BC Clean Air Research Fund

Final Report

April 1, 2013 to March 14, 2014

A wireless sensor array to assess neighborhood air quality in Metro Vancouver

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PROJECT OVERVIEW

Abstract

We assessed the feasibility for deployment of wireless sensory arrays to complement the existing regional air quality monitoring network. These wireless sensors are comparatively inexpensive devices that transmit air quality measurements in real-time to servers with immediate data processing and online visualization. Through review of the published and grey literature and by collaboration with two research groups currently evaluating sensors researchers, we identified specific sensor instrumentation to deploy for local testing. Local testing was initiated by co-locating sensors with traditional air quality monitoring equipment at a Metro Vancouver air quality monitoring site. In addition, we developed a prototype model to identify street canyon locations in Metro Vancouver for future sensor deployment.

FINANCIAL OVERVIEW

Revenue Description

Table 1 Projected Total Project Revenue (cash and in-kind)

Organization	2012/13		2013/14		Total
	Cash	In-kind	Cash	In-kind	
BC CLEAR - Fraser Basin Council			$5,000		$5,000
Kings College London				$5,000	$5,000
British High Commission	$2,500				$2,500
UBC (CREATE-AAP)			$16,000		$16,000
UBC (SPPH)			$1,000		$1,000
TOTAL	$2,500		$22,000	$5,000	$29,500

Table 2 Actual Revenue for Reporting Period (cash and in-kind)

Organization	2012/13		2013/14		Total
	Cash	In-kind	Cash	In-kind	
BC CLEAR - Fraser Basin Council			$5,000		$5,000

Kings College London				$5,000	$5,000
British High Commission	$2,500				$2,500
UBC (CREATE-AAP)			$16,000		$16,000
UBC (SPPH)			$1,000		$1,000
TOTAL	$2,500		$22,000	$5,000	$29,500

Note: Please attach copies of letters or agreements confirming additional funds.

Please explain revenue discrepancies (if any)

Expenses Description

Table 3 Projected Expenses for Reporting Period (cash and in-kind)

Project Costs	**Expenses**		
	All Sources		
	Cash	*In-kind*	*Total*
Salaries and fees	8,000	5,000	13,000
Travel and accommodation	2,500	0	2,500
Equipment and supplies	5,000	0	5,000
Communications and outreach	0	0	0
Analysis	0	0	0
TOTAL PROJECT COSTS	15,500	5,000	20,500

Table 4 Actual Expenses for Reporting Period (cash and in-kind)

Project Costs	**Expenses**		
	All Sources		
	Cash	*In-kind*	*Total*
Salaries and fees	13,000	5,000	18,000
Travel and accommodation	2,500	0	2,500
Equipment and supplies	0	18,000	18,000
Communications and outreach	0	0	0
Analysis	0	0	0
TOTAL PROJECT COSTS	15,500	23,000	38,500

Please explain expense discrepancies (if any)

We experienced delays in the commercial availability of the desired sensors and had to delay the sensor acquisition and testing component of the project. During this waiting period we completed a review of available sensor technologies for Environment Canada (https://circle.ubc.ca/handle/2429/46628) and developed a street canyon model to guide the placement of sensors in the future as part of testing. When sensors finally became commercially available, the cost was substantially higher than anticipated (~$9,000 per unit). We were fortunate to have Environment Canada purchase two sensors for our testing and were able to deploy these at the Robson Square monitoring site near the end of May 2014. We used the BC CLEAR funding for personnel to work on the review of sensor technologies, the development of the street canyon model and for the actual sensor deployment.

RESULTS OVERVIEW

Activity Description

Table 5 Summary of Activities for the Reporting Period

Activity*	Completion Date	Description of Results
Sensor Deployment	May 16, 2014	Sensors installed and verified that data were being streamed to server (see photo in Appendix)
Street Canyon Model	December 2013	Prototype model developed - http://www.geog.ubc.ca/courses/geob370/students/class13/bho/
Street Canyon Model Optimized	April, 2014	Model was altered to include the entire downtown area and a better method for linking data was used (see Appendix 2)
Literature review of sensor technologies	March 15, 2014	Publication available at https://circle.ubc.ca/handle/2429/46628 Webinar presented via BC Lung Association on April 16, 2014 http://www.bc.lung.ca/association_and_services/airquality-webinar.html

*As outlined in the project contribution agreement or contract.

Please explain activity discrepancies (if any)

Deliverable Description

Please include copies of all deliverables with the final report (e.g. publications, presentations, research reports, etc.). The final report will be considered incomplete without copies of the project deliverables.

Table 6 Summary of Key Deliverable Accomplishments for the Reporting period

Deliverable*	Description	Description of Results
Sensor deployment	Initial deployment of sensor and demonstration of data stream and server communication.	See Appendix 1
Street canyon model	Description of street canyon model	See Appendix 2
Sensor technologies review	Review of sensor technologies	See attached webinar slides – Appendix 3 (full report at https://circle.ubc.ca/handle/2429/46628)

*As outlined in the project contribution agreement or contract.

Please explain deliverables discrepancies (if any)

