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Emission patterns of urban air pollution

Patrones de emisión de la contaminación urbana

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Abstract

The estimation of air quality and greenhouse emissions at urban centres is based on detailed source inventories, pollution and meteorological monitoring data and an adequate modelling capability. These inventories are normally assembled either in a top-down or bottom-up approach, depending on the available information and the desired spatial and temporal resolution. In this paper we first present the inventories calculated under both methods, for the city of Mendoza, Argentina. The emission estimations are spatially distributed using a geographical information system leading to an urban emission pattern or grid. This emission grid is used to compute the air pollutant concentrations, which are calculated using two dispersion algorithms: ISC3P and CALPUF. Finally the results are compared with data from monitoring stations.

---------- *Key words:* urban air quality, atmospheric dispersion, greenhouse emissions, area sources, geographical information system.

Resumen

El cálculo de las emisiones urbanas de contaminantes aéreos y gases de efecto invernadero se realizan sobre la base de un buen inventario de fuentes, datos de meteorología y monitoreo de contaminantes que se aplican luego sobre modelos de dispersión adecuados. La preparación de estos inventarios puede realizarse desde dos puntos de vista, uno general, de arriba a abajo, y el otro más detallado, de abajo hacia arriba, dependiendo de la disponibilidad de información y las resoluciones espacio-temporales deseadas. En este trabajo se presentan los inventarios para la ciudad de Mendoza calculados de ambas maneras. Las estimaciones de las emisiones se distribuyen espacialmente usando un sistema de información geográfico generando

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un patrón o grilla de emisiones urbanas. Esta grilla de emisiones se usa luego para calcular las concentraciones ambientales usando dos modelos de dispersión, el ISC3P y el CALPUFF. Finalmente los resultados se compararon con los datos de las estaciones de monitoreo.

---------- *Palabras clave:* calidad del aire urbano, dispersión atmosférica, emisiones de gases de efecto invernadero, fuentes de área, sistemas de información geográfico.

Introduction

Two complementary approaches are generally proposed to estimate the emissions from urban areas: the top-down approach and the bottom-up approach. The selection of one of these methods will depend on the availability of input data and the desired spatial and temporal resolution.

The emissions from fixed sources, (i. e., residential, industrial, commercial, etc.) are normally calculated using a top-down approach, assuming a relative low temporal or seasonal variability based on ambient temperatures, school activity, holiday's distributions, and so on.

The inventory computes yearly energy consumption, using population density, economic activity and emission factors. Additionally to the emissions from fuel combustion, it is necessary to collect the industrial emissions from the production process, together with their proper engineer information, i.e. stack height, diameter, exit fluxes and emission rates, which will feed the input data requirements of a dispersion model calculation.

The estimation of mobile sources' emissions is more difficult, due to their inherent high variability. In a top-down approach, the total annual emission from mobile sources is calculated using the number of road (active) vehicles actually running for a given region. At any time and street, the vehicle flux is estimated through indirect information such as population density, structure of the automotive park (vehicle fleet distribution according to power, size, fuel, and typical vehicle use), fuel consumption, number of cars per inhabitants, average speed, annual mean traveled distance, and annual emission factors based on fuel consumption or annual traveled kilometers. This information has acceptable spatial distribution, but a poor temporal resolution, usually an annual base.

To estimate the emissions from road vehicles in a bottom-up approach, it is necessary to record traffic fluxes and speed in several streets. The bottom-up method has high temporal resolution (normally an hourly base) with variable spatial resolution. It is clear, then, that this approach is more accurate but requires high data density. The emissions in each street are calculated using emission factors based on average traveled distances for each vehicle category. This latter approach is usually selected in urban areas where this information is available, normally using a Geographical Information System (GIS) environment [1]. One important advantage in using GIS is its Web-based application, which allows any user, department or agency, to access common geographical data.

The main objective of this study is to develop an evaluation and planning tool compatible with existing databases and systems, which would help to estimate the present air quality. Consequently, the paper is organized in the following way: after the above brief introduction, the second section presents the main socio-economics and meteorological aspects of the area under study, while the third section shows the methodology used to prepare a gridded emission map. The fourth section describes the calculated air quality at the urban scale, using two dispersion models: ISC3P and CALPUFF. The results will be compared with available monitoring data. Finally the fifth section concludes.

Description of the area under study

The Province of Mendoza, located west of the national territory by the Andes Mountain Range, is one of 23 provinces making up the Argentine Republic. Its most distinctive feature is that most of its territory —about 250000 km^2— is arid or semiarid, with the exception of the man-made oases. Almost 70% of Mendoza's population is located in the Northern Oasis (33° S, 68° W, 750 m. a. N. s. l.) —the largest of them— with around 900000 inhabitants, a population concentration ranking fourth amongst the Argentine cities with an urban extension of approximate 370 square km and an average urban population density of 2800 hab/km^2. Table 1 summarizes the main socio-demographic aspects. The Province of Mendoza participates around 4.5% of the national GDP while the metropolitan area reaches the 2.5%. The main primary economic activity of Mendoza is the agriculture followed by the energy production. The agriculture is concentrated in oases, which occupy 3.5% of the surface of the province, conditioned by water shortage. The fine wine production sector has been one of the most dynamic sectors. The oil and energy sector has undergone a deep transformation from the privatization of YPF (former State-controlled oil company), and the purchase of this one by Repsol, representing almost 50% of the Provincial exports. The Commerce and services sector has been a very dynamic one undergoing the greatest transformations in 1990-2000 decade. Banks, telephone companies, insurance agencies, big shopping centers, have pressured the sector to a new dynamic, but with different results. After the financial crisis and with new exchanges rates, the tourism sector has become a very dynamic sector as well, with new investments [2].

