CALIFORNIA
AIR RESOURCES BOARD

# Real-world Tire and Brake Wear Emissions

June 2, 2022
10:00 AM – 12:00 PM PST

# Thank you for joining us!
# Before we start

- This meeting will be recorded, final report and presentation slides will be available online
- We encourage questions AFTER the presentation
- Attendees will be muted during the presentation
- Use Chat to type in questions or Raise hand
- Email comments/questions to qi.yao@arb.ca.gov

# Online Resource

https://ww3.arb.ca.gov/research/single-project.php?row_id=67669


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Title: Real-World Tire and Brake-Wear Emissions

Principal Investigator / Author(s): Jung, Heejung

Contractor: UC Riverside

Contract Number: 18RD017

Project at a Glance

- Project Status: active

**Research Program Area:** Emissions Monitoring & Control, Health & Exposure

**Topic Areas:** Field Studies, Mobile Sources & Fuels, Modeling, Monitoring, Toxic Air Contaminants

**Research Summary:**

Vehicles emit inhalable particulates from two major sources: the exhaust system, which has been extensively characterized and regulated; and non-exhaust sources including brake-wear, tire-wear, and road dust resuspension. Increasingly stringent standards for exhaust emissions have led to the non-exhaust fraction becoming increasingly important. Model predictions (both MOVES and EMFAC) suggest that traffic-related emissions of both PM2.5 and PM10 from non-exhaust sources are currently on par with exhaust sources and will continue to increase in importance. Additionally, there is a growing concern over their potential toxicity due to their high metal content. Given the increased relevance of non-exhaust emissions and associated health concerns, new studies are needed to better estimate their magnitude and their impact on communities situated near major roadways. A greater understanding of the physical and compositional characteristics as well as overall emissions is needed for non-exhaust sources. Currently, a laboratory project is being funded to measure brake-wear particulate matter (PM) under controlled laboratory conditions, but an additional study is needed to determine how those emissions behave in the real-world. The objective of this project is to deploy a comprehensive measurement campaign near major roadway sites to capture a variety of driving behavior and fleet compositions. Real-time instrumentation will capture transient effects and discern the influence of driving conditions (smooth freeway driving verses stop and-go) and fleet mix (light-duty vs. heavy-duty). Filter measurements will help quantify total PM mass and identify tracers of individual non-exhaust sources. The information gathered will be analyzed to derive emission factors of non-exhaust emissions and in particular individual sources such as brake and tire-wear. It will also be input into a dispersion model to validate the derived emission factors and to estimate the potential exposure of downwind communities to these PM sources. The University of California, Riverside (UCR) proposes to deploy a comprehensive suite of instruments designed to detect PM in a wide size range as well as tracers unique to the individual non-exhaust sources. The results of this project will be compared to current and future laboratory tests measuring brake and tire-wear PM under controlled

Final report
Presentation

Also in the meeting description

CARB

# Research Motivation

- Brake and tire-wear will become more significant contributors to vehicle sourced PM
- new gasoline-powered cars and passenger trucks will not be sold in California by 2035 (N-79-20)
- The magnitude, physical and chemical characteristics of non-exhaust emissions need to be characterized

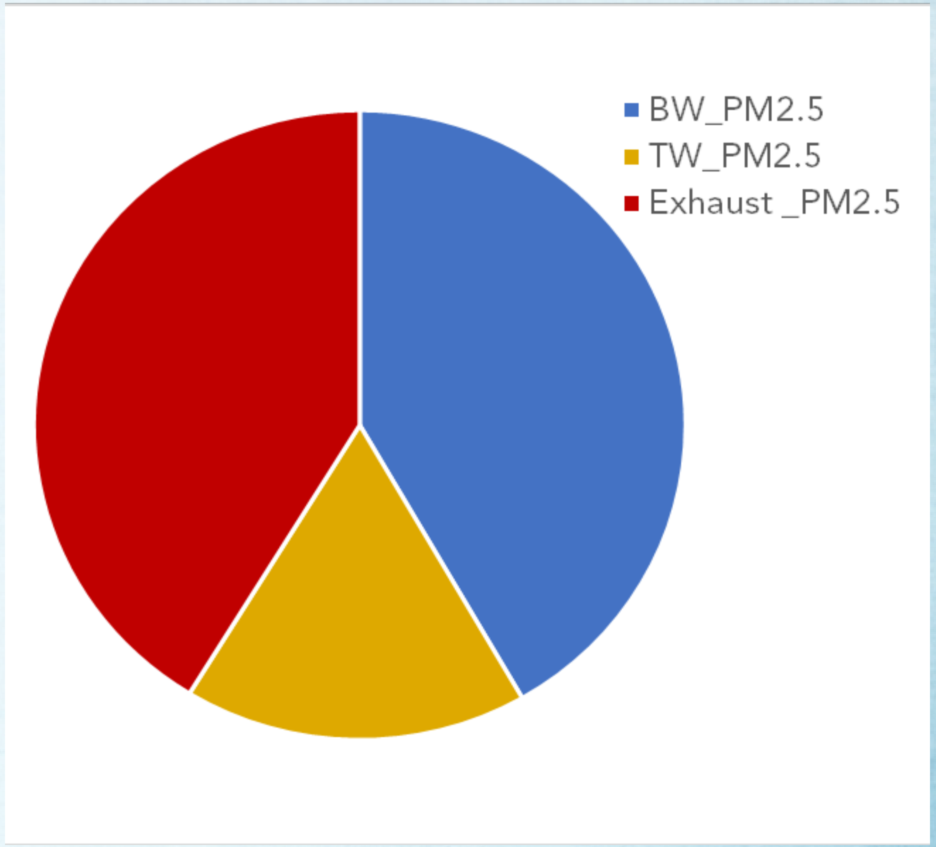
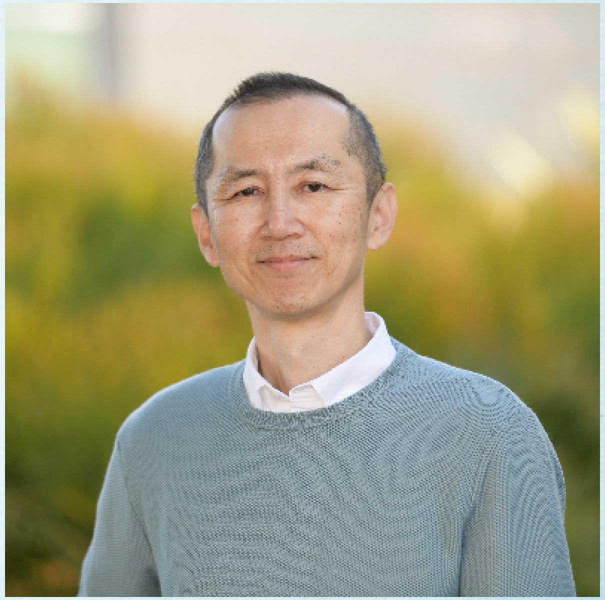



Figure 1. Primary PM2.5 emissions for on-road vehicles are broken down by source type based on EFMAC2021 emission inventory.

CARB

# Today's Speaker

Dr. Heejung Jung
Professor
CE-Cert,
University of California, Riverside.



Research Interest:

- Aerosol science
- Air pollution

https://intra.engr.ucr.edu/~heejung/research/

# Real-World Tire and Brake Wear Emissions

Heejung Jung, Xiaoliang Wang, L.-W. Antony Chen, Guoyuan Wu, Max Zhang

UCR College of Engineering – Center for Environmental Research and Technology

DRI Impactful science, inspiring solutions.

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June 2nd CARB Research Seminar

# Acknowledgement

- CARB for funding (18RD017)
- Seungju Yoon, Qi Yao, Chris Ruehl, Sonya Collier for managing the project
- Other CARB staff who attended monthly meeting to give advice.
- SCAQMD staff who allowed access and escorted access to their NR sites.
- Business owners and managers who allowed the team to access their parking lots for upwind sites.

# Acknowledgement


- Students and staff from 4 institutions
- Brenda Lopez, Chas Frederickson, Steve Gronstal, David Mendez-Jimenez, Tianyi Ma, Ling Cobb, Jesse Stuart, and Chengguo Li.
- Manabu Shiraiwa (UCI) for a health effect study, Kihong Park (GIST) for XRF and ICP-MS analysis, Steven Ho (Hong Kong Premium Services and Research Laboratory) for chemical analysis, Marko Princevac (UCR) for turbulence measurement, Guenter Engling (CARB) for tire particles. Tyler Beck (Particle Instrument) for ELPI+, Yusuke Mizuno (Horiba) for PX375 and TSI for QCM-MOUDI.

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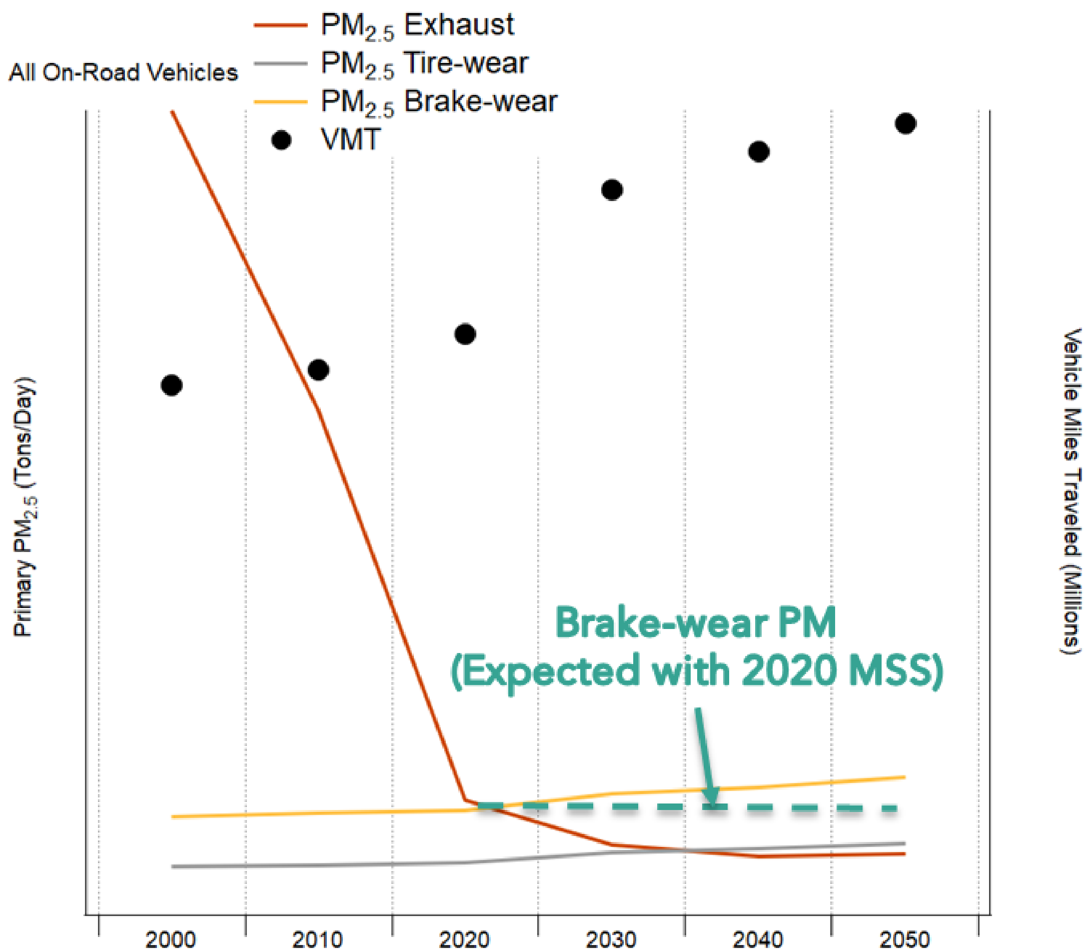
- Background and objectives
- Field test
  - Locations, instruments, and measurements.
- Results and analysis
  - Chemical composition
  - Source apportionment
  - Dispersion modeling
  - Particle size distributions
- Takeaways

# Non-tailpipe emissions are becoming a larger fraction of total vehicle emissions




EMFAC2021 Projection

# Study Objectives

- Measure time-resolved $PM_{2.5}$ and $PM_{10}$ mass at near road locations to quantify exposure at near road locations.
- Measure real-time particle number distribution and semi-real time metal content analysis to distinguish brake and tire PM from background and exhaust particles.

# Objectives

- Conduct source apportionment analysis to determine contribution of brake and tire particles to $PM_{2.5}$ and $PM_{10}$.
- Determine unique tracers for brake and tire-wear emissions from source apportionment.
- Dispersion modeling to evaluate impact of brake and tire wear particles on nearby communities at downwind locations.

