

### 6.31 AIR QUALITY MODELLING OVER BOGOTA CITY

*Erika Zárate<sup>1</sup>, Luis C. Belalcázar<sup>2</sup>, Diego Echeverry<sup>2</sup>, Alain Clappier<sup>1</sup>*

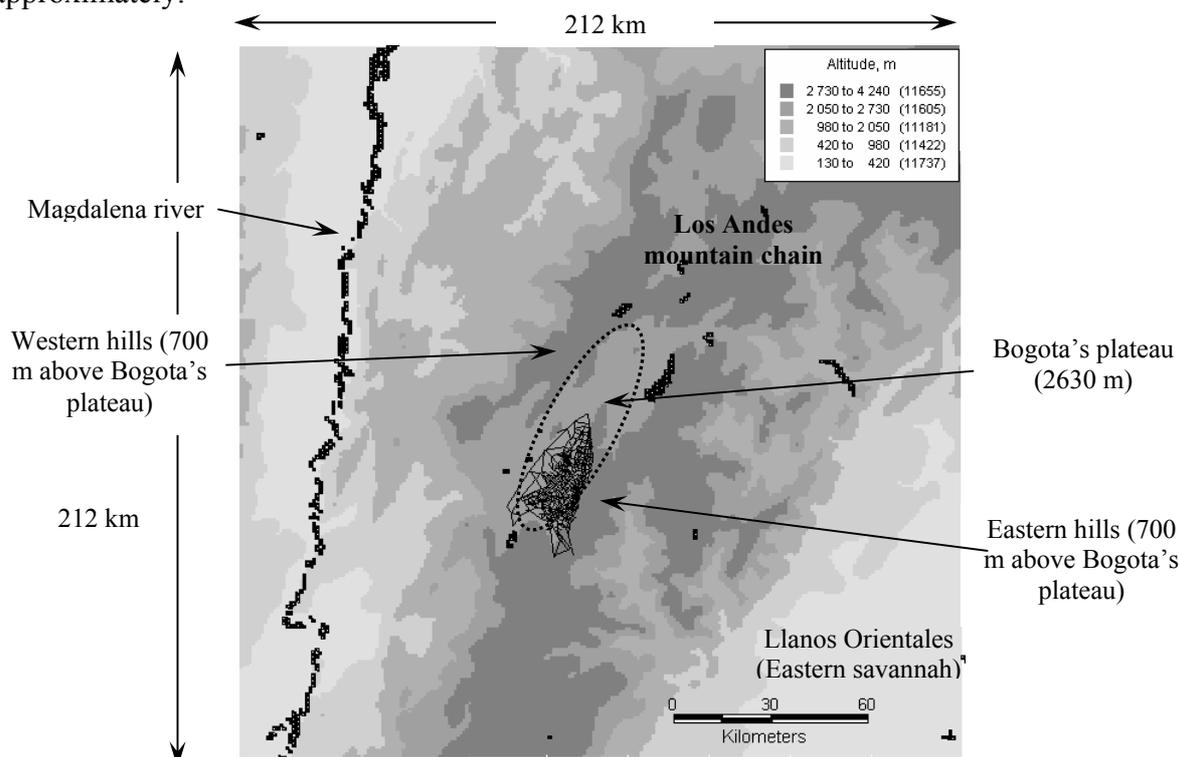
<sup>1</sup> Air and soil pollution laboratory (LPAS) - Swiss Federal Institute of Technology (EPFL),  
Lausanne, Switzerland

<sup>2</sup> Environmental Engineering Department - Universidad de los Andes, Bogotá, Colombia

#### INTRODUCTION

Bogota and its surroundings is one of the biggest urban centres in Latin America, accounting with more than 7 million people, one million vehicles and more than 20.000 small-scale industries. During the last 20 years, the city has grown rapidly, thus its economical and industrial activities, decreasing notoriously its air quality and in consequence, affecting human health as well as the environment.

Bogota is located over one of the Andean mountain chains that cross the country. The city lies on a huge savannah, at 2.630 m over the sea level (see figure 1). It is located at 4° of latitude, which means it is inside the tropical fringe. The altitude and the latitude, make of Bogota a city with a gentle weather, which does not change a lot throughout the year. 2 main seasons are recognized: first, the dry season, running from December to March and from June to August; and the rainy season, running from March to May and from September to November approximately.



