SMOKE Implementation and CMAQ Preliminary Evaluation for Bogotá, Colombia

Colleen Baublitz[1], Barron Henderson[1], Jorge E. Pachon[2], Alex P. Rincón[2], Robert Nedbor-Gross[1] and Boris Galvis[2]
cbaublitz@ufl.edu, barronh@ufl.edu, jpachon@unisalle.edu.co
Environmental Engineering Sciences, University of Florida[1], Ingeniería Ambiental y Sanitaria, Universidad de la Salle[2]

Bogotá's air pollution

Bogotá is the largest city in Colombia, with over 6.5 million inhabitants and a 2.08% growth rate. This growth has caused deterioration of ambient air quality, 70% of which can be attributed to cars. According to the Secretaría Distrital de Ambiente in Bogotá, while many contaminants of concern were present, only particulate matter exceeded the local standard, though it did so as much as 37 times for a given monitoring station in 2010[1].

Figure 1 (left). An air pollution episode in Bogotá, Colombia during the summer[2].

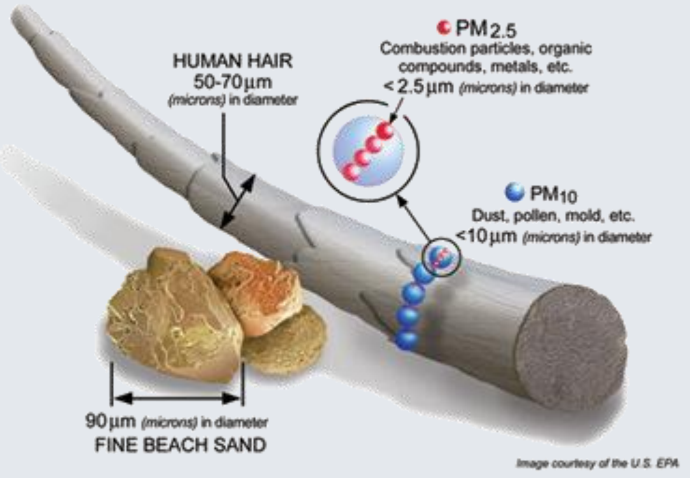

Figure 2 (right). Smaller particles have greater potential for health impacts, like lung and heart damage[3].

As a result of this poor air quality, the Secretaria Distrital de Ambiente (SDA), the local regulatory agency of Bogotá, has decided to evaluate regulatory strategies to improve air quality. Developing a credible model requires accurate emissions, meteorology, chemistry, and boundary conditions. The Sparse Matrix Operating Kernel for Emissions (SMOKE) is a program that uses raw emission inventories as input and processes them to create files that may be input into a chemical transport model for Community Multiscale Air Quality (CMAQ). The framework within SMOKE facilitates easy manipulation of the existing inventories. The altered inventories can then be visualized using CMAQ and compared to determine which is the most protective of public health. Here, SMOKE v. 3.5.1 was used with the base configuration.

Existing inventory data

The emission inventories for this project were created by the Universidad de La Salle (ULS) for 2012. The source types used here are for industrial, mobile and commercial sources, along with service stations. Activity (mobile) or emissions information, temporal distributions and source locations were taken from these files for use in SMOKE.

Mobile

Generated using two methods:
- Traffic counts determined what types and how many vehicles passed various intersections in the city
- Emission factor applied to vehicle activity attained from historic tax records
- Resuspended dust was also collected (see presentation by Boris Galvis)

Commercial
- Treated as a series of points with latitude and longitude
- Emission factor based on the type of meat sold
- Temporal distribution obtained and assigned for a few types of restaurants

Industrial
- Treated as a series of points with longitude and latitude
- Emissions factor applied to activity information on fuel use available through the SDA and the National Statistics Department.

Service stations
- Physical parameters for service stations were collected and processed using the TANKS model by the EPA
- Estimated the volatile organic carbon (VOC) emissions from storage or distribution by type of fuel sold.

