, exceeded somewhere in Belgium each year.

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 20 000 (µg/m³).h was specified. This reference value is more stringent than the target value of 18 000 (µg/m³).h for the protection of vegetation. The last Mapping Manual of the UNECE also specified a critical value of 10 000 (µg/m³).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 found in the eastern part of the country, where also most forest resources are situated. The maximum in 2015 totalled 24 618 (µg/m³).h. 30% of Belgian forests were exposed to an AOT40 above the reference value of 20 000 (µg/m³).h. In virtually all forest resources (98%), the AOT40 exceeded the critical UNECE level of 10 000 (µg/m³).h.

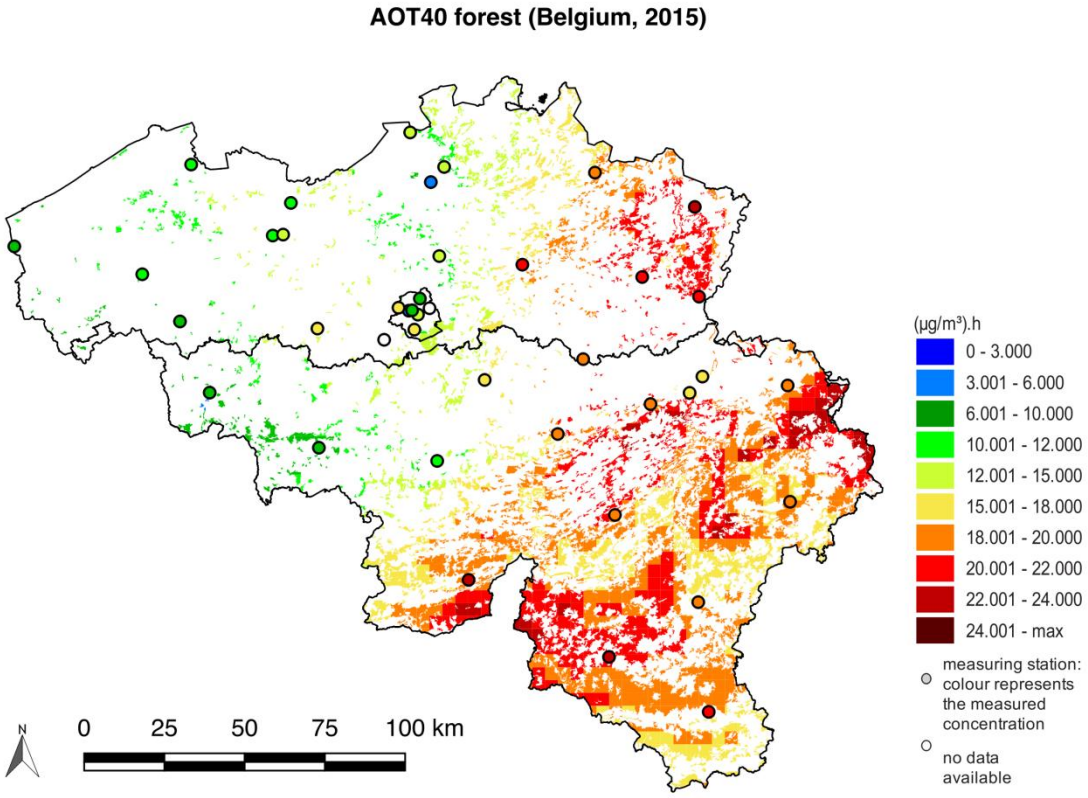


Figure 46: Spatial distribution of the ozone excess for forests (AOT40 for forests) in 2015. 'No data available' means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique.

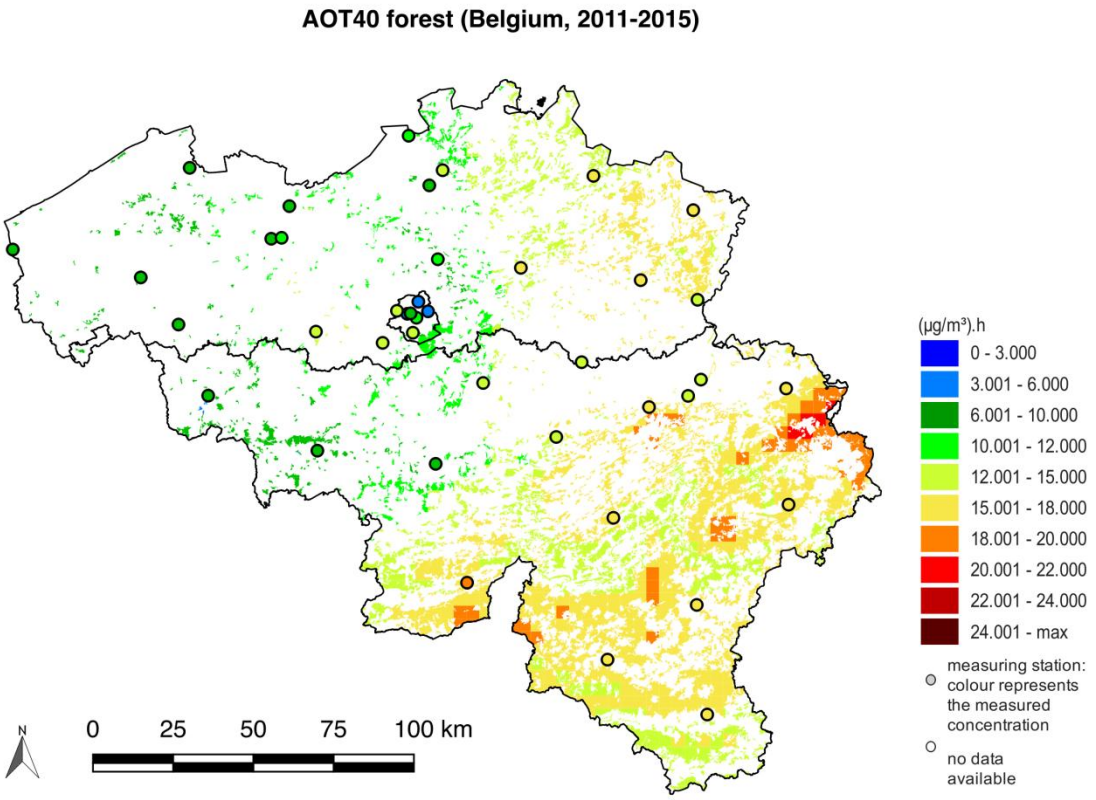


Figure 47: Spatial distribution of the ozone excess for forests (AOT40_forests), 5-year average 2011 – 2015. 'No data available' means that the data do not meet the criteria set out in 2008/50/EC Annex VII for aggregating the measurement data. All data were calculated using the RIO interpolation technique.

5.4 O_3 annual mean

The annual mean ozone concentration is a measure of the background concentration in Belgium. Figure 48 shows the spatial distribution of the annual mean ozone concentrations in 2015. 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 2015 and the period 2010-2014 reveals hardly any difference in this relationship, the 2015 mean being slightly greater.

In 2015, the annual mean concentrations for Brussels, Flanders and Wallonia were 40.7 µg/m³, 47.1 µg/m³ and 50 µg/m³ respectively. The average across Belgium is 48.7 µg/m³. The population-weighted annual mean ozone concentration in Belgium lies between the Flemish and Brussels average and amounts to 44.7 µg/m³.

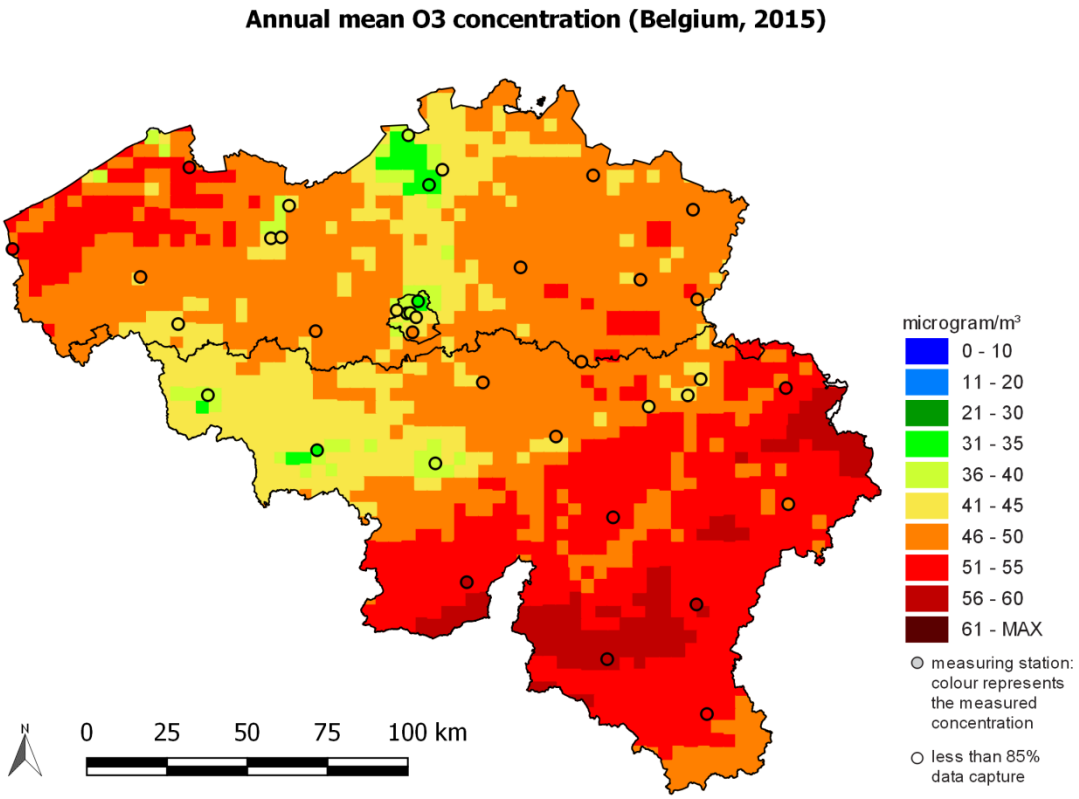


Figure 48: Spatial distribution of the O_3 annual mean concentrations in Belgium, 2015. All data were calculated using the RIO interpolation technique.

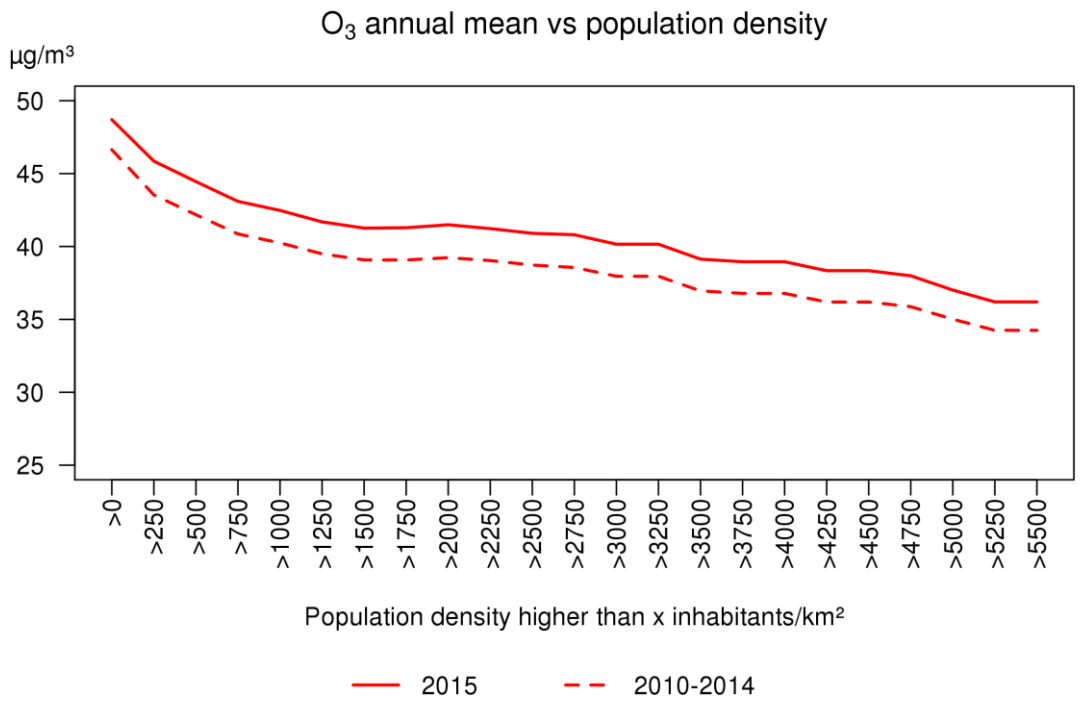


Figure 49: Relationship between the interpolated annual mean O_3 concentrations based on the RIO interpolation technique and the population density (inhabitants/km²).