*Figure 1. Location of Bogotá city in Los Andes chain mountains. It is located over a large plateau at 2630 m.o.s.l. The eastern border of the city is limited by a chain of hills that go up to 700 m from the plateau (around 3300 m.o.s.l). Further in the northwest, there is another chain of hills, while in the southwest there are the steep slopes that go down to the Magdalena river valley. In the southeast there are also steep slopes that go down to “Los Llanos Orientales”, behind the eastern hills, to reach nearly the sea level in both cases.*

An air quality monitoring network, accounting for 14 monitoring stations, was implanted in 1997 in the city. Data coming from this network permitted to establish the city's situation in terms of Ozone. For example, during the year 2000, 29 photochemical episodes were identified over the city, with hourly-Ozone values between 120 and 160 ppb (the maximum permitted hourly value, according to the environmental regulators is 83 ppb) (UNIANDES, 2002). Bogota's air quality model emerged as a response to the need of a tool able to test in advance the repercussion of different emission scenarios over air quality, aiming to control such photochemical episodes.

## **METHODS**

An air quality simulation over a region consists of generating certain concentrations of pollutants, distributed over a geographical region. These concentrations are generated through the numerical calculations of the model TAPOM (Transport and air Pollution Model). It was developed at the Federal Institute of Technology, Lausanne (EPFL). It is a three dimensional eulerian model with terrain-following mesh using the finite volume discretisation. It includes modules for transport, gaseous and aerosols chemistry, dry deposition and solar radiation. It includes de RACM lumped species mechanism, the Gong and Cho chemical solver, an improved highly accurate transport algorithm and the solar radiation module TUV developed by Madronich to calculate the photolysis rate constants (Martilli et al, 2003).

3 basic sets of input data are needed for a given simulation: (1) meteorological data: obtained from the FVM (Finite volume model) model, developed at EPFL. It is a three dimensional eulerian meteorological model, using a terrain-following grid with finite volume discretisation (Martilli, 2001). It has also the ability to perform one-way nesting to refine some parts of the grid. (2) Emission data (UNIANDES, 2002, 2004), not reported in this paper; and (3) topographic and land use data (UNIANDES, 2002). The results of both meteorological and air quality models were validated with data obtained for a photochemical episode that took place during the measuring campaign hold in March 2002 for Bogota and its surroundings.

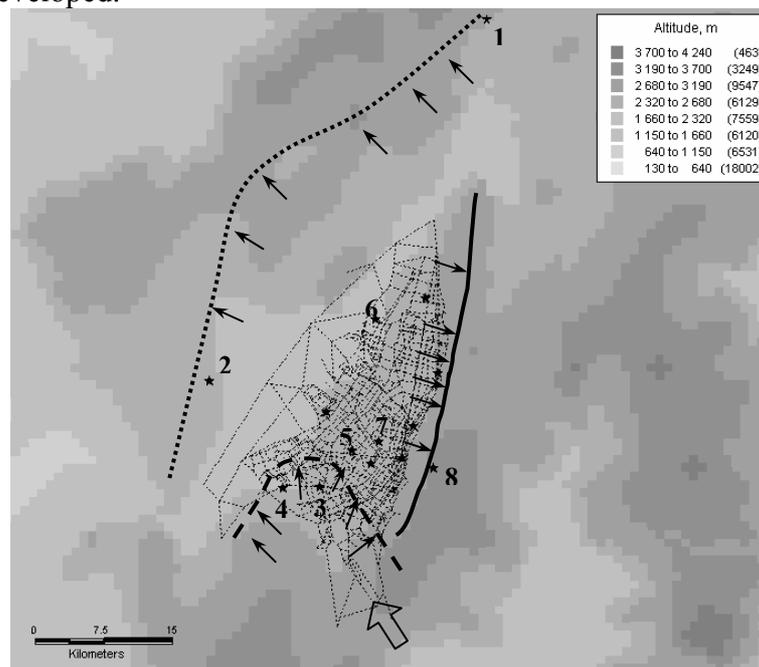
## **RESULTS**

The preliminary analysis of the existing air quality data from the monitoring network, (UNIANDES, 2002) allowed the selection of the size of the domain to be simulated. It was chosen aiming to fully cover two main aspects: (i) the plume of pollutants generated by the city on a daily basis, as it spreads out; and (ii) all the topographical accidents affecting the meteorological behaviour over the plateau. The domain is a square of 212 km by 212 km (see figure 1), with square cells of 4 by 4 km.

