Vehicle Emissions Remote Sensing Systems: A Comparison of Technologies

车辆尾气遥测系统：技术比较

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Overview 概述

Brief Introduction (简单的介绍):
Possibly a different definition of remote sensing(可能是遥感的不同定义)

A Comparison of Technologies (技术比较)

FEAT, RSD, ETC, EDAR, OHMS, PEAQS

Some thoughts on common issues (关于共同问题的一些看法):

Moving from surveillance to bad vehicle targeting
(从监控转向针对不良的车辆)

(VSP and plume chasers)

Acknowledgements (鸣谢)

*Introduction*介绍

Contents lists available at ScienceDirect

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Review article

Remote sensing of on-road vehicle emissions: Mechanism, applications and a case study from Hong Kong

Yuhan Huang[a], Bruce Organ[a,b], John L. Zhou[a,*], Nic C. Surawski[a], Guang Hong[c], Edward F.C. Chan[b], Yat Shing Yam[d]

Remote Sensing is Established Technology in Hong Kong

…but for some my definition may be a little more inclusive than your own…
我的定义可能比你们一些人的定义更具包容性

Table 1
Comparison of vehicle emission measurement techniques under real-world driving conditions.

Technique	Method	Advantage	Disadvantage
PEMS	Measures target vehicle emissions by carrying measurement instruments on-board	High accuracy Emission data of a journey Individual vehicles & vehicle classes	Small sample size Extra weight of PEMS may bias the measurements, especially for light vehicles
Plume chasing	Measures target vehicle emissions by a following laboratory vehicle carrying measurement instruments	Emission data of a journey Individual vehicles & vehicle classes	Small sample size Limited speed and minimum distance for safety
Tunnel measurement	Measures pollutant concentrations at tunnel's entrance and exit	Large sample size Well-defined wind	Difficult to determine emissions of specific vehicle classes or individual vehicles Limited driving conditions (steady speed) Induced wind by large vehicles Non-exhaust emissions (e.g., tyre and brake wear)
Ambient measurement	Measures ambient pollutant concentrations at roadside	Large sample size	Difficult to determine emissions of specific vehicle classes or individual vehicles Non-exhaust emissions (e.g., household and industry) Indirect measurements
Remote sensing	Measures vehicle emissions when passing through IR and UV beams on-road	Large sample size Individual vehicles & vehicle classes Cheapest on per vehicle basis	Only measures ratios of pollutants over CO_2 Emission data measured in half a second Limitations in site selection (positive road grade, single lane and free flowing traffic)

I consider Remote sensing not just the open-path systems…
我认为遥测不仅仅是开放式系统

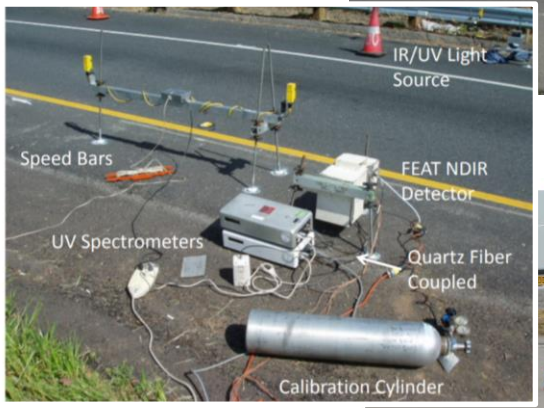
… but also anything non-intrusive; anything that measures vehicle emissions without a monitoring system installed on that vehicle
但也包括任何非侵入性的及任何没有车载监控况下测量车辆排放的系统

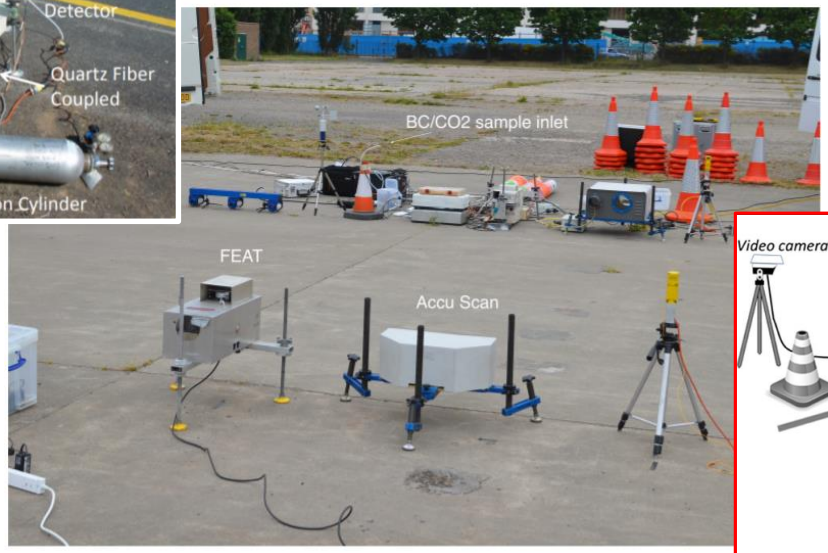
…and that gives a 'per vehicle' output
并给出"每辆车"的输出

Conventional (open-path) across-road systems

(常规（开放式）道路系统)

(FEAT*)

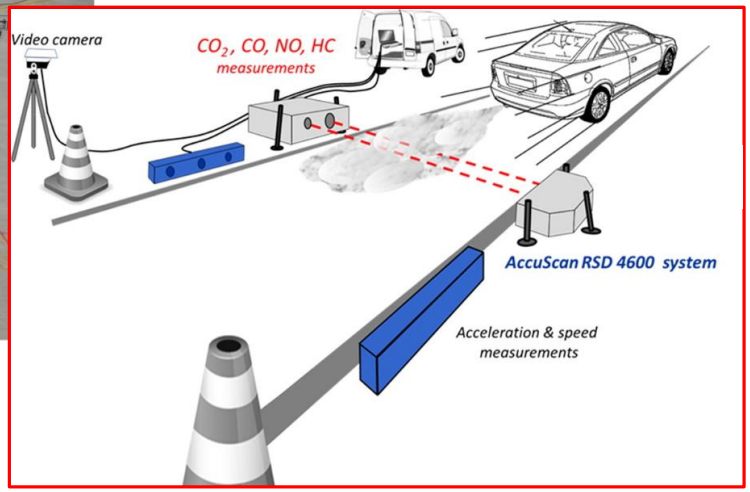




(FEAT RSD comparison, King's 2013)

Examples:

- Stedman and Bishop's FEAT
- Commercialised as the ESP/OPUS RSD series
- ETC in Hong Kong
- Other similar systems include Smogdog, REVEAL, etc



(Figure from Pujadas et al, 2017)

Donald H. Stedman 50 Years of Air Quality Instrument Inventions and Measurements 2016 (RIP DON)

Conventional (open-path) across-road systems

(常规（开放式）道路系统)

Reports optical measures of CO_2 plume ratios

Established technology
成熟的技术

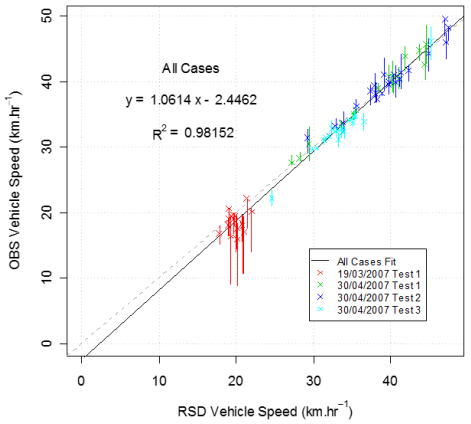
(Bishop et al, 1989)

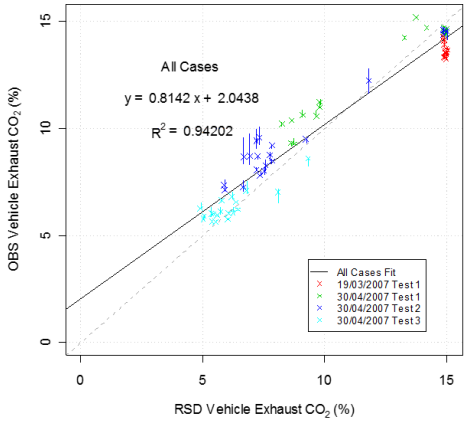
For example, for FEAT typically:

- CO_2, CO, HC, NO by NDIR
- (NO,) NO_2, SO_2, NH_3 by UV
- PM Surrogate by opacity

Wide range of applications
应用范围广泛

Extensively evaluated, both in-house and third-party 内部和第三方广泛评估

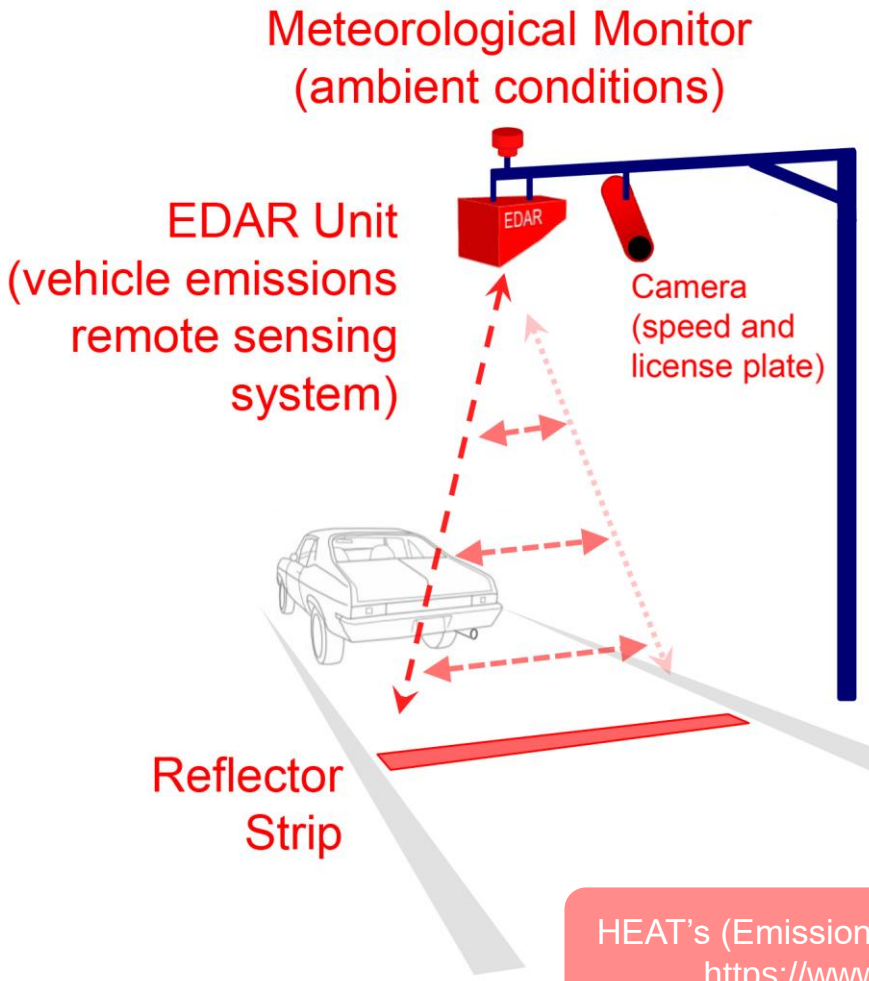




(Source: Ropkins, K., Oates, C. and Tate, J.E. Evaluation of a Remote Sensing System 'Dirty Emitter' Measurement. 18th CRC On-Road Vehicle Emission Workshop. San Diego, US, 31 March - 2 April, 2008)

One of my first projects when I joined ITS…

Down facing (open-path) across-road systems
(朝下（开放式）道路系统)



- Down-facing DiAL VERSS
- Scans down onto road to remotely measure passing vehicle emissions(扫描到道路上以远程测量经过车辆的排放)
- Measures CO_2, CO, NO, NO_2, SO_2, HC* (e.g. discrete CH_4, C_3H_8, etc.), PM…
- One footprint for both heavy and light duty vehicles (重型和轻型车辆使用同一个足印)

(In London, 2016)

(In Scotland, 2017)

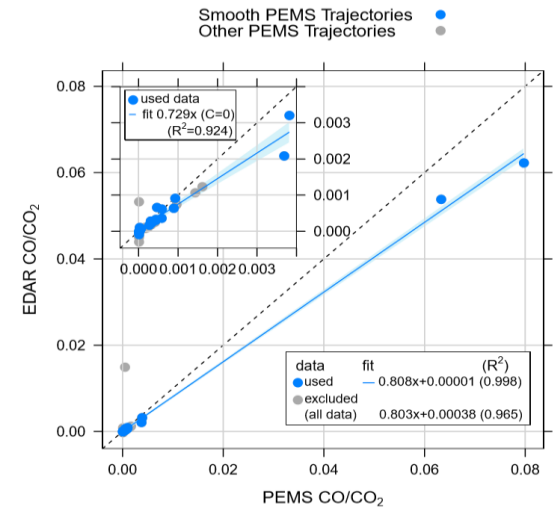
HEAT's (Emission Detection And Reporting) EDAR
https://www.heatremotesensing.com/