Table 1. Estimate of the contributions of each source type in Bogotá's inventories to the criteria pollutants, carbon dioxide (CO_2) and VOCs.
The units of each contaminant is metric tons per year.[1]

Source	CO_2	CO	NO_x	VOC	PM	SO_2
Mobile	10,458,221	866,445	66,540	91,885	1,163	14,109
Commercial	40	2,326	54	7	82	201
Industrial	867,594	676	1,618	2,889	994	1,546
Service stations	N/A	N/A	N/A	979	N/A	N/A

Information from these inventories was selected for use in the implementation of SMOKE. Sometimes, there were inconsistencies with the formatting of this data and the requisites of the program, which is elaborated in the following section.

Harmonizing international source codes

SMOKE's requirements are well-adapted to work with U.S. emission inventories. As a result, the emission inventories from Bogotá needed to be adapted to fit several domestic conventions.

Standard Industrial Codes (SICs)
- Identify industrial sources for speciation by the type of products they manufacture.
- These match well with similar codes from Colombia and are easy to implement.

Table 2. Comparison of the Colombian industrial codes with those from the United States.

CIIU	Description (Colombian)	SIC	Description (United States)
D3694	Manufacture of games and toys	F5092	Toys and hobby goods and supplies
N8511	Activities of the institutions providing in-patient health services	I8000	Health services

Table 3. Comparison of the categorization of sources in Colombia with that of the United States.

Category (Colombian)	Category pairing (United States)
Passenger vehicles	Highway – Gasoline – Light Duty Vehicles – Total: All Road Types
Campers and trucks (Diesel)	Highway – Diesel – Light Duty Trucks 1 through 4 – Total: All Road Types

Source classification codes (SCCs)
- Identify the source type associated with an activity or set of emissions.
- They are a less specific means of identification for speciation than SICs.
- They paired well with Bogotá's inventories, with an example of the exceptions noted here.

Road types (mobile sources):
- SCCs for onroad sources are segregated per road type, while the city's activity records are only segregated by class.
- The codes that related to "All Road Types" were used for all vehicle classes.

Selected features

In the same way that several components of Bogotá's inventories needed to be adapted to U.S. conventions, there were certain features in SMOKE that better fit with the available information in Bogotá.

Temporal
- Distributions are calculated for mobile sources and service stations and assumed for industrial and commercial sources.
- Integers are used as a proportion of the total to represent the hourly distribution.

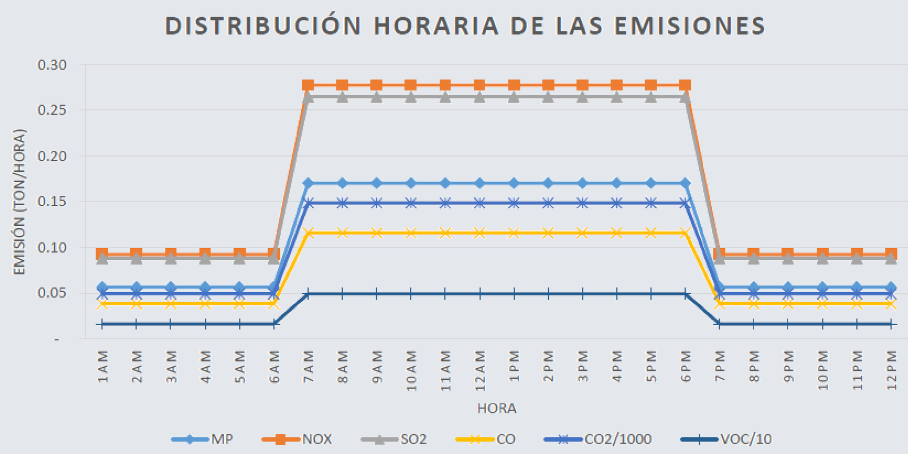

Figure 3. Hourly distribution for industrial sources[1]

