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MAKING HIGH RESOLUTION AIR QUALITY MAPS FOR FLANDERS, BELGIUM

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Abstract: Using a combination of models, high resolution air quality maps for Flanders (Belgium) have been made. First of all, the Eulerian air quality model AURORA has simulated for a complete year the air pollutant concentrations over the region on a 3x3 km² grid resolution. These results are calibrated using the RIO-corine interpolation model that uses measured air quality data. Thereafter, an extra simulation using the bi-Gaussian IFDM model is made on a regular grid with a resolution of 1x1 km². A finer resolution (up to 25m) close to the major roads is used for an irregular grid that follows the traffic roads. The nesting methodology of IFDM in AURORA is designed to avoid double counting of the roads. The results are highly detailed PM_{10}, $PM_{2.5}$, NO_2 and EC maps for Flanders. Using monitoring data and data from several measurement campaigns, the maps have been validated and it has been shown that the maps can provide a highly detailed picture of the air quality in Flanders. The impact of policy scenarios on future air quality are also calculated. These data will be used for the assessment of air quality and the calculation of human exposure in Flanders.

Key words: air quality, modelling, high resolution, particulate matter, elementary carbon, NOx.

INTRODUCTION

The European Union requires its member states to protect the health of their citizens by obtaining good air quality and thus keeping air pollution under predefined limits. Therefore, monitoring of air quality is necessary. However, it is impossible to monitor the air quality at every single place in the country. This paper describes an effort in combining monitoring data with modelled data for Flanders, the northern part of Belgium, in order to obtain high resolution maps.

METHODOLOGY

An overview of the methodology can be found in Figure . 1.

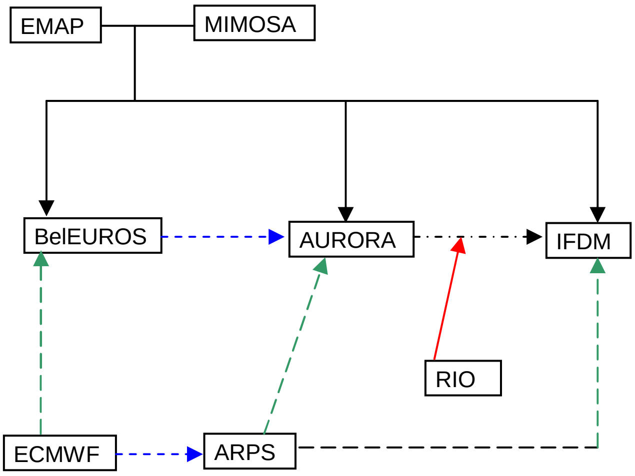

Figure 1: A schematic representation of the used methodology. A black solid line denotes input data. A blue short dashed line denotes nesting. A long dashed green line denotes meteorology input. A red solid line denotes calibration. A black dashed-dotted line denotes the procedure as described below.

Emissions (EMAP and MIMOSA)

For the road traffic emissions, MIMOSA4 has been used. MIMOSA4 is the most recent version of the MIMOSA traffic model (original version: Mensink *et al.*, 2000; current version: Vankerkom *et al.*, 2009), which generates hourly output for different types of emissions, such as NO_x, NO_2, EC, PM_{10} and $PM_{2.5}$ at individual road level for Flanders. Based on the modelled amounts of different types of vehicles for each road, MIMOSA calculates the corresponding emissions by splitting up the total amount of vehicles into different categories, depending on *e.g.* weight, EURO classes … This distribution is based on statistical data of the vehicle fleet in Flanders. In order to calculate these emissions, the COPERT-IV methodology (COPERT IV, 2007) has been used. Emissions due to cold start and loss by evaporation are also modelled. For particulate matter, not only exhaust emissions are simulated but also non-exhaust emissions, for instance due to braking. The speed on the roads is a generic speed. This means that no traffic jams are taken into account.

For Flanders, the non-traffic emissions are those based on the inventory made by the Flemish Environment Agency. For Brussels, Wallonia and the neighbouring countries, the EMAP tool is used. EMAP downscales country total emissions at an arbitrary resolution using proxy data such as population density, road networks, industrial activity, etc. More information on the use of the emissions in this study can be found in Maes *et al.* (2009).

