Measuring air pollution along Toronto's bicycle network

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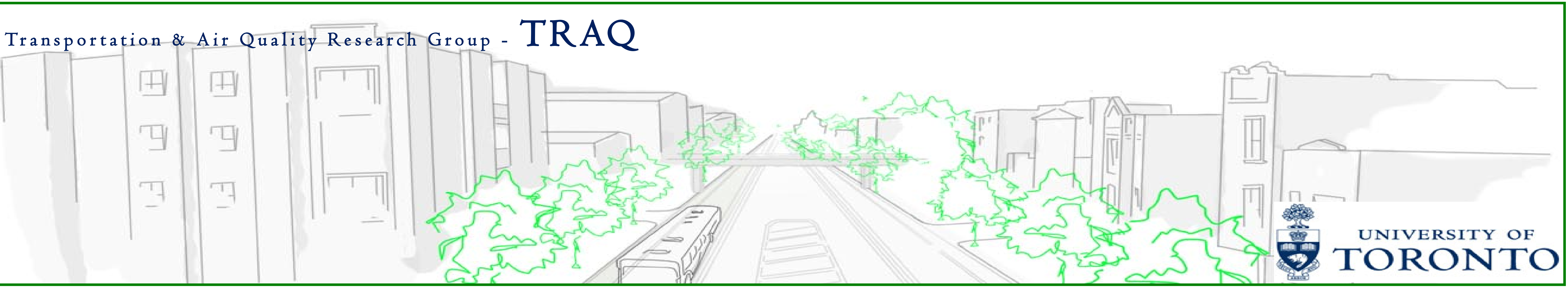


December 2, 2016

DISCLAIMER

THE BENEFITS OF CYCLING FAR OUTWEIGH THE RISKS

IF YOU ARE A HEALTHY INDIVIDUAL, THE PHYSICAL ACTIVITY BENEFITS
LARGELY OFFSET AIR POLLUTION EXPOSURE

IF YOU HAVE ASTHMA, DIABETES, A CARDIOVASCULAR CONDITION,
YOU MAY NOT WANT TO RIDE ON POOR AIR QUALITY DAYS

IN FACT, WE HAVE IDENTIFIED SMALL YET MEASURABLE CARDIOVASCULAR
EFFECTS ASSOCIATED WITH AIR POLLUTION AMONG A PANEL
OF HEALTHY CYCLISTS

Motivation and objectives

Why are we doing this research?

- Because air pollution remains a concern in Canadian cities
- Because generally cyclists have the highest exposure among other road users

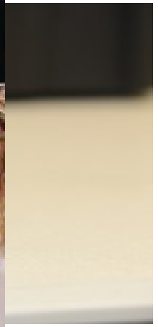
And also because we can!

Aeroqual sensor (NO2 and O3)

DiscMini (UFP)

MicroAeth (BC)

Technology is an enabler of personal exposure studies



Aeroqual s
and

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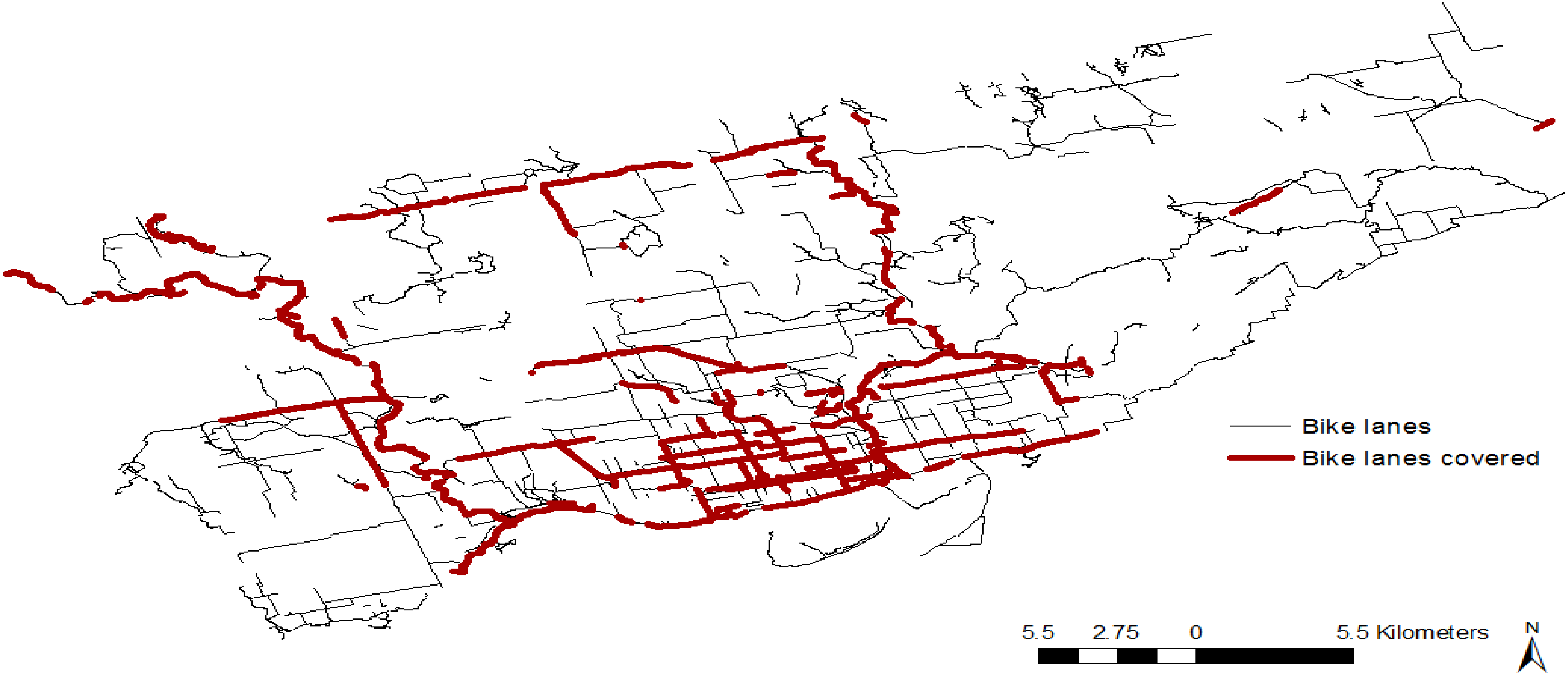
Data collection

Cycling routes



Cycling routes

- 10 routes, 24 to 31 km each
- Each route was repeated 6 to 8 times, at least once per time block
- 270 km of unique roads
- Total of 1860 km (approx. 60Km/day per cyclist!)
- **3,895** unique road segments
- **19,465 observations** segments/visits

Time block	Time
1	7 am to 9 am
2	9 am to 11 am
3	11 am to 1 pm
4	1 pm to 3 pm
5	3 pm to 5 pm
6	5 pm to 7 pm

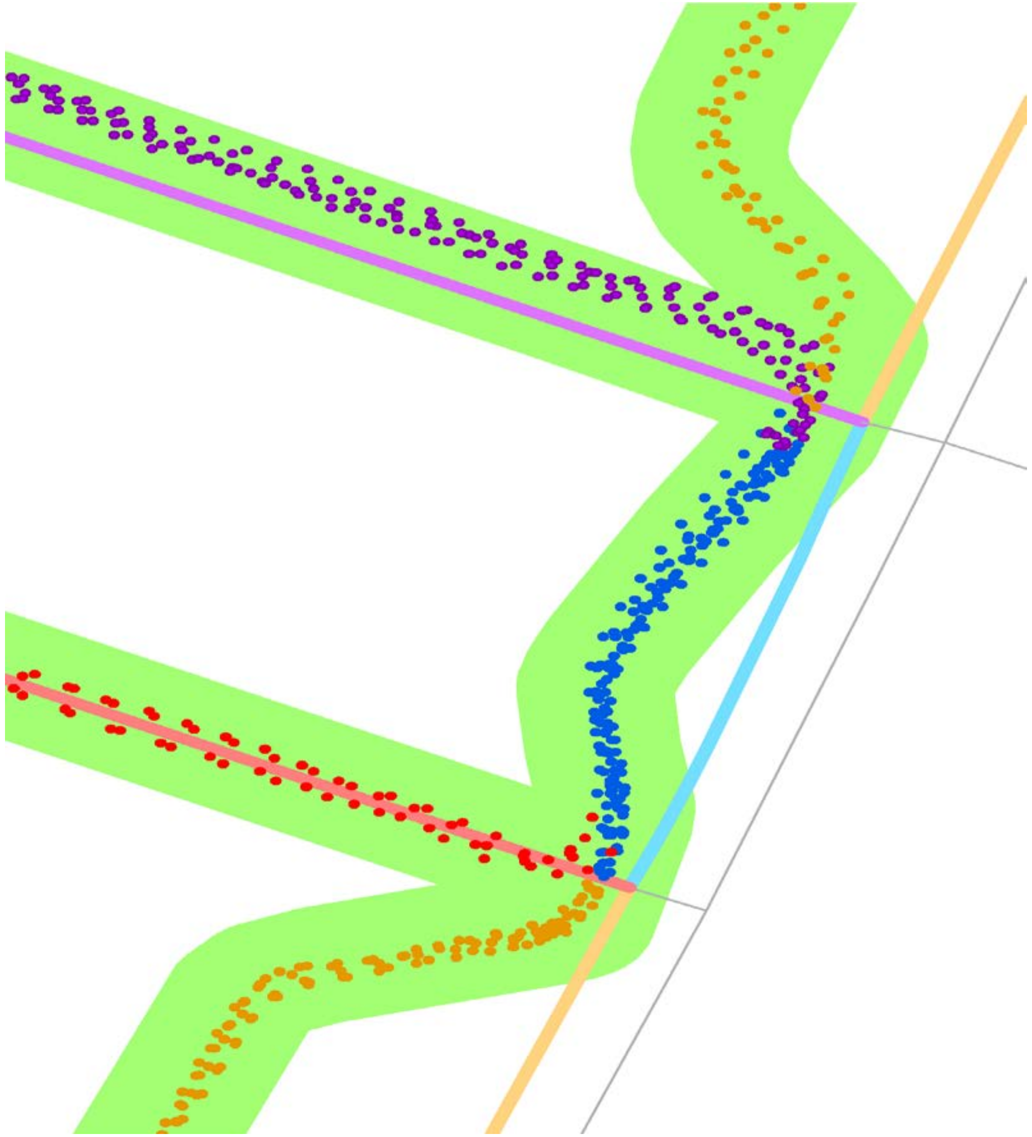
Database

- Every GPS point is given a unique ID and associated with:
  - Road segment
  - Day
  - Time
  - Meteorology (wind speed, direction, RH, temperature)

