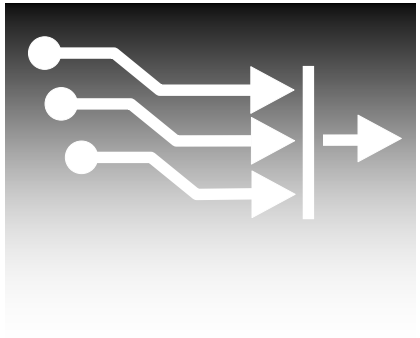

Next Generation
(Smaller, Lower Cost, Lower Energy Consumption)
Portable Emissions Measurement Systems

Karl Ropkins[1], **Hu Li**[1]

and Andrew Burnette[2]

6th International PEMS Conference and Workshop

UCR CE-CERT

17th & 18th March 2016

UNIVERSITY OF LEEDS

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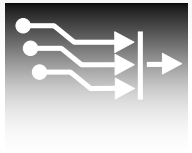
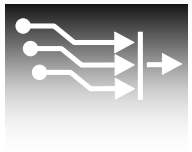


Overview

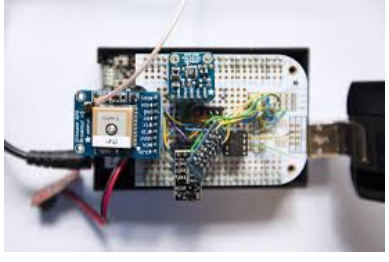
1. Research Rationale
2. Building a Smaller (Integrated) PEMS
3. Gas-phase Species Measurement
4. Particulate Measurement



Do We Need a Smaller PEMS?

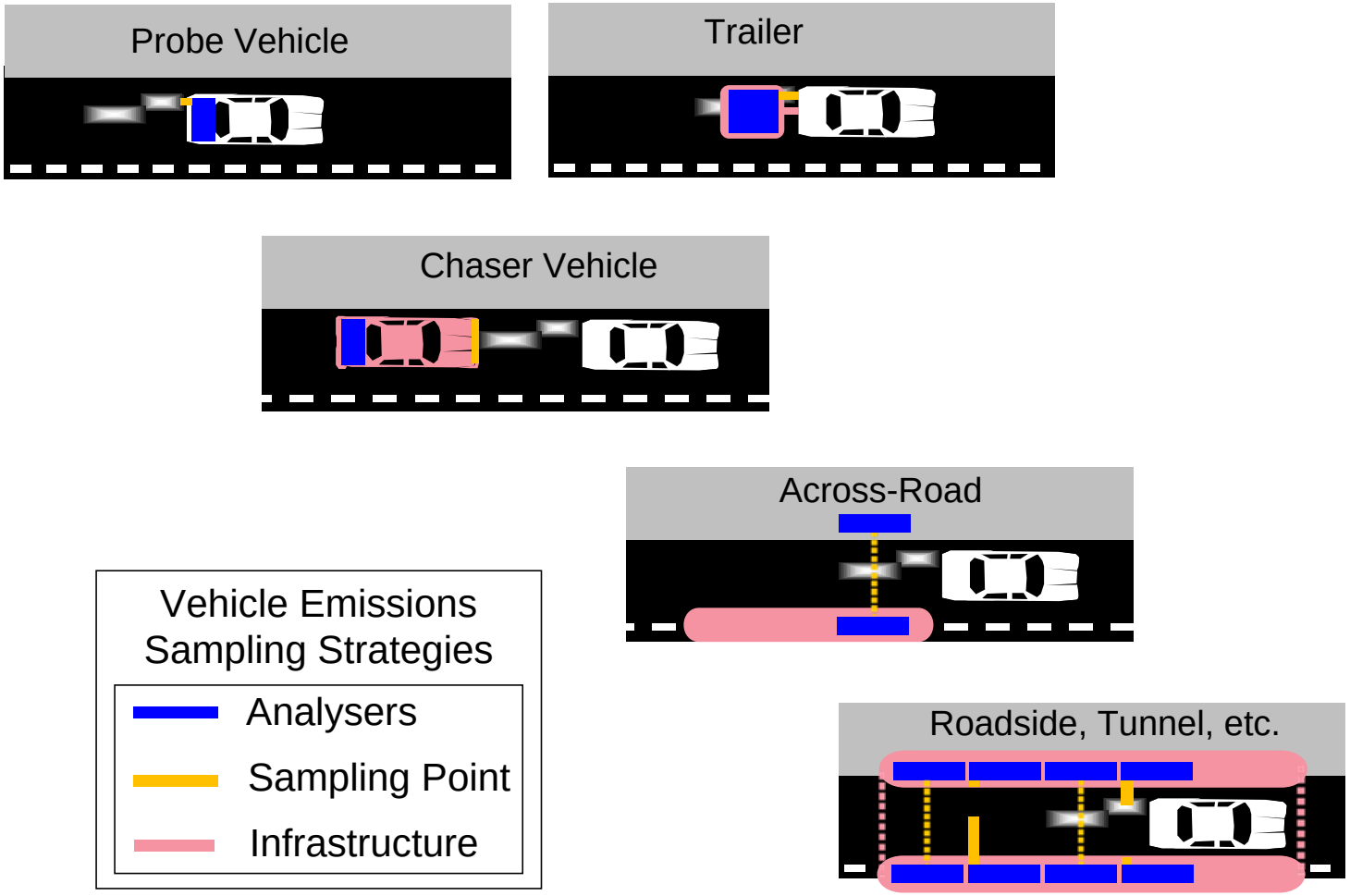
The size, weight and power consumption of the current generation of commercial PEMS is a well-documented concern

- Even an entry-level PEMS could significantly extend our monitoring, inventorying and research capabilities
  - Low-cost real-world optimization and/or validation for new technologies
  - An option for the more challenging (and more mundane?) applications
- And, such an entry-level PEMS is closer than you might think - *we are already delivering 'prototype' and 'early-to-market' systems*
- But we should be aiming for more...

