Exposure Studies
Utilizing Low and High cost data: Future Regulations

14th OSAR International Conference and Workshop

Dr. Kent Johnson

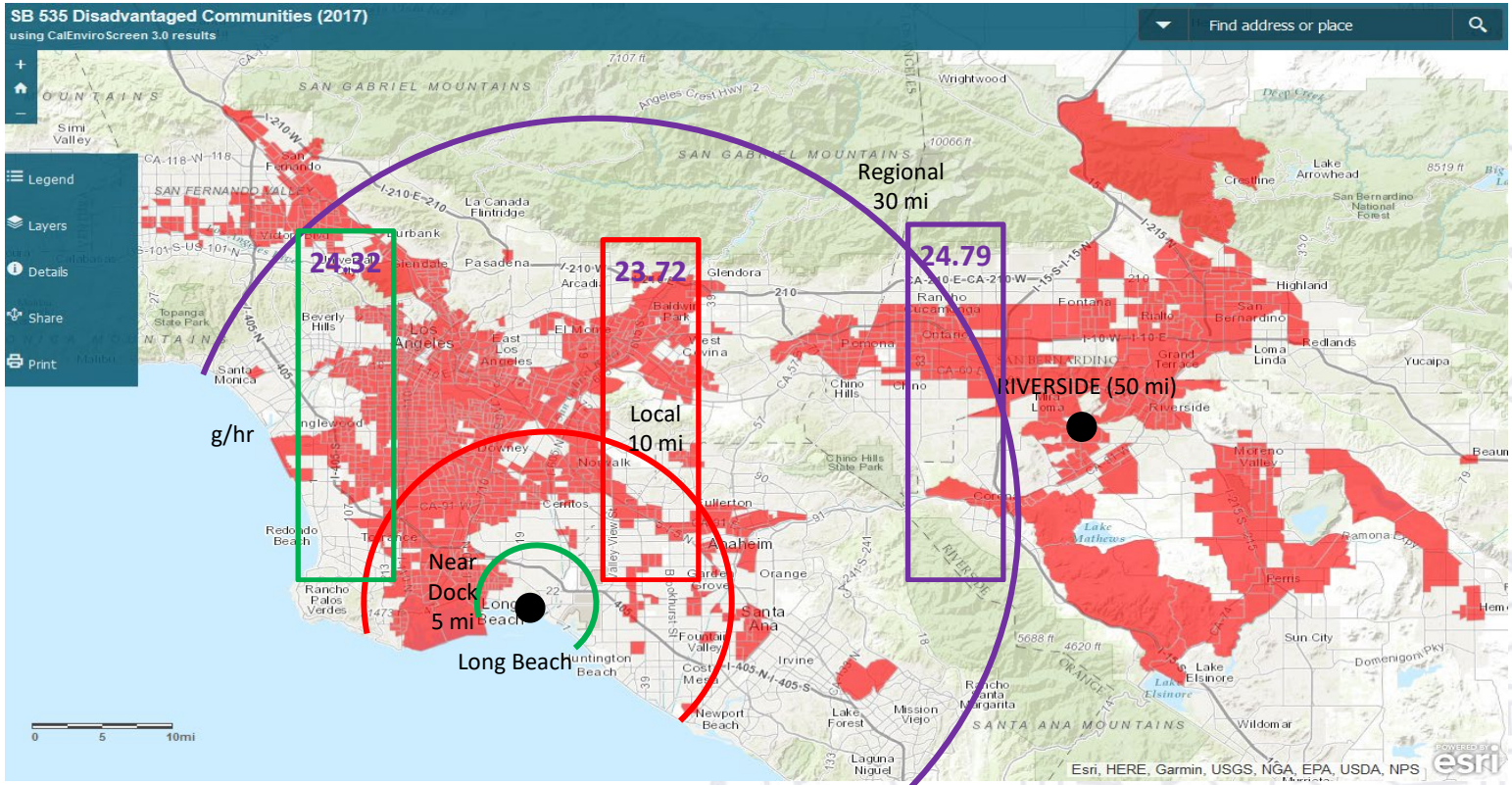
Co-Authors Drs. Thomas D. Durbin, Georgios Karavalakis, Zisimos Toumasatos, and Grace Johnson (PhD Candidate)

CE-CERT

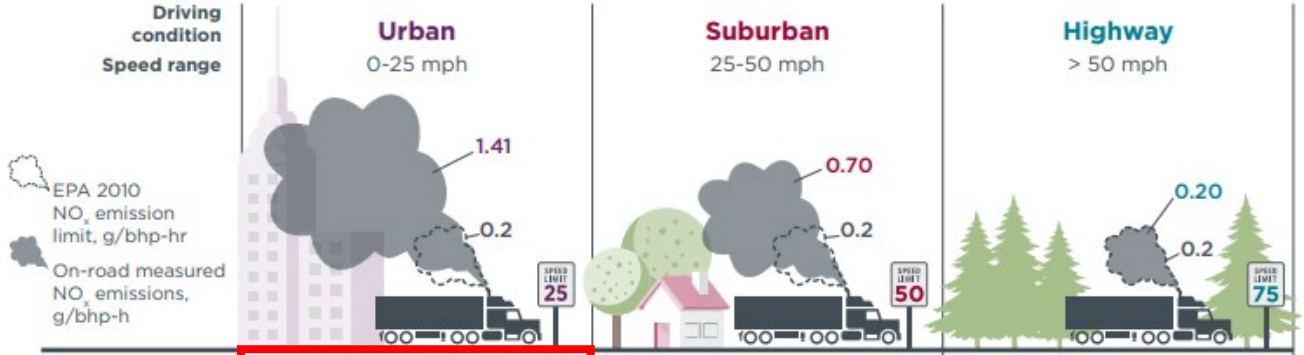
UC RIVERSIDE UNIVERSITY OF CALIFORNIA

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

Low Duty Cycle Operation Does Matter



In Use Emissions Vary By The Vehicles Use



Driving condition	Urban	Suburban	Highway
Speed range	0-25 mph	25-50 mph	> 50 mph
Average time spent at this condition	43%	11%	46%
Average share NO_x mass	40%	23%	37%
Brake specific NO_x emissions, g/bhp-hr	1.41*	0.70	0.20
Conformity Factor - CF	7.1*	3.5	1.0
Distance-specific NO_x emissions, g/mile	7.0*	2.4	0.6

** Brake and distance specific NOx emissions for Urban bin do not include Idle operation, only 1-25 mph operation is included*

- 189 tests between 2010 and 2019
- MY 2010-2016 with SCR Technology

- **43%** of the activity is between 0-25 mph
- This represents **40%** of the NOx mass

