Vehicle Specific Power: A Useful Parameter for Remote Sensing and Emission Studies

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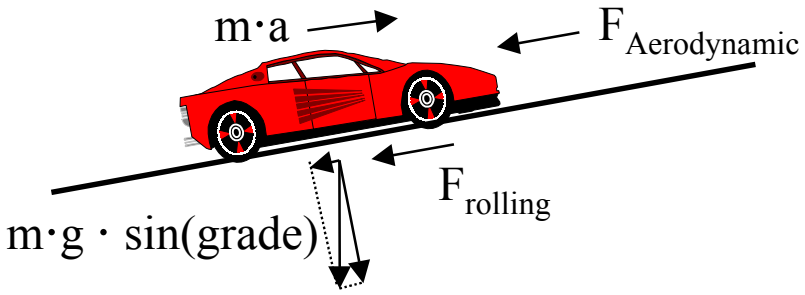
Effect of Driving Conditions on Emissions

- Driving conditions may strongly influence emissions
  - e.g. commanded enrichment at high power demand
- Problems:
  - False high emitters / False clean cars in remote sensing
    - Texas Remote Sensing Study (CRC 98): 65% of cars at 5-6 mph/sec are high CO emitters
  - Difficult to compare between RS, dyno cycles, & models
  - Difficult to capture on emissions models
    - MOBILE, EMFAC: EF * Speed Correction * Cycle Correction
    - Modal, Neural Network: very detailed & complex

Vehicle Specific Power (VSP)



$$VSP = \frac{Power}{Mass} = \frac{\frac{d}{dt}(E_{Kinetic} + E_{Potential}) + F_{Rolling} \cdot v + F_{Aerodynamic} \cdot v + F_{internal\ friction} \cdot v}{m} =$$

$$\approx v \cdot a \cdot (1 + \varepsilon_i) + g \cdot grade \cdot v + g \cdot C_R \cdot v + \frac{1}{2} \rho_a C_D \frac{A}{m} (v + v_w)^2 \cdot v + C_{if} \cdot v$$

Previous Work:

• Specific Power	$= 2 \cdot v \cdot a$	(EPA, 1993)
• Positive Kinetic Energy	$= \Sigma\ pos(SP_i) / \Sigma$ distance	(Watson et al., 1983)
• DPWRSUM	$= \Sigma\ \lvert SP_i - SP_{i-1} \rvert$	(Webster and Shih, 1996)

Vehicle Specific Power (II)

For typical U.S. light - duty vehicles and light - duty trucks (better estimates of the resistance coefficients should be used when available):

$$VSP = \frac{Power}{Mass} \approx 1.1 \cdot v \cdot a + 9.81 \cdot grade \cdot v + 0.213 \cdot v + 0.000305 \cdot (v + v_w)^2 \cdot v$$

with VSP in kW/Metric Ton, v (speed) and v_w (headwind into the vehicle) in m/s, a (acceleration) in m/s^2, grade defined as vertical rise/horizontal distance