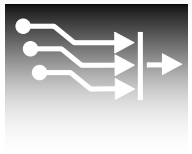


Examples:
Global MVR Firefly
3DATX parSYNC
WVU/Carder

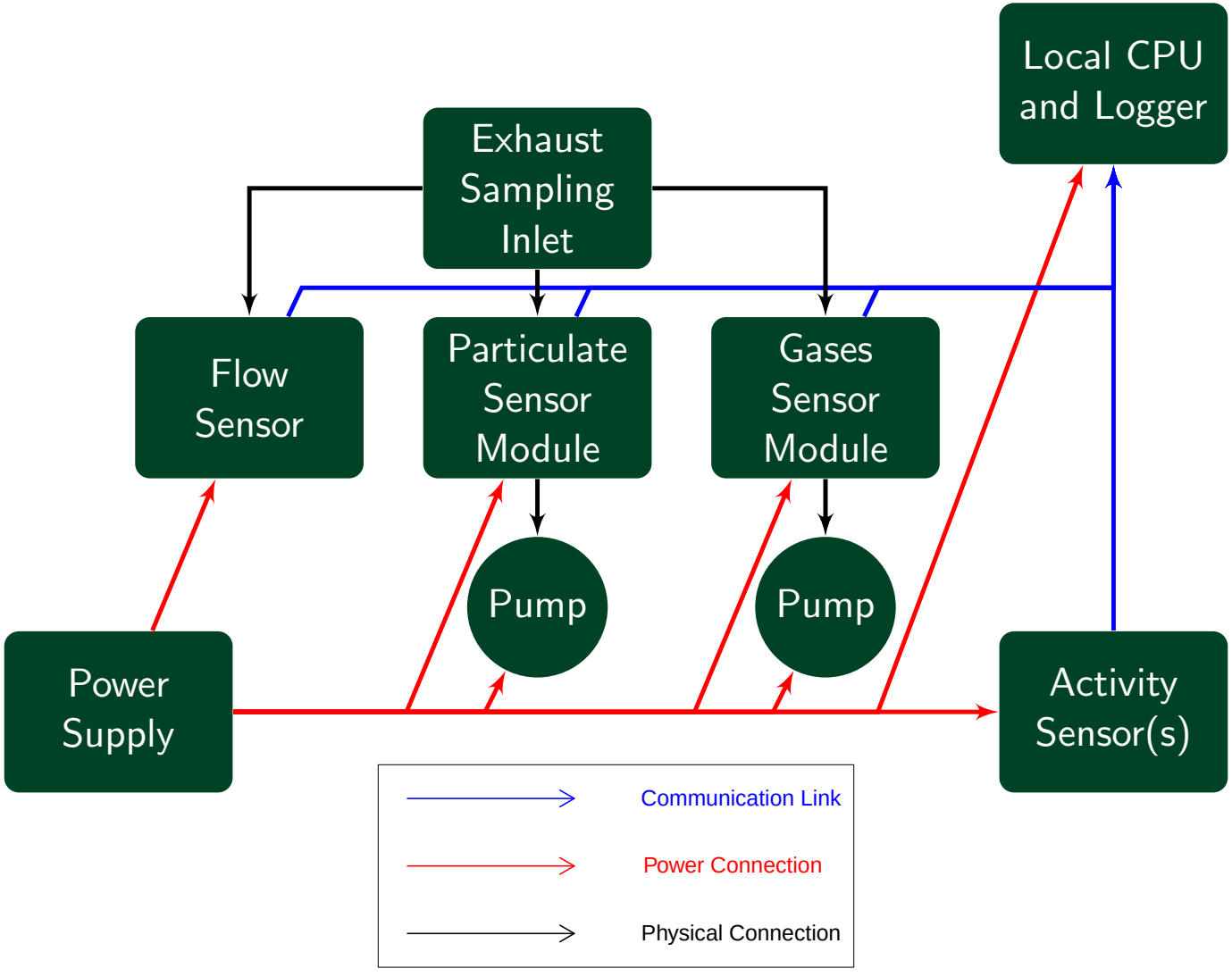
The Bigger Picture



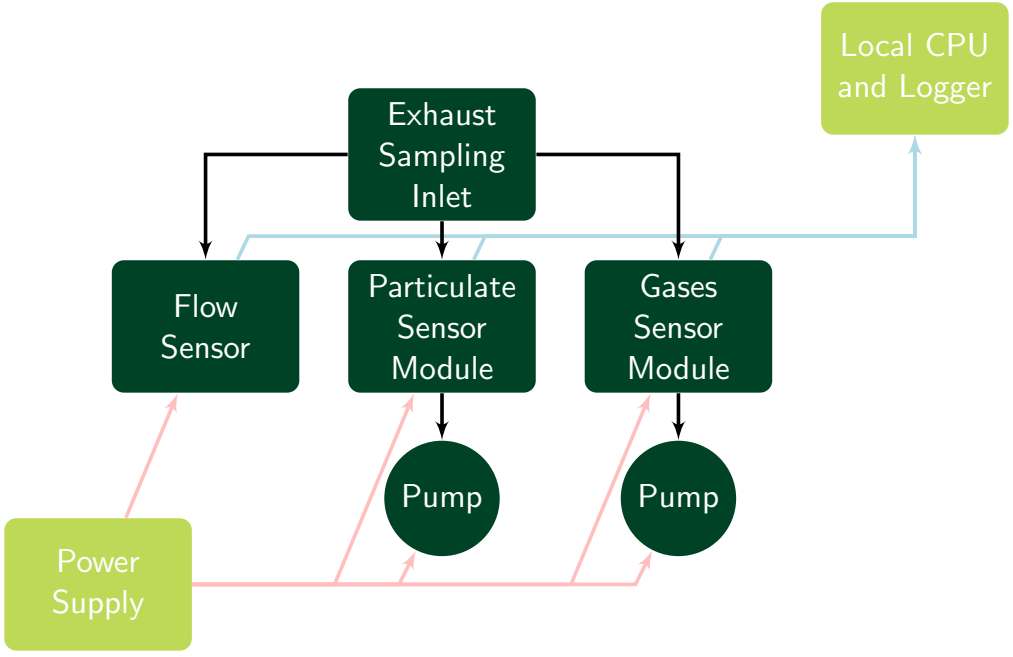
(From Ropkins, K. Real-time Mobile Monitoring of Vehicle Emissions. Royal Society of Chemistry AAMG Air Analysis Out of the Laboratory and into the Field, National Physical Laboratory, UK, 2008.)



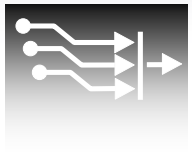
Modular Design



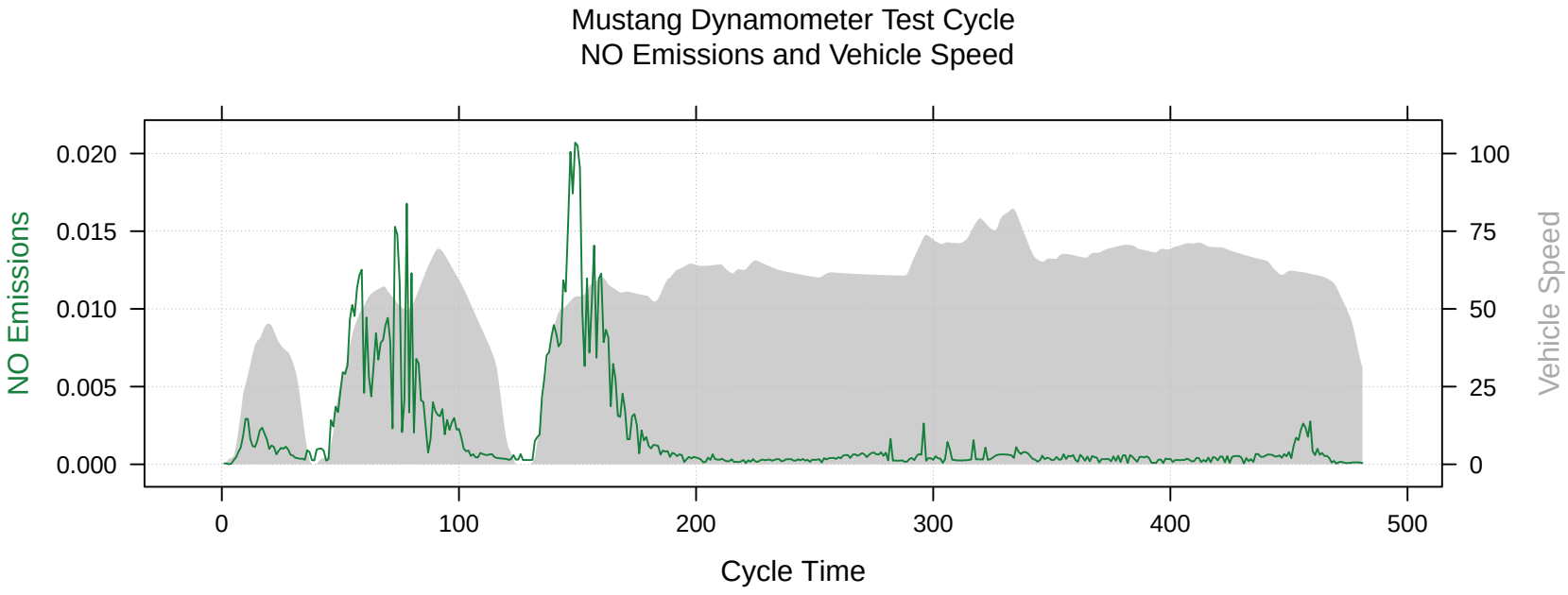
The Exhaust Inlet



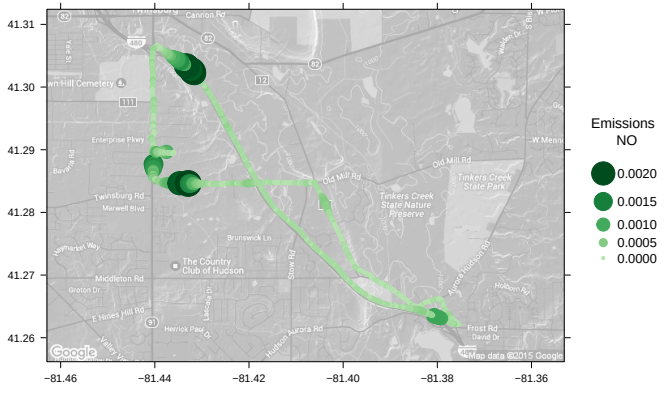
We are not talking about the exhaust inlet today, but it is important to emphasize that good sample delivery is fundamental - *It simply does not matter how good your analyzer/sensor/etc is, if you are not delivering a representative sample to it...*