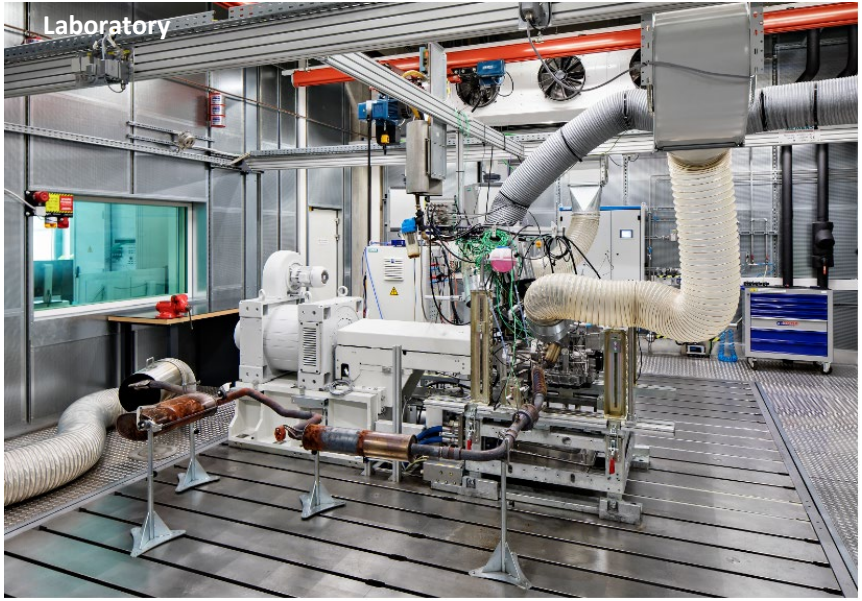
Source: ICCT white paper Nov 2019

Mobile Sources and Their Measurement

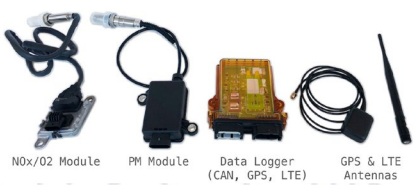
UNIVERSITY OF CALIFORNIA
UC RIVERSIDE

Laboratory, Portable Reference, and On Board Sensing

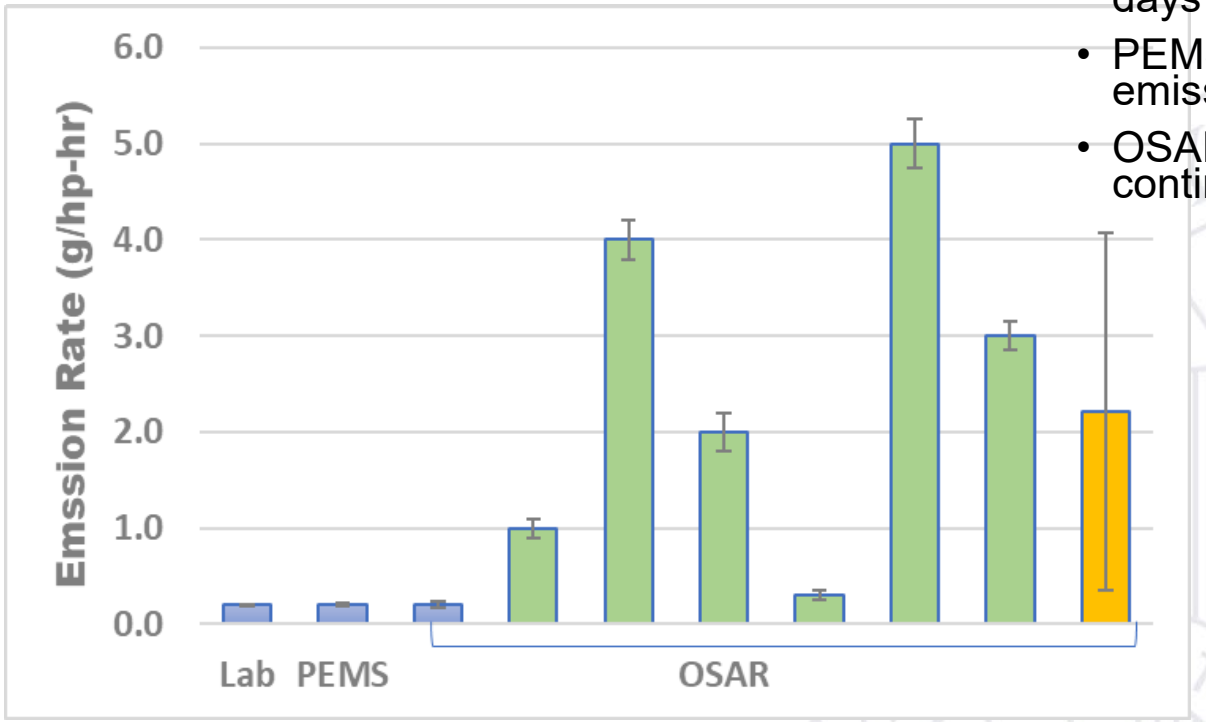
- Laboratory 2% accuracy (1 day data takes weeks/months for in-use setup)
- Portable reference 5% (1 day data takes 4-6 hrs)
- On board sensing 10% (1 year data takes <1 hr)



On Board Sensing

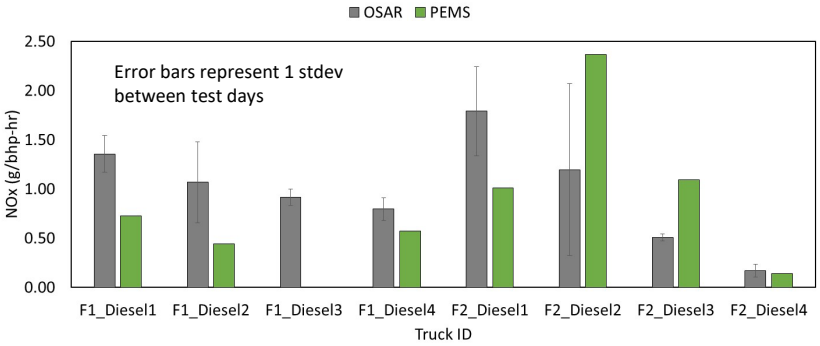


Traditionally Accuracy is Better, but it has Limitations In-use

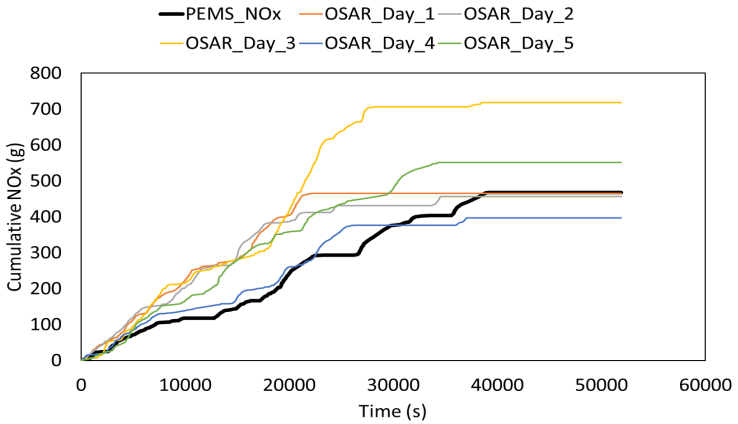


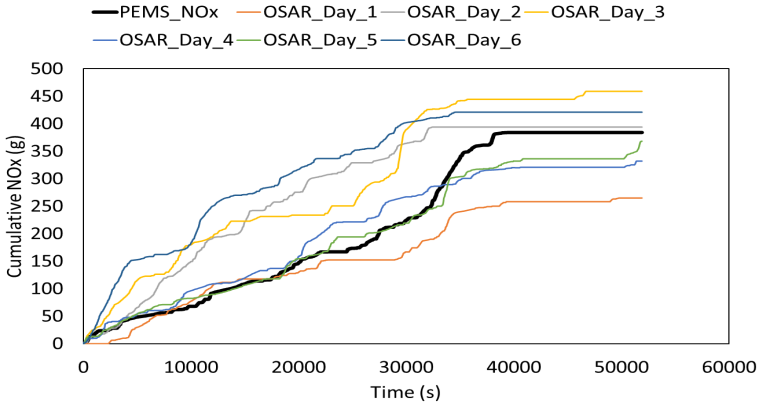
- The emissions change between days on the same vehicle.
- PEMS data presented the emissions measured by one day.
- OSAR data showed several days continuous monitoring results.

One Day of PEMS Testing Is Not Representative



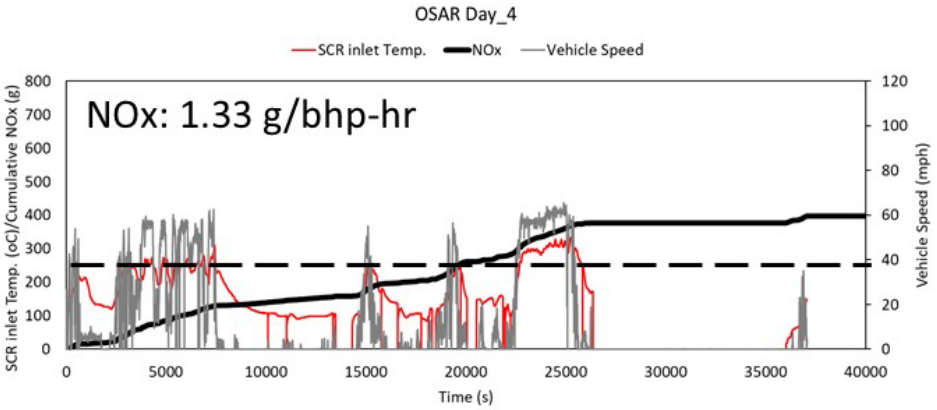
- The emissions change between days on the same vehicle.
- PEMS data presented the emissions measured by one day.
- OSAR data showed several days continuous monitoring results.