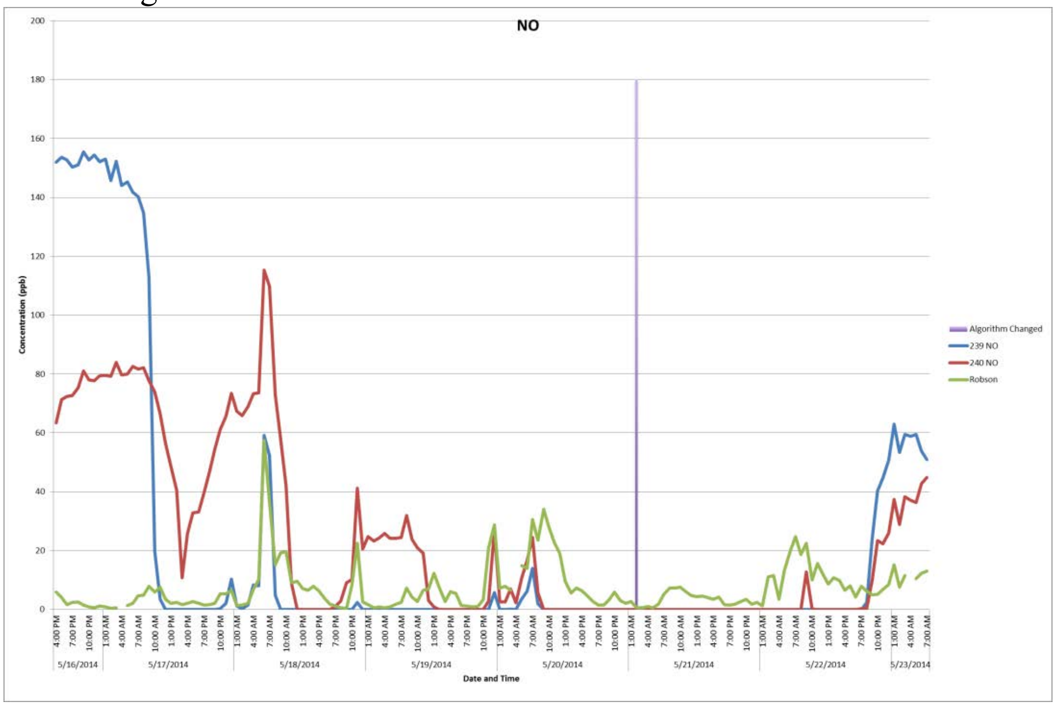
DELIVERABLES

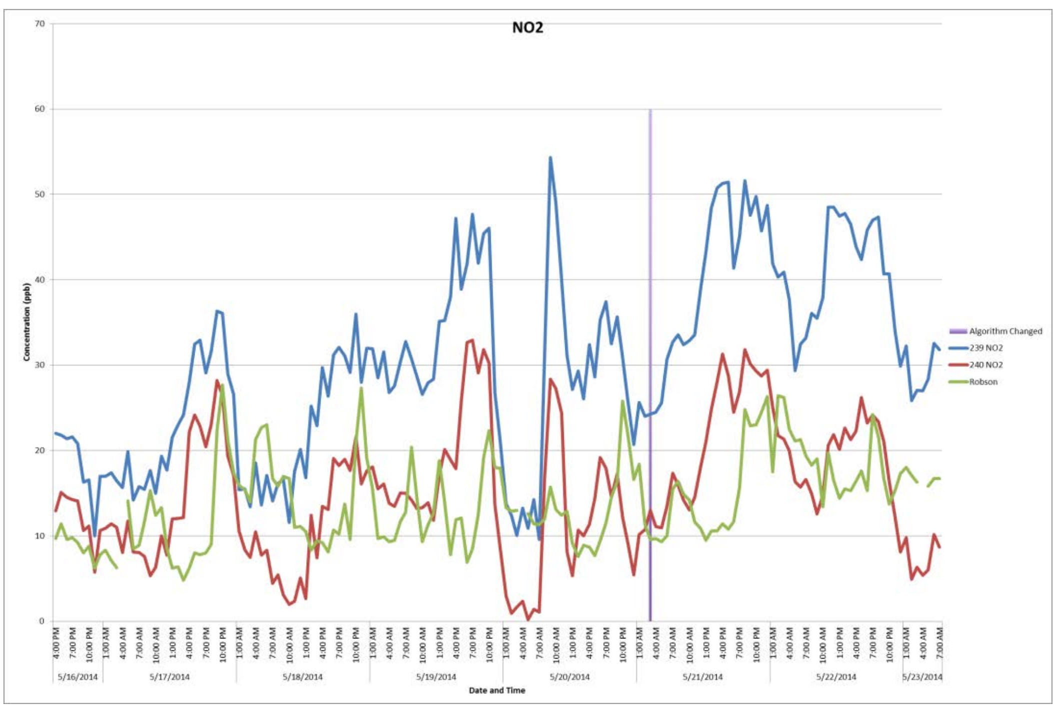
Appendix 1: Sensor deployment

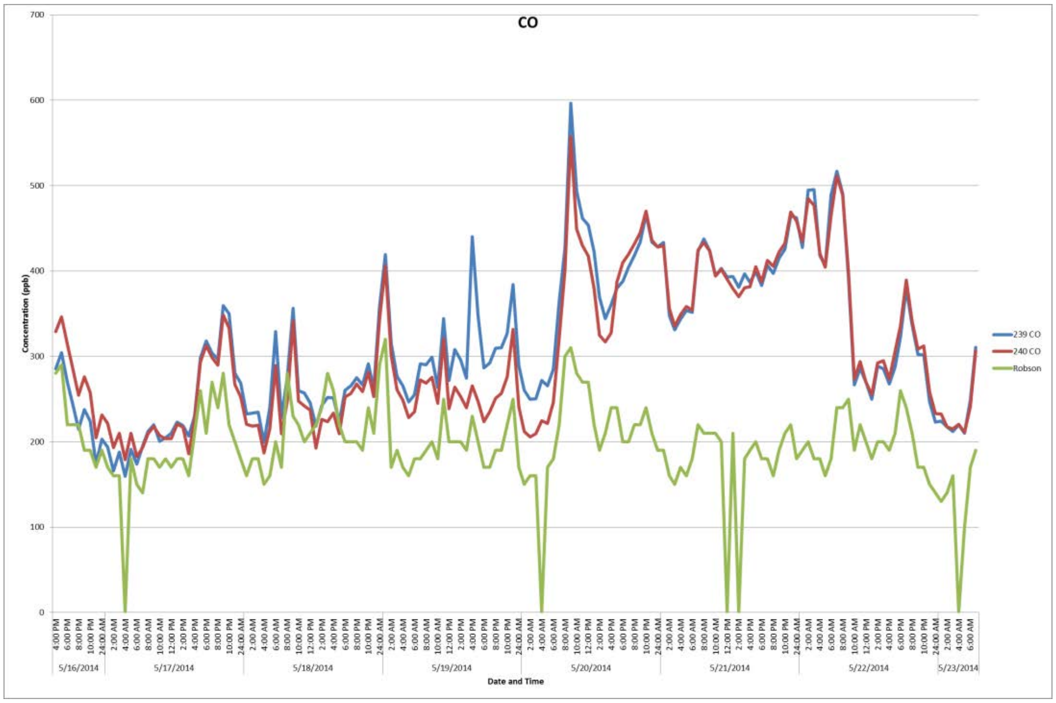
The attached figures show the initial deployment of 2 AQMesh (#239150, #240150) sensor units in downtown Vancouver. The graphs illustrate the processed data set from the AQMesh server for the first week of deployment, along with data from the Metro Vancouver air quality monitoring site. These figures are provided to indicate that data are being collected and streamed. These data should not be used for comparison to reference monitoring given the short time of deployment and the fact that sensors had not yet stabilized. Furthermore, the AQMesh manufacturers are still in the process of updating and refining their post-processing algorithm. These data can, however, be used to assess agreement between the two sensor units. During this period the correlation between the two sensor units was 0.71 for NO, 0.87 for NO_2, 0.95 for CO, 0.76 for SO_2 and 0.97 for O_3.