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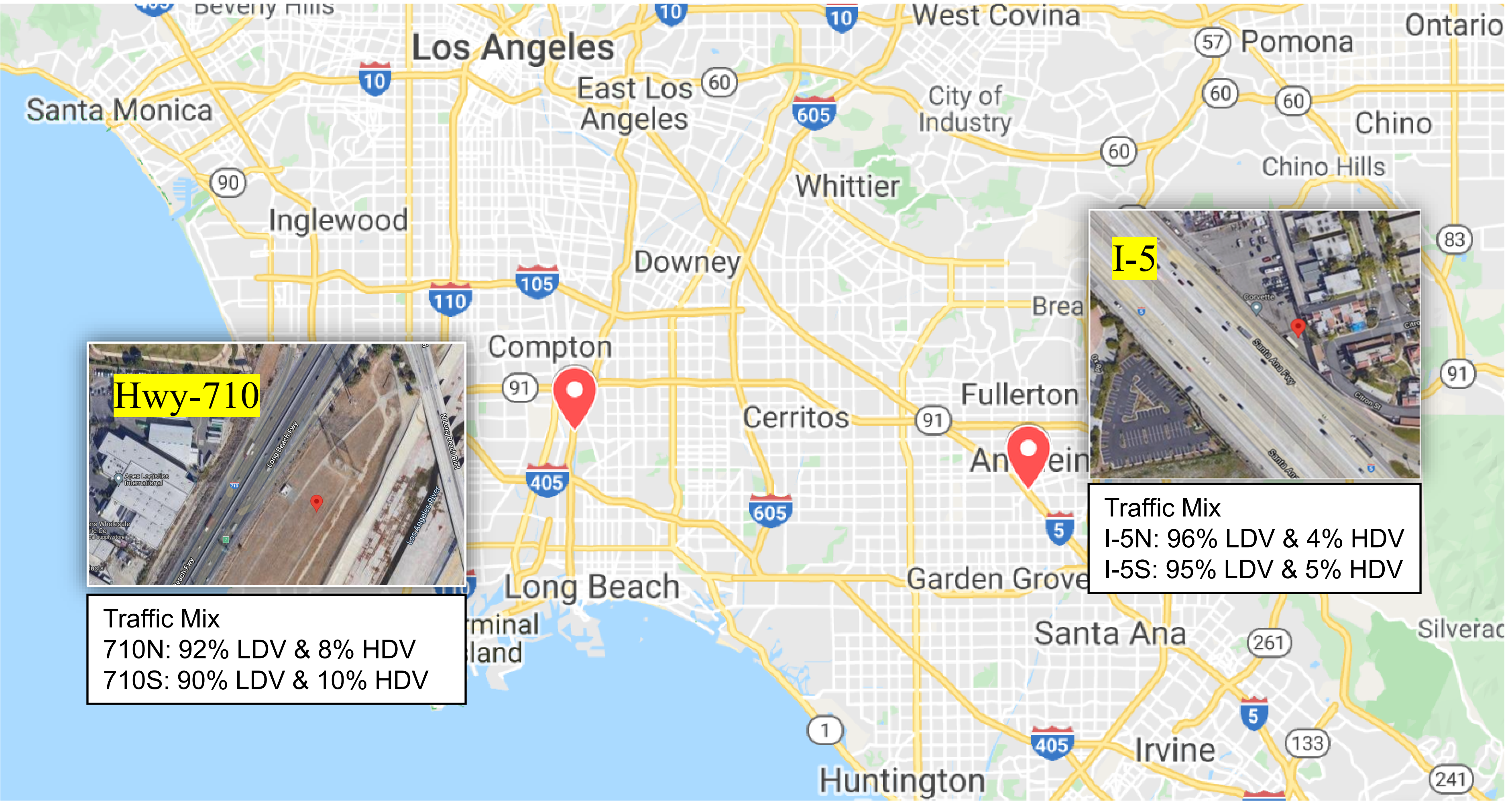
# Monitoring Sites in Southern California (January – February, 2020)



# Anaheim sites

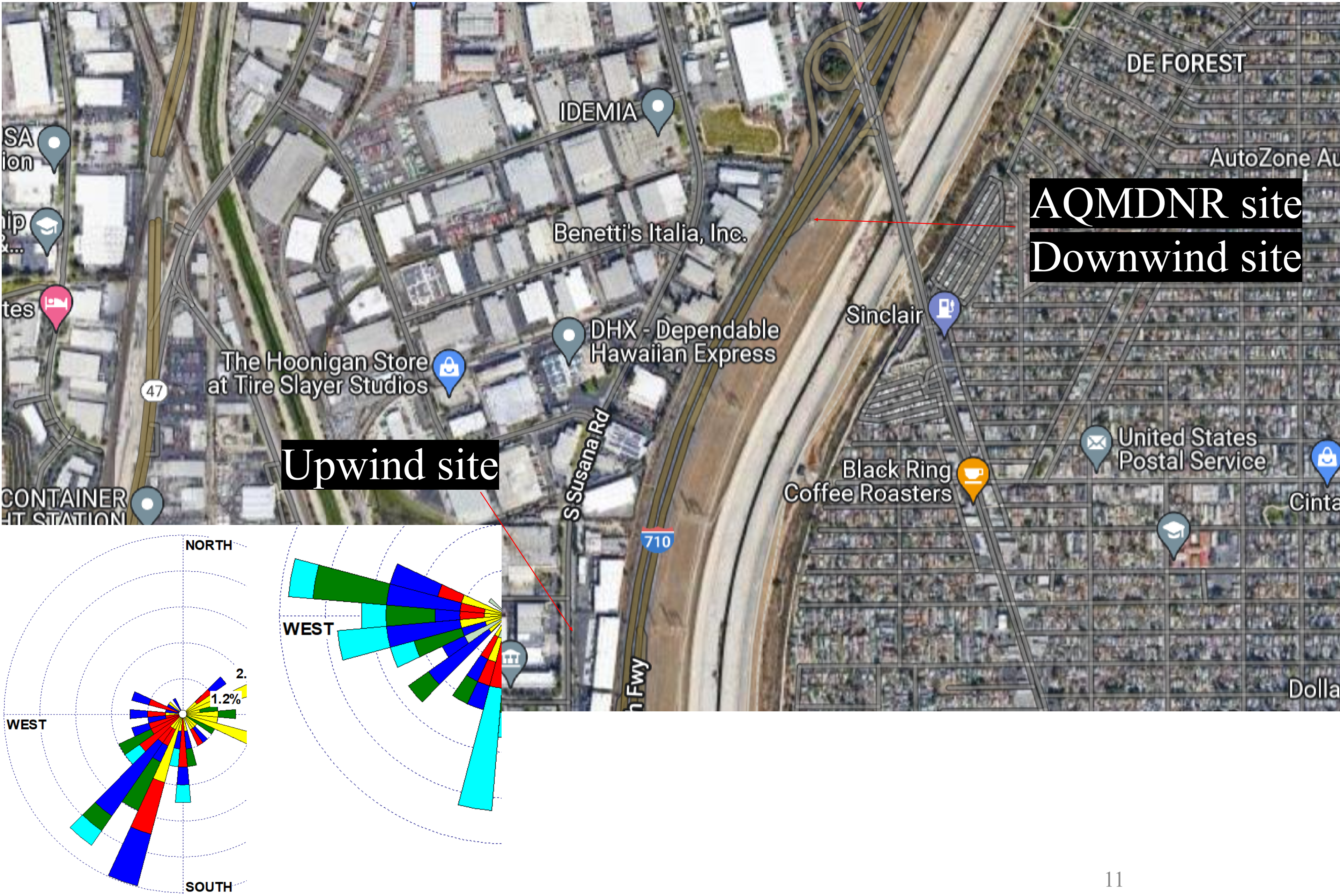
Anaheim ambient site

Continuous: CO, $NO_2$, $O_3$ $PM_{10}$, $PM_{2.5}$

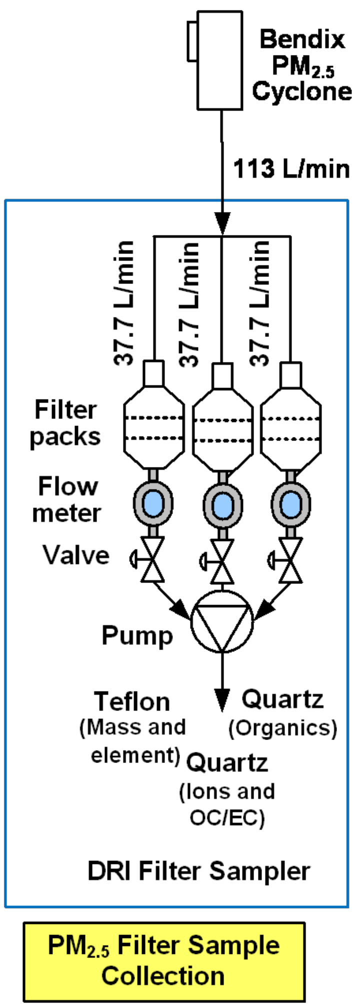
24hr: $PM_{10}$, $PM_{2.5}$

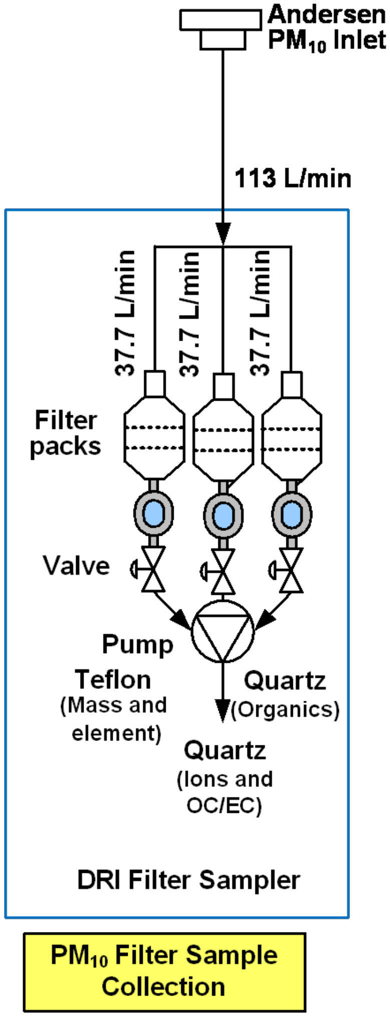

Anaheim NR site
Downwind site

# Long Beach sites



# $PM_{2.5}$ and $PM_{10}$ filter pairs were collected upwind and downwind of highways




Typical sampling periods:

- 0600-1000; 1000-1400; 1400-1800
- 1/28/2020–2/3/2020 (I-5); 18 sets
- 2/4/2020–2/10/2020 (I-710); 14 sets
- A total of 128 filters.

# Filters were analyzed for source markers

| Measurement Method | Species | Potential Markers |
|---|---|---|
| **Gravimetry** | PM mass | |
| **X-ray Fluorescence (XRF)** | Elements from sodium (Na) to uranium (U) | • Mineral dust: Al, Si, Ca, and K;<br>• Brake wear: Cu, Sb, Ba, Fe, Zr, Mo, and Sn;<br>• Tire wear: Zn;<br>• Concrete road wear: Ca and S |
| **Thermal/Optical Analysis** | Organic, elemental carbon (OC and EC) and thermal fractions | • Tailpipe emissions |
| **Ion Chromatography** | Water soluble ions $Cl^-$, $NO_3^-$, $SO_4^{2-}$, $NH_4^+$, $Na^+$, $Mg^{2+}$, $K^+$, and $Ca^{2+}$ | • Primary salt: $Cl^-$ and $Na^+$<br>• Secondary salts: $NO_3^-$, $SO_4^{2-}$, and $NH_4^+$<br>• Biomass burning: $K^+$ |
| **Thermal desorption GC/MS** | Nonpolar organics, including PAHs alkanes, cycloalkanes, hopanes, steranes, phthalates | • Tire wear: alkanes ($C_{34}$-$C_{36}$)<br>• Tire wear: pyrene, benzo(ghi)perylene, fluoranthene, phenanthrene, and dibenzopyrenes<br>• Motor oil emissions: hopanes and steranes |
| **pyrolysis-GC/MS** | Rubber markers, including styrene, isoprene, butadiene, dipentene, and vinylcyclohexene | • NR: isoprene, dipentene<br>• BR: butadiene, vinylcyclohexene<br>• SBR: styrene, butadiene, vinylcyclohexene |
| **Ultra-performance liquid chromatography (UPLC)** | Benzothiazole and derivatives | • Tire wear |

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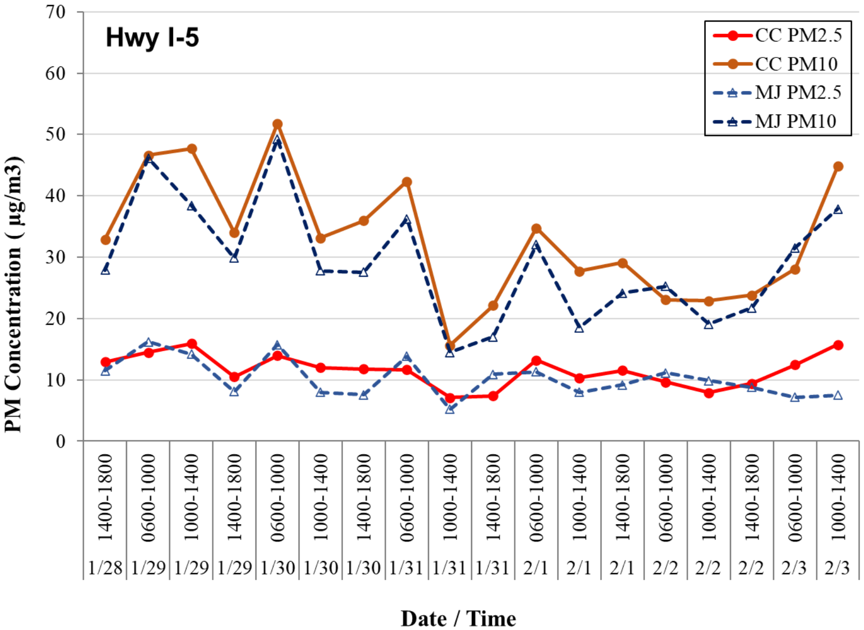
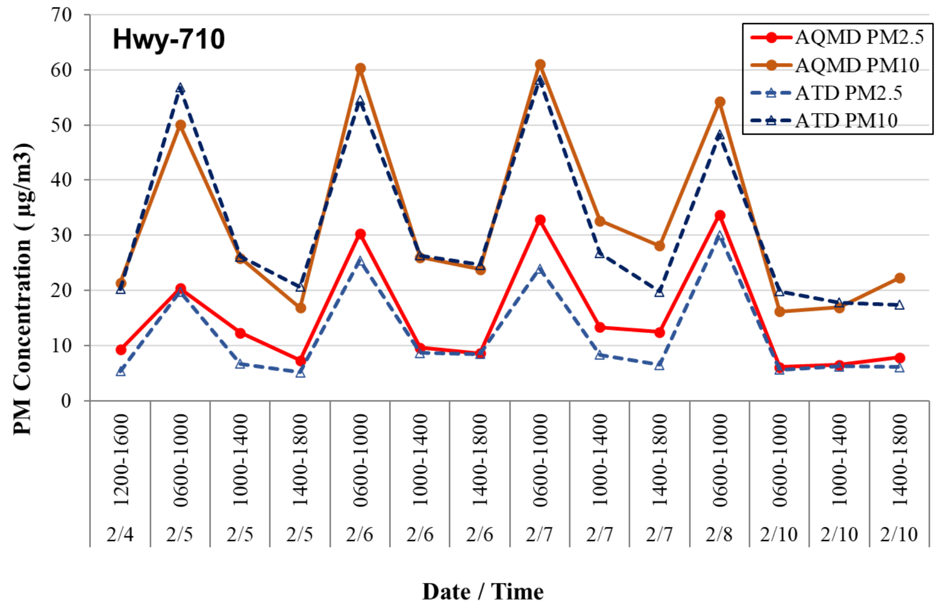
# $PM_{10}$ concentrations were 2-3 times of $PM_{2.5}$; Up/downwind differences were small