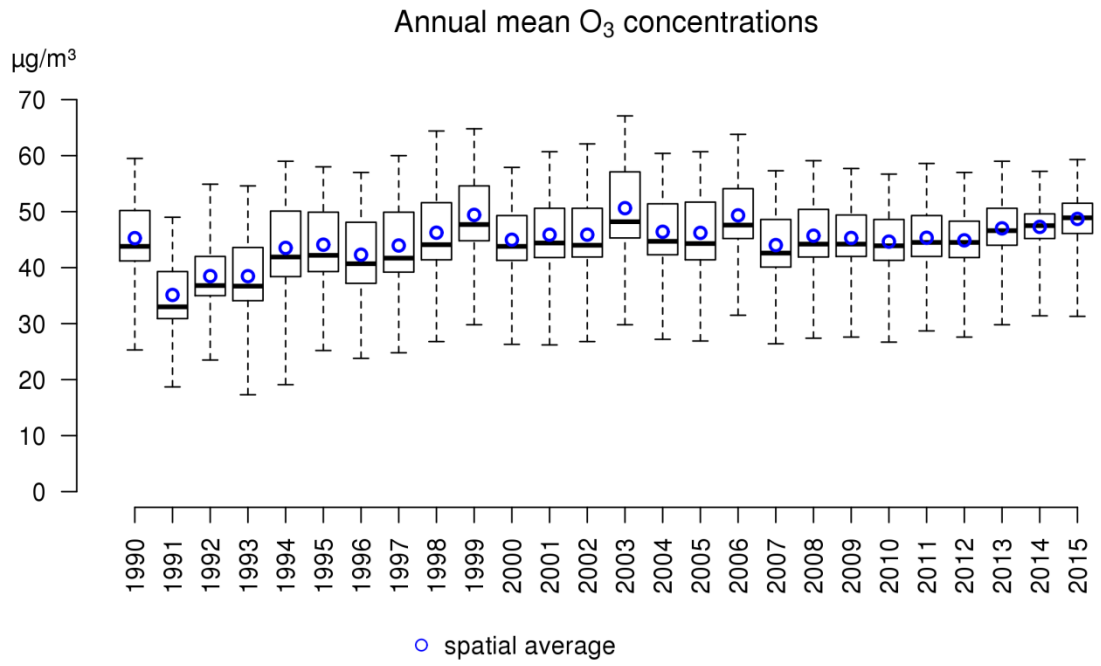


Figure 50: Box plot of annual mean O3 concentrations over the period 1990-2015. The spatial average is represented by the blue circles. All data were calculated using the RIO interpolation technique.

Figure 51 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.

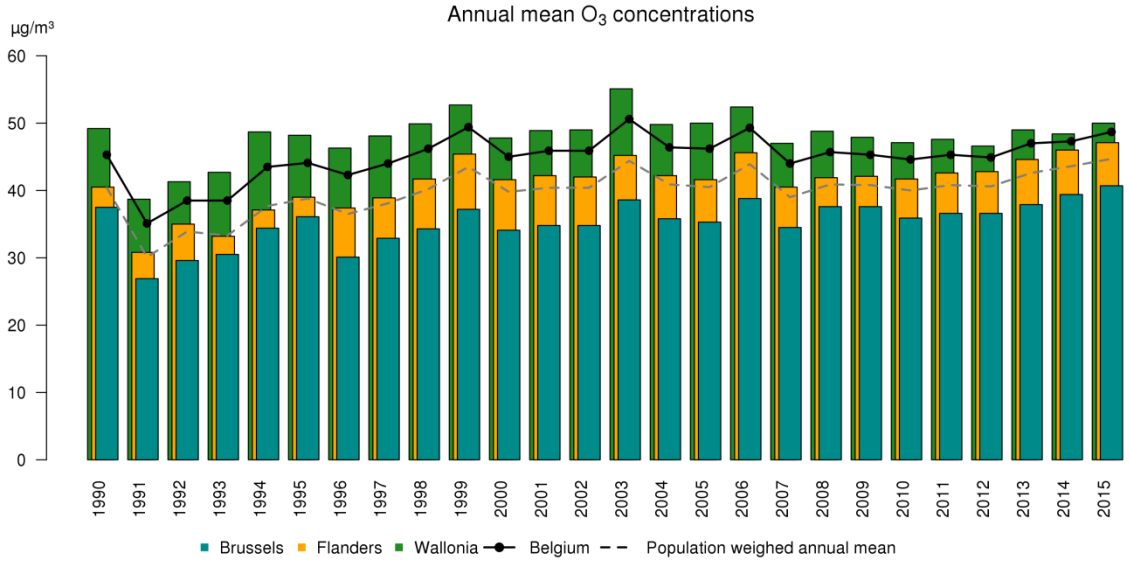


Figure 51: Evolution of the annual mean concentration in Belgium and the three Regions based on the RIO interpolation technique.

The spatial distribution of the increase in the O_3 annual mean over the period 1990-2015 is shown in Figure 52. The greatest increases, between 0.2 and 0.5 µg/m³/year, occur in Flanders and Brussels.

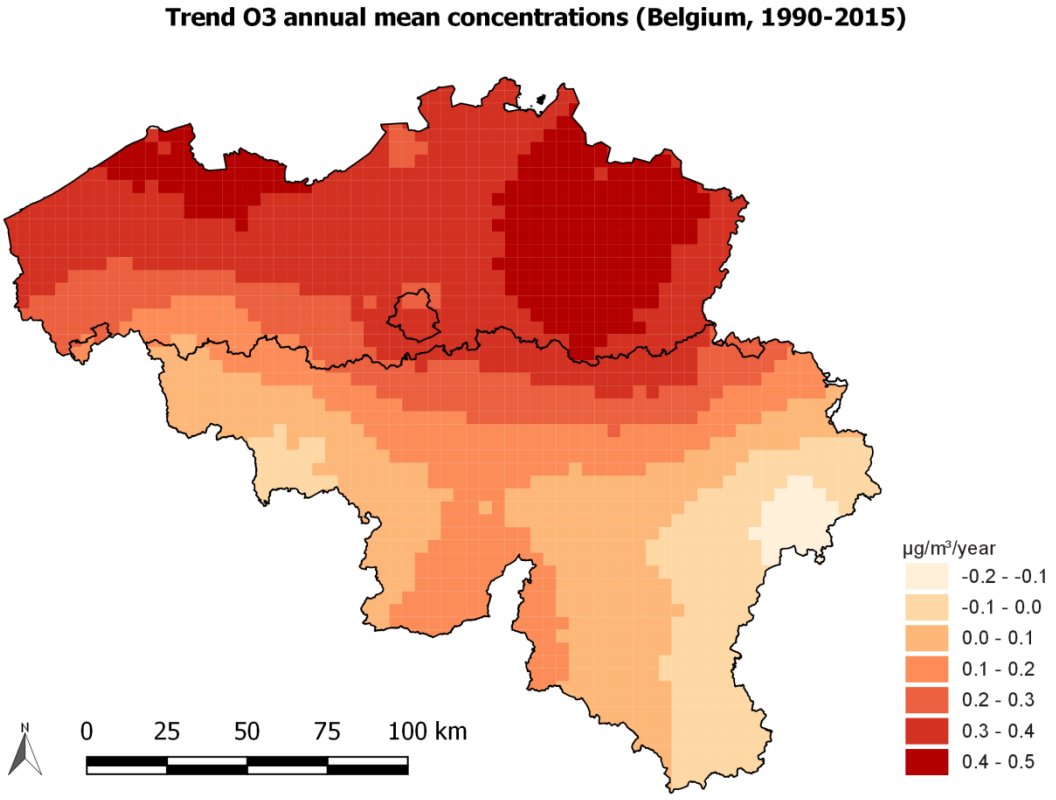


Figure 52: Spatial trend in annual mean O_3 concentration (µg/m³/year) over the period 1990-2015. The data for the trend analysis were generated based on the RIO interpolation technique.

5.5 Evolution of trend in O_3 concentration classes

To analyse the long-term trend in ozone concentrations, it is important to distinguish between 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 (of around and above 180 µg/m³) are represented by the 99.9th percentile. The evolution of both percentiles 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 1990-1999 and 2006-2015, and subsequently the difference in the percentiles between these two periods was calculated. Figure 53 shows this variation as a function of the percentiles over the period 2006-2015. This clearly shows that the ozone background concentrations, represented by the 50th and 90th percentiles, have slightly increased over the period 2006-2015 as compared to the period 1990-1999, with a maximum of 10 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 40 µg/m³. This trend, an increase of low concentrations and a

decrease of ozone peaks, are comparable to those observed in the network of the European Monitoring and Evaluation Programme (EMEP; Torseth et al., 2012).

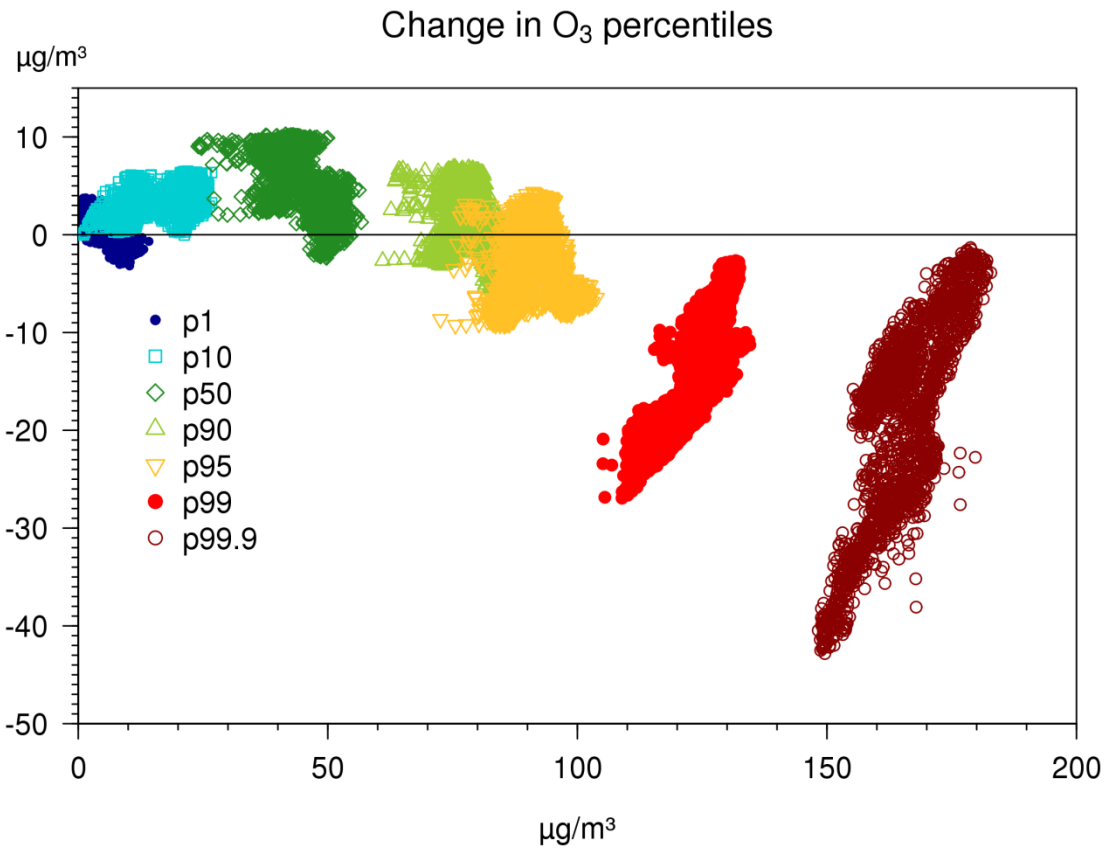


Figure 53: Variation in O_3 percentiles between the periods 1990-1999 and 2006-2015 in relation to the percentile values in the period 2006-2015 for all RIO grid cells. The data were generated based on the RIO interpolation technique. The different colours indicate the different percentile values.