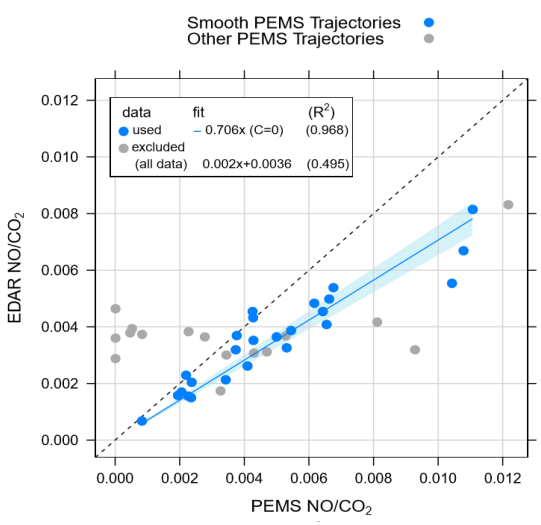
Down facing (open-path) across-road systems

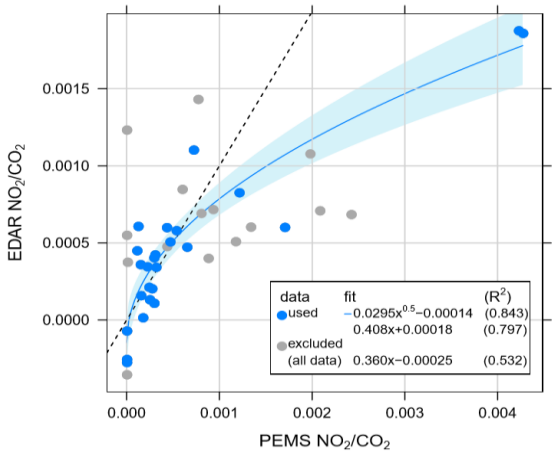
(朝下（开放式）道路系统)

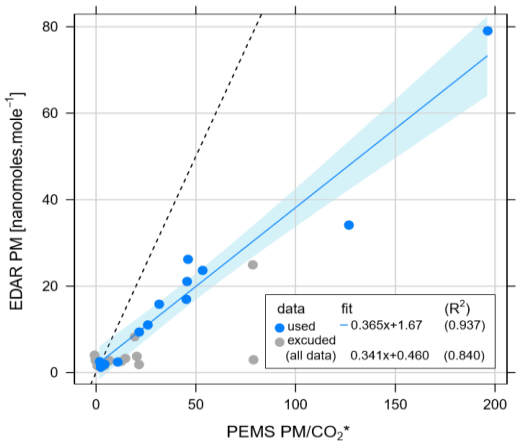
The technology is younger than FEAT/RSD and company smaller than OPUS but the early benchmarking is highly encouraging, e.g.:

(Ropkins et al, 2017)

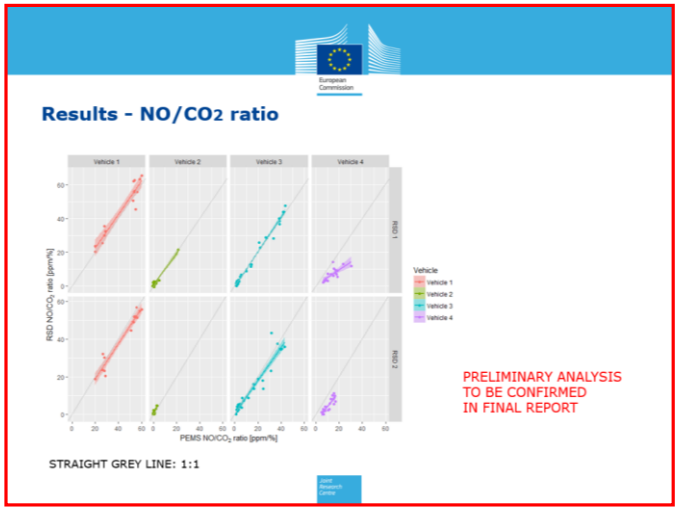








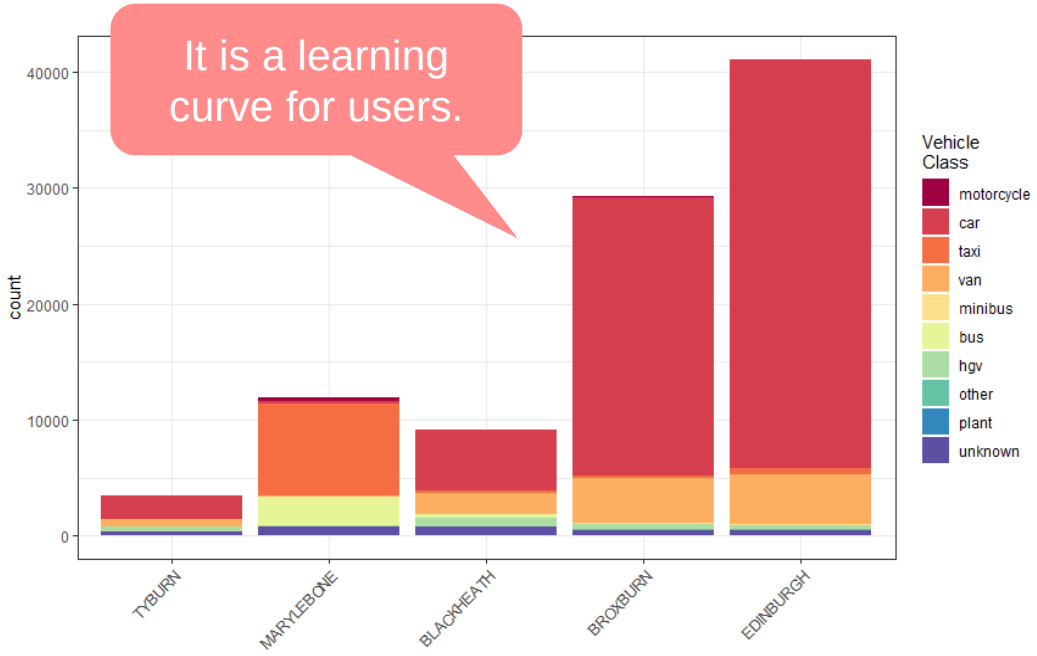
(And in more recent work by JCR as part of CONOX)

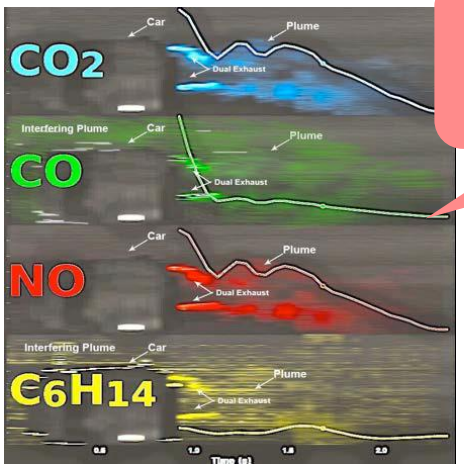


Down facing (open-path) across-road systems
(朝下（开放式）道路系统)

Some preliminary comments:

- DiAL should be more sensitive (更灵敏) and drift less (漂移少) than conventional optical methods(常规的光学方法)
- Down-facing measurement less sensitive to exhaust height(对排气高度不太敏感), so potentially better across-fleet coverage
- High-up sampling less susceptible to 'splash-back' lens fouling (不容易'飞溅'弄污镜头)
- More readily automated, so potential for longer low-cost operation (更容易自动化，可实现更长时间的低成本运营)





Some features that might provide new diagnostics…
一些可能提供新诊断的功能.....

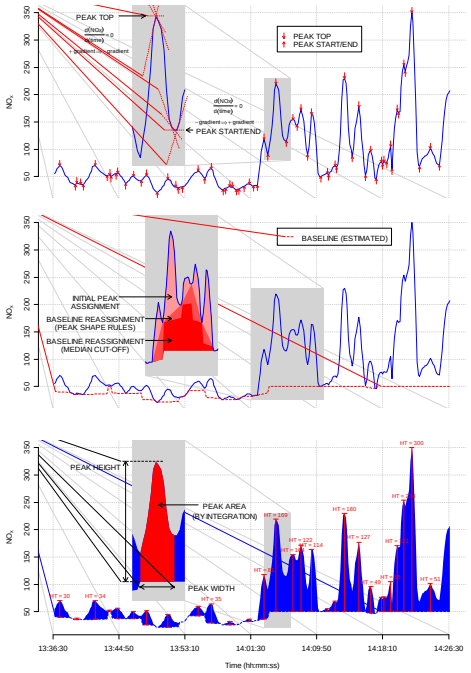
But also some we would like to understand better (e.g. exhaust temperature)

Ambient measurement plume extraction

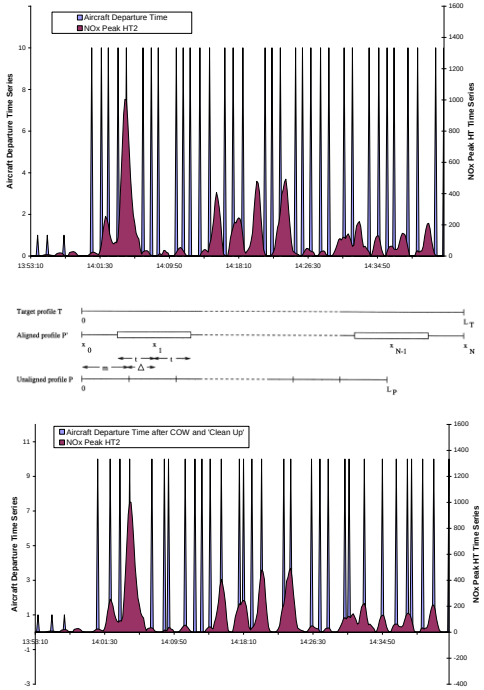
(环境测量中萃取煙柱)

My main experience of emission plume extraction from ambient datasets is with data from Heathrow Airport in the UK…
(我从环境数据中萃取煙柱的主要经验来自英国希思罗机场的数据)

Plume peak identification and extraction
(烟柱峰值鉴定和萃取)

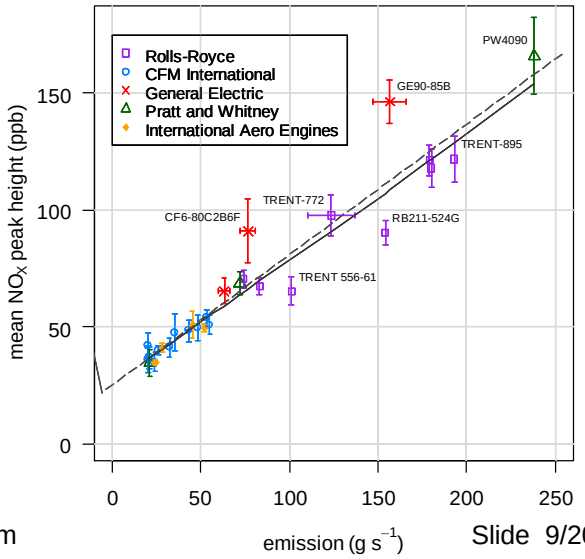


Plume peak alignment and assignment
(煙柱峰值对齐和分配)



… and here the challenge was the post-processing
(这里的挑战是后期处理)

… and meteorology was a serious confounder
(气象是个严重的混淆因素)



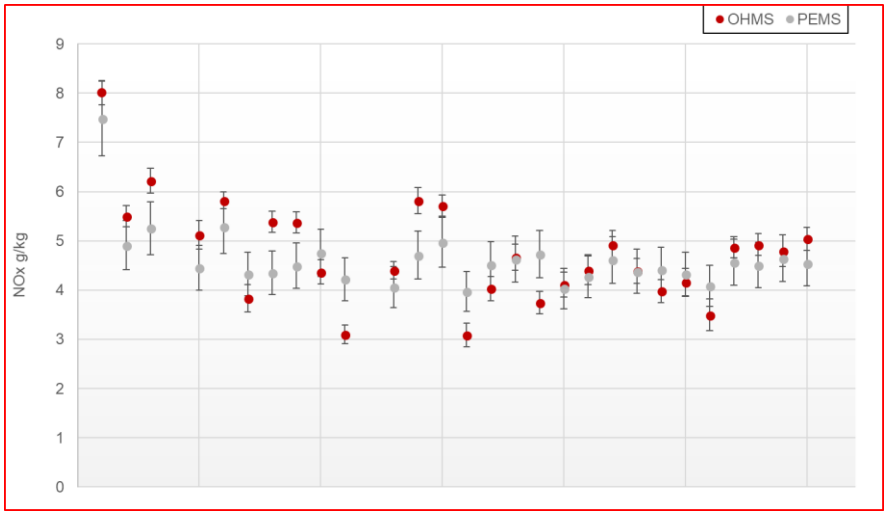
(Carslaw, Ropkins, Laxen, Marner, and Williams, 2008, and Ropkins, Carslaw, Goodman, Tate, 2009)