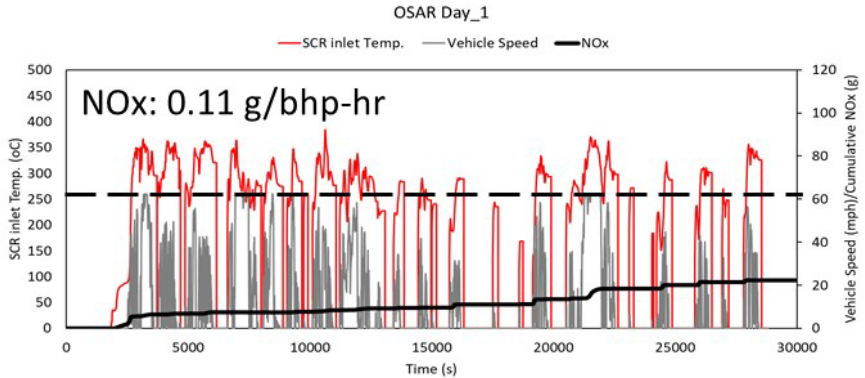




Source ARB funded ZANZEFF project Lights and AQMD Phase 1

NOx Emissions Vary: Routes Vary

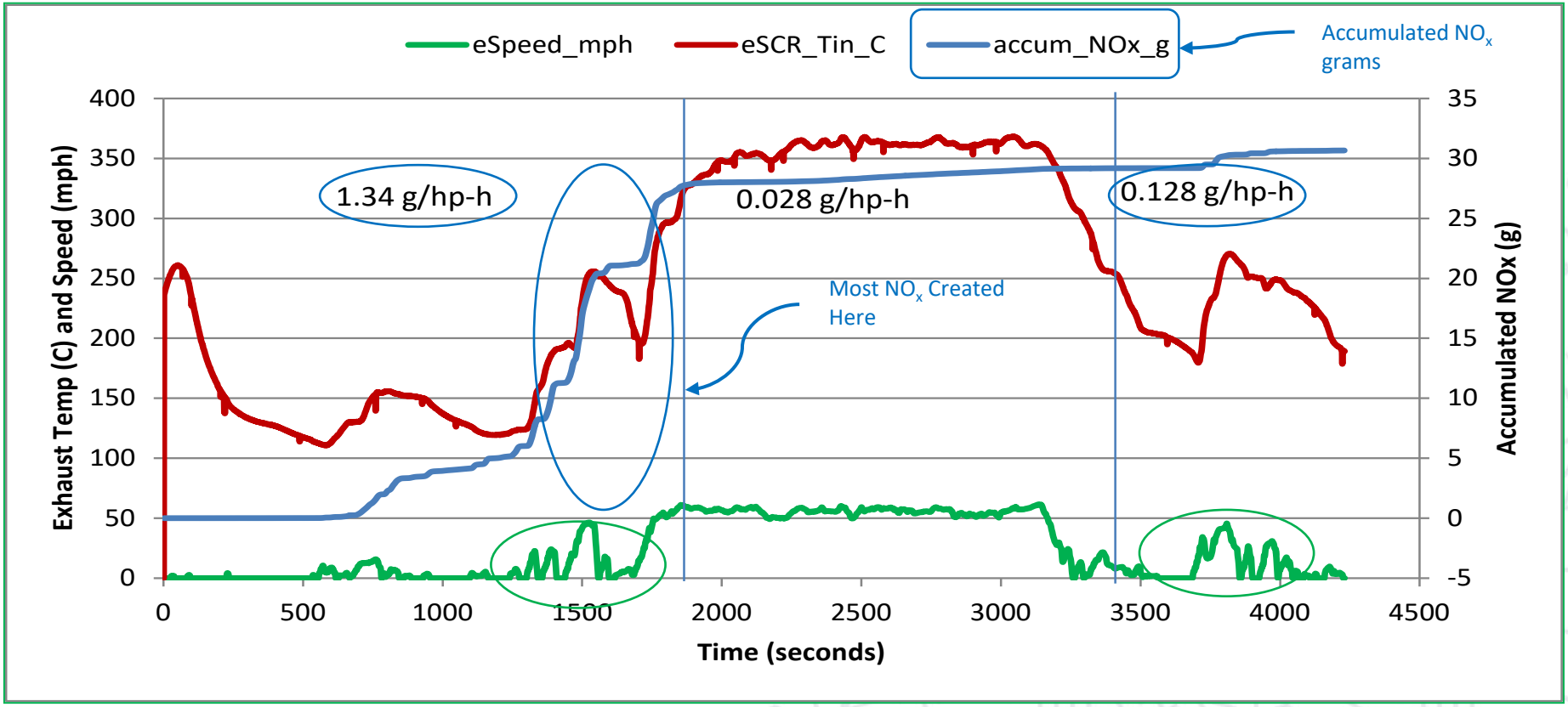




- Accumulated NOx with Vehicle speed and SCR inlet temperature
  - Graphs for NOx 0.11 & 1.33 g/bhp-hr
- Average NOx emissions change for different days.
  - Route for vehicles was usually different from day to day operation,
  - This impacts the SCR temperature and the formation of NOx emissions.

Source ARB funded ZANZEFF project Lights and AQMD Phase 1

These Higher Emissions Result from Real Operation



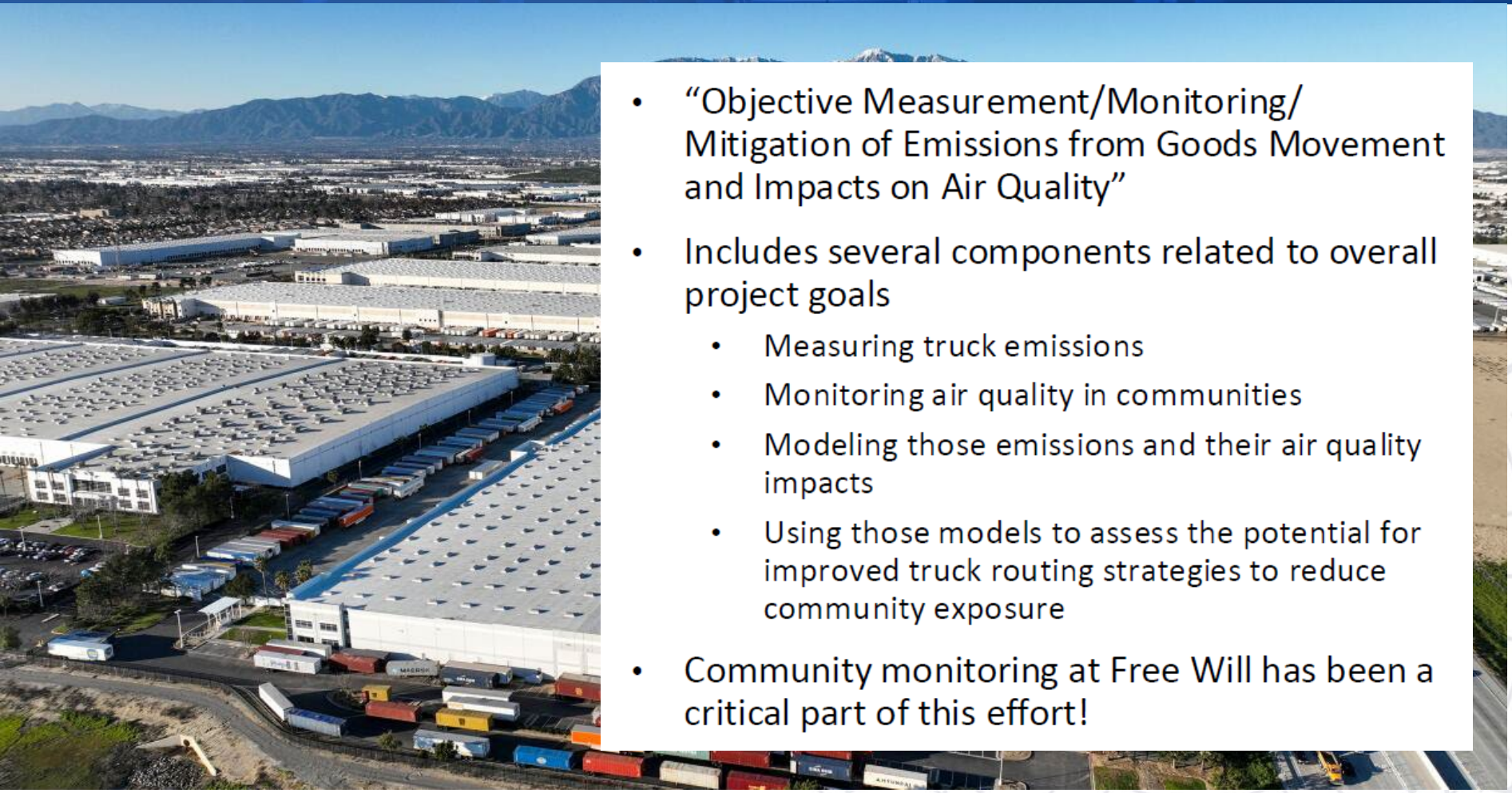
Source: UCR Miller et al (2013), Final report to SC-AQMD and CWI "In-Use Emissions Testing and Demonstration of Retrofit Technology for Control of On-Road Heavy Duty Engines", Sep 2013

OMEGA:
Warehouse Community Analysis

UNIVERSITY OF CALIFORNIA
UC RIVERSIDE

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

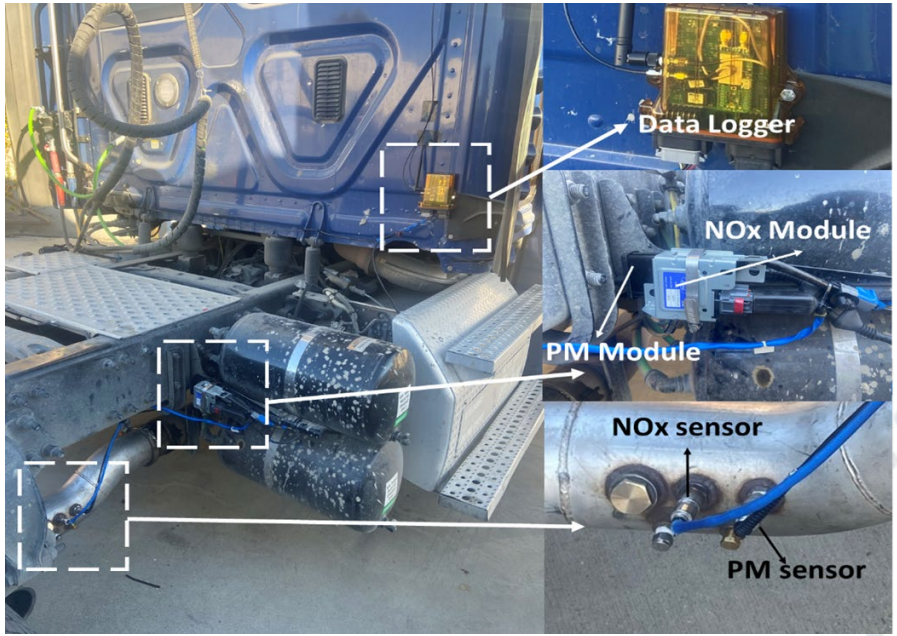
OMEGA



- "Objective Measurement/Monitoring/ Mitigation of Emissions from Goods Movement and Impacts on Air Quality"
- Includes several components related to overall project goals
  - Measuring truck emissions
  - Monitoring air quality in communities
  - Modeling those emissions and their air quality impacts
  - Using those models to assess the potential for improved truck routing strategies to reduce community exposure
- Community monitoring at Free Will has been a critical part of this effort!