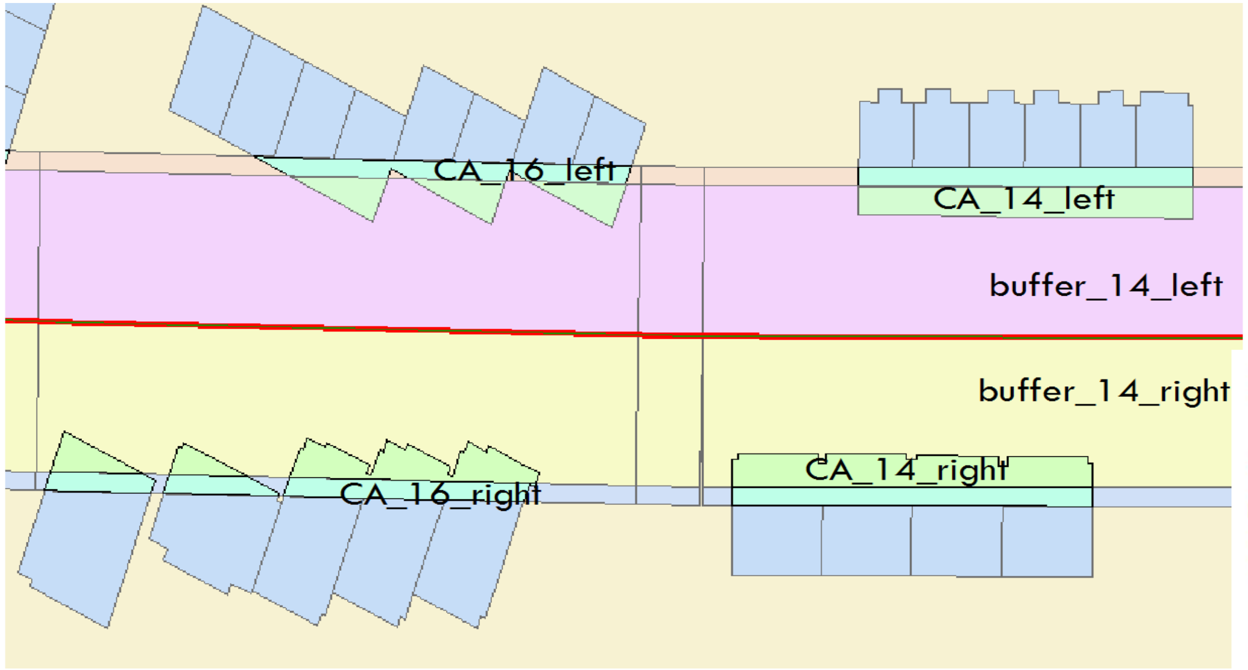
- Average air pollutant concentration per segment per visit is the outcome variable (UFP, BC, noise)

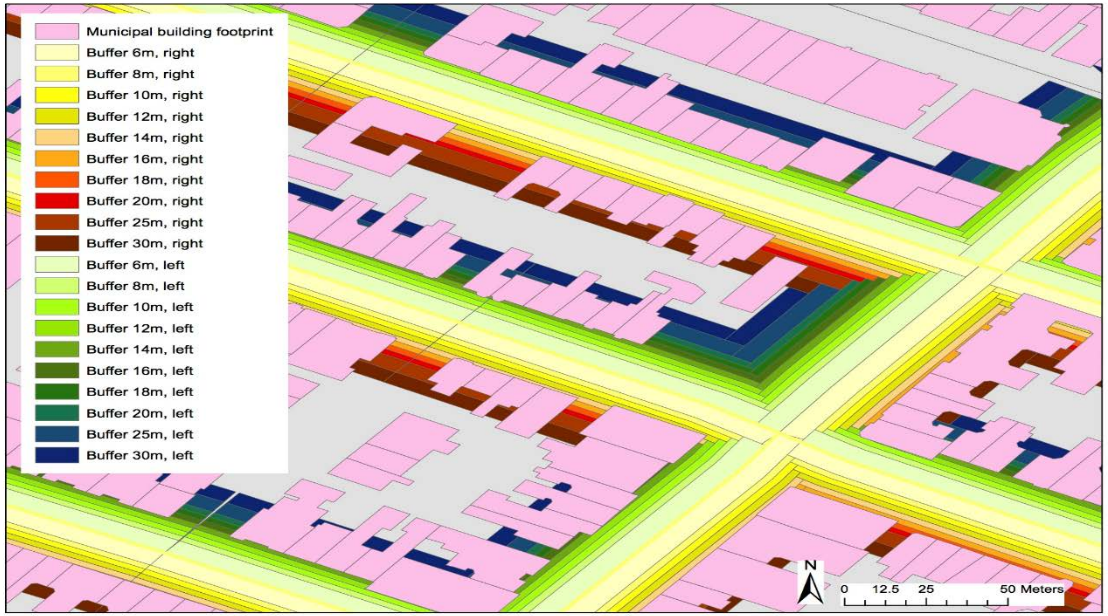
- Coefficient of variation for each segment/visit

