Implementation of a WRF-CMAQ Air Quality Modeling System in Bogotá, Colombia

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Motivation

Studies have shown that O_3 and Particulate Matter (PM) are associated with an estimated 0.7 ± 0.3 million respiratory mortalities and with 3.5 ± 0.9 million cardiopulmonary cancer cases annually.[1] Mortality estimates were reduced approximately 30% when low-concentration thresholds for O_3 and PM were assumed.[1]

Air pollution is often a problem in developing cities due to economic growth outpacing government regulations. Bogotá, Colombia is one of these cities, and its citizens have demanded improvements in air quality. Figures 1 and 2 show observations of PM_{10} and O_3 for 2012 in Bogotá from the Red de Monitoreo de Calidad del Aire de Bogotá (RMCAB) monitoring network. Bogotá's government will use an air quality modeling system, detailed in this poster, to help determine an emissions reduction strategy. Please see "Developing Modeling Tools to Asses Emissions Reductions Strategies for Bogotá, Colombia" by Jorge E. Pachon for more information on emission reduction strategies.

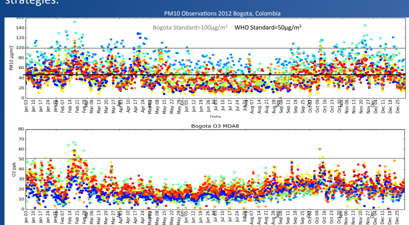


Figure 1. Observations for PM_{10} in Bogotá from 19 monitors in the RMCAB network

Figure 2. Observations for O_3 in Bogotá from 19 monitors in the RMCAB network

Figure 3. Bus in Bogotá

Legend for Figures 1 and 2

Methods

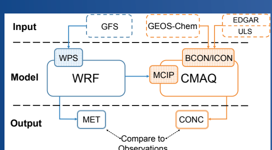


Figure 4. Modeling system schematic

- Figure 4 shows a schematic of the modeling system for Bogotá.
- Meteorological boundary and initial conditions (BC's and IC's) from the Global Forecast System (GFS)[2] are applied to the Weather Research and Forecasting Model (WRF)[3].
- BC's and IC's for the atmospheric chemistry model come from GEOS-Chem[4].
- Emissions for outer domains (see figure 5) are obtained from the emissions database for global atmospheric research (EDGAR)[5]
- Emissions for the domain over Bogotá, were developed by researchers at the Universidad de la Salle (ULS) (Figure 7).
- Please see "Analysis of the air quality in Bogotá, Colombia in the last decade" by Boris Galvis

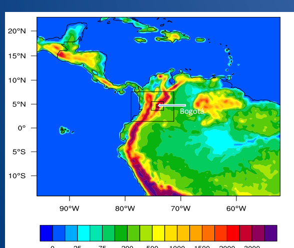


Figure 5. The domain configuration. The outermost domain (d01) is the entire image, the innermost domain (d04) is situated over Bogotá. Topography is shaded in magl

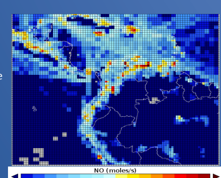


Figure 6. Emissions of NO in moles/s for the outermost domain for 2012-02-17 at 20 UTC.

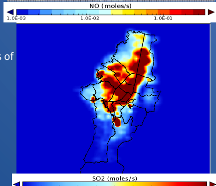


Figure 7. Emissions of SO2 in moles/s for the innermost domain (situated over Bogotá) for 2012-02-17 at 20 UTC.

WRF in Bogotá

- WRF was run for all domains for 5, 5.5 (half-day spin-up) day segments over two time periods in 2012.
- One time period for the dry season in February and one for the rainy season in October.
- The domains were nested with a 3:1 nesting ratio.
- Four physics configurations were tested against the RMCAB monitoring network . One chosen
- Figure 8 shows a sample output from WRF of temperature, wind direction, and pressure over Bogotá.

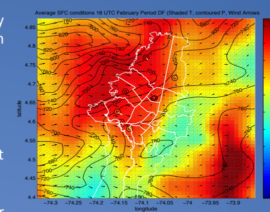
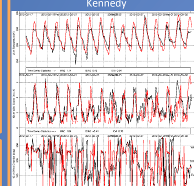
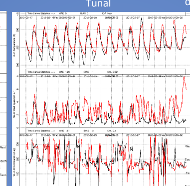


Figure 8. Sample output from WRF of temperature, wind direction, and pressure for the innermost domain with monitor locations as shaded dots.

Kennedy



Tunal



Figures 9 and 10. Time series plots for observations at the Kennedy and Tunal monitoring stations (red) compared to WRF (black) output for temperature, wind speed, and win direction (top to bottom).

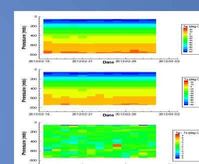


Figure 11. Averaged vertical temperature for WRF (top), RMCAB observations (middle), and the difference (bottom).