6 Sulphur dioxide

Sulphur dioxide (SO_2) is a colourless gas with a characteristic irritating odour and taste at high concentrations (above 1000 µg/m³). SO_2 is mainly emitted into the air by 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 traffic. 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 soluble in water, 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, also causing damage in more remote areas.

6.1 SO_2 monitoring stations

Figure 54 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 53 in 2014, while 55 were active in 2015. In the years with fewer monitoring stations, the interpolated values have a larger uncertainty.

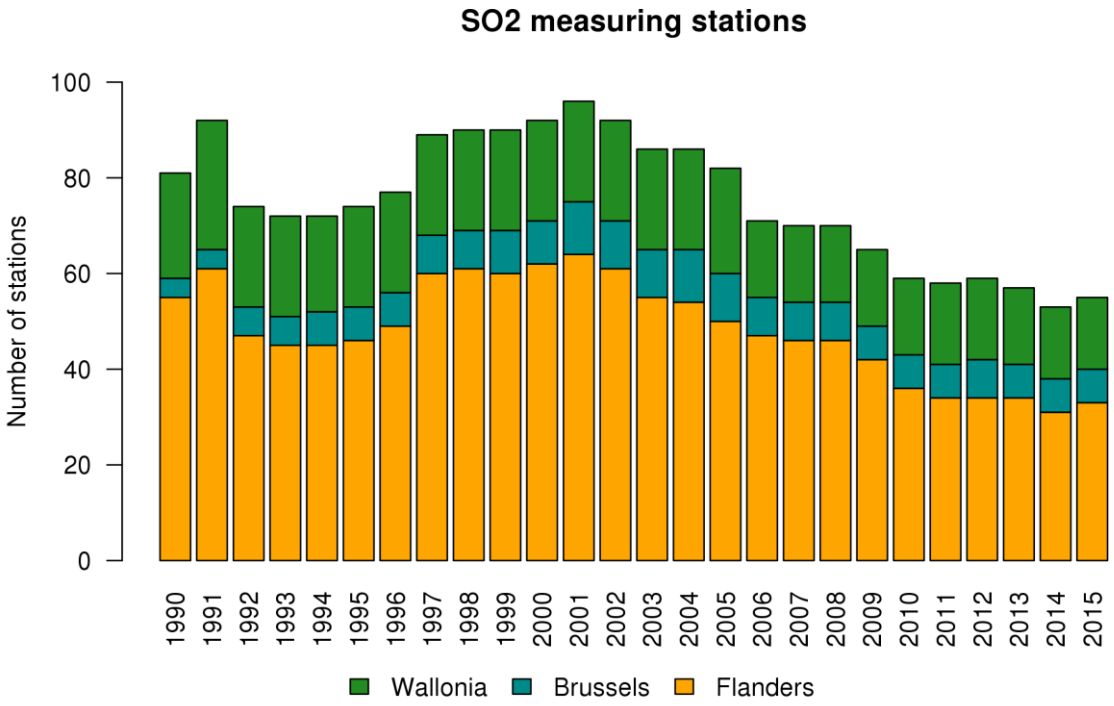


Figure 54: Evolution of the number of SO_2 monitoring stations in Belgium.

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. Because of the low resolution of the RIO interpolation method, local exceedances would not necessarily be visible.

It can, however, be said that the hourly limit value is amply met in Belgium (Figure 55, Figure 56 and Figure 57). 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 2015, representative of an area of 4x4 km², is 21.6 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. After a slight increase in 2014, the concentrations of 2015 have once again decreased to the level of 2013.

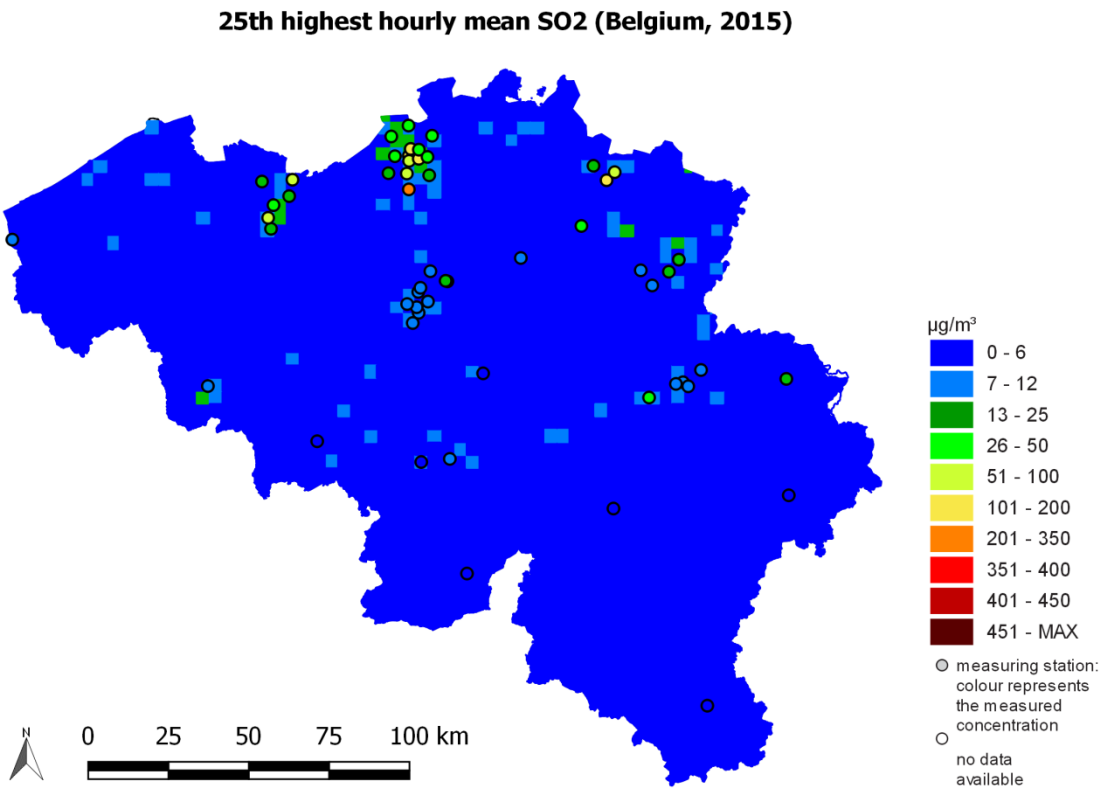


Figure 55: Spatial distribution of the 25th highest hourly mean SO_2 concentration in 2015. All data have been calculated based on the RIO interpolation technique.

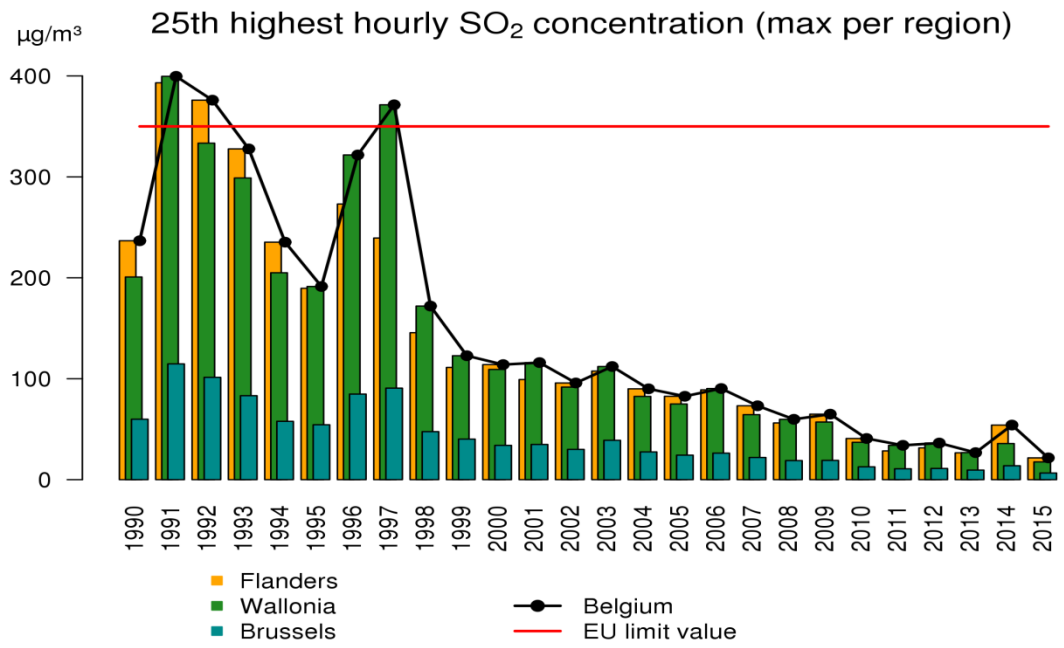


Figure 56: Evolution of the maximum 25th highest hourly mean SO_2 concentration per Region and Belgium based on the RIO interpolation technique.

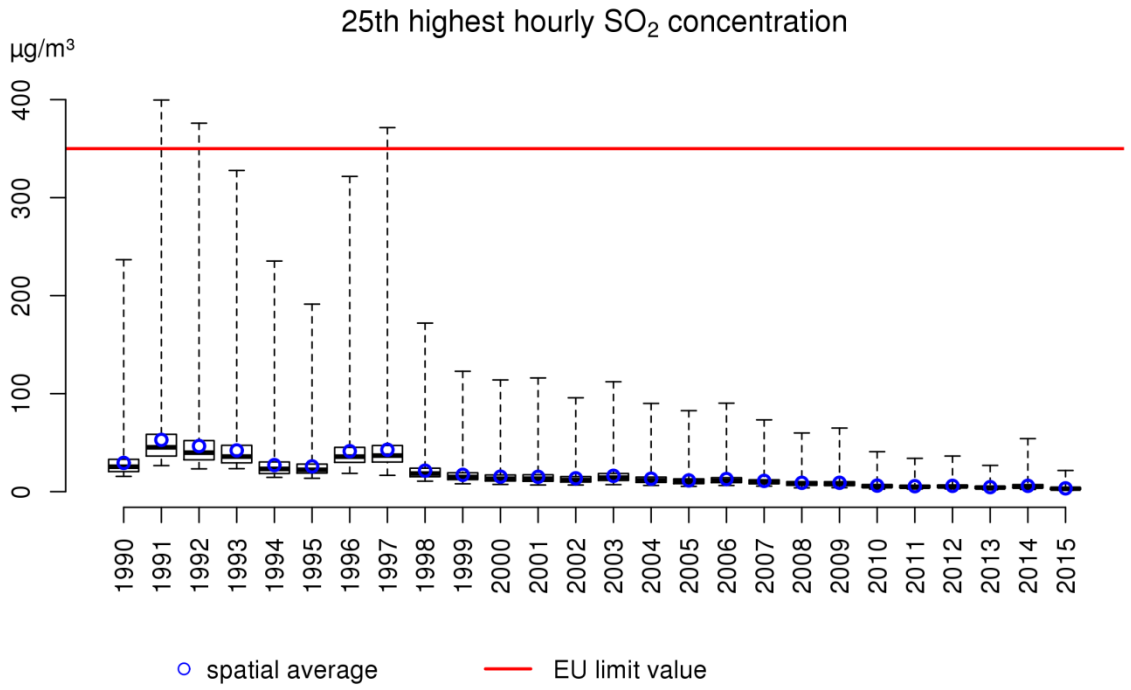


Figure 57: Box plot of the 25th highest hourly mean SO_2 concentration over the period 1990-2015 in Belgium based on the RIO interpolation technique.

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 made more stringent, to 20 µg/m³, since 2006. The EU limit value is amply met everywhere in Belgium. The WHO guideline value was, however, still exceeded sometimes in industrial zones. This was however not the case in 2015.

Just as for the SO_2 hourly mean values, the evolution of the 4th highest daily mean values shows a continuously downward trend (Figure 58 and Figure 59) until 2015, with the exception of 2014, when a slight increase was observed.