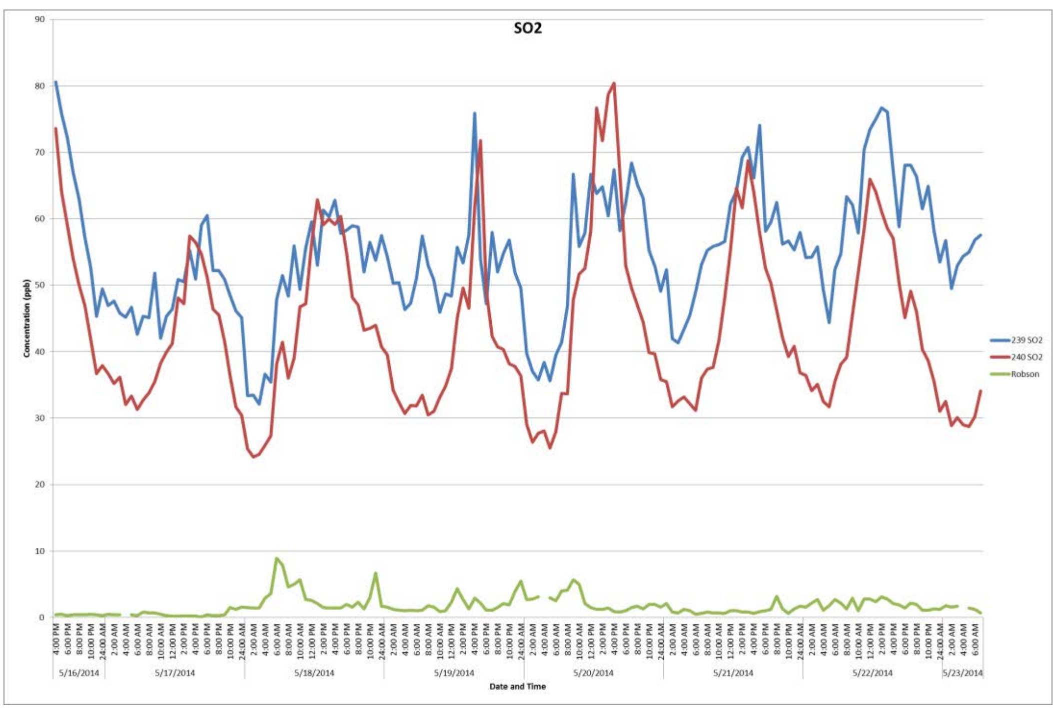

AQ Mesh Sensors
Approximate location of inlet for Metro Van monitoring site
STOP

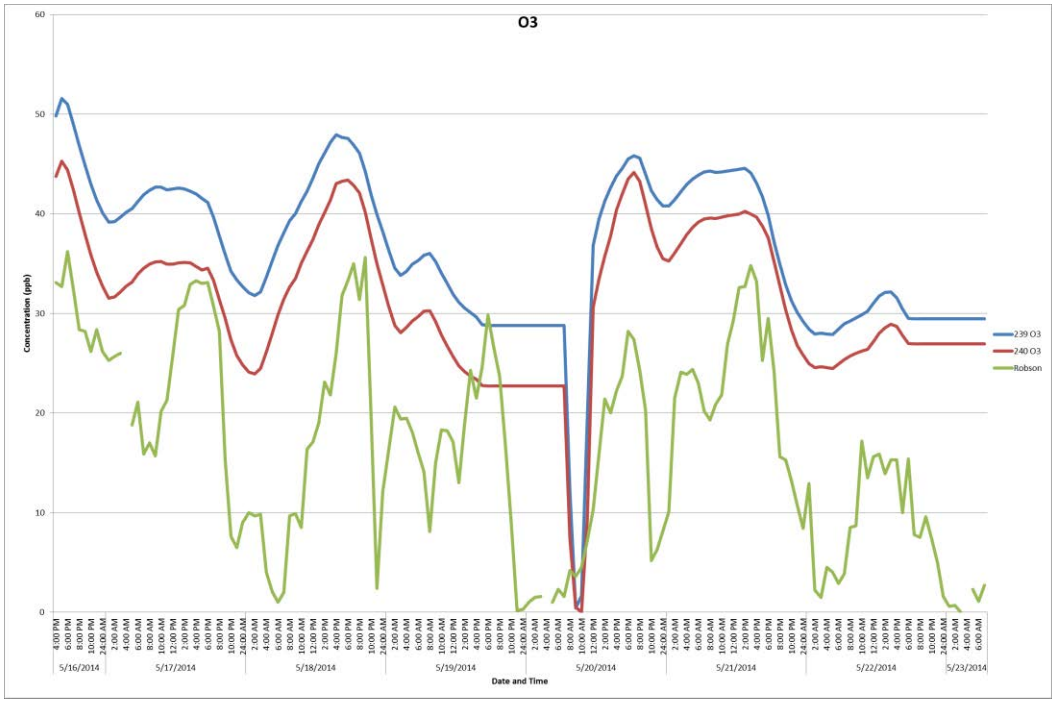
Two AQMesh Sensors deployed adjacent to Metro Vancouver Robson Square monitoring site.






CO
Concentration (ppb)
Date and Time
239 CO
240 CO
Robson
5/16/2014
5/17/2014
5/18/2014
5/19/2014
5/20/2014
5/21/2014
5/22/2014
5/23/2014


SO2
Concentration (ppb)
Date and Time
239 SO2
240 SO2
Robson
5/16/2014
5/17/2014
5/18/2014
5/19/2014
5/20/2014
5/21/2014
5/22/2014
5/23/2014


O3
Concentration (ppb)
Date and Time
239 O3
240 O3
Robson
5/16/2014
5/17/2014
5/18/2014
5/19/2014
5/20/2014
5/21/2014
5/22/2014
5/23/2014

Appendix 2: Street Canyon Model

Abstract

Urban street canyon formation has become a growing concern over the past decade due to the prevalence of high-rise, high-density residential and commercial development in the downtown core. Since this phenomenon poses significant implications on health, the purpose of our study is to identify the areas in downtown Vancouver where street canyons are most likely to occur. By combining the effects of aspect ratio and wind direction, our results indicate that there is high potential for street canyon formation along the vast majority of streets in our study area, with some streets having multiple ideal locations.

Background

Air pollution has been a significant environmental and health concern for centuries. This exposure is widespread and important for all populations since it is unavoidable. The Global Burden of Disease 2010 estimated that 3.1, 3.5, and 0.2 million deaths occurred annually as a result of exposures to ambient particulate matter, household solid fuels and ambient ozone pollution, respectively. (1) With rapid urbanization of the world population, air quality is anticipated to be on the decline as sources of pollution aggregate. In highly populated cities, energy consumption and human activities (e.g. power generation and vehicle use) must rise to keep up with the demands of growing regions.

In a dense urban environment, such as downtown Vancouver, the main contribution to spatially varying pollutants is traffic-related air pollution (TRAP). These spatial gradients are largely explained by road traffic density. Motor vehicle emissions are produced in combustion processes leading to the formation of nitrogen oxides and carbon monoxide. Sulfur dioxides can arise from fossil fuel combustion in industrial processes. In metropolitan areas, non-exhaust emissions are possible from mechanical abrasion (a source of coarse particulate matter) of brakes, tires and road surfaces. (2) An important secondary pollutant that contributes largely to climate change that is formed in the photochemical reaction between volatile organic compounds (VOCs) and nitrogen monoxide (NO) is tropospheric ozone (O_3).

Traditional air quality monitoring networks are the groundwork for understanding pollution trends (temporal and spatial patterns), compliance evaluations, health effects research and assessment of air quality management programs. Currently, the networks in place not only measure limited surrogate air pollutants, but also are limited in capturing important neighborhood-scale spatial patterns, despite having fine temporal resolution. To supplement these discrete monitoring sites, a number of smaller and more portable devices have been used to capture pollutant variability in 2-dimensions.

Detailed spatial information has important implications for health - for example, numerous studies have reported association between TRAP and birth outcomes (low birth weight and pre-term births), (3) cardiovascular effects, (4) childhood asthma and respiratory disease (bronchiolitis and otitis media). (5-8)

Because various adverse health effects have been linked to TRAP recently, there is a push to better resolve pollution gradients related to traffic sources. Two-dimensional models fail to include the vertical gradients that exist in air pollution. Although previous models may be sufficient for estimating exposures of occupants in small residential buildings where single households reside, errors and uncertainty in approximating personal exposures for individuals living in high-rise residential developments may be considerable.

Overview of Street Canyons

Aspect ratios are determined by the ratio of building heights to street width. The likelihood of street canyon formation increases with aspect ratio; with 0.7 being the level beyond which we can assume there is a risk of pollutant accumulation - as relatively stagnant air is present near the base of the canyon. Within the street canyon, air recirculation is poor. (9)

Prevailing wind direction also plays a critical role in street canyon formation. If wind direction runs perpendicular to the length of the street, the likelihood of there being a canyon increases as the airflow above building tops is unable to adequately exchange with air trapped within the canyons. Therefore, aspect ratio and wind direction are cumulatively accounted for in our multi-criteria analysis of potential urban street canyons.

Objectives

The aim of this project is to develop a simple geospatial model using readily available information to assist in the identification of potential street canyons in downtown Vancouver.

Data

Building Heights: Building footprint data was obtained from Dr. Rory Tooke from University of British Columbia's Faculty of Forestry.

Public Streets: Street data was downloaded from the City of Vancouver Open Data Catalogue.

Wind: Wind data was obtained from http://vancouver.weatherstats.ca/charts/wind_direction-1year.html.

Projection: Prior to any analysis, all of the input data was georeferenced to the Universal Transverse Mercator (UTM) projection system using zone 10N of the North American Datum of 1983 (NAD 1983).

Methods

The basic scheme of the model development is outlined in the flowchart below.

Step 1: Determining Aspect Ratio

The first task was to construct a polygon that covered the area of interest (downtown Vancouver) for which building height information was available. The building height data was an attribute in the geospatial building footprint dataset provided to us by Dr. Rory Tooke (who obtained it from the City of Vancouver). This polygon was used to truncate the public streets, right of way street widths, and building footprints layers to the area of interest (using the “select layer by location” and “polygon to raster” tool) (Figure 1).