Meteorology (ARPS)

Meteorological fields, required as input for AURORA and IFDM, were simulated using the Advanced Regional Prediction System (ARPS), a non-hydrostatic mesoscale atmospheric model developed by the University of Oklahoma (Xue *et al.*, 2000; 2001). The APRS model is nested into ECMWF data.

AURORA

The regional air quality model used in this study is AURORA (Air quality modeling in urban regions using an optimal resolution approach, Mensink *et al.* (2001)). In this model, the vertical diffusion is calculated with the Crank-Nicholson method (De Ridder and Mensink, 2002), while the horizontal diffusion uses a Walcek (2000) scheme. The gas phase chemistry is treated by the Carbon-Bond IV scheme (Gery *et al.*, 1989), which has been enhanced to take into account biogenic isoprene emissions. For particulate matter (PM_{10} and $PM_{2.5}$), a distinction has been made between primary and secondary particles. These secondary particles are simulated in a simple fashion using constant gas-to-particle conversion rates for both the transitions between SO_2 and sulphate aerosols and between HNO_3 and nitrate aerosols. More information on the AURORA model can be found in the European Model Database (http://air-climate.eionet.europa.eu/databases/MDS/index_html).

The AURORA model simulates, in three successive nesting steps, the air quality over the region of Flanders at a resolution of respectively 25x25 , 9x9 and 3x3 km². The boundary conditions for the outermost 25km resolution simulation are taken from the BelEUROS model which simulated the whole of Europe at a resolution of 60km (Deutsch *et al.*, 2009). More information on the BelEUROS model can be found in the European Model Database (http://air-climate.eionet.europa.eu/databases/MDS/index_html).

RIO

The available measurements are interpolated over Flanders with the RIO-Corine-tool (Janssen *et al.*, 2008). The fundamental principle of the RIO methodology is a de/re-trending mechanism. As a result of this mechanism, the interpolation technique accounts for the local character of every grid cell. Trend functions are establised showing the relation between the long term average concentrations and a parameter, called beta, which parameterises the land use around the stations. In the de-trending step, the measurements are made devoid of these local characteristics. This means that the measured concentrations that are used in the interpolation scheme are made homogeneous. The detrended measurements are than interpolated using an Ordinary Kriging technique. In the last step, known as the trending step, the local characteristics of each grid cell are again taken into account by using the same trend functions as discussed above. It has been shown (Janssen *et al.*, 2008), that the statistical validation for the RIO interpolation gives better results than when normal Kriging interpolation is used. This interpolation is done on a grid of 3x3 km².

Calibration

In the calibration step (red line in Figure 1), the 3x3 km² AURORA results are calibrated with the RIO-data, which are also available on a 3x3 km² grid. For pollutants where the AURORA-model results are close to the measured concentrations (NO_2, O_3, ...), a linear regression is applied between the model data and the RIO-data. This is done for every grid cell separately. For pollutants where the model bias is higher (PM), the model data for every grid cell and every hour are replaced by the RIO data and a correction factor is calculated. For the pollutants for which no or few measurements were available (EC), the modeled data were not calibrated. A regression function and correction factors are used to correct AURORA calculated scenario simulations (not reported here).

IFDM

In order to increase the spatial resolution of the AURORA-calibrated results in the direct vicinity to major roads, the bi-Gaussian IFDM model is applied at a regular resolution grid of 1x1 km² and at a road following an irregular grid with a maximum resolution of 25 meters.

IFDM is a bi-Gaussian air quality model, designed to simulate non-reactive pollutant dispersion on a local scale. The dispersion parameters are dependent on the stability of the atmosphere and the wind speed following the Bultynck and Malet formulation (Bultynck and Malet, 1972). Line sources are treated as in Venkatram and Horst (2006), except for the cases where the wind is parallel or almost parallel to the road. In the latter case, numerical integration of a series of point sources is applied. The meteorology input for the model is the same as for the AURORA model, i.e., hourly meteorological fields simulated by ARPS. More information on the IFDM model can be found in the European Model Database (http://air-climate.eionet.europa.eu/databases/MDS/index_html).