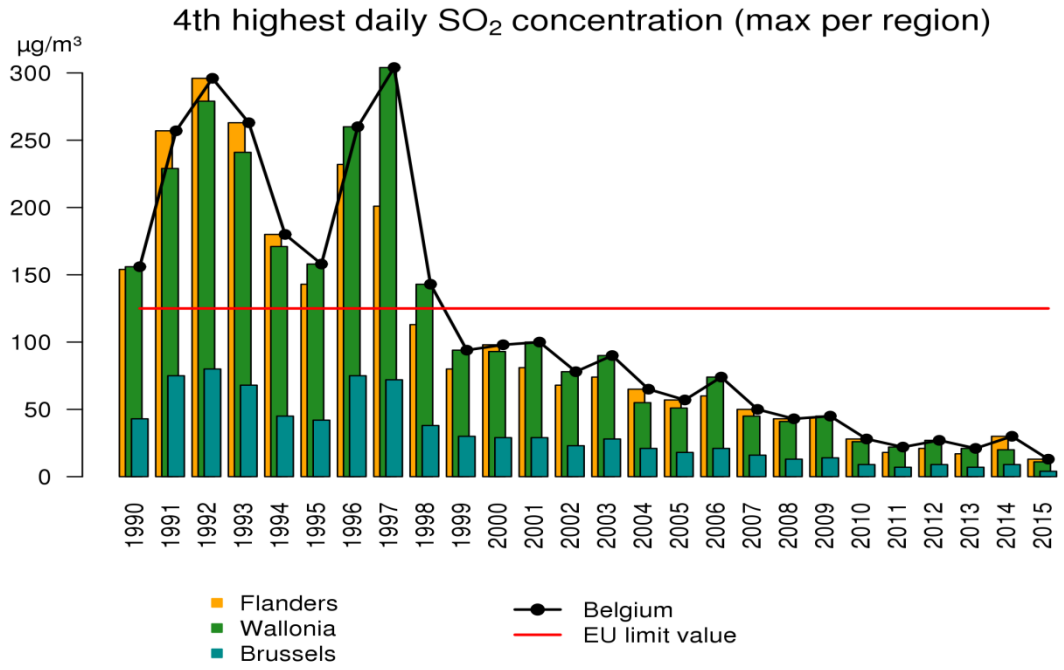


Figure 58: Evolution of the maximum 4th highest daily mean SO_2 concentration per Region and in Belgium based on the RIO interpolation technique.

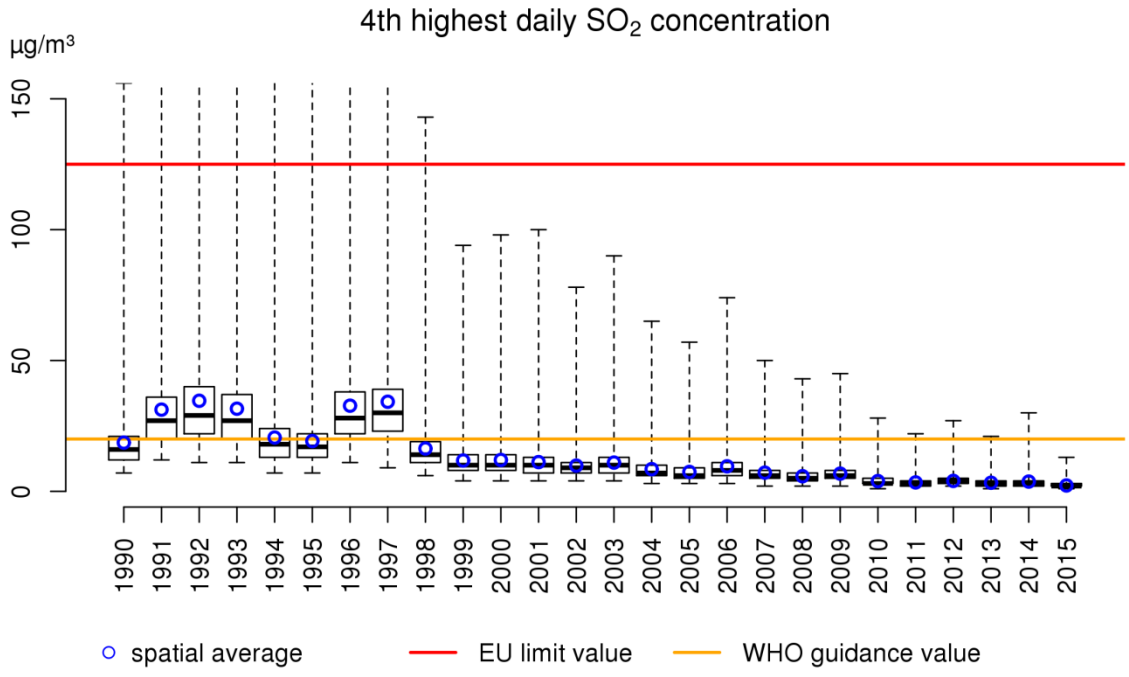


Figure 59: Box plot of the 4th highest daily mean SO_2 concentration over the period 1990-2015 across Belgium based on the RIO interpolation technique.

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 for 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.

Prospect: improvement of the RIO interpolation technique

To improve the spatial resolution, IRCEL-CELINE worked, in the context of the Atmosys EU project, on the development of an interpolation technique coupled to a dispersion model, RIO-IFDM (Lefebvre et al., 2013). Specifically, it 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 (industries) to calculate concentrations at a much higher resolution (up to 10x10 m²). Notice that this resolution accords to the maximal resolution of the underlying grid, on which the model calculations are based. Practically, the resolution of the model is situated in the order of magnitude from 100 meters up to a kilometre. The rest of the contributions (agriculture, households, …) is supposed to be included in background concentrations provided by RIO. An example of a RIO-IFDM map of Belgium for the daily mean NO_2 concentrations on 28/03/2014 is shown in Figure 60.

Models like this will make it possible in the future to monitor the air quality and the population exposure with a higher level of spatial accuracy.

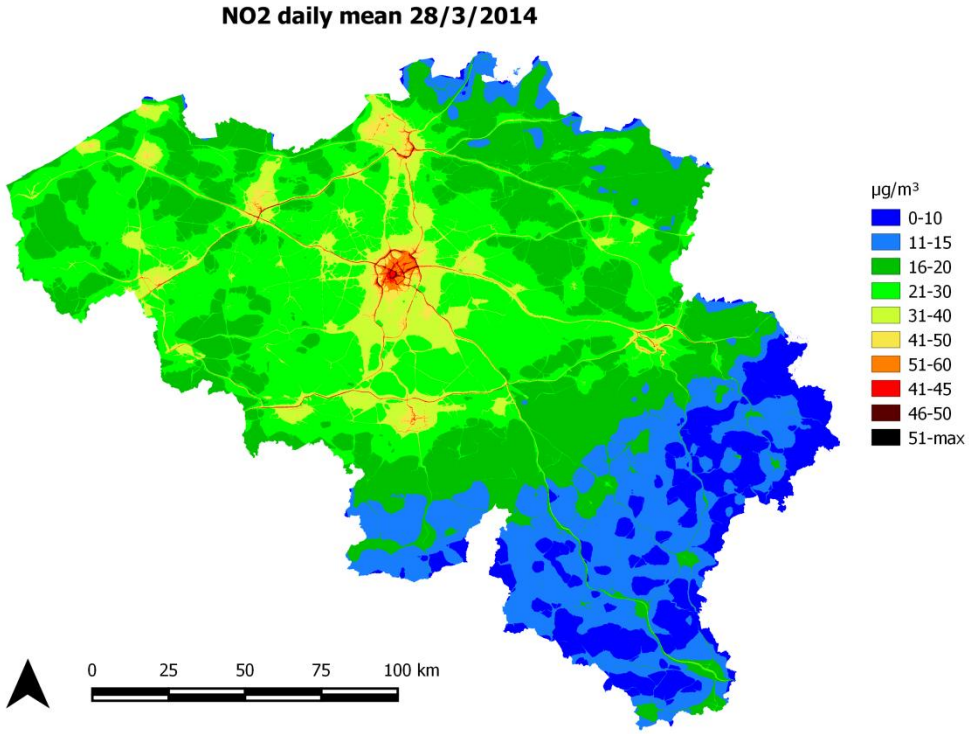


Figure 60: RIO-IFDM map of Belgium for the daily mean NO_2 concentrations on 28/03/2014.

Conclusion

This annual report gives an overview of the spatial distribution of the air quality in Belgium in the year 2015, with special attention for the spatial distribution of the four major pollutants (PM, NO_2, O_3 and SO_2), and also discusses the evolution of the various indicators over time. All indicators show a general diminution since the beginning of the measures. As can also be seen in Table 1 and Table 2 in the summary, the minimum, mean and maximum of nearly all indicators this year are either lower or comparable to the averages over the 10 last years. As a general pattern, 2015 was a favourable year for the air quality in comparison to the last 10 years.

However, Belgium still exceeds the European limit or target value for the number of days with maximum 8-hour mean ozone concentration > 120 µg/m³ (and the accumulated excess or AOT60), which is the long-term target for the protection of human health for ozone, and for the ozone AOT40 for forests and vegetation. When we compare the values with the more stringent and health-related WHO guideline values, we find that almost all pollutants, except NO_2 and SO_2 (and associated indicators), exceed 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 four most important air pollutants with health impact. 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.). Local case-by-case studies should be performed to distinguish more specific effects, but this is beyond the scope of the report, which aims at providing an overview of the problems and at mapping the air quality in Belgium.

References

Amann M., Bertok I., Cabala R., Cofala J., Heyes C., Gyarfas F., Klimont Z., Schöpp W. & Wagner F. (2005) A final set of scenarios for the Clean Air For Europe (CAFE) programme. Studie in opdracht van de Europese Commissie. Final Report, International Institute for Applied Systems Analysis (IIASA), Austria.

Brunekreef B. & Forsberg B. (2005) Epidemiological evidence of effects of coarse airborne particles on health. European Respiratory Journal 26: 309-318.

Buekers J., Torfs R., Deutsch F., Lefebvre W. & Bossuyt M. (2012) Inschatting ziektelast en externe kosten veroorzaakt door verschillende milieufactoren in Vlaanderen, studie uitgevoerd in opdracht van de Vlaamse Milieumaatschapprij, MIRA, MIRA/2012/06, VITO, 2012/MRG/R/187.

David C. & Ropkins K. (2012) Openair: Open-source tools for the analysis of air pollution data. R package version 0.6-0.

EU (1996) Directive 96/62/EC on ambient air quality assessment and management.

EU (2001) Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants.

EU (2008) Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe.

EU (2011) Uitvoeringsbesluit 2011/850/EU van de commissie houdende uitvoeringsbepalingen van Richtlijnen 2004/107/EG en 2008/50/EG van het Europees Parlement en de Raad met betrekking tot de onderlinge uitwisseling van informatie en de verslaglegging over de luchtkwaliteit.

Grice S., Stedman J., Kent A., Hobson M., Norris J., Abott J. & Cooke S. (2009) Recent trends and projections of primary NO2 emissions in Europe. Atmospheric Environment 43: 2154-2167.

Hooyberghs J., Mensink C., Dumont G. & Fierens F. (2006) Spatial interpolation of ambient ozoneconcentrations from sparse monitoring points in Belgium. Journal of Environmental Monitoring 8: 1129-1135.

Janssen S., Dumont G., Fierens F. & Mensink C (2008) Spatial interpolation of air pollution measurements using CORINE land cover data. Atmospheric Environment 42: 4884-4903.

Jerret M., Burnett R.T., Pope A., Ito K., Thurston G, Krewski D, Shi Y., Calle E. & Thun M. (2009) Long-term ozone exposure and mortality. New England Journal of Medicine 360-11: 1085-1095.

Lefebvre W., Degrawe G., Beckx C., Vanhulel M., Kochan B., Bellemans T., Janssens D., Wets G., Janssen S., de Vlieger I., Int Panis L. & Dhondt S. (2013) Presentation and evaluation of an integrated model chain to respond to traffic and health –related policy questions. Environmental Modelling and Software 40: 160-170.

LNE (2012) Luchtkwaliteitsplan in het kader van de uitstelaanvraag voor de normen van NO_2, Joke Schauvliege, Vlaams minister van Leefmilieu, Natuur en Cultuur, http://www.lne.be/themas/luchtverontreiniging/bijlage1-luchtkwaliteitsplan-v5.pdf.