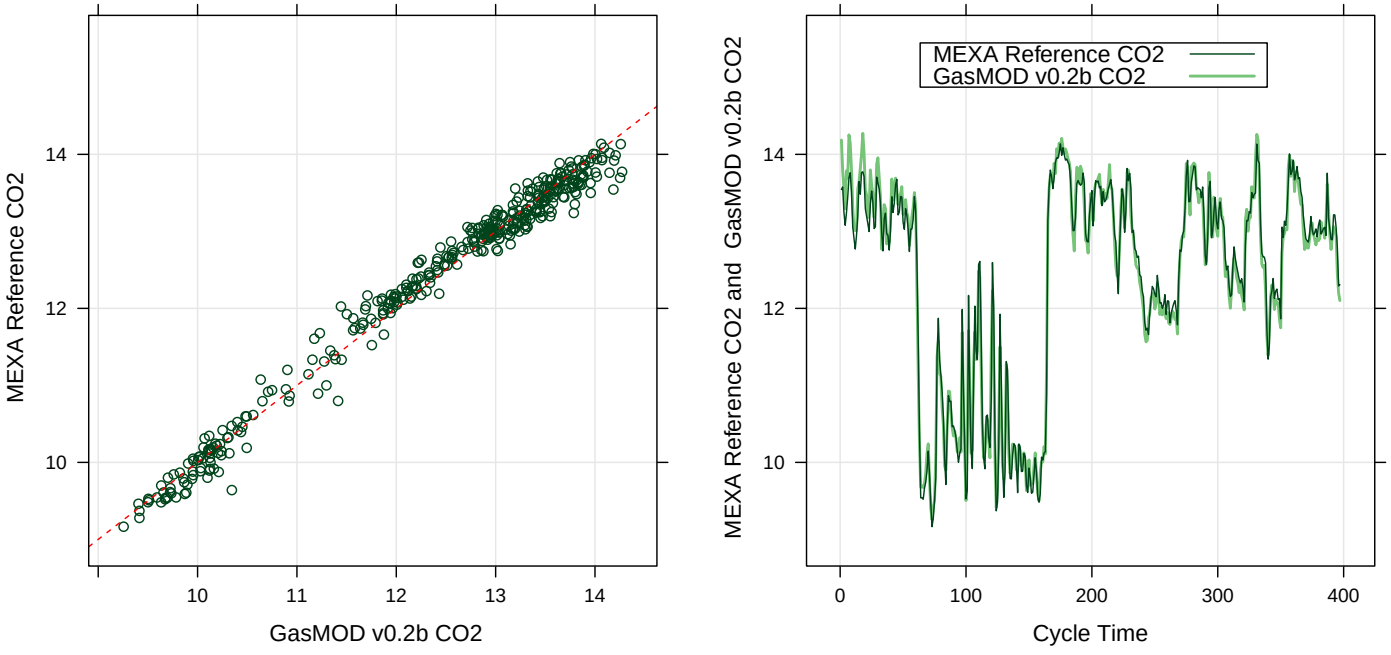
Dynamometer and On-Road Data



- From recent work with Mustang Dynamometer
- Validation on-going



Gas Sensor Evaluation

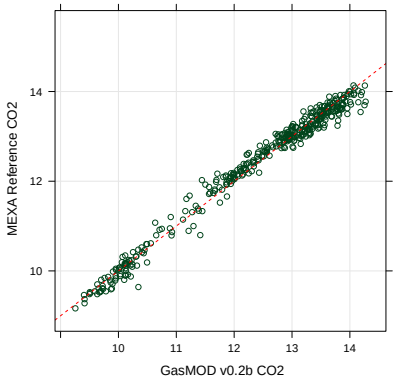


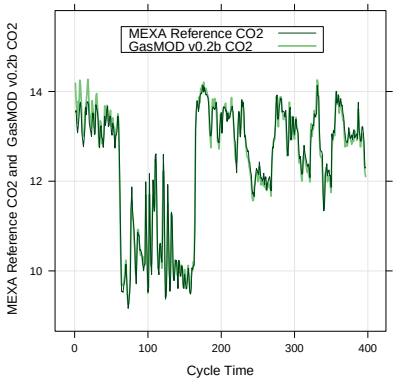
Agreement MEXA NDIR / parSYNC PLUS® Module R ≈ 0.98
(Clean IR diode sensor; prior calibration)

So, the 'take home' message here is that you can get good data out of sensors, but there are caveats...

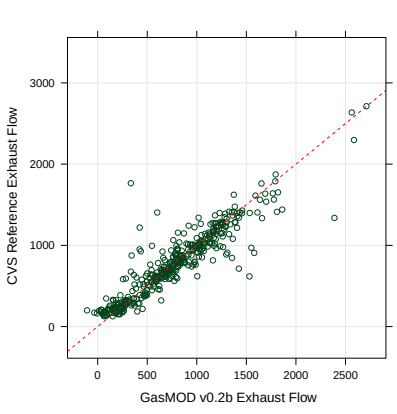
Concentrations, Flows and Emissions

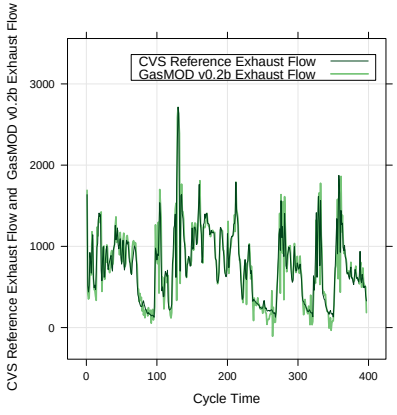
Concentrations $R \approx 0.98$



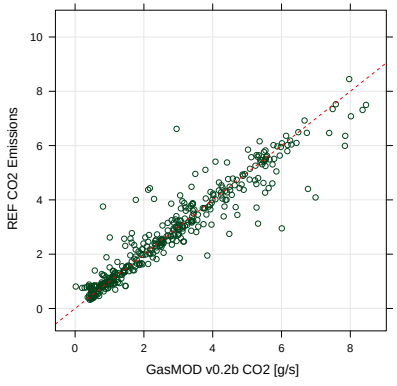


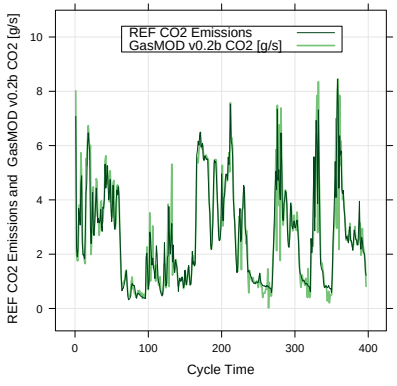
Exhaust Flow $R \approx 0.95$





Emissions $R \approx 0.94$





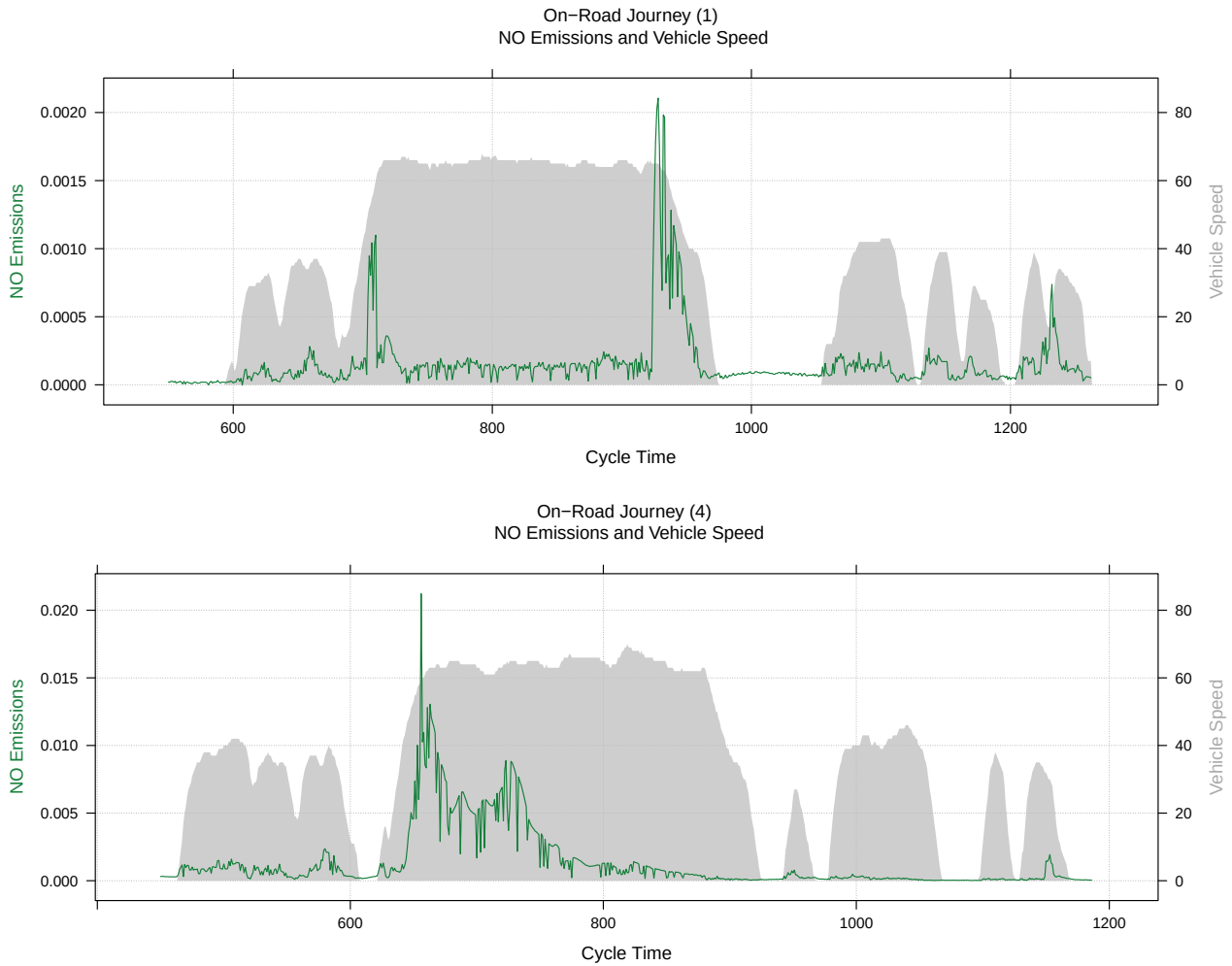
Some early ‘lessons learnt’

Observations coming out of work on the parSYNC GasMOD^{TM} module

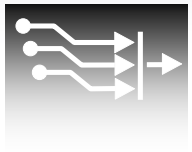
- Optics are bad news - *high power, weight and heat overheads* - but they are still the current best option
- There are size and power trade-offs building an optics sensor bundle and the ‘first gen’ cartridge measures
  - CO_2 - *GHG, fuel consumption*
  - NO, NO_2 - *air quality priority, not* NO_x (A regulatory $CO_2/CO/THC/NO_x$ cartridge would be demand driven)
- The issue is not getting good sensors - *that just costs money*; it is keeping those sensors alive as long as possible, drift correcting and spotting when they die...

