Mobile Measurement Platform

An Innovative Tool for Studying the Impacts of Traffic Emissions

by Kathleen Kozawa, Seong Park, Walter Ham, Steve Mara, and Abhilash Vijayan

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Over the past decade, the California Air Resources Board (CARB) has applied an innovative mobile measurement technique designed to help characterize site-specific traffic emissions and community air pollution exposures. The CARB Mobile Measurement Platform (MMP) is able to collect air quality data with high temporal and spatial resolution, and has been used to study near-roadway exposures in highly impacted communities and measure pollutant gradients under a variety of conditions. This research tool is an important supplement to regional air quality monitoring networks and new federal requirements for near-road monitoring.

Use of the MMP has enabled researchers to increase the granularity of measurements, providing more details about when and where increased pollutant exposures may occur. For situations where a known source dominates the air pollution (e.g., truck fleets on freeways, individual vehicles in neighborhoods), these platforms can also be used to study the emission behavior of the sources to complement traditional measurement techniques, such as remote sensing, and dynamometer studies.

The Mobile Measurement Platform

CARB has operated an MMP program since 2003. CARB's MMPs have been designed for and built into Toyota RAV4 electric vehicles (see Figure 1). Each MMP is outfitted with instruments to measure

Figure 1. CARB's Mobile Measurement Platform.

a variety of gas-phase pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), and greenhouse gases, as well as instruments to measure particle-phase pollutants such as particulate matter (PM_{10} and $PM_{2.5}$), black carbon (BC), and ultrafine particles (UFP). These analyzers sample from a central manifold that draws air from outside of the vehicle. CARB's MMPs are all outfitted with a separate electrical system to power the instrumentation inside the vehicle, which can be run for up to 6 hours. Each MMP has a driving range of 75 miles.

Specifically, the MMP was designed around three important features: vehicle selection, instrument selection, and operational information. First, a zero-emitting vehicle was selected to eliminate any contamination of the environmental sample. Second, the instruments selected for the MMP feature high accuracy and precision, fast response times, have an ability to withstand vibration, and have relatively small sizes and power usage. Third, the MMP contains high-quality geographical positioning to correlate air quality measurement to their spatial location, and a camera system to record the surrounding and operating conditions. The platform also contains meteorological instruments to measure wind speed and direction.

MMP Application

The CARB MMP has been successfully applied to a variety of air quality and emission research projects including: assessing near-road exposures in heavily impacted communities; using on-road freeway measurements to determine rule benefits; and chase studies to characterize individual vehicle emissions.