LNE (Euronormen voor voertuigen), http://www.lne.be/themas/milieu-en-mobiliteit/milieuvriendelijke-voertuigen/ecoscore-en-euronormen/euronormen-voor-voertuigen

MIRA (2006) Milieu Vlaanderen, Achtergronddocument 2006 Verzuring, Van Avermaet P., Van Hooste H. & Overloop S.. Vlaamse Milieumaatschappij, http://www.milieurapport.be

MIRA (2011) Milieurapport Vlaanderen, Achtergronddocument 2011 Vermesting. Overloop S., Bossuyt M., Claeys D., D'hooghe J., Elsen A., Eppinger R. & Wustenberghs H., Vlaamse Milieumaatschappij, www.milieurapport.be

Quantum GIS Development Team (2012) Quantum GIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org

R Core Team (2012) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.ISBN 3-900051-07-0, URL http://www.R-project.org/

Sen P.K. (1986) Estimates of regression coefficient based on Kendall's tau. Journal of the American Statiscal Association 63 (324).

Theil H. (1950) A rank invariant method of linear and polynomial regression analysis. Proceedings of the Koninklijke Nederlandse Akademie Wetenschappen, Series A- Mathematical Sciences 53: 386-392, 521-525, 1397-1412.

Torseth K., Aas W., Breivik K., Fjaeraa A.M., Fiebig M., Hjellbrekke A.G., Lund Myhre C., Solberg S. & Yttri K.E. (2012) Introduction to the European Monitoring and Evaluation Programme (EMEP) and observed atmospheric composition change during 1972-2009. Atmospheric Chemistry and Physics 12, 5447-5481.

VMM (2009) Chemkar PM_{10}: Chemische karakterisatie van fijn stof in Vlaanderen, 2006-2007

VMM (2010) Chemkar PM_{10} 'hotspots': Chemische karakterisatie van fijn stof in Vlaanderen, 2008-2009

WHO (2006) *Air quality guidelines — global update 2005*, World Health Organization Regional Office for Europe, Copenhagen.

WHO (2012), http://www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf

WHO (2013), Review of evidence on health aspects of air pollution (REVIHAAP): http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/review-of-evidence-on-health-aspects-of-air-pollution-revihaap-project-final-technical-report

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.

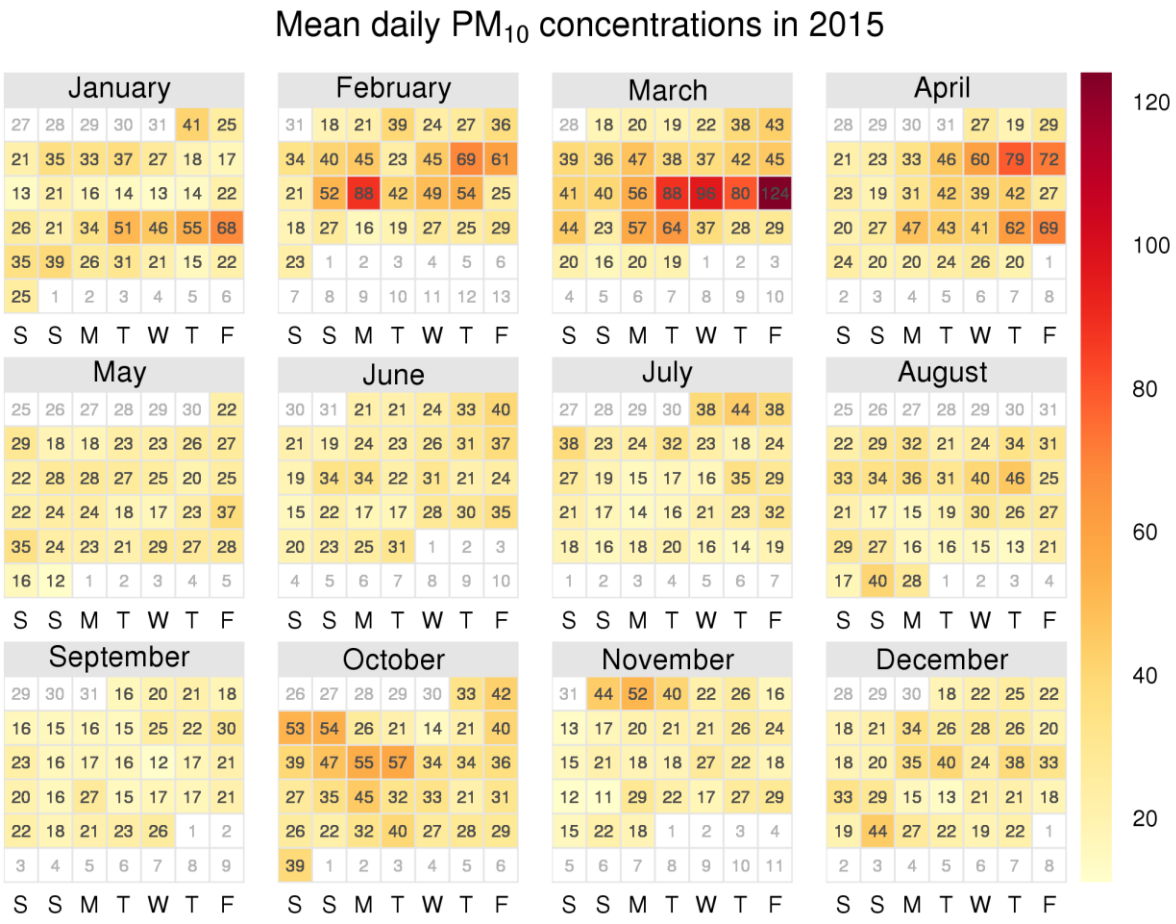
Station code	Location	PM_{10}	$PM_{2,5}$	O_3	NO_2	BC	SO_2
40AB01	ANTWERPEN (BOUDEWIJNSLUIS)	X	X			X	
40AB02	BERENDRECHT	X	X				
40AL01	ANTWERPEN-LINKEROEVER	X	X		X	X	
40AL02	DOEL (ENGELSESTEENWEG)	X					
40AL03	BEVEREN		X				
40AL04	BEVEREN		X				
40AL05	KALLO (SLUIS KALLO)	X					
40BE06	BEERSE						
40GK06	DIEPENBEEK	X	X				
40GK09	GENK				X		X
40HB23	HOBOKEN	X	X		X		X
40LD01	LAAKDAL-GEEL				X		
40LD02	LAAKDAL - GEEL				X		
40LM05	LOMMEL						X
40MN01	MENEN	X	X				
40OB01	OOSTROZEBEKE	X	X				
40OB02	WIELSBEKE	X	X				
40R833	STABROEK				X		
40RL01	ROESELARE (BRUGSESTEENWEG)	X	X				
40SA04	HOEVENEN	X	X		X	X	
40SZ01	STEENOKKERZEEL	X	X		X	X	X
40SZ02	STEENOKKERZEEL	X	X		X	X	X
40TS21	TESSENDERLO						X
40WZ02	MOL (WEZEL)						X
41B004	BRUSSEL (SINT-KATELIJNE)			X	X		
41B005	BRUSSEL						
41B006	BRUSSEL (EU-PARLEMENT)			X	X		
41B008	BRUSSEL (BELLIARD)				X		X
41B011	SINT-AGATHA-BERCHEM	X	X	X	X		

41MEU1	SINT-LAMBRECHTS-WOLUWE	X	X		X		X
41N043	HAREN	X	X	X	X	X	X
41R001	SINT-JANS-MOLENBEEK	X	X	X	X	X	X
41R002	ELSENE				X	X	X
41R012	UKKEL	X	X	X	X	X	X
41WOL1	SINT-LAMBRECHTS-WOLUWE	X		X	X	X	X
42M802	ANTWERPEN LUCHTBAL	X	X		X	X	X
42N016	DESSEL	X	X	X	X	X	X
42N027	BREE			X	X		
42N035	AARSCHOT	X	X	X	X		X
42N040	SINT-PIETERS-LEEUW			X	X		
42N045	HASSELT	X	X	X	X	X	X
42N046	GELLIK			X	X		
42N054	LANDEN	X	X	X	X		
42R010	SINT-STEVENS-WOLUWE				X		
42R020	VILVOORDE	X	X		X		X
42R801	ANTWERPEN	X	X	X	X	X	X
42R802	ANTWERPEN	X	X		X	X	
42R803	ANTWERPEN	X	X		X	X	
42R805	ANTWERPEN	X	X		X	X	
42R811	SCHOTEN	X	X	X	X		
42R815	ZWIJNDRECHT	X	X		X	X	X
42R817	ANTWERPEN	X	X		X	X	
42R820	KAPELLEN				X		X
42R821	BEVEREN-WAAS				X		X
42R822	ANTWERPEN				X		X
42R830	DOEL				X		X
42R831	BERENDRECHT	X	X	X	X		X
42R832	RUISBROEK						
42R833	STABROEK						
42R834	BOOM	X	X		X		
42R841	MECHELEN	X	X	X	X		
42R891	ANTWERPEN				X		X
42R892	KALLO				X		X
42R893	ANTWERPEN				X		X
42R894	ANTWERPEN				X		X
42R897	ANTWERPEN				X		X
43H201	SAINT NICOLAS	X	X				X
43M204	ANGLEUR	X	X				
43N060	HAVINNES	X	X	X	X		X
43N063	CORROY LE GRAND	X	X	X	X		X
43N066	EUPEN			X	X		X
43N067	MEMBACH	X	X				

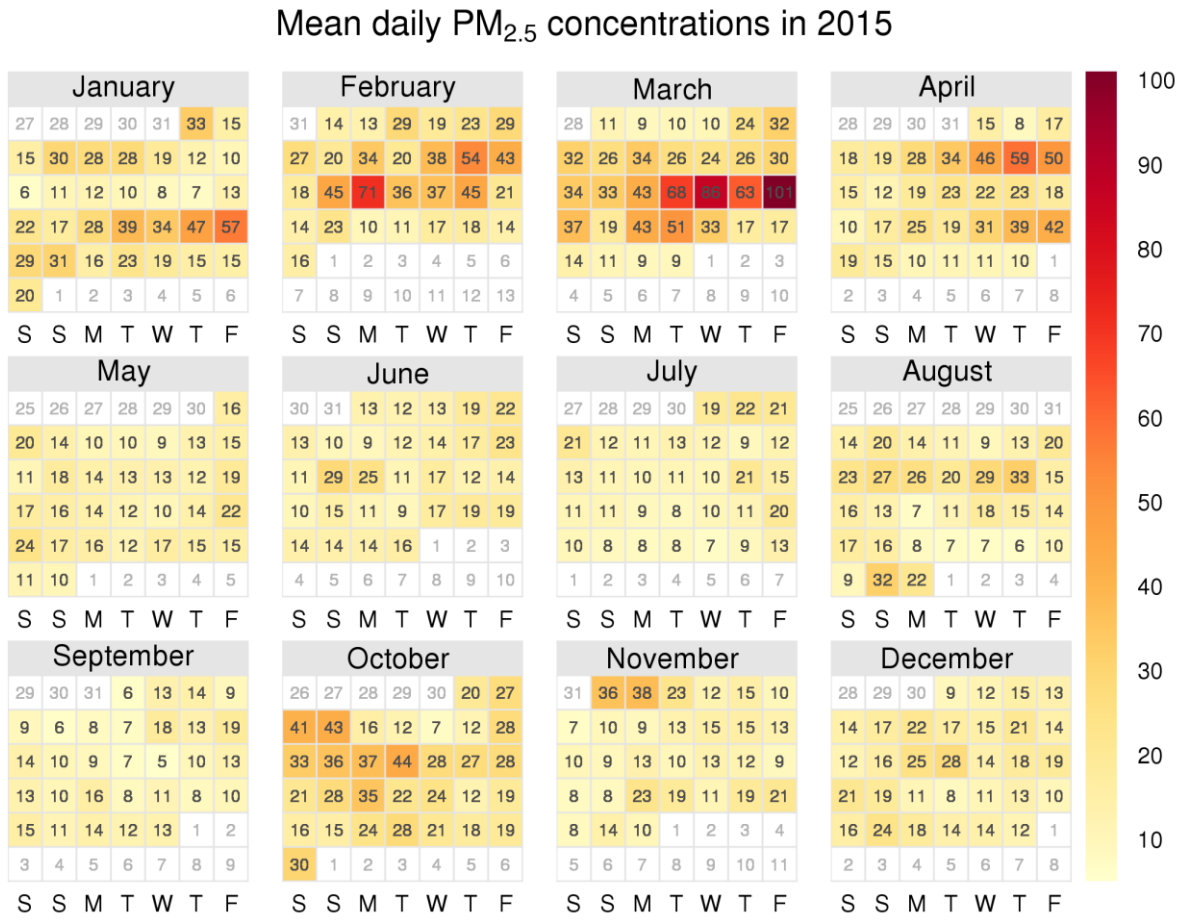
43N070	MONS	X	X	X	X		X
43N073	VEZIN	X	X	X	X		
43N085	VIELSALM	X	X	X	X	X	X
43N093	SINSIN	X	X	X	X		X
43N100	DOURBES	X	X	X	X		X
43N113	SAINT-ODE	X	X	X	X		
43N121	OFFAGNE	X	X	X	X		
43N132	HABAY-LA-NEUVE	X	X	X	X		X
43R201	LUIK						
43R221	LUIK	X	X	X	X	X	X
43R222	LUIK	X	X	X	X		X
43R223	JEMEPPE	X	X		X		X
43R240	ENGIS	X	X	X	X		X
44M702	ERTVELDE				X		
44M705	ROESELARE	X	X	X	X	X	
44N012	MOERKERKE	X	X	X	X		
44N029	HOUTEM	X	X	X	X	X	X
44N051	IDEGEM			X	X		
44N052	ZWEVEGEM	X	X	X	X		
44R701	GENT	X	X	X	X	X	X
44R702	GENT	X	X		X	X	
44R710	DESTELBERGEN	X	X	X	X		
44R721	WONDELGEM				X		X
44R731	EVERGEM	X	X		X		X
44R740	SINT-KRUIS-WINKEL	X	X	X	X		X
44R750	ZELZATE	X	X		X	X	X
45R501	CHARLEROI	X	X		X		
45R502	LODELINSART	X	X	X	X		
45R510	CHATELINEAU	X	X				X
45R511	MARCINELLE	X	X				
45R512	MARCHIENNE AU PONT	X	X		X	X	X
47E007	SINT-PIETERS-LEEUW				X		
47E008	GRIMBERGEN				X		
47E009	ZEMST				X		
47E013	VORST				X		
47E701	VICHTE						
47E702	ELSEGEM						
47E703	OOSTEEKLO				X		X
47E704	WACHTEBEKE				X		
47E714	DUDZELE				X		
47E715	ZUIENKERKE				X		
47E716	MARIAKERKE				X		
47E804	MOL						
47E811	DIEPENBEEK				X		X