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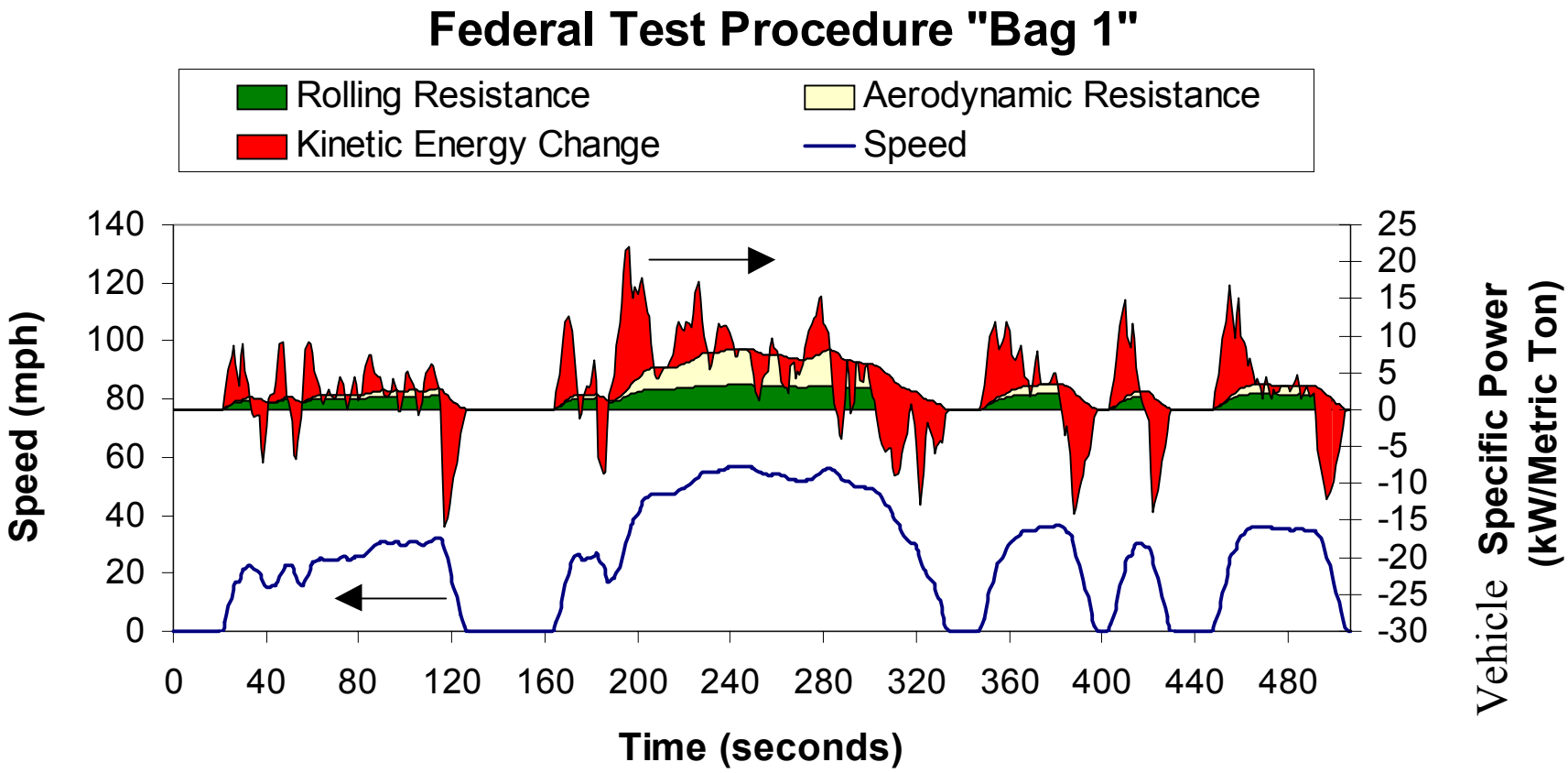
$$VSP = \frac{Power}{Mass} \approx 0.22 \cdot v \cdot a + 4.39 \cdot grade \cdot v + 0.0954 \cdot v + 0.0000272 \cdot (v + v_w)^2 \cdot v$$