Table 1 Key socio-demographic indicators

Indicator	***Years***	***1970***	***1980***	***1990***	***2000***
Demographic aspects	***Units***				
Population Nation	Inhab.	23,364,000	27,949,480	32,615,528	36,260,130
Urban Population in city Mendoza	Inhab.	456,794	618,702	778,972	902,539
Population growth, city	%/Ann.		3.5%	2.6%	1.6%
Economic aspects					
GDP Nation constant 1990	Mill. U$S	122,811	158,046	141,346	213,758
GDP of the city	Mill. U$S	2,564	3,471	3,181	4,870
GDP per capita of the city	U$S	5,614	5,610	4,084	5,396
Income distribution (city level)	U$S	468	467	340	458
Urban aspects					
Urban density in the city	Inhab./K m^2	1,893	2,252	2,577	2,768
Urbanized area	km^2	317	336	357	376
Rate of urbanization (decade)	km^2/ann		3	3.5	4.8

Source: [1, 12, 13].

The annual mean wind intensity is 2.6 m/s, with 19% of calm days, and annual rain falls of 220 mm, the predominant wind directions are: S-SW, 30%, E-SE, 24%, N-NE: 14%, W-NW, 8%. Due to Mendoza's closeness to the mountains, Zonda winds –similar to Föhn or Chinook winds, prevail in the higher layers most of the year. This is a warm and dry NW wind with speeds ranging 5-6 m/s, and gusting up to 12 m/s. Zonda winds and anticyclone situations in the winter months (May to October) with high probability of frost, contributes to a higher degree of pollution due to the occurrence of strong thermal inversion layers. The area presents low relative humidity (50%), low incidences of fog, and few days with covered skies (65-75 days/annum). The solar global radiation varies from 270 MJ/m^2 in winter to 780 MJ/m^2 in summer, with an annual mean daily heliophany of 7.9 hours.

The expanding urbanization increases the traffic congestion and air pollution, at the expense of green or agricultural spaces. The main industrial sources relevant to carbon or pollutant emissions are located in three areas: a) an oil refinery, a petrochemical industry and a power plant; situated SW of the city; b) two cement industries and other minor sources on the north edge; and finally c) the agro and food production mostly located on the east side. Pollution emitted from private and public vehicles is the main responsible for worsening the air quality in the downtown (central) area. Particulate and gaseous emissions of pollutants from industries and auto-exhaust are responsible for rising discomfort, increasing airway diseases, decreasing productivity and the deterioration of artistic and cultural patrimony in this urban center [1, 3].

Calculation of the emission patterns

Bottom up approach

The top down approach can be characterized as a sectoral analysis of the energetic consumption. There are five sectors emitting carbon and air pollutant to the atmosphere: the energy production and industrial sector, the agricultural sector, the service sector, the residential sector, and the transport sector. a) Energy and industrial sector. Two main activities stand up: on one side the oil refinery with production of gasoline and other fuels, which are not only consumed in the city but exported to the rest of Argentina and to some of the neighbor countries; on the other side the petrochemical industry, a ferroalloy industry, a power plant mainly fed by natural gas, and a cement production, b) Agricultural sector: Mendoza has an important agricultural activity focusing in wine and olive oil production, fruits and vegetables. All of these products feed the local, national and also international markets, c) Service: In this area we may include the business sector, the educational and institutional activities, d) Residential, e) Transport: Finally, a very important linking activity of the above ones is without doubt the transport of goods and passengers.

The inventory is computed using the yearly energy consumption, population density and economic activity. Additionally to the emissions from fuel combustion, it is necessary to collect the industrial emissions from the production process. The general equation for emission estimation [4] is:

$$E = A \times F \times (1 - R/100) \qquad (1)$$

Where *E* is the annual emission (i. e. kg of pollutants per year), *A* is the process activity rate or fuel consumption (i. e. metric tons of fuel per year –Tn/year), *F* is the emission factor (kg of pollutant per Tn of consumed fuel) and *R* is overall emission reduction efficiency (%) if present in the activity. *R* is also defined as the product of the control device destruction or removal efficiency and the capture efficiency of the control system.

An emission factor is a representative value that relates the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant per unit weight, volume, distance, or duration of the activity emitting the pollutant (e. g., kilograms of particulate emitted per Tn of fuel burned). Such factors facilitate the estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages (i. e. annual averages) for all facilities in the source category. Emission factors are generally developed to represent long-term average emissions, thus using emission factors to estimate short-term emissions may produce high uncertainties. Short-term emissions from a single specific source often vary significantly with time (i. e., within-source variability) because of fluctuations in process operating conditions, control device operating conditions, raw materials, ambient conditions, and other such factors.

Table 2 shows the energy consumption by fuel type and sector. Two sectors arise as main consumers: energy, which includes the energy production and transformation, and the transport sector. Agriculture energy consumption is mainly electricity or gas-oil (used mainly for pumping underground water and for freight transport). Manufacturing industries (such as the wine industry) are low energy consumption, with the exception of the Ferro-alloy and cement fabrication located in the periphery of the metropolitan area. The second emitter in Mendoza is the transport sector. In table 3 we show the statistics for public transportation in terms of amount of passengers and traveled distances during 1994-2000. At the bottom of table 3 it is computed the yearly incorporation of new cars of the private and public fleet, as well as the total vehicles circulating in the city. Complementing this information, table 4 shows two source-destiny surveys, performed in years 1986 and 1998. As it can be seen from both tables, there is a decrease in the use of public transportation, and consequently an important increase in the use of private cars, as well as the motorization rate. The daily trip demand using particular cars reaches 39% for year 1998, whereas in year 1986 it was only of 30%. The use of vehicle grew in significant form reaching more than 200,000 vehicles for the area of the Great Mendoza. Several important problems are associated to the use of particular vehicles: a) the high demand for space needed to circulate, and for parking in the central area; b) the high amount of accidents, and the associated death rate; c) the increase of pollution by gases and suspended particles. The use of cars as main transportation mean, on the other hand, has favored the preferences to live in residential districts away from the central business area, searching for a better quality of life. Another consequence is the installation of new big shopping malls and supermarkets also in the new residential areas, accentuating the urban sprawl.

