AIR POLLUTION EXPORT FROM A CITY TO ITS NEIGHBOURING AREAS

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INTRODUCTION

The urban atmosphere is subjected to large inputs of anthropogenic contaminants arising from both stationary and mobile sources. Urban air pollution poses a significant threat to human health. Air pollutant emissions within cities deteriorate local urban air quality. Cities interact with their surroundings by exporting and importing pollution. The pollution transported through the city borders can be considered as a component of the background pollution at each neighbouring area. The objective of this study is to develop and to implement a methodology to estimate the transport of air pollutants emitted in an urban area, across city borders towards neighbouring areas. The application of the proposed methodology to the carbon monoxide (CO) emitted in the city of Buenos Aires is presented. Furthermore, the impact of CO emitted in Buenos Aires city on its neighbouring areas is estimated. Ground-level air concentrations of CO in different districts of the Greater Buenos Aires produced by the emissions from sources located in the city are calculated. The urban atmospheric dispersion model DAUMOD is used in the computations of air pollutant concentrations.

METHODOLOGY TO ESTIMATE TRANSPORT OF POLLUTANTS FROM A CITY TO ITS SURROUNDINGS

The air pollutant mass transported through the border of a city towards the zone "k" (a neighbouring district) per unit of time (F_k), can be estimated by the following expression:

$$F_k = \sum_{j=1}^{M_k} \left(\Delta l \int_{z_0}^{h} C(x,z)\; u_n(z)\, dz \right)_j \qquad (1)$$

where the boundary between the city and the zone "k" is formed by M_k grid cells, C(x,z) is the vertical profile of air pollutant concentration at each grid cell "j" which bounds the zone "k", $u_n(z)$ is the vertical profile of the component of wind speed perpendicular to the city boundary at grid cell "j", Δl is the horizontal extension of the city border at grid cell "j" and h is the vertical extension of the plume of contaminants.

The component (u_n) of wind speed perpendicular to the city border at each grid cell, can be obtained from the wind speed (u) and the direction (θ) of the airflow vector measured from the North. Being (ω) the direction perpendicular to the city boundary plane, measured from the North, it results $u_n(z)=u(z)\cos(\theta-\omega)$. The transport of mass of air pollutant from the city towards its surroundings occurs when $\cos(\theta-\omega)>0$. It is considered that $u(z)=(u_*/k_v)[\ln(z/z_0)+\psi(z/L)]$ (*Arya*, 1999), for $z=z_1$ (with z_1=100m) and u(z)=u(100m)=constant for $z>z_1$ (u_* is the friction velocity, k_v is von Karman´s constant, z_0 is the surface roughness length, L is the Monin-Obukhov´s length and $\Psi(z/L)$ functions determine stability correction due to stratification).

Furthermore, the DAUMOD urban atmospheric dispersion model can be used to estimate C(x,z) due to area source emissions. This model has been described elsewhere (*Mazzeo and Venegas*, 1991; *Venegas and Mazzeo*, 2002, 2006). The form of C(x,z) used in DAUMOD model (*Mazzeo and Venegas*, 1991) is given by

$$C(x,z) = C(x,0) \sum_{a=0}^{6} A_a \left(\frac{z}{h}\right)^{a} \qquad (2)$$

with

$$C(x,0) = \frac{a\left[Q_0\, x^{b} + \sum_{i=1}^{N} (Q_i - Q_{i-1})(x - x_i)^{b}\right]}{\left(\left|A_1\right| k_v\, z_0^{b}\, u_*\right)} \qquad (3)$$

and the height h is obtained from following expression

$$\frac{h}{z_0} = a\left(\frac{x}{z_0}\right)^{b} \qquad (4)$$

where each grid square has a uniform source strength Q_i (i = 0, 1, 2, …, N), the x-axis in the direction of the mean wind, the z-axis vertical, A_a (a=0,…6), a and b are functions of (z_0/L) (*Venegas and Mazzeo*, 2006).

Substituting equation (2) and $u_h(z)$ in equation (1), the following expression for F_k can be obtained integrating analytically:

$$F_k = \frac{u_*}{k_v} \sum_{j=1}^{M_k} \left(C(x,0)\, \cos(q - w)\, h\, \Delta l \sum_{a=0}^{6} \frac{A_a\, I_a}{a+1} \right)_j \qquad (5)$$

where I_a is a function given by

$$I_a = \begin{cases} \ln\left(\frac{h}{z_0}\right) + \frac{a}{a+1}\left[1 - V_0^{a+1}\right] + f_a & h \le z_1 \\ \ln\left(\frac{z_1}{z_0}\right) + \frac{a}{a+1}\left[V_1^{a+1} - V_0^{a+1}\right] + g_{1a} + g_{2a} & h > z_1 \end{cases}$$