### **Preliminary analysis of the meteorological information**

Prior to the modelling, the wind behaviour over Bogota's plateau was analysed for the photochemical episode case-study (6<sup>th</sup> and 7<sup>th</sup> of March, 2002), using the data obtained during the measuring campaign. The wind at ground level is ruled by a thermal regime, affected by the topography of the region. Those measuring stations located in the city showed a wind blowing to the eastern hills during the afternoon, when the ground has been heated by the sun. Meanwhile, stations like Cogua and Tisquesusa (see figure 2) register also the predominant thermal regime of the wind, blowing towards the farther north-western hills. Two stations located in the south of the city (Sony and Cazuca, see figure 2), show a different behaviour. During the afternoon, the wind is blowing from the southeast, in opposition to the other stations. Those results allowed the identification of three main fronts of convergence, shown in figure 2. Concerning wind speeds, maximum values between 1.5 and 7 m/s were measured,

depending on the station. This maximum is seen between 2 and 3:00 p.m., when the wind pattern is fully developed.



1 Cogua 2 Tisquesusa 3 Sony 4 Cauzaca 5 Merck 6 Corpas 7 Nacional 8 Monserrate  
 — Eastern hills front .....Cogua – Tisquesusa front - - - .Sony – Cauzaca front

*Figure 2. Convergence fronts and measuring stations. Behind the south-eastern hills, there are the steep slopes that descend to “Los llanos orientales”. In between these hills, there is a pass that may allow the entrance of air masses to the plateau during the afternoon.*

## Meteorological Modelling

### Influence of the urban island

FVM provides an urban turbulence module that specifically simulates the effects of urban areas on the meteorology (Martilli, 2001). For the Bogotá case, the influence of the urban island of concrete is important. Simulations were made including cells considered as “urban”, that is, considering soil moisture equal to zero. Two types of buildings were taken into account, tight high buildings for downtown, and low separated buildings for the suburbs (UNIANDES, 2003). Figure 3 shows temperature and wind speed results for two stations, one located at an urban cell (Nacional), and the other one at a rural site (Corpas), both located over the plateau (see figure 2 for location of the stations). Nacional station develops less strong wind speeds, and the simulation reproduces this effect. Basically, the inclusion of the city decreases the wind speeds and the day-night gradient of temperature (Martilli, 2001). There are no temperature measurements for Nacional, but this effect is well seen in figure 3.

### Wind field

FVM confirms the strong thermal regime of the zone, and the wind patterns ruled by the topography. Bogotá's plateau receives air masses during the afternoon coming uphill from the Magdalena valley, which continue up to the surrounding hills. This result is seen in figure 4. The third front of converge (Sony-Cauzaca, see figure 2), corresponding to those stations located in the southeast of the city, though reproduced by FVM, appears shifted a few kilometres southwards (See figure 4). This indicates that such front of convergence exists indeed, and it is formed due a thermal wind that also comes uphill blowing from Los Llanos Orientales (southeast part of the domain, see figure 1) during the afternoon. The reason for this displacement is attributed to the resolution of the topography employed up to now (4km

by 4km). A better resolution would permit FVM to better take into account the steep slopes from the eastern part of the mountain chain and the path the wind has to follow to arrive to the open plateau.