Table 2 Net energy consumption in Tera Joules by sector

Year	*1980*		*1990*		*2000*	
Sector	*TJ*	*%*	*TJ*	*%*	*TJ*	*%*
Energy production	15133	34.2%	17540	36.2%	17385	34.0%
Residential	5022	11.4%	6970	14.4%	9676	18.9%
Rural	1293	2.9%	1198	2.5%	1307	2.6%
Industry	8812	19.9%	8320	17.2%	6051	11.8%
Transport	12978	29.3%	12838	26.5%	14143	27.7%
Service	982	2.2%	1569	3.2%	2527	4.9%
Total	44219	100.0%	48435	100.0%	51089	100.0%

Source: [1, 12, 13].

Table 3 Transportation key indicators

Public Transport	*Unit / year*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*
Total passengers	Mill. pass./ann.	167	156	151	150	149	147	139
Commuting distance	Mill. Km/ann.	82	79	80	80	80	78	77
Urban Passengers	Mill. pass/ann.	141	133	129	125	122	120	114
Distance per urban bus	Thous. km/bus-ann.	94	99	90	90	87	86	81
Suburban Passengers	mill. pass/ann.	26	24	22	25	27	27	25
Suburban trip	mill km/ann.	16	15	15	16	18	17	16
Distance per suburban bus	Thous. km/bus-ann.	101	96	95	90	85	87	88
Public Transport	Veh.	627	628	629	630	631	632	633
Freight	Thous. veh. / ann.	28	30	33	37	41	44	47
Private vehicles	Thous. Veh.	188	203	217	234	252	265	287

Source: [12].

Table 4 Daily trips in Mendoza Metropolitan Area for years 1986 and 1998.

Source destiny Survey	*Public / private transport city of Mendoza, daily trips*			
Description	1986	Relative to total trips	1998	Relative to total trips
Public Bus (diesel)	398,190	50.8%	493,600	36.3%
Trolley bus (elect)	16,230	2.1%	14,950	1.1%
Corporative Bus	5,360	0.7%	6,000	0.4%
School Bus	1,450	0.2%	13,400	1.0%
Taxi (diesel-GNC)	7,030	0.9%	18,000	1.3%
Private Car	200,000	25.5%	354,750	26.1%
Share private car ride	43,000	5.5%	210,000	15.4%
Motorcycle	2,560	0.3%	35,150	2.6%
Bicycle	37,490	4.8%	102,665	7.6%
Walk > 1km	72,170	9.2%	111,150	8.2%
Total daily trips	783,480	100.0%	1,359,665	100.0%

Source [12].

Table 5 Energy consumption of the transport sector for year 1999 (TJoules)

Year 1999	*Net energy consumption TJoules*					
	NCG	*GR*	*GE*	*GO*	*EE*	*Total*
Private (auto, taxi)	1,505	1,139	2,306	1,605	0	6,555
Public (bus, trolleybuses)	15	0	0	1,101	11	1126
Freight	699	679	108	4,840	0	6,325
Total	2,219	1,818	2,414	7,546	11	14,006

NCG: Natural Compressed Gas, GR: Car gasoline regular, GE: Car gasoline especial, GO: gas Oil, EE: Electricity.
Source [1, 12, 13].

Table 5 shows the structure of consumption by the transportation sector, in terms of Tera Joules. Both tables are presented for year 1999. Two main groups arise from these tables as mayor consumers: the private motorization (6500 TJ) and the freight sector (6300 TJ); comparatively the public transportation consumes only 1300 TJ.

From an energy consumption perspective, table 6 a passenger using private transportation consumes about 1 J per traveled kilometer, while using the public systems only consumes 0.2 J. Despite the uses of old diesel buses the per capita and per kilometer consumption of the public system is almost five times better. Given the present tendency of private car uses, and the location of new residential/ business area in the periphery of the metropolitan area, it is expected that the energy consumption will increase, but at a lower rate, especially due to the incorporation of new vehicle technology. The main automotive park in Mendoza does not have catalytic converter, thus the incorporation of such new technology will help partially to compensate the pollutant emissions increase by higher number of vehicles and daily trips. The use of natural compressed gas as an alternative fuel for vehicles, in general, decreases the emissions of CO, hydrocarbons and suspended particles, but increases the methane emissions.

Table 6 Main indicators of the energy use in the transport sector

Energy use		*1980*	*1990*	*2000*
Private passenger transport energy use per capita	MJ/cap	9,649	7,581	7,208
Public transport energy use per capita	MJ/cap	1,888	1,483	1,410
Energy use per private passenger KM	J/(km.pass)		2.4	0.9
Energy use per public passenger KM	J/(km.pass)		0.1	0.2

Source: [2].