Time series plots for two monitor locations are compared to WRF in Figures 9 and 10. A vertical temperature comparison is also shown in Figure 11. Statistical analysis of WRF's performance can be seen in Table 1 for temperature, relative humidity (Q), wind speed, and wind direction.

Threshholds (complex)	Temperature			Q			Wind Speed			Wind Direction	
	Gross Error	Bias	IOA*	Gross Error*	Bias*	IOA*	RMSE	Bias	IOA*	Gross Error	Bias*
*=default	3.5	2	0.8	2	1	0.6	2.5	1.5	0.6	55	10
v4n_df_s_feb_s3s4s5_d01	100%	100%	100%	100%	100%	100%	60%	100%	100%	100%	100%
v4n_df_s_feb_s3s4s5_d02	100%	100%	100%	60%	47%	100%	93%	100%	40%	20%	67%
v4n_df_s_feb_s3s4s5_d03	100%	100%	100%	93%	100%	100%	93%	100%	40%	13%	80%
v4n_df_s_feb_s3s4s5_d04	100%	100%	93%	100%	80%	80%	93%	100%	33%	7%	73%

Table 1. Statistics for WRF's temperature, relative humidity, wind speed, and wind direction compared to RMCAB monitors for February 2012. Colors and percentages indicate how often the desired thresholds at the top of the table for statistics are met.

Table 1 indicates that the WRF simulations perform well in all categories except wind direction. Wind direction is especially difficult to predictin the mountainous region (see figure 5 for topography).

CMAQ in Bogotá

- CMAQ was run for the same two periods as WRF
- WRF's input meteorology processed through the Meteorology-Chemistry Interface Processor (MCIP)
- CMAQ output was also compared with observations from the RMCAB monitoring network.
- Temporal comparisons are shown for two locations in Figures 12 and 13 Maximum daily 8 hour ozone plots are shown for 3 stations in Figure 14.
- Table 3 shows the statistical evaluation of CMAQ in the innermost domain

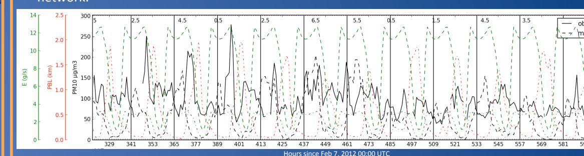


Figure 12. Hourly PM_{10} (dashed for observations and solid for model), planetary boundary layer (PBL) height, emissions for Kennedy

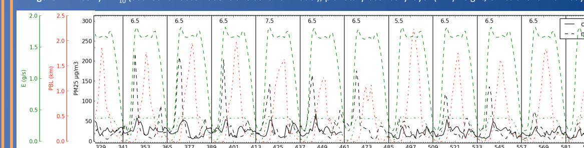


Figure 13. Hourly PM_{10} (dashed for observations and solid for model), planetary boundary layer (PBL) height, emissions for Fontibon.

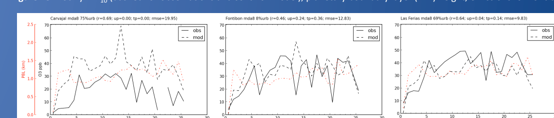


Figure 14. Maximum daily 8-hour average O_3 concentrations for (a) Carvajal station, (b), Fontibon station, and (c) Las Ferias station. Observations are dashed lines, model is solid line. The red dashed line is the modeled PBL.

	Mean Obs	Mean Mod	MB	MdnB	MGE	RMSE	IOA
Ozone (ppb)	16.5	20.62	3.29	1.27	11.66	15.21	0.75
PM_{10} (ug/m³)	64.98	58.00	1.31	-17.02	52.55	17.28	0.40
$PM_{2.5}$ (ug/m³)	39.37	21.86	-11.66	-14.38	22.27	16.99	0.52

Table 2. Statistical evaluation of CMAQ for the innermost domain with RMCAB observational data. Statisitics shown are the means for observations and model, mean bias (MB), median bias (MdnB), mean gross error (MGE), root mean squared error (RMSE), and the index of agreement (IOA) .

Summary and Conclusions

WRF and CMAQ have been successfully configured and run for Bogotá, Colombia. Emissions data came from EDGAR and ULS. IC's and BC's came from GFS for WRF and GEOS-Chem for CMAQ. Both models were evaluated for the innermost domain of a nested 4 domain configuration. Evaluations have indicated generally good performance for both models. Meteorological variables evaluated were temperature, wind speed, wind direction, and relative humidity. The most challenging variable was wind direction due to the mountainous topography. CMAQ's output of PM_{10}, $PM_{2.5}$, and O_3 were evaluated with generally strong performance. This modeling configuration will be used to help determine which emissions reductions strategies will be chosen by Bogotá's government. The QR code to the right links to our website of up-to-date figures for this project.

Acknowledgements

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