Allocating GPS points to road segments

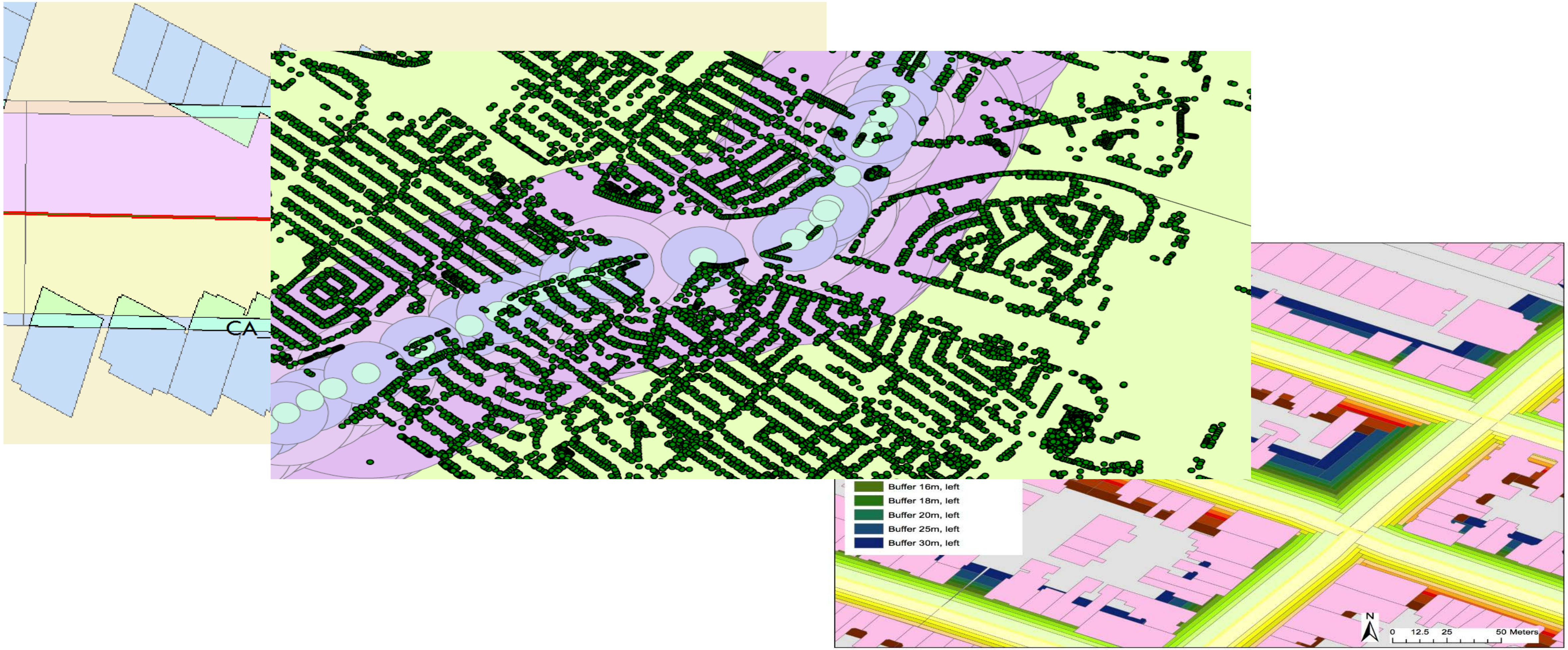


Land-use and built environment around each road segment





Land-use and built environment around each road segment

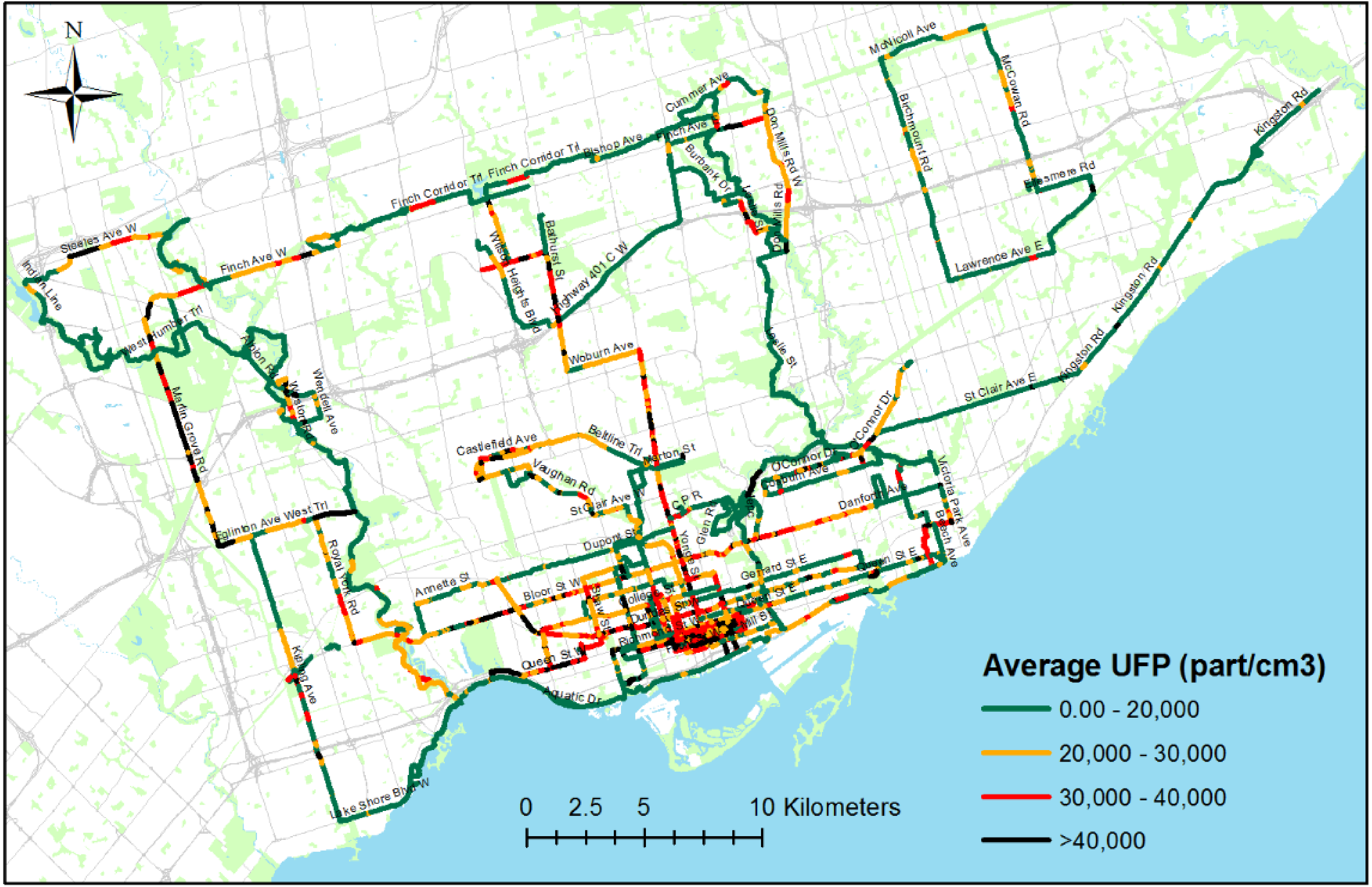


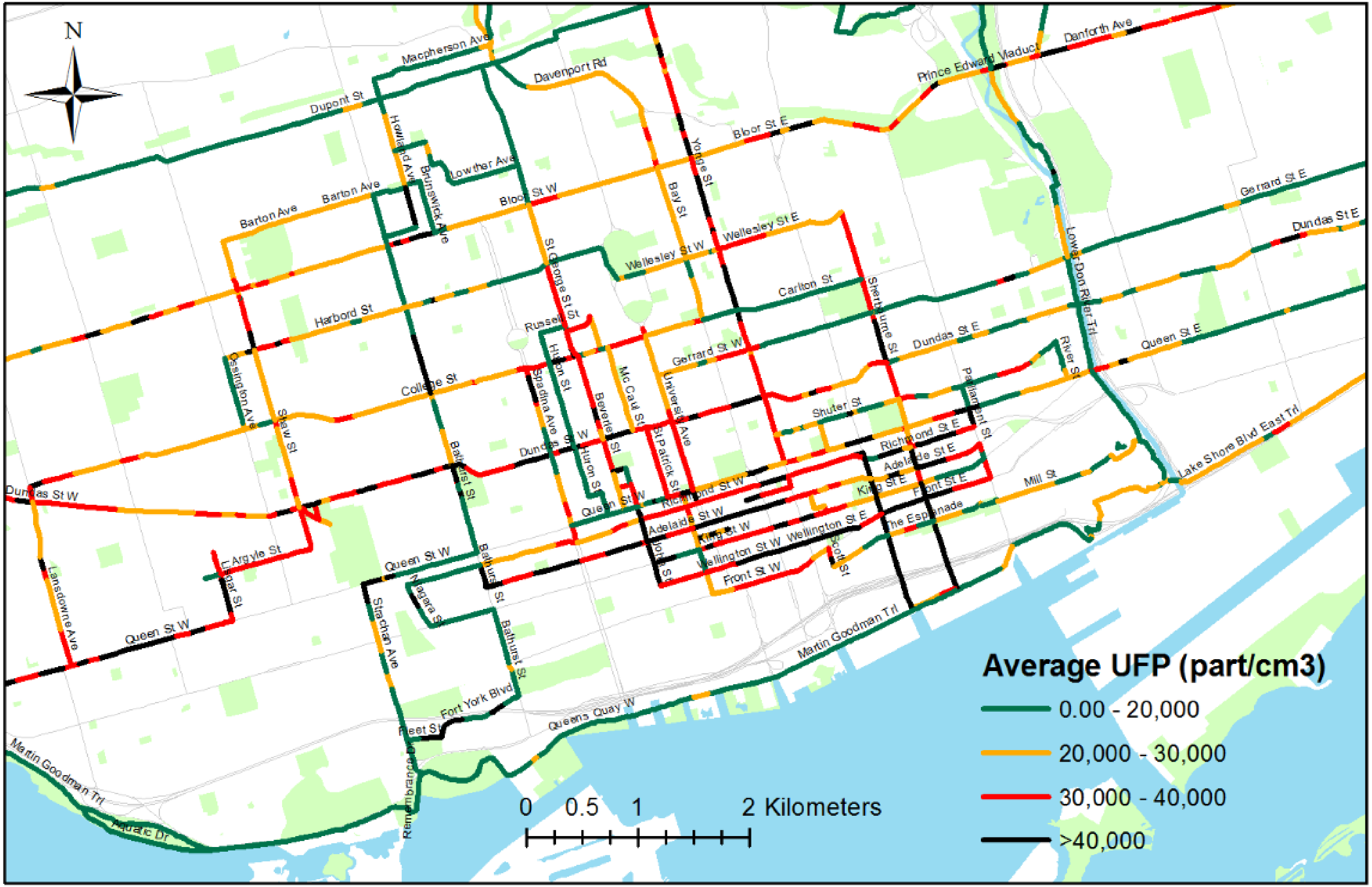
List of road segment characteristics

Buffers of
25, 50, 100, 200, 300, 500, 1000m

- Distance from the shore (m) (d_shore)
- Distance from the closest railline (m) (d_railline)
- Distance from the closest major road (m) (d_majrd)
- Distance from the closest highway (m) (d_highway)
- Distance from the closest airport (m) (d_airport)
- Distance to the closest NOx emitting chimney (m) (d_NPRI_NOx)
- Distance to the closest PM emitting chimney (m) (d_NPRI_PM)
- Area of the buildings (m2) (build_25m to build_1000m)
- Area of the commercial land use (m2) (com_25m to com_1000m)
- Area of the governmental and institutional land use (m2) (gov_25m to gov_1000m)
- Area of the resource and industrial land use (m2) (ind_25m to ind_1000m)
- Area of the open area land use (m2) (open_25m to open_1000m)
- Area of the parks land use (m2) (park_25m to park_1000m)
- Area of the residential land use (m2) (resid_25m to resid_1000m)
- Area of the waterbody land use (m2) (water_25m to water_1000m)
- Length of the bus routes (m) (busline_25m to busline_route_1000m)
- Length of the major roads (type 4) (m) (majrd_25m to majrd_1000m)
- Length of the highways (types 1, 2 and 3) (m) (highway_25m to highway_1000m)
- Length of the roads (types 1, 2, 3, 4, 5 and 6) (m) (roads_25m to roads_1000m)
- Number of bus stops (count) (bus_25m to bus_1000m)
- Number of intersections (count) (inter_25m to inter_1000m)
- Number of trees (count) (trees_25m to trees_1000m)
- Population (count) (pop_500m to pop_1000m)
- Average height of buildings (m) (build_height_25m to build_height_100m)
- Maximum height of buildings (m) (max_build_height_25m to max_build_height_100m)
- Number of NOx emitting chimneys (count) (NPRI_NOx_25m to NPRI_NOx_1000m)
- Number of PM emitting chimneys (count) (NPRI_PM_25m to NPRI_PM_1000m)
- Length of rail lines (m) (rai_25m to rail_1000m)
- Traffic volumes based on EMME2 (count) (traffic_25m to traffic_100m)

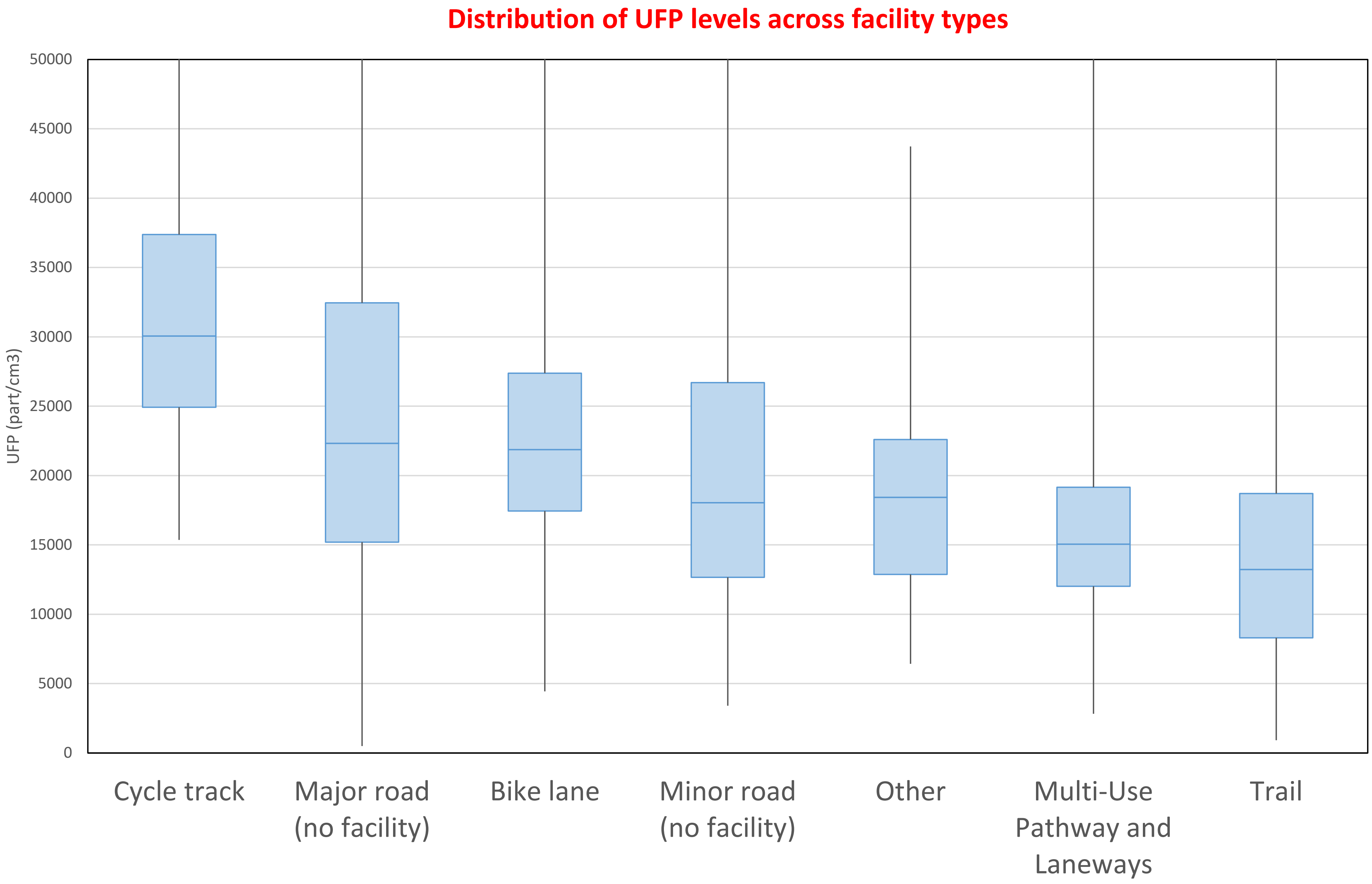
Descriptive Results


N
Average UFP (part/cm3)
0.00 - 20,000
20,000 - 30,000
30,000 - 40,000
>40,000
0 2.5 5 10 Kilometers