Emission patterns

In this section we will describe the main emission pattern of the metropolitan area. After calculating the energy consumption, it is possible to calculate the approximated average emission of the metropolitan area by multiplying the energy consumption by the proper emission factors for each gas, using, for example, the emission factor proposed by the International Panel for Climate Change [5, 6]. Table 7 shows the proposed emission factor for each type of fuel, while table 7 shows the total annual emission estimation for the transportation sector in thousands of metric tons or Gigagrams (Gg). The energy production and transportation are the main emitters and their emissions have increased in time. A second group is formed by the industry and residential sector. While the energy production, industry and the residential sector are based mainly on natural gas, the transportation sector consumption is based on liquid fuels, and a small percentage on natural gas (especially for private cars). CO emissions table 8 generated by incomplete combustion process are closely related to CO_2 emissions, table 9. These are more evident in the transport sector and small industry. The bigger industrial processes and the energy production have a better control on the CO emissions. Nitrogen Oxide emissions table 10 are produced mainly during high temperature combustion processes, being the main emitters the industry, transport and energy production. Despite the increase in energy consumption, an improvement in the technological processes is producing a decline in the NOx emissions. Only transport is growing, but as we will analyze it from the air quality point of view, this is due to the increasing amount of vehicles and the aging of the automotive park. The top-down calculation gives an overall (annual) estimation of the total amount of emissions. This information is then distributed in rectangular cells on a geographical information system, according to the population density and the land use for each particular cell, (i.e. residential, commercial, educational, etc.). This implies a characterization of the relative consumption and emission of each cell with respect to the other neighbor cells. This was done by taking into consideration the land use, the population density and the approximate energy consumption of each cell, for example from information of service companies (natural gas, water, electricity, telephone; other), and particular surveys. This produces a gridded emission pattern for each pollutant and GHG. Figure 1 shows a map with the spatiol distribution of sheet hierarchies for the Metropolitan area or Mendoza.

Table 7 Used emission factors from energy consumption

Emission factors	*Tn/TJ*	*kg/TJ*	*kg/TJ*	*kg/TJ*
Fuel / Pollutant	CO_2	CO	NOx	CH_4
Natural Gas	53.67	723.00	198.00	320.00
Gasoline	69.30	7,330.00	390.00	57.00
Kerosene	73.46	296.50	170.00	5.20
Gas Oil	73.30	510.00	716.00	60.00
Diesel Oil	73.30	510.00	790.00	0.80
Fuel Oil	73.30	503.20	790.00	0.80

Source [5].

Table 8 Carbon monoxide emissions (Tn)

Sector	*1980*	*1990*	*2000*
Energy own	235	267	269
Residential	776	721	784
Rural	47	64	91
Industry	3,868	3,633	2,656
Transport	64,888	63,532	70,713
Service	15	24	39
Total	69,829	68,240	74,553

Source [2].

Table 9 CO_2 emission by sector (Thousands Tn. and %)

Year	*1980*		*1990*		*2000*	
Sector	*Th. Tn.*	*%*	*Th. Tn.*	*%*	*Th. Tn.*	*%*
Energy own	1,180	36.1%	1,342	38.3%	1,355	36.7%
Residential	299	9.1%	404	11.5%	576	15.6%
Rural	95	2.9%	88	2.5%	96	2.6%
Industry	668	20.4%	628	17.9%	459	12.4%
Transport	973	29.8%	953	27.2%	1,061	28.8%
Service	55	1.7%	86	2.4%	142	3.9%
Total	3,270	100.0%	3,500	100.0%	3,689	100.0%

Source [2].

Table 10 NOx emissions by sector (Tn)

	1980		*1990*		*2000*	
Sector	*Tn*	*%*	*Tn*	*%*	*Tn*	*%*
Energy own	3,117	14.4%	3,546	16.6%	3,581	18.8%
Residential	776	3.6%	721	3.4%	784	4.1%
Rural	246	1.1%	331	1.6%	473	2.5%
Industry	12,336	56.8%	11,585	54.3%	8,471	44.4%
Transport	5,191	23.9%	5,083	23.8%	5,657	29.6%
Service	48	0.2%	74	0.3%	124	0.6%
Total	21,714	100.0%	21,340	100.0%	19,090	100.0%

Source [2].

Figure 1 Street hierarchies for the Mendoza metropolitan area

Bottom up approach for mobile sources

Top down calculations are usually enough to estimate annual averages, but if more detailed information is required it is necessary to perform a bottom up approach. This is especially necessary for vehicular emissions, due to their high variances. To characterize the mobile emissions from a bottom-up approach it is necessary to gather traffic counting in main streets intersections and compute average driving speed. The vehicles at each street are grouped in different fuel, size and types categories. The emission factors are based on average emission per traveled distance (in g/km). The emissions of air pollutants from vehicular sources, for a given street, and for an (yearly) average period, are characterized by three main factors:

$$E = N \times F \times L \tag{2}$$

Where E (g/unit time) is the total emission in the time considered, N is the number of average circulating vehicles in the period, F is the pollutant specific average emission factor measured in g/km per vehicles, and L is the mean traveled distance in km. The total pollutant emission $E(k)$ for each pollutant k is calculated as:

$$E(k)=\sum_i L_i\times\left(\sum_m \frac{p_m}{100}F(m,k,v)\times N(m,i)\right) \tag{3}$$

Where, the emission factor $F(m,k,v)$ is expressed as the mass of pollutant per unit length as a function of the traveled speed v and the vehicular type m, and pollutant k; the traffic flow $N(m,i)$ is expressed for each segment street i and vehicular type m; $Pm/100$ is the vehicular proportion for each vehicular type (%). The emission factors for CO and HC, were taken from our own measurements [7] for NOx, CH_4 and PM_{10} we used data from the literature [4, 5].