47E812	GENK				**X**		**X**
47E813	HAM						
47E814	HAM				**X**		

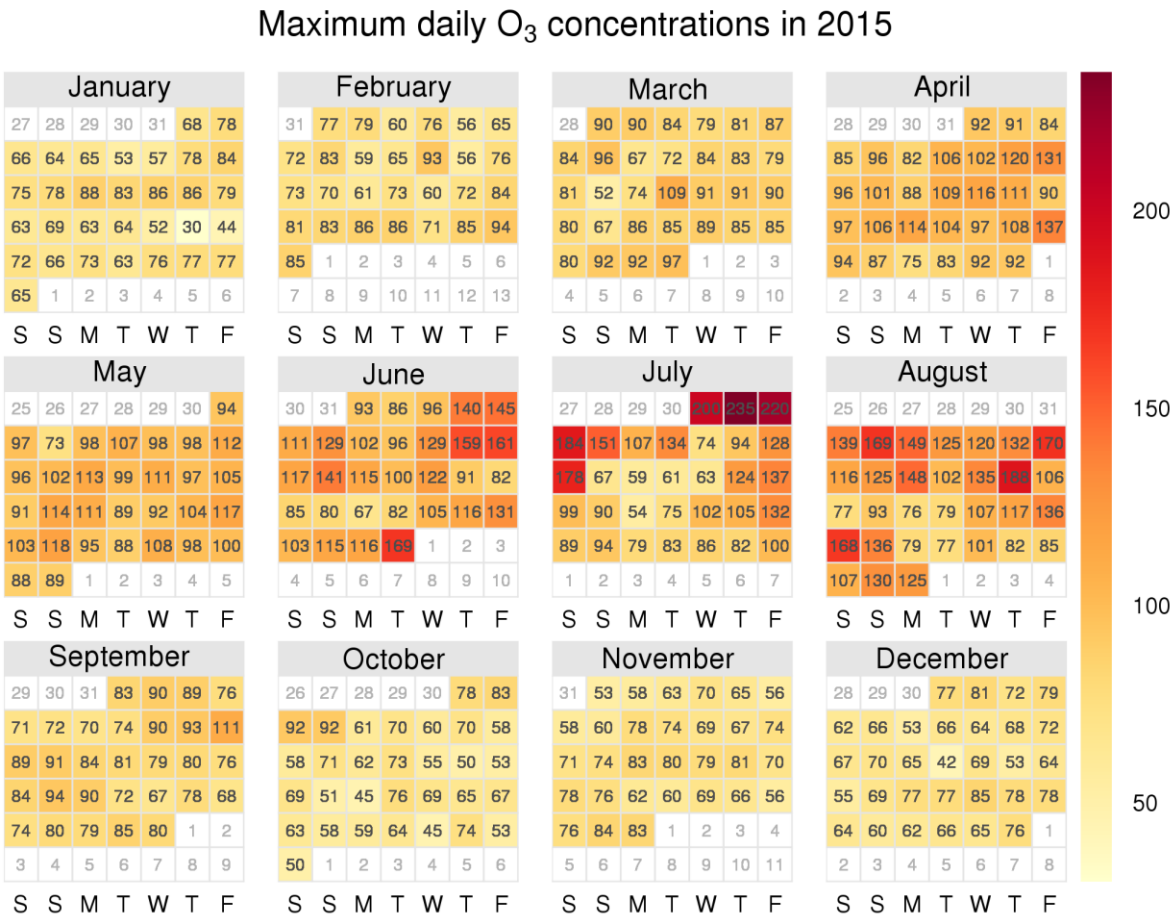
Annex B: Annual overview of air quality pollutants



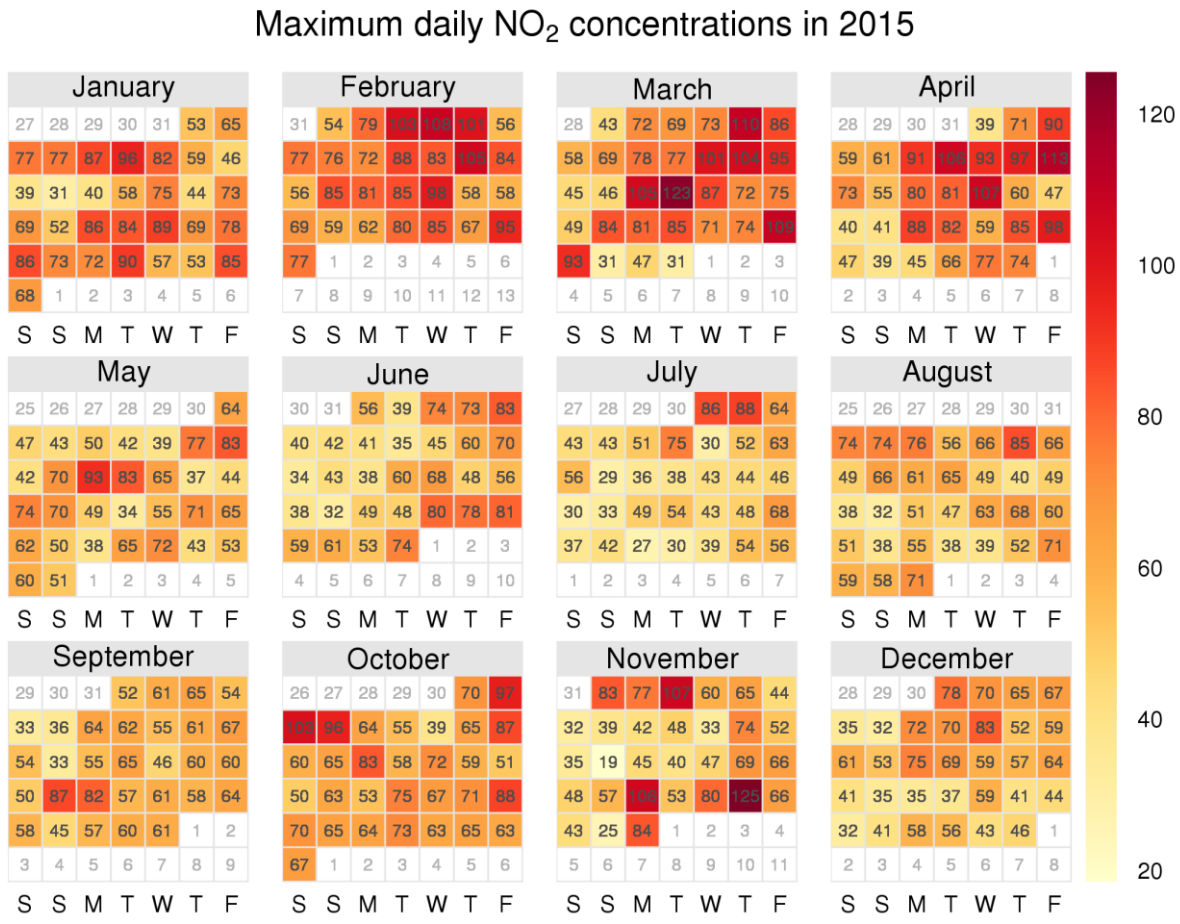
Spatial maximum of daily mean PM_{10} concentrations in 2015



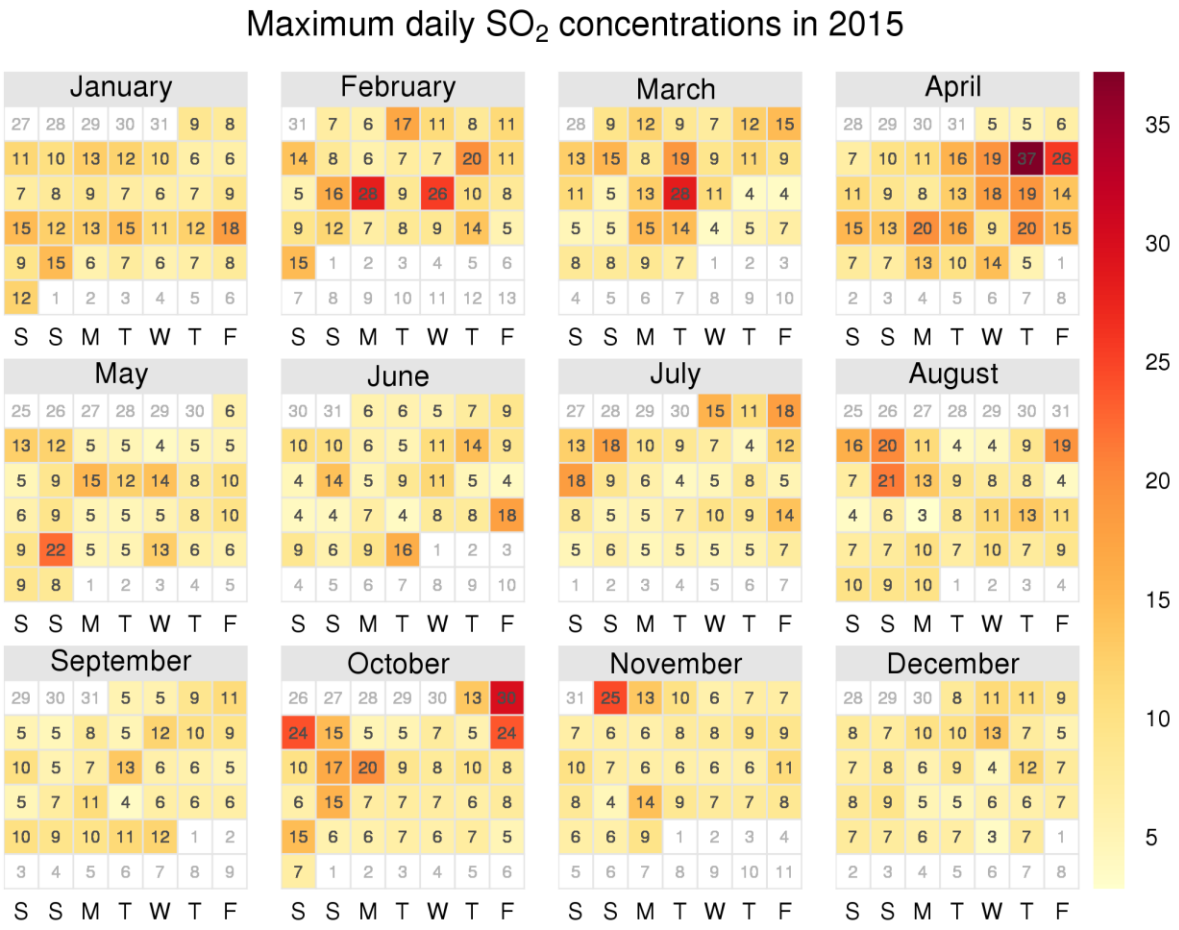
Spatial maximum of daily mean $PM_{2,5}$-concentrations in 2015