(maybe not always going to be so; patents possible)

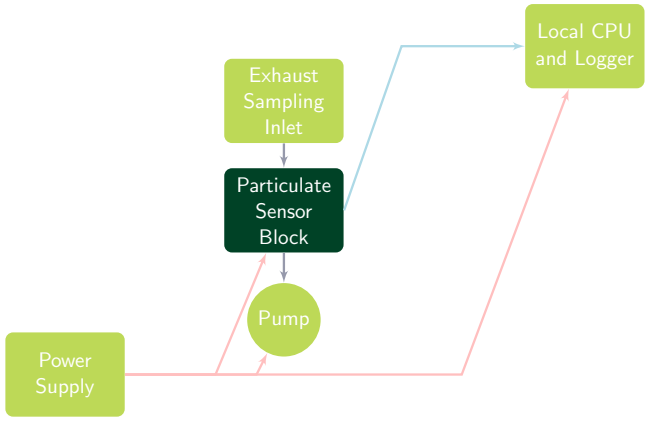
A Comment about Defeat Devices

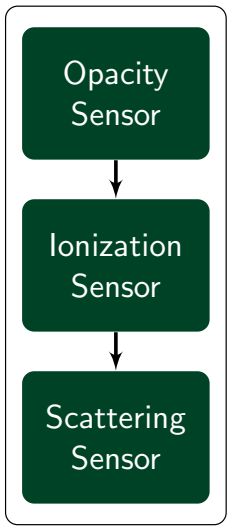


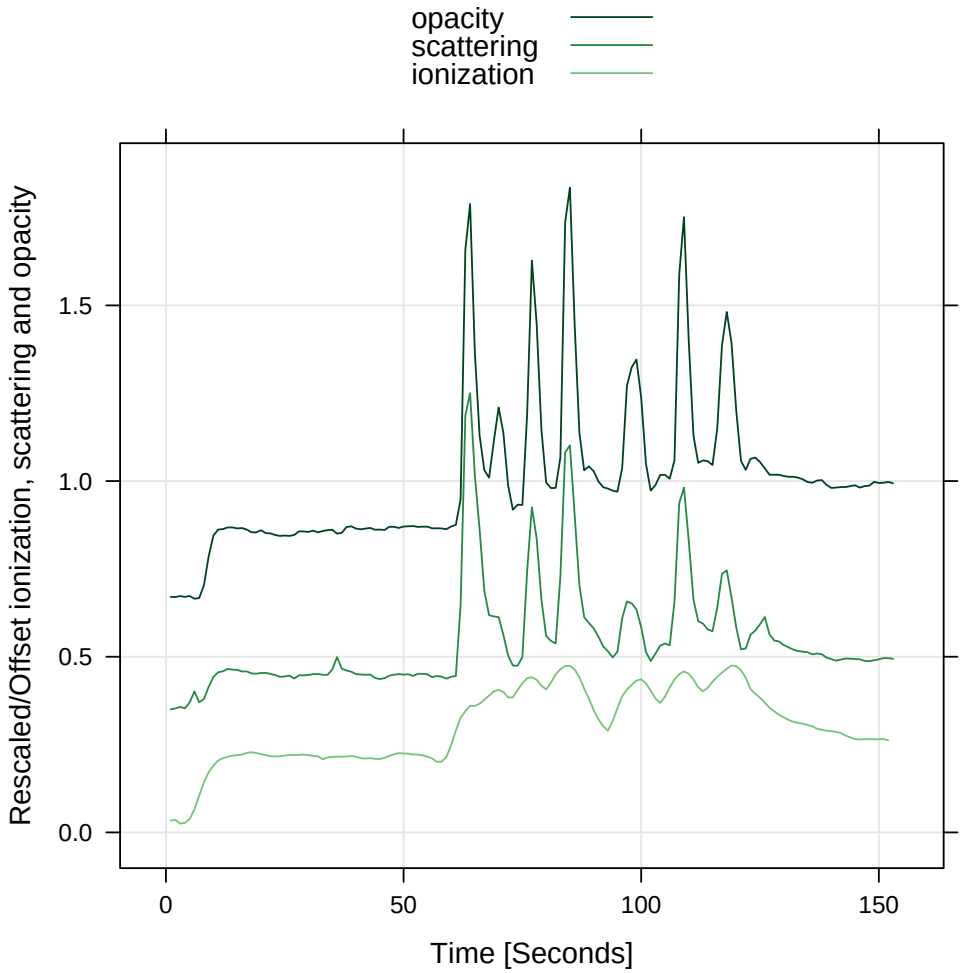
It does not need a very accurate PEMS to see a defeat device - *but it does need a PEMS in the car with a defeat device...*



parSYNC® Sensor Module



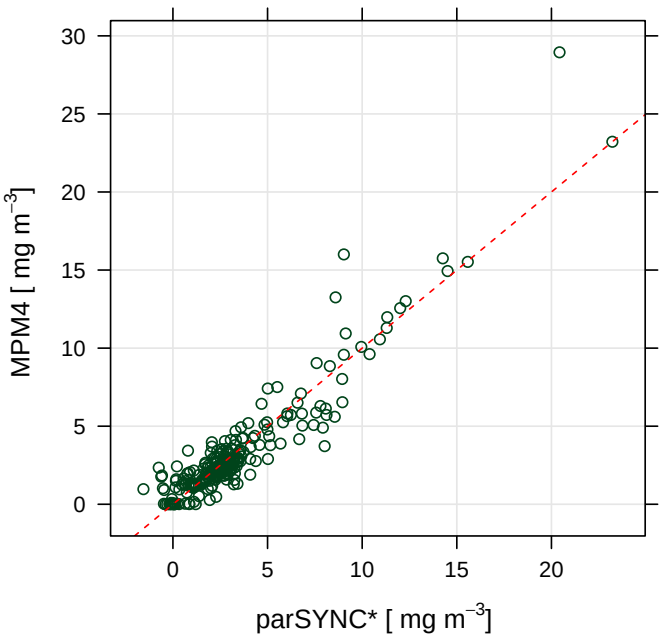


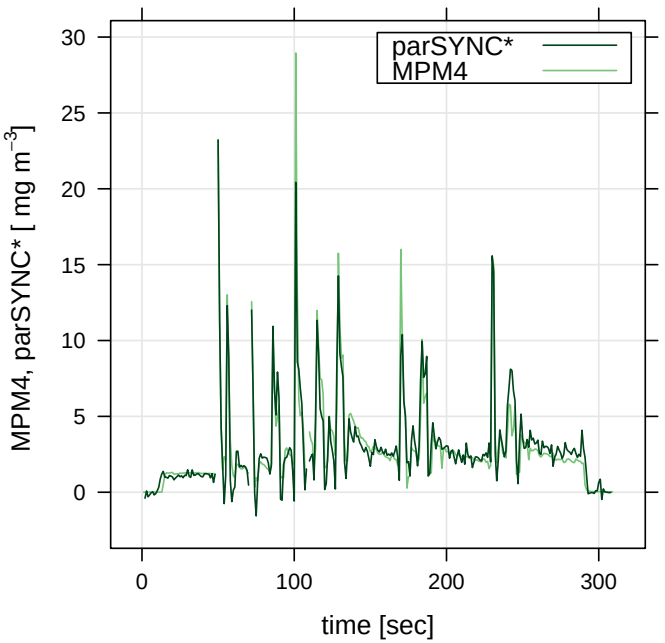


Multiplex PM/PN Sensor Model

Three Sensor Fit

$$\text{parSYNC*} = [\text{MPM4}] = f(\text{parSYNC1}_{t=-1,0,1}) + f(\text{parSYNC2}_{t=-1,0,1}) + f(\text{parSYNC3}_{t=-1,0,1})$$



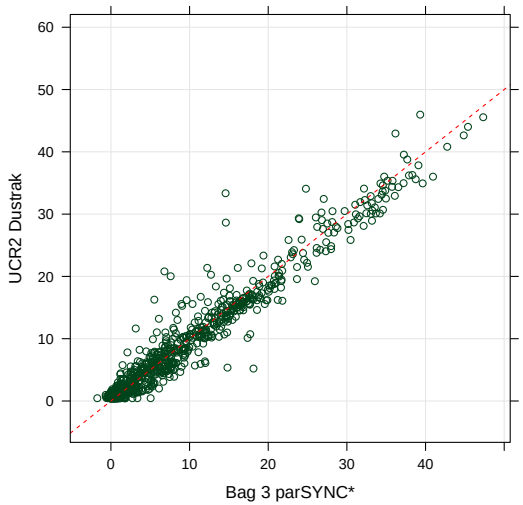


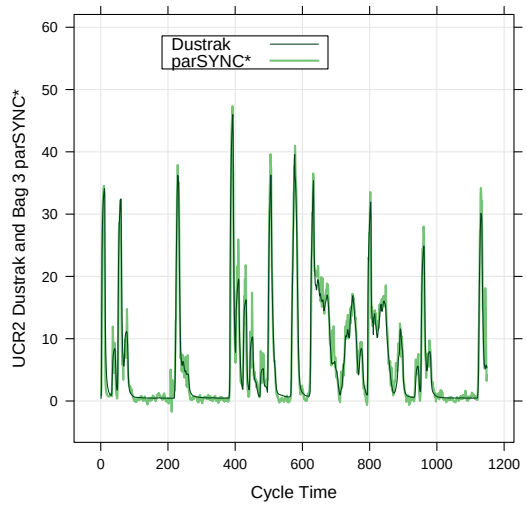
Agreement MPM4 / parSYNC® multiplex sensor R ≈ 0.92
(two sensor, scattering and opacity, parSYNC* model)