Low cost data to feed the models

Limited to large fleets limited owner operated

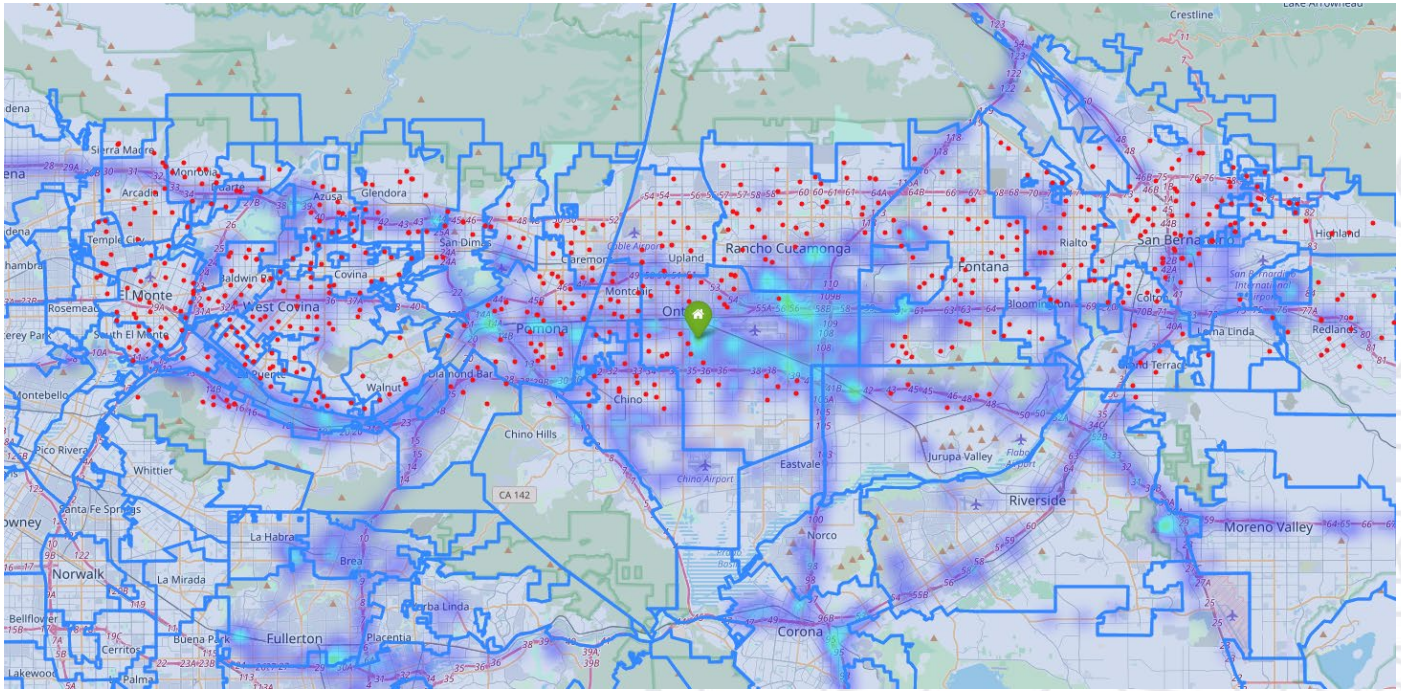


Installed OSAR on 120 plus vehicles NG and diesel vehicles operating from 2 mo to 1 year with up to 200 planned

Captured every truck operating in this area
Large fleet and owner operated expected 50/50 split

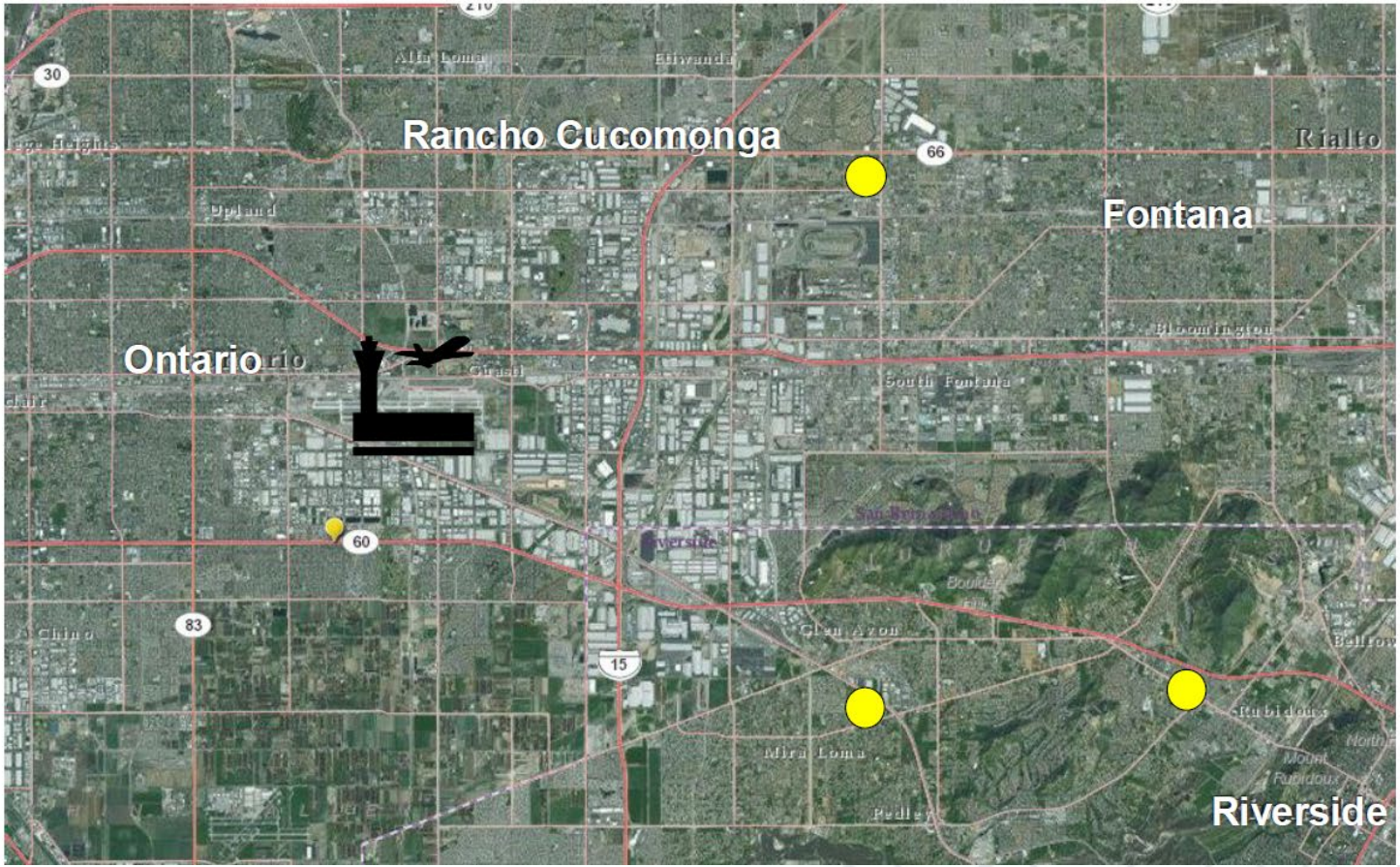
Measured emissions with remote sensing two weeks utilizing the HEAT technology. 49,000 vehicles identified. Still evaluating the data.