In a GIS format, segments in the line type database represent a street; therefore the length of the segment is directly obtained. Additionally, each record also stores other relevant information such as street width, number of vehicles, speed, etc. The streets are characterized according to three hierarchies: a) primary, including main city access and inter county freeway, b) secondary or intra county roads, and c) tertiary or residential roads. The hierarchies had been selected according to their traffic intensity, hourly variation, and dominant use. One important source of uncertainty is given by the actual distribution of the number of vehicles N. A detailed discussion on the assignment of N and V in each street segment has been published before [7, 8]. Figure 2 displays the emission pattern for NOx and figure 3 that of CO. Once the N, V and E are assigned to each segment it is possible to produce an emission pattern of the mobile sources for different pollutants. To produce a gridded emission pattern, the calculated emission for each segment is added in pixels or grids of 350 × 350 m. The total emission of the city for each considered pollutant is computed by adding the emissions of all cells.

Calculation of the ambient concentration

Gaussian Dispersion

The ambient concentration at a particular cell located at coordinates (x,y,z) from a fixed point source is generally calculated using a bidimensional Gaussian plume moving in the wind direction x. At ground level ($z = 0$) the concentration $C(\text{g/m}^3)$ is [9, 10]:

$$C(x,y,0)=\frac{Q}{u}\frac{1}{\pi\sigma_y\sigma_z}exp(-\frac{H^2}{2\sigma_z^2})exp(-\frac{y^2}{2\sigma_y^2}) \tag{4}$$

Where Q (g/m.s) is the emission rate of the source, H(m) is the effective stack height, y is the distance transversal to the wind direction in the horizontal plane, z is the altitude above ground, and u(m/s) is the wind speed. The lateral and vertical dispersion coefficients $\sigma_x\,\sigma_y$ (m) depend on the stability class (and indirectly on the wind speed) and increase with increasing distance to the source x. The pollutant dispersion due to big industrial sources can be calculated using the standard point source procedures of the regulatory models [11]. The computed area sources should be then added as

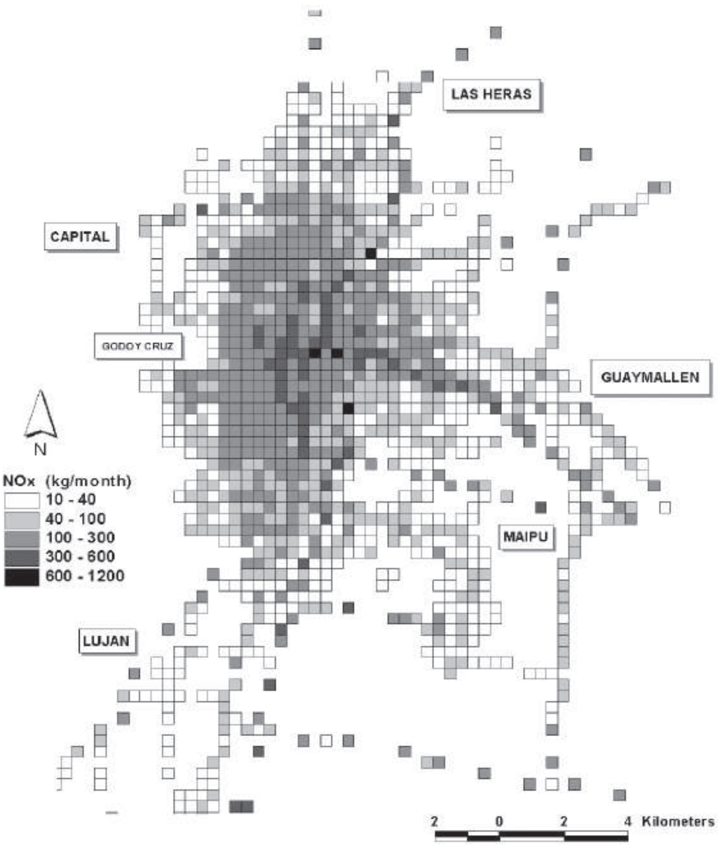

Figure 2 Emission pattern for NOx mobile sources in Mendoza

background concentrations to the fixed source calculations.

In this work, two different dispersion models are compared: EPA Industrial Source Complex (ISC3P) dispersion model and CALPUFF non-steady-state air quality modeling system. The ISC3P is a steady Gaussian-plume dispersion model, as presented above in equation (4).

Puff-dispersion algorithm

CALPUFF is a transport and dispersion model that advects "puffs" of material emitted from modeled sources, simulating dispersion and transformation processes along the way. Also contains algorithms for near-source effects, transitional plume rise, partial plume penetration as well as longer-range effects such as pollutant removal. Puff models represent a continuous plume as a number of discrete packets of pollutant material. The basic equation for the contribution of a puff at a receptor is:

$$C=\frac{Q}{2\pi\sigma_x\sigma_y}\,g\exp\left[\frac{-d_a^{2}}{2\sigma_x^{2}}\right]\exp\left[\frac{-d_c^{2}}{2\sigma_y^{2}}\right]$$
$$g=\frac{2}{(2\pi)^{1/2}\sigma_z}\sum_{n=-\infty}^{\infty}\exp\left[-(H_e+2nh)^2/\left(2\sigma_z^{2}\right)\right] \qquad (5)$$

Where C, is the ground- level (g/m3), Q is the pollutant mass (g) in the puff, σx, σy and σz are the standard deviations (m) of the Gaussian distribution along-wind direction, cross-wind direction and the vertical direction respectively; d_a and d_c are the distances (m) from the puff center