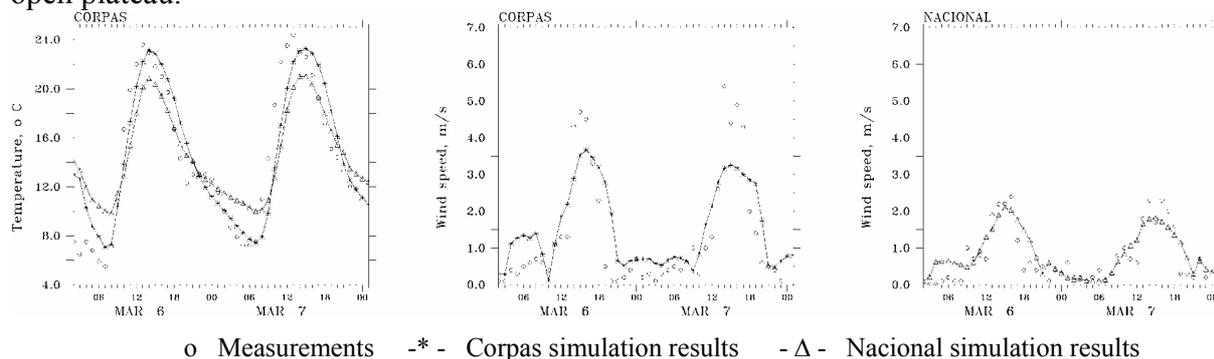


Figure 3. Temperature and wind speed for CORPAS and NACIONAL monitoring stations

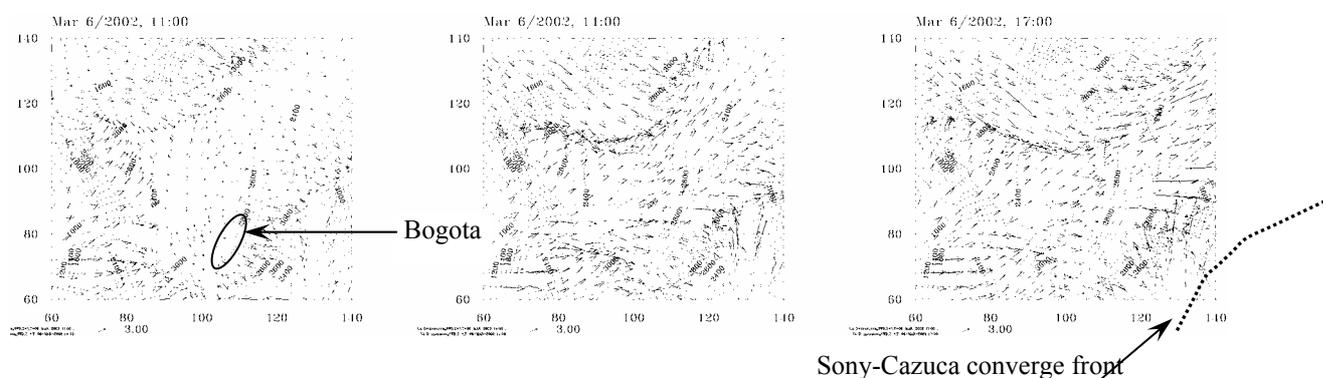


Figure 4. Wind model results for Bogota city. Simulation at ground level. This figure shows a zoom of the simulated domain, between the 60<sup>th</sup> and 140<sup>th</sup> km. The arrow and the value "3.00", outside the figure, indicate that such arrow size corresponds to a wind of 3 m/s. Measurements are represented with a thicker arrow.

## AIR QUALITY MODEL

The model TAPOM reproduces adequately the formation and dispersion of pollutants in Bogota's atmosphere. Figure 5 presents the Ozone comparison between the model results and measurements. Ozone peaks are formed at midday, from west to east (see stations Nacional and Merck in figure 5 and 2 for location). Corpas station can see a portion of the plume, though it does not reach so high values as the others. The peak in this station is 2 hours in advance with respect to the measurement, which may happen due to the slightly strong wind speeds simulated by the model in this part of the city. The decrease of the measured values in March 7<sup>th</sup> corresponds to a decrease in solar radiation for this day (the model does not take into account the cloud coverage). Results obtained for Monserrate station (it is located at the top of one of the eastern hills, see figure 2) show that pollutants are indeed blown uphill to the surrounding hills, as the model has reproduced it. The overestimation of the second-day peak corresponds with the decrease in solar radiation. An overestimation of Ozone destruction during the night is also observed, which may be due to the values assigned as nightly NO<sub>x</sub> emissions.