Our Telemetry Activity Data Shows Traffic Patterns, but not Vehicle Starts/Restarts



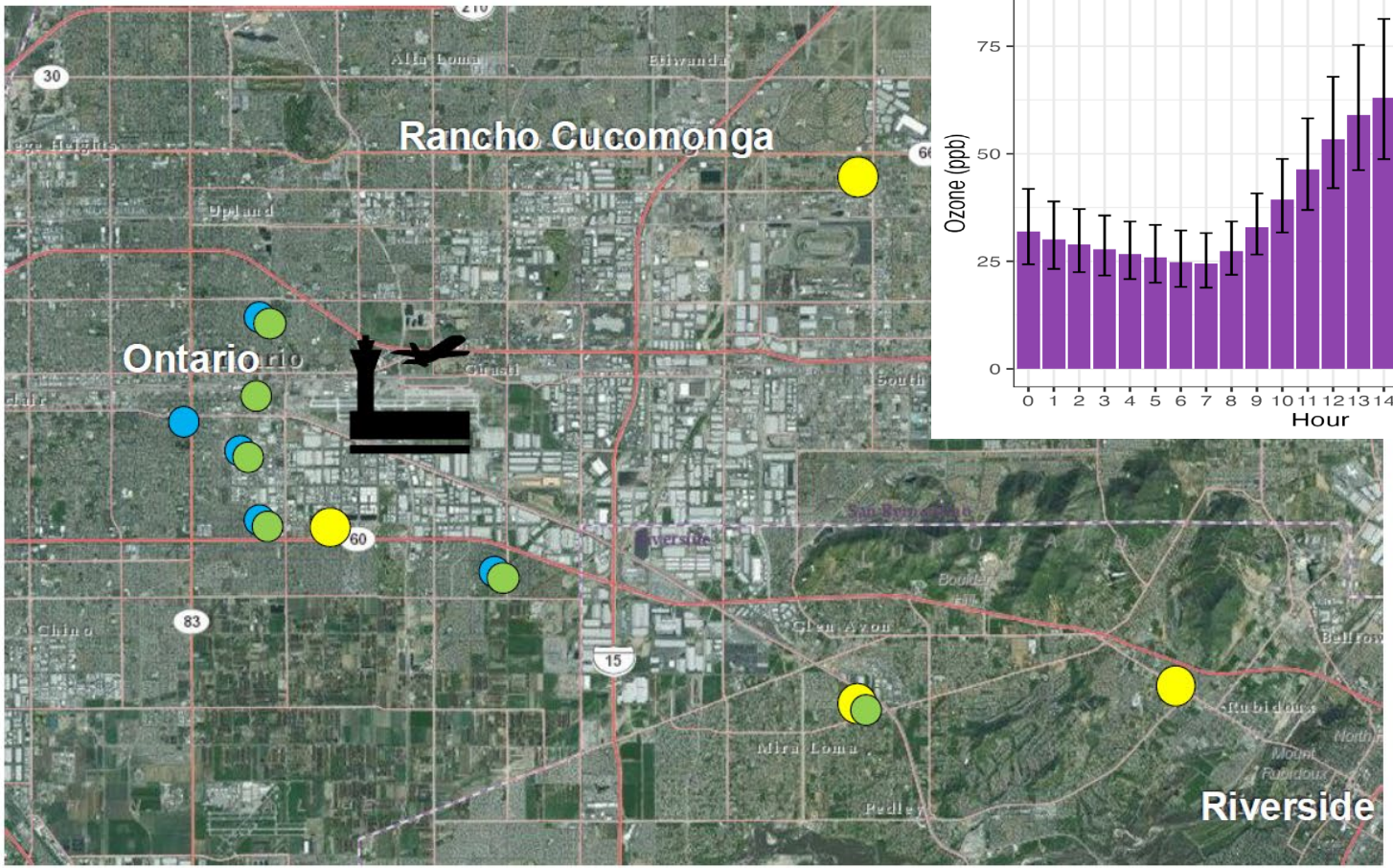
Density heatmap of the trajectories (based on historical telemetry data)
*including city boundaries and school zones near the depot

High cost fixed monitors, validation



UC RIVERSIDE UNIVERSITY OF CALIFORNIA

OMEGA added high cost fixed monitors for added validation



Site

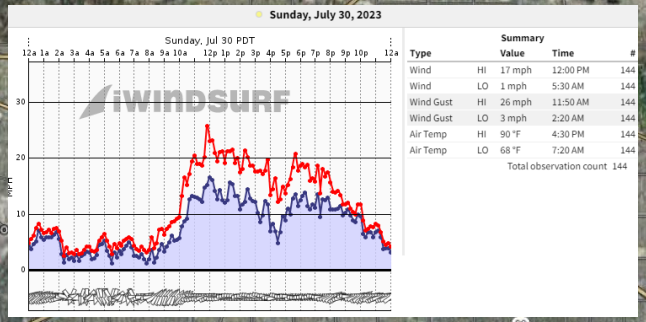
GA

Indoor

OMEGA Outdoor

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

Ports and Warehousing impact Community Exposure



56 mi^2

Fleet 1

4 am wind direction 5 mph 65 F

5 pm wind direction, 15 mph, 95 F

4 mi^2

1.5 mi^2

Fleet 2

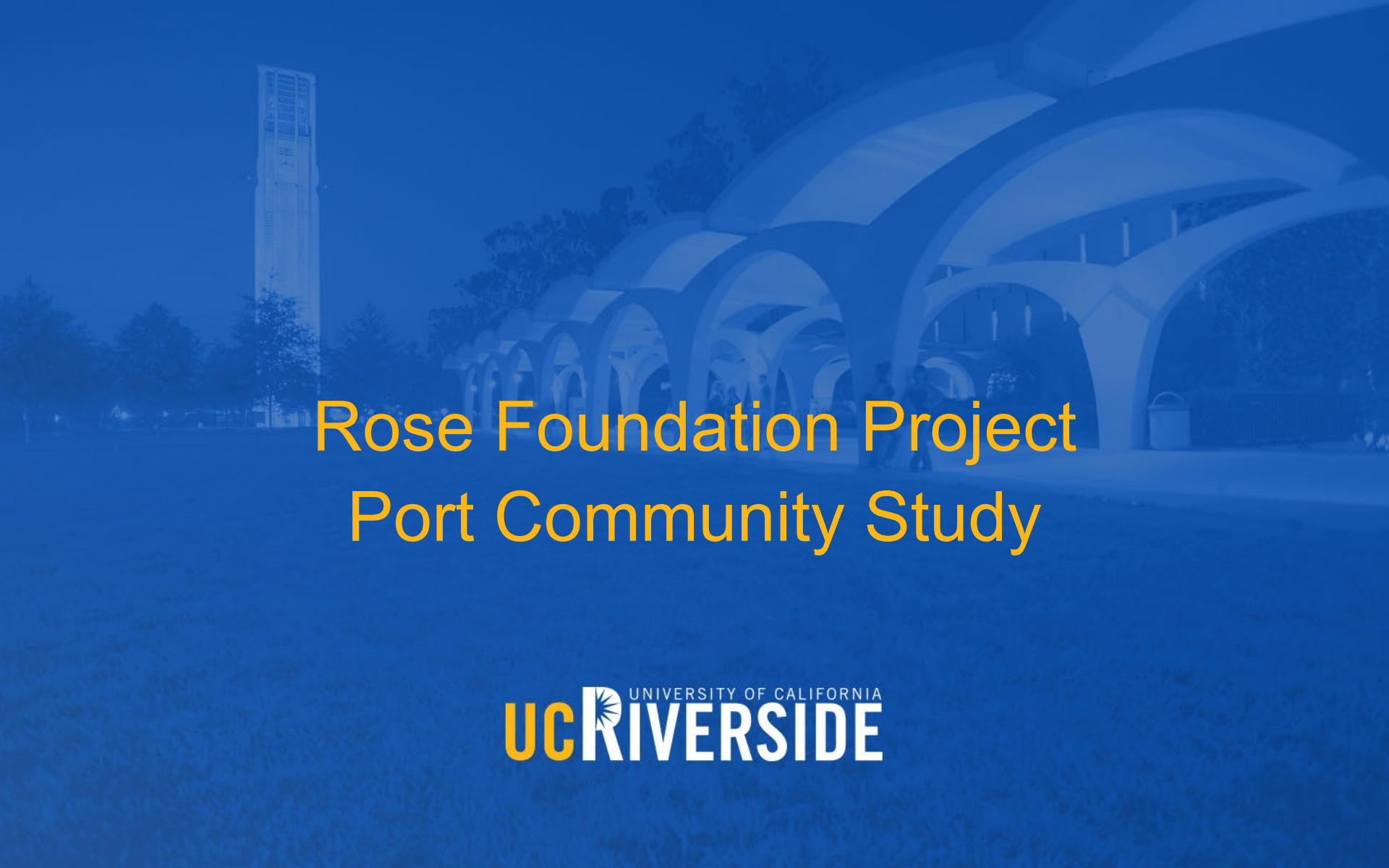
https://www.ready.noaa.gov/HYSPLIT.php

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

Next Steps

- Input in-use measured data into model to predict exposure found outdoor and indoor.
- Assess impact of localized Wearhouse on impact for cold starts for time, location, and metrology data
- Evaluate average concentration and impacts of sensitivity
- Estimate exposure from concentrations

- Use lessons learned for Rose Port Community Study



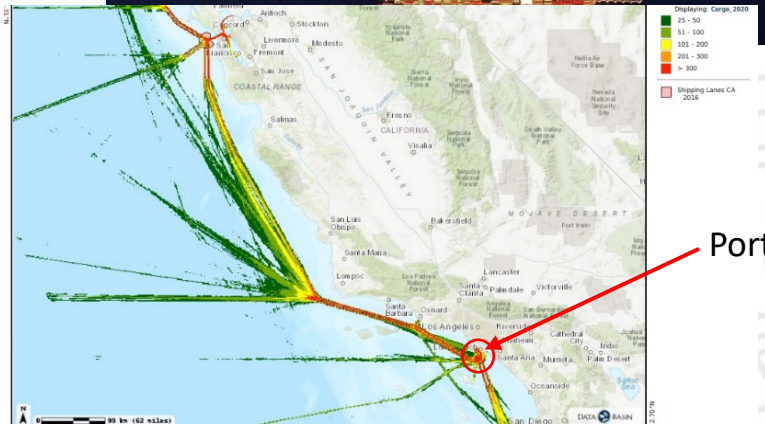
Rose Foundation Project
Port Community Study