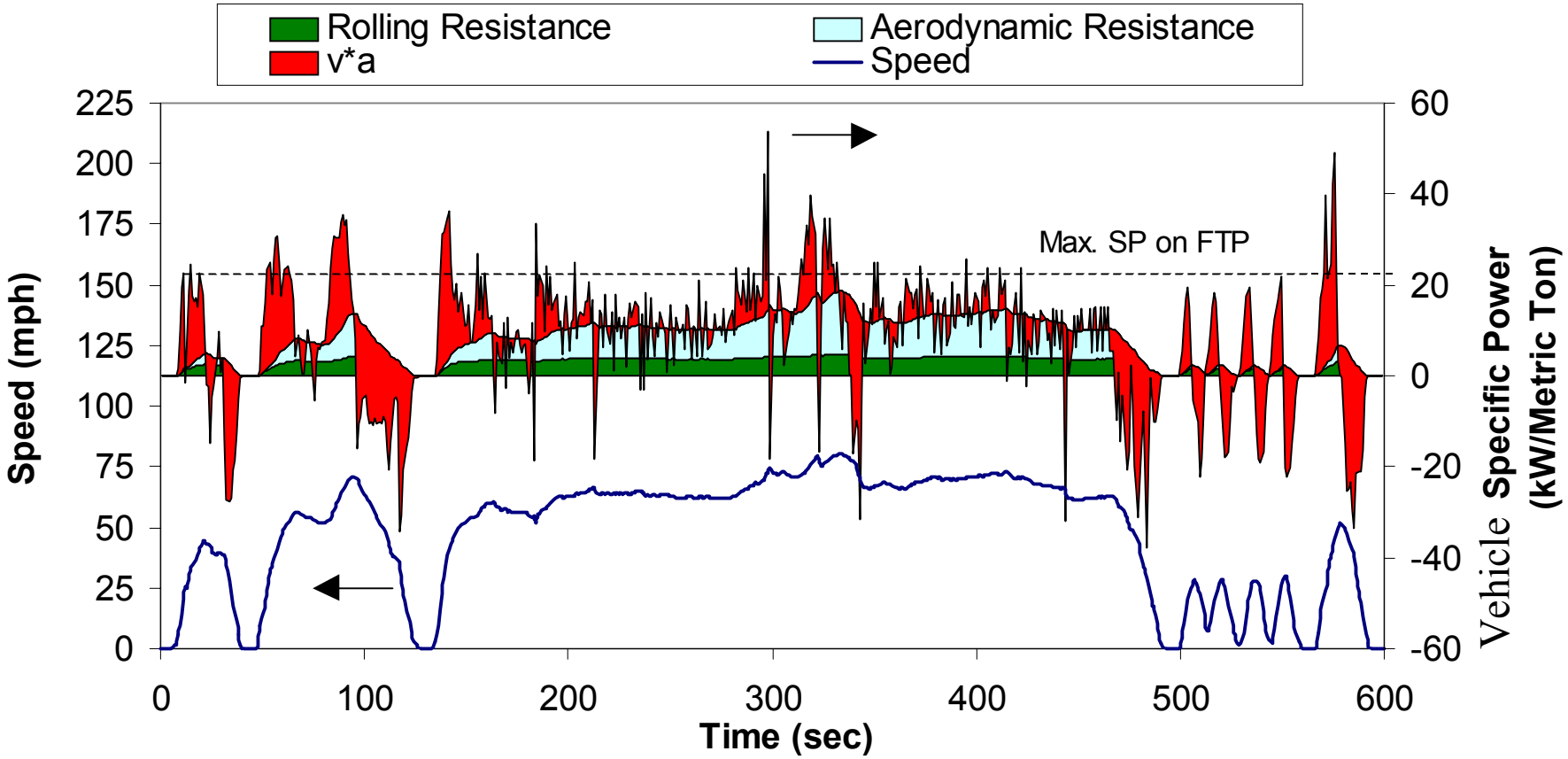
(VSP in kW/Metric Ton, v and v_w in mph, a in mph/sec)