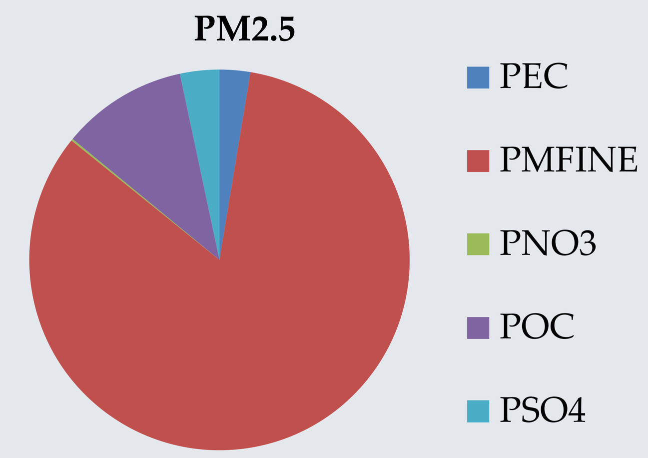

Figure 4. Speciation split for PM2.5 emissions through CB05

Speciation
- Using Carbon Bond Mechanism 05 with secondary organic aerosols.
- Profiles were paired with the most specific information available (see SICs above for example
- Imperfect pairing, but incorporation of European codes could improve this.

Gridding
- Industrial and commercial sources as well as service stations are gridded via their lat, lon coordinates.
- Mobile sources are gridded using codes called "links" that pair emissions with road segments.

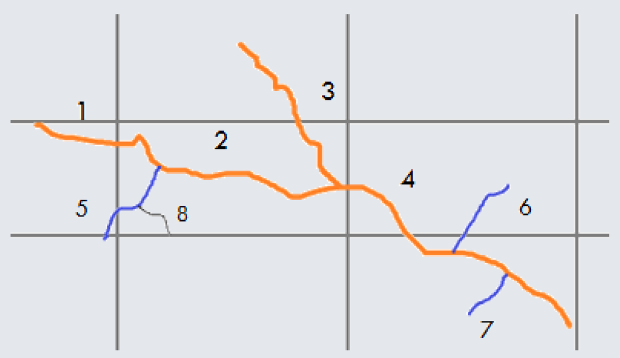

Figure 5. Simplified example of the link pairing for mobile sources

Preliminary CMAQ evaluation

The next step following the implementation of SMOKE is CMAQ evaluation of the proposed regulatory strategies to determine the benefits and detriments of each. CMAQ results have already been obtained using Bogotá's emission inventories and emissions from the Emissions Database for Global Atmospheric Research.

