CHARACTERIZING NEAR-ROAD AIR POLLUTION USING LOCAL-SCALE EMISSION AND DISPERSION MODELS AND VALIDATION AGAINST IN-SITU MEASUREMENTS

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1. Introduction

Traffic-related air pollution is associated with a number of chronic and acute health effects (Crouse, Goldberg, Ross, Chen, & Labrèche, 2010; United States Environmental Protection Agency, 2008). In particular, a number of studies have established positive associations between various health outcomes (e.g. cancers, heart attacks, asthma) and exposure to nitrogen dioxide (NO_2), an accepted marker of traffic-related air pollution (Parent et al., 2013; Wu, Wilhelm, Chung, & Ritz, 2011). In urban areas, air pollution is affected largely by the built environment, traffic composition and meteorological conditions (Weichenthal, Farrell, Goldberg, Joseph, & Hatzopoulou, 2014). In this study, we developed a traffic simulation for four consecutive road segments along a busy corridor in Montreal. The four segments exhibit different configuration and built environments, yet they share almost the same traffic characteristics. Based on the traffic simulation results, we simulated emissions of nitrogen oxides (NO_x) and modeled the resulting NO_2 concentrations along the road. We conducted the dispersion of traffic emissions along the four different segments under varying traffic and meteorological conditions using three different dispersion models with vastly different dispersion algorithms (CALINE 4, OSPM, and SIRANE). In-situ roadside measurements of NO_2 concentrations were also conducted in order to validate and inter-compare the models.

2. Methodology

2.1 Corridor Selection

Air quality data were collected at four different sites varying in built environment characteristics along Papineau Avenue in Montreal. FIGURE 1 illustrates the four different segments (1 to 4) and their surrounding vastly various built environment. The four segments were selected in an effort to maximize variations in the set of potential built environment predictors of NO_2, while maintaining relative consistency in terms of traffic volume and composition.

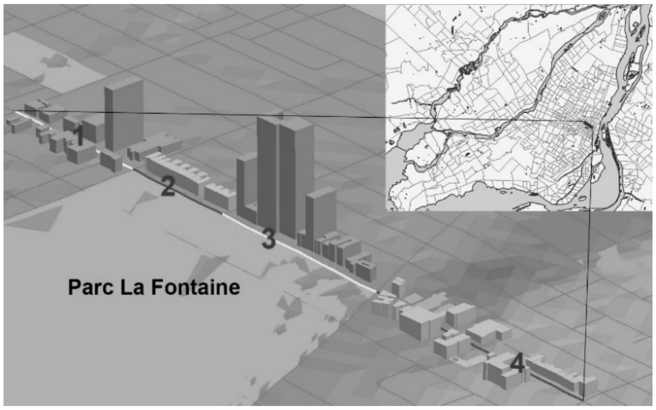

FIGURE 1: Study corridor and measurement locations

2.2 Field Data Collection

Field data measurements were conducted on 16 weekdays over a four-week period in the months of March and April 2015. Meteorological data including temperature and humidity, traffic volume and NO_2 concentrations were measured on site. To avoid selection bias, visits to the measurement locations were randomly scheduled on the principle that each segment would be measured once in each time period each day. Monitoring occurred for 2 consecutive hours at each location and visit. Every location was therefore visited 16 times, leading to 32 hours of data collected per road segment.

2.3 Field Data Processing

Traffic information at each intersection was manually extracted from video camera recordings. Volumes of passenger cars, passenger trucks, school buses, transit buses, single unit short-haul trucks, and single unit long-haul trucks were noted. All turning movements were also noted. Traffic data were processed to generate hourly patterns at each intersection, thus leading to two observations per time period. Temperature and relative humidity data collected by the on-site station were averaged per hour (one reading every 15minutes) while wind speed and direction collected by the fixed station at McGill was already hourly. The wind direction recorded by the fixed station represents the angle difference with respect to the true north, and ranges from 1 to 360 degrees. Air quality data recorded by the fixed monitoring station were also provided as hourly averages.

In order to be consistent with traffic information and meteorological data, minute-by-minute corrected NO_2 concentrations were averaged into hourly values and synchronized with these data so that at each location and during each visit, only two values for NO_2 were available. Data for Ozone were not used subsequently.

2.4 Traffic and Emission Simulation

We implemented a traffic micro-scopic simulation of the four segments along Papineau Avenue using the PTV VISSIM platform. We used a combination of orthophotos, topographic maps, and cartographic maps to develop the base network. We included signal timings and routing decisions based on the collected data. Since traffic data were collected at each intersection over 4 different time periods -each time period extending 2 hours- we averaged the data from the multiple visits and created 8 traffic simulation cases, each representing an average weekday at a specific hour. After each of the 8 traffic simulation runs, we extracted instantaneous speeds and traffic volumes for each segment and for 3,600 sec.