UNIVERSITY OF CALIFORNIA
UC RIVERSIDE

Year Long Study at the Ports of LA/LB

One Year Of

- Indoor outdoor monitoring
- 3-4 Ocean Going Vessels source testing
- Up to 300 OGV plume measurements



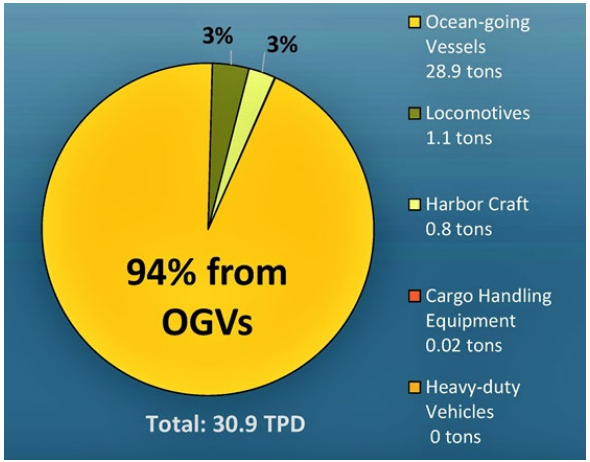
Ports of LA and Long Beach

OGV Emissions Are Higher At Ports

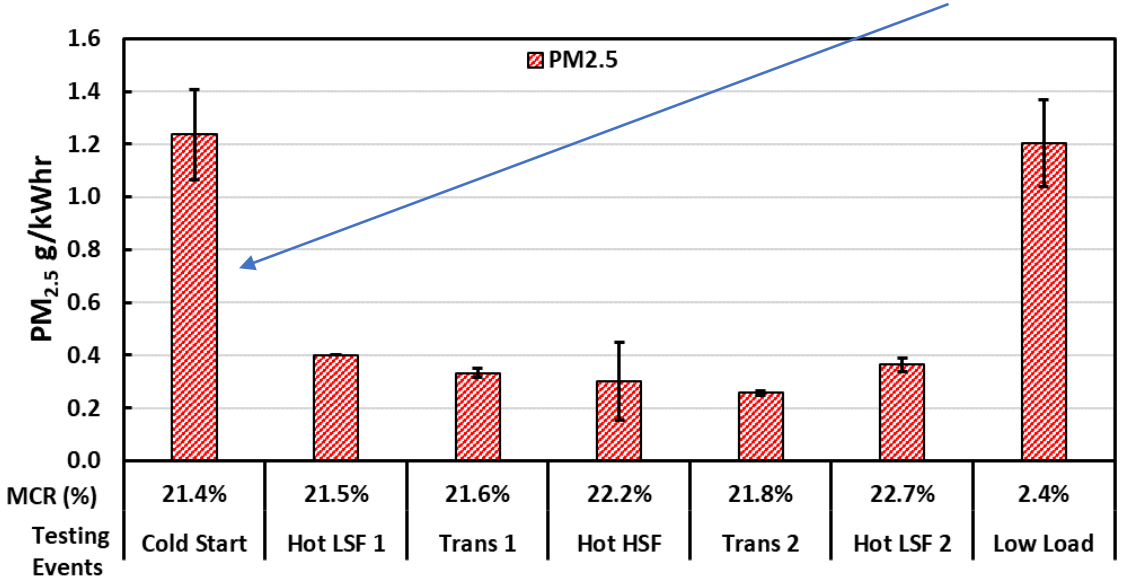
Observations to investigate

- Low Speed Operation 5-12% load
- Cold start emissions last about 1 hr
- Hazardous air pollutants and speciated PM emissions low speed and cold

OGV during a cold start exiting the port (see data below)



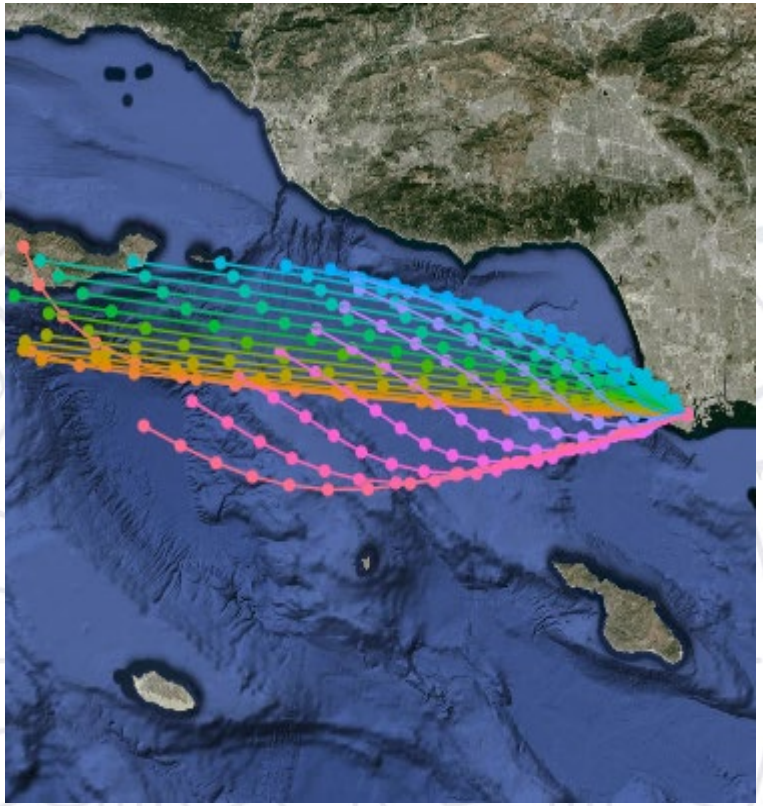
OGV contribution to port NOX sources anticipated 2037 (12)



Air Parcel Modeling Backward in Time

- Back trajectory modeling (Hysplit) compliment community exposure
- Review on-ship and plume measurements and update mechanism in GOES Chem.
- Quantify average contribution from Shipping and Not from Shipping
- Estimate exposure from concentrations

- Use lessons learned for future projects on large port complexes



WRF-GC platform, which is a coupling between WRF (a weather and atmospheric dynamics model) and GEOS-Chem

Port Impacts Have Reached 50 Miles

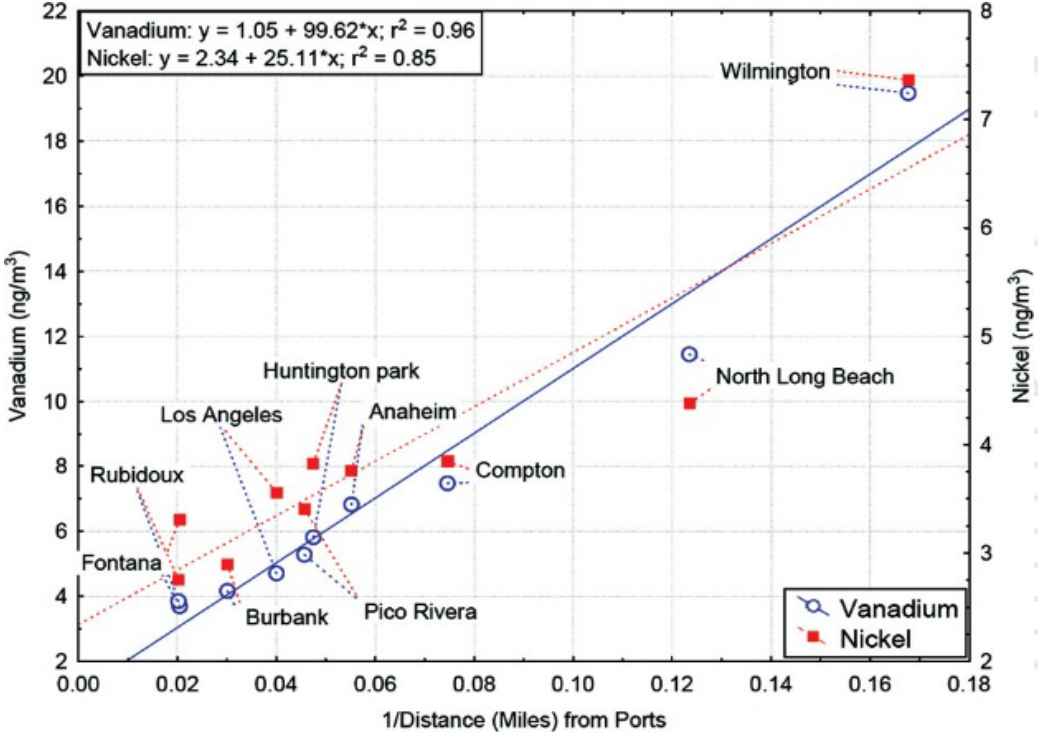


Figure *PM composition metrics used to estimate impact of HFO ship emissions in Southern California (Agrawal et al 2009)*