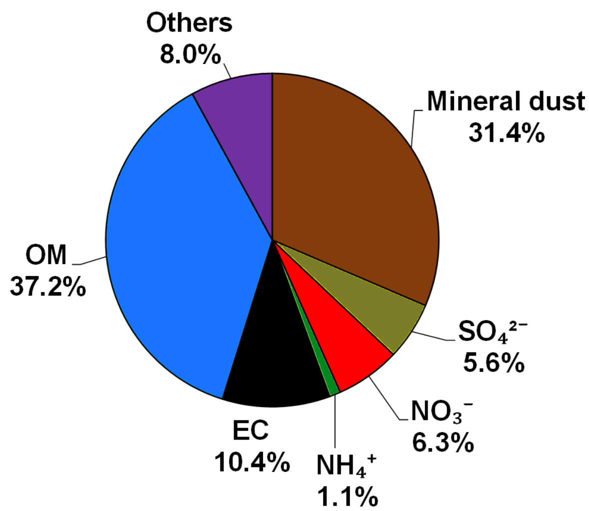


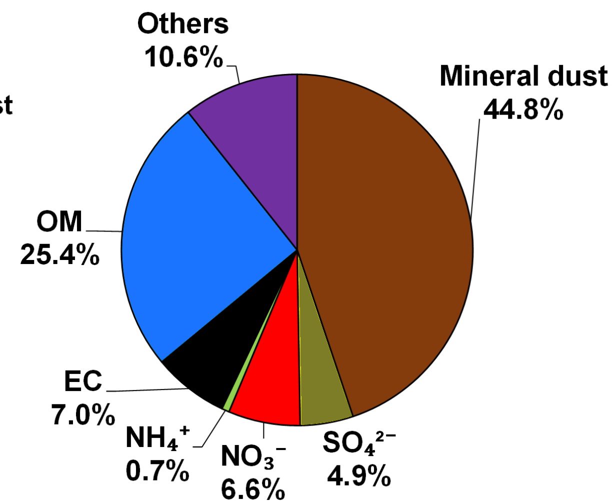

| Average PM Concentrations (µg/m³) | | | | |
|---|---|---|---|---|
| Site | Upwind $PM_{2.5}$ | Upwind $PM_{10}$ | Downwind $PM_{2.5}$ | Downwind $PM_{10}$ |
| I-5 | 9.56 | 28.47 | 10.88 | 32.49 |
| I-710 | 11.00 | 30.37 | 14.36 | 31.87 |

# Mineral dust and carbon were major PM components

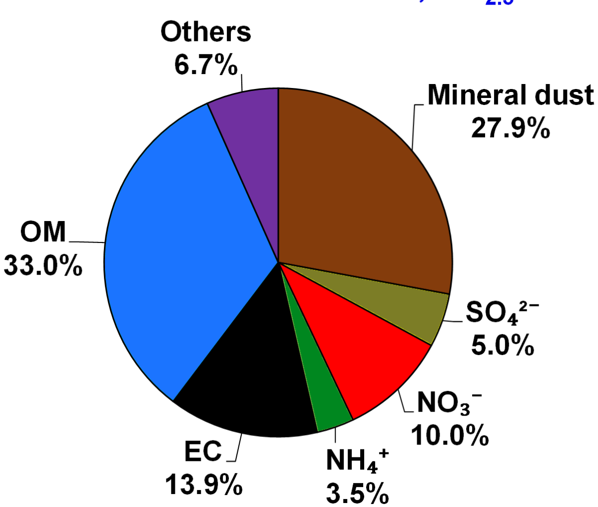
I-5 Downwind, $PM_{2.5}$



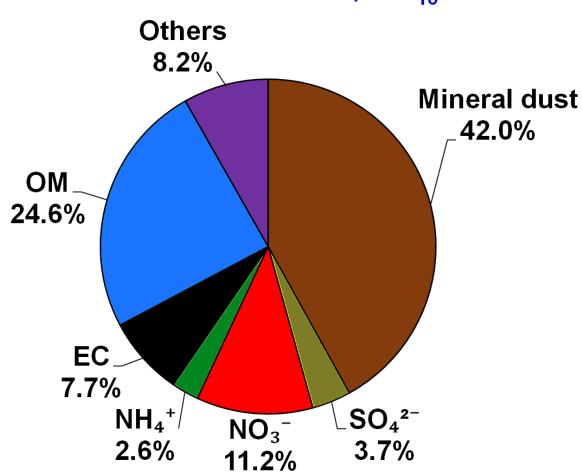

I-5 Downwind, $PM_{10}$




I-710 Downwind, $PM_{2.5}$




I-710 Downwind, $PM_{10}$

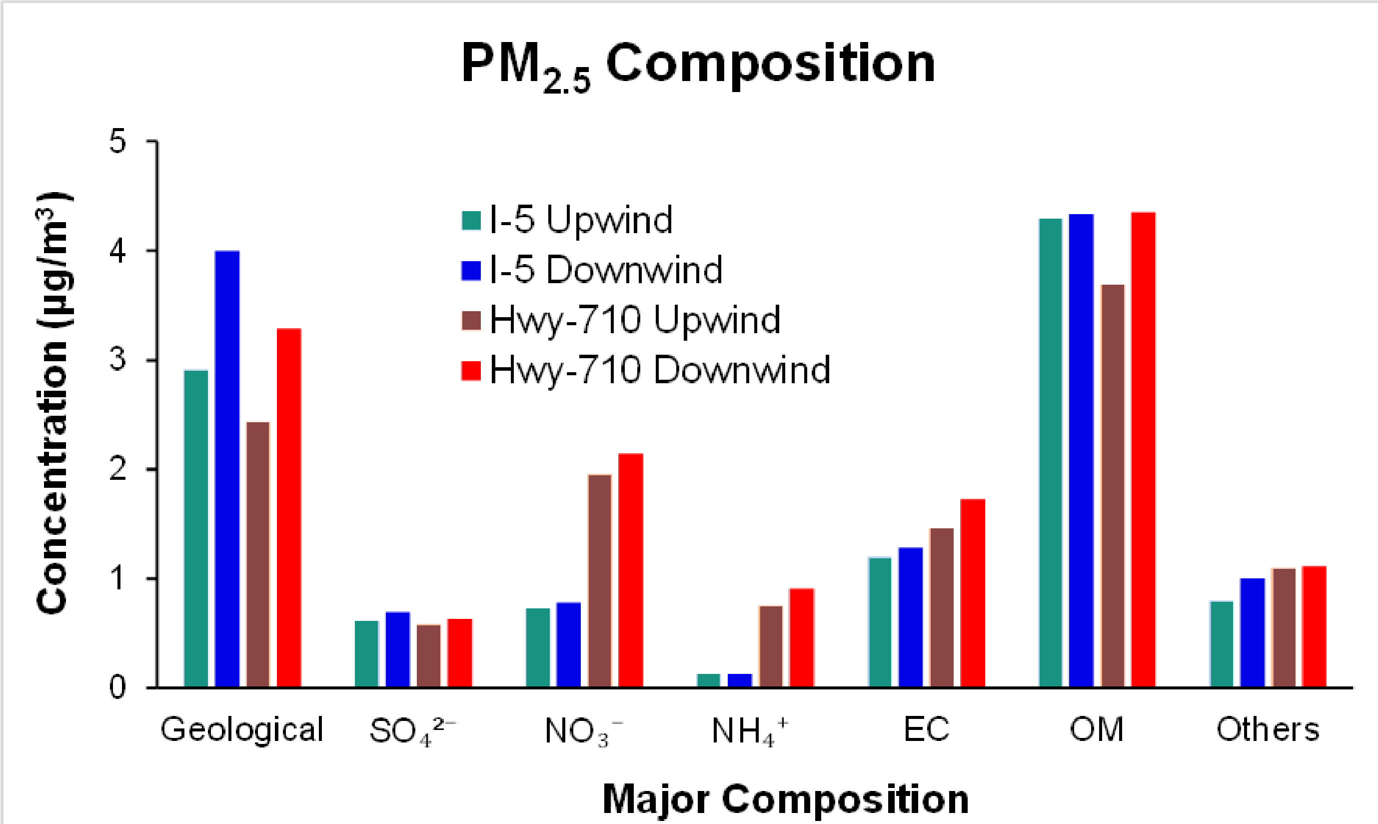



Main composition:

- $PM_{2.5}$: Organic matter (OM; ~30–40%), mineral dust (~30%), and elemental carbon (EC; ~10–15%)
- $PM_{10}$: mineral dust (>40%), OM (~25%); coarse $NO_3^-$?
- More OM and EC% in $PM_{2.5}$ than $PM_{10}$; more dust and others (elements and ions) in $PM_{10}$

- OM=1.2 × OC
- Mineral dust = 2.2×Al + 2.49×Si + 1.63×Ca + 2.42×Fe + 1.94×Ti

# Differences are found between upwind/downwind and I-5/I-710




- Downwind > Upwind
- EC is ~20% higher at I-710 than I-5
- $SO_4^{2-}$ is similar → regional distribution
- $NO_3^-$ and $NH_4^+$ much higher at I-710, due to two high $NH_4NO_3$ events

# High correlations were found among elements from common sources

(a) I-5 Δ $PM_{10}$

| | Fe | Si | Ca | Al | K | Zn | Ti | Cu | Ba | Sb | Sr | Cr | Mn | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fe | | | | | | | | | | | | | | |
| Si | 0.31 | | | | | | | | | | | | | |
| Ca | 0.41 | 0.79 | | | | | | | | | | | | |
| Al | 0.26 | 0.81 | 0.68 | | | | | | | | | | | |
| K | 0.56 | 0.33 | 0.22 | 0.24 | | | | | | | | | | |
| Zn | 0.69 | 0.32 | 0.46 | 0.39 | 0.29 | | | | | | | | | |
| Ti | 0.90 | 0.27 | 0.30 | 0.21 | 0.49 | 0.70 | | | | | | | | |
| Cu | 0.90 | 0.14 | 0.23 | 0.13 | 0.39 | 0.69 | 0.90 | | | | | | | |
| Ba | 0.69 | 0.07 | 0.17 | 0.07 | 0.32 | 0.63 | 0.76 | 0.80 | | | | | | |
| Sb | 0.01 | 0.17 | 0.09 | 0.30 | 0.01 | 0.00 | 0.01 | 0.04 | 0.02 | | | | | |
| Sr | 0.53 | 0.22 | 0.23 | 0.12 | 0.27 | 0.38 | 0.43 | 0.46 | 0.28 | 0.00 | | | | |
| Cr | 0.29 | 0.02 | 0.08 | 0.11 | 0.26 | 0.21 | 0.20 | 0.29 | 0.22 | 0.01 | 0.03 | | | |
| Mn | 0.67 | 0.25 | 0.34 | 0.12 | 0.43 | 0.26 | 0.48 | 0.49 | 0.26 | 0.07 | 0.50 | 0.08 | | |
| Zr | 0.87 | 0.15 | 0.25 | 0.13 | 0.35 | 0.70 | 0.89 | 0.94 | 0.81 | 0.04 | 0.37 | 0.28 | 0.43 | |
| Mo | 0.01 | 0.03 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.06 | 0.00 | 0.02 | 0.00 | 0.25 | 0.00 | 0.04 |