AURORA-IFDM coupling

AURORA and IFDM have been coupled by using a simple algorithm to avoid double counting of the traffic emissions (see also Lefebvre *et al.*, 2010):

1. First of all, the AURORA simulations on a 3x3 km² grid are calculated using all emission sources. The results of these simulations are calibrated using RIO-data.
2. Secondly, IFDM simulates on a regular 1x1 km² grid the air pollution due to the traffic sources in which we are interested (in this case, traffic emissions on the major roads).

3. Thirdly, the concentration in each AURORA-cell is adapted cell by cell, hour by hour, by subtracting the spatial mean of all the IFDM receptor point concentrations in this cell. This results in the AURORA-concentrations without the effect of the traffic sources in which we are interested.
4. Finally, using an irregular road following grid, IFDM simulates the traffic induced air pollution (of the major roads, same sources as in the second step). These values are added to the values calculated in step 3. As a result, a detailed hourly concentration field is created.

It can be easily understood that the procedure described above will indeed avoid double counting for pollutants that are known to be passive, such as primary PM and EC. In IFDM, only the primary PM is taken into account by IFDM. The effect on the secondary particulate matter concentrations is calculated by the AURORA model. The scheme however can also be applied for chemically reactive pollutants such as NO_2 and ozone. To treat this, the IFDM-model uses a very simple chemistry module. All calculations within the dispersion model are made for NO_x. Thereafter, the following equation is solved (Palmgren *et al.*, 1996; Berkowicz *et al.*, 1997):

$$NO + O_3 \leftrightarrow NO_2 + O_2 \qquad (1).$$

As the concentration of oxygen in the air is considered constant, one can derive an equilibrium constant E:

$$E = \frac{[NO_2]}{[NO][O_3]} \qquad (2),$$

which is dependent of the amount of UV-radiation and the ambient temperature. This E is calculated in IFDM. As no RIO interpolation results are available, the NO-concentration is calculated using the calibrated O_3 and NO_2 concentrations based on equation (2). In IFDM, the complete NO_x-chemistry is simulated using NO_x-concentrations. At the end of the simulations (thus after the correction for the double-counting), the basic chemistry as discussed above is used to split the NO_x-concentrations in NO_2 and NO-concentrations.

RESULTS

Figures 2 and 3 show some examples of maps obtained in this study. It can be seen that the local EC-concentration gradient is high around the major roads, while for the number of exceedances of the PM_{10} daily mean limit value, this gradient is small. The observed west-east gradient in PM_{10} exceedance days is also clearly visible in the results.

These results can also be used to get a more detailed image of the population exposure to air pollution in Flanders. An example of such an exposure graph can be found in Figure 4. This can only be obtained if detailed information on the population density is known. Thanks to the Flemish Environmental Agency, this data was made available for this study. We can see in Figure 3 that almost 35% of the population in Flanders is exposed to daily mean PM_{10} concentrations higher than 50 µg/m³ on more than 35 days . Removing the primary traffic emissions reduces this percentage of the Flemish population slightly to around 30%.