Agrawal, H., Eden, R., Zhang, X., Fine, P., Katzenstein, A., Miller, J., Ospital, J., Teffera, S., Cocker, D. (2009). Primary Particulate Matter from Ocean-Going Engines in the Southern California Air Basin, Environmental Science and Technology, 43(14), 2009

Previous low cost plume captures on OGV

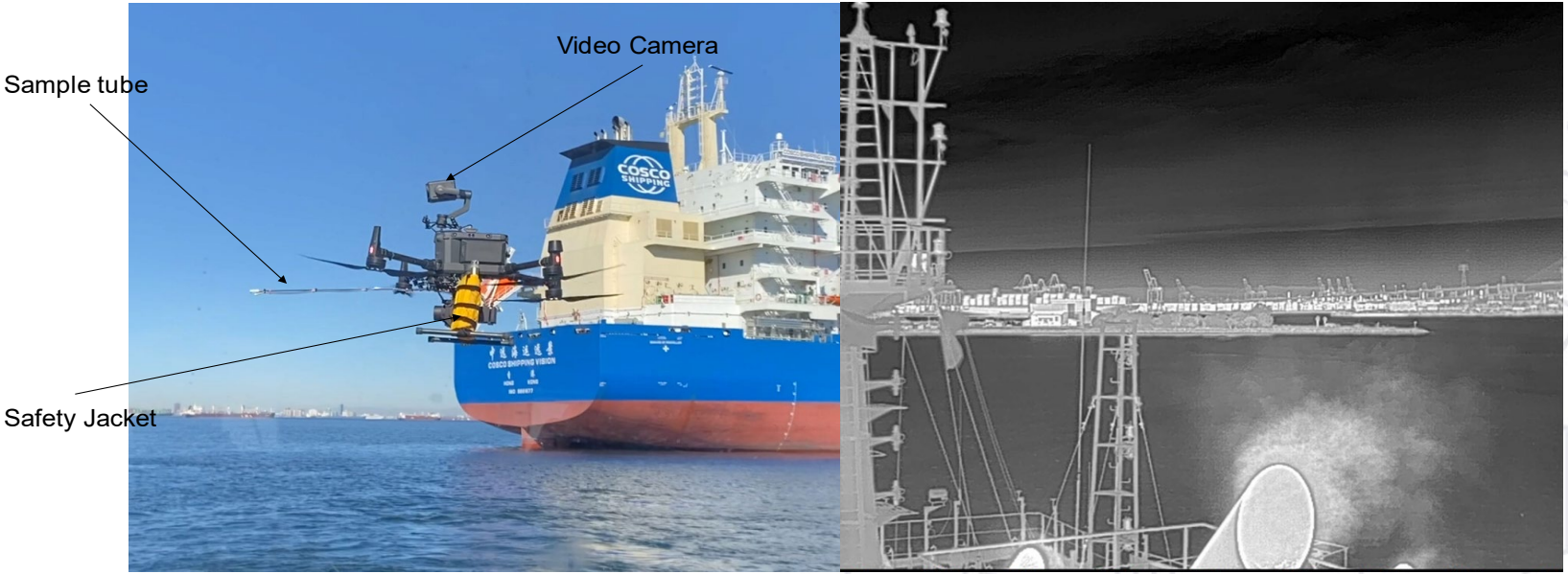


Figure Previous UCR drone system with sample tube (left) and IR camera with specific filter to pick up water vapor signature (right)

- In 2022, UCR conducted a drone study in collaboration with the U.S. Coast Guard, U.S. EPA, and CARB
- The Coast Guard is considering sulfur fuel compliance with some type quick measurement method (drones or a plume gas detecting camera by FLIR)

Our Telemetry Data Shows Traffic Patterns, but not Vehicle Starts/Restarts

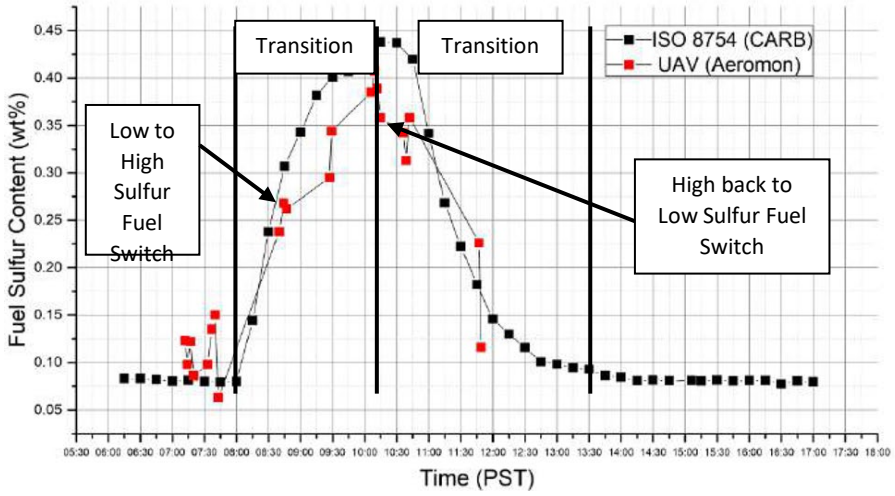
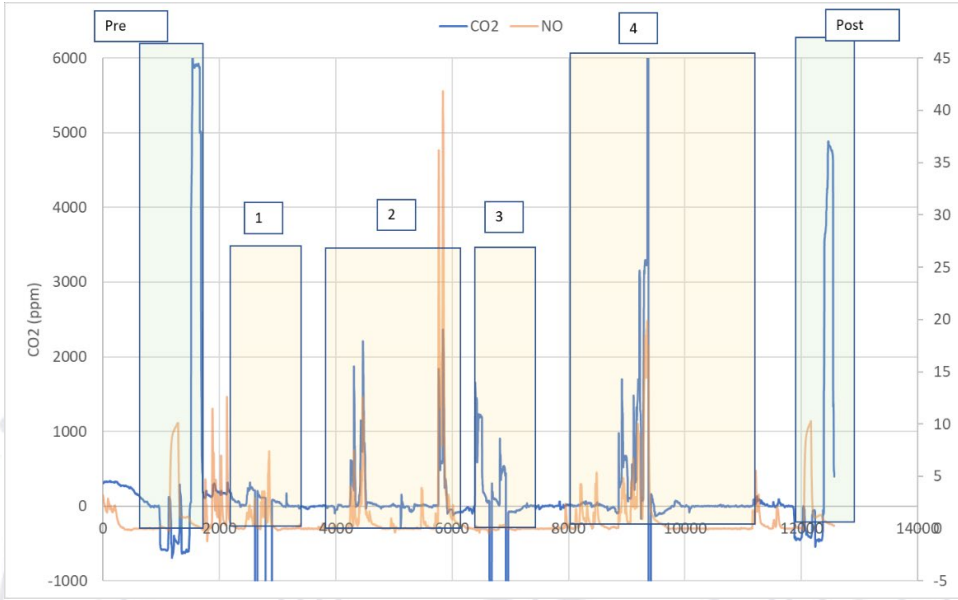
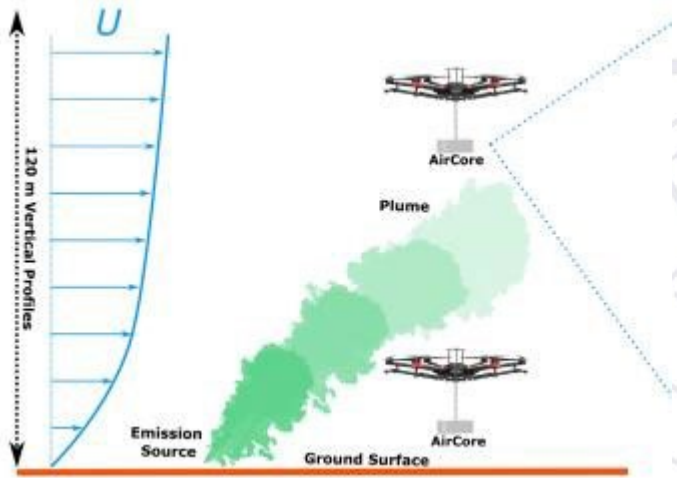


Figure UAV (drone) method comparison to ISO stack (8178) and laboratory (8754) methods (ref)



- In 2023 UCR worked with MARAD, CARB and a large Container Vessel owner to evaluate sampling with drones in a plume while also sampling sulfur in the fuel
- Although the data came out supporting drones work, plume data analysis has a lot of variability to it thus, suggesting there may be an opportunity for improvement

Drone based sampling system



Example of sample collection and return using a drone during a prior UCR project that was focused on methane emissions from dairies