Alternative active sampling options

(主动采样的替代选项)

On-road Heavy-duty Measurement System (OHMS) :
(道路重载测量系统)

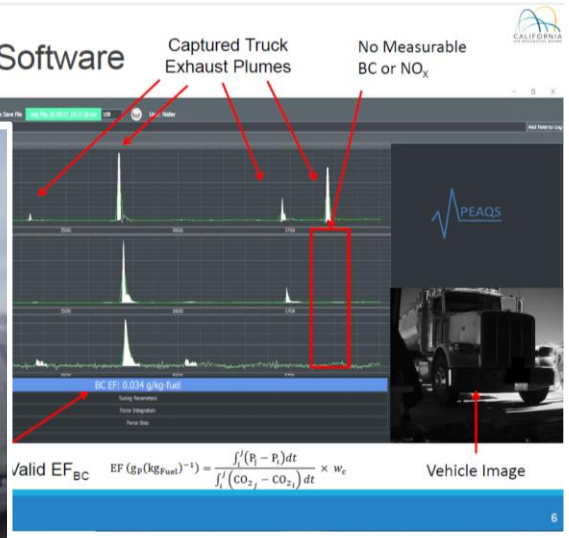
- Developed by Don Stedman for high exhaust sampling (用于高排气采样)
- (earlier version called (早期版本叫)SHED)
- Been used in campaigns in US
- Evaluated by TTI (PEMS comparison)



(PEMS comparison courtesy of Jeremy Johnson, TTI TAMU)

Alternative active sampling options

(主动采样的替代选项)



Portable Emissions AcQuisition System (PEAQS):

- Developed by Jeremy Smith and colleagues at CARB as a low-cost alternative to conventional (open path) vehicle emissions remote sensing
  (作为常规（开放式）车辆排放遥测的低成本替代方案)
- Been used in campaigns across California
- Evaluated currently on-going (仍在评估中)

Open-path versus active sampling

(开放式与主动采样比对)

There are a number of trade-offs

(有许多权衡取舍)

Open-path costs more

Active sampling is lower-cost

Open-path can only be used with open-path monitors

Active sampling can be used with a wider range of monitoring methods, e.g. not limited to optical measures of particulate

Active sampling has lower capture rate

Open-path has higher capture rate

Active sampling is more disruptive

Open-path is less disruptive

…and considerations like sampling time (faster for remote sensing) are not clear-cut…

Regarding passing vehicle measurement

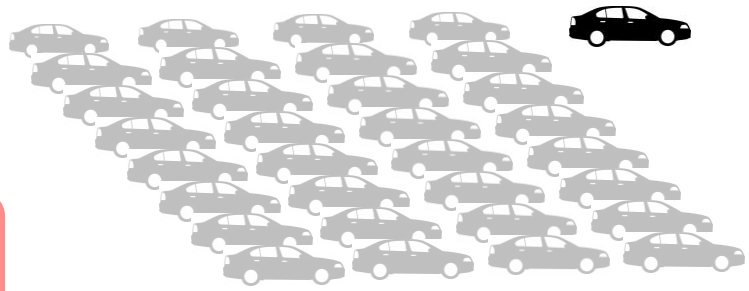
(关于测量通过的车辆)

Across-road open-path	• Most established/widely used • Large track record with multiple applications • Very extensively evaluated
Down-facing open-path	• New technology, less well understood • Elevations are encouraging but early stage • But multiple potential advantages
Ambient Plume	• Potentially the lowest-cost option • Limited information on elevation • Data handling could be hidden cost
Active sampling	• Highest potential for disruption • Elevations are encouraging but early stage • Amenable to more measurement methods

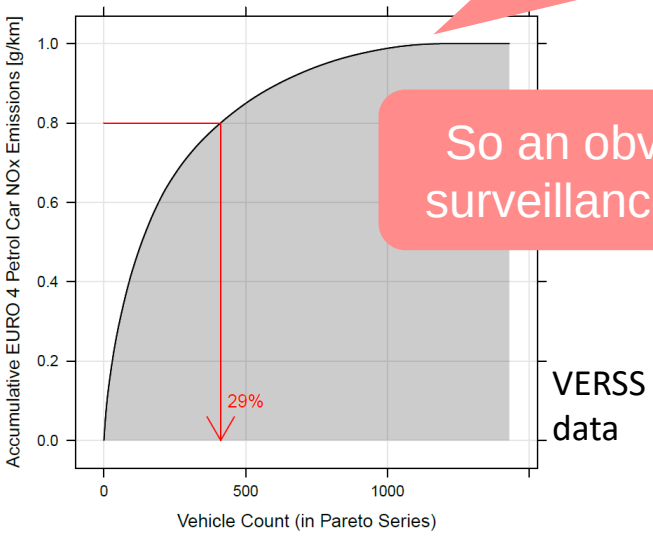
Emissions reduction policy (减排政策)

- Current regulations focus on in-laboratory (dynamometer) and on-board (PEMS) measurement
- But these techniques are unable to provide the fleet coverage necessary to reliably identify high emitters

One bad vehicle in an otherwise clean fleet…

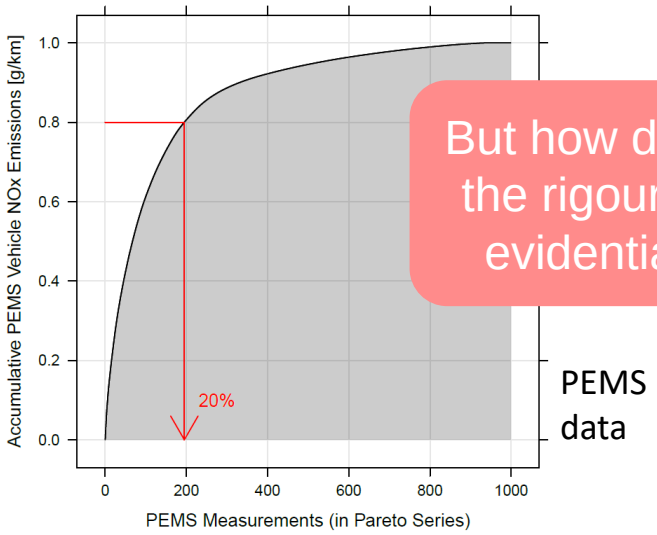


Remote sensing methods could provide the coverage



So an obvious surveillance tool

VERSS data

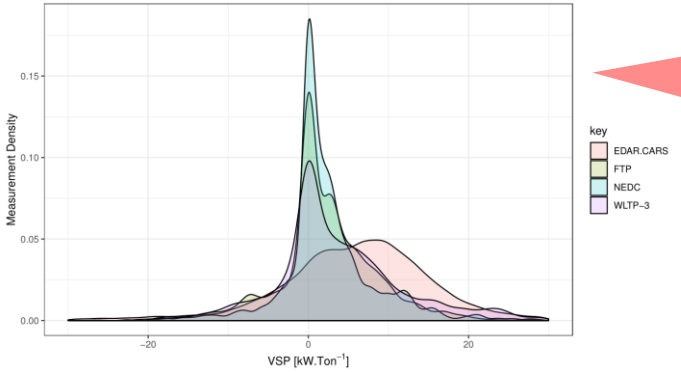


But how do we build in the rigour needed for evidentiary action?

PEMS data

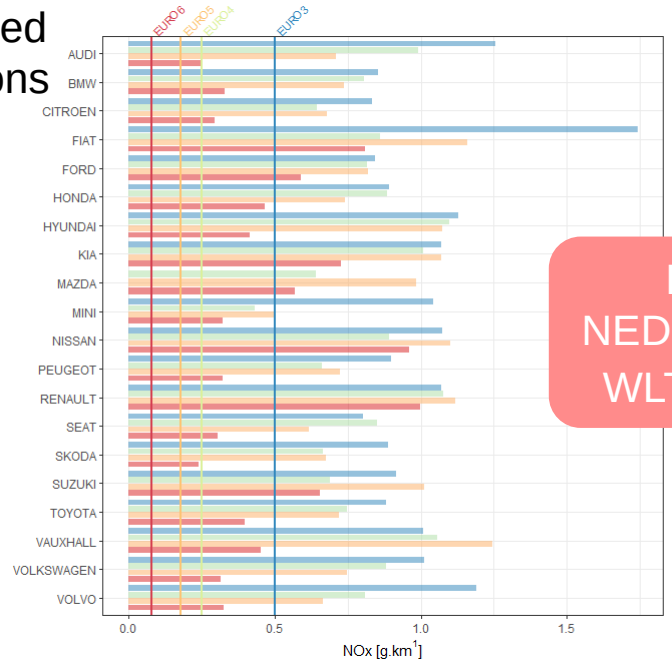
Vehicle Specific Power (VSP)(车辆比功率)

Important to take into account vehicle activity/load



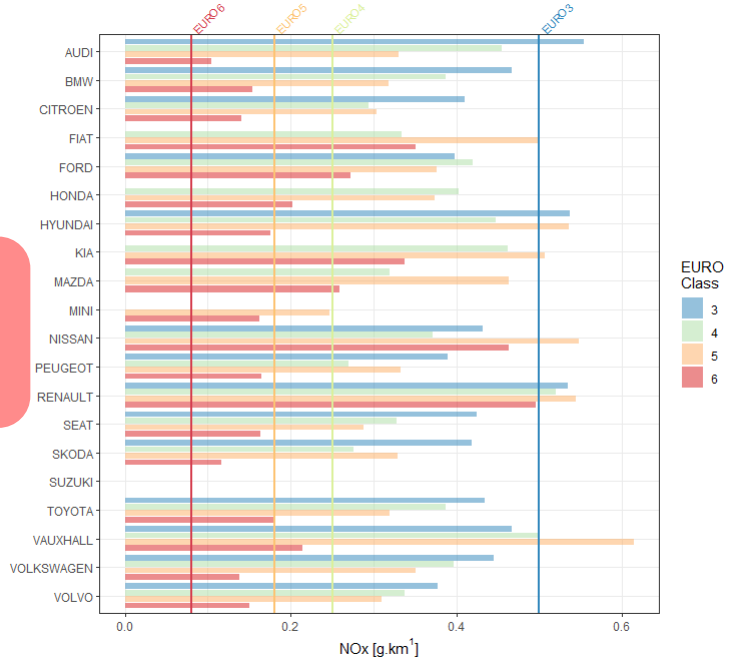
The VERSS data VSP distribution is typically higher load than many test cycles…

VERSS estimated emissions



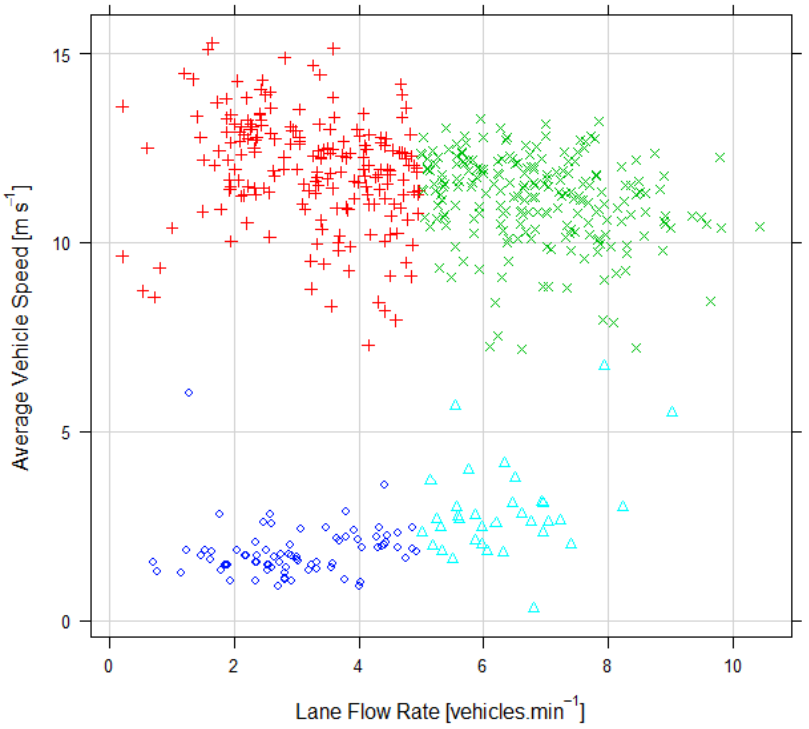
Reweight
NEDC (EURO3-5)
WLTP (EURO6)

