A coupled experimental-modelling approach to estimate black carbon concentrations at urban level

by Lenartz F. [1*], Brasseur O. [2], Declerck P. [2] and Bertrand L. [1]

[1] Institut Scientifique de Service Public, Rue du Chéra 200, 4000 Liège

[2] Brussels Environment, Gulledelle 100, 1200 Brussels

Context

Black carbon (BC) is a component of particulate matter (PM) generated by incomplete combustion of fossil fuels, biofuels, and biomass [1] (see Figure 1). In urban environments, the two main sources of this atmospheric pollutant are domestic heating and traffic (see Figure 2). It is not sure yet whether health effects due to PM or BC exposure are different, however black carbon is thought to operate as a universal carrier of a wide variety of chemical constituents of varying toxicity [2]. As it is, BC is an inert pollutant and therefore an excellent candidate for modelling experiments.

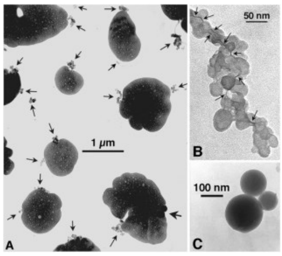

Figure 1 - Transmission electron microscopy (TEM) images of aerosol particles, including black carbon from Posfai et al. (1999). Drawn from EGU blogs (http://blogs.egu.eu/network/hazeblog/2013/08/16/sweeping-soot-out-of-the-atmosphere/).

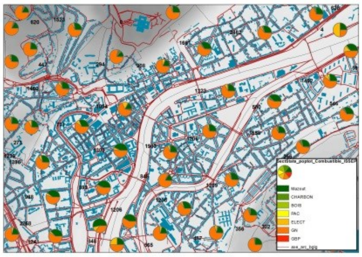

Figure 2 – Number of houses and distribution of the main domestic heating types in each *statistical sector* of Liège. The different heating-fuels or systems are fuel oil, coal, wood, heat pump, electricity, natural gas, butane or propane. In blue is represented the built-up area of the city. ; in red, the road network.

Its measurement relies on filter-based optical techniques. In Belgium, aethalometers from Magee Scientific or multi-angle absorption photometers from Thermo Scientific are used at the fixed stations of the three regional monitoring networks. For the assessment of personal exposure, the portable devices from AethLabs are commonly used throughout the country (see Figure 3). When synchronized with a GPS track recorder - we use GlobalSat DG200's in this study (see Figure 4) - and after appropriate data treatment, the latter allow one to pinpoint hot spots.

Figure 3 – AE51 portable aethalometers working at 880 nm. Dimensions: 117 mm x 66 mm x 38 mm. Weight: 280 g.

Figure 4 – DG200 GPS. Dimensions: 70 mm x 40 mm x 9 mm. Weight: 36 g.

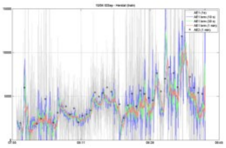

Figure 5 – Comparison of raw and moving-averaged signals with various widths of time window.

Objectives

The ExTraCar (*Exposition, trafic et carbone noir*) project aims at mapping and assessing, at a high spatial resolution (of about 10 m), BC concentrations in the city of Liège, by using data analysis and modelling.

Material and method

An intensive measurement campaign, started in April 2014 and is going to end in December 2015. BC concentrations and GPS positions are recorded simultaneously, at a 1 Hz frequency, along six pre-defined tracks all around the city (see Figure 6). Repetitions are performed to avoid a particular event to weigh too much in the derived statistics, during morning and evening rush hours, and different dispersion conditions (see Table 1). Further off-hours measurements are made to evaluate off-peak concentrations during several "10-h of measurements" days. All these assessments provide us with a snapshot of pollution levels in Liège and are compared with the ones made at two nearby fixed stations, in the inner city, and at northeastern boundary of Liège. All information is stored in a georeferenced PostgreSQL/PostGIS data base, which allows one to easily retrieve pollution levels in a specific area where we ride our bikes (see Figure 7).

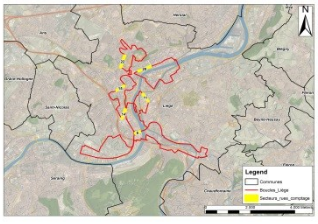

Figure 6 – In red, the six urban rides covering contrasted situations; in yellow, the six sections for which $CANS_{BC}$ is run encompassing a variety of H/W ratios and street orientations..

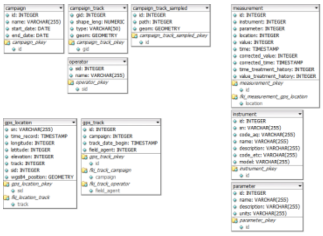

Figure 7 – Structure of the data base. Each rectangle corresponds to a table and each line to a field of this table; primary keys are recalled in the lower part of each frame.