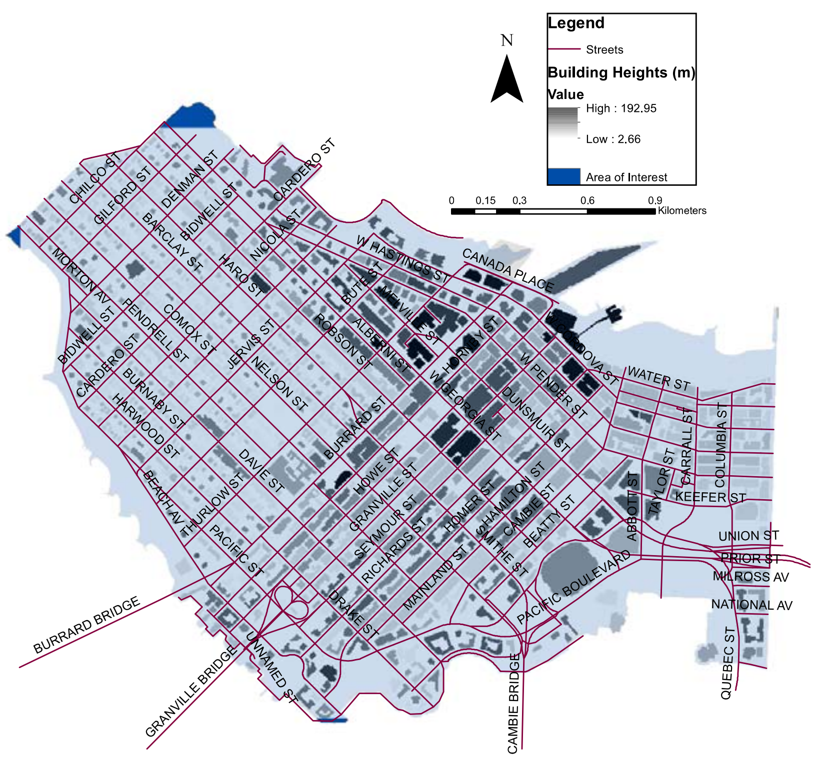


Figure 1. Streets and buildings in the area of interest.

Some data cleanup was performed on the street widths layer as metrics used in the raw file included both feet and meters. Individual road segment data on the public streets layer was made continuous by applying the “dissolve” tool. Then a 5 m buffer (round end type with full sides) was created around the dissolved public streets. A 5 m buffered centroid (with “feature to point” tool) was made for each buffered street within this new layer to ensure adequate spatial joining to the street width layer.

We used the “densify” tool to create vertices every 0.5 m along the streets in the street width layer. Next, we employed the “dice” tool to subdivide the streets in this layer into smaller segments at every tenth vertex. We were able to make midpoints on these smaller segments using the “create perpendicular lines at midpoint” tool (downloaded from GIS Stack Exchange) and the “feature vertices to points” tool. These midpoints were joined back with the public streets layer in order to obtain a diced street layer containing width information as an attribute.

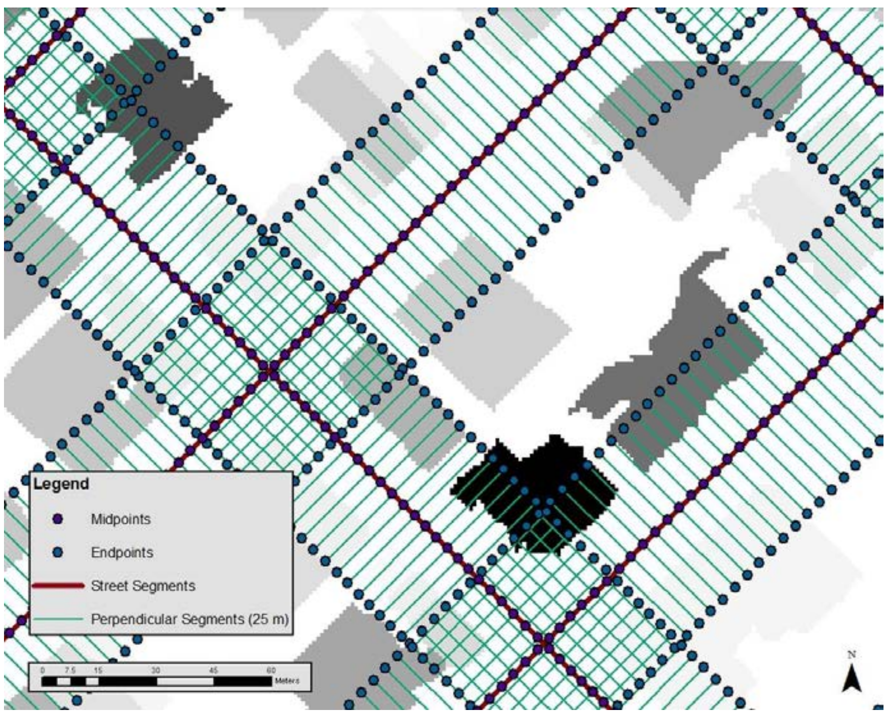


Figure 2. Extraction of street width data

This layer served as the input for all further analysis. We deleted all fields in which the street width values were “0 m”, since street width is the denominator in the aspect ratio calculation. The “0 m” streets corresponded to bike lanes along the Seawall and streets that no longer existed.

Before moving on to the next step, we needed to determine the street bearings in order to find buildings that were perpendicular to the street. This was accomplished using an Easy Calculate Add-In downloaded from www.ian-ko.com/free/EC/EC_download.htm. A new field for street bearings was added to the layer, and the values were entered based on the “polyline_Get_Azimuth” expression.

The “generate near table” tool was applied to our new layer to search for the 5 nearest neighbors (i.e. closeby buildings from the building footprint layer) falling within a suitable search radius (i.e. 35 m). The tabulated data was spatially joined to the street segments and exported for manipulations in Excel. The street bearings coordinate system (0°=north, 90°=east, 180°=south, 270°=west) from the previous step was converted to the polar coordinate system to match the way in which nearest-distance angle data (0°= east, 90°=north, ±180°=west, -90°=south) was reported. Conditional nested “if” statements were used to select the 2 nearest perpendicular buildings (falling within 90°± 5° of the street bearing) from the 5 potential nearest neighbors. The ouput from this analysis (building identification numbers) was sorted into 2 columns using R. The “index”, “match”, “if” and “sum” functions in Excel helped compile the street width data for each street segment centroid (by summing the shortest distance between the centroid and the 2 nearest perpendicular neighbors). In instances where a centroid only had 1 near neighbor, the right of way street width was used as a proxy for street width.

This information was saved and added to ArcMap 10.1. By spatially joining this layer based on building identification number, up to 2 corresponding building heights were extracted as 2 new attribute columns (one height for each near building). Aspect ratio was determined with the “Field Calculator”.

Step 2: Determining Ideal Street Bearing with Respect to Wind Direction

For the purposes of this study, we chose the dominant wind direction from the previous year. According to Environment Canada data (http://vancouver.weatherstats.ca/charts/wind_direction-1year.html), the dominant direction was East. A limitation to this model is the use of regional weather station data rather than data specific to our area of interest. Extrapolating this weather monitoring data to our area of interest involves making an assumption that weather conditions remain stable and are applicable to the downtown area. The preferred street bearings (i.e. 180º and 360º) run perpendicular to the wind direction (i.e. East=90º) and are dealt with in the normalization step (explained in section 3).

Step 3: Multi-criteria Analysis

The final step in our analysis was to perform a multi-criteria analysis. First, we needed to normalize the aspect ratio and street bearings so that they may be compared with one another. The normalization tool we used was “fuzzy membership”. Only aspect ratios exceeding 0.7 were exported for this stage of assessment. After converting the aspect ratio shapefile into a raster using the “point to raster” tool, this layer was assigned values from 0 to 1 based on a “linear” membership type. The highest aspect ratio was assigned a value of 1, and the lowest aspect ratio (=0.7) was assigned a value of 0, because higher aspect ratios indicate greater likelihood of street canyon formation.