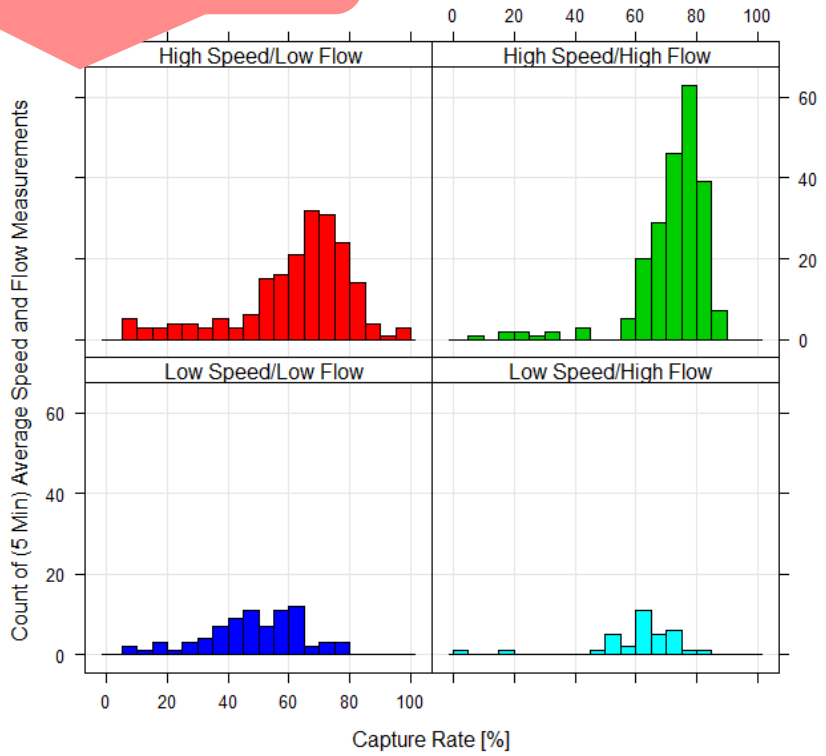
Drive-cycle reweighted emissions



Vehicle Specific Power (VSP) (车辆比功率)

And it is not simply that the drive cycles are milder than real-world driving…

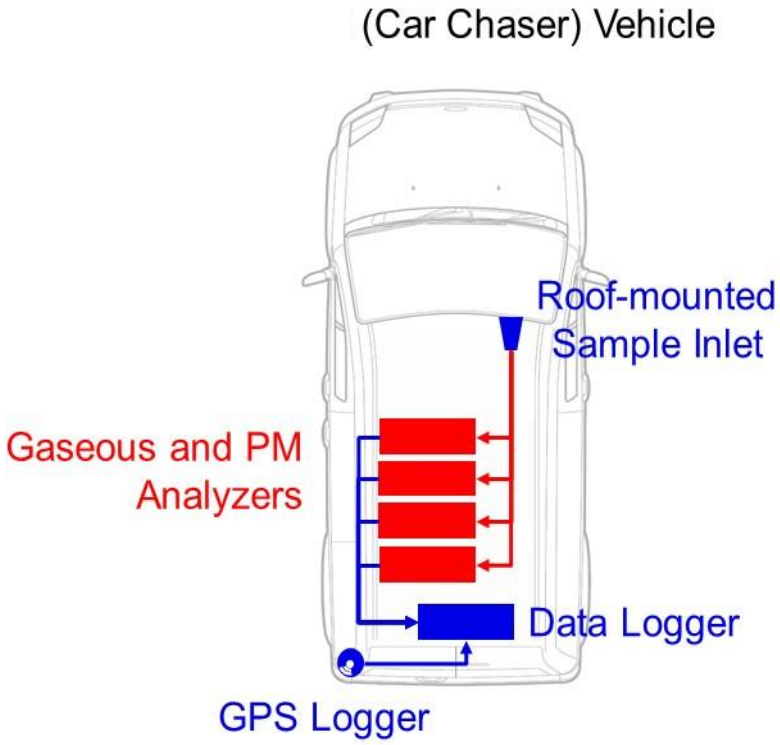




There are important real-world driving activities/situations that VERSS is under-represents:
(有VERSS代表的活动/情况低估了重要的现实的驾驶活动/情况)

- Decelerating
- Idling
- Congestion

The car (plume) chaser (汽车（煤柱）追逐者)



(schematic of Birmingham's SNIFFER used in EDAR evaluation)

Plume chaser as a complement to static remote sensing(作为静态遥测的补充):

- Will not provide the fleet coverage of static remote sensing…
- But for suspect vehicles (e.g. identified by static remote sensing) could be used to chase confirm measurements

Option for longer sampling:

- Produces more confident measurement
- Provides option to map emission onto a range of VSPs
- Integrate into expert system

The use of an active sampling:

- Means non-optical regulatory methods (e.g. CPC for SPN) can be incorporated

CONOX CARES

Call: H2020 LC-MG-1-1-2018:
InCo flagship on reduction of transport impact on air quality

Subtopic C) Sensing and monitoring emission in urban road transportation system

Proposal:
CARES – City Air Remote Emission Sensing

Coordinator: Åke Sjödin
IVL Swedish Environmental Research Institute
ake.sjodin@ivl.se

H2020 Proposal specifically looks at multiple aspects of the science underpinning Remote Sensing and options for its robust integrating into policy and regulation

Final Comments(最后评论）

Most definitely remote sensing is no longer just across-road open-path vehicle emissions measurements

(明确地說遥测不再仅仅是跨越道路开放式的测量车辆的排放)

EDAR with its down-facing design is a highly credible alternative As are active sampling methods

(EDAR使用朝下（开放式）道路系统与主动采样方法都是可靠的替代方案)

But it is also important to acknowledge that none of the options are without their limitations and that correctly handling the outputs is likely to be just as import as the methods we adopt

(没有一个选项没有它们的限制，正确处理输出可能与我们采用的方法一样重要)

Vehicle specific power (VSP) is likely to be an important diagnostic But if it is also going to be a quantitative correction VSP (speed and acceleration) emissions measurement alignment will be critical

（VSP可能是一个重要的诊断法，但如果它也将是一个定量修正，VSP排放测量的对准将十分重要）

Acknowledgements (鸣谢)

UK Department for Transport, Transport Scotland, Transport Systems Catapult, EPSRC

Hong Kong Environmental Protection Department, Chinese Ministry of Ecology and Environment, ICCT and Energy Foundation-China

… and I would also like to thank you

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Additional Information

The followings slides are supplied as background and supporting information

Simulated Exhaust (SE)

Project

CDPHE/ERG Simulated Exhaust Gas EDAR (Emissions Detection And Reporting) Study

EDAR Developers:	HEAT LLC
Project Partners:	Colorado Department of Public Health and Environment, Eastern Research Group
Project contact:	Tim DeFries (ERG)
Project Implemented by:	EPA United States Environmental Protection Agency

PEMS + SNIFFER

Project

Birmingham and London EDAR (Emissions Detection And Reporting) Demonstration and Evaluation

EDAR Developers:	HEAT LLC
Project Partners:	King's College London University of Birmingham University of Leeds
Project Funding:	

DfT LOCAL TRANSPORT AIR QUALITY CHALLENGE INNOVATION GRANT OCTOBER 2015

Department for Transport

Project

Birmingham and London EDAR (Emissions Detection And Reporting) Phase 2: EDAR Data Analysis

Project Partners:	University of Birmingham University of Leeds
Project Funding:	

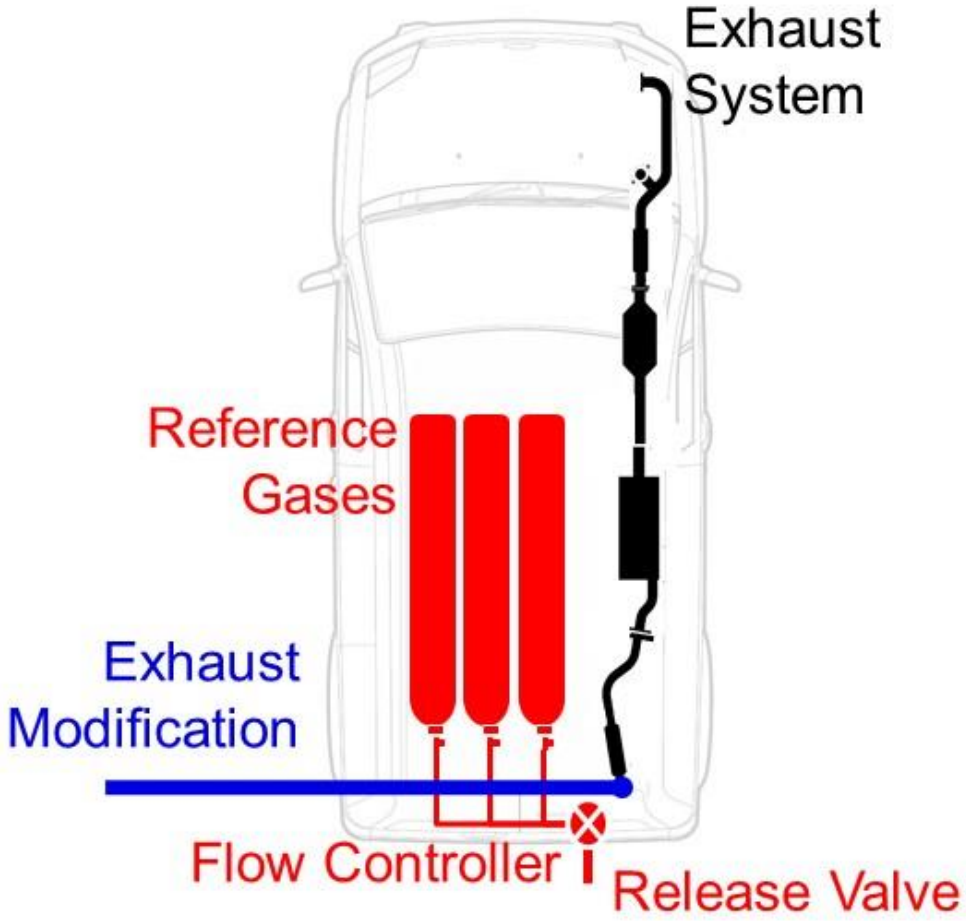
CATAPULT Transport Systems

Department for Transport

Gas Audit Evaluation

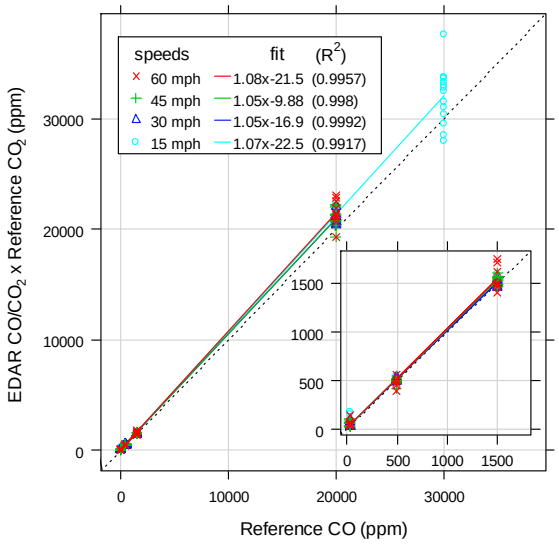
EDAR (Boom Arm) Deployment

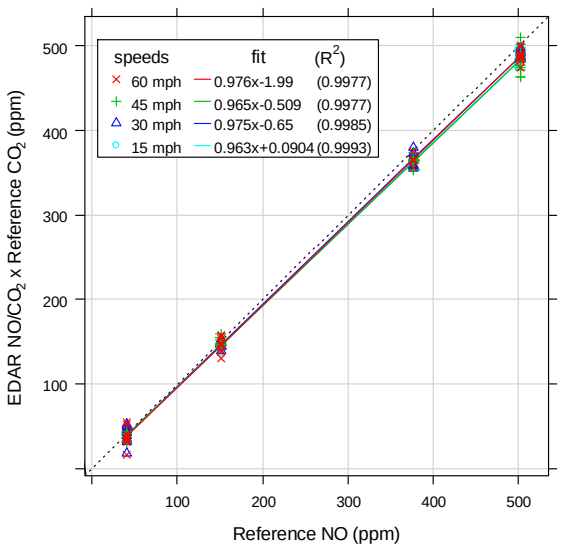
Simulated Exhaust Gas Release

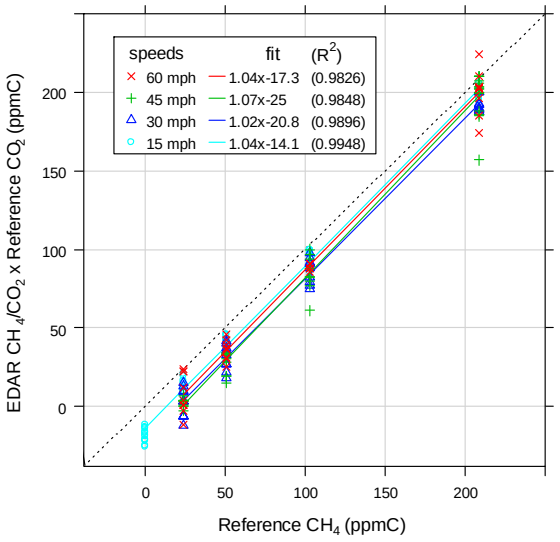


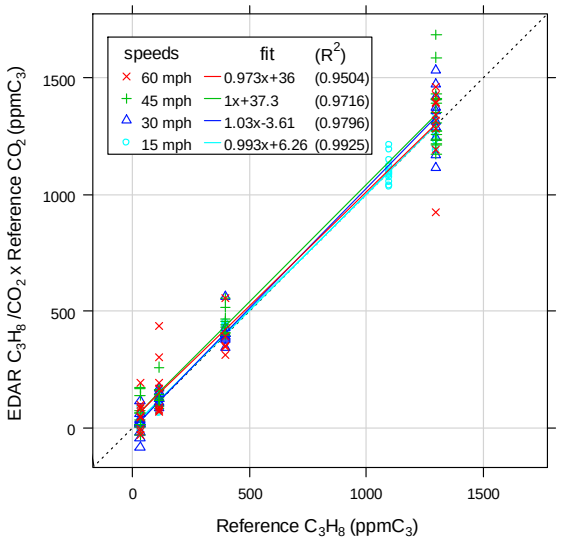
Drive-through reference gas release sampling

