From Near-Road to Urban Background Lessons Learned from Mobile Lab Monitoring

A look at Environment Canada’s innovative mobile air quality monitoring laboratory project, CRUISER, designed to obtain measurements from the field quickly and gain a better understanding of spatial variations in multi-pollutant interrelationships and potential exposures in a near-road environment.

Motor vehicles are a ubiquitous source of air pollutants, so it is not surprising they impact air quality throughout cities. Combustion-related pollutant levels such as nitrogen oxides, carbon monoxide, volatile and semi-volatile organic compounds (VOCs, SVOCs), and fine particles (PM$_{2.5}$) of certain sizes and composition, are noticeably elevated in locations directly impacted by traffic. Larger road dust particles from multiple sources are also elevated.

An increasing amount of research suggests there are health risks associated with living and/or spending considerable time in places with higher traffic-related air pollution, which is often shown to involve elevated nitrogen dioxide (NO$_2$) concentrations. Consequently, enhanced monitoring near roadways is needed to better understand current conditions for NO$_2$ and other related air pollutants, to track compliance (i.e., with the revised U.S. National Ambient Air Quality Standards) and to support future health and exposure studies. New monitoring sites are thus being identified, evaluated, and installed across the United States and Canada.
Mobile air quality monitoring laboratories are valuable for site selection and to obtain a better understanding of context, that is, how each site relates to conditions throughout the metropolitan area of interest. Mobile labs can provide a more cost-effective way to explore multi-pollutant conditions near-roadways leading to a better understanding of what else we are breathing when NO₂ is high and what sources and/or processes are contributing to this complex mix of gases and particles.

**Canadian Regional and Urban Investigation System for Environmental Research (CRUISER)**

In 2004, Environment Canada built CRUISER; a multi-pollutant mobile lab capable of measuring while driving. This project was motivated by the need to be able to obtain measurements from the field quickly and to gain a more-detailed understanding of spatial variations in multi-pollutant interrelationships and potential exposures. Being able to drive and measure can greatly increase the number of locations examined within a prescribed time period complementing deployment to pre-selected points for longer periods of sustained monitoring. NO₂ has been of interest on CRUISER because of the epidemiological evidence of health impacts surrounding NO₂.¹² and because NO₂ is a key pollutant in Canada’s Air Quality Health Index.³

Since its first campaign, CRUISER has visited nine Canadian cities from Montréal, Québec, to Victoria, British Columbia, conducted surveys in four rural regions and even spent time in Detroit, Michigan. From the beginning, CRUISER's goal was to house multiple instruments covering both particles and gases, including two mass spectrometers. With experience, the suite of instruments has evolved with the aim of improving time resolution and sensitivity.

**High Time Resolution Measurements**

True mobile measurements require one-second time resolution, but availability of proven instrumentation, including reliability and level of effort to...
Challenges with PM$_{2.5}$

One-second time resolution for PM$_{2.5}$ meeting EPA specifications is elusive. While light scattering instruments (e.g., nephelometers) respond quickly, their relationship with mass is variable. CRUISER has had some success at achieving around 6-second resolution using an optical particle counter (GRIMM Dustmonitor) and the combined light scattering and beta attenuation instrument (Thermo Scientific SHARP) has shown promise. Fast (one-second) particle size distributions are sometimes part of CRUISER given the development of the Fast Mobility Particle Sizer (TSI), but high time resolution particle composition is not possible. With a large investment in capital and expertise, one-to-two-minute resolution, corresponding to about one kilometer of distance when driving and measuring, can be obtained (Aerodyne Aerosol Mass Spectrometer). However, fast particle mass and composition measurement for mobile application is an ongoing challenge.

Obtaining Representative Measurements from Mobile Lab Surveys

Urban surveys are costly and it is important to consider how to deploy the lab to obtain the most useful data. As noted in EPA’s Near-Road NO$_2$ Monitoring Technical Assistance Document, a number of key concepts and measurement routines should be considered, including repeating travel loops over the course of hours and/or days and determining how much data collection is sufficient for comparisons. These can help deal with mobile monitoring’s key limitation of not being able to simultaneously monitor at multiple sites. Other limitations are the potential of missing maximum concentrations when changes in emissions occur over short time periods and the lack of correlation with 1-hr average concentrations given that with mobile measurements visits to each location are often less than an hour. Some of these issues have been explored during CRUISER’s studies, particularly the question of how many times a travel loop needs to be repeated to obtain representative data.
More visits to a location lead to better estimates of the average and upper percentile concentrations, but what is the minimum number of visits required? To guide CRUISER deployments random sampling from existing hourly monitoring site data was undertaken to show that 25 independent 1-hr visits per season, would lead to a 95% chance of estimating the annual average NO2 with an accuracy of 10%.