Normalizing street bearings required a more complicated method as there were more than one ideal bearing. In addition, 0º and 360º indicate the same bearing, so a “linear” membership type would not suffice. To work around this, we selected all street bearings that fell between 0º and 90º, and added 360º to them. Then we separated the streets layer into two distinct layers: one layer included only street bearings from 90º to 269º, and the other included only street bearings from 270º to 449º. This way, we were able to assign an ideal value of 1 to two bearings (i.e. 180º and 360º)- those streets that run perpendicular to wind direction. A non-ideal value of 0 was assigned to those streets that run parallel to wind direction (i.e. 90º and 270º).

First, we converted our street bearings layers into raster format. Then, we used the "fuzzy membership" tool for each of the separate street bearing layers, this time using the "Gaussian" membership type with a spread of 0.0001. For the 90º to 269º and 270º to 449º layers, the assigned midpoints were 180º (South) and 360º (North), respectively. We chose the “Gaussian” membership type since we wanted our two ideal bearings (180º and 360º) to be assigned the highest values. Street bearings falling on either side of these ideals would gradually decrease in importance as a smaller spread (0.0001) was selected.

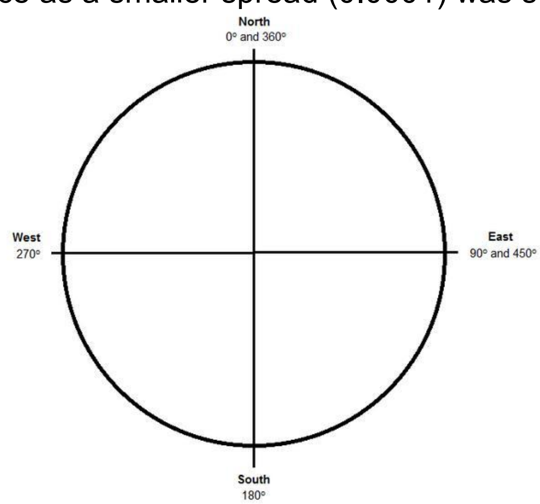


Figure 3. Wind direction

After normalizing the aspect ratios and street bearings, we performed a multi-criteria analysis by adding the normalized values together using the “raster calculator”. In order to do this, we had to convert all "no data" values to zeroes first. By removing the "no data" values, we were able to equally weight the aspect ratio and the wind direction in a multi-criteria analysis. In theory, the best street canyons would hence have a total value of 2.

Figure 4. Multi-criteria Analysis of Potential Street Canyons Classified by Natural Breaks

Results

The model will be evaluated with mobile monitoring to be conducted in summer 2014 (Figures 5, 6).

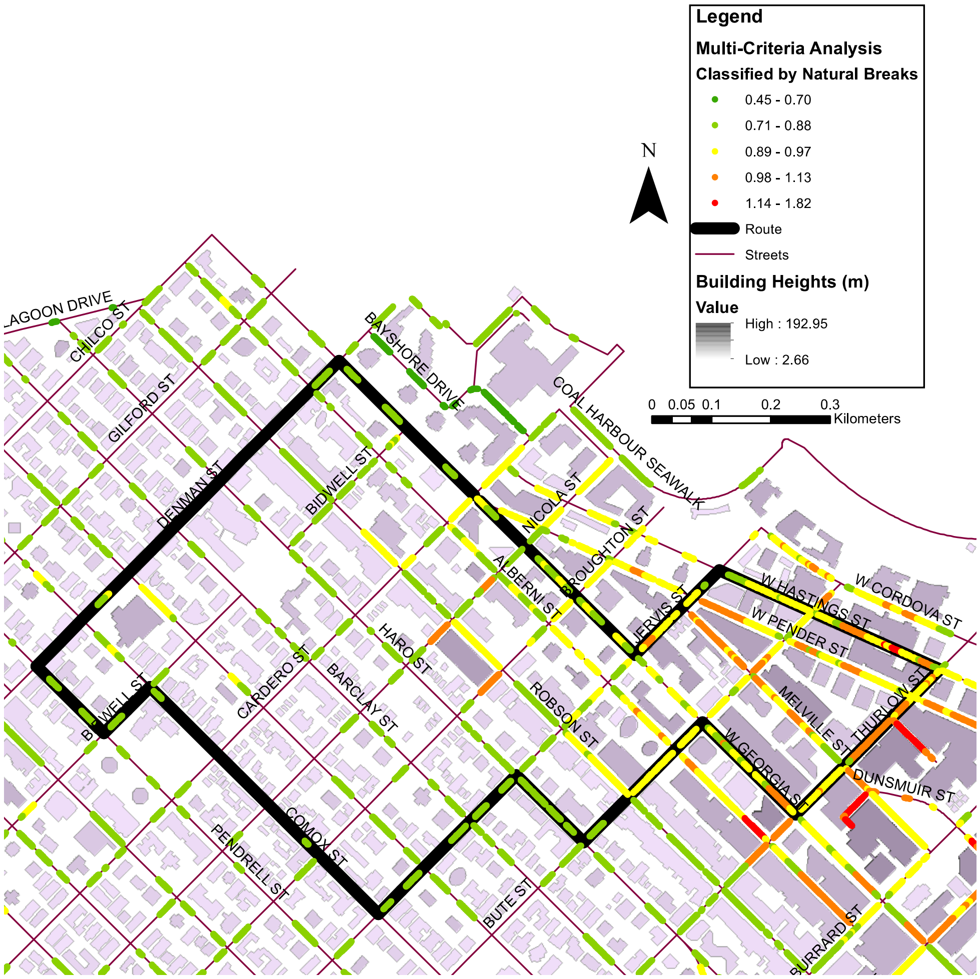


Figure 5. Mobile Monitoring Route Overlaid with the Multi-criteria Analysis
Figure 5 shows the mobile monitoring route (thick black line) that will be used to evaluate the model. Where any color besides black is visualized, a canyon is expected. Warmer tones show more pronounced canyons while cooler tones show less pronounced canyons.

Figure 6. Mobile Monitoring Route Classification Scheme

Figure 6 splits the route into 4 classifications for analytical purposes: Canyon [mean aspect ratio = 1.9] – high traffic (green), Canyon [mean aspect ratio = 1.0] – low traffic (black), Non-canyon [mean aspect ratio = 0.2] – high traffic (brown), Non-canyon [mean aspect ratio = 0.3] – low traffic (blue).

An initial trial of mobile monitoring is indicated below with plots (Figures 7,8) of particle number concentration and $PM_{2.5}$ mass. Canyon sections with higher traffic had higher mean $PM_{2.5}$ concentrations (15 µg/m3) compared to the other classifications (9 – 12 µg/m3).

Figure 7. Particle number concentrations - Mobile Monitoring Route

Figure 8. $PM_{2.5}$ concentrations - Mobile Monitoring Route

Bibliography

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disease hospitalization and mortality. Environ Health Perspect. 2011 Apr;119(4):501-7.