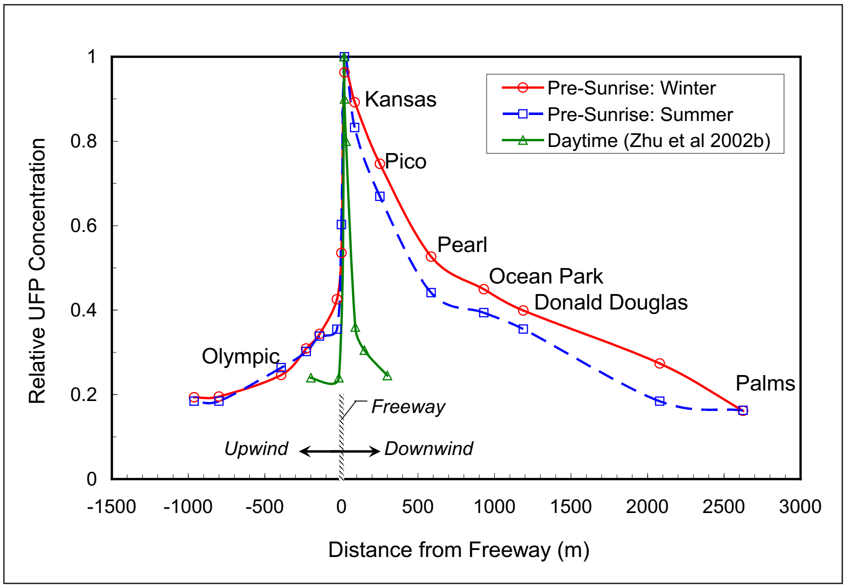
Near-Road Exposures

Stationary monitoring sites have historically been sited to measure compliance with National Ambient Air Quality Standards (NAAQS) on a regional level, which do not capture the dynamic pollution profiles in environments such as near roadways. Only recently has near-roadway monitoring been mandated by the U.S. Environmental Protection Agency (EPA).[1] As the numbers of such sites are limited, other tools can help to characterize pollutants in the near-road environment. Mobile measurements have the advantage of providing information on pollutant levels in many different locations. This supplements data from the more limited number of fixed monitoring sites. The MMP shows greatest promise in expanding the geographic coverage of measurements, however, it is important to note that the MMP does not provide the long-term data required for assessing NAAQS compliance.

While numerous near-road studies have been conducted in the United States,[2-8] this article will highlight only the MMP studies funded by CARB. The MMP has been used to collect mobile measurements in southern California communities such as Long Beach, Boyle Heights, and West Los Angeles over the past decade. The research focuses on the near-roadway concentrations on a carefully planned and prescribed route over a long study period. The MMP was driven twice per day during rush hour periods to capture the highest pollution levels intruding into neighborhoods from the freeways.

In 2007 and 2008, mobile measurements studies in Long Beach[9] and Santa Monica[10] illustrated the range of impacts observed near busy freeways. In a study conducted by Kozawa et al.,[9] near-road pollutant levels were found to be highest within the first 500 feet of a busy freeway, particularly during the day. While this study was consistent with the many near-road studies conducted, Hu et al.[10] found these impacts can be much larger during the early morning hours before sunrise (see Figure 2). In both studies, the effect of meteorology, particularly wind speed and direction, were important factors when the impacts were greatest. The orientation of the road relative to wind direction, whether the wind was normal to the freeway, was also found to

Figure 2. Pre-sunrise gradients measured in Santa Monica, CA,[10] compared to daytime gradients observed by Zhu et al.[2]



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be important for near-road environments, particularly for UFP and their distributions.[11]

Rule Impact Evaluation

In California, comprehensive regulations and incentive programs continue to reduce vehicle emissions from both gasoline and diesel-fueled vehicles and equipment despite increased travel and economic activity. CARB's mobile source and fuels programs are designed to make progress toward attainment of NAAQS for ozone and $PM_{2.5}$, and to reduce the health risk from diesel particulate matter (diesel PM).

In response to the identification of diesel PM as a toxic air contaminant, CARB adopted the Diesel Risk Reduction Plan,[12] which recommends a number of control measures to reduce diesel PM emissions with a goal of 85% reduction by 2020. Efforts to achieve these reductions included a major regulatory component; the Drayage Truck Rule[13] and Truck and Bus Rule,[14] which were both passed by CARB in late 2008 and required either retrofits or accelerated vehicle turnover. Emission reductions from 2007 and 2010 model-year engines that are required under these rules have been found to be significant.[15] Since emission testing is conducted in a laboratory setting, the MMP can complement the testing by providing verification of these reductions in the in-use fleet.

Two major southern California freeways were chosen to study the real-world benefits from CARB's diesel truck regulations. I-710 was chosen because it is used by drayage trucks serving the Ports of Los Angeles and Long Beach, one of the largest port complexes in the world. The CA-60 route was added to target non-drayage trucks that would be subject to the Truck and Bus Rule. Another freeway with only light-duty traffic (CA-110) was also selected to represent the light-duty contribution for both the I-710 and CA-60 freeways. Measurements were made starting in 2009 through 2012 on I-710, with the CA-60 route added in 2012.