with

$$f_a = \begin{cases} V_0^{a+1} - 1 + 6.9\frac{h}{L}\left(\frac{a+1}{a+2}\right)\left[1 - V_0^{a+2}\right] & \frac{z_0}{L} \ge 0 \\ \frac{(a+1)}{h^{a+1}} \sum_{n=0}^{a} \frac{a!\,h^{n}}{n!} \frac{(1 - g\,h)^{\frac{5}{4}+a-n}}{g^{1+a-n}} \left[1 - V_0^{n}\left(\frac{1 - g\,z_0}{1 - g\,h}\right)^{\frac{5}{4}+a-n}\right] \left[\prod_{m=0}^{a-n}\left(\frac{5}{4} + a - n - m\right)\right]^{-1} & \frac{z_0}{L} < 0 \end{cases}$$

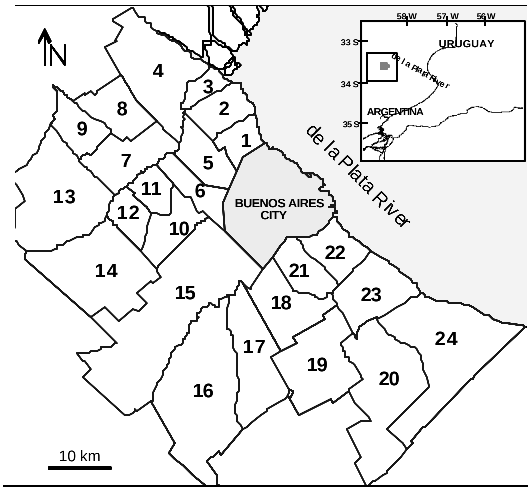
$$g_{1a} = \begin{cases} 6.9\frac{h}{L}\left(\frac{a+1}{a+2}\right)\left[V_1^{a+2} - V_0^{a+2}\right] & \frac{z_0}{L} \ge 0 \\ \left[1 - (1 - g\,z_1)^{\frac{1}{4}}\right]\left[1 - V_1^{a+1}\right] & \frac{z_0}{L} < 0 \end{cases}$$

$$g_{2a} = \begin{cases} V_0^{a+1} - V_1^{a+1} + 6.9\frac{z_1}{L}\left[1 - V_1^{a+1}\right] & \frac{z_0}{L} \ge 0 \\ \frac{(a+1)}{h^{a+1}} \sum_{n=0}^{a} \frac{a!\,z_1^{n}}{n!} \frac{(1 - g\,z_1)^{\frac{5}{4}+a-n}}{g^{1+a-n}} \left[1 - \left(\frac{z_0}{z_1}\right)^{n}\left(\frac{1 - g\,z_0}{1 - g\,z_1}\right)^{\frac{5}{4}+a-n}\right] \left[\prod_{m=0}^{a-n}\left(\frac{5}{4} + a - n - m\right)\right]^{-1} & \frac{z_0}{L} < 0 \end{cases}$$

γ=22/L, ζ_0=z_0/h and ζ_1=z_1/h. In each grid square, C(x,0) and h are estimated from equations (3) and (4).

APPLICATION TO BUENOS AIRES

Buenos Aires city is located on the west coast of the de la Plata River. It has an extension of 203km^2 and 2776138 inhabitants. The city (see Figure 1) is surrounded by the Greater Buenos Aires (24 districts) of 3627km^2 and 8684437 inhabitants. Both, the city of Buenos Aires and the Greater Buenos Aires form the Metropolitan Area of Buenos Aires (MABA). The MABA is located on a flat terrain with height differences less than 30m. The de la Plata River is 320km length, and its width varies from 38km to 230km in the upper and lower regions, respectively.



Districts of the Greater Buenos Aires:

1: Vicente López;	2: San Isidro;
3: San Fernando;	4: Tigre;
5: San Martín;	6: Tres de Febrero;
7: San Miguel;	8: Malvinas Argentinas;
9: José C. Paz,	10: Morón;
11: Hurlingham;	12: Ituzaingó;
13: Moreno;	14: Merlo;
15: La Matanza;	16: Ezeiza;
17: Esteban Echeverría;	18: Lomas de Zamora;
19: Almirante Brown;	20: Florencio Varela;
21: Lanús;	22: Avellaneda;
23: Quilmes;	24: Berazategui.

Fig. 1; Map of the Metropolitan Area of Buenos Aires, including Buenos Aires City and the Greater Buenos Aires.