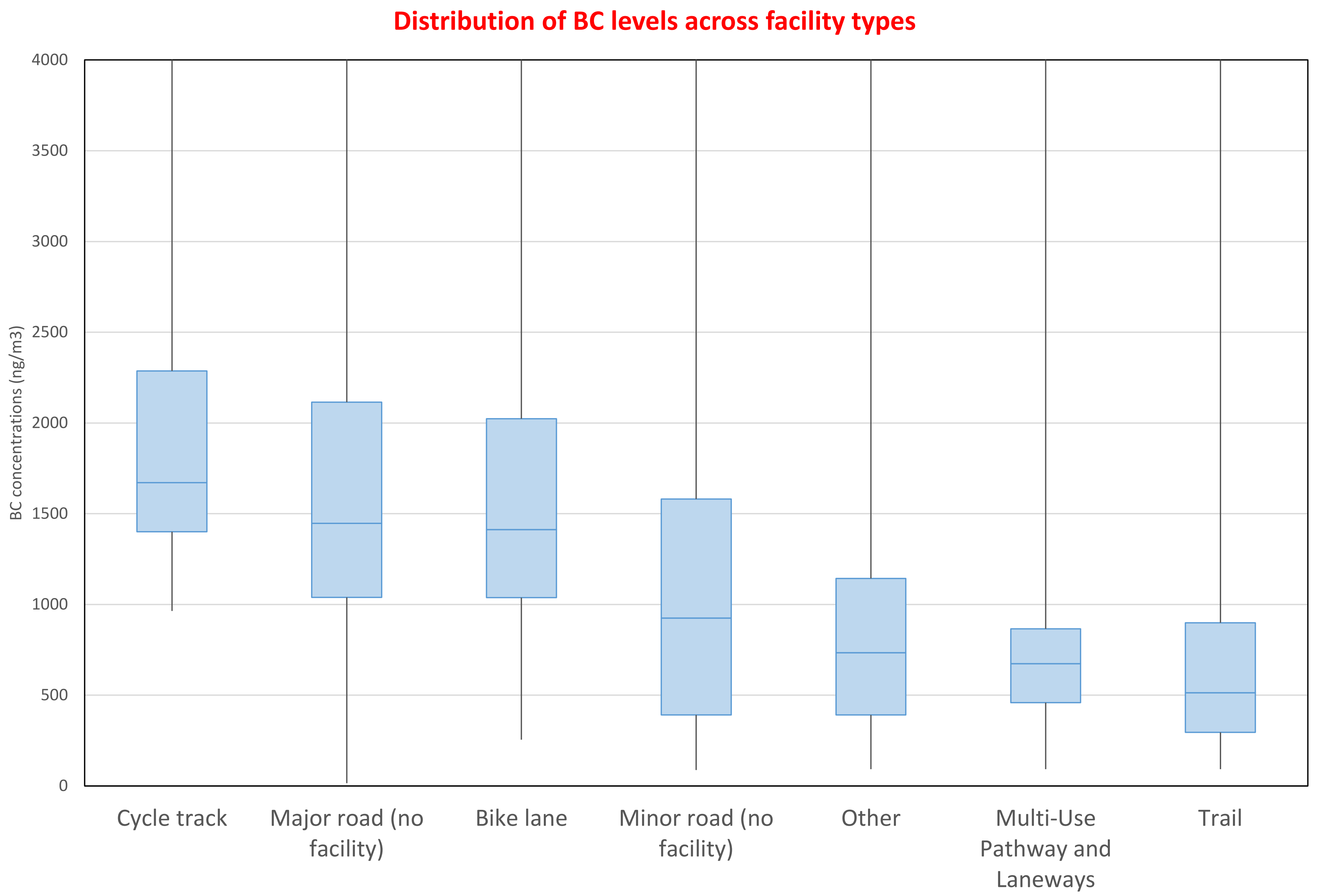

N
Average UFP (part/cm3)
0.00 - 20,000
20,000 - 30,000
30,000 - 40,000
>40,000
0
0.5
1
2 Kilometers
Macpherson Ave
Davenport Rd
Dupont St
Danforth Ave
Prince Edward Viaduct
Bloor St E
Bloor St W
Lowther Ave
Barton Ave
Howland Ave
Brunswick Ave
Yonge St
Bay St
Gerrard St E
Dundas St E
Wellesley St E
Wellesley St W
Lower Don River Trl
Carlton St
Harbord St
Sherbourne St
St George St
Russell St
Gerrard St W
Queen St E
River St
College St
Ossington Ave
Shaw St
Spadina Ave
Mc Caul St
University Ave
Shuter St
Parliament St
Richmond St E
Adelaide St E
King St E
Front St E
The Esplanade
Mill St
Lake Shore Blvd East Trl
Dundas St W
Bathurst St
Beverley St
St Patrick St
Queen St W
Richmond St W
Adelaide St W
King St W
Wellington St W
Wellington St E
Front St W
York St
Scott St
Argyle St
Lisgar St
Lansdowne Ave
Niagara St
Strachan Ave
Fort York Blvd
Fleet St
Queens Quay W
Martin Goodman Trl
Aquatic Dr
Remembrance Dr

Average UFP levels across selected corridors

Measurement on	From (cross street)	To (cross street)	Average UFP concentration (particles/cm3)
Adelaide	Bathurst	Parliament	39,000
Richmond	Bathurst	Parliament	33,000
Wellington/Front East	John	Parliament	41,600
King	John	Parliament	25,700
Bloor West	Royal York	Yonge	30,700
Anette/Dupont	Jane	Yonge	17,600
Spadina	College	Queen	30,400
Beverley	College	Queen	30,000
McCaul	College	Queen	28,300
Huron/Soho	College	Queen	13,000

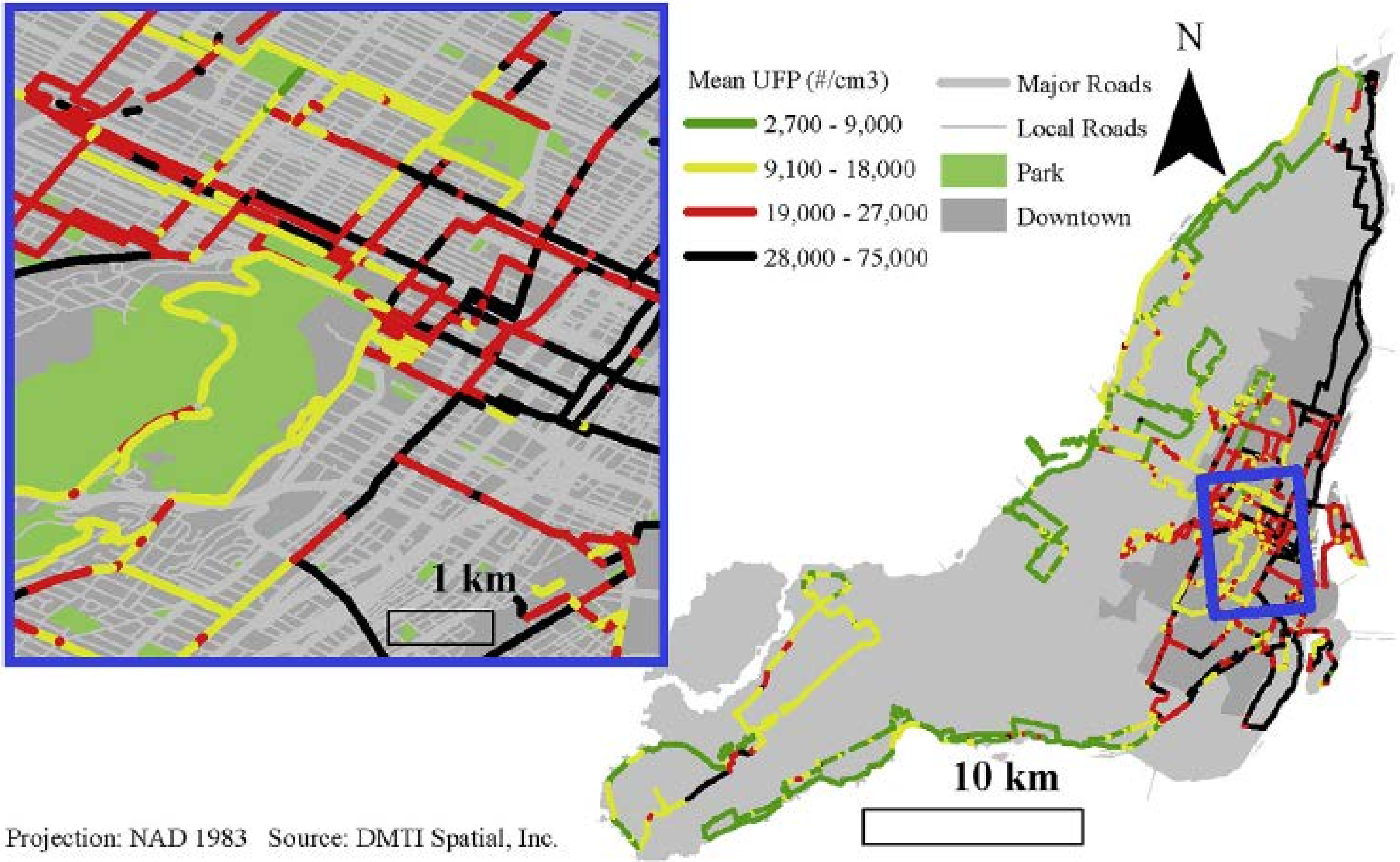


Distribution of UFP levels across facility types
UFP (part/cm3)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Cycle track
Major road (no facility)
Bike lane
Minor road (no facility)
Other
Multi-Use Pathway and Laneways
Trail


Distribution of BC levels across facility types
BC concentrations (ng/m3)
4000
3500
3000
2500
2000
1500
1000
500
0
Cycle track
Major road (no facility)
Bike lane
Minor road (no facility)
Other
Multi-Use Pathway and Laneways
Trail

Comparison with Montreal study

Montreal (n=4058 segments)

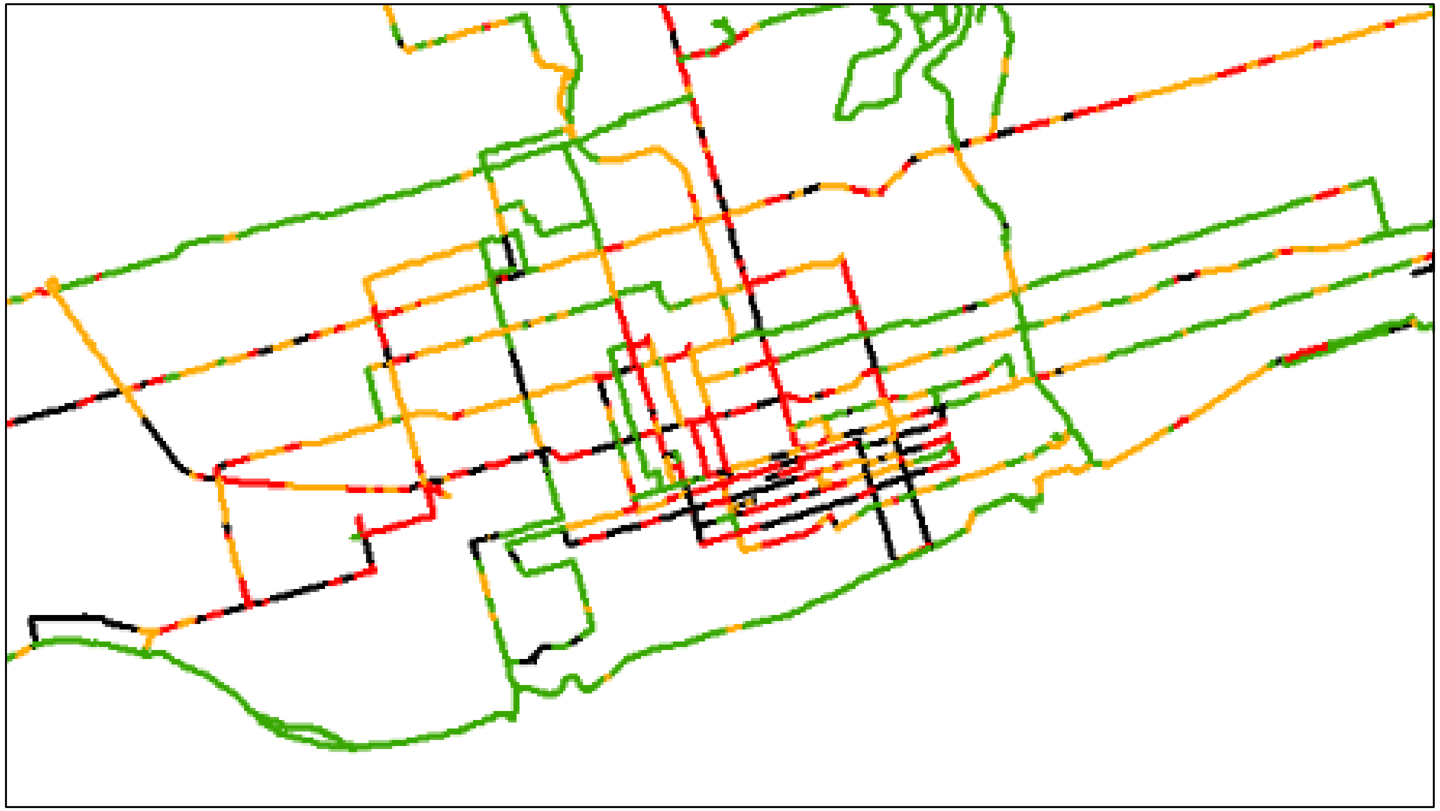


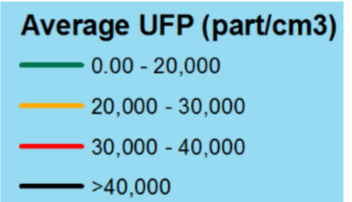
Toronto 2016 (n=3895 segments)