VSP in Emissions Certification Cycles

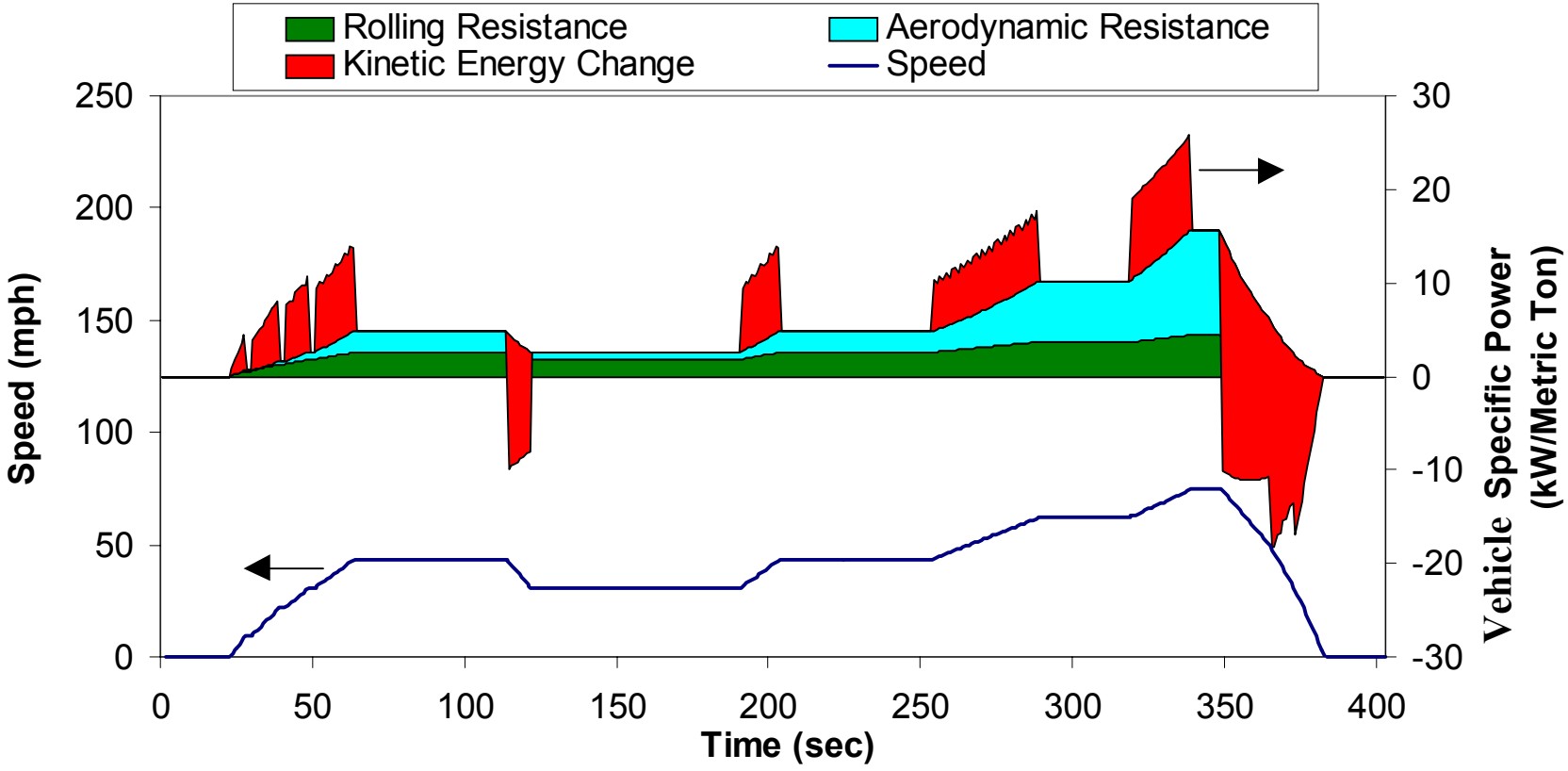


VSP Specified at each point

VSP in US06 Driving Cycle



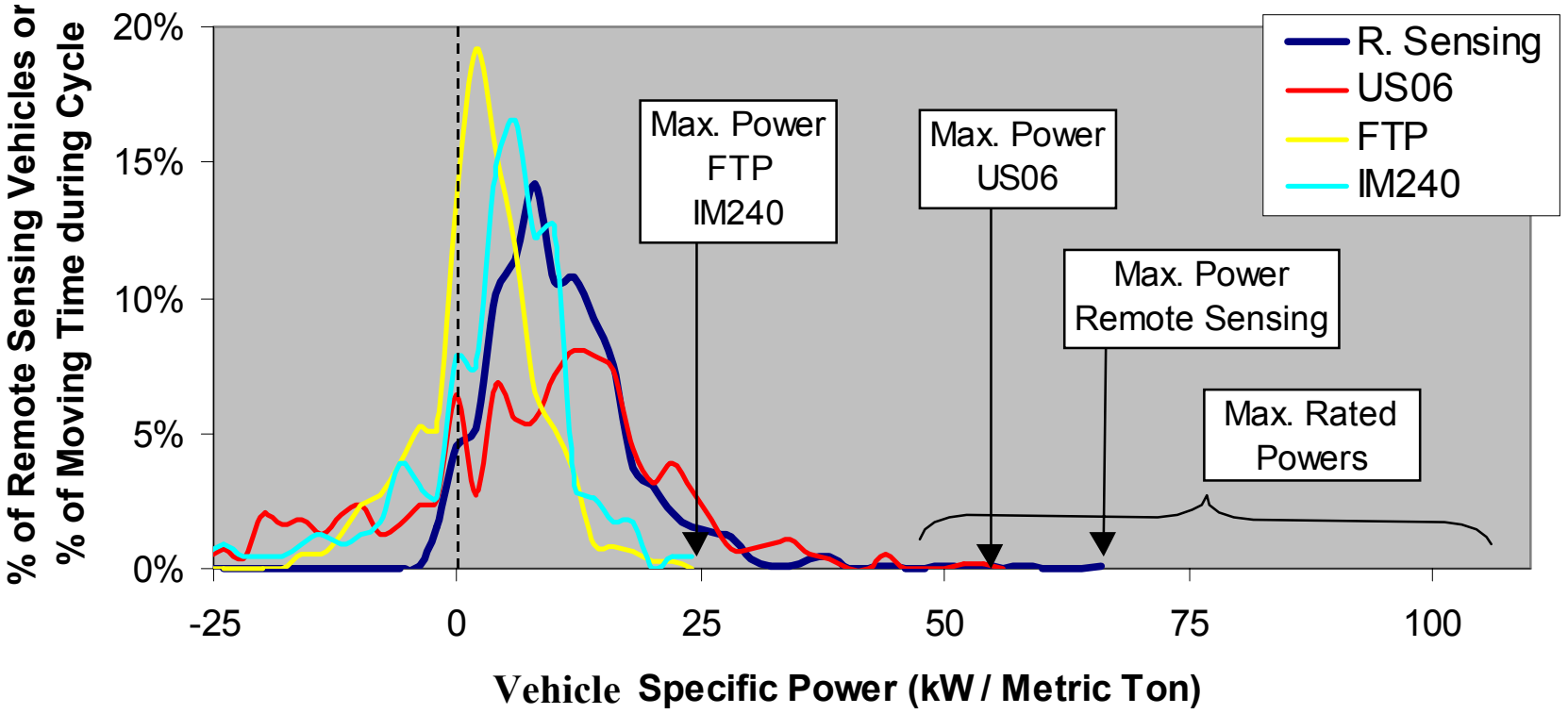