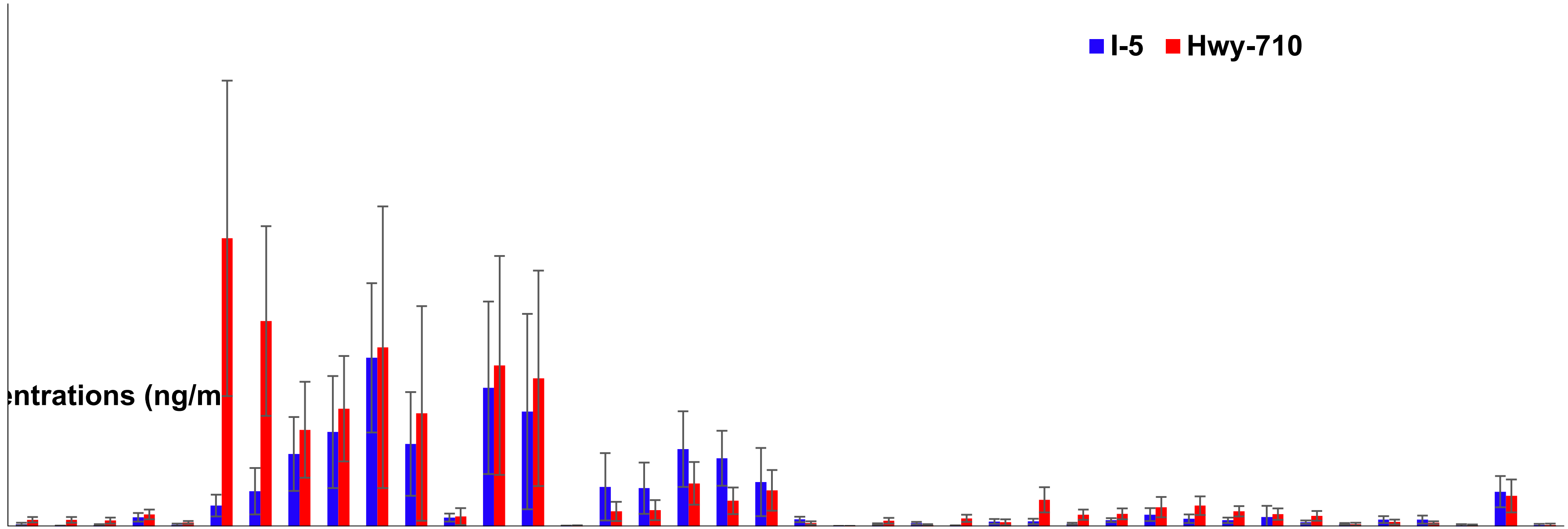
(b) I-710 Δ $PM_{10}$

| | Fe | Si | Ca | Al | K | Zn | Ti | Cu | Ba | Sb | Sr | Cr | Mn | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fe | | | | | | | | | | | | | | |
| Si | 0.40 | | | | | | | | | | | | | |
| Ca | 0.64 | 0.38 | | | | | | | | | | | | |
| Al | 0.34 | 0.70 | 0.35 | | | | | | | | | | | |
| K | 0.46 | 0.94 | 0.32 | 0.61 | | | | | | | | | | |
| Zn | 0.42 | 0.74 | 0.43 | 0.64 | 0.62 | | | | | | | | | |
| Ti | 0.08 | 0.20 | 0.39 | 0.49 | 0.10 | 0.38 | | | | | | | | |
| Cu | 0.75 | 0.07 | 0.32 | 0.11 | 0.14 | 0.08 | 0.01 | | | | | | | |
| Ba | 0.44 | 0.03 | 0.38 | 0.10 | 0.04 | 0.11 | 0.15 | 0.40 | | | | | | |
| Sb | 0.15 | 0.31 | 0.27 | 0.26 | 0.30 | 0.33 | 0.17 | 0.01 | 0.05 | | | | | |
| Sr | 0.19 | 0.07 | 0.35 | 0.13 | 0.04 | 0.11 | 0.22 | 0.12 | 0.01 | 0.14 | | | | |
| Cr | 0.35 | 0.30 | 0.07 | 0.29 | 0.30 | 0.45 | 0.00 | 0.15 | 0.09 | 0.07 | 0.02 | | | |
| Mn | 0.37 | 0.38 | 0.23 | 0.29 | 0.34 | 0.24 | 0.05 | 0.14 | 0.17 | 0.19 | 0.00 | 0.09 | | |
| Zr | 0.50 | 0.01 | 0.16 | 0.02 | 0.04 | 0.05 | 0.00 | 0.76 | 0.31 | 0.04 | 0.03 | 0.12 | 0.07 | |
| Mo | 0.01 | 0.10 | 0.02 | 0.13 | 0.09 | 0.07 | 0.01 | 0.01 | 0.03 | 0.23 | 0.07 | 0.17 | 0.30 | 0.05 |

**Darker green $R^2 \geq 0.8$; Light green: $R^2 = 0.6$-$0.8$.**

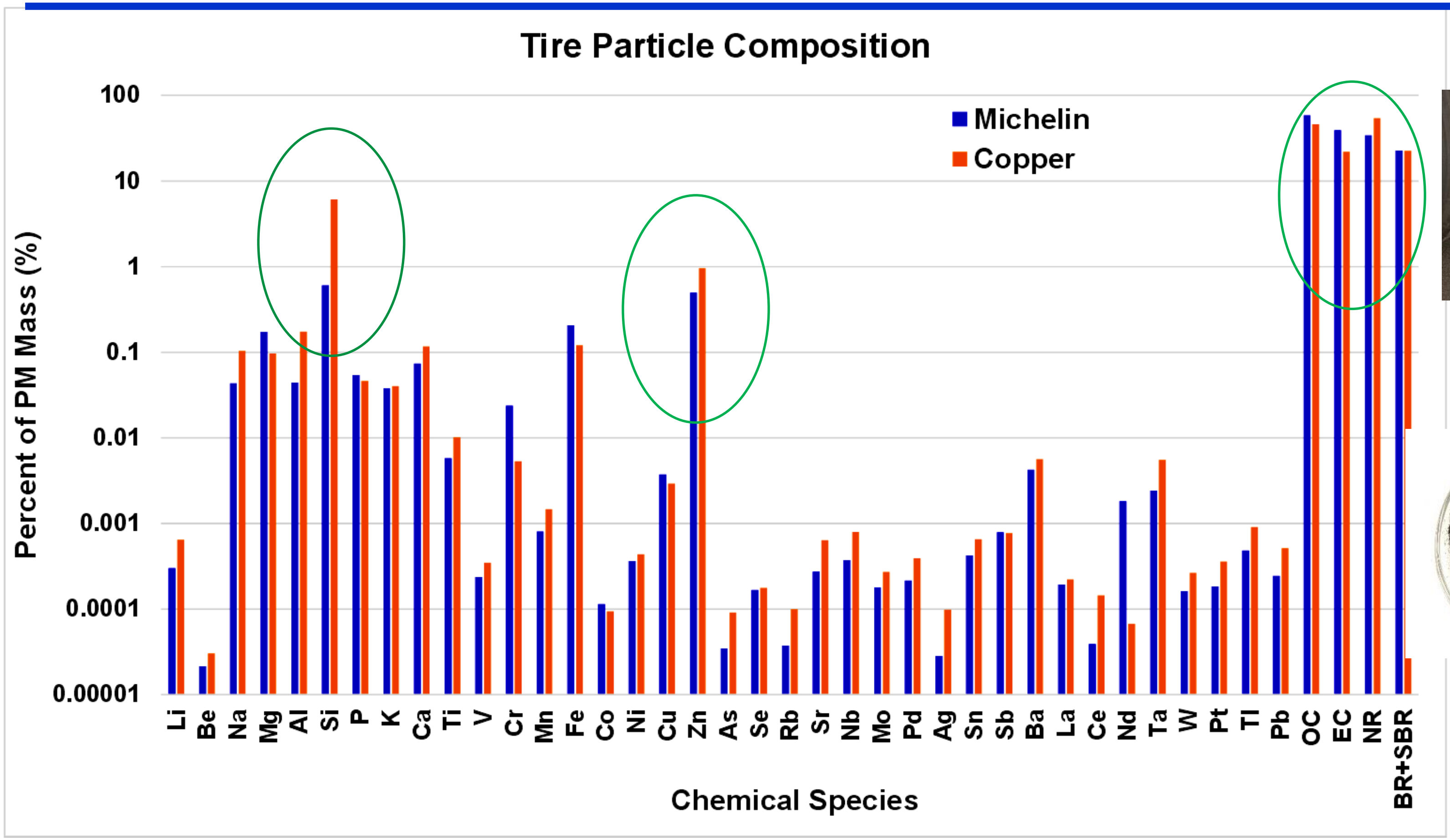
Brake wear: Ba, Cu, and Zr
Road dust: Al, Si, K, and Ca
(Measured by XRF)

# PAH Concentrations and Distributions near I-5 and I-710




- I-710 PAH concentrations are 47% higher than I-5
- Both highways have similar PAH distributions, except I-710 has higher fluoranthene and pyrene

# Tire particles show elemental and organic differences




| Mass Percent (%) | | | | | | |
|---|---|---|---|---|---|---|
| Composition | Si | Zn | OC | EC | NR | BR+SBR |
| Michelin | 0.6 | 0.5 | 59 | 39 | 34 | 23 |
| Cooper | 6.1 | 1.0 | 46 | 22 | 54 | 23 |

NR: natural rubber
BR: butadiene rubber
SBR: styrene–butadiene rubber

# Summary

- Average concentrations of near-road $PM_{2.5}$ and $PM_{10}$ were 10-15 and ~30 µg/m$^3$, respectively.
- Organic matter, mineral dust, and elemental carbon (EC) were major PM components.
- Higher concentrations of EC (19-26%) and particulate PAHs (47%) were found near I-710 than near I-5, likely due to more diesel vehicles on I-710.
- High correlations were found for elements with common sources, such as markers for brake wear (e.g., Ba, Cu, and Zr) and road dust (e.g., Al, Si, K, and Ca ).
- Differences in elemental and rubber abundances are found in different tires.

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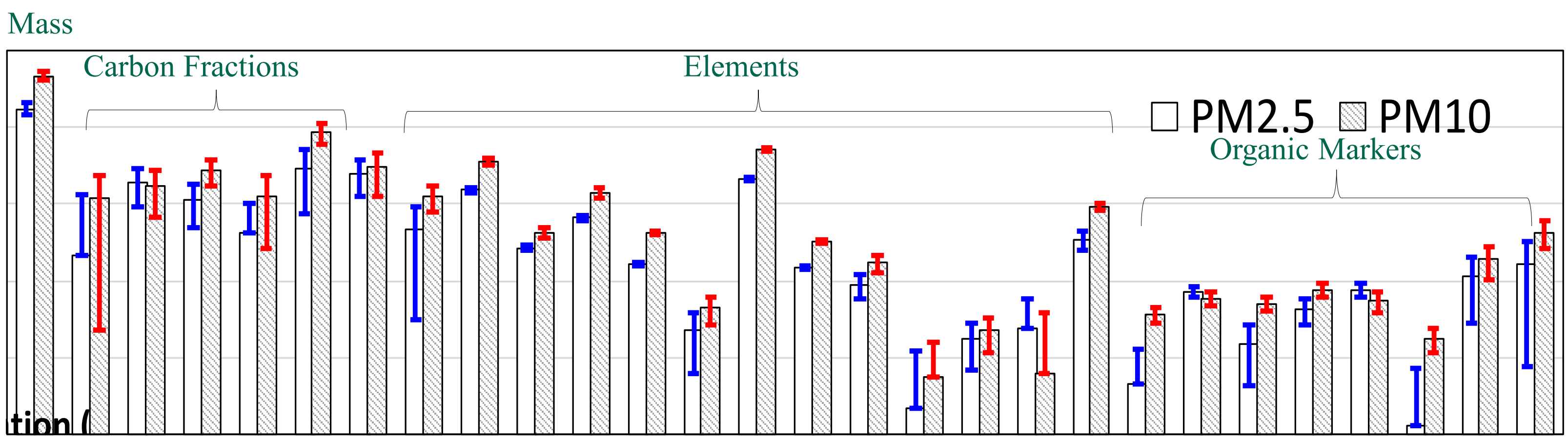
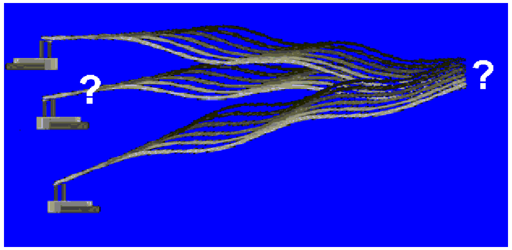
# Average PM Chemical Composition (Downwind – Upwind)




- The downwind-upwind difference may be entirely attributed to the on-road traffic emissions (exhaust + non-exhaust). It is the starting point of source apportionment

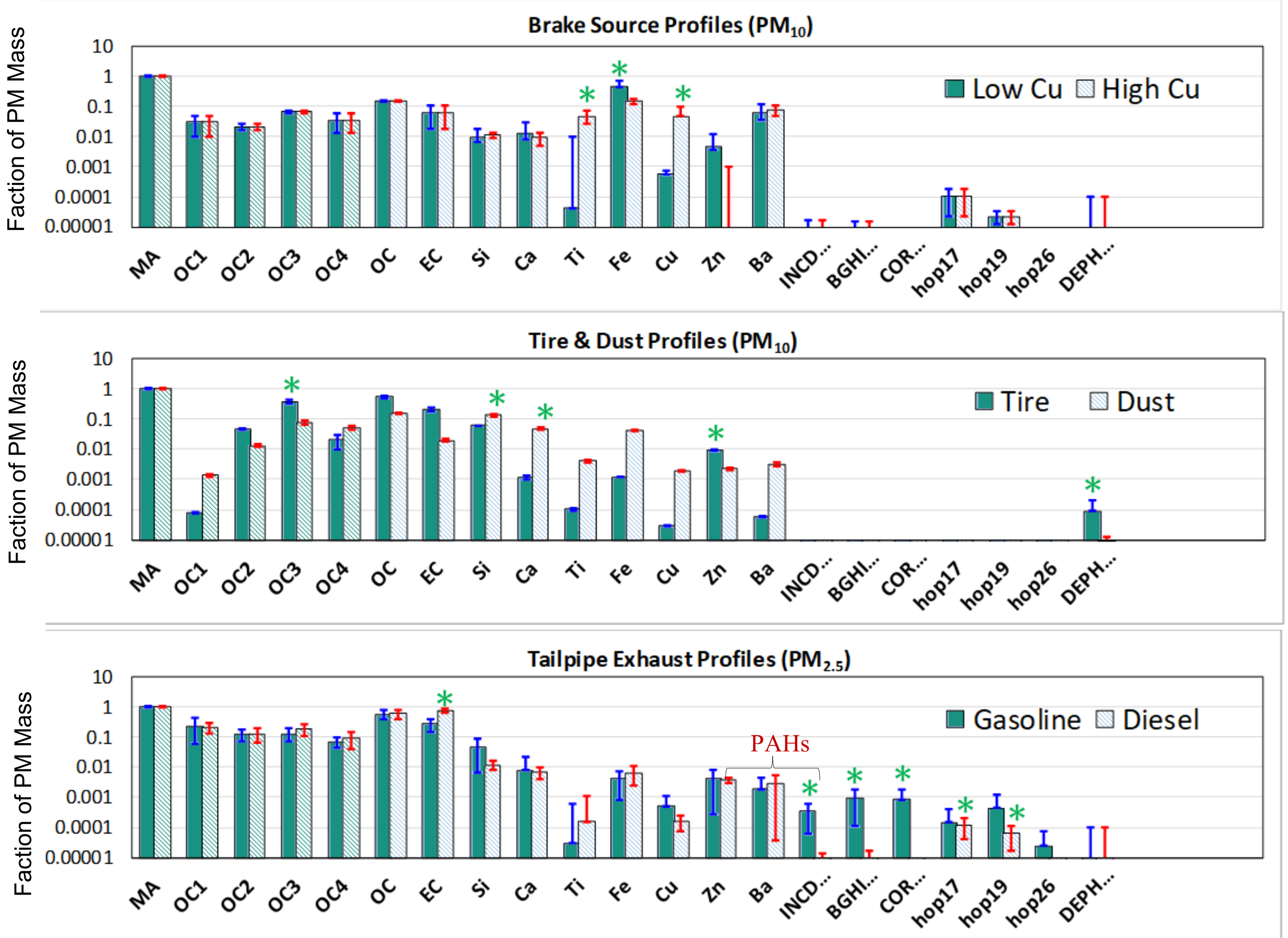
# Chemical Mass Balance (CMB) for Source Apportionment




$$\Delta \boldsymbol{c}_{i,k} = \sum_{j=1}^{m} F_{i,j} \boldsymbol{S}_{j,k} + \boldsymbol{e}_{i,k}$$