In the city of Buenos Aires, there are three Thermal Power Plants situated in the coastal region and some small industries. Also, more than two million vehicles circulate daily on the streets of the city. *Mazzeo and Venegas* (2003) developed a first version of CO emission inventory for Buenos Aires city. This inventory includes the following sources: residential, commercial, small industries, aircrafts landing/take-off at the domestic airport, road traffic and Power Plants. Since the Power Plants burn natural gas most of the year and fuel oil as much as twenty days in wintertime, they are responsible for less than 0.04% of total CO annual emission in the city. For this reason, only the CO emitted from area sources are considered in this study.

TRANSPORT OF CO FROM BUENOS AIRES CITY TO ITS SURROUNDINGS

The amount of CO emitted from area sources located in Buenos Aires city that is transported towards the different neighbouring districts and the de la Plata River, is estimated considering a spatial resolution on 1x1km and using the method described above (equation (5)). One year of hourly meteorological information obtained at the domestic airport of Buenos Aires city and hourly data of the CO emission inventory have been used as input data. The mass of CO emitted within the city that is annually exported to its neighbouring districts and the de la Plata River is shown in Figure 2. The maximum annual transport of CO (77736 ton towards the de la Plata River) is 4.2

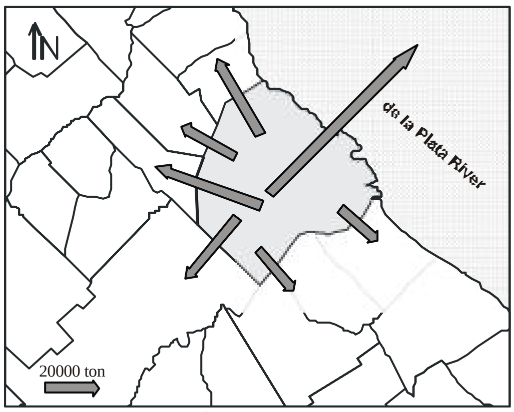


Fig. 2; Mass of CO generated in the city of Buenos Aires and annually transported towards neighbouring zones.

times the minimum (18274 ton, towards Avellaneda). Some factors very much condition the outflow of CO across the city border. For example, the extension of the boundary between the city and de la Plata River is about 2 to 4 times larger than the extension of other borders. Also, the annual number of times with "effective flux" towards the river is between 1.2 and 1.5 times the number of situations with "effective" transport towards the neighbouring districts. Furthermore, estimated annual mean concentrations of CO at the border of the city with de la Plata River is 1.20 mg m^{-3} and at Avellaneda is 0.75 mg m^{-3}, mainly determined by the spatial distribution of CO emission within the city. On the other hand, the mean "effective wind" (responsible for outflow flux and considered as an indicator of the transport of CO) towards de la Plata River is approximately 3.7 times lower than the observed towards the West (San Martín) and 1.3 times lower than towards South (Lomas de Zamora-Lanús and Avellaneda).

Impact of CO emitted in Buenos Aires city on the air quality in the Greater Buenos Aires

In order to calculate ground-level CO concentrations in the Greater Buenos Aires, due to CO emitted from area sources located in the city of Buenos Aires, the urban atmospheric dispersion model DAUMOD has been applied to one year of hourly meteorological and emission information. The Air Quality Standard (AQS) for CO in the Greater Buenos Aires is 10mg m^{-3} (8-hour mean). Spatial distributions of 8-hour CO concentrations (C_{8h}) are estimated. The isopleths of annual number of C_{8h} > 1mg m^{-3} (10% of the AQS) are plotted in Figure 3. It can be seen that C_{8h}>1mg m^{-3} is more frequent in the districts located NW to W from the city (Vicente López, San Martín and Tres de Febrero), with an occurrence of more than 200 cases/year. This result agrees with the high frequency of wind direction from the E-SE sector. The fraction (%) of the district area where C_{8h}>1mg m^{-3} a certain number of cases (>200, >50, >10 cases/year) is shown in Figure 4.

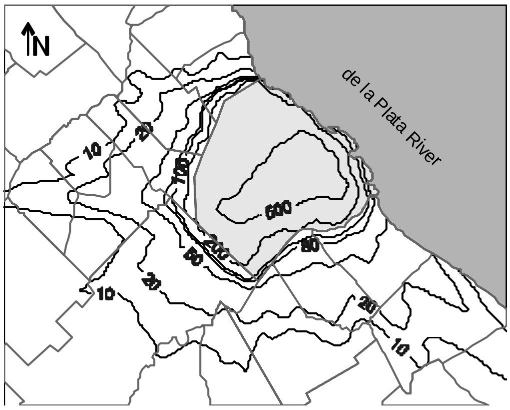


Fig. 3; Isopleths of absolute annual frequency of 8-hour CO concentrations > 1mg m^{-3}.