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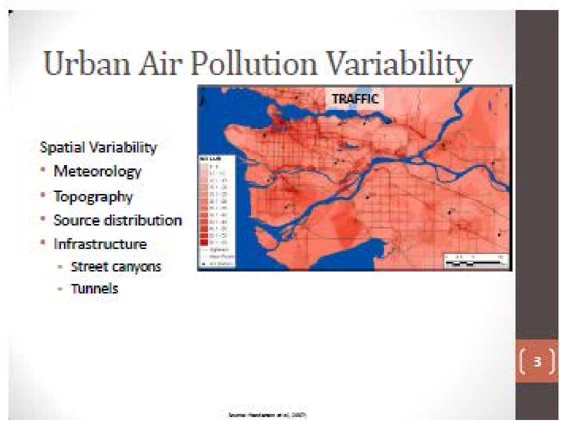
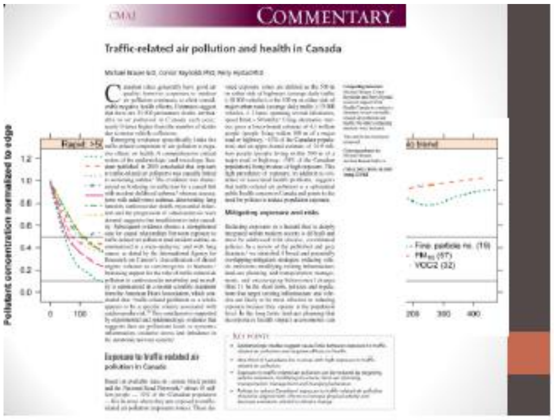
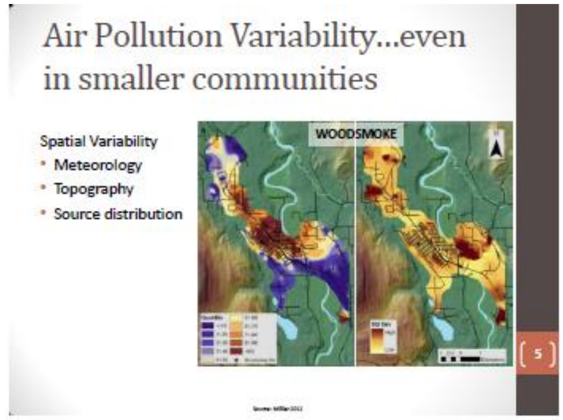
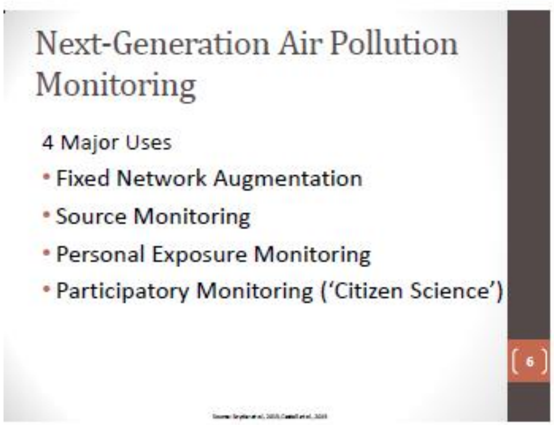
9. Classification and Criteria for Setting Up Air-Quality Monitoring Stations [Internet]. ADEME Publ. 2002 [cited 2013 Nov 28]. Available from: http://www2.ademe.fr/servlet/KBaseShow?sort=-1&cid=96&m=3&catid=17618&p1=00&p2=00

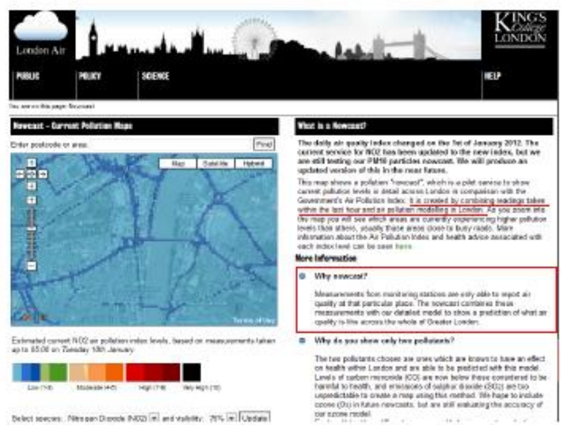
Appendix 3: Sensor Technologies Review (webinar slides)



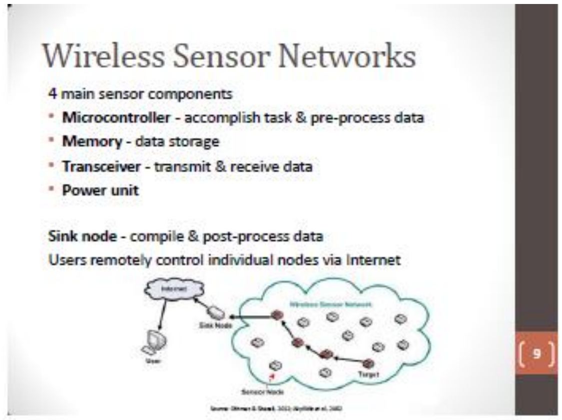

CMAJ
COMMENTARY
Traffic-related air pollution and health in Canada
Fine particle no. (19)
VOC2 (32)

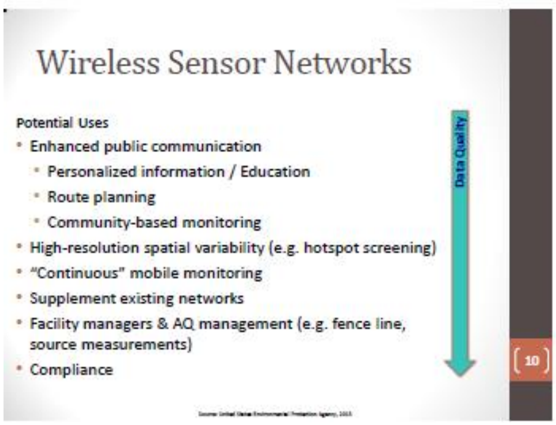

Air Pollution Variability…even in smaller communities
Spatial Variability
Meteorology
Topography
Source distribution
WOODSMOKE
5

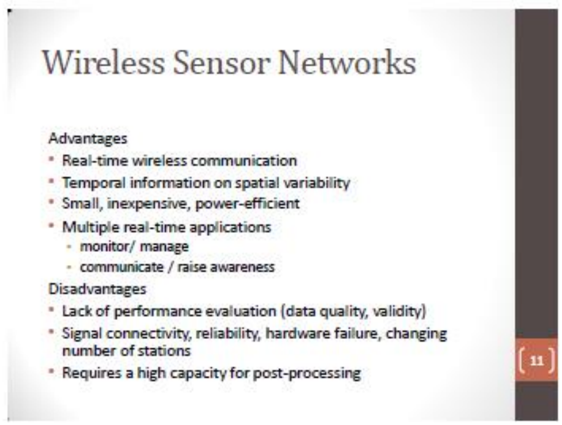

Next-Generation Air Pollution Monitoring
4 Major Uses
Fixed Network Augmentation
Source Monitoring
Personal Exposure Monitoring
Participatory Monitoring ('Citizen Science')
6


London Air
KINGS College LONDON
PUBLIC
POLICY
SCIENCE
HELP
Nowcast - Current Pollution Maps
What is a Nowcast?
More information
Why nowcast?
Why do you show only two pollutants?