- $\Delta \boldsymbol{C}_{i,k}$: Difference in species i concentrations between downwind and upwind measurement at time k
- $\boldsymbol{F}_{i,j}$: Source profiles for source j, normalized to $PM_{2.5}$ or $PM_{10}$ concentration
- $\boldsymbol{S}_{i,k}$: Source contribution from source j at time k
- $\boldsymbol{e}_{i,k}$: Deviation between measured and modeled species concentrations
- Solved for $\boldsymbol{S}_{i,k}$ by EPA CMB 8.2 or **Hybrid Environmental Receptor Model (Chen and Cao, 2018)**

# Examples of Source Profiles Explored




- Brake profiles: Dynamometer studies (CRPAQS, 2004; CARB, 2020)
- Tire profiles: Tire dust collected in the lab and analyzed by DRI
- Dust profiles: Dust samples collected at monitoring sites, and analyzed after resuspension by DRI
- Exhaust Profiles: Dynamometer studies (Gas-Diesel Split Study 2001, CARB database)

***Potential markers for each profile marked**

# Example of CMB Sensitivity Tests

| Source | Profile | I | II | III | IV | V | VI | VII |
|---|---|---|---|---|---|---|---|---|
| Geological | MADust ($PM_{10}$) | **8.21 ± 0.50** | **4.26 ± 0.47** | | | | | |
| | CCDust ($PM_{10}$) | | | **2.58 ± 0.28** | **2.52 ± 0.30** | **2.56 ± 0.29** | | |
| | MCDust ($PM_{10}$) | | | | | | **3.33 ± 0.79** | **3.44 ± 0.80** |
| | BEAKE-C | **0.43 ± 0.19** | **0.52 ± 0.24** | **0.53± 0.25** | **0.53 ± 0.25** | **0.55 ± 0.26** | **0.51 ± 0.25** | **0.52 ± 0.25** |
| | BEAKE-D | | **0.35 ± 0.17** | **0.43± 0.19** | **0.43 ± 0.19** | **0.44 ± 0.19** | **0.40 ± 0.18** | **0.40 ± 0.18** |
| Tire | COTIRE | | | | **0.18 ± 0.27** | **0.10 ± 0.26** | **0.18 ± 0.34** | **0.10 ± 0.32** |
| | LATIRE | **-0.53 ± 0.27** | **0.03 ± 0.26** | **0.11 ± 0.26** | | | | |
| Gasoline | CS-L | | | | | **0.05 ± 0.02** | | **0.05 ± 0.02** |
| | GAS | **0.05 ± 0.03** | **0.06 ± 0.03** | **0.08 ± 0.04** | **0.08 ± 0.04** | | **0.07 ± 0.04** | |
| | DIESEL | **0.25 ± 0.21** | **0.17 ± 0.22** | **0.12 ± 0.22** | **0.10 ± 0.21** | **0.21 ± 0.19** | **0.10 ± 0.22** | **0.19 ± 0.19** |
| $r^2$ | | *0.71* | *0.93* | *0.93* | *0.93* | *0.93* | *0.89* | *0.89* |
| $\chi^2$ | | *8.28* | *0.75* | *0.77* | *0.75* | *0.84* | *0.63* | *0.69* |
| *%MASS* | | *183.3* | *117.7* | *84.0* | *84.1* | *85.1* | *100.2* | *102.1* |

- CMB sensitivity tests confirm that average Upwind-Downwind difference can be explained by exhaust and non-exhaust emissions
- Two brake wear profiles (low Cu and high Cu) are required to achieve an acceptable solution

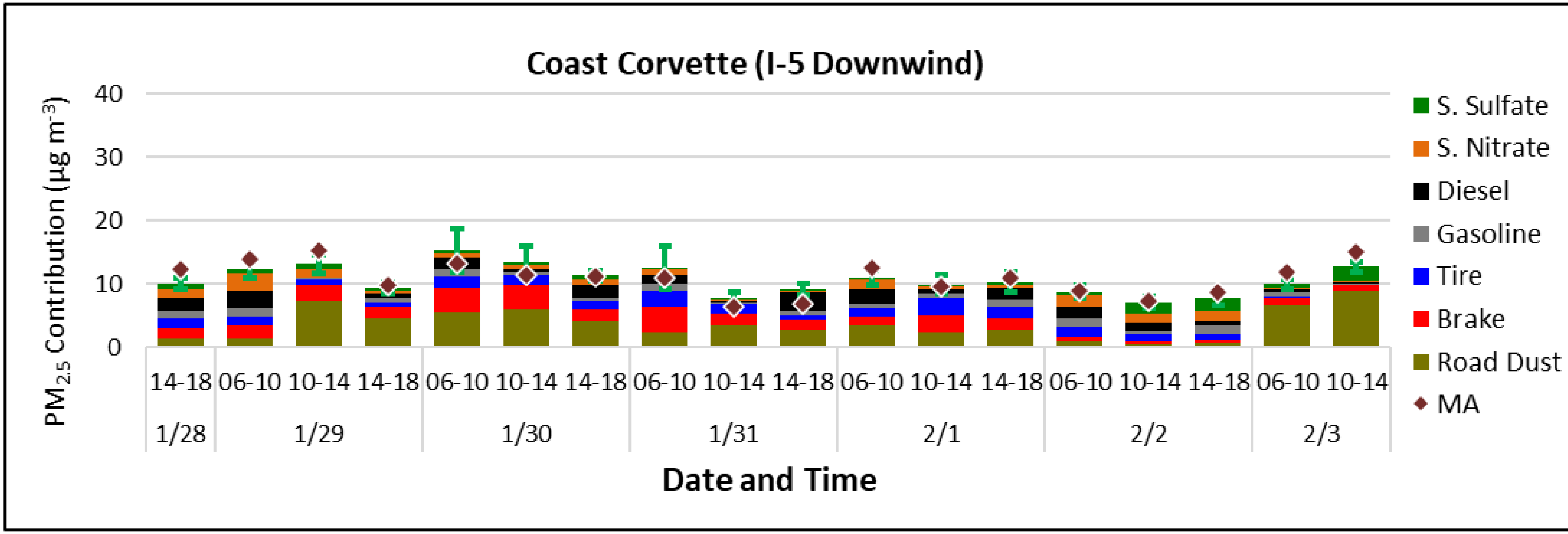
# MPIN Matrix Confirms Source Markers

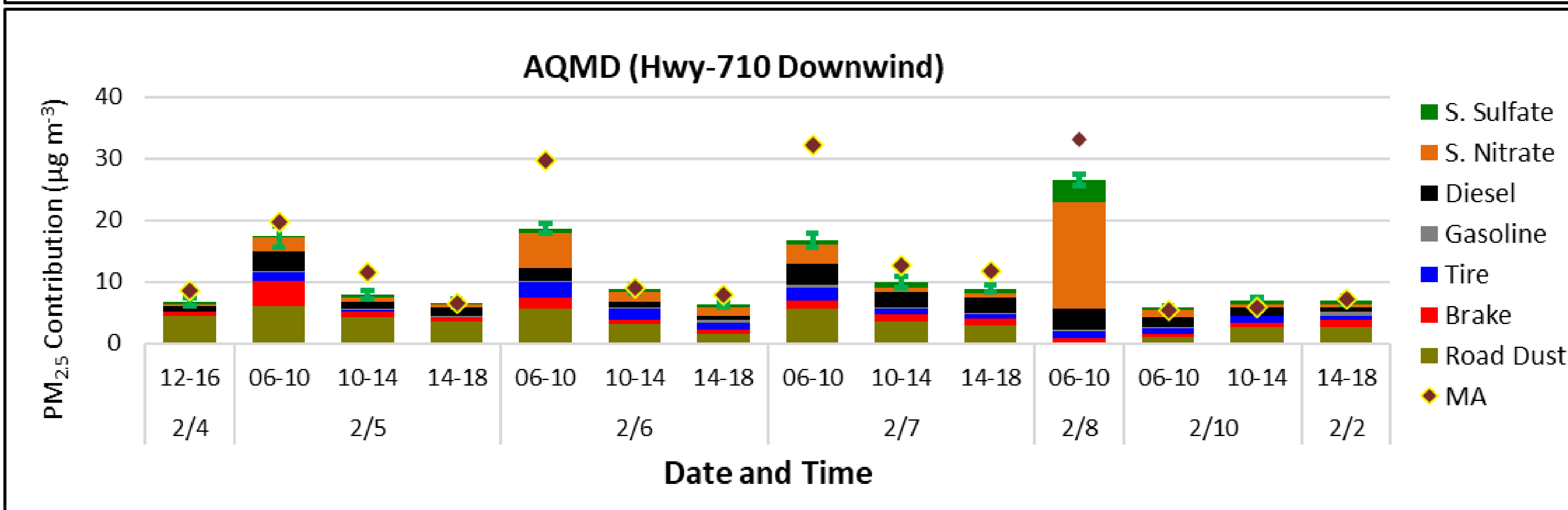
| SPECIES[a] | | | | | | |
|---|---|---|---|---|---|---|
| OC1 | -0.03 | -0.04 | 0.51 | 0.02 | -0.3 | |
| OC2 | -0.03 | -0.02 | 0.25 | 0.01 | -0.05 | |
| OC3 | 0.01 | 0.12 | -0.37 | 0.03 | 1.00 | |
| OC4 | -0.01 | -0.07 | 0.21 | -0.03 | -0.22 | |
| OC | -0.03 | 0.01 | 0.14 | 0.02 | 0.33 | |
| EC | -0.14 | -0.04 | 1.00 | -0.13 | -0.2 | |
| Al | -0.06 | -0.18 | 0.09 | -0.04 | -0.32 | |
| Si | -0.13 | -0.27 | 0.04 | -0.04 | -0.35 | |
| Ca | -0.03 | -0.16 | 0.1 | -0.04 | -0.32 | |
| Ti | -0.43 | 1.00 | -0.09 | -0.03 | -0.01 | |
| Mn | 0.12 | 0.24 | -0.08 | -0.03 | -0.01 | |
| Fe | 1.00 | -0.25 | -0.21 | -0.08 | -0.09 | |
| Cu | -0.2 | 0.56 | -0.07 | -0.01 | 0.06 | |
| Zn | 0.17 | -0.11 | -0.23 | 0.02 | 0.44 | |
| Sb | -0.13 | 0.28 | -0.02 | -0.01 | -0.02 | |
| Ba | 0.40 | 0.3 | -0.16 | -0.03 | 0.08 | |
| INCDPY | 0.02 | 0.02 | -0.15 | 0.96 | 0.05 | |
| BGHIPE | -0.03 | -0.01 | -0.13 | 1.00 | 0.03 | |
| CORONE | -0.03 | -0.01 | -0.11 | 0.81 | 0.02 | |
| hop17 | 0.29 | 0.13 | 0.44 | 0.01 | -0.28 | |
| hop19 | 0.01 | -0.01 | 0.23 | 0.41 | -0.18 | |
| hop26 | -0.02 | -0.02 | -0.01 | 0.19 | -0.04 | |
| DEPHTH | -0.01 | 0.01 | -0.18 | 0.01 | 0.27 | |

- The CMB modified pseudo-inverse normalized (MPIN) matrix indicates the most influential species for each source type.
- For a sensitivity test, five to ten different source combinations are attempted until the best solution, in terms of CMB fitting performance and MPIN matrix, is attained.