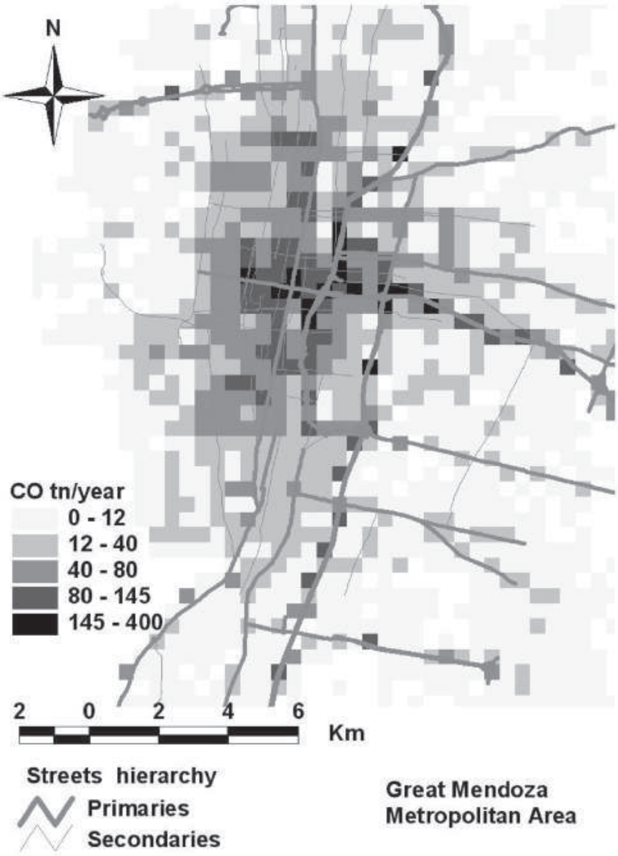

Figure 3 Gridded emission pattern for CO for the city of Mendoza

to the receptor in the along-wind direction and in the cross-wind direction; *g* is the vertical term (m) of the Gaussian equation, *H* is the effective height (m) above the ground of the puff center, and *h* is the mixed-layer height (m). The computational grid (defined equal to the meteorological grid) was defined from 32.8º S to 33.1º S and from 68.6º W to 69º W. The modeling domain chosen for this analysis covers an area of 42 km by 31.5 km over, including the entire Metropolitan Area of the Mendoza City. A resolution of 1.05 km in the horizontal is used to represent the variations of the terrain elevations in the area. We used the digital topography from the SRTM3 dataset compiled by the USGS (US Geographical Survey). Within each grid cell the data is averaged to produce a mean elevation at each grid point. The 1.05 km resolution produces a workable number of grid cells (40 x 30). Additionally the USGS land use data in the vicinity of the study area have been incorporated to produce a gridded field of the dominant land use categories.

For both models we used one-year surface hourly data at a single meteorological station. The emission estimates included point, area and line sources. The Industrial and Energy sector was characterized as constant emission point sources. Detailed point source emission data are specified in table 11. The GHG emissions from the transport sector were modeled using line sources with adequate location, spacing and orientation. Gridded emission data from buoyant areas sources modeled the residential, commercial and agricultural sector. The emissions rates were assumed to be constant over the entire period of the simulation.

Table 11 NOx emission point sources

Source Name	*X (UTM Easting-m)*	*Y (UTM Northing-m)*	*Z (m NSL)*	*NOx Emision rate (g/s)*	*Stack Height (m)*	*Exit temperature (ºC)*	*Exit velocity (m/s)*	*Stack diameter (m)*
Southern Region								
LDC11/12	501,780	6,342,508	1075	61.2	50.0	120	14.8	4.1
LDC 21/22	501,838	6,342,866	1075	74.3	19.8	195	7.5	5.3
LDC 23/24	501,937	6,342,796	1075	35.1	8.2	510	64.0	2.4
LDC 25/15	501,955	6,342,455	1075	68.2	50.0	100	12.1	7.0
CH1	502,302	6,341,341	1100	6.0	53.0	567	10.0	8.5
CH2A	502,302	6,341,341	1100	7.0	53.0	449	10.0	2.2
CH2B	502,302	6,341,341	1100	7.0	53.0	451	10.0	2.2
ANTORCHA 1	502,969	6,341,553	1100	15.0	80.0	630	2.0	0.4
ANTORCHA 2	503,118	6,341,321	1100	20.0	136.0	930	3.0	0.4
CH1 - CH2	500,816	6,342,349	1105	2.0	20.0	200	13.2	1.7
CH3 -CH4 -CH5	500,814	6,342,386	1105	2.0	20.0	200	7.1	0.8
D700A-B (x2)	501,346	6,340,764	1105	0.0	15.0	120	1.0	0.7
D720A	501,346	6,340,,784	1105	0.1	15.0	290	0.7	0.4
D720B	501,346	6,340,804	1105	0.0	12.0	290	0.9	0.4
ANTORCHA	501,366	6,340,830	1105	2.0	45.0	700	3.0	0.4
Northern Region								
Planta 5	515,151	6,377,812	800	45.0	90.0	122	4.5	4.8
Planta 3	519,098	6,376,266	800	30.0	50.0	550	4.5	4.6
Minetti	516,607	6,372,243	800	30.0	60.0	162	9.0	2.8
CuyoPlacas	519,300	6,365,966	800	0.2	21.0	102	14.0	1.5
RayenP1	525,740	6,358,509	800	3.0	25.0	177	9.4	1.3
RayenP2	525,780	6,358,679	800	11.0	40.0	277	7.8	2.3

Results

To compare the results of both models, we calculated the concentration of nitrogen oxides values only from the industrial point sources. Figure 4 shows the estimated concentrations at the receptors for ISC3P and figure 5 for CALPUFF. The results indicate an average difference for all receptors of 2.4 µg/m^3, giving ISC3P most of the time smaller values than CALPUFF. Maximum values, near the sources, are also higher in CALPUFF than in ISC3P. Figure 6 shows the frequency distribution of the differences between both models (above) a dispersion plot for the NOx concentration values (below). Despite the differences both methods capture closely the long-term average values, but differ in the extreme values.