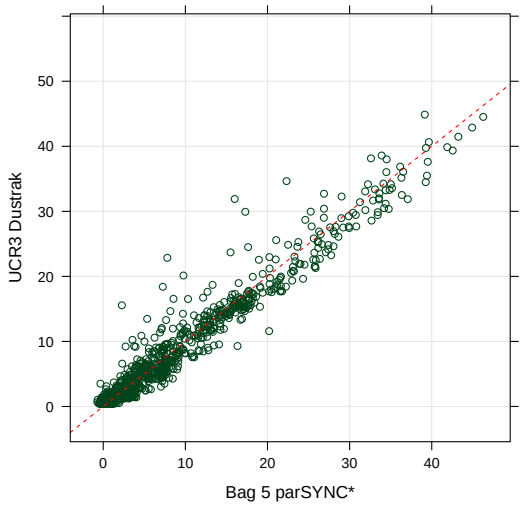
[Ropkins *et al*, 2015]

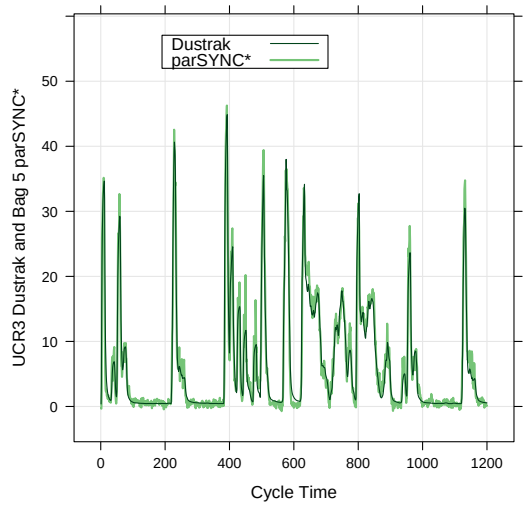
PM Sensor Module Validation

- UCR CE-CERT Dynamometer
- FTP Cycle
- Replicate runs
- DUSTRAK reference
- parSYNC® three sensor multiplex
- ($R \approx 0.98$)



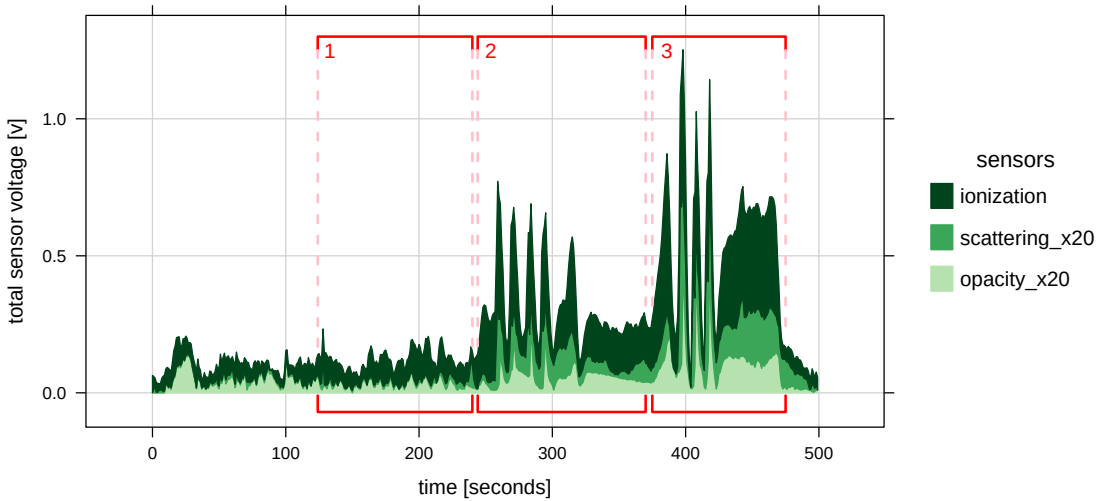


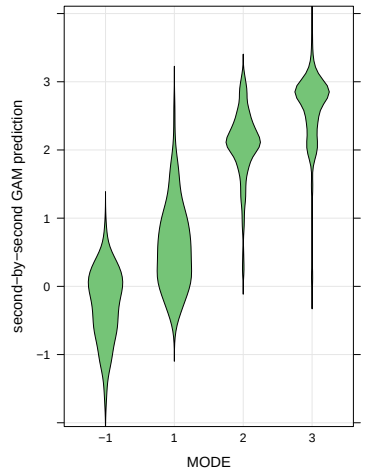


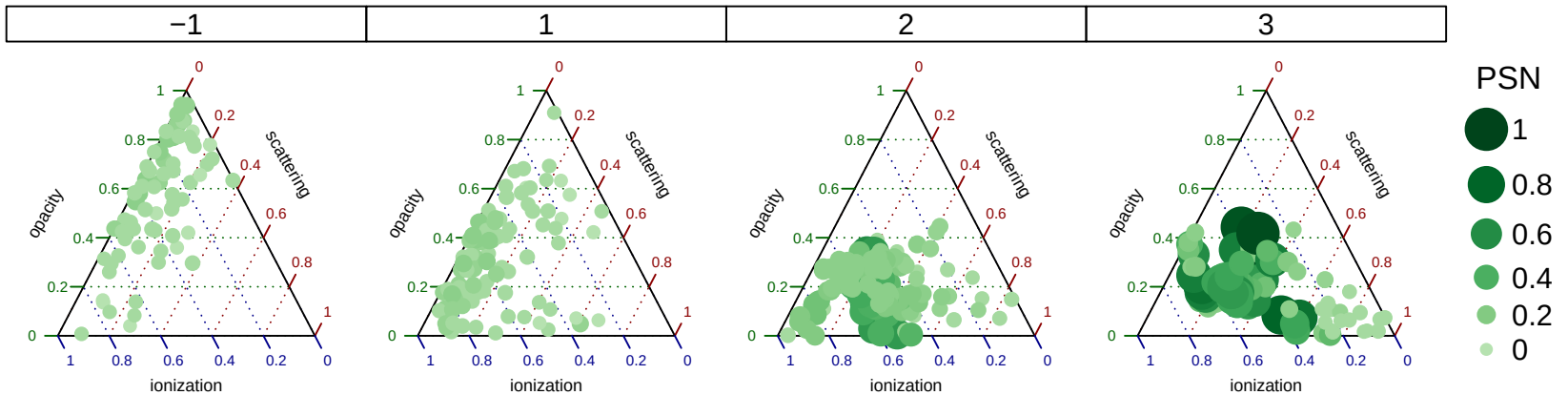


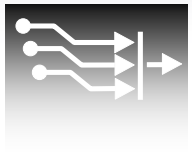
Example Application

Test vehicle with modified DPF; modes 1 (working) to 3 (failed)









Thank You

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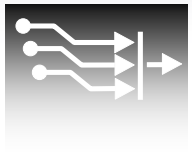
Hu Li - fuehli@leeds.ac.uk
Andrew Burnette - andrew.burnette@infowedge.com



Selected References

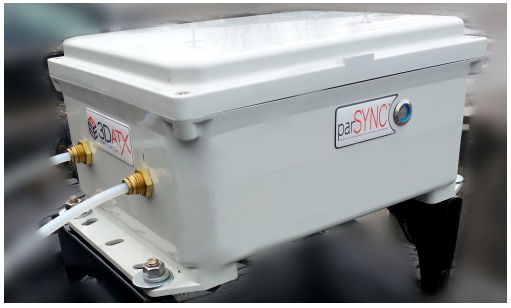
- PEMS Instrument and Software Development/Evaluation
  - Ropkins, Sandhu, Burnette, A Novel Multiplexed Sensor-Based Approach to Mobile Particle Mass and Number Measurement. 25th CRC Real World Emissions Workshop, 2015.
  - Ropkins, Tate, Li, Andrews, Hawley, Bell, Chassis Dynamometer Evaluation of On-board Exhaust Emission Measurement System Performance in SI Car under Transient Operating Conditions. SAE Technical Paper 2008-01-1826, 2008.
- Flow Measurement/Correction
  - Ropkins, Li, Hawley, Chen, Tate, Andrews, Bell, Robust surrogate measurement correction using generalised additive model. Chemometrics and Intelligent Laboratory Systems, 95(2), 2009.
- Data Time Alignment
  - Ropkins, Carslaw, Goodman, Tate, Application of non-linear time-alignment and integration methods to environmental time series. TrAC Trends in Analytical Chemistry, 28, 2009.
  - Carslaw, Ropkins, Laxen, Marner, Williams, Near-Field Commercial Aircraft Contribution to Nitrogen Oxides by Engine, Aircraft Type and Airline by Multiple Plume Sampling. Environmental Science and Technology, 42(6), 2008.
- Mobile Data Software/Analytics
  - Ropkins, Abdalla, Hanley. New methods for PEMS micro-trip analysis. 24th CRC Real-World Emissions Workshop, 2014.
  - Ropkins, Abdalla, Hanley, Automating PEMS micro-trip analysis. 2014 PEMS Conference and Workshop No.4, 2014.