- Highly accurate/stable reference
- Good measure of instrumental accuracy



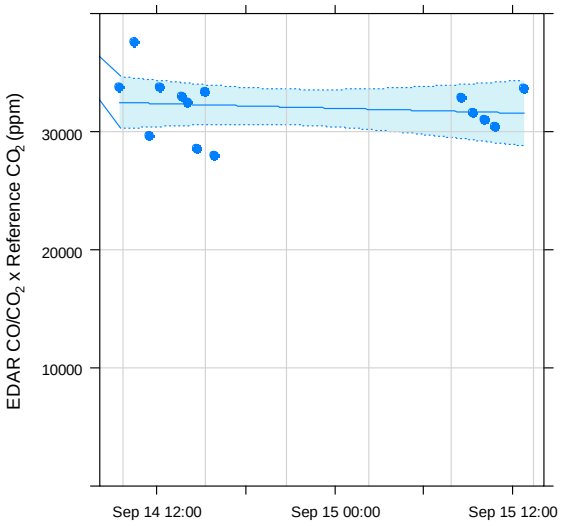


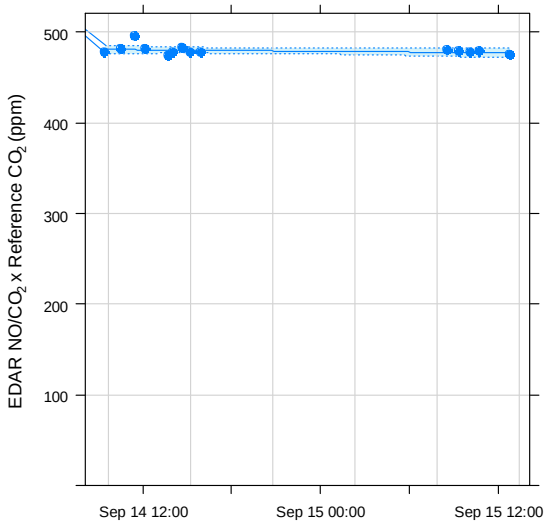


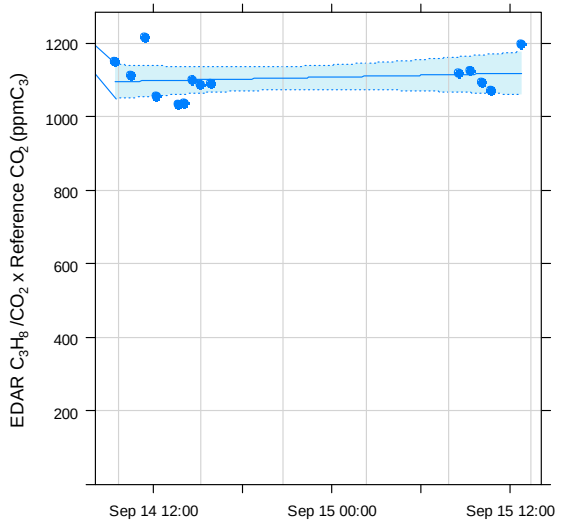


Gas Audit Results

- Good agreement with references (R^2 >0.99 for CO and NO; R^2 >0.95 for HCs)
- Selectivity e.g. discrete hydrocarbons



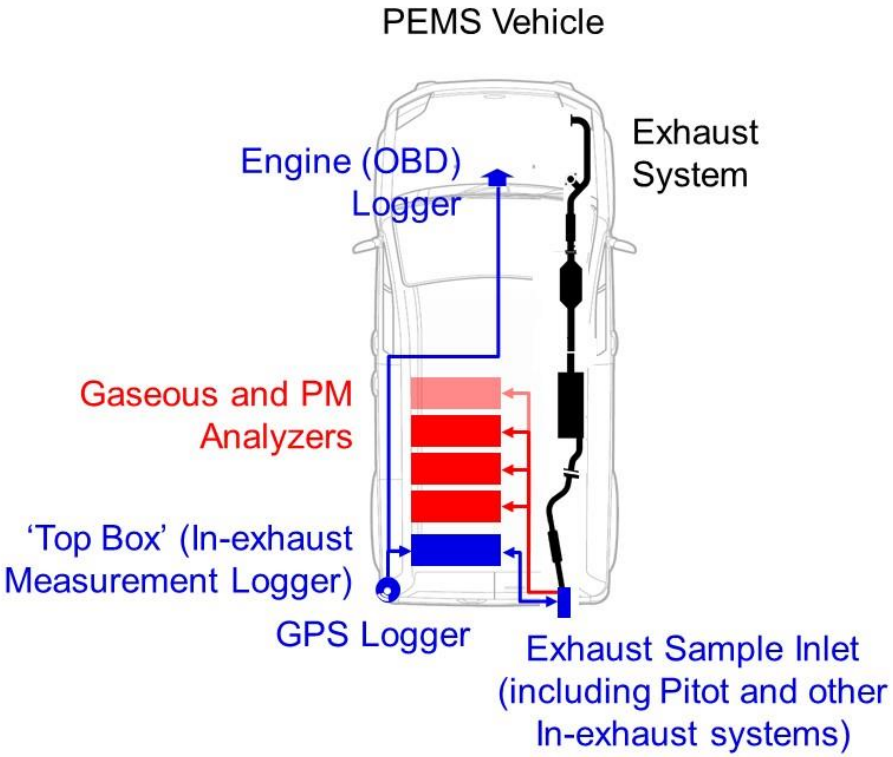


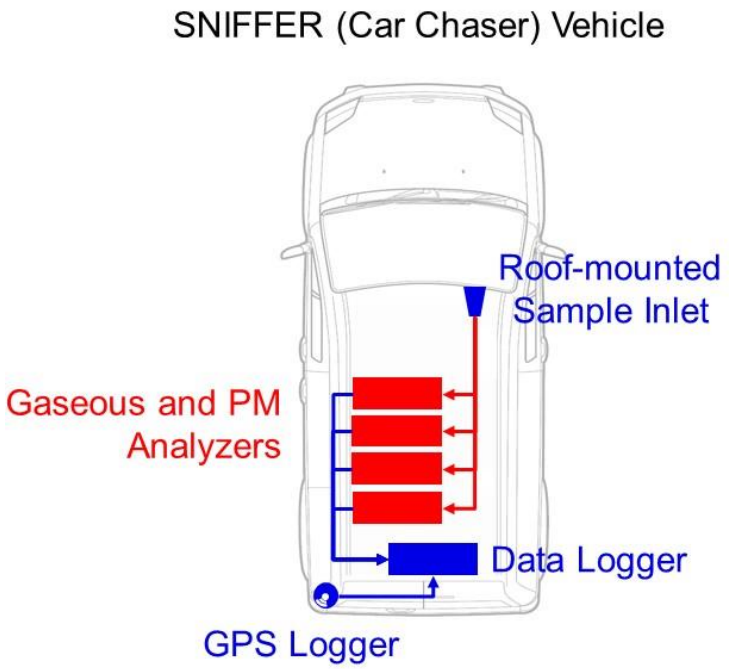


Gas Audit Results

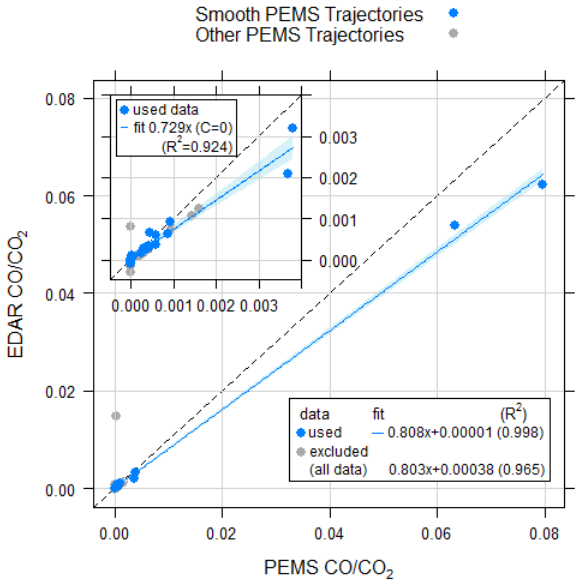
- Low drift during routine operation

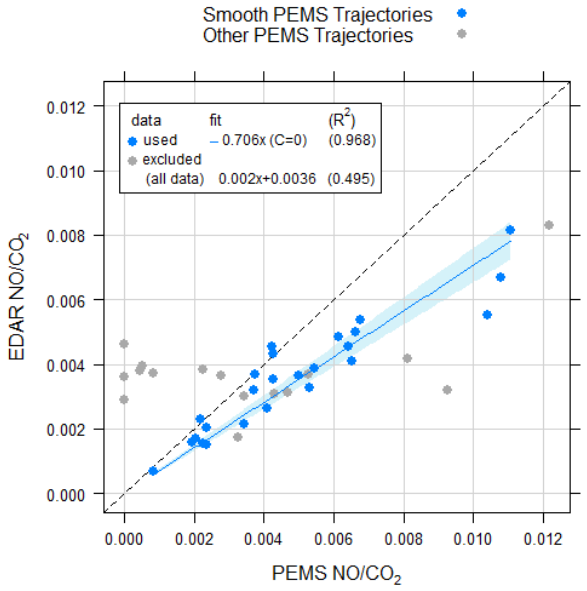
Real-world Comparison

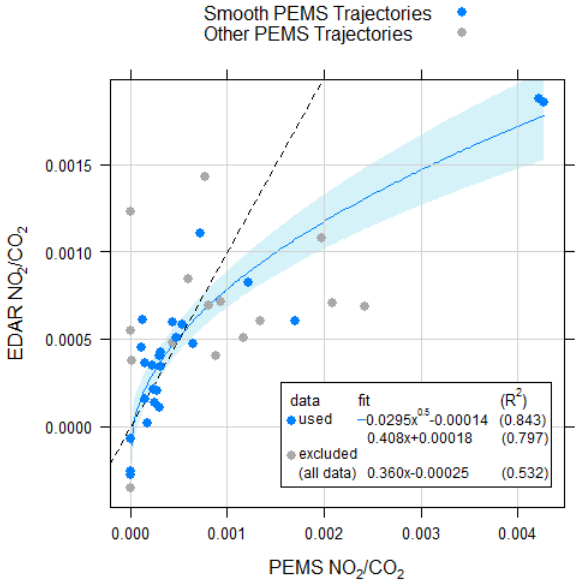


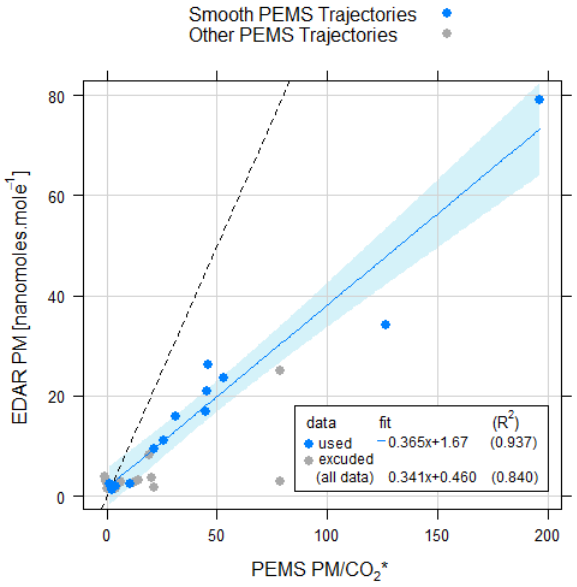


- Real-world (challenging) deployment
- Drive-through comparisons
  - PEMS
  - SNIFFER (car chaser)