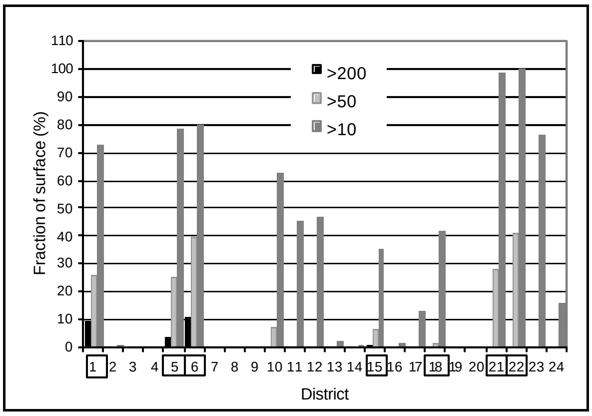


Fig. 4; Fraction (%) of district area where C_{8h}>1mg m^{-3} during > 200, > 50 and > 10 cases/year (number of district is shown in Fig. 1). Marked districts border the city of Buenos Aires

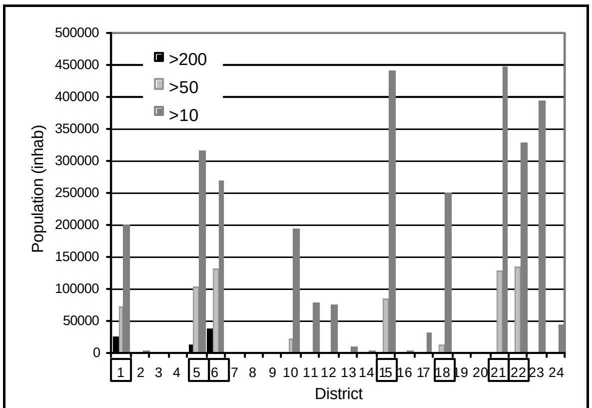


Fig. 5; Population exposed to C_{8h}>1mg m^{-3} during >200, >50 and >10 cases/year in each district of the Greater Buenos Aires (number of district is shown in Fig. 1). Marked districts border the city of Buenos Aires

The number of inhabitants exposed to C_{8h}>1mg m^{-3} (due to emissions in the city of Buenos Aires) in each district of the Greater Buenos Aires can be seen in Figure 5. Greater exposures (more than 200 cases/year) are obtained for the districts of **6:**Tres de Febrero (5.1 km^2 – 37300 inhab.), **1:**Vicente López (3.7 km^2 – 25800 inhab.) and **5:**San Martín (1.8 km^2 – 13300 inhab.). On the other hand, all districts in the Greater Buenos Aires (with the exception of **19:**Almirante Brown, **20:**Florencio Varela, **9:**José C. Paz, **8:**Malvinas Argentinas, **3:**San Fernando, **7:**San Miguel and **4:**Tigre) show more than 10 cases/year with C_{8h}>1 mg m^{-3} (Figure 3). The highest value (15 mg m^{-3}) 8-hour CO ground-level concentration is obtained in Buenos Aires city downtown. Furthermore, estimated results show that ground-level 8-hour CO concentration may exceed 10 mg m^{-3} (Air Quality Standard for the city of Buenos Aires) at least once a year, in 31 km^2 of the city (approximately 15% of its extension).

CONCLUSIONS

This work presents a methodology to estimate the transport of air pollutants emitted in an urban area, across city borders towards neighbouring areas. This methodology includes analytical expressions developed considering the expressions of air pollutant concentration and wind speed profiles included in DAUMOD urban atmospheric dispersion model. As an application of this method, the transport of CO across the borders of the city of Buenos Aires is evaluated. Most of the CO emitted in the city of Buenos Aires is transported towards the de la Plata River (77736ton/year) on the East side of the city, and the smallest amount (18274ton/year) is exported to the South of the city (district of Avellaneda). Relative importance of main factors (wind direction, wind speed, length of the border between the city and each neighbouring district, air pollutant concentration at the border, annual number of hours with effective flux across the border) conditioning the outflow flux of CO through the city boundary is discussed. Ground-level CO concentrations in the Greater Buenos Aires, due to CO emitted form area sources located in the city of Buenos Aires using the DAUMOD model are estimated. These results show that the major impact of the emissions in the city affect the districts located North-to-West of the city (Vicente López, San Martín and Tres de Febrero). The largest 8-hour CO concentration value (15 mg m^{-3}) is found in Buenos Aires city downtown.

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