We collapsed traffic and emission data into the 8 abovementioned cases in order to eliminate day-to-day variations in traffic and emissions, thus allowing us to better observe the effects of meteorology and the built environment.

2.5 Dispersion Modeling

Link-level emissions of NO_x derived from MOVES were used as input for dispersion modeling to simulate near-road concentrations of NO_2.While the traffic and emissions were simulated for 8 cases only (each representing an average weekday at a specific hour), dispersion modeling was conducted for a larger number of cases.

In fact, for each of the 8 different hours of traffic/emission modeling, we extracted all meteorological conditions that were encountered over the duration of the campaign at this specific time. As such, for each of the 8 hours, we had 2880 combinations of wind speed and direction. In turn, dispersion modeling was conducted under all of these meteorological combinations in the aforementioned three dispersion models, the OSPM, CALINE 4 and SIRANE model. Simulated NO_2 concentrations reflected an hourly average concentration for each segment, at a specific hour, and under all possible meteorological cases.

3. Results

3.1 Dispersion Modeling Results

NO_2 concentrations on each link were simulated for each of the four segments, under different time periods and various wind speed and direction combinations, leading to a total of 2880 traffic and meteorology combinations simulated by each of the three dispersion models. FIGURE 2 illustrates the variation in measured and simulated results. Roadside measurements have more variability than simulated values (and more variability that fixed-station measurement as pointed out earlier). This indicates that the dispersion models are still unable to capture the entire variability in measured concentrations (e.g. due to short-term peaks caused by long queues or a large amount of heavy vehicles passing) while capturing the general trend in near-road concentrations of NO_2.

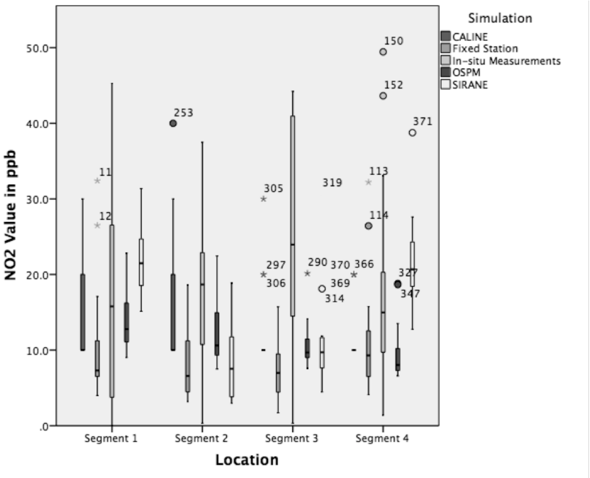

FIGURE 2 Box plot of simulated results

3.2 Validation and Comparison Results

To validate the results of dispersion, a set of performance measures and acceptance criteria were adopted. The rural and urban acceptance criteria proposed by Hanna and Chang (Chang & Hanna, 2004; Hanna & Chang, 2012) were set as higher and lower level criteria respectively, with the rural criterion being more stringent. Both roadside measurements and fixed station data were used to conduct the validation. TABLE 1 and 2 summarize the results of our validation exercise.

TABLE 1. Validation against roadside measurements (share the same footnotes as Table 2)

Segment	Simulation	|FB|[a]	NMSE[a]	FAC2[b]	NAD[a]	MG[b]	VG[b]	Pearson[b]
1	**OSPM**	0.37*	1.87**	0.48*	0.43*	0.61	34.48	0.463
	CALINE	0.26**	1.50**	0.33*	0.43*	0.58	33.6	0.49
	SIRANE	0.08**	1.34**	0.52**	0.38*	0.38	72.05	-0.05
2	**OSPM**	0.46*	1.27**	0.52**	0.42*	1.12[c]	6.36	-0.296
	CALINE	0.26**	1.29**	0.52**	0.43*	0.97[c]	8.22	-0.387
	SIRANE	0.83	2.14**	0.33*	0.50*	1.92	8.8	0.11
3	**OSPM**	0.82	1.54**	0.33*	0.46*	1.72	6.75	0.106
	CALINE	0.67	1.25**	0.4*	0.44*	1.51	7.49	-0.034
	SIRANE	0.79	1.54**	0.40*	0.45*	1.83	5.52	0.11
4	**OSPM**	0.69	2.02**	0.52**	0.45*	1.56	2.88	-0.098
	CALINE	0.50*	1.54**	0.5**	0.39*	1.26	2.5	-0.197
	SIRANE	0.06**	0.80**	0.54**	0.34*	0.7[c]	2.9	-0.23
Pooled	**OSPM**	0.57*	1.69**	0.48*	0.44*	1.13[c]	8.08	0.08
	CALINE	0.41*	1.39**	0.44*	0.42*	0.99[c]	8.42	0.026
	SIRANE	0.27**	1.27**	0.46*	0.40*	0.94[c]	10.34	-0.06

a: The ideal value for this criterion is 0; b: The ideal value for this criterion is 1;

c: recommended value between [0.7, 1.3]; *: Complying with lower level acceptance criterion