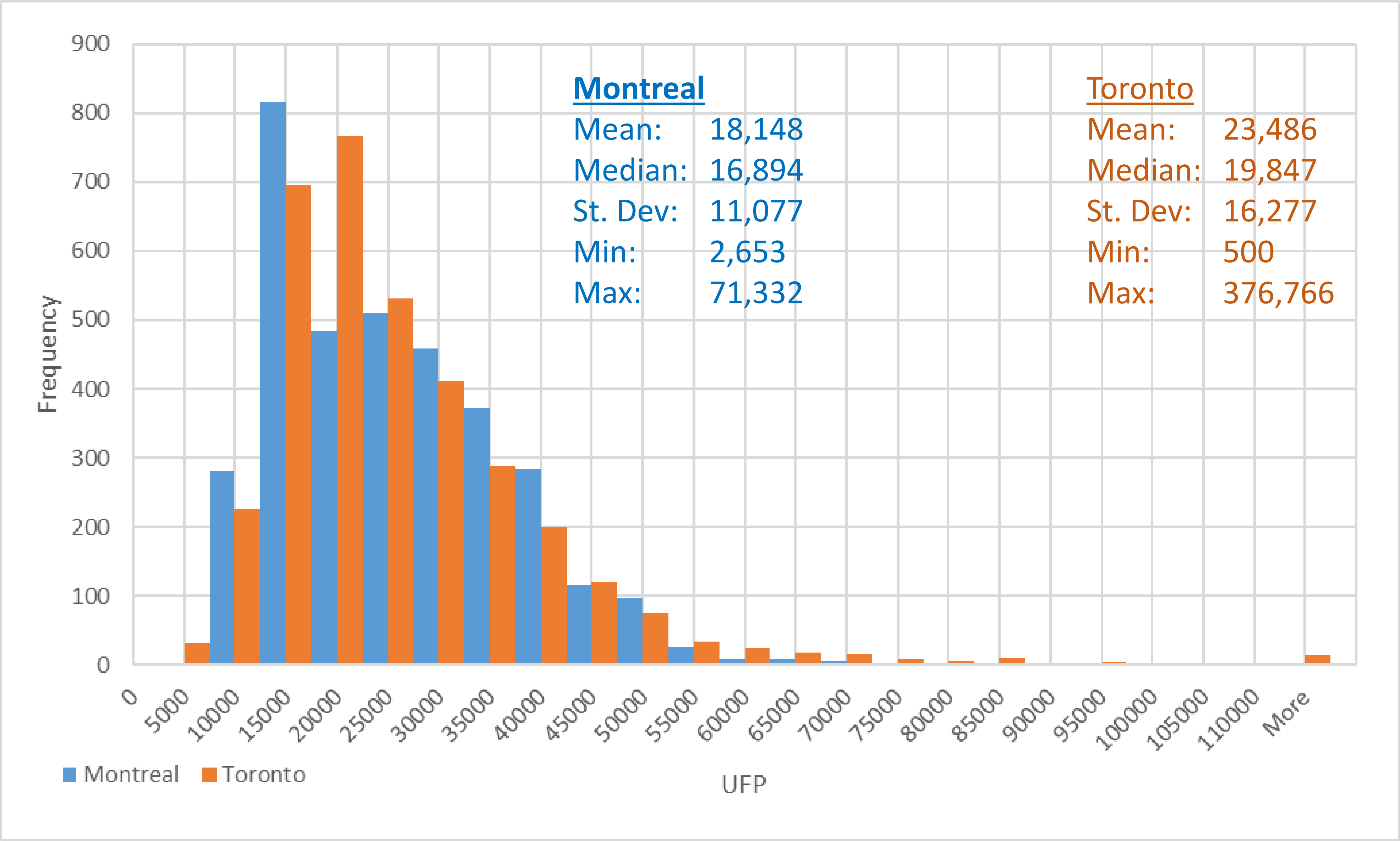
Montreal (n=4058 segments)

Downtown Montreal

Downtown Toronto







Montreal
Mean: 18,148
Median: 16,894
St. Dev: 11,077
Min: 2,653
Max: 71,332
Toronto
Mean: 23,486
Median: 19,847
St. Dev: 16,277
Min: 500
Max: 376,766
Frequency
900
800
700
600
500
400
300
200
100
0
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
55000
60000
65000
70000
75000
80000
85000
90000
95000
100000
105000
110000
More
UFP
Montreal
Toronto

Linear mixed effects models

Linear mixed-effects model (19,465 obs. with 3,895 different segments)

	AIC = 31611.28 Adjusted R^2 = 0.2892	For ln(UFP) for increase of IQ if not otherwise indicated	
		Mean Change	95% CI for Mean Change
Meteorology	Wind Speed	-0.247	-0.266, -0.229
	Temperature	0.038	0.021, 0.056
	Relative Humidity	-0.113	-0.131, -0.094
Day and time	Timeblock - A (6, 7 and 8) - Reference	1	
	Timeblock - B (9 and 10)	-0.308	-0.347, -0.270
	Timeblock - C (11 and 12)	-0.057	-0.099, -0.014
	Timeblock - D (13 and 14)	0.034	-0.007, 0.074
	Timeblock - E (15 and 16)	-0.293	-0.335, -0.251
	Timeblock - F (17, 18 and 19)	-0.295	-0.340, -0.250
	Day of the week - A-Weekend - Reference	1	
	Day of the week - B-Monday	0.178	0.125, 0.232
	Day of the week - C-Tuesday	0.434	0.389, 0.478
	Day of the week - D-Wednesday	0.183	0.140, 0.226
	Day of the week - E-Thursday	0.431	0.391, 0.472
	Day of the week - F-Friday	0.306	0.263, 0.349
Built environment	Distance to Pearson airport	-0.187	-0.200, -0.174
	Distance to the shore	-0.057	-0.069, -0.046
	Building footprint (within 1000m buffer)	0.058	0.045, 0.071
	Park area (within 1000m buffer)	-0.026	-0.041, -0.011
	Max building height (within 25m buffer)	0.030	0.007, 0.053
	Number of trees (within 750m buffer)	0.072	0.052, 0.092
	Open area (within 1000m buffer)	0.030	0.020, 0.040
	Length of highways (within 25m buffer)	0.0009	0.0006, 0.0012
Road type	Type of road - A - Major and Cycle track - Reference	1	
	Type of road - B - Multi-Use	-0.310	-0.340, -0.280
	Type of road - C - Bike lane	-0.130	-0.160, -0.101
	Type of road - D - Minor	-0.178	-0.220, -0.136
	Type of road - E - Trail	-0.277	-0.337, -0.218
	Type of road - G - Other	-0.188	-0.278, -0.099

Meteorology effects

Negative effects (decreases UFP)

- Wind speed
- Relative humidity

Positive effects (increases UFP)

- Temperature (unexpected)

Day and Time

Day of the week

- Weekend is best
- Monday is best day of working week
- Tuesday and Thursday are the worst

Time of day (temperature adjusted)

- 6-8am is worst
- 11-2pm is best

Built environment effects

Negative effects (decreases UFP)

- Distance to Pearson
- Distance to the shore
- Parks

Positive effects (increases UFP)

- Building footprint
- Maximum building height
- Number of trees
- Open area
- Proximity to highways

Road type

Worst to best

- Major roads and cycle tracks
- Bike lanes and minor roads (no facility)
- Trails and multi-use pathways

OLS regressions of mean UFP concentrations for the purpose of building a LUR model