Daily maximal O_3-concentrations in 2015



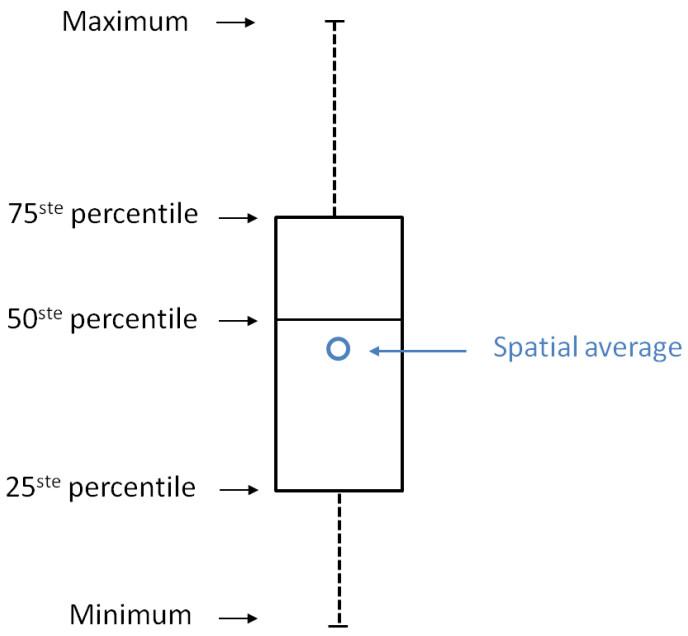
Daily maximal NO_2-concentrations in 2015



Daily maximal SO_2-concentrations in 2015

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.



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:

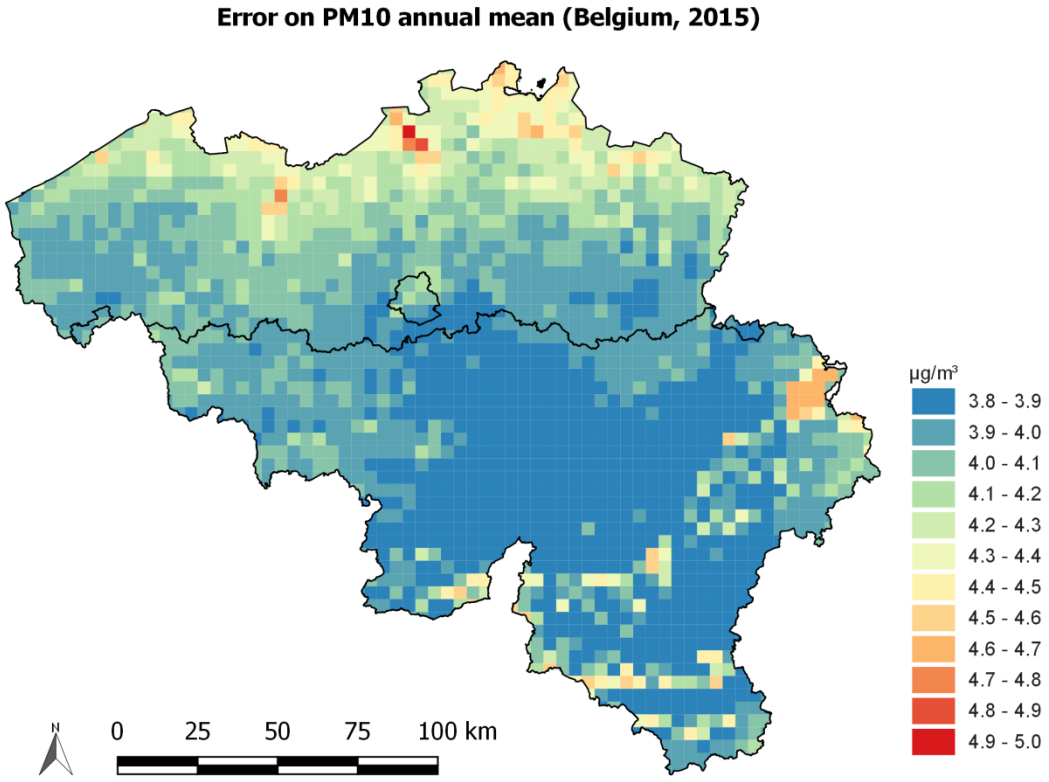
1. Error on measured values: this error is taken indirectly into account because the variogram used in the Kriging (i.e. a component of the RIO interpolation technique) exhibits a "nugget" effect (i.e. at distance 0 between monitoring stations, not the same measured concentration is assumed).
2. Clustering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

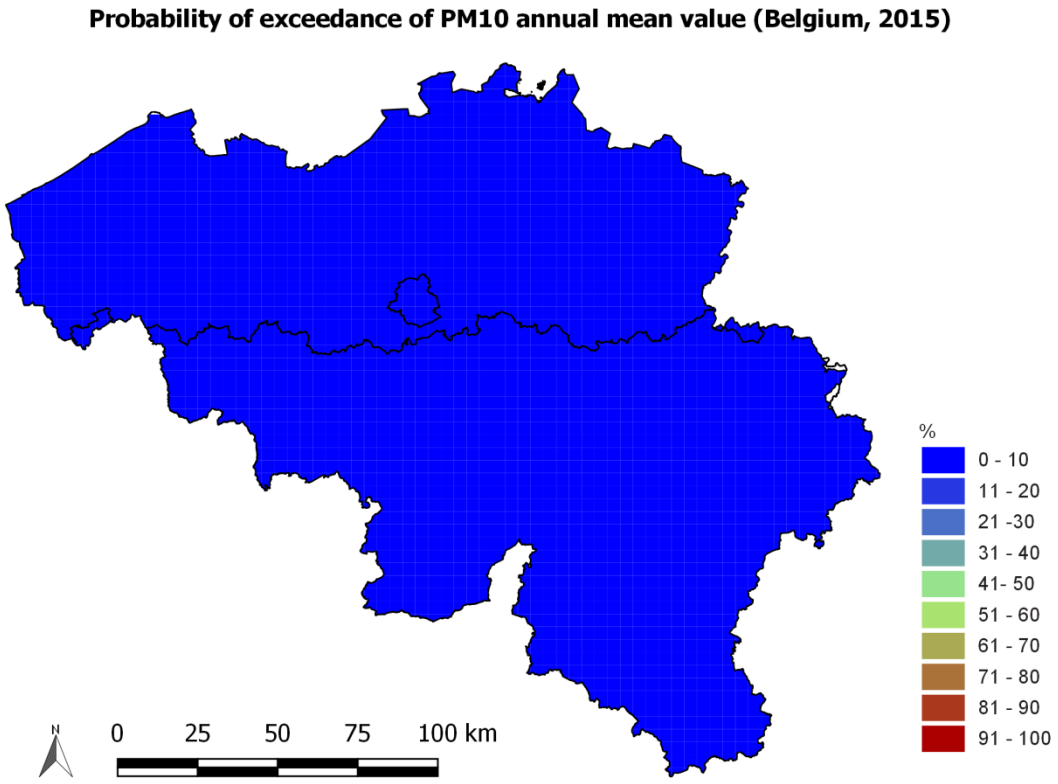
1. Autocorrelation due to the fact that overall less information will be available, e.g. because the concentrations of today are dependent on those of yesterday.
2. Covariance between the various grid cells which at all times exhibit a fixed spatial pattern over time.

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.

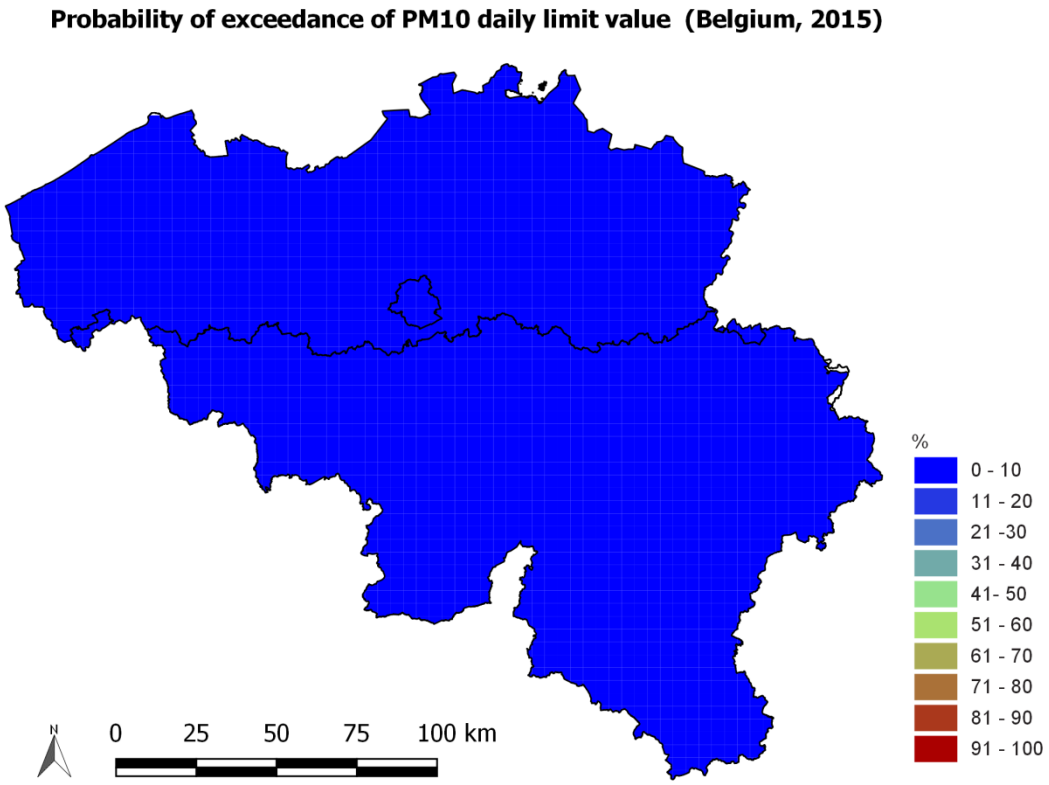
PM_{10}



Spatial distribution of the absolute error (µg/m³) on the annual mean PM_{10} concentration.

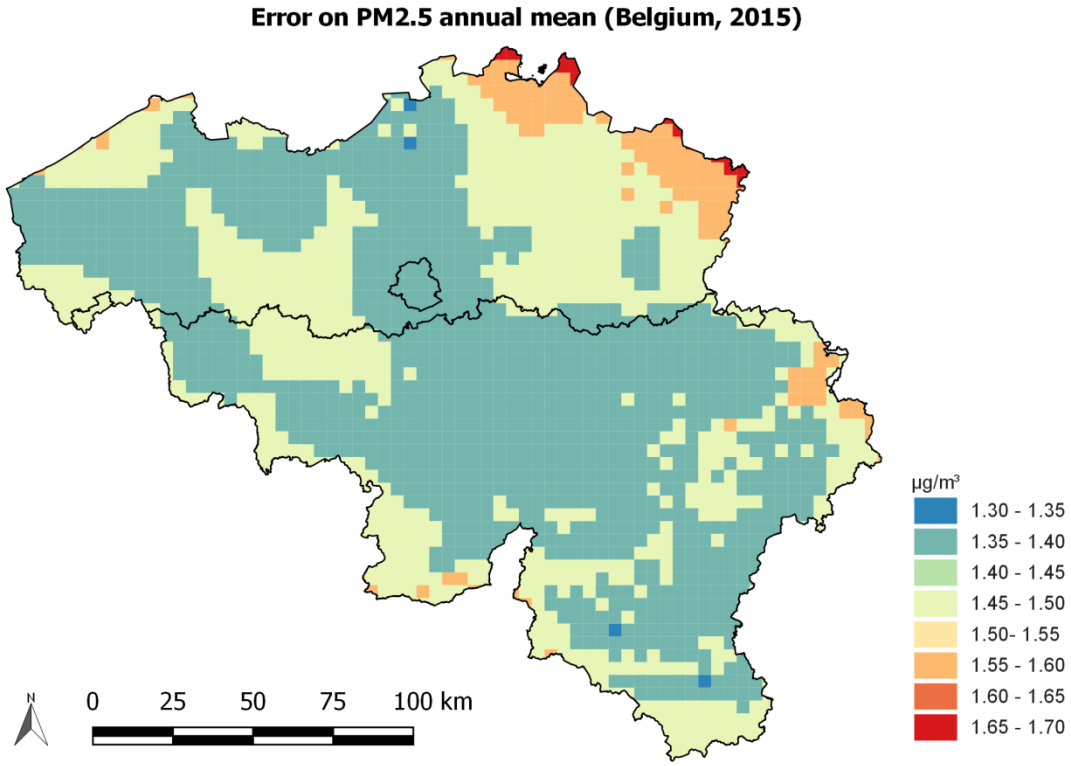


Probability (%) that the annual mean PM_{10} concentration exceeds the European limit value of 40 µg/m³.