**: Complying with higher level acceptance criterion

When validating against roadside measurements, all three models seemed to exhibit the best performance at segment 1 which is lined by buildings on both sides with an aspect ratio of 0.6. OSPM performed better than the other two at segment 1 (a street canyon) and much worse at segments 2, 3 and 4. SIRANE had the best overall performance among the three and especially along segments 1 and 4CALINE performed better than the other two models at segments 2 and 3.

TABLE 2. Validation against fixed station data

Simulation	|FB|[a]	NMSE[a]	FAC2[b]	NAD[a]	MG[b]	VG[b]	Pearson[b]
OSPM	0.22**	1.06**	0.47*	0.37*	1.55	2.35	-0.25
CALINE	0.39*	0.83**	0.56**	0.40*	1.28	2.04	-0.37
SIRANE	0.20**	0.84**	0.59**	0.37*	1.23[c]	3	-0.19

a: The ideal value for this criterion is 0; b: The ideal value for this criterion is 1;

c: recommended value between [0.7, 1.3]; *: Complying with lower level acceptance

**: Complying with higher level acceptance criterion

Comparing to fixed station data, the SIRANE model still demonstrated the best overall performance. All three models had better agreement with fixed station data rather than roadside measurements.

In this study, we also investigated the effect of wind speed by segmenting the output of the three models according to two classes: winds above or below 1.5 m/s. OSPM and CALINE exhibited better performance under wind speeds higher than 1.5m/s. This is also true for SIRANE. The results were agreed with previous studies. Additionally, we examined the effect of wind directions. The results demonstrated that the SIRANE model does not exhibit a large variation in the two performance measures based on the wind direction.

4. Conclusion

The integration of microscopic traffic simulation, emission modeling, and air pollution dispersion was used to simulate near-road NO_2 concentrations. With in-situ roadside measured and fixed station NO_2 concentrations, the feasibility and performance of this methodology and simulation results were evaluated and validated.

A set of performance measures was used to evaluate and compare the performance of the different models. We observed that the SIRANE model had the best overall performance. This is especially the case on the segments with buildings on both sides. Also, CALINE 4 model, had the best agreement with roadside measurements when the surrounding built environment included open terrain. While all three models were not suitable for conditions with lower or even calm wind speeds (<1m/s), SIRANE was the only model that had stable performance under all wind directions.

References

Chang, J. C., & Hanna, S. R. (2004). Air quality model performance evaluation. *Meteorology and Atmospheric Physics*, *87*(1-3), 167–196. http://doi.org/10.1007/s00703-003-0070-7

Crouse, D. L., Goldberg, M. S., Ross, N. a., Chen, H., & Labrèche, F. (2010). Postmenopausal breast cancer is associated with exposure to traffic-related air pollution in Montreal, Canada: A case-control study. *Environmental Health Perspectives*, *118*(11), 1578–1583. http://doi.org/10.1289/ehp.1002221

Hanna, S., & Chang, J. (2012). Acceptance criteria for urban dispersion model evaluation. *Meteorology and Atmospheric Physics*, *116*(3-4), 133–146. http://doi.org/10.1007/s00703-011-0177-1

Parent, M.-E., Goldberg, M. S., Crouse, D. L., Ross, N. a., Chen, H., Valois, M.-F., & Liautaud, a. (2013). Traffic-related air pollution and prostate cancer risk: a case-control study in Montreal, Canada. *Occupational and Environmental Medicine*, *70*(7), 511–518. http://doi.org/10.1136/oemed-2012-101211

United States Environmental Protection Agency. (2008). Risk and Exposure Assessment to Support the Review of the NO 2 Primary National Ambient Air Quality Standard, (EPA-452/R-08-008a).

Weichenthal, S., Farrell, W., Goldberg, M., Joseph, L., & Hatzopoulou, M. (2014). Characterizing the impact of traffic and the built environment on near-road ultrafine particle and black carbon concentrations. *Environmental Research*, *132*, 305–310. http://doi.org/10.1016/j.envres.2014.04.007

Wu, J., Wilhelm, M., Chung, J., & Ritz, B. (2011). Comparing exposure assessment methods for traffic-related air pollution in an adverse pregnancy outcome study. *Environmental Research*, *111*(5), 685–692. http://doi.org/10.1016/j.envres.2011.03.008