Figure 6 shows the spatial and temporal evolution of the plume of pollutants for Bogota city. It is seen how during the morning, the plume starts being formed and it is pushed to the northeast. As the day advances, the wind and the plume address more eastwards. This is the reason why Corpas station reaches 80 ppb of Ozone but not more. Nacional station reaches

150 ppb of Ozone while Merck station (more to the west) reaches 120 ppb. The plume in Bogota is therefore fully developed over the city, reaching a maximum value of 168 ppb and blowing after uphill to Monserrate. At the 2:00 p.m, the peak concentrations have already passed.

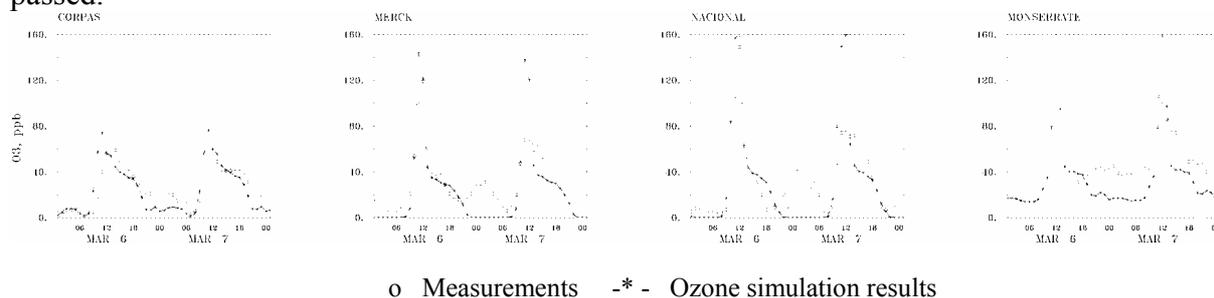


Figure 5. Ozone simulation for Bogota's plateau during the photochemical episode of March 6<sup>th</sup> and 7<sup>th</sup>, 2002 – Corpas, Merck, Nacional, Monserrate (see figure 2 for location).

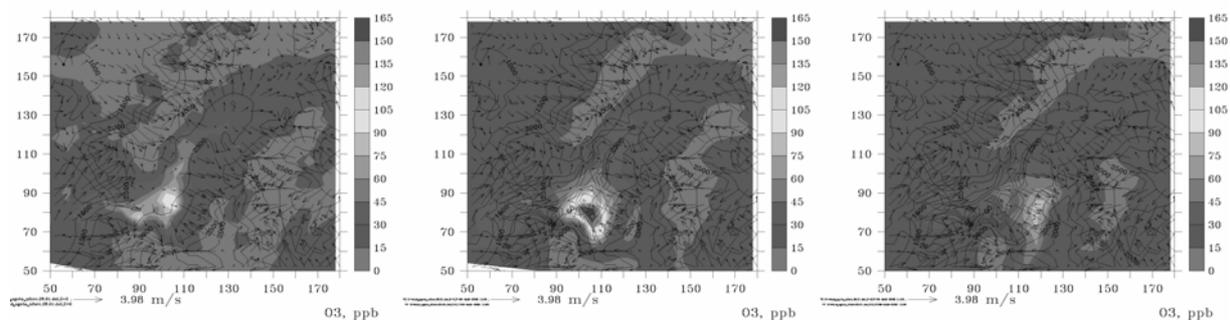


Figure 6. Plume of pollutants – Ozone simulation for Bogota city, March 6<sup>th</sup>, 2002.

## CONCLUSION

Bogota case showed several particularities of interest for modellers and air quality scientists: The plume of pollutants is fully developed over the city due its size and its level of pollution. This plume covers an approximate area of 40 km by 40 km, and it reaches a maximum of 168 ppb of Ozone. The wind in the region is strongly influenced by the thermal effects caused by the complex topography. Both Meteorological and air quality models (FVM and TAPOM) reproduced adequately the phenomena taking place.

## ACKNOWLEDGEMENTS

The authors thank DAMA (Departamento Técnico Administrativo del Medio Ambiente), Bogota's environmental agency, for its financial and technical support to this project.

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- UNIANDÉS, 2002, 2003 and 2004. 6-month reports of the project “Development and Implementation of an air quality model for Bogota city”. EPFL, UNIANDÉS, DAMA. For contact and more information about these reports: Erika.zarate@epfl.ch