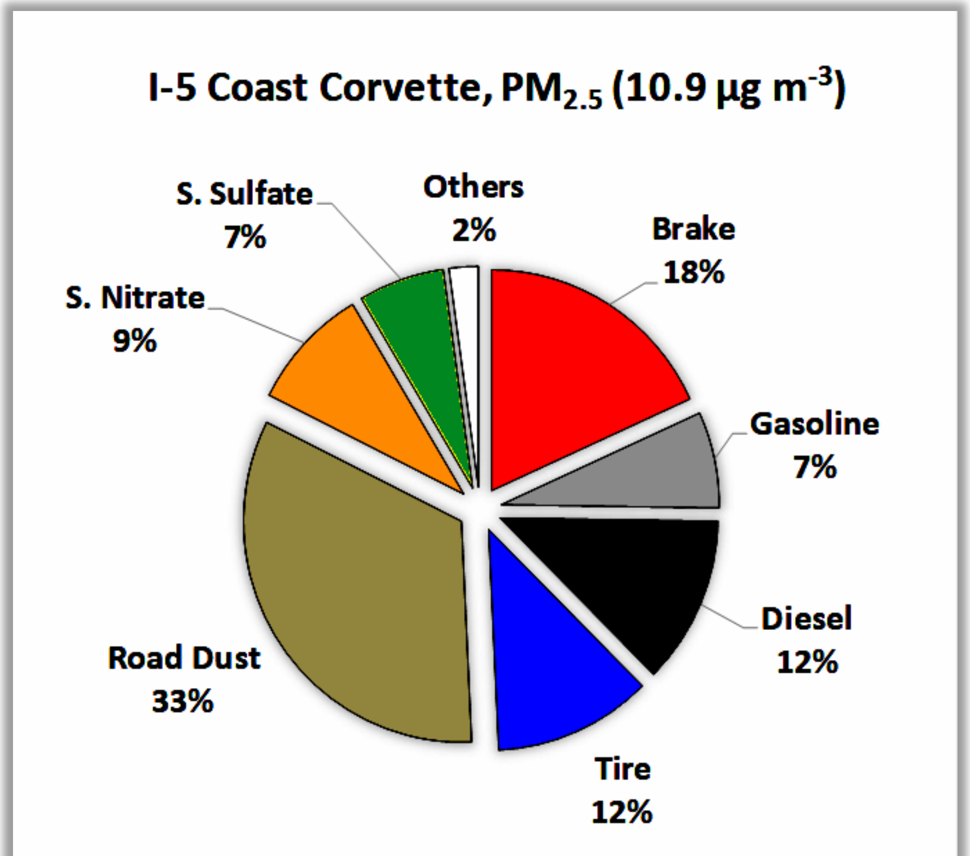
*MPIN of the best CMB solution with values (>0.4) marked in red and moderate values (0.2 – 0.4) marked in yellow to confirm source markers*

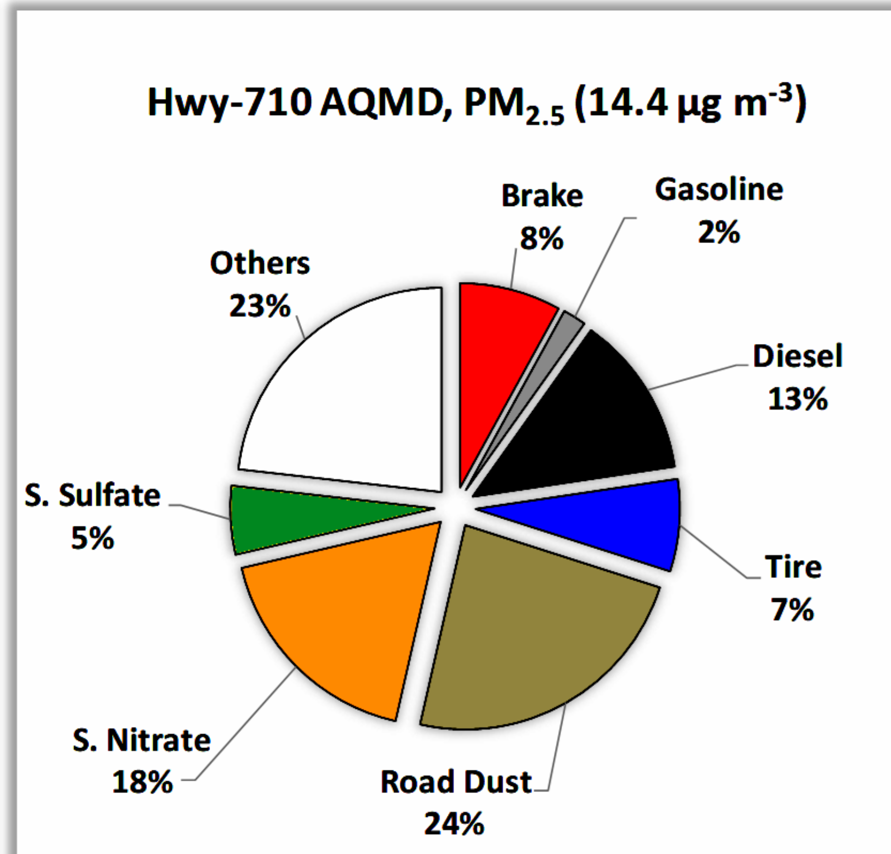
# Applying CMB to Near-Road $PM_{2.5}$ Samples



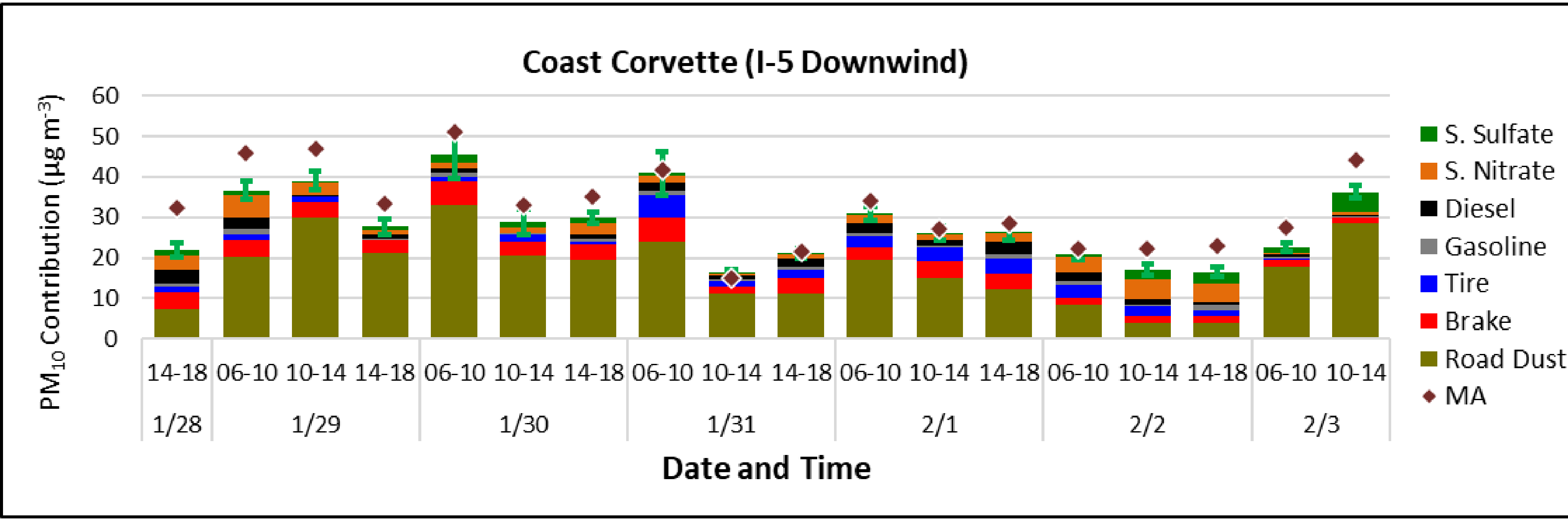



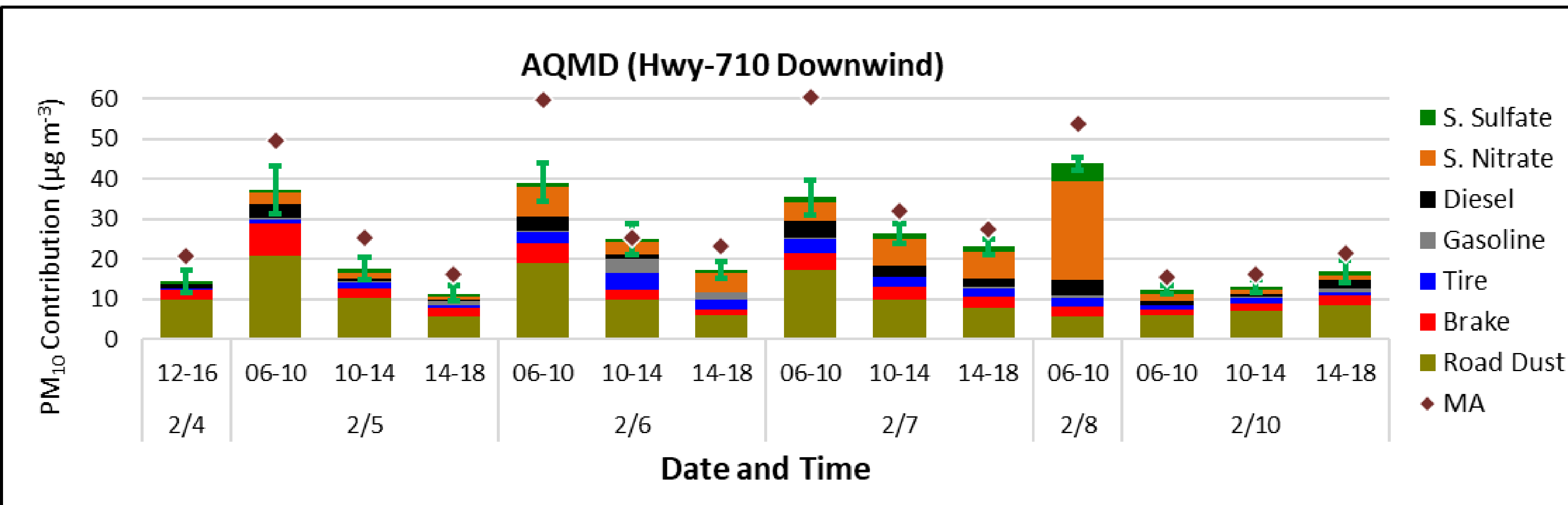
# Applying CMB to Near-Road $PM_{2.5}$ Samples



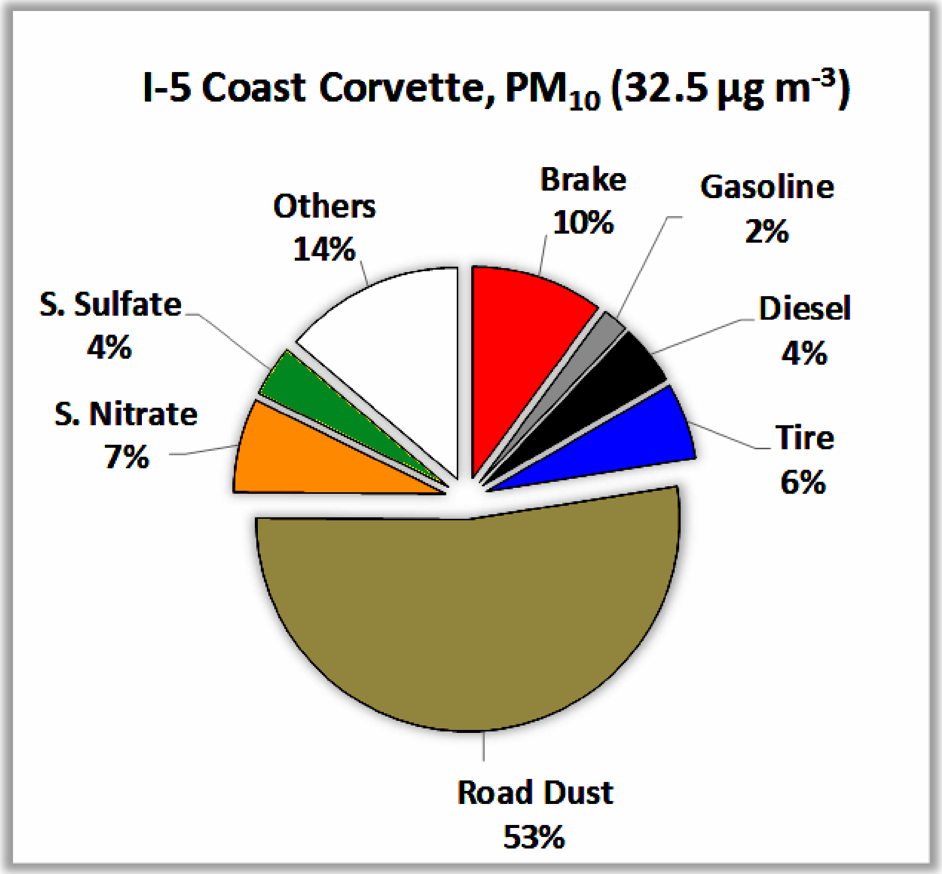



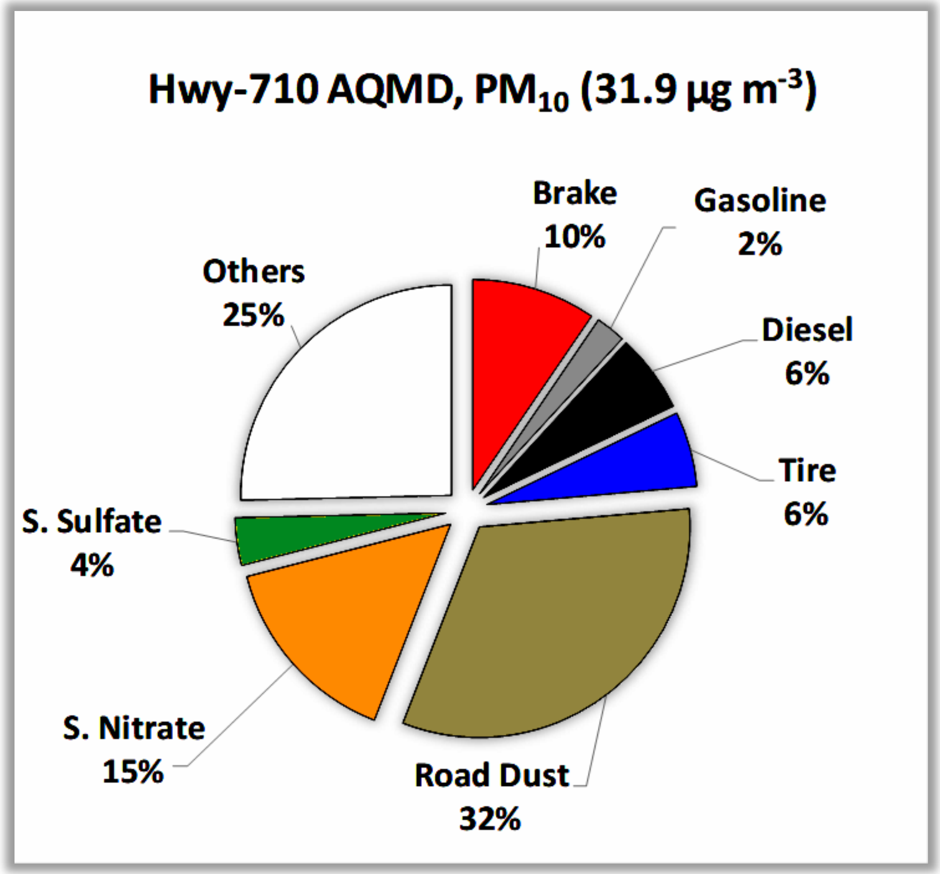
# Applying CMB to Near-Road $PM_{10}$ Samples