PEMS Applications

PEMS are already used in multiple applications

...and we would use PEMS even more widely if we could

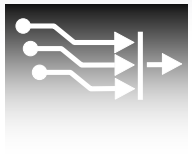
parSYNC®and parSYNC PLUS®



The 3DATX parSYNC® systems

- parSYNC® PM/PN analyzer - *at least 'entry level' technology currently being commercialized*
- parSYNC PLUS® gaseous and PM/PN analyzer - *currently undergoing ruggedization and validation*
- Both small footprint
  - *ca.* 3 kg including batteries
  - Nominally 280 × 215 × 140 mm
- Both have long battery life
- Both are easy to deploy, install and run

(Patents Pending)

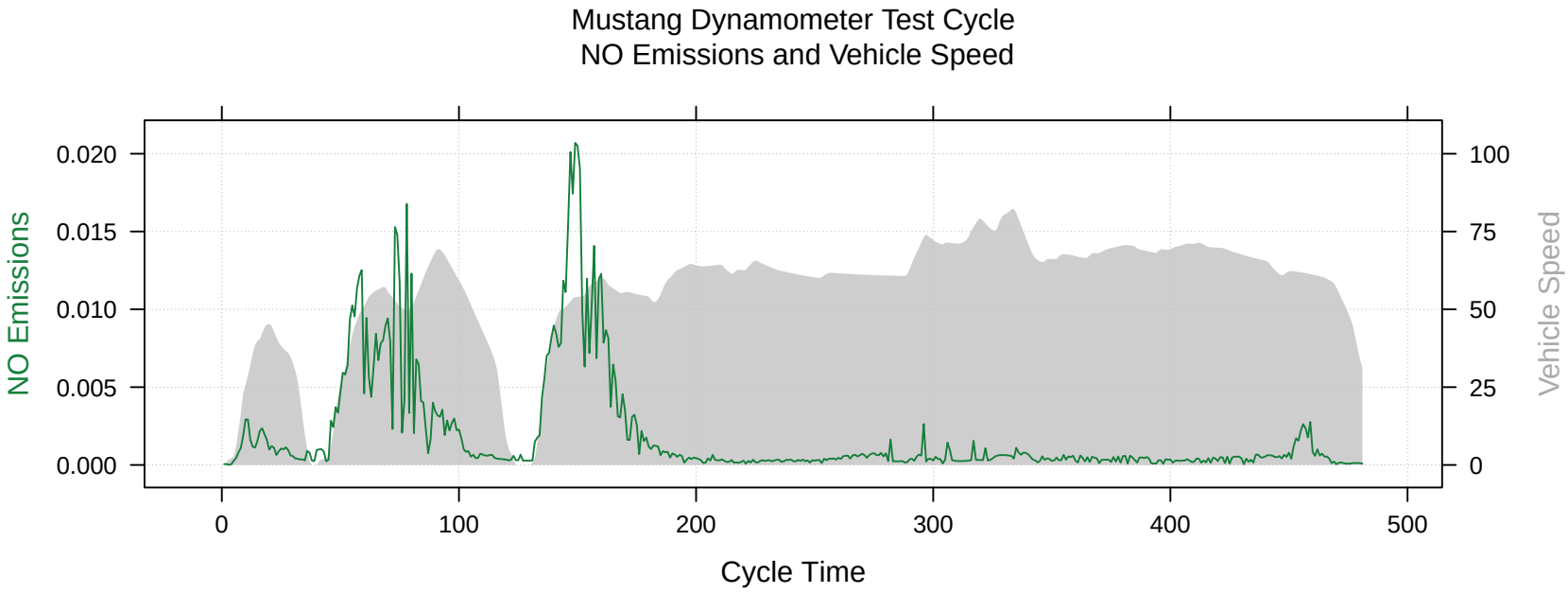


Why 3kg, 280 x 215 x 140mm?

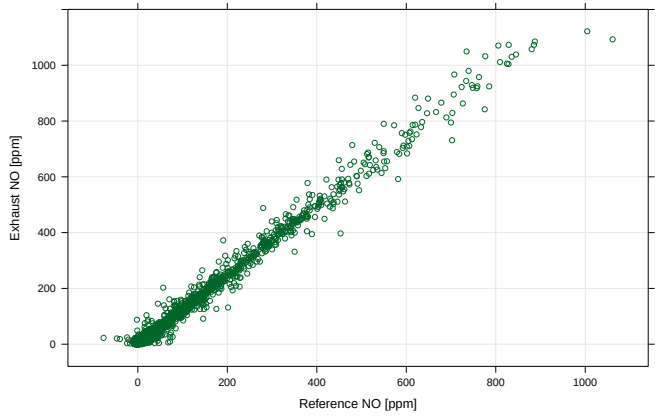
Obviously the long-term aim is even smaller/lighter but why this as the first target?

- It is a user-friend size
  - Unit is small/light enough to be truly portable
  - Single person installation
- It is a good size for a third-party system
  - Small enough to courier
  - But not so small that it is easily lost, run-over, etc
- And there is still room inside
  - Scope to add new modules or reconfigure existing ones
  - (So early adopters can benefit from ‘lessons learnt’)

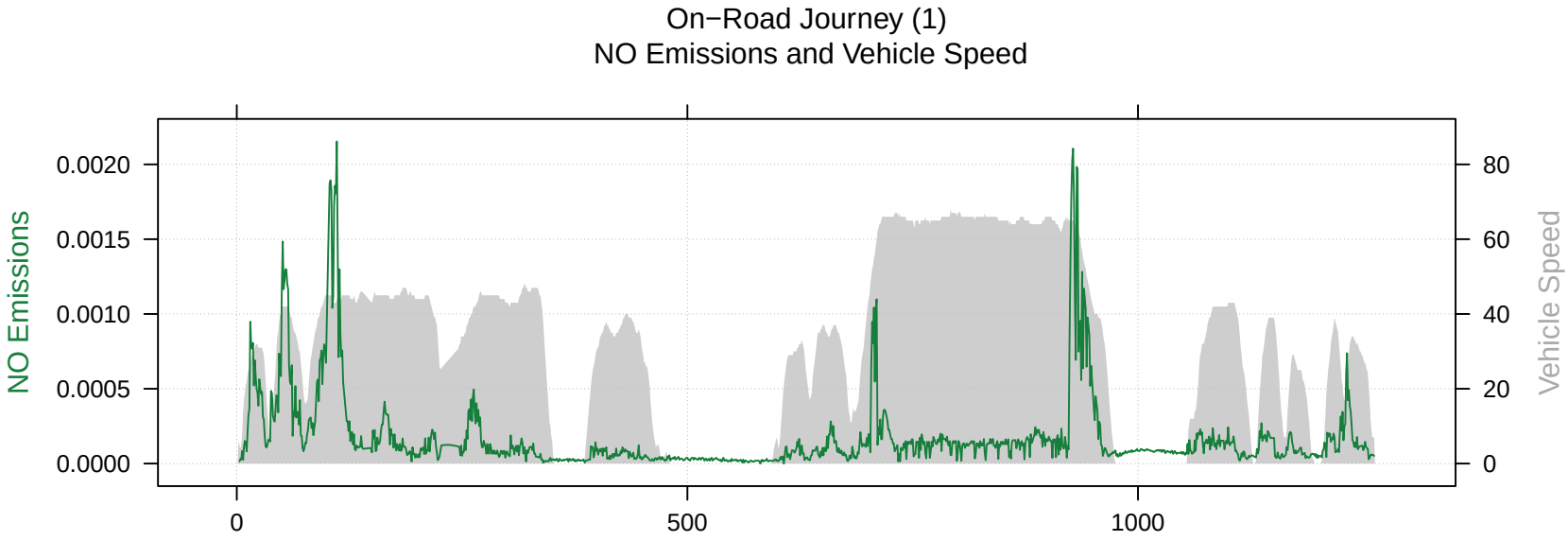
Early Dynamometer Data

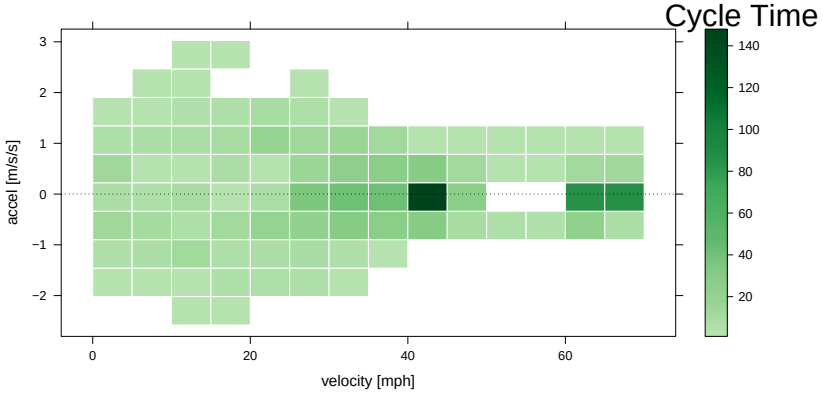


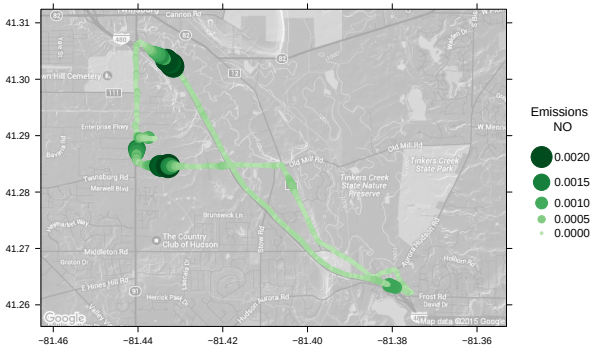
- From recent work with Mustang Dynamometer
- Validation on-going