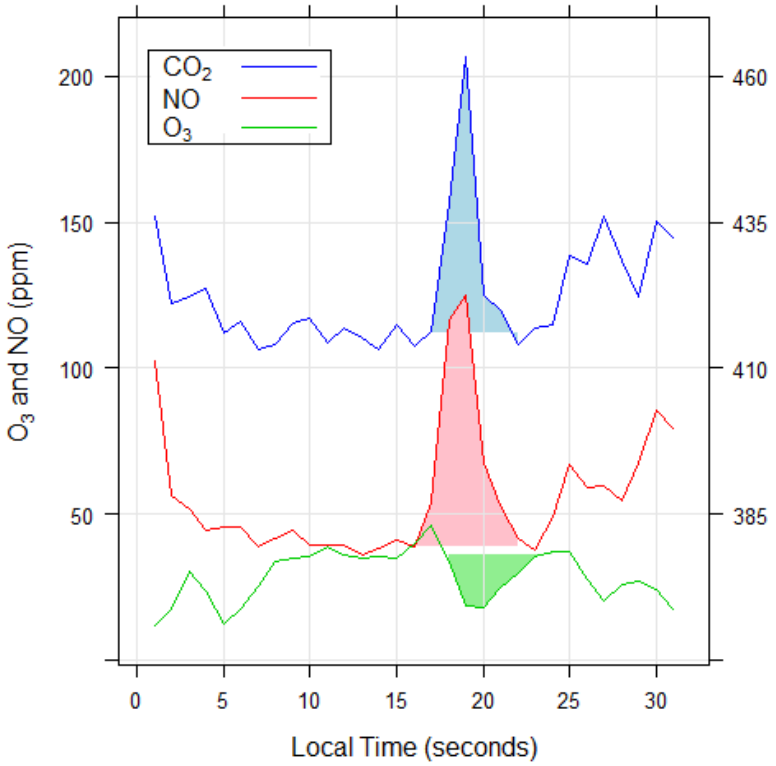


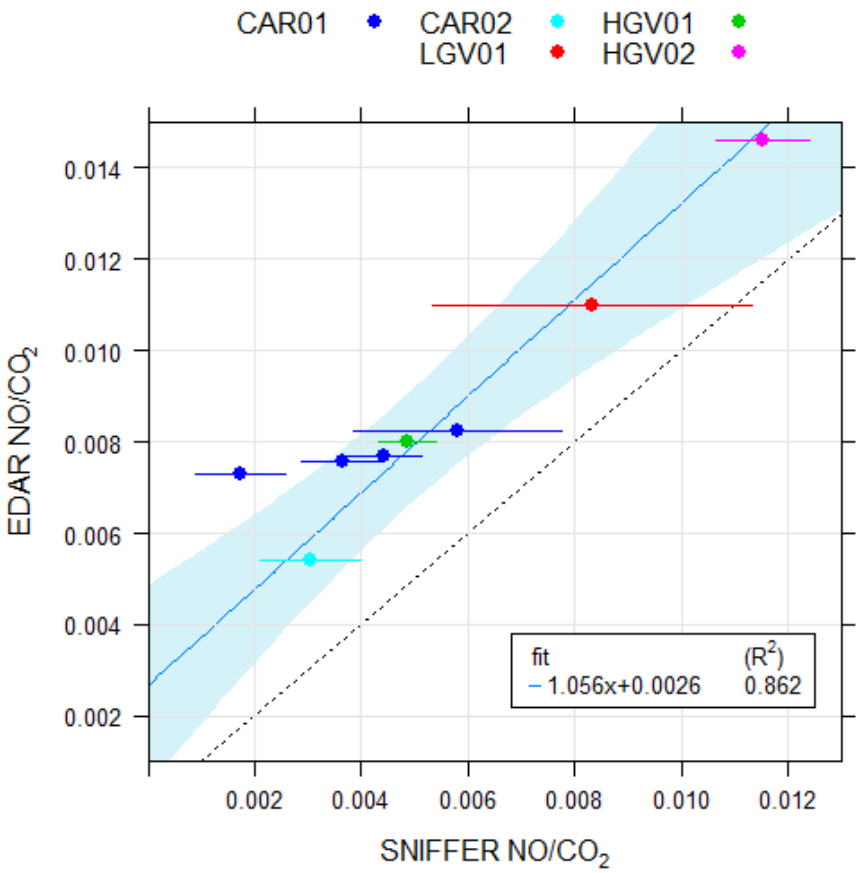




PEMS Comparisons

- Good agreement (within experimental limits)
- R^2 >0.95 for NO/CO_2; R^2 >0.90 for CO/CO_2 and PM/CO_2;
- R^2 >0.80 for NO_2/CO_2 (but arguably least certain measurement)





SNIFFER (car chaser) Comparisons

- Measurement required correction for post-exhaust chemistry (e.g. NO depletion by O_3)
- Good agreement (within experimental limits) e.g. $R^2 > 0.85$ for NO/CO_2
- Results also indicate similar agreement for different vehicle types

Conclusions

From the CDPHE/ERG Simulated Exhaust Gas Study:

EDAR has:
- High instrumental accuracy (e.g., R^2 >0.99 CO, NO; >0.95 HCs)
- Low drift and negligible speed dependency

From the UoB/UoL/KCL Real-world Comparison:

(In conventional use) EDAR was:
- In good agreement with other real-world measurement methods
  e.g., NO/CO_2 R^2 = 0.96 and 0.86 for PEMS and SNIFFER, respectively
- Results for NO_2 and PM were also highly encouraging

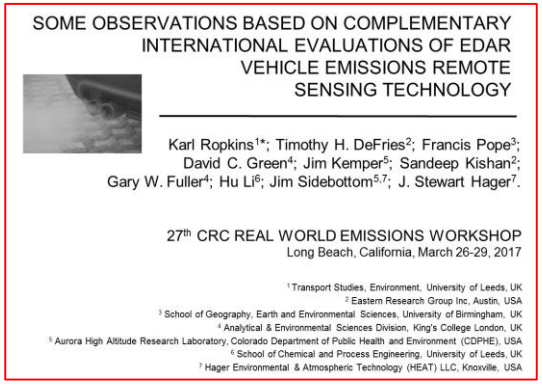
NOTE: *while we cannot say unequivocally that EDAR performs as well in the real-world as it does relative to a simulated exhaust gas, we have no evidence that it does not*

BUT more generally…

This combination provides a comprehensive basis for the independent third-party evaluation of EDAR (or VERSS) performance

Associated Outputs

Conference Papers

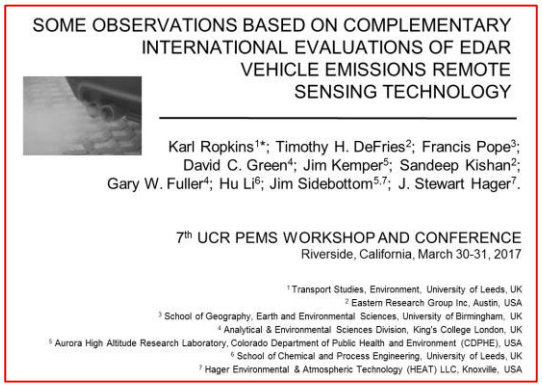


SOME OBSERVATIONS BASED ON COMPLEMENTARY INTERNATIONAL EVALUATIONS OF EDAR VEHICLE EMISSIONS REMOTE SENSING TECHNOLOGY

Karl Ropkins[1]*; Timothy H. DeFries[2]; Francis Pope[3]; David C. Green[4]; Jim Kemper[5]; Sandeep Kishan[2]; Gary W. Fuller[4]; Hu Li[6]; Jim Sidebottom[5,7]; J. Stewart Hager[7].

27th CRC REAL WORLD EMISSIONS WORKSHOP
Long Beach, California, March 26-29, 2017

[1] Transport Studies, Environment, University of Leeds, UK
[2] Eastern Research Group Inc, Austin, USA
[3] School of Geography, Earth and Environmental Sciences, University of Birmingham, UK
[4] Analytical & Environmental Sciences Division, King's College London, UK
[5] Aurora High Altitude Research Laboratory, Colorado Department of Public Health and Environment (CDPHE), USA
[6] School of Chemical and Process Engineering, University of Leeds, UK
[7] Hager Environmental & Atmospheric Technology (HEAT) LLC, Knoxville, USA



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7th UCR PEMS WORKSHOP AND CONFERENCE
Riverside, California, March 30-31, 2017

[1] Transport Studies, Environment, University of Leeds, UK
[2] Eastern Research Group Inc, Austin, USA
[3] School of Geography, Earth and Environmental Sciences, University of Birmingham, UK
[4] Analytical & Environmental Sciences Division, King's College London, UK
[5] Aurora High Altitude Research Laboratory, Colorado Department of Public Health and Environment (CDPHE), USA
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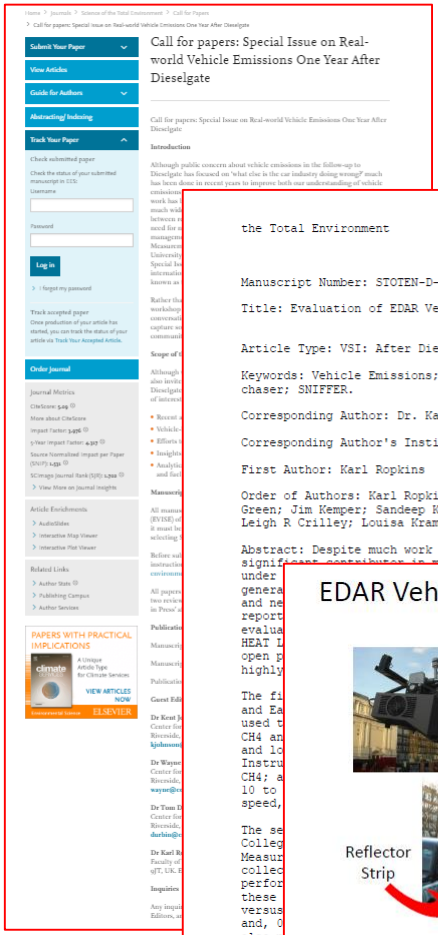
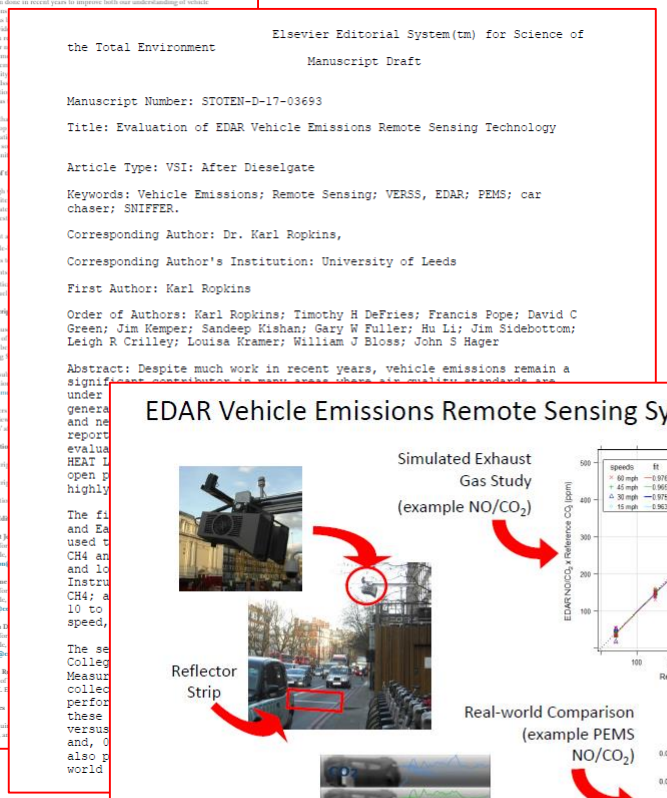
[7] Hager Environmental & Atmospheric Technology (HEAT) LLC, Knoxville, USA

STOTEN Paper



Call for papers: Special Issue on Real-world Vehicle Emissions One Year After Dieselgate



Elsevier Editorial System(tm) for Science of the Total Environment

Manuscript Draft

Manuscript Number: STOTEN-D-17-03693

Title: Evaluation of EDAR Vehicle Emissions Remote Sensing Technology

Article Type: VSI: After Dieselgate

Keywords: Vehicle Emissions; Remote Sensing; VERSS, EDAR; PEMS; car chaser; SNIFFER.