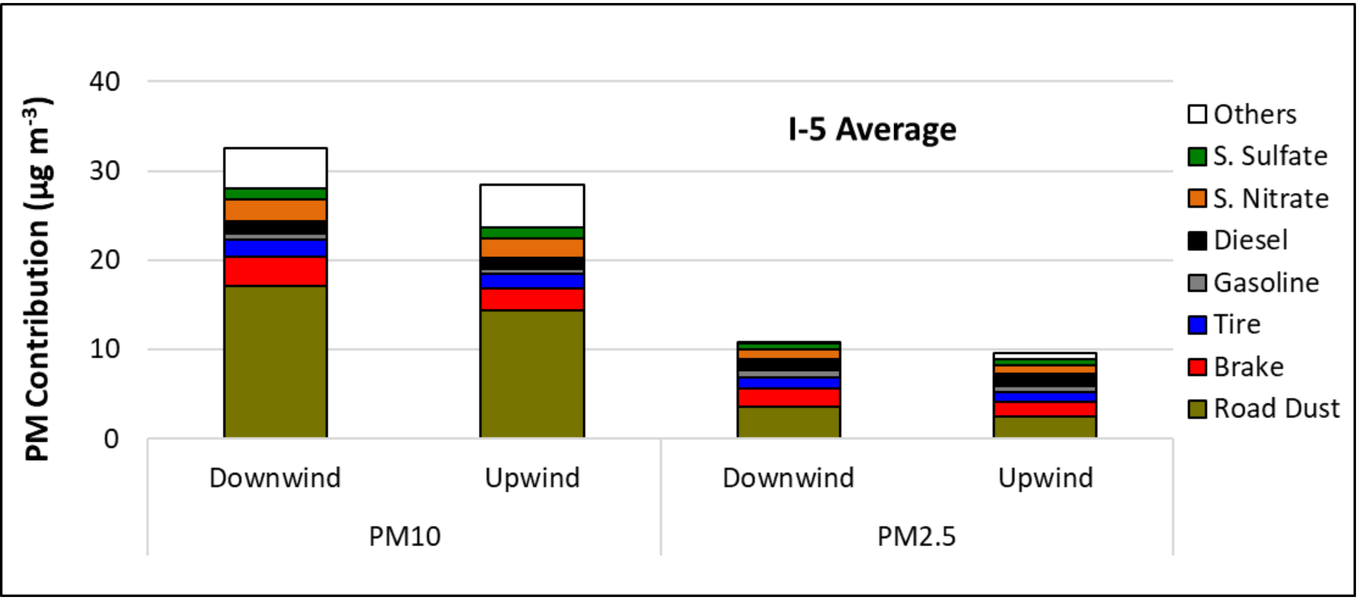



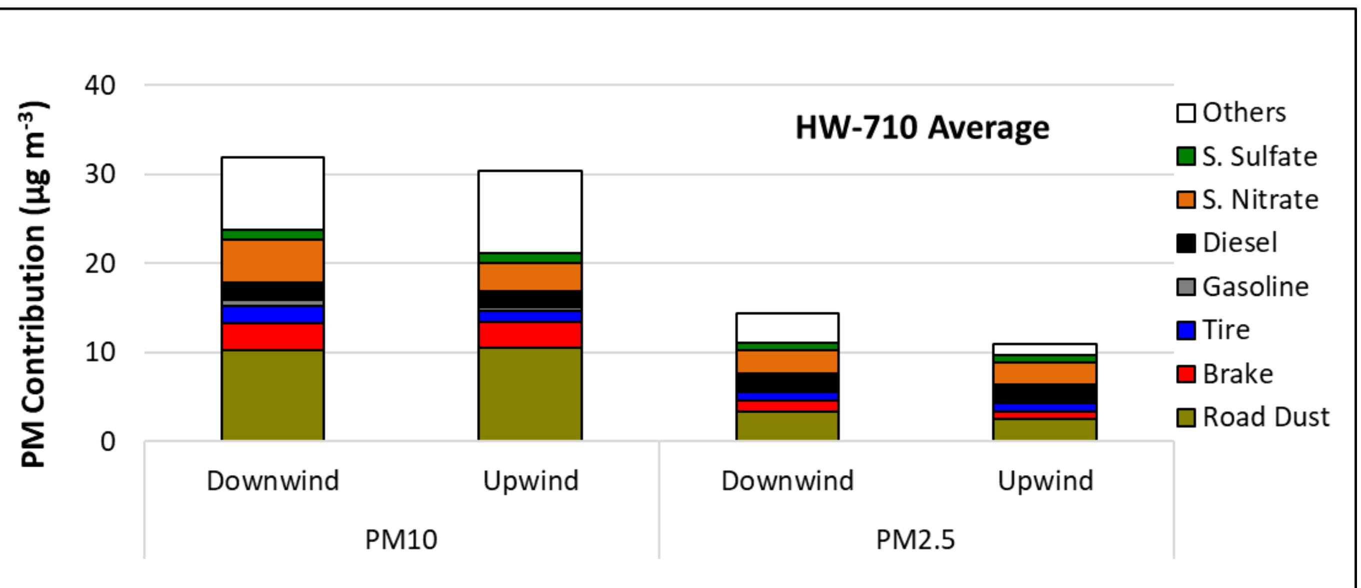
# Applying CMB to Near-Road $PM_{10}$ Samples



# Small Differences Between Downwind and Upwind




- Levels of exhaust particles are similar between downwind and upwind samples
- Levels of non-exhaust particles are slightly higher in downwind samples
- Traffic impacts downwind and upwind sites similarly in this study
- Substantial “Others” may be attributed to fresh and aged sea salt

# Summary

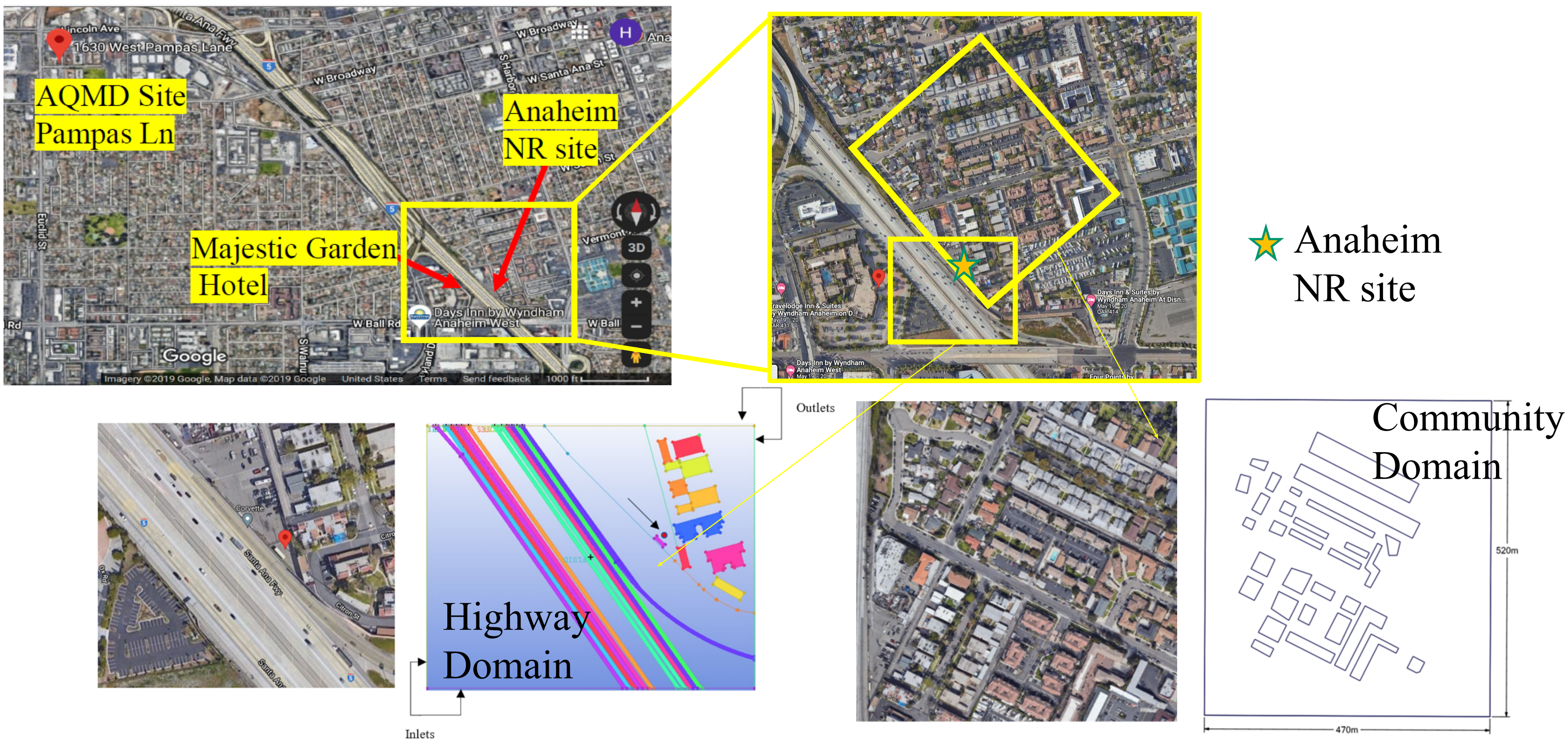
- Averaged over the upwind and downwind samples, contributions of the non-exhaust fractions (brake + tire) to $PM_{2.5}$ exceed those of exhaust fractions (diesel + gasoline) for I-5 (29–30% vs. 19–21%) while they are comparable for Hwy-710 (15–17% vs. 15–19%).
- For $PM_{10}$, the non-exhaust contributions are 2 – 3 times the exhaust contributions
- Brake wear particles are generally more abundant than tire wear particles, though there is a higher uncertainty in the tire wear contribution estimates

# Table of Contents

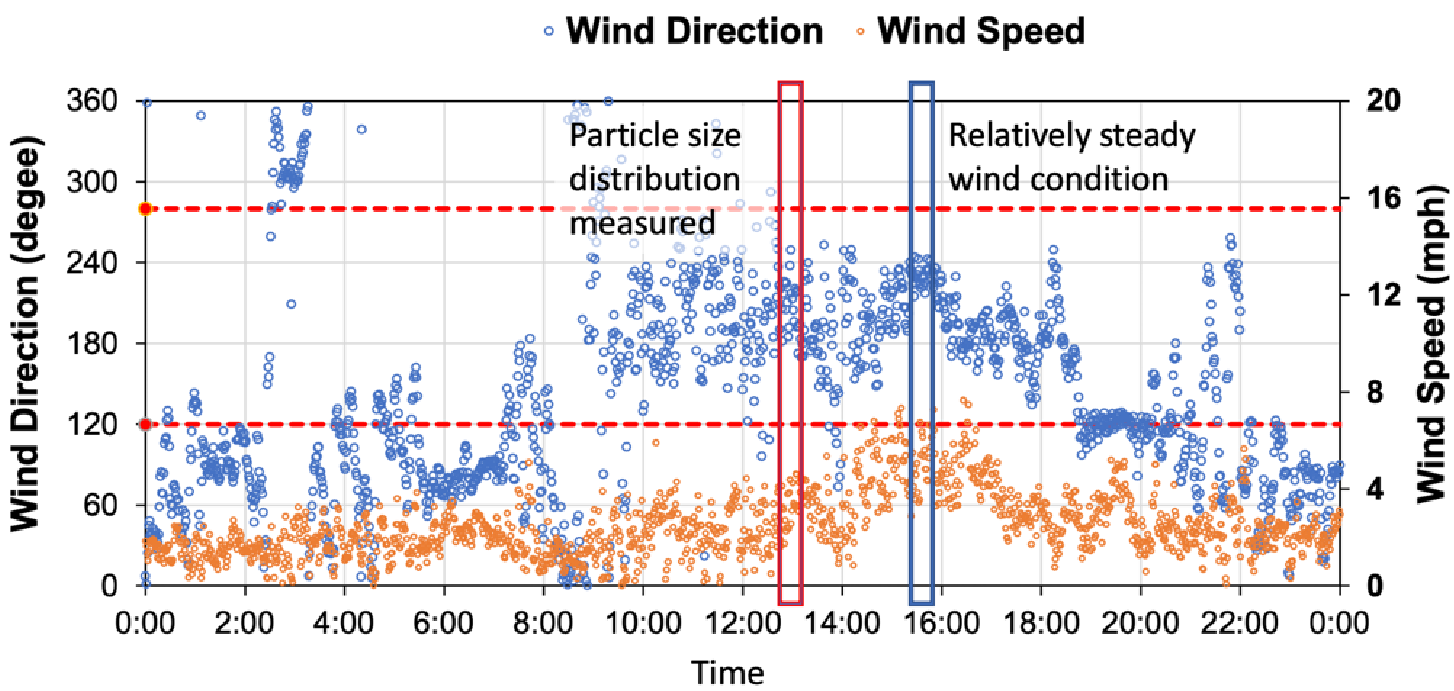
# Overview

- **Objective**: We aim to assess the impact of exhaust and non-exhaust emissions on the downwind communities.
- **Challenges**: Simulations require setting up boundary conditions (BC) and selecting emission profiles (EP). Uncertainties related to BC and EP lead to uncertainties in the modeling results.
- **Strategy**: In our modeling efforts, we try to leveraging the field measurements to constrain the simulations as much as possible to reduce modeling uncertainties. We implemented a <u>two-domain approach </u>to execute this strategy.