	Morning rush hour						Evening rush hour						Intermediate hours					
Stability classes	**Stable [G-E]**		**Neutral [D]**		**Unstable [C-A]**		**Stable [G-E]**		**Neutral [D]**		**Unstable [C-A]**		**Stable [G-E]**		**Neutral [D]**		**Unstable [C-A]**	
Status	Goal	Now	Goal	Nowl	Goal	Now	Goal	Now	Goal	Now	Goal	Now	Goal	Now	Goal	Now	Goal	Now
Chênée	10	8	10	0	10	0	10	4	10	10	10	0	/	0	/	4	/	0
Bressoux	10	9	10	11	10	0	10	7	10	26	10	0	/	0	/	13	/	0
Citadelle	10	10	10	3	10	0	10	4	10	11	10	0	/	0	/	1	/	0
Louvrex	10	18	10	11	10	0	10	3	10	34	10	0	/	0	/	16	/	0
Médiacité	10	13	10	3	10	0	10	4	10	36	10	0	/	0	/	11	/	0
Sclessin	10	11	10	3	10	0	10	4	10	15	10	0	/	0	/	1	/	0

Table 1 – Number of repetitions made in each stability situation (as reported on April 3rd, 2015). The latter is determined via the vertical gradient of temperature, computed at the air quality station of Saint-Nicolas, as a proxy to the Pasquill-Gifford classes.

A street canyon model, namely $CANS_{BC}$, based on OSPM's equations (Operational Street Pollution Model) and implemented at Brussels Environment [3], is used to evaluate BC concentrations in the transverse direction of a limited number of streets. This semi-empirical model computes two main terms: the direct contribution of traffic emissions and the recirculation of the pollutant due to the vortex generated within the canyon (see Figure 8). Its input arguments are wind direction and velocity above building height (see Figure 9), geometrical characteristics of the street canyon, vehicle counts and emission rates (see Figure 10).

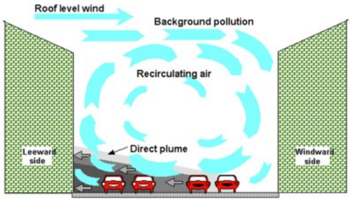

Figure 8 – Schematic illustration of flow and dispersion conditions in street canyons. Drawn from Berkowicz et al [4].

Figure 9 – Automatic anemometer and weather vane at the meteorological mast.

Figure 10 – Radar for automatic traffic count. Distinction is made between short and long vehicles.

Traffic related emission factors are usually expressed in terms of PM_{10} or $PM_{2.5}$, the conversion for BC is done by using the 0.6611 factor reported by Lefebvre et al. 2011 [5]. The aggregated factor will be computed using EMEP-EEA emission inventory guidebook but first simulations are performed by using the value by HBEFA for France on one hand (0.017 g of PM2.5/km), and for Germany on the other hand (0.006 g of PM2.5/km). Finally, in order to compare the results with on-field measurements (see Figure 12), one needs to take into account the background concentrations. These are taken from the Herstal station, lcoated in the suburb of Liège. However, for wintertime situations we try and evaluate them via the Lagrangian model Austal2000 [6].

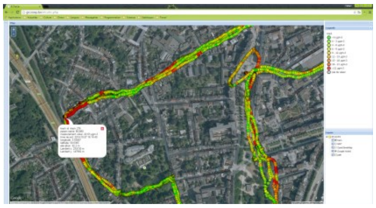

Figure 12 – Web interface used to visualize the georeferenced measurements.

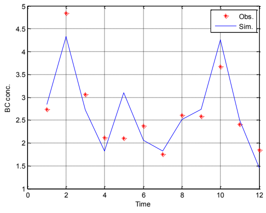

Figure 13 – Monthly averages for a one-year simulation.

Results

At this very early stage of the work, we only ran a limited number of test cases. Nevertheless, so far the model seems to perform pretty well both in terms of monthly averages (see Figure 13) and diurnal evolutions. From these first simulations, one can already see that (obviously) the model displays an important sensitivity to traffic counts and emission rates.

References

[1] United States Environmental Protection Agency (2012) Report to Congress on Black Carbon. http://www.epa.gov/blackcarbon/2012report/fullreport.pdf. Accessed 16 Mar 2015.

[2] World Health Organization Regional Office for Europe (2012) Health effects of Black Carbon. http://www.epa.gov/blackcarbon/2012report/fullreport.pdf. Accessed 16 Mar 2015.

[3] Brasseur O et al (2015) Modelling Black Carbon concentrations in two busy street canyons in Brussels using CANSBC. Atmos. Environ. doI:10.1016/j.atmosenv.2014.10.049.

[4] Berkowicz R et al (2008), Evaluation and application of OSPM for traffic pollution assessment for a large number of street locations. Environ. Model. Softw. doi:10.1016/j.envsoft.2007.04.007

[5] Lefebvre et al (2011), Validation of the MIMOSA-AURORA-IFDM model chain for policy support: modelling concentration of elemental carbon in Flanders. Atmos. Environ. doi:10.1016/j.atmosenv.2011.08.033

[6] German Federal Environmental Agency (2014) Austal2000 – Program Documentation of Version 2.6. http://www.austal2000.de. Accessed 16 Mar 2015.