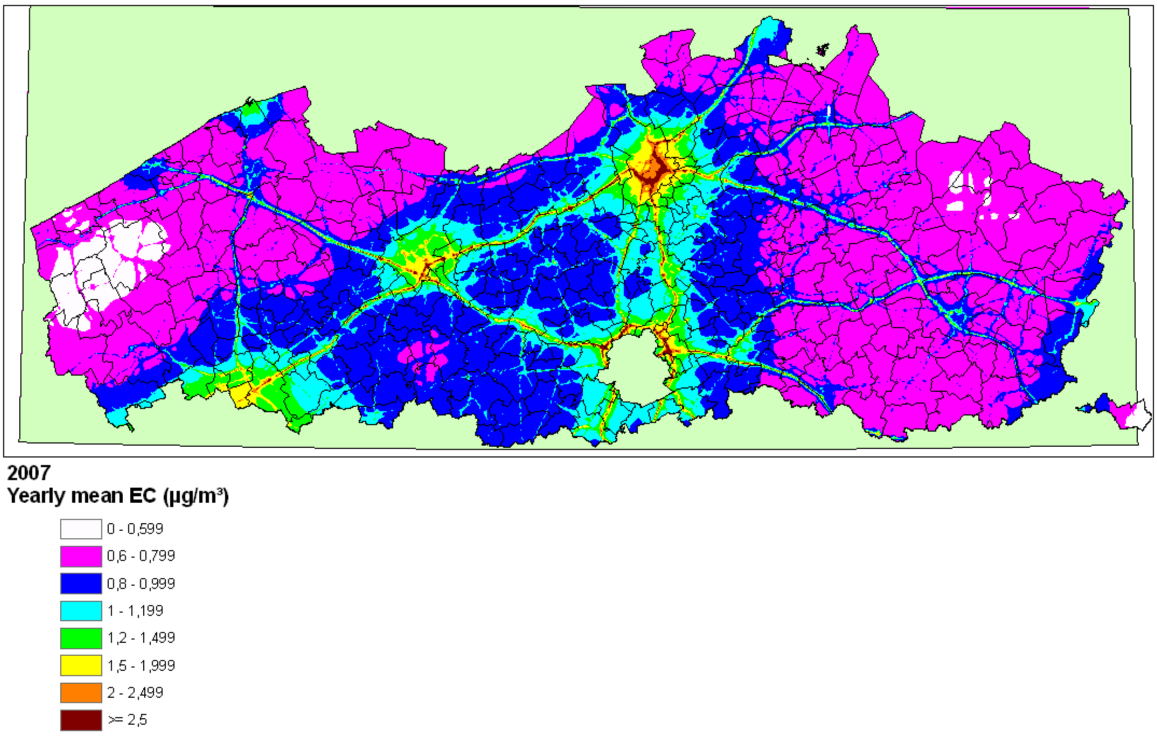

Figure 2: Yearly mean simulated EC-concentration (in µg/m³) for the year 2007.

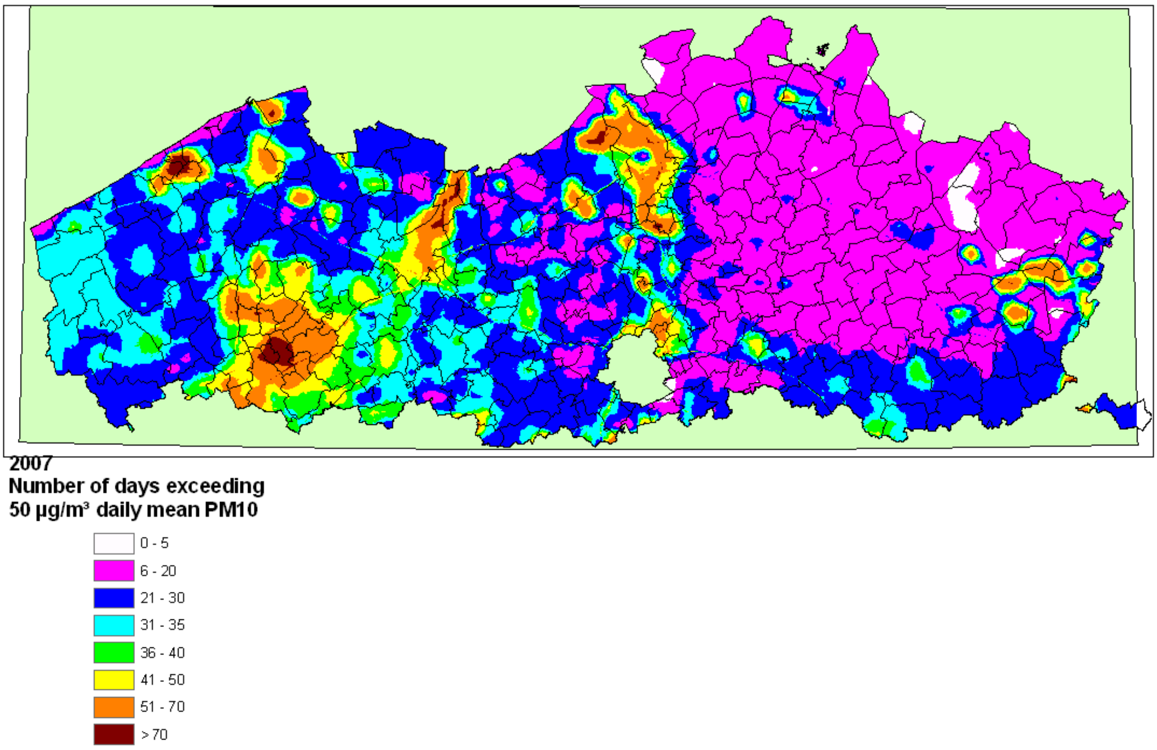

Figure 3: Number of days in the year 2007 for which the daily average PM-concentration exceeds the European limit of $50\ \mu g/m^3$.