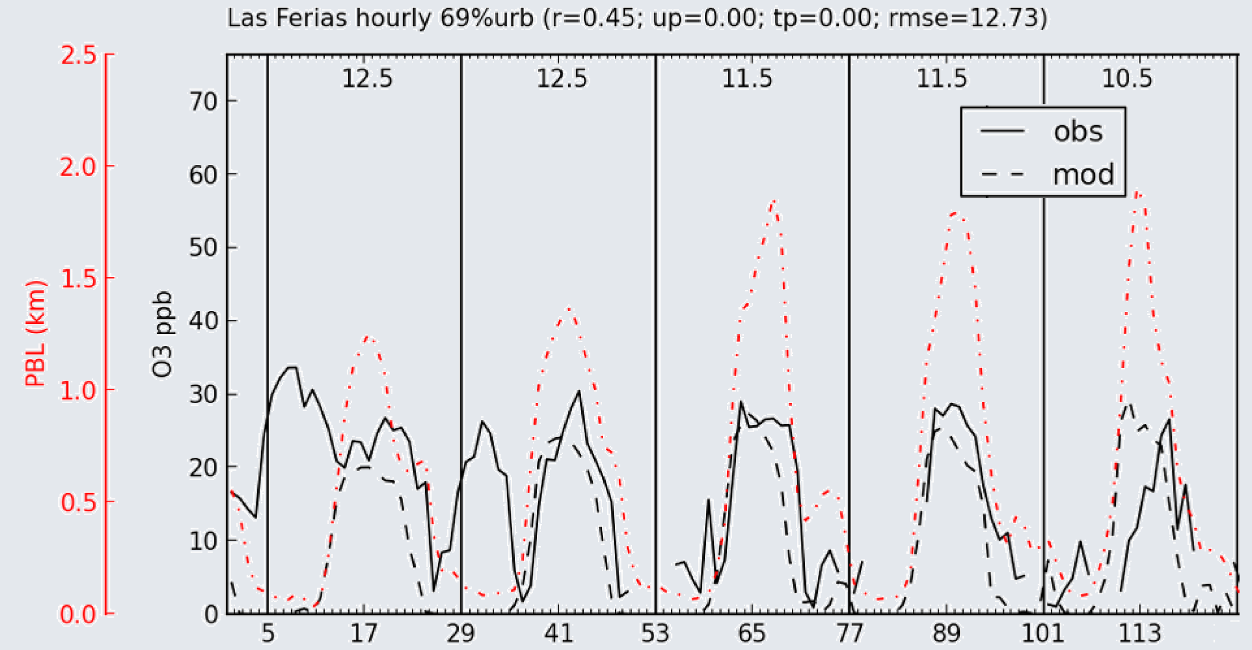

Figure 6. Example of CMAQ preliminary results of ozone hourly emissions, the height of the planetary boundary layer and the rate of emissions per second.

- Initial results are based on GIS gridding and regridding, simple temporal distributions, and aerosol speciation assuming US average speciation.
- They serve as preliminary results to verify that the results from SMOKE appear to be reasonable. For more detail, see the presentation by Robert Nedbor-Gross entitled **Implementation of a WRF-CMAQ Air Quality Modeling System in Bogotá, Colombia.**
- SMOKE is beneficial because it helps to automate this process and facilitates in the manipulation of the emission inventories for the evaluation of separate regulatory strategies.

Future work

SMOKE has been implemented for rudimentary estimates of the 2012 inventories, but it needs to be updated to include the final emissions for this year. These results will be manipulated in CMAQ to evaluate the regulatory strategies proposed by the SDA to determine which strategy is best suited. The technological knowledge of this program will be passed to the SDA in November, 2014 so that regulators may use it in the future.

Summary

1. Bogotá, Colombia needs an air quality modeling system to test regulatory strategies. This process should be easy to replicate for the environmental agency to use in the future.
2. SMOKE streamlines the process of manipulating or updating raw emission inventories to visualize the resulting change in chemical composition through the CMAQ model.
3. Emission inventories for Bogotá have been created recently by the Universidad de La Salle, and those for point, area and mobile sources will be implemented.
4. This data underwent several changes, especially as a result of the imperfect pairing of their categorizations to codes used in the United States (SCCs and SICs).
5. Some features of SMOKE were additionally more useful in this case than others, in particular the ARTOPNT program and the use of links for gridding of mobile sources.
6. This data will be simulated in CMAQ for several proposed regulatory strategies to determine the strengths and benefits of each.

References and acknowledgements

1. Secretaría Distrital de Ambiente. "Informe Anual de Calidad del Aire de Bogotá, Año 2010." 2011. URL retrieved:
2. Belalcazar, et. al. "VOCs Concentrations in the Ambient Air of Bogota City: Source Identification and Apportionment." Date unavailable. URL retrieved: <http://www.kfpe.ch/projects/jeuneschercheurs/belalcazar.php>.
3. USEPA. "Particulate Matter (PM10) Research." April 2, 2013. URL retrieved: <http://www.epa.gov/airscience/air-particulatematter.htm>.

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