Calculations of fleet-averaged, fuel-based emission profiles (amount of pollutant emitted for a unit of fuel burnt, or g/kg of fuel) were conducted using a carbon balance method frequently used for such real-world applications.[16-18] Fuel-based emission profile calculations were based on the ratio of background subtracted pollutant levels to the amount of fuel burned (expressed as carbon in CO and CO_2 assuming minimal contributions from volatile organic compounds). Diesel truck emission profiles were calculated by subtracting the light-duty contribution (on CA-110) from diesel-dominated freeway emissions. Assumptions were made on travel distance and fuel economy for gasoline vehicles and diesel trucks. The parameters of most interest were black carbon (as a proxy for diesel PM) and NO_x. Using this method of on-road freeway measurements provides an overall picture of the changing emissions of diesel trucks on these heavily traveled freeways.

Researchers observed that the fleet-averaged emissions estimates on the I-710 showed reductions of almost 50% or more for NO_x and BC between 2009 and 2011,[19] and BC showed stepwise reductions for each measurement year (see Figure 3). This is consistent with the influx of 2007 and 2010 model-year trucks into the fleet. These results highlight that diesel truck emissions are dramatically decreasing near the ports due to diesel controls, and the control rates are consistent with what was predicted with the adopted CARB regulations and California's incentive programs. The results also highlight the reduction in air pollution exposure of residents who live near the roadways, and those who travel and commute on these roadways.

Real-World Emissions

Although overall fleet-average vehicle emissions have declined significantly due to increasingly strict emission standards and improved control technologies, several researchers have suggested that a small, malfunctioning fraction of the fleet contributes a disproportionate fraction of overall vehicle emissions.[20,21] However, few measurements have been made of the emission characteristics of on-road high emitters. Furthermore, the real-world emission behavior of vehicles may be significantly different from the standard test cycles. While EPA's not-to-exceed (NTE) emission limits and testing requirements include tailpipe measurements of real-world emissions from in-use vehicles, MMP can provide complementary on-road data. Researchers have noted that vehicle emission behavior is a function of vehicle conditions (age, accrued mileage, fuel, emission controls, inspection and maintenance), vehicle route (route type, traffic, pavement conditions), and operating conditions (weather, speed, acceleration, load, driver behavior). Therefore, it is important to study the real-world emissions to help improve regional emissions estimates and to devise effective control programs.

Traditional methods for emissions testing of individual vehicles have significant limitations, including high costs (dynamometer experiments), limitation to fleet average emission rates (tunnel studies), limited location and operating conditions (remote sensing technology), and sample contamination from self-pollution ("follower" mobile units). The CARB MMP has a demonstrable advantage of using a zero-emission MMP for on-road emission measurements and the ability to sample individual vehicles under many different operating conditions.

In this research, the MMP was used in a study of individual on-road light-duty gasoline vehicles in three neighborhoods of Los Angeles in 2010 to investigate the relationship of emissions of high emitters with socioeconomic indicators. Sampling locations were chosen at two low socioeconomic status (SES) communities and one high SES community. Individual vehicle exhaust plumes were measured while the MMP encountered a target vehicle with no interference of other vehicles. Vehicles were selected randomly and followed for periods of time necessary to assure valid data were collected. Approximately 130 vehicles in each community were measured for calculation of emission profiles.

Fuel-based emission profiles were calculated based on concurrent elevations in CO, CO_2, NOx, BC, $PM_{2.5}$, and UFP above the baselines (measured in the absence of the target vehicles). The MMP data found that the average emission profiles for the sampled vehicles in low SES communities were roughly 2–3 times higher for CO, NOx, BC, and UFP, and 4–11 times higher for $PM_{2.5}$, compared to the high SES community.