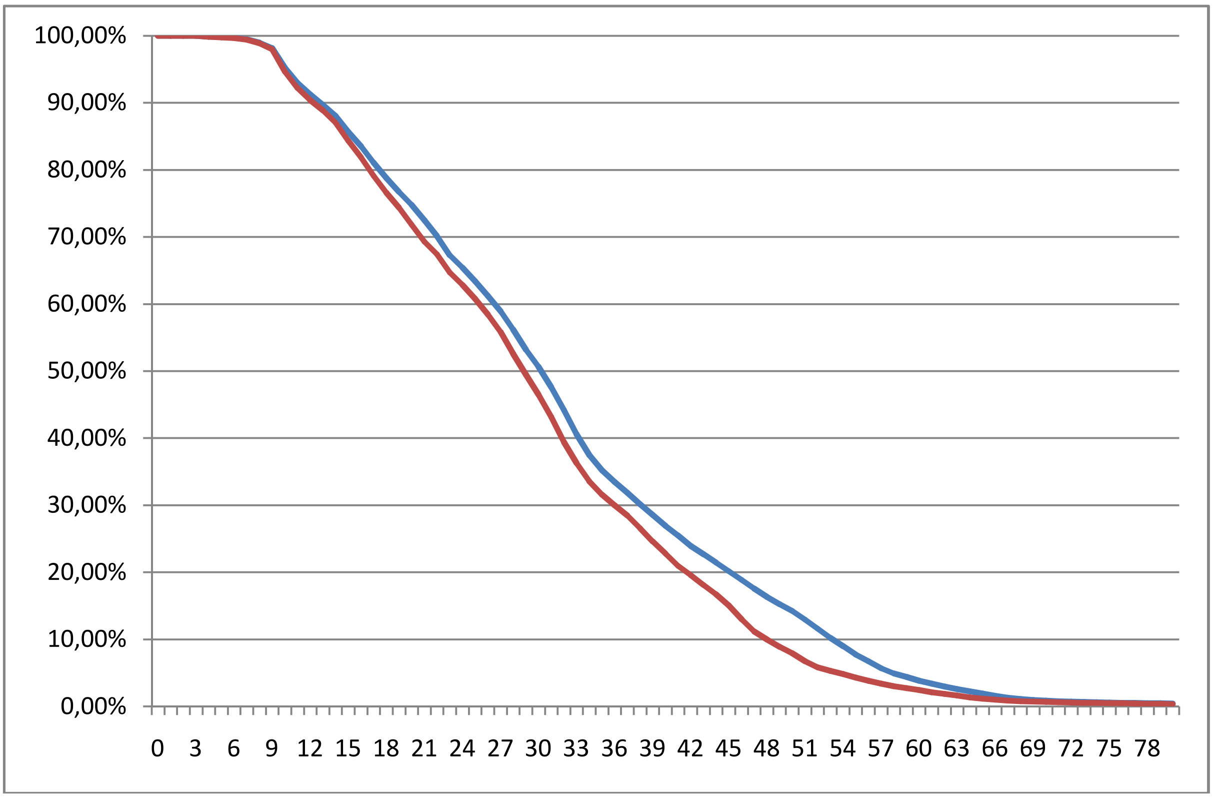

Figure 4: Exposure to the number of exceedance days for PM_{10} for the year 2007. On the X-axis: the number of exceedances of the PM_{10} daily limit of $50\mu g/m^3$. In blue: % of the Flemish population exposed to at least x days of exceedances of the PM_{10} daily limit. In red: % of the population exposed to at least x days of exceedances of the PM_{10} daily limit without taking into account the primary PM emissions of the roads.

CONCLUSIONS

By using both model results and measurement data, it is possible to get a much more precise spatial view of the air quality in a certain region. This was done here for Flemish region, but the methodology can be extended to other regions, when all necessary data is available. This information can help local governments to assess air quality on a higher spatial resolution.

With the methodology the impact of regional action plans that reduce emissions can be estimated together with the attainability of the current and future European air quality standards.

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