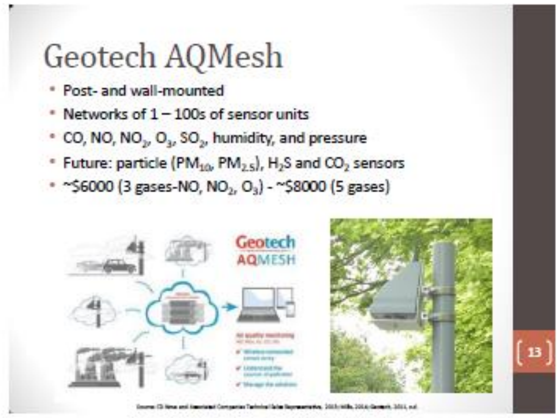

Cycling Route Planner
Cycling

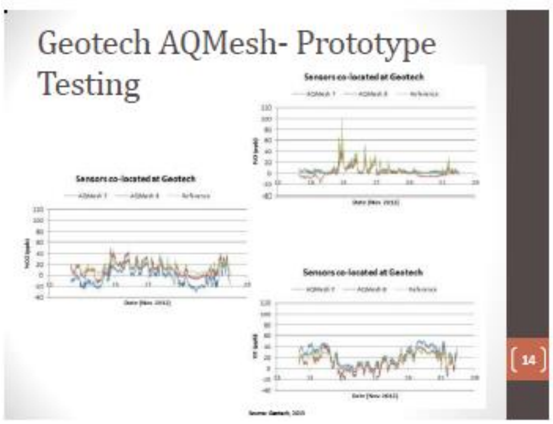

Wireless Sensor Networks
4 main sensor components
Microcontroller - accomplish task & pre-process data
Memory - data storage
Transceiver - transmit & receive data
Power unit
Sink node - compile & post-process data
Users remotely control individual nodes via Internet
Sink Node
User
Target
Sensor Node
9

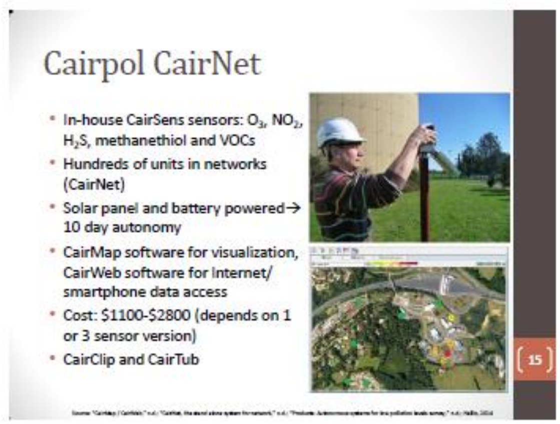

Wireless Sensor Networks
Potential Uses
Enhanced public communication
Personalized information / Education
Route planning
Community-based monitoring
High-resolution spatial variability (e.g. hotspot screening)
"Continuous" mobile monitoring
Supplement existing networks
Facility managers & AQ management (e.g. fence line, source measurements)
Compliance
Data Quality
10

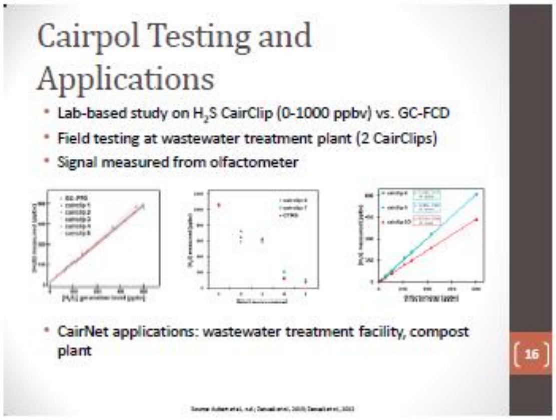

Wireless Sensor Networks
Advantages
Real-time wireless communication
Temporal information on spatial variability
Small, inexpensive, power-efficient
Multiple real-time applications
monitor/ manage
communicate / raise awareness
Disadvantages
Lack of performance evaluation (data quality, validity)
Signal connectivity, reliability, hardware failure, changing number of stations
Requires a high capacity for post-processing
11


Roadmap of Wireless Sensor Network Designs
• Geotech AQMesh
• Cairpol CairNet
• AirBase CanarIT™ 1.0
• Libelium Waspmote Plug & Sense
• Sensaris SensPods
• Smart Citizen
• Air Quality Egg
12


Geotech AQMesh
• Post- and wall-mounted
• Networks of 1 – 100s of sensor units
• CO, NO, NO_2, O_3, SO_2, humidity, and pressure
• Future: particle (PM_{10}, $PM_{2.5}$), H_2S and CO_2 sensors
• ~$6000 (3 gases-NO, NO_2, O_3) - ~$8000 (5 gases)
Geotech
AQMESH
13


Geotech AQMesh- Prototype Testing
Sensors co-located at Geotech
Sensors co-located at Geotech
Sensors co-located at Geotech
14


Cairpol CairNet
• In-house CairSens sensors: O_3, NO_2, H_2S, methanethiol and VOCs
• Hundreds of units in networks (CairNet)
• Solar panel and battery powered→ 10 day autonomy
• CairMap software for visualization, CairWeb software for Internet/ smartphone data access
• Cost: $1100-$2800 (depends on 1 or 3 sensor version)
• CairClip and CairTub
15


Cairpol Testing and Applications
Lab-based study on H2S CairClip (0-1000 ppbv) vs. GC-FCD
Field testing at wastewater treatment plant (2 CairClips)
Signal measured from olfactometer
CairNet applications: wastewater treatment facility, compost plant
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AirBase
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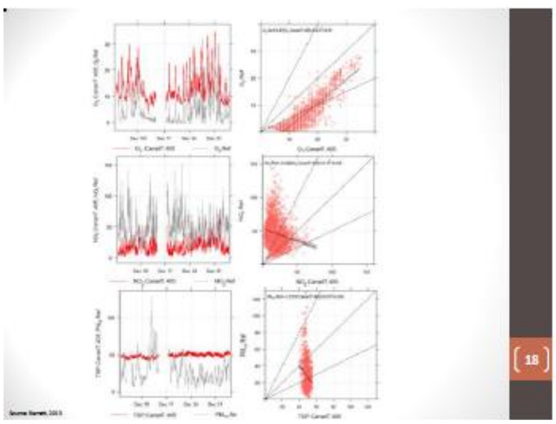
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Libelium Waspmote Plug & Sense
Street lights and building fronts
8 configurations with > 60 sensors
All configurations have 2 built-in sensors (temperature, accelerometer); changeable sensors (20 g each)
Rechargeable battery using solar panels
Cost: Communications: $550-$920, Power: $50-$110, Sensors: $20-$750, Gateway: $1040-$2000
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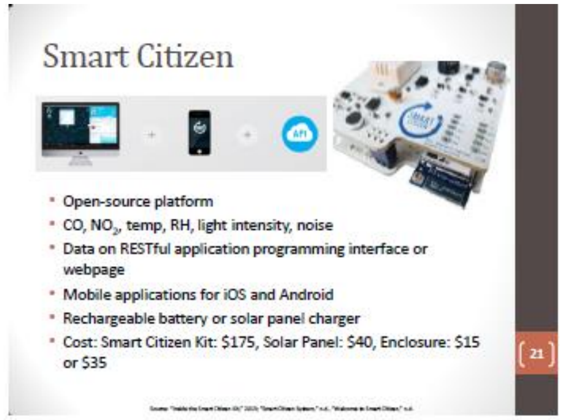
Sensaris SensPods
SensPODS are linked to an Android app and the web via Sensdots interface
Cost: ~$500-$650
4 SensPods
ECOsense for CO, NO_x, noise, temp, RH → "not calibrated for the moment"
ECO_2sense for CO_2 → pre-calibrated NDIR sensor
EcO_3sense for O_3, luminosity, temperature, humidity → not calibrated
EcoPM for particles (>1 µm)
20