One hundred monitoring days with an advanced mobile lab covering multiple locations, weekdays and weekends, and at different hours of the day would be very challenging. However, if a 20% error versus the true average is acceptable for NO2, then six visits per season is sufficient and may be a feasible target. Although more visits would be necessary to obtain comparable accuracy for more-variable pollutants (e.g., NO).

Representativeness of short duration mobile measurements with CRUISER was evaluated from studies in Windsor, Ontario, and Montréal, Québec. First, passive sampler (PSD) and CRUISER measurements for NO2 were compared across ten locations in Windsor, Ontario, over a two-week period in October 2006. The PSD collected continuously while CRUISER only visited each of these points for approximately 15 minutes on 7 or 8 different occasions during the period. The resulting 10-site NO2 averages were 12.7 parts per billion (ppb) and 13.0 ppb for CRUISER and PSD, respectively (RMSE=1.1 ppb) and their spatial correlation was 0.67 (unpublished), suggesting that a relatively short mobile survey has the potential to provide similar data to a saturation monitoring campaign using PSDs.

Figure 2. Distribution of CRUISER observed average (>18 visits in 3 seasons) NO2, ultrafine (UFP) particle, and black carbon (BC) concentrations determined from mobile measurements across multiple road segments in Montréal, Québec. These data are mostly from the eastern route (Figure 1) due to the greater number of days spent in that part of the city.
CRUISER further assessed representativeness in Montréal, while also seeking to characterize average intra-urban differences in multi-pollutant chronic exposures. Two different 6-to-8-hr loops were covered at different times in 2009 over 34 days during winter, summer and fall (see Figure 1). More than 600 road segments were traversed each day and three or more permanent monitoring sites were visited each loop for “ground truthing”. At the two sites reporting NO₂ and with >18 valid CRUISER visits, the 2009 annual averages were 16.1 and 16.6 ppb, while the averages based upon CRUISER’s visits were higher but within 20%, at 17.4 and 19.8 ppb.

**Average Urban Background to Near-Road Conditions: Montréal Example**

CRUISER’s mobile NO₂ measurements represent some of the first data of this kind, especially with respect to the quantity of urban observations and the suite of other pollutants measured simultaneously. The distribution plots (Figure 2) show the range of average NO₂, BC, and UFP concentrations observed across all road segments with valid data for 18 or more days. Given the diversity of locations covered, from neighborhood streets to service roads adjacent to busy highways, these values span from clean urban background (NO₂ ~ 6 ppb) to typical near/on-road conditions. Typical urban background is represented by the median (NO₂ ~ 12 ppb), which is consistent with the average observed across the current monitoring network, excluding the near road and downtown sites.

NO₂ in 2009 was 18 ppb at the city’s long-term near-road site. A secondary mode in the CRUISER distribution is consistent with this value. The mobile survey reveals that one can expect on-road locations with considerably higher NO₂ values with peaks potentially approaching 50 ppb. Not surprisingly, the location with the peak NO₂ had BC (6.8 μg/m³) and UFP (36,300 #/cm³) in the upper part of their distributions. Among the highest 10 segments for NO₂, two are in the port area and three are along a main road through an industrial area. The other five are more difficult to explain, as they include less busy roads near residential areas, but with some evidence of activities that might increase traffic.

Direct influence by trucks or buses can have a large influence on an average based upon limited visits. CRUISER’s own plume cannot be completely ruled out, despite efforts to avoid self-pollution and objectively censor such data. These two factors present an ongoing challenge associated with mobile measurements. Thus, while the relatively limited comparisons with other fixed measurements suggest approximately 20% agreement, extra caution is required in interpreting estimated multi-visit road segment averages from true mobile data.

**Summary**

When deployed in a systematic fashion a mobile lab can provide unique insight into air quality across a city. An obvious application is the identification of areas requiring closer study and possible establishment of longer-term near-road monitoring sites. Montréal is a typical northeastern North American city, and mobile monitoring there reveals areas that may approach the new annual U.S. NO₂ NAAQS. Depending upon resources and technical capabilities, mobile labs can monitor for multiple pollutants although achieving high time resolution for many measurements of interest is not always feasible.

**References**


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