Results of OLS regression on average UFP per segment

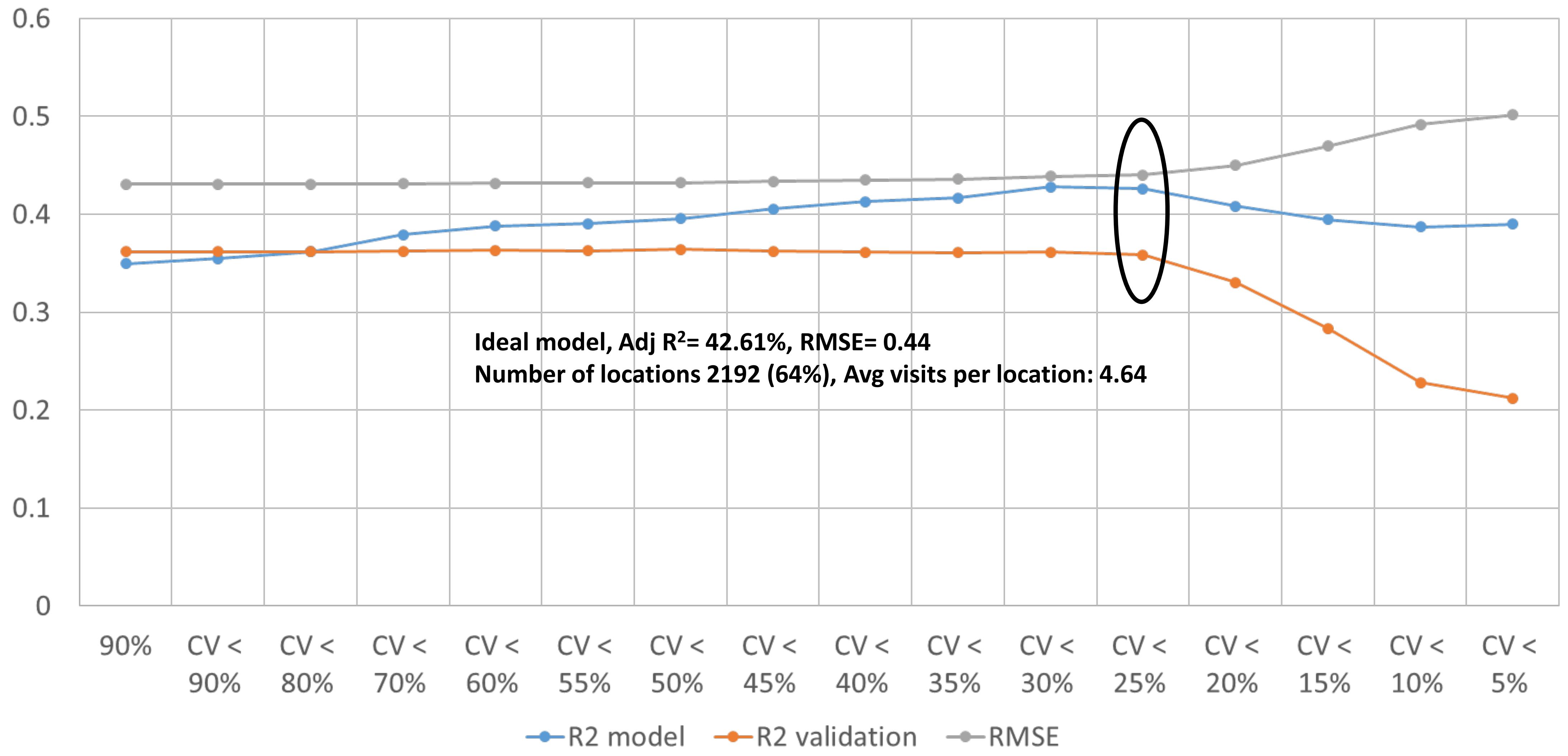
Adjusted $R^2 = 0.3548$ N = 3,411 different segments (10% hold-out sample)	For LN of UFP average for increase of IQ if not otherwise indicated	
	Mean Change	95% CI for Mean Change
Wind Speed	-0.132	-0.144, -0.119
Relative Humidity	-0.071	-0.085, -0.056
Temperature	0.039	0.024, 0.054
Distance to Pearson airport	-0.100	-0.121, -0.078
Distance to the shore	-0.057	-0.077, -0.037
Distance to the nearest major road	-0.027	-0.037, -0.016
Building footprint (within 1000m buffer)	0.107	0.087, 0.127
Number of trees (within 750m buffer)	0.183	0.150, 0.215
Open area (within 1000m buffer)	0.031	0.013, 0.048
Residential area (within 200m buffer)	-0.039	-0.067, -0.010
Length of highways (within 25m buffer)	0.0007	0.0001, 0.0012
Traffic volume (within 300m buffer)	0.040	0.025, 0.055

Summer of OLS regression on various “sub-samples” based on coefficient of variation of the mean UFP across the different visits

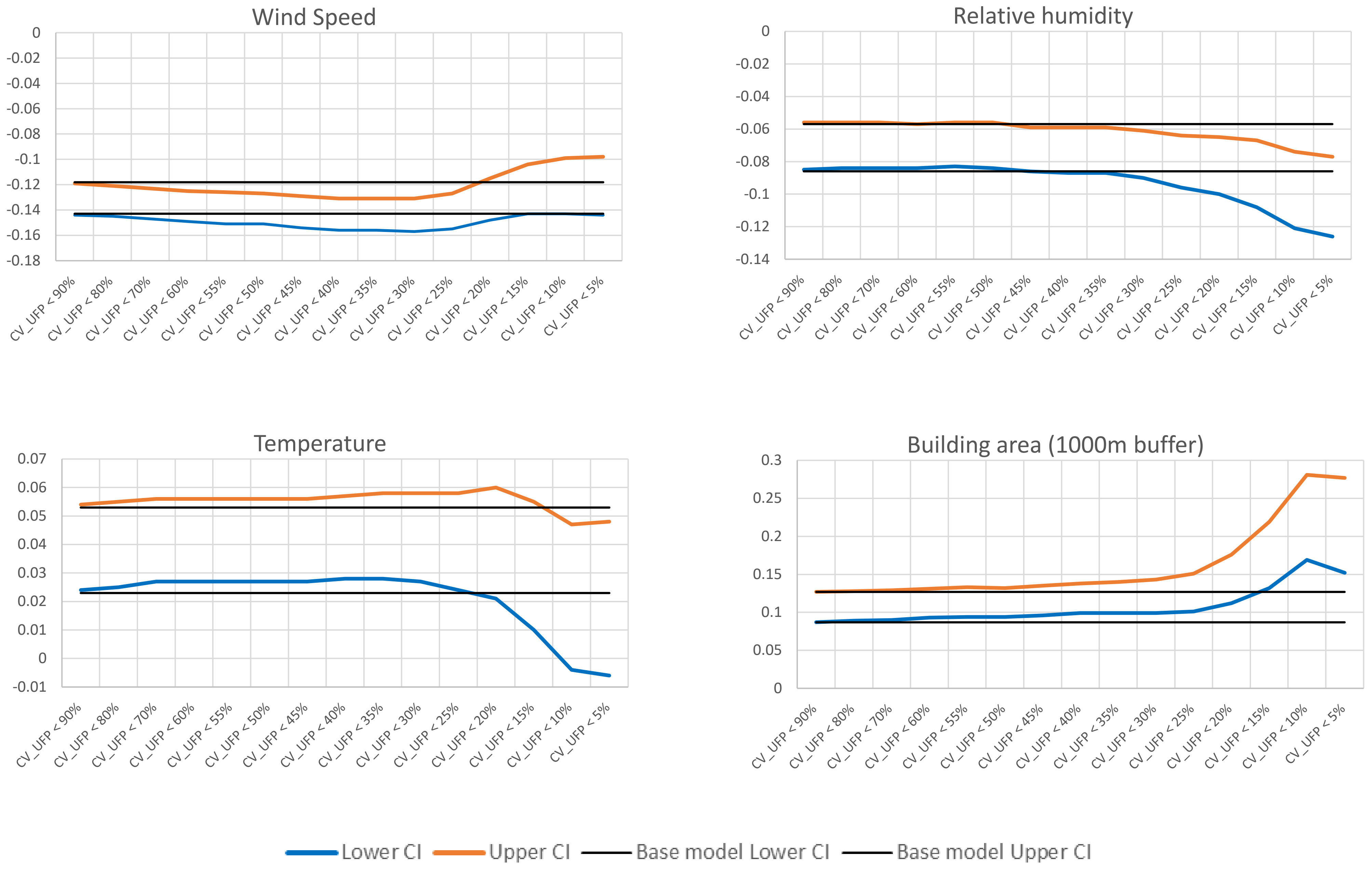
Segments included	Number of different segments	Mean number of visits	Adjusted R^2
All segments	3791	5.10	0.3528
90% sample used	3412	5.13	0.3495
Segments with CV_UFP $\leq$ 90% (from the 90% sample)	3411	5.13	0.3548
Segments with CV_UFP $\leq$ 80% (from the 90% sample)	3403	5.13	0.3616
Segments with CV_UFP $\leq$ 70% (from the 90% sample)	3376	5.12	0.3792
Segments with CV_UFP $\leq$ 60% (from the 90% sample)	3345	5.11	0.3880
Segments with CV_UFP $\leq$ 55% (from the 90% sample)	3307	5.11	0.3906
Segments with CV_UFP $\leq$ 50% (from the 90% sample)	3251	5.11	0.3955
Segments with CV_UFP $\leq$ 45% (from the 90% sample)	3176	5.10	0.4056
Segments with CV_UFP $\leq$ 40% (from the 90% sample)	3064	5.10	0.4130
Segments with CV_UFP $\leq$ 35% (from the 90% sample)	2909	5.06	0.4166
Segments with CV_UFP $\leq$ 30% (from the 90% sample)	2613	4.92	0.4279
Segments with CV_UFP $\leq$ 25% (from the 90% sample)	2192	4.64	0.4261
Segments with CV_UFP $\leq$ 20% (from the 90% sample)	1649	4.00	0.4085
Segments with CV_UFP $\leq$ 15% (from the 90% sample)	1149	2.68	0.3947
Segments with CV_UFP $\leq$ 10% (from the 90% sample)	872	1.55	0.3874
Segments with CV_UFP $\leq$ 5% (from the 90% sample)	795	1.21	0.3901

Predictions for hold-out sample using estimates from different models

	Number of different segments	Pearson Corr. between observed and predicted LN of UFP	RMSE between observed and predicted LN of UFP
10% Hold-out sample - using estimates from all of 90% sample	379	0.6015	0.4307
10% Hold-out sample - using estimates from CV_UFP $\leq$ 90%	379	0.6017	0.4306
10% Hold-out sample - using estimates from CV_UFP $\leq$ 80%	379	0.6014	0.4310
10% Hold-out sample - using estimates from CV_UFP $\leq$ 70%	379	0.6021	0.4314
10% Hold-out sample - using estimates from CV_UFP $\leq$ 60%	379	0.6026	0.4318
10% Hold-out sample - using estimates from CV_UFP $\leq$ 55%	379	0.6024	0.4322
10% Hold-out sample - using estimates from CV_UFP $\leq$ 50%	379	0.6035	0.4324
10% Hold-out sample - using estimates from CV_UFP $\leq$ 45%	379	0.6021	0.4337
10% Hold-out sample - using estimates from CV_UFP $\leq$ 40%	379	0.6013	0.4348
10% Hold-out sample - using estimates from CV_UFP $\leq$ 35%	379	0.6009	0.4358
10% Hold-out sample - using estimates from CV_UFP $\leq$ 30%	379	0.6011	0.4386
10% Hold-out sample - using estimates from CV_UFP $\leq$ 25%	379	0.5989	0.4401
10% Hold-out sample - using estimates from CV_UFP $\leq$ 20%	379	0.5750	0.4500
10% Hold-out sample - using estimates from CV_UFP $\leq$ 15%	379	0.5326	0.4697
10% Hold-out sample - using estimates from CV_UFP $\leq$ 10%	379	0.4777	0.4920
10% Hold-out sample - using estimates from CV_UFP $\leq$ 5%	379	0.4608	0.5014


0.6
0.5
0.4
0.3
0.2
0.1
0
Ideal model, Adj R²= 42.61%, RMSE= 0.44
Number of locations 2192 (64%), Avg visits per location: 4.64
90%
CV < 90%
CV < 80%
CV < 70%
CV < 60%
CV < 55%
CV < 50%
CV < 45%
CV < 40%
CV < 35%
CV < 30%
CV < 25%
CV < 20%
CV < 15%
CV < 10%
CV < 5%
R2 model
R2 validation
RMSE