VSP in European ECE2 Cycle



VSP Levels of Various Activities

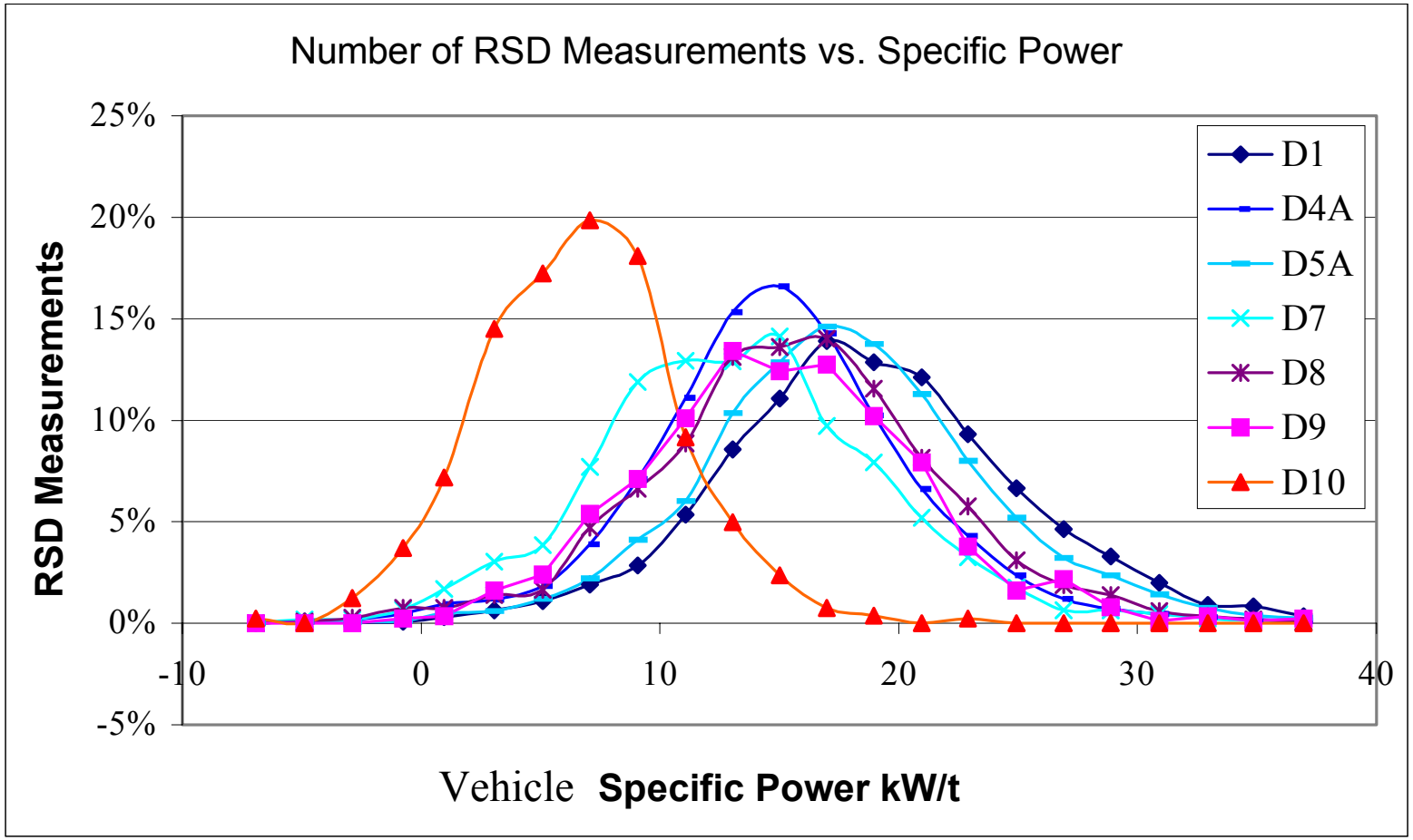
Activity	VSP (kW/ Metric Ton):
• Max. Rated Powers	44 - 112
• 0 to 60 mph in 15 seconds	33
• 60 mph up a 4% grade	23
• Maximum in FTP/IM240	23
• Rem. Sensing site means	10 -15
• Average in IM240	8
• ASM 5015	6
• ASM 2525	5