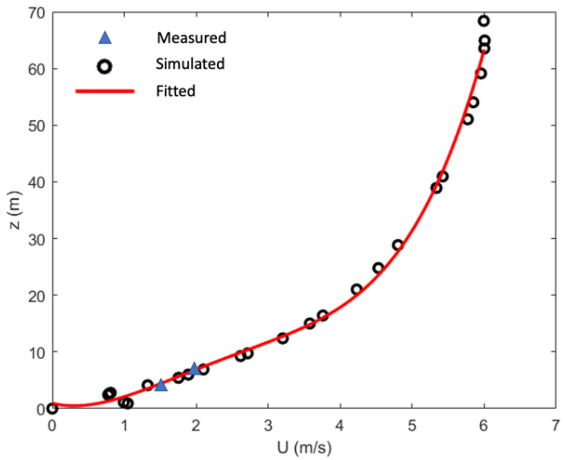
# Two-domain approach



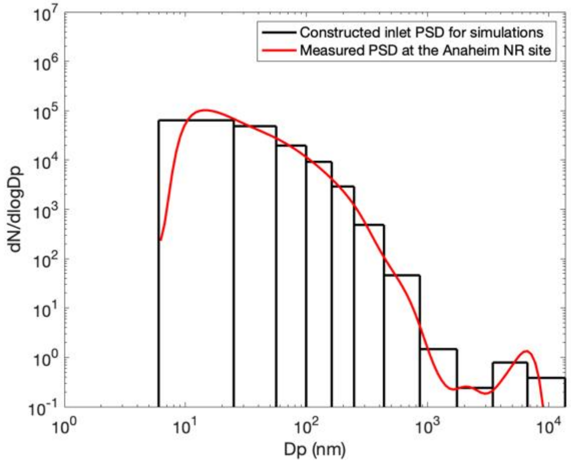
# Quasi-steady conditions captured by the field measurements



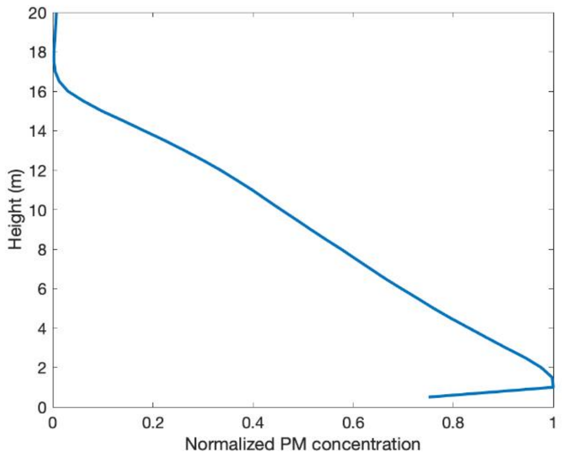
# BC and EP for the Community Domain




Inlet velocity profile

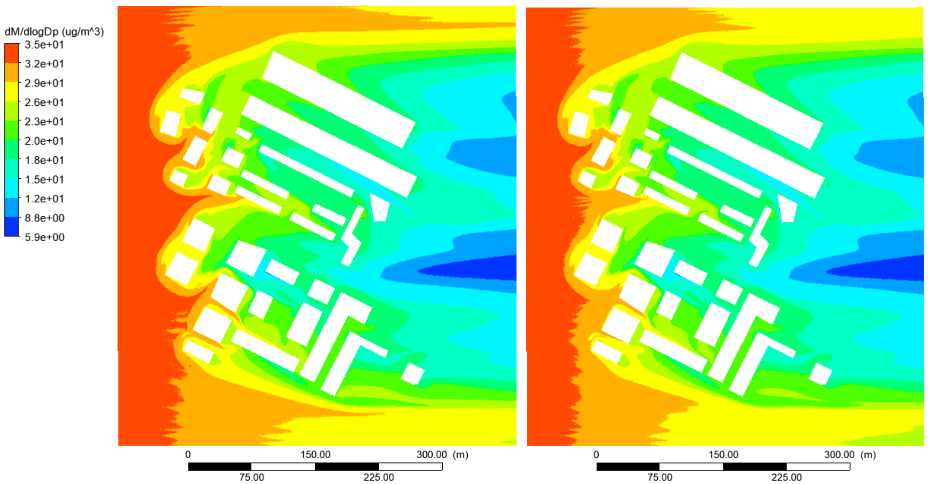



Inlet particle size distribution




Inlet vertical conc. profile

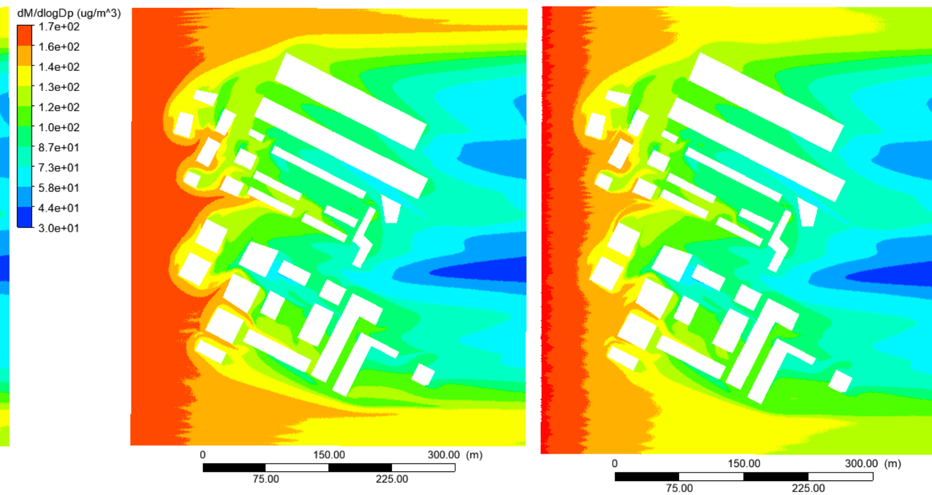
# Effect of deposition




w/o deposition w/ deposition

4.5 µm (brake PM?)

Deposition leads to 1 to 2% reduction in the Community domain.




w/o deposition w/ deposition

10 µm (Road dust?)

Deposition leads to 5 to 7% reduction in the Community domain.

# Summary

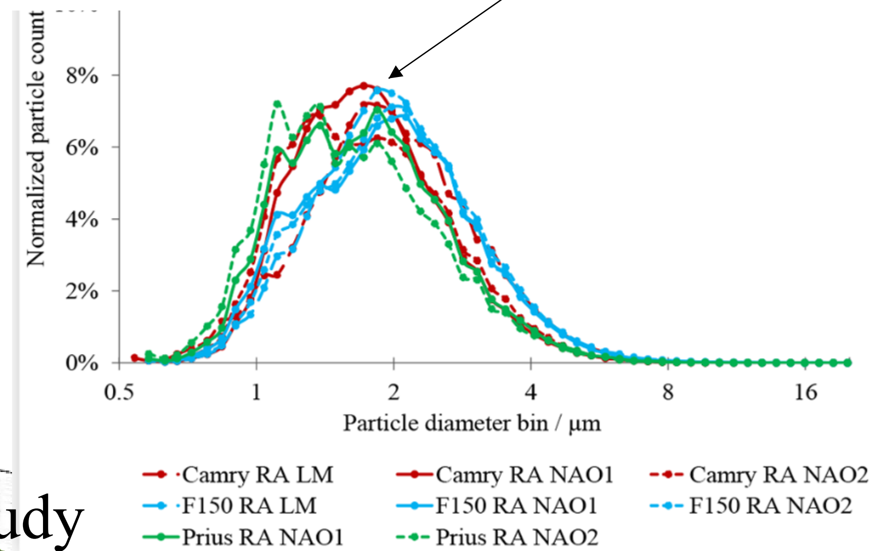
- We developed a two-domain approach to take advantage of the field measurement data to greatly reduce the uncertainties in modeling inputs while making the computational costs manageable.
- Our results suggest that the deposition can reduce particle mass concentrations by 1 to 2% for the size range pertain to brake PM in the downwind community and by 4-7% for the size range relevant to road dust.
- The implication is while non-tailpipe particles have relatively higher deposition velocity compared to the exhaust particles, deposition of non-tailpipe particles are less significant compared to that of the exhaust particles as such near-road communities are exposed to non-tailpipe emissions close to the concentration experienced at the location closest to the road.

# Table of Contents

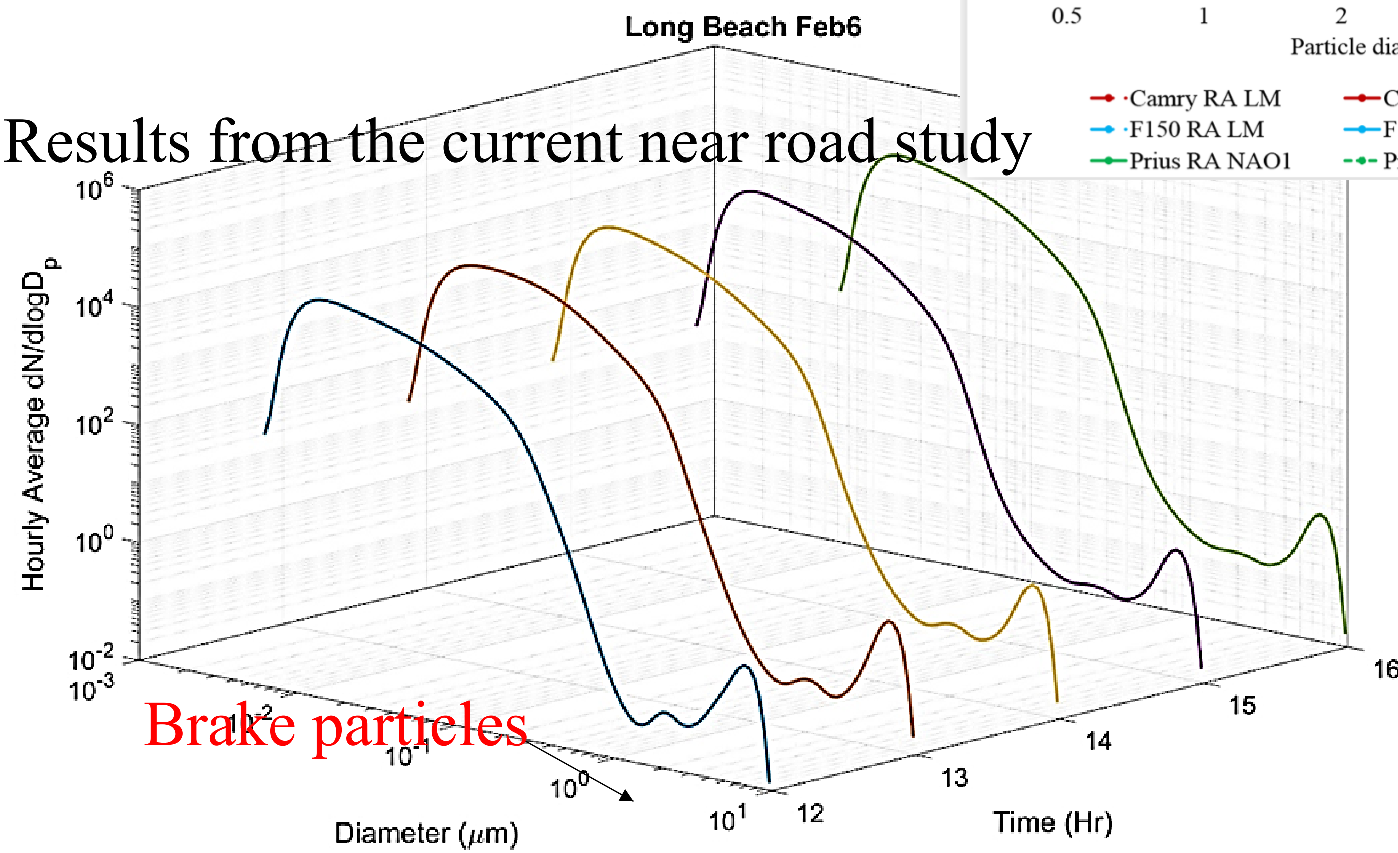
- Background
- Field test
  - Locations, instruments, and measurements.
- Results and analysis
  - Chemical composition
  - Source apportionment
  - Dispersion modeling
  - Particle size distributions
- Takeaways

# Aerodynamic particle size distribution

Results from the CARB dynamometer study, SAE 2020-01-1637




Results from the current near road study




Brake particles

# Takeaways

- Average concentrations of near-road $PM_{2.5}$ and $PM_{10}$ were 10-15 and ~30 μg/$m^3$, respectively.
- Averaged over the upwind and downwind samples, contributions of the non-exhaust fractions (brake + tire) to $PM_{2.5}$ exceed those of exhaust fractions (diesel + gasoline) for I-5 (29–30% vs. 19–21%) while they are comparable for Hwy-710 (15–17% vs. 15–19%).
- For $PM_{10}$, the non-exhaust contributions are 2 – 3 times the exhaust contributions

# Takeaways

- Particle size distribution measured at near road shows the brake mode observed in the laboratory test.
- The deposition can reduce particle mass concentrations by 1 to 2% for the size range pertain to brake PM in the downwind community and by 4-7% for the size range relevant to road dust.