Variations in coefficient sizes across the different models



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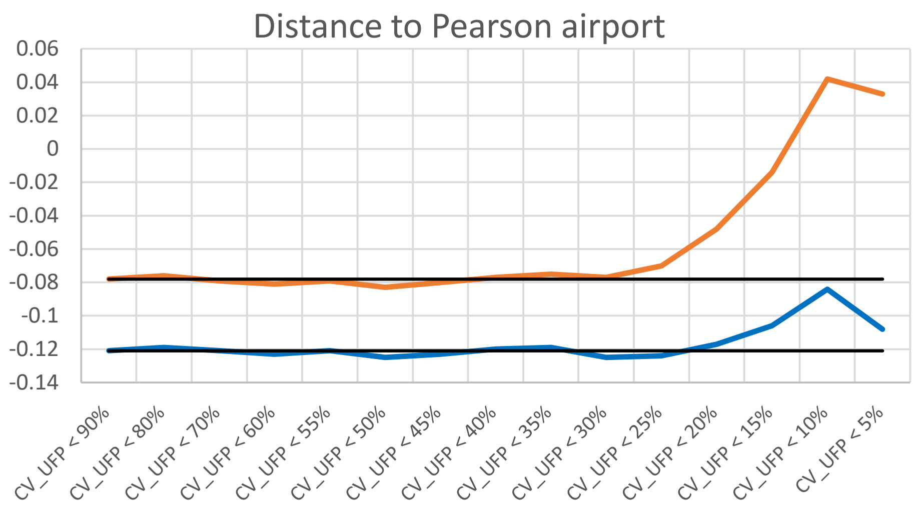
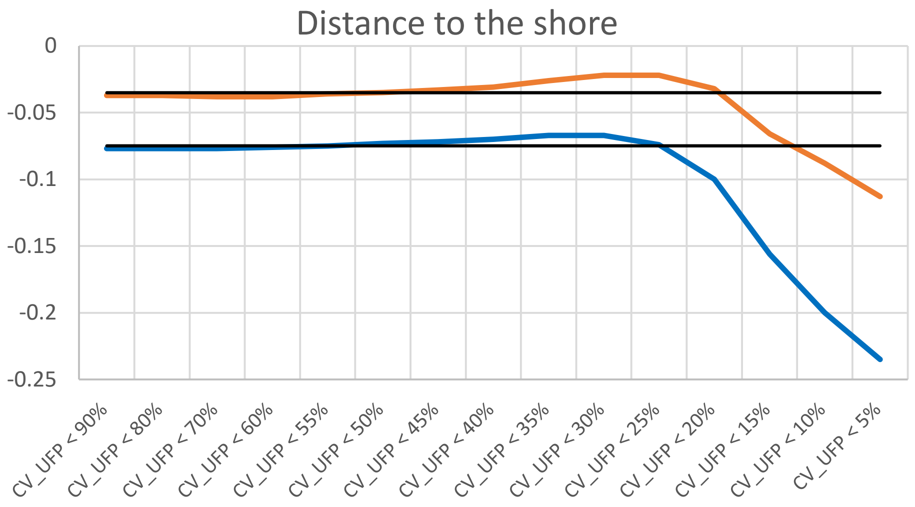
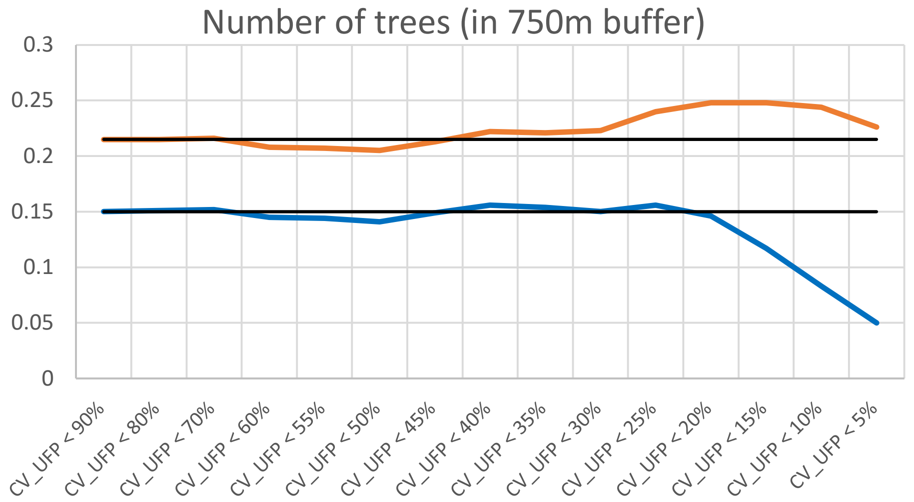
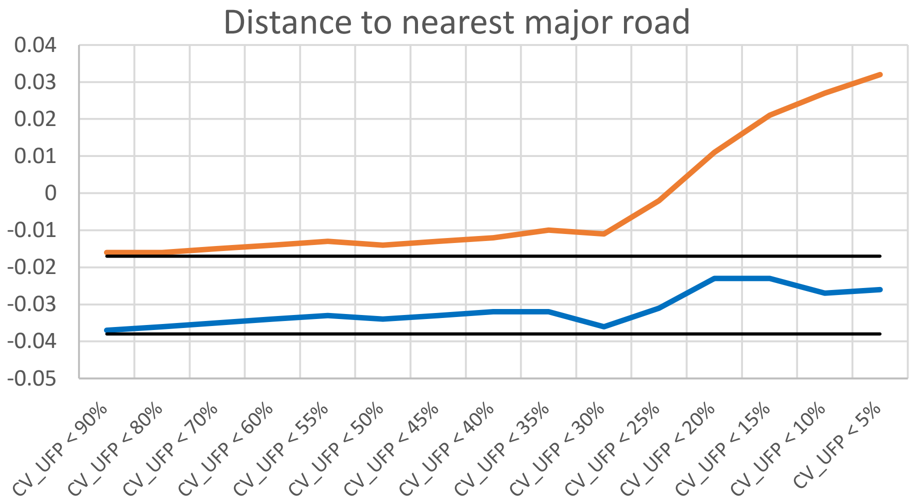
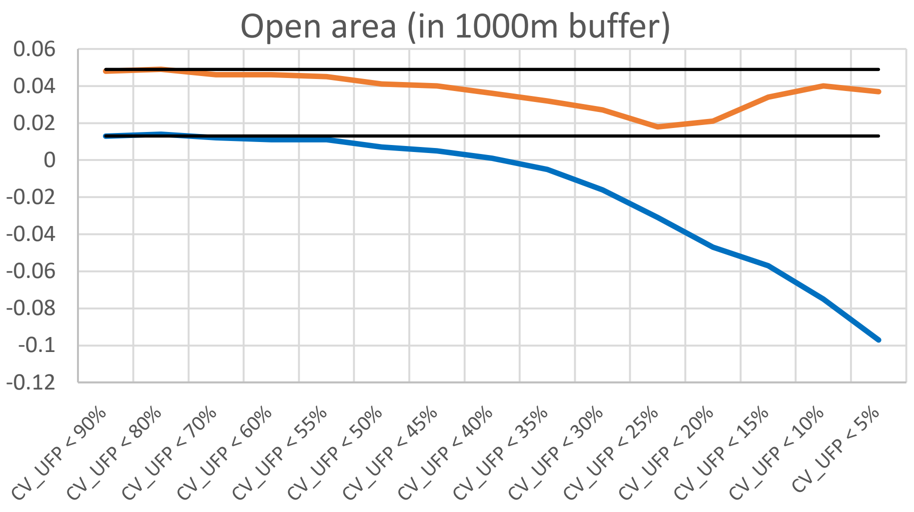


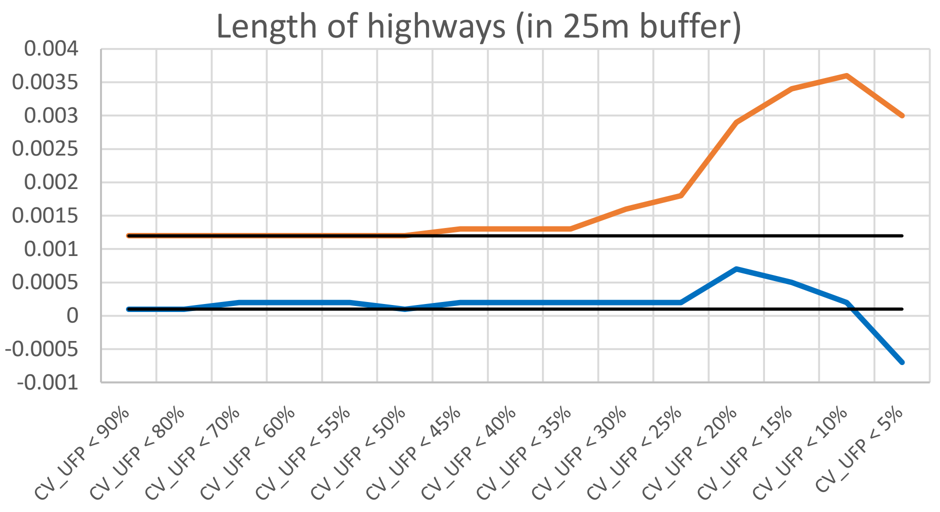


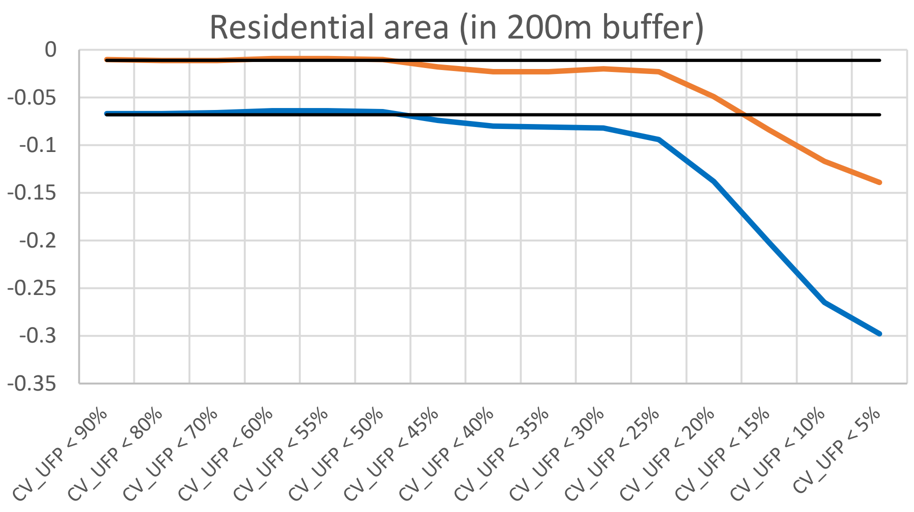


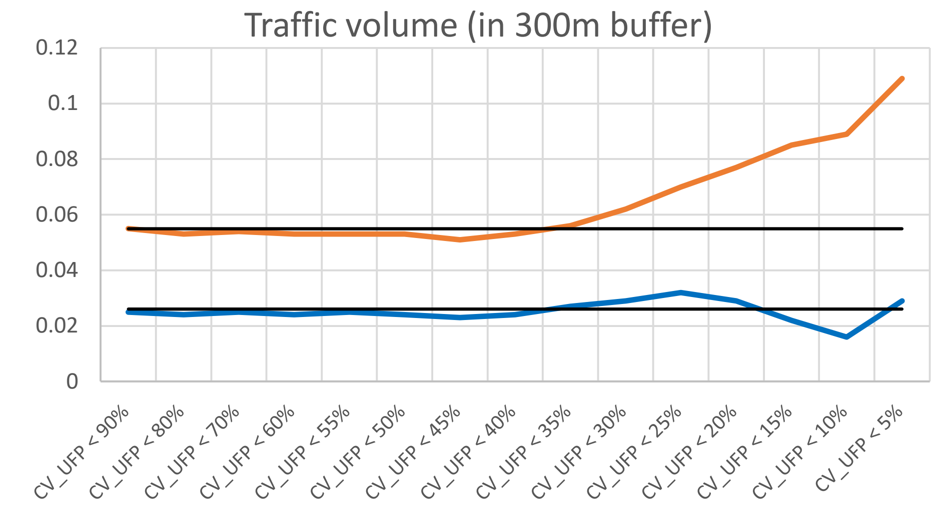


Variations in coefficient sizes across the different models









Objective of LUR modelling is to generate a surface, to spatially interpolate our measurements and achieve full coverage of the city