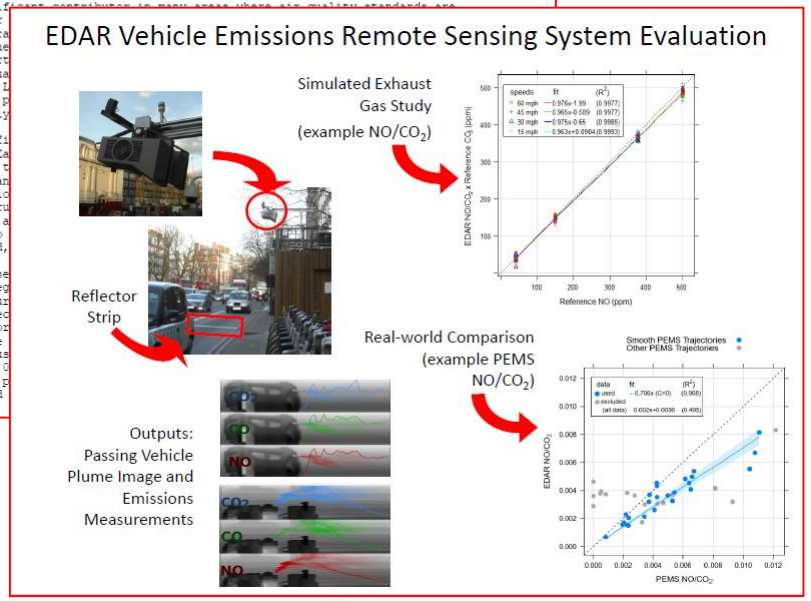
Corresponding Author: Dr. Karl Ropkins,

Corresponding Author's Institution: University of Leeds

First Author: Karl Ropkins

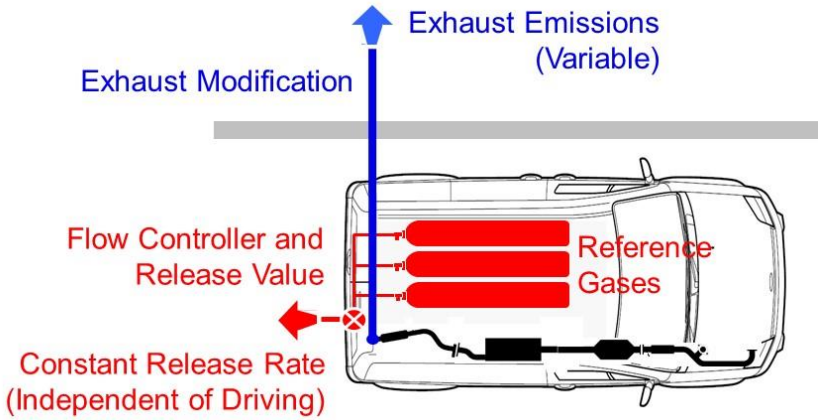
Order of Authors: Karl Ropkins; Timothy H DeFries; Francis Pope; David C Green; Jim Kemper; Sandeep Kishan; Gary W Fuller; Hu Li; Jim Sidebottom; Leigh R Crilley; Louisa Kramer; William J Bloss; John S Hager

Abstract: Despite much work in recent years, vehicle emissions remain a



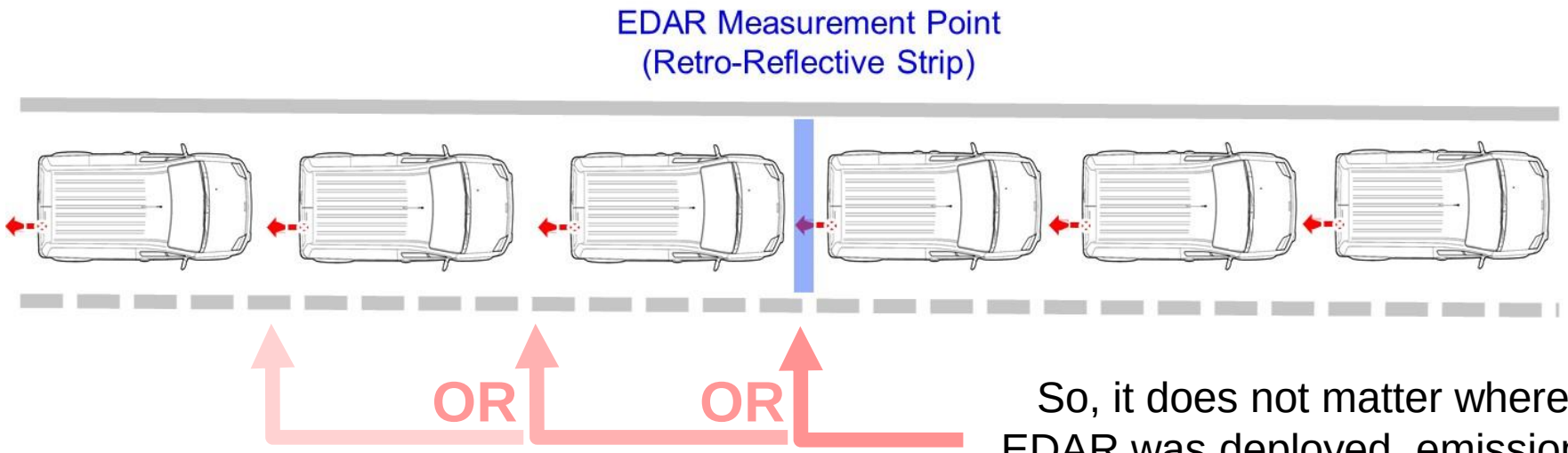
Ropkins, K., DeFries, T.H., Pope, F., Green, D.C., Kemper, J., Kishan, S., Fuller, G.W., Li, H., Sidebottom, J., Crilley, L.R. and Kramer, L., 2017. Evaluation of EDAR vehicle emissions remote sensing technology. *Science of the Total Environment*, *609*, pp.1464-1474.

EDAR and SE Data Alignment



Simulated Exhaust (SE)

- Reference gas release is CONSTANT
- Highly accurate/stable reference

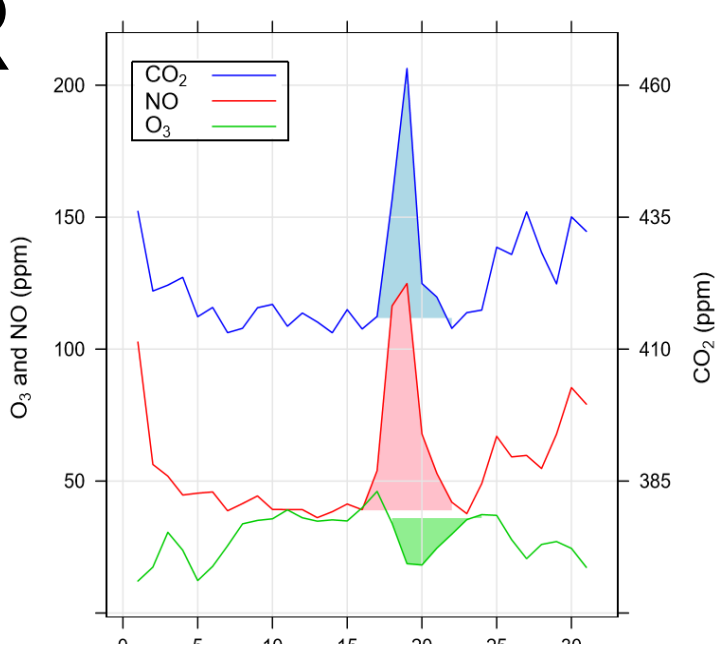


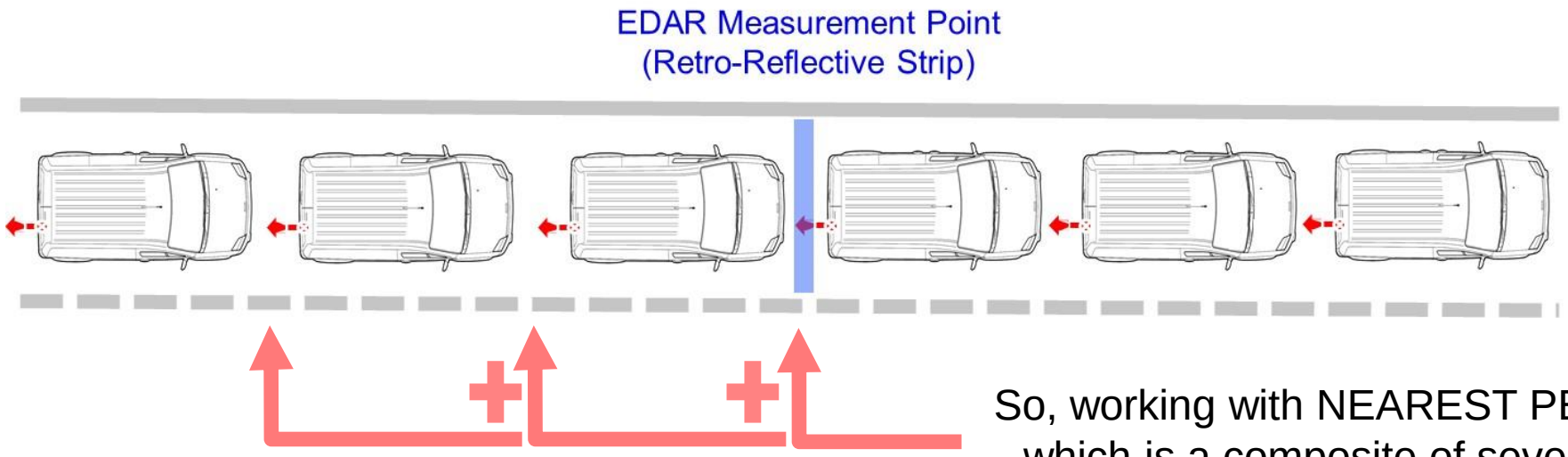
So, it does not matter where EDAR was deployed, emissions anywhere on a drive-through are the SAME

EDAR and SNIFFER Data Alignment

SNIFFER Measurement

- Based on ‘chased vehicle’ emission plume peak isolation
- ‘Chased’ plume peaks typically *ca.* 3-5 seconds wide

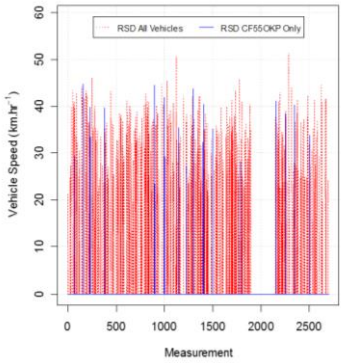




So, working with NEAREST PEAK which is a composite of several measurements spanning EDAR measurement

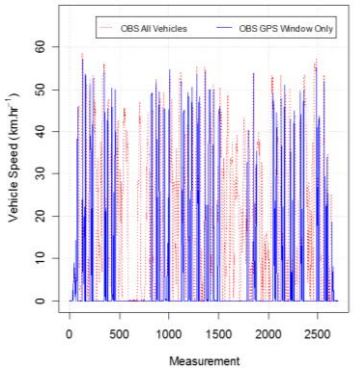
VERSS and PEMS Data Alignment

VERSS (RSD)



(filtering)

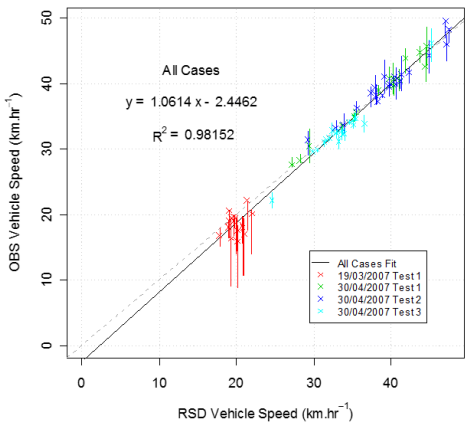
PEMS vehicle

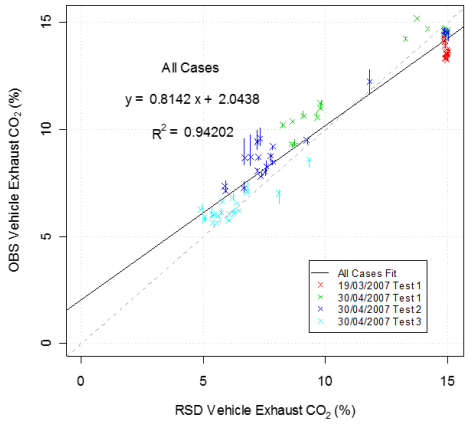


(filtering)

We know we need:

- Accurate GPS filtering, and
- Accurate data timestamp(s)





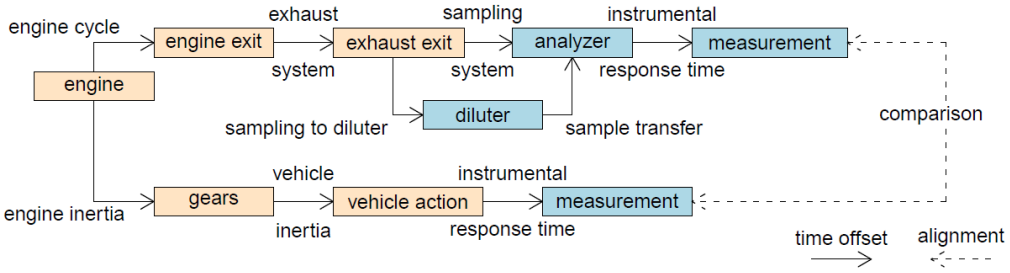
Previous RSD/PEMS Alignment
(been doing this type of thing for a while)

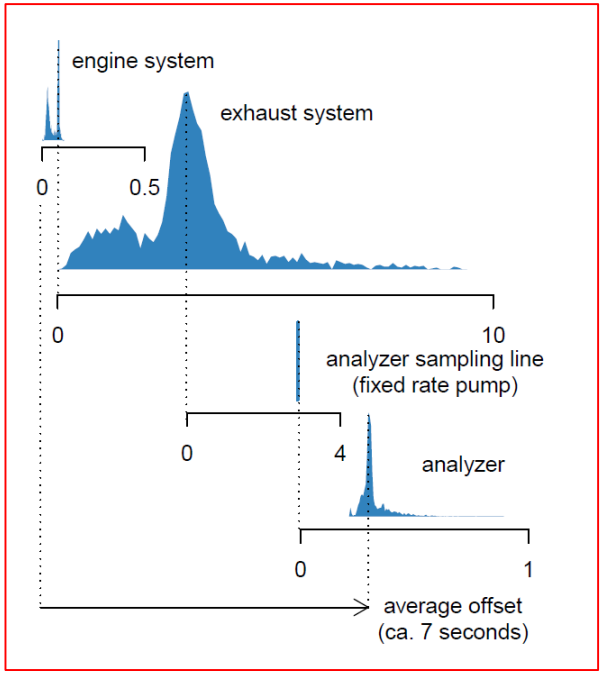
(Source: Ropkins, K., Oates, C. and Tate, J.E. Evaluation of a Remote Sensing System 'Dirty Emitter' Measurement. 18th CRC On-Road Vehicle Emission Workshop. San Diego, US, 31 March - 2 April, 2008; Ropkins, K., Carslaw, D.C., Goodman, P.S. and Tate, J.E. Application of non-linear time-alignment and integration methods to environmental time series. TrAC Trends in Analytical Chemistry. 28, 2009, 373-391.)