Early On-Road Data



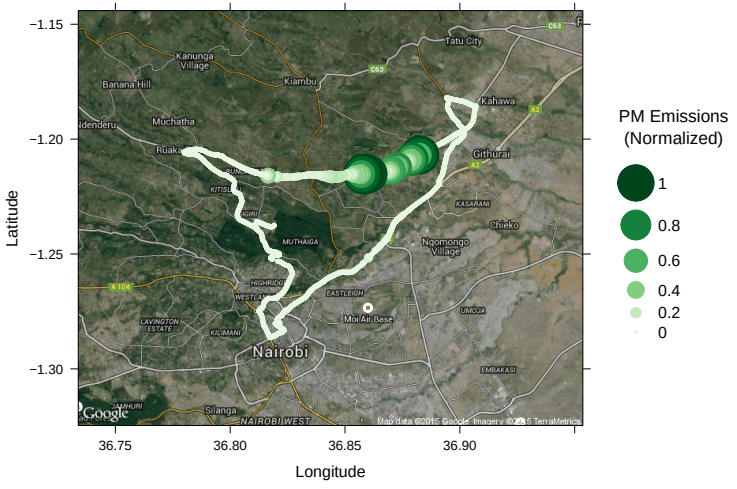


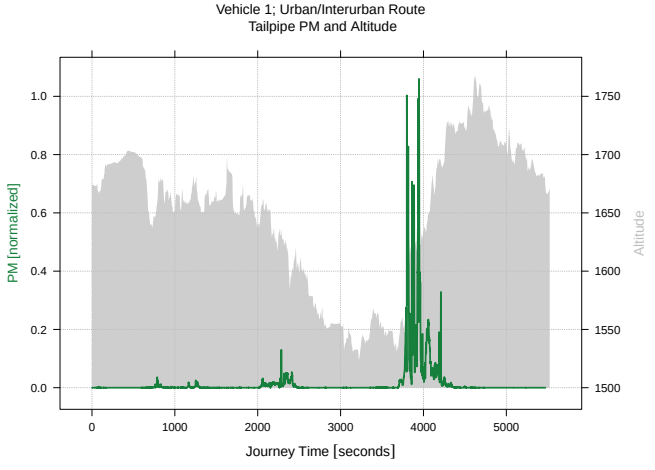


Demonstrator Study

Third-party deployment

- Working with University of YORK/SEI
- African/Kenyan PEMS field study
  - Early emissions data on poorly understood local vehicle fleet
- Proof of concept
  - Third-party study model
  - Courier ‘PEMS by Post’





Next Demonstrator

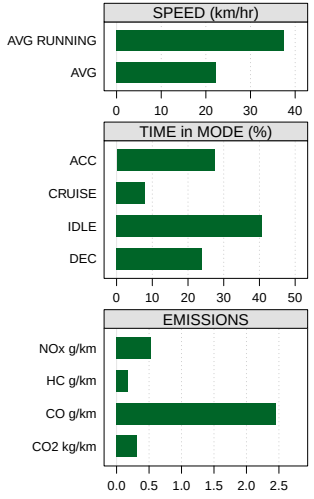
From: Work by Karim/CARB

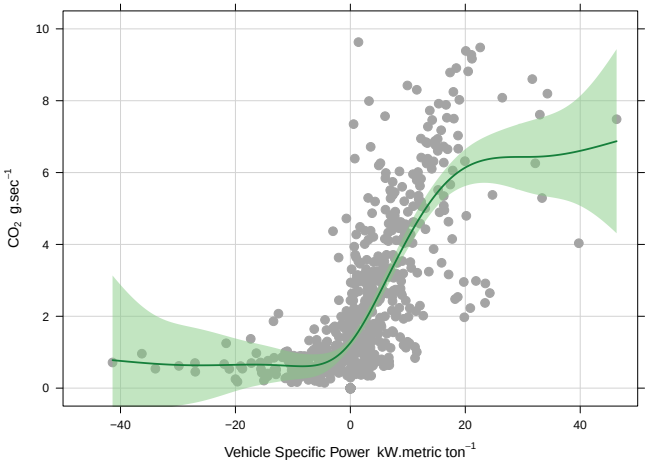
Motorcycle deployment

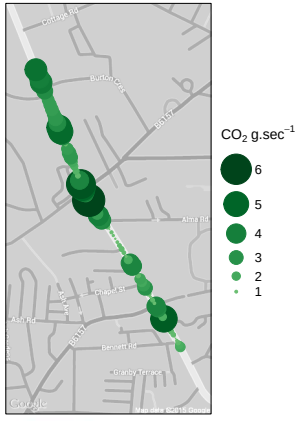
- To complement African deployment (a challenging environment)
- A challenging installation
  - Small instrument footprint
  - High in-use stress/strain
- Selection rationale
  - Currently no real-world data on motorcycle fleets
  - Particular issue in e.g. Asia where local fleets are large
  - 'If motorbikes, where not...?'
- Move towards 'wrap around' solution

A Comment on PEMS Data Analytics

PEMS log multiple measurements at 1Hz (or higher) resolution
So even small studies generate large datasets







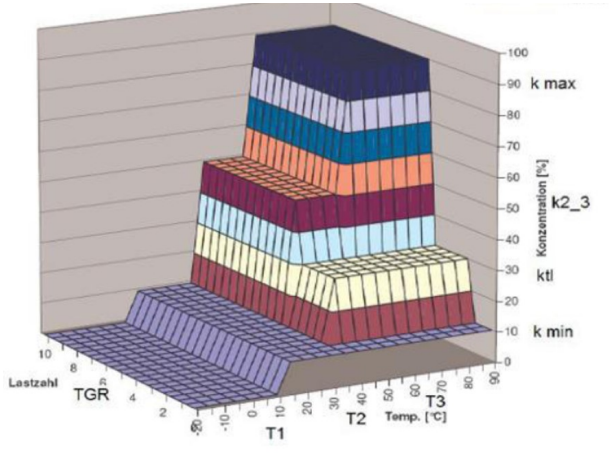
And a need for robust analytics because of the inherent risk in treating PEMS data like dynamometer data

Example PEMS Data Analytics

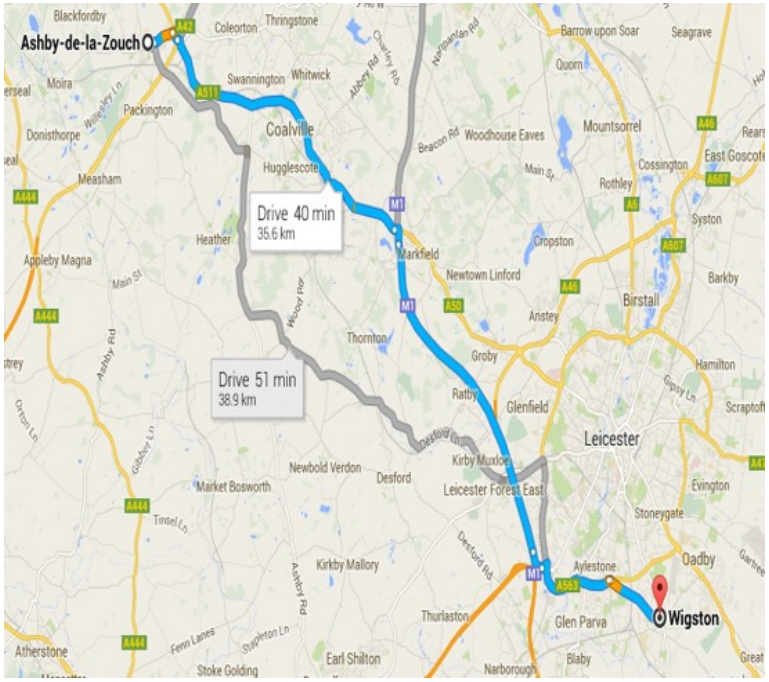
HDV vehicle retrofit project

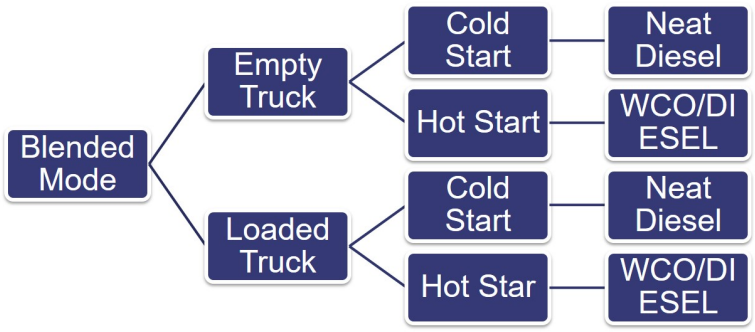
- Euro V 44 tonne articulated truck

  (DICI turbo-charged 6-cylinder in-line Mercedes tractor unit, *axor C 2543*, diesel engine; engine capacity 11.97 l, maximum output power of 315 kW@1900 rpm; maximum torque is 2100 Nm@1100 rpm)
- HDV fuel system modified to run on Diesel(PD)/biofuel blends
- Full studies looked at a full suite of engine data, and gaseous and PM measurements but here focuses is on the analysis of FC data