Other relevant work

- Fixed points

- Pedestrians

- Cyclists

- Panel

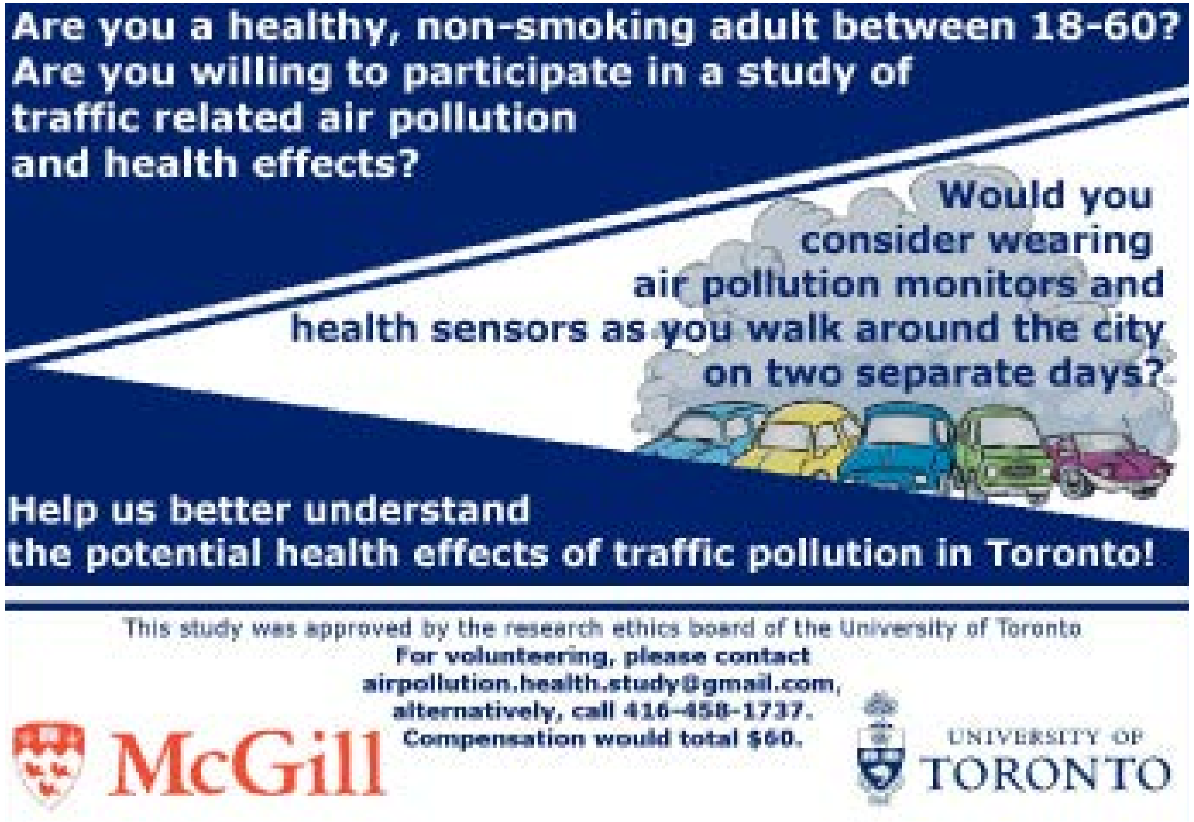
- Fixed points

- Cyclists

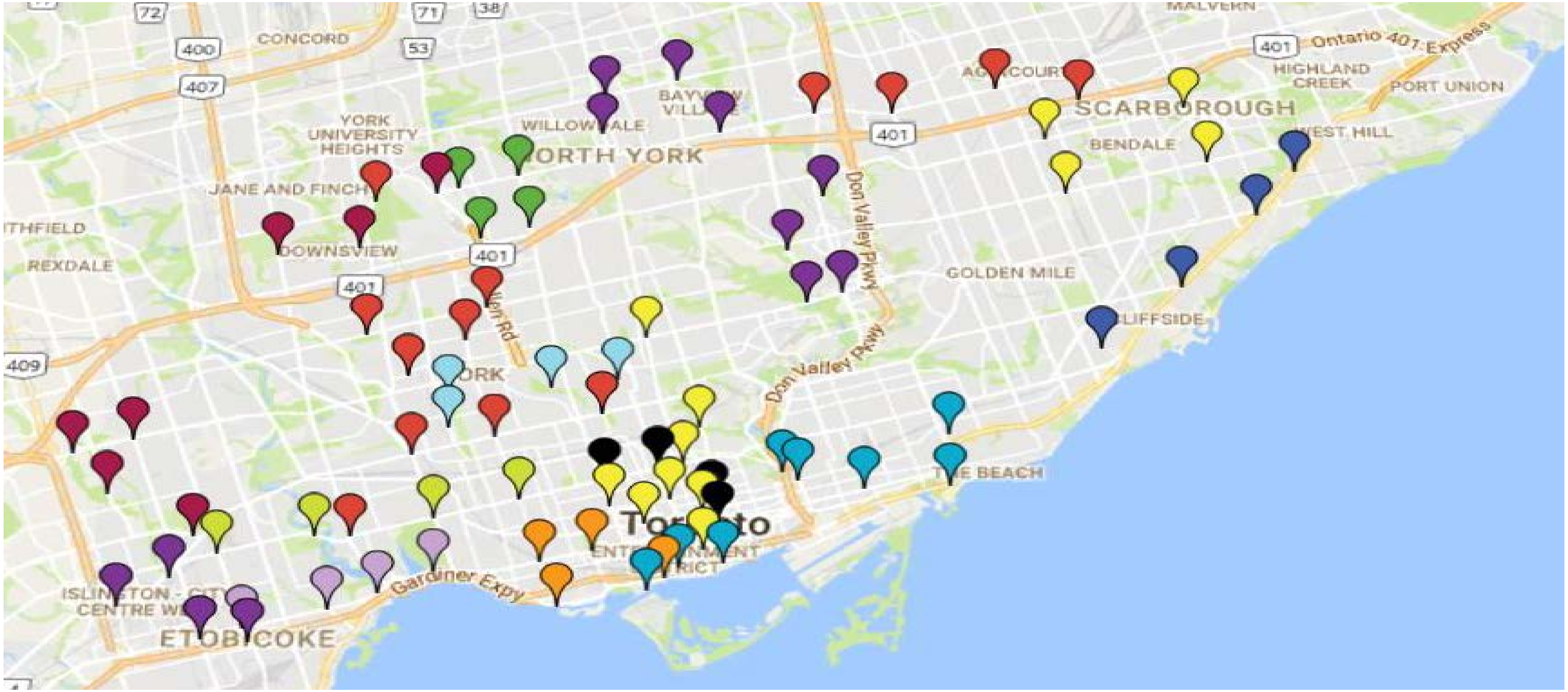
Four data collection protocols conducted in the same campaign (May-Sept 2016)

Panel study

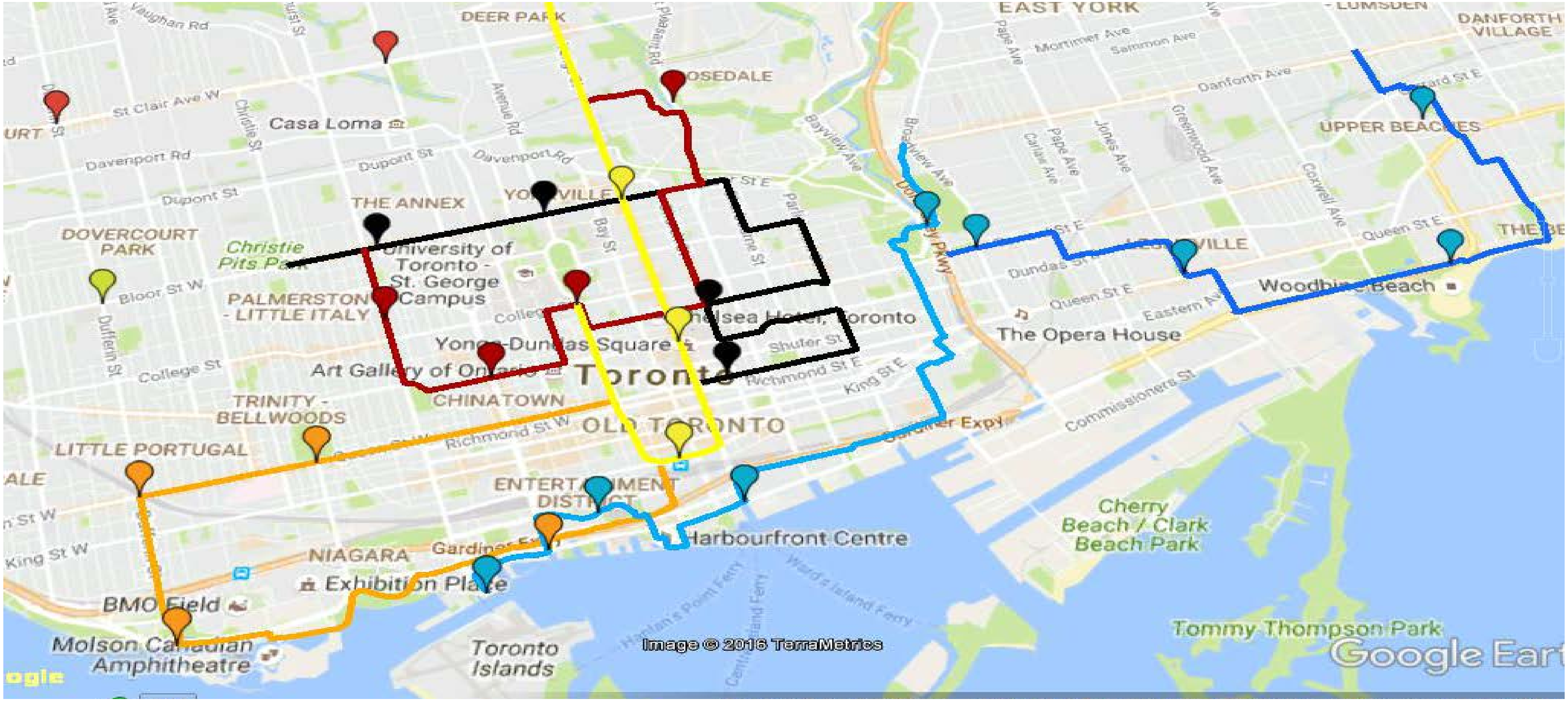
- Gold standard for measuring exposure
- Recruiting participants from the general population
- Personal exposure measured throughout the day, monitors are close to the body
- Physiological measures conducted to relate with acute health effects



Fixed points



Pedestrian routes designed to overlap with fixed locations



Conclusions and final thoughts

Air pollution remains a concern in Canadian cities even at levels below standards

Rapid changes in vehicle technology have led to gains in fuel efficiency but not necessarily in the emissions of air pollutants

Exposure while commuting largely affects one’s mean daily exposure

Policies encouraging active transportation should be fair: cyclists and pedestrians who are responsible for the success of these policies should not carry the burden

THANK YOU

THE BENEFITS OF CYCLING FAR OUTWEIGH THE RISKS