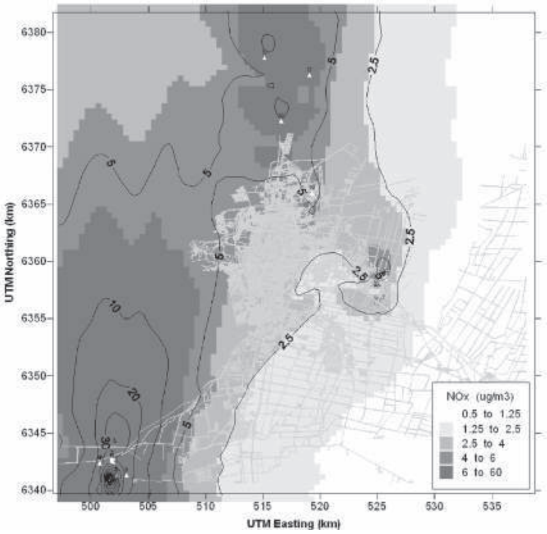

Figure 4 Average daily concentration of NO$_X$ calculated using ISC3P. White triangles represent the main industrial sources

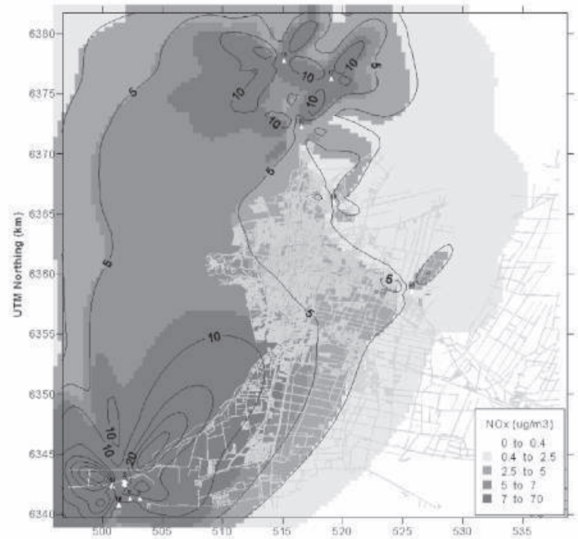

Figure 5 Average daily concentration of NO$_X$ calculated using CALPUFF. White triangles represent the main industrial sources

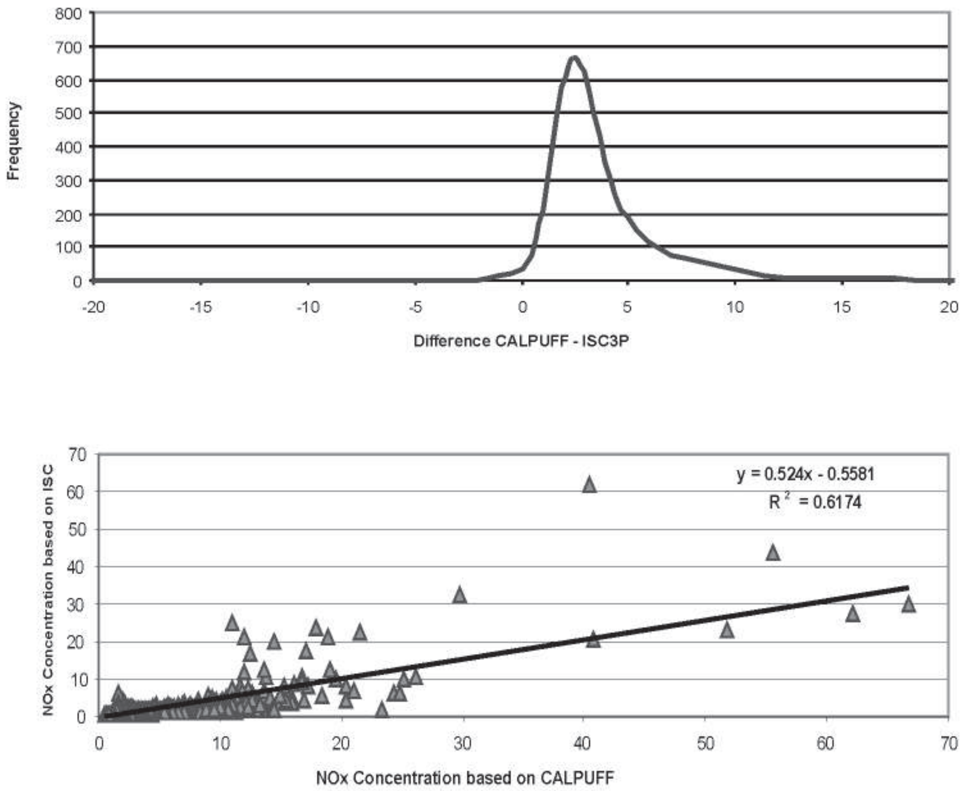

Figure 6 Comparison of the calculated NO_X concentration using ISC3P and CALPUFF. Above: Frequency distribution of the differences for all receptors. Below: Dispersion plot of the calculated concentrations

We compared the CALPUFF values with one monitoring station in downtown Mendoza. We chose this station since it presents the longer monitoring records. Figure 7 shows a time-series for NOx concentrations at this station. This downtown station is characterized mainly by the pollution generated by vehicular activity. As presented in the above sections, the inventories consider an annual mean value estimation of the vehicular activity, but it does not include the short random variation of the vehicles running at neighboring streets, therefore a direct comparison of hour to hour model versus data is not possible. However the model captures adequately the mean statistical information as shown by the frequency distribution of the calculated and measured NOx concentrations at the measuring station (figure 8). Finally, figure 9 shows the simulation results obtained with CALPUFF for hourly CO annual mean concentrations over de Metropolitan Area including all sources: point, area and line, according to the inventory presented in the first sections.