Example PEMS Data Analytics





- Strictly defined routes

  Supply to Delivery Depo (A2W) and

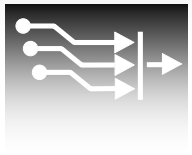
  Delivery to Supply (W2A) Depo

- So, ideal scenario for ‘on-road drive cycle’

- Total journey for A2W:

  FC on Diesel Only Journeys 21% higher than on Blended Fuel Journeys

  (Arguably a ‘great but usual’ result)



Example PEMS Data Analytics

Work by MSc Adrian Ortega Calle using the R package **pems.utils**

His work includes:

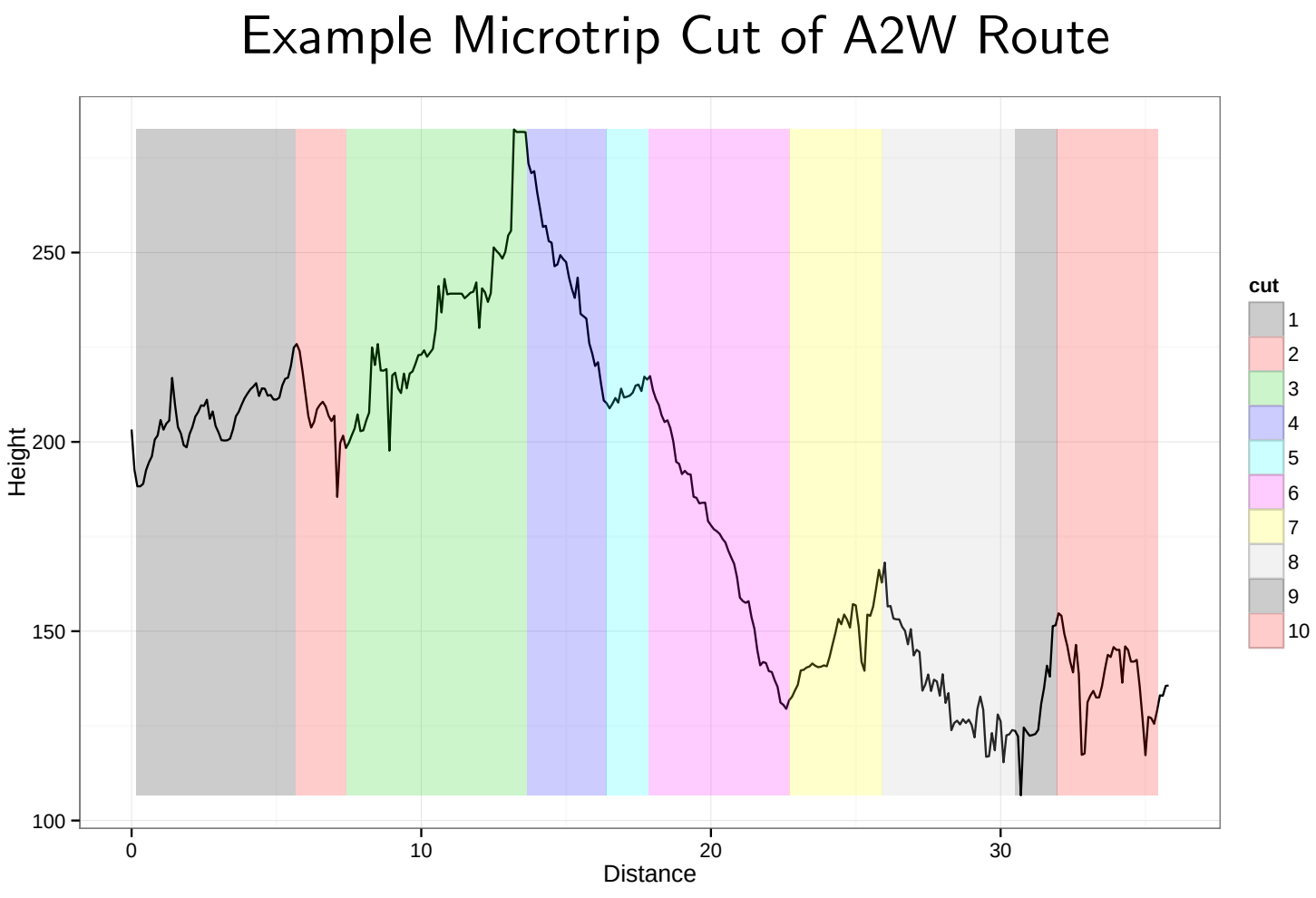
- A 'hole filing' strategy for the handling of irregular time stamped records

  (A lot of nice work that we'll not be talking about...)

- Microtrip analysis of Fuel consumption data

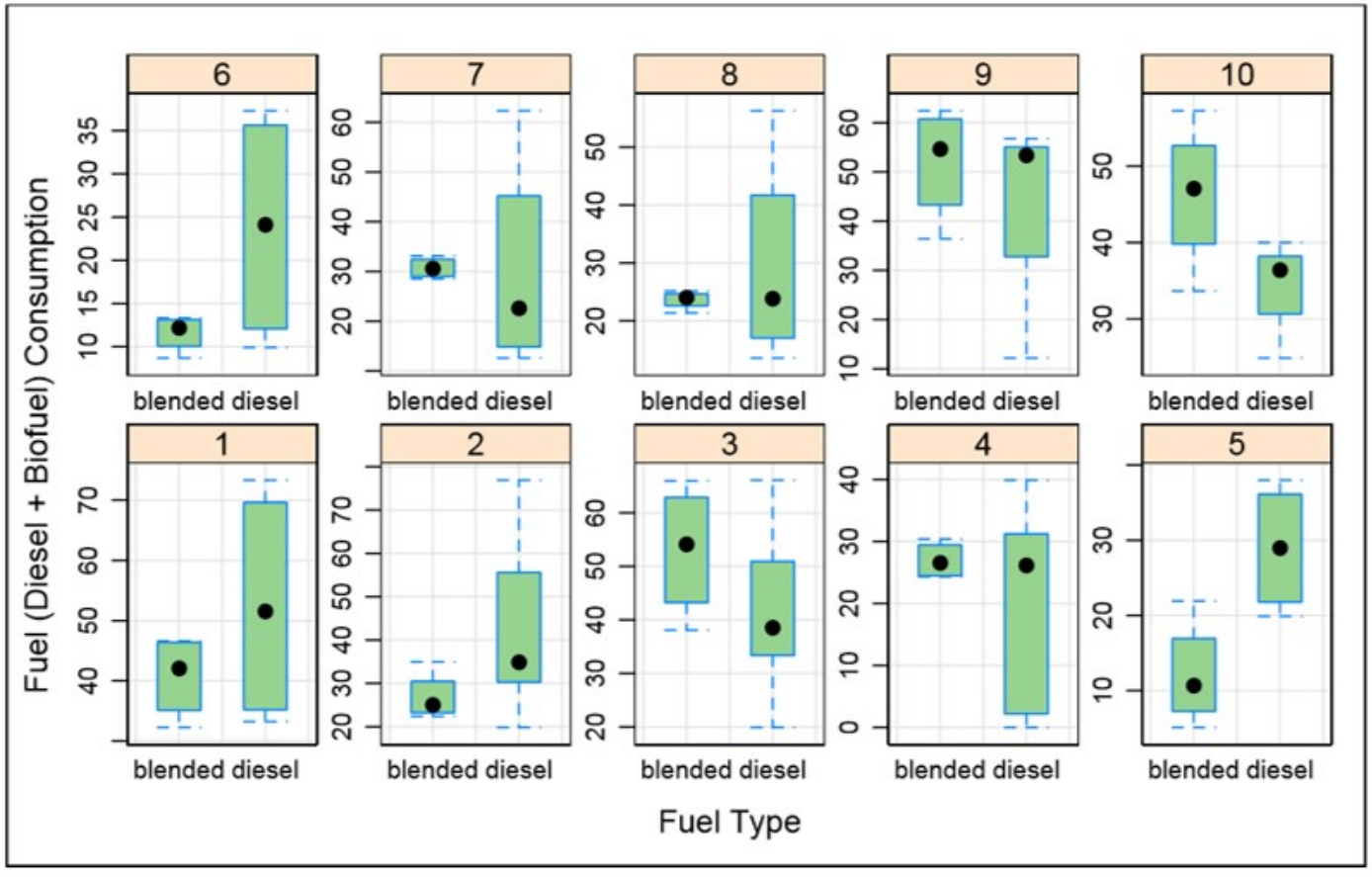
  (That we will...)

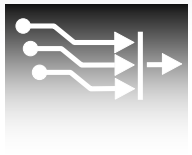
Example PEMS Data Analytics



Example PEMS Data Analytics

Example Microtrip Analysis A2W Route Fuel Consumption





Example PEMS Data Analytics

Comments:

- Microtrip analysis provides a useful means of exploring journey data
- R provides a means to automating large volume ‘By microtrip cut’ analysis of multiple journey datasets
- And VSP binning appears to be a highly robust metric for explaining observed differences