These research applications highlight the importance of Smog Check and other programs to identify and repair or scrap high-emitting vehicles. This study also found that real-world emission behavior of vehicles was not only a function of age, technology group, and speeds, but were also influenced by other factors such as the route characteristics, driving modes (acceleration, deceleration, and idling), and vehicle maintenance history. The real-world fuel-based emission profiles measured by the MMP, although different from the traditional activity-based emission factors, can be very useful in informing and improving the emission inventories by adding the real-world driving behavior element, and evaluating and validating the effectiveness of current programs under different operational conditions.

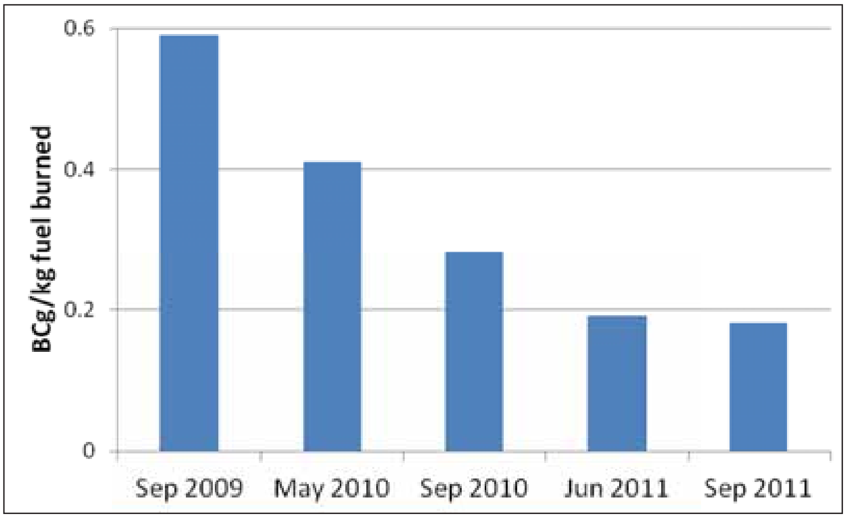

Figure 3. Reduction of BC emissions since 2009 in the diesel fleet on I-710 freeway

Challenges of Mobile Monitoring

Although mobile platforms present a number of advantages such as greater spatial resolution, and the flexibility to monitor air quality in a number of applications ranging from community-level measurements to source emission behavior, they also present some challenges in terms of data interpretation and management.

One of these challenges is how to translate short-term measurements to daily, monthly, and annual exposures. Compliance with NAAQS is determined based on the averaging period established by EPA for each air quality standard. The requirements for siting and ongoing operation of stationary monitoring networks, as well as data completeness criteria, are all mandated by EPA.

Additionally, mobile measurements also bring about the question of representativeness of data, from temporal variations, to changing meteorological and surrounding conditions. At this time,

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mobile measurements provide snapshots in space and time and do not replace long-term stationary monitoring programs. However, if repeated numerous times, mobile monitoring can provide supplemental information about potential long-term exposures. Statistical analyses, such as linear regression, may be able to be used to determine the most important variables that influence pollutant levels in the near-road environment.

Conclusion

The mobile platform has been used effectively in a number of different settings, including in neighborhoods, on freeways, and chasing vehicles. For near-road and neighborhood work, mobile measurements help fill in the data gaps that exist between stationary monitoring sites which are often placed miles away from each other. Mobile measurements also provide a unique method to assess vehicle emissions, either on an individual basis, or for a group of vehicles.

The real-world nature of mobile measurement makes it a powerful tool. However, the strength of this tool also makes it challenging to manage and interpret the many gigabytes of data. The near real-time measurements by a mobile platform are also impacted by considerations, including confounding sources and local meteorology. In addition, mobile measurements provide only snapshots in space and time, so making use of the data for long-term exposure and health effects assessment is challenging.

Despite the challenges of data interpretation, mobile measurements do provide a novel and useful tool for augmenting more traditional sampling methodologies. The method is not only a very useful device for air quality research programs, it has also proved to be a powerful tool for evaluating the success of air quality programs and control strategies, and a resource to inform the process of improving regional emissions inventories. **em**

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