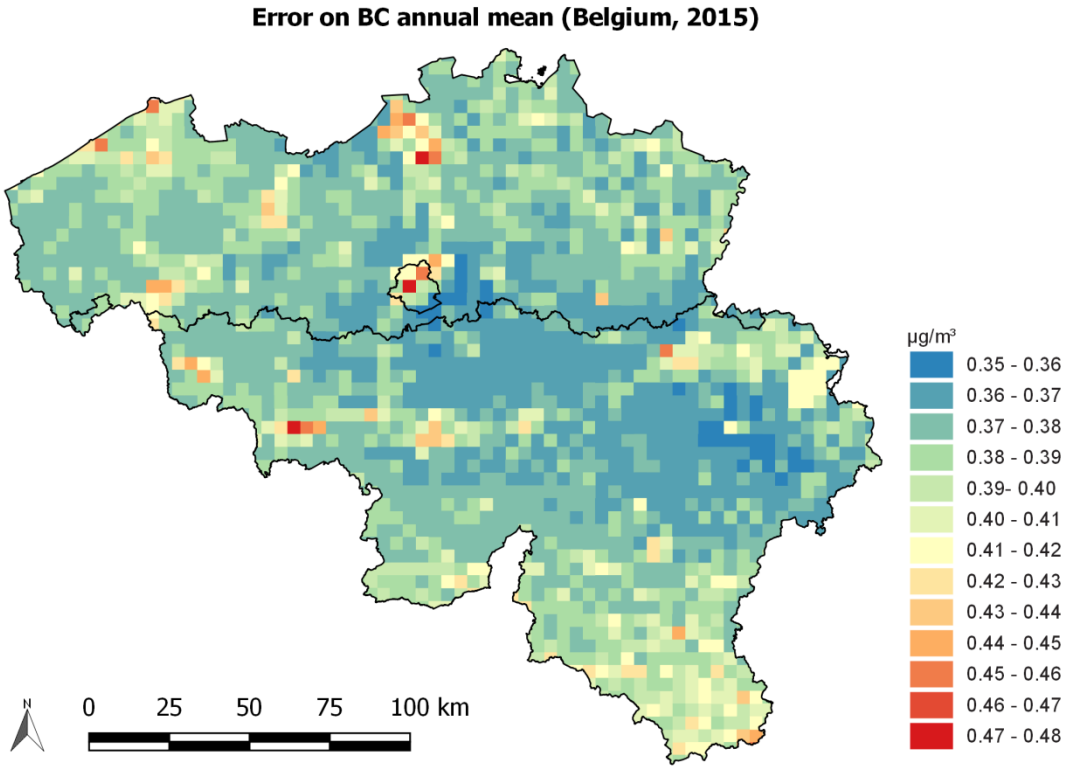
Probability (%) that the PM_{10} daily limit value of 50 µg/m³ is exceeded on more than 35 days.

$PM_{2,5}$



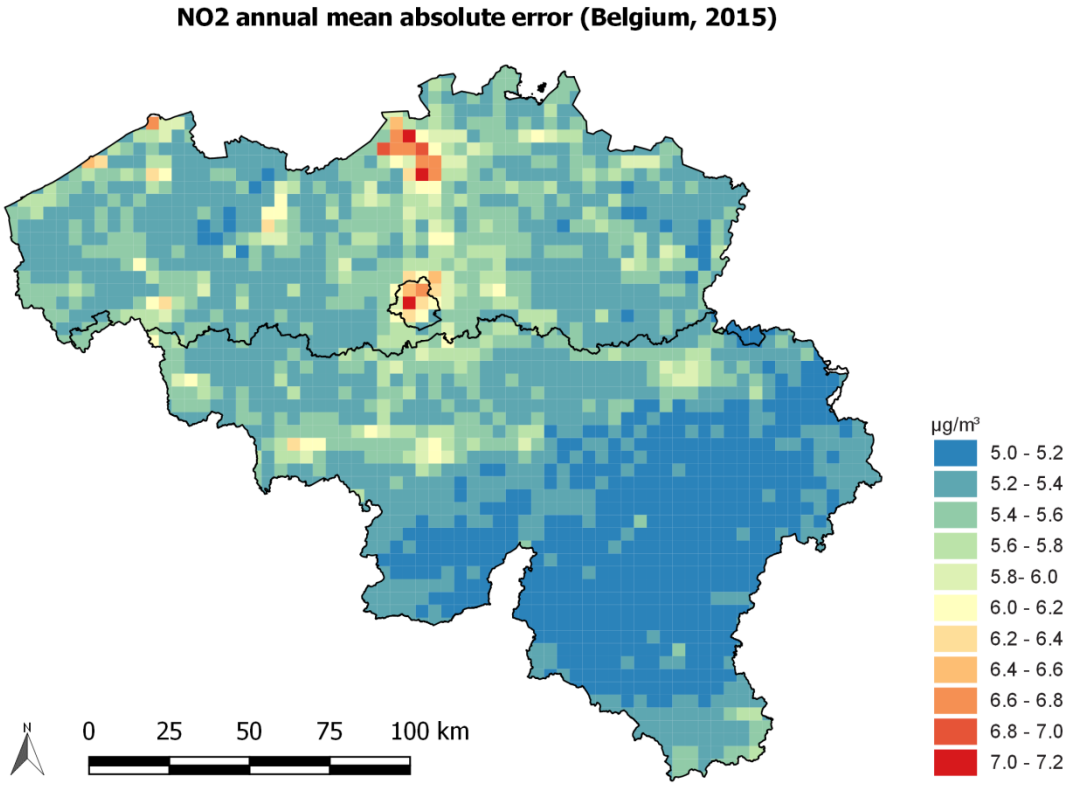
Spatial distribution of the absolute error (µg/m³) on the annual mean $PM_{2.5}$ concentration.

BC

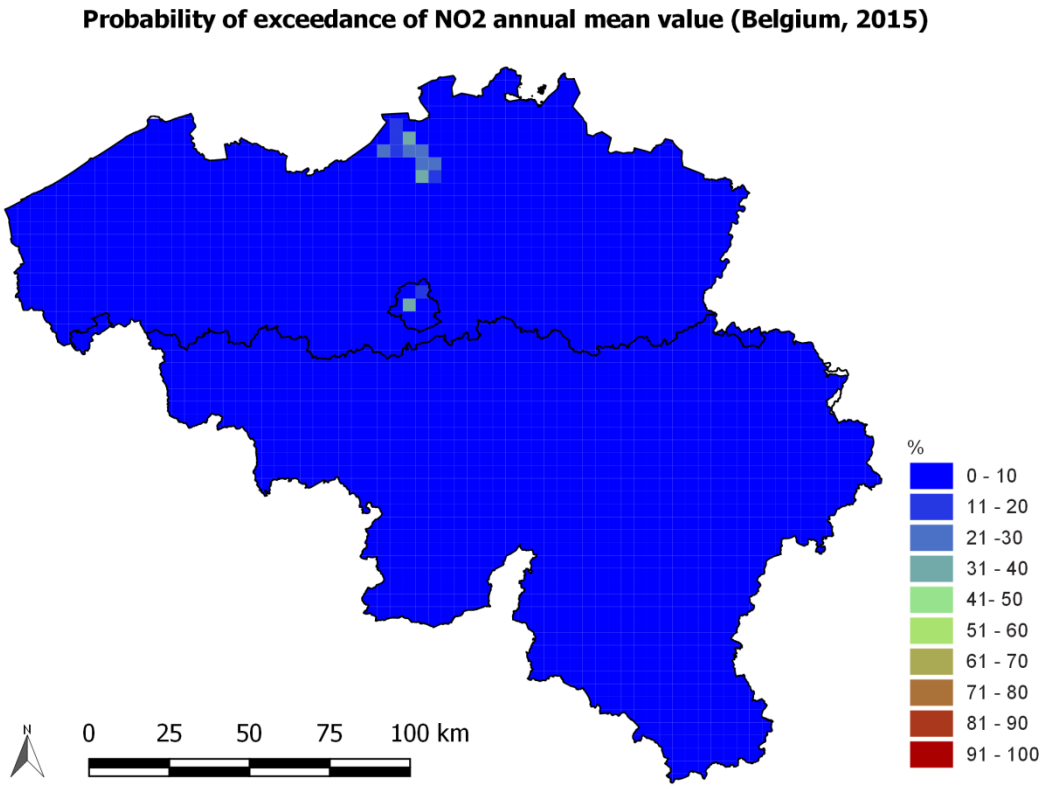


Spatial distribution of the absolute error (µg/m³) on the annual mean BC concentration.

NO_2

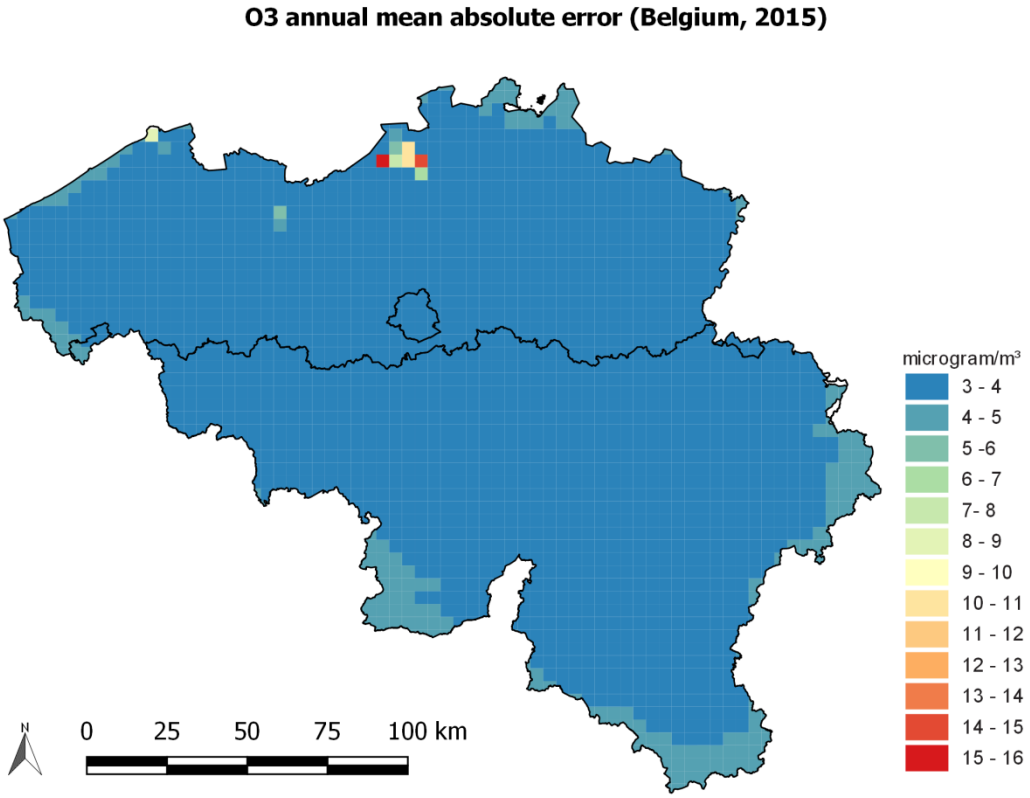


Spatial distribution of the absolute error (µg/m³) on the annual mean NO_2 concentration.



Probability (%) that the annual mean NO_2 concentration exceeds the European limit value of 40 µg/m³.

O_3



Spatial distribution of the absolute error (µg/m³) on the annual mean O_3 concentration.