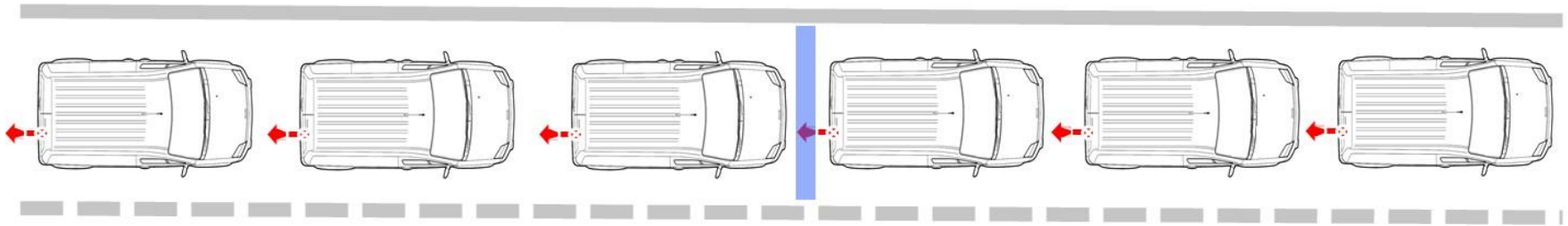
EDAR and PEMS Data Alignment

(Source: Ropkins, K. Li, H and Carslaw, D.C. Time Alignment of Instantaneous Emissions Data. 20th CRC On-Road Vehicle Emission Workshop. San Diego, US, 22-24 March, 2010. Workshop URL: http://www.crcao.org/workshops/index.html).

PEMS measurements based on at-engine, in-exhaust and post-exhaust measurements







ONLY

With PEMS/EDAR alignment, there is only ONE point of comparison and alignment is CRITICAL

Previous Recommendations about PEMS Driver Behaviour

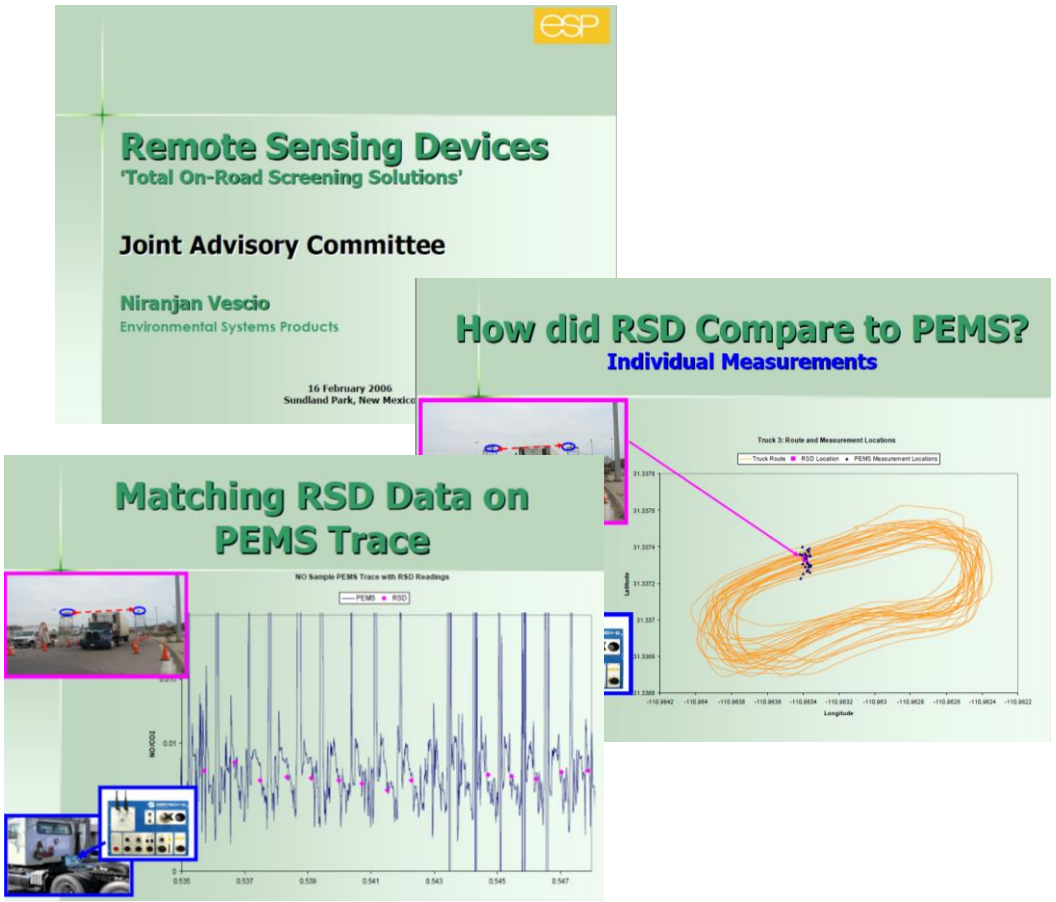
When Don Stedman first looked at VERSS (his FEAT) and PEMS comparisons

- He undertook an off-road (test track) study, and
- Recommended driving the PEMS vehicle very smoothly by the VERSS

(Source: Lawson, D.R., Groblicki, P.J., Stedman, D.H., Bishop, G.A., and Guenther, P.L., 1990. Emissions from in-use motor vehicles in Los Angeles: a pilot study of remote sensing and the inspection and maintenance programs, Journal of the Air & Waste Management Association, 40 (8), 1096-1105.)

This was to reduce the effect of the different sampling resolutions of VERSSs (10Hz or faster) and PEMS (1Hz)

BUT folks have been 'pushing the envelope' ever since, for example:



Moving Forward

We wanted OUR PEMS comparisons to be MORE REPRESENTATIVE

Simulated exhaust was a better measure of instrumental accuracy

We wanted on-road, in amongst other vehicles, looking (much as possible) at *in-situ* performance:

- On-road, the PEMS vehicle driver's priority is safety, so not all drive-throughs would be smooth
- BUT then none of vehicles surveyed in a conventional study would necessarily be driven smoothly…

…However, like Don, we acknowledge that every real-world PEMS drive-through may NOT be a suitable point for PEMS and VERSS comparison…

…BUT we also felt that whatever we did should complement the simulated exhaust study rather than be a 'poor man's version'…

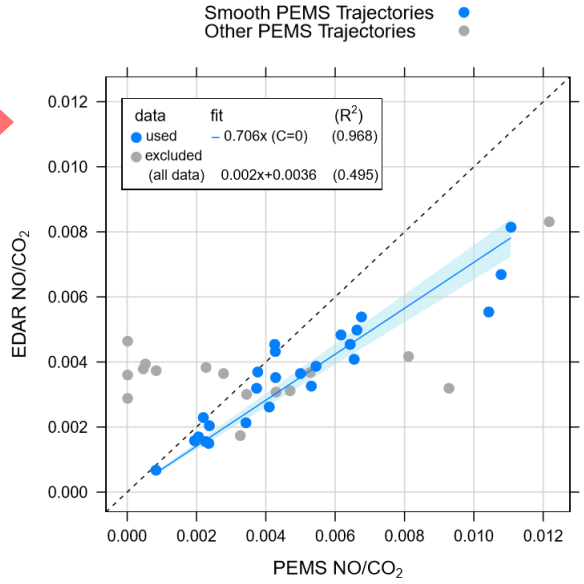
PEMS Data Filtrating

…so we undertook our comparisons in-situ…

…as part of a challenging deployment…

… and we filtered out data for smoother driver behaviour by testing if the 'second-before to second-after drive through' was smooth for the PEMS/EDAR comparisons…

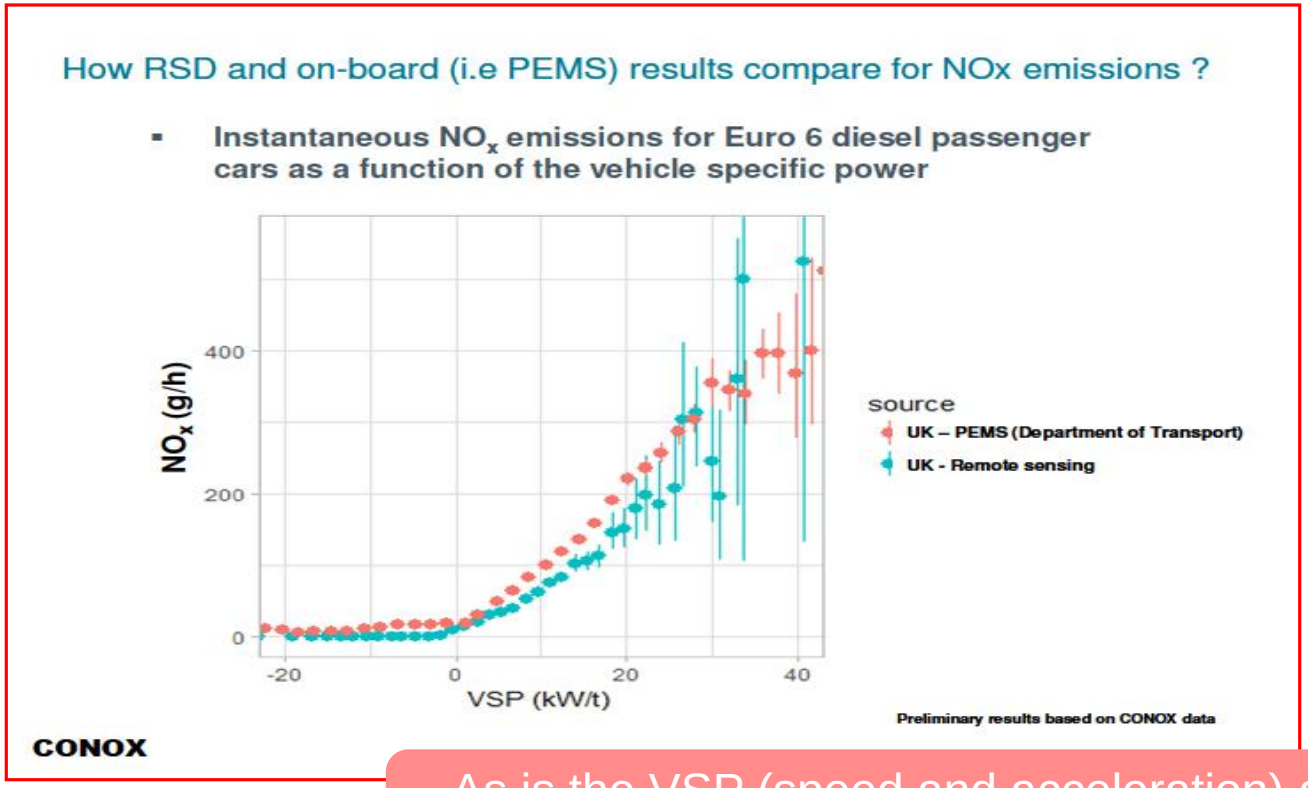
… So we have the datasets for both a traditional comparison and one for future work, and a method to differentiate the two



More recently…

CONOX have matched VSP to compare remote sensing and PEMS measurement:

The results are encouraging and the method is worth considering:



As is the VSP (speed and acceleration) alignment with remote sensing measured emissions…