Smart Citizen
Open-source platform
CO, NO_2, temp, RH, light intensity, noise
Data on RESTful application programming interface or webpage
Mobile applications for iOS and Android
Rechargeable battery or solar panel charger
Cost: Smart Citizen Kit: $175, Solar Panel: $40, Enclosure: $15 or $35
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Air Quality Egg
SYSTEMS DIAGRAM
xively
DIY community-led sensing network
CO, NO_2, temp, RH
Particulate matter (>1 µm; Shinyei sensor), O_3, VOCs (MiCS 5521 sensor) add-ons
Sensors not calibrated and "their precision and sensitivity is mediocre"
Gives "raw" and "calculated" measurements
Cost: ~$200 + $50/add-on
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Air Quality Egg
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Roadmap of Wearable or Smartphone Compatible Sensor Designs
CitiSense
Sensorcon Sensordrone
AirCasting Air Monitor
Speck and GPSpeck
AirWaves Mask
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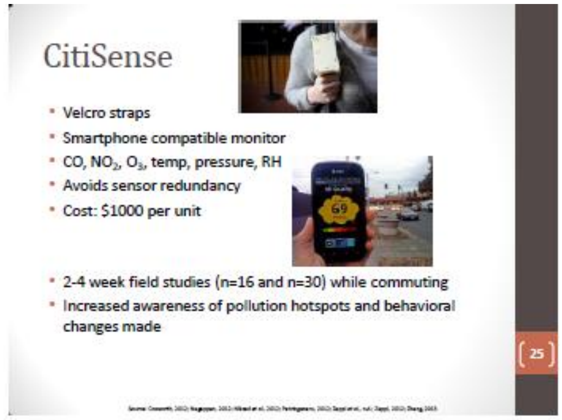
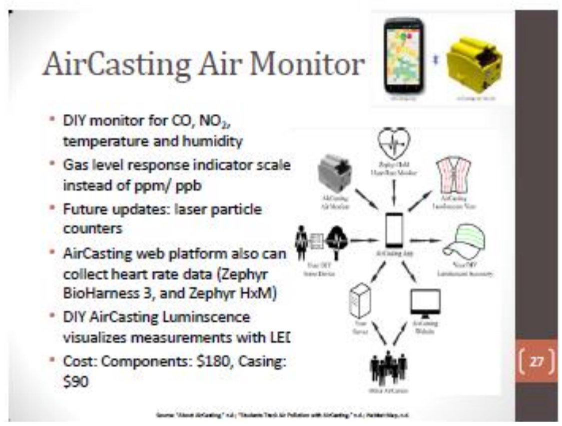

CitiSense
Velcro straps
Smartphone compatible monitor
CO, NO2, O3, temp, pressure, RH
Avoids sensor redundancy
Cost: $1000 per unit
2-4 week field studies (n=16 and n=30) while commuting
Increased awareness of pollution hotspots and behavioral changes made
25


Sensorcon Sensordrone
Keychain, necklace attachable
Monitors groups of gases: e.g. oxidizing and reducing gases
Limits use to instances where user knows detectable gas
Temperature, humidity, pressure, non-contact temperature, capacitance, color intensity, illumination sensors
Operation modes: call-response, streaming, data logging
Cost: $199
26


AirCasting Air Monitor
DIY monitor for CO, NO2, temperature and humidity
Gas level response indicator scale instead of ppm/ ppb
Future updates: laser particle counters
AirCasting web platform also can collect heart rate data (Zephyr BioHarness 3, and Zephyr HxM)
DIY AirCasting Luminscence visualizes measurements with LEI
Cost: Components: $180, Casing: $90
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Speck and GPSpeck

- Previously called AirBot
- Uses commercial sensors for PM, temperature, humidity
- USB port for data transfer to Speck Gateway
- Cost: $99

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AirWaves Mask

- Filtering air pollution mask with particle sensor
- Collects real-time air quality inside and outside mask
- Mobile apps alert system
- Bluetooth sharing for crowd sourced networks

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Next-Generation Air Monitors Summary

Tiers	Cost Range	Anticipated User	Air Monitors[1]
V (most sophisticated)	10 to 50 K	Regulators[2]	—
IV	5 to 10 K	Regulators[2]	Geotech AQMesh
III	2 to 5 K	Community Groups and Regulators[2]	Libelium Waspmote Plug & Sense
II	$100 to 2 K	Community Groups	AirBase CanarIT Cairpol CairTub and CairNet Envirologger CO_2 CitiSense Sensaris SensPods Sensorcon Sensordrone Air Quality Egg Smart Citizen AirCasting Air Monitor
I (more limited)	<$100	Citizens[3]	Speck and GPSpeck

[1] In organizing the next generation air monitors into tiers, the cost took precedence over the anticipated user group for consistency in classification.
[2] Supplement existing monitoring: ambient and source
[3] Educational and personal health purposes

Source: United States Environmental Protection Agency, 2013

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Evaluation of Wireless Sensor Networks

Stage 1: Controlled laboratory testing

- Accuracy
  - Comparison to reference / known concentrations
- Precision (e.g. inter-sensor correlation)
  - High density networks
- Selectivity (discriminate constituent in a mixture)
- Sensitivity
- Detection range and resolution
  - Relative to typical ambient concentrations
- Response time
  - Mobile monitoring
- Interference (e.g. NO_2 and O_3 electrochemical sensors)

Stage 2: Test multiple sensors in range of unknown environments and compare with reference monitors

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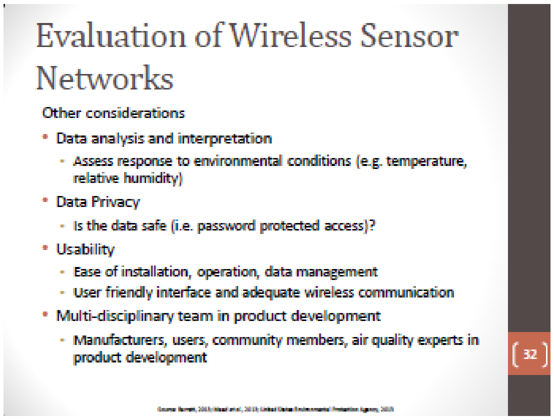
Evaluation of Wireless Sensor Networks
Other considerations
Data analysis and interpretation
Assess response to environmental conditions (e.g. temperature, relative humidity)
Data Privacy
Is the data safe (i.e. password protected access)?
Usability
Ease of installation, operation, data management
User friendly interface and adequate wireless communication
Multi-disciplinary team in product development
Manufacturers, users, community members, air quality experts in product development
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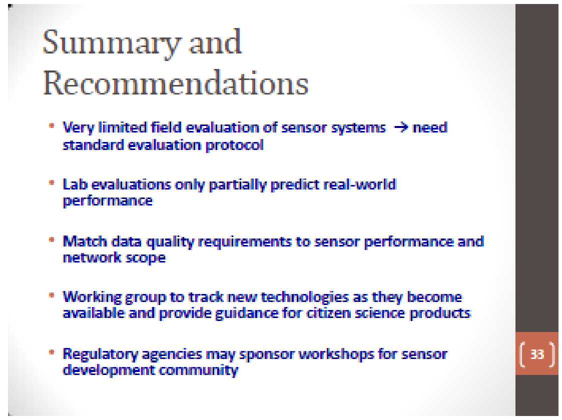
Summary and Recommendations
Very limited field evaluation of sensor systems → need standard evaluation protocol
Lab evaluations only partially predict real-world performance
Match data quality requirements to sensor performance and network scope
Working group to track new technologies as they become available and provide guidance for citizen science products
Regulatory agencies may sponsor workshops for sensor development community
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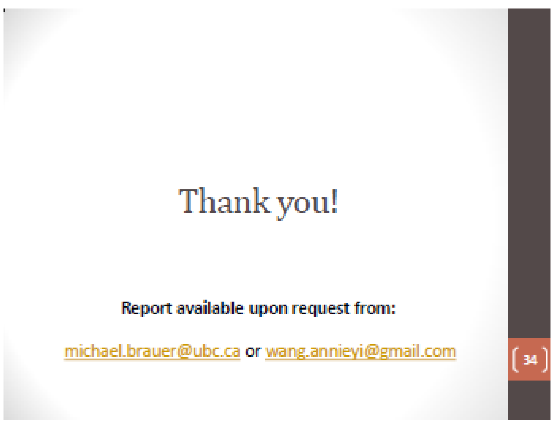
Thank you!
Report available upon request from:
michael.brauer@ubc.ca or wang.annieyi@gmail.com
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