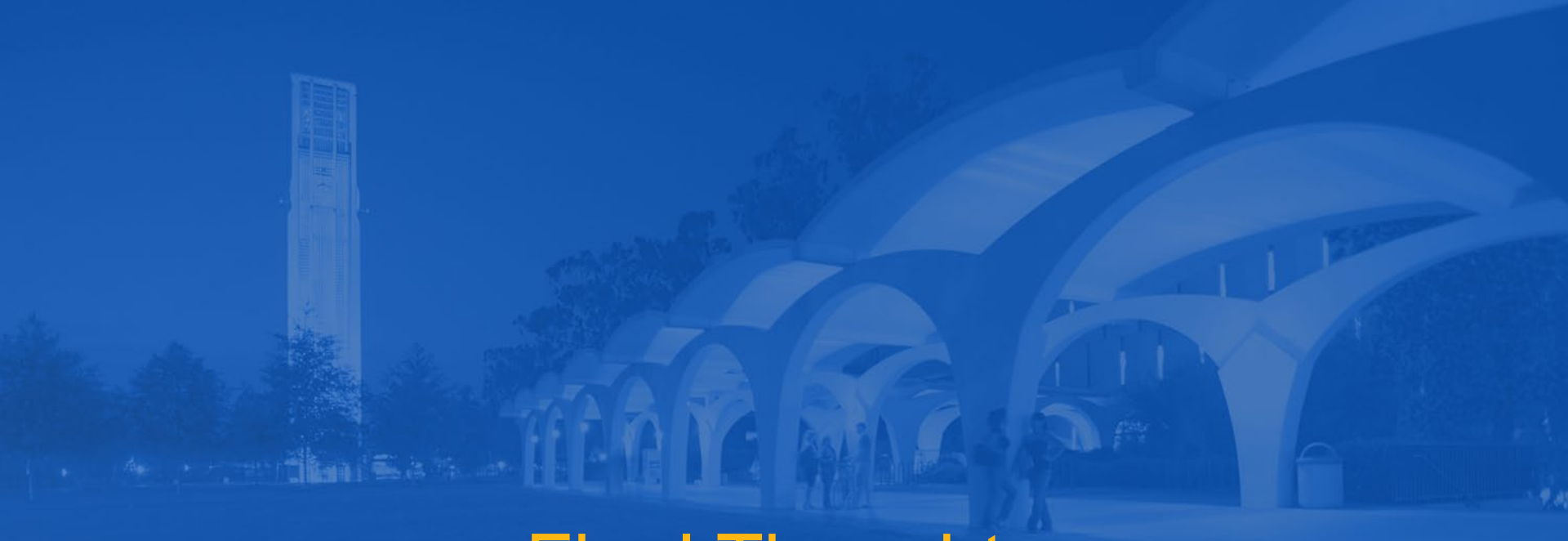
- For the Rose Port Project, UCR proposes to grab a sample and collect it in a cylinder and bring it back to the ground for reference laboratory measurements of HAPs, PM, and gaseous analysis
- On-board sensors will be used to track and maintain plume quality to fill the sample volumes (~20 liters or more) in minutes.

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

Desired Outcome

- Quantify the impacts of commercial shipping on community air by
  - High Cost
    - Measuring 3-4 vessels emissions from ocean going vessels operating following high cost reference methods
    - Measuring exposure indoor and outdoor in port communities
    - Utilize existing ambient monitoring stations
  - Low Cost
    - Measure up to 300 vessels utilizing drones and plume grabs
  - Modeling the in source measurements and connect the model with the community exposure.
  - Recommend mitigation strategies for PM and NOx emissions

- Communicate results to local community, media, ports, and regulatory agencies.



Final Thoughts

UNIVERSITY OF CALIFORNIA
UC RIVERSIDE

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

Overall Discussion

- Low cost sensing is needed to understand the variability of emissions in order to determine proper exposure averages in 1km grids
- Low cost sensing in combination with high cost sensing is important for maintaining our understanding of inventory and exposure
- Back trajectory modeling may be helpful for understand exposure from sources to different communities.
- The Rose Project will help investigate sensitives in atmospheric chemistry as it relates to exposure and the diversity of emission sources

What Can You Do About PM Exposure DYI For Engineers

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

Build it Yourself

Materials for your CR Box

4 20”x20” MERV 13 Filters

1 Box Fan

Duct Tape

Box Cutter

1 Square Cardboard

1 Circle Cutout Cardboard

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

Build it Yourself

Steps to build your CR Box

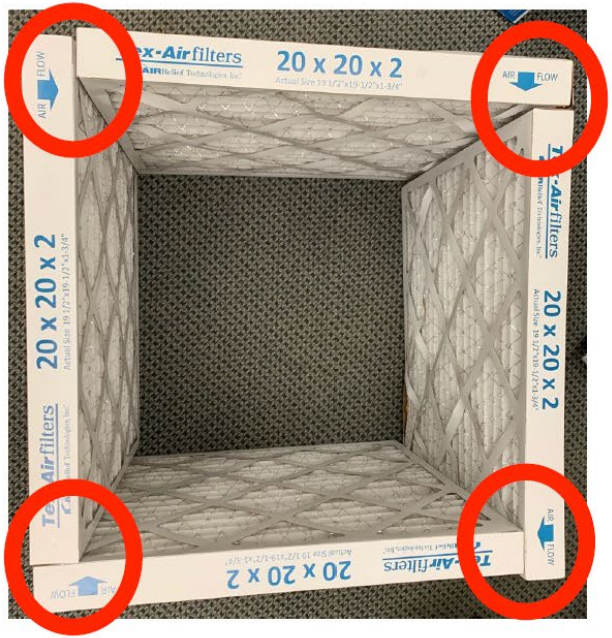
- Take your filters and identify which direction the **arrows** are pointing.

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

Build it Yourself

Steps to build your CR Box

- Take your filters and identify which direction the **arrows** are pointing.
- With the **arrows pointing inwards**, tape the sides of your four filters together to make a box.



UC RIVERSIDE UNIVERSITY OF CALIFORNIA

Build it Yourself

Steps to build your CR Box

- Take your filters and identify which direction the **arrows** are pointing.
- With the **arrows pointing inwards**, tape the sides of your four filters together to make a box.
- Tape **square cardboard** on the top of your box.

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

Build it Yourself

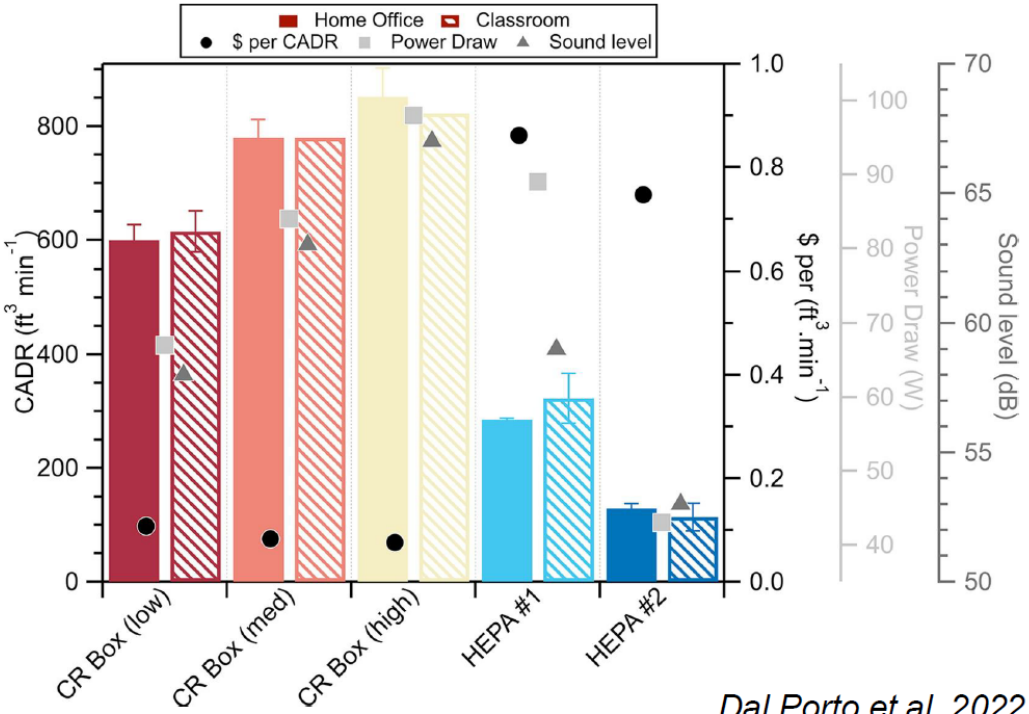
Steps to build your CR Box

- Take your filters and identify which direction the **arrows** are pointing.
- With the **arrows pointing inwards**, tape the sides of your four filters together to make a box.
- Tape **square cardboard** on the top of your box.
- Flip your box so that the square cardboard is on the bottom. **Tape the fan** on top of your box so that the fan is facing upwards.

UC RIVERSIDE UNIVERSITY OF CALIFORNIA

Build it Yourself

Studies confirm that DIY solutions can outperform commercial products costing 10x more



Dal Porto et al, 2022

- **Clean air delivery rate (CADR)** measures filtration effectiveness (shown in color bars in figure)
- **CR Box CADR values** (on left) were much higher than two tested commercial products (on right)

Questions

UNIVERSITY OF CALIFORNIA
UC RIVERSIDE