Conclusions

The estimation of urban air pollution and greenhouse-gases (GHG) emissions requires the elaboration of good source inventories. Two complementary calculations are generally proposed to estimate these emissions: the top-down and the bottom-up approach, whose application will depend on the desired temporal and geographical resolution of such inventories. In the first sections of this paper we presented a sectoral analysis of the main urban pollution and

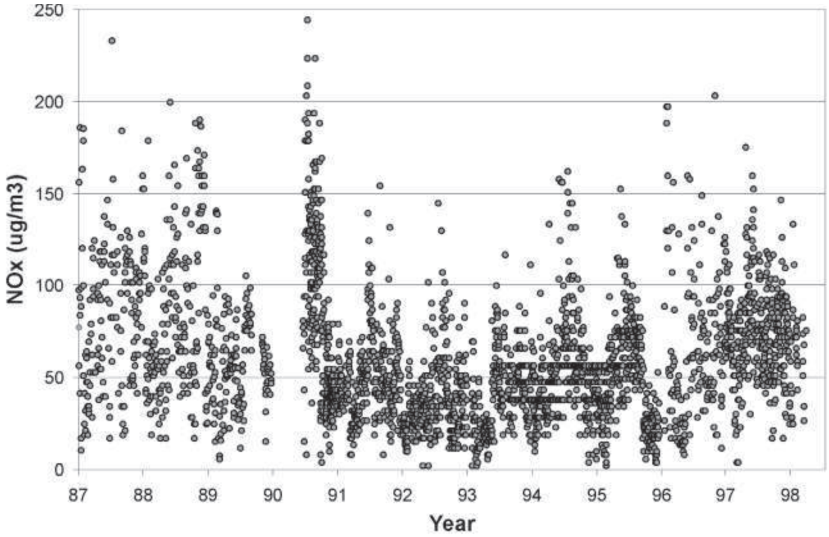

Figure 7 Daily concentration values for nitrogen oxides at a downtown street in Mendoza, 1987-1998

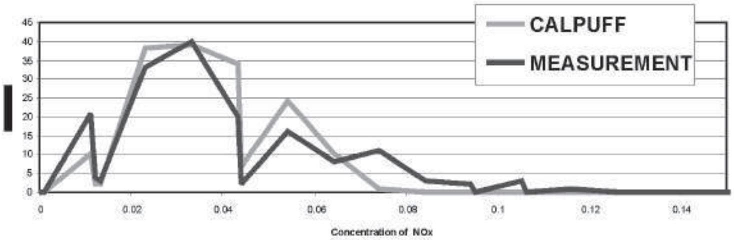

Figure 8 Comparison between calculated and measured NO_X daily mean values for year 1996

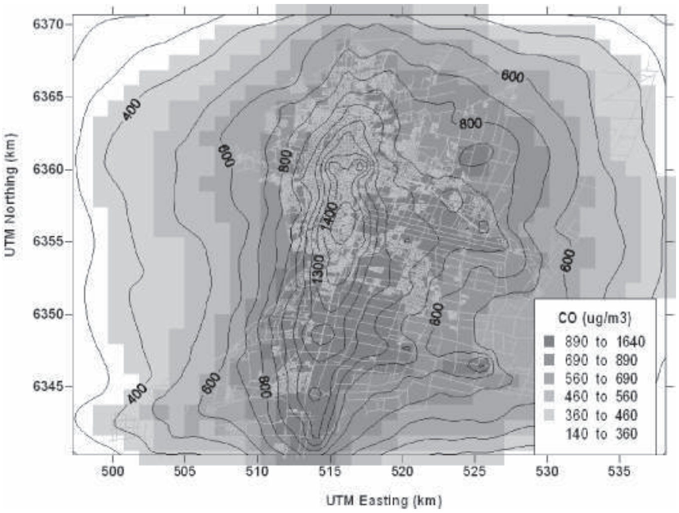

Figure 9 Calculated hourly mean values for CO (ug/m^3) including all sources for Mendoza Metropolitan Area using CALPUFF

GHG sources for five sectors: industrial and energy production, transportation, residential, service and rural, based on energy consumption, population density, and other available information. The overall information, obtained from the top-down approach, was then distributed in rectangular cells on a geographical information system, according to the population density and the land use for each particular cell, (i. e. residential, commercial, educational, etc.) leading to a gridded emission pattern. In the fourth section, this map was then used to calculate the air quality concentration using two different Gaussian dispersion models ISC3P and CALPUFF. These results indicate an average difference for all receptors of 2.4 $\mu g/m^3$, being ISC3P most of the time smaller than CALPUFF. Maximum values are also higher in CALPUFF than ISC3P. Despite the differences both methods capture closely the long-term average values, but differ in the extreme values. Finally the results are cross calibrated with the data from an air pollution monitoring station, showing a good match of the frequency distribution of the calculated and measured NOx concentrations.

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