Use of VSP Distributions



➡ Characterize & Compare Driving Cycles, Remote Sensing Sites, or Models

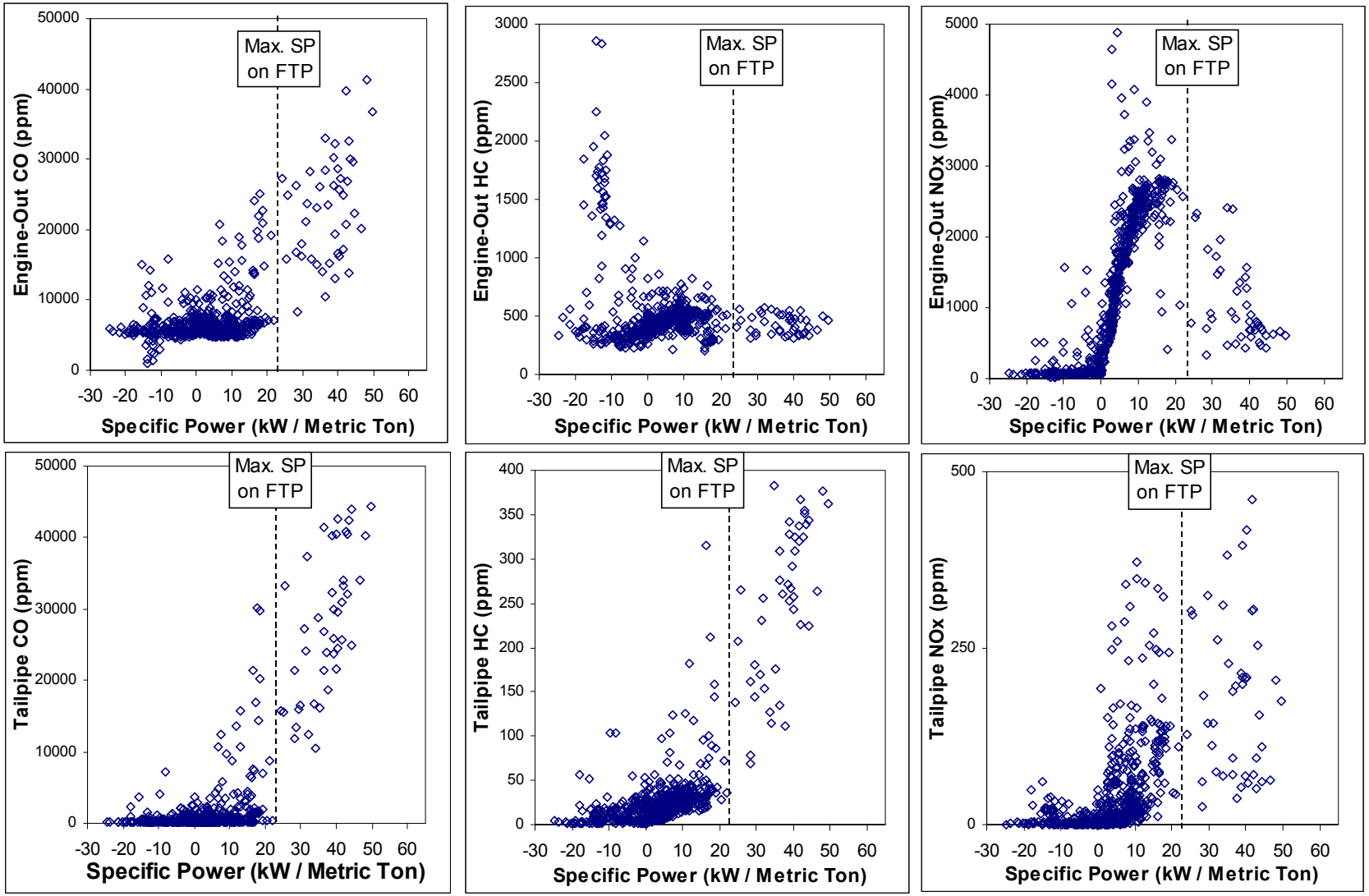
VSP Distributions at RS Sites in Denver



Advantages of VSP

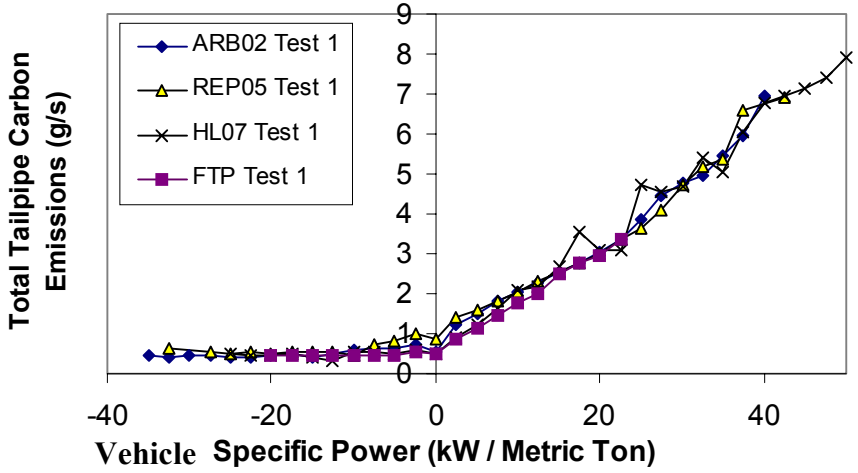
- Captures dependence of emissions on power
  - Directly specified in certification cycles
- Can be calculated from roadside measurements
  - Mass only appears in aerodynamic term
- One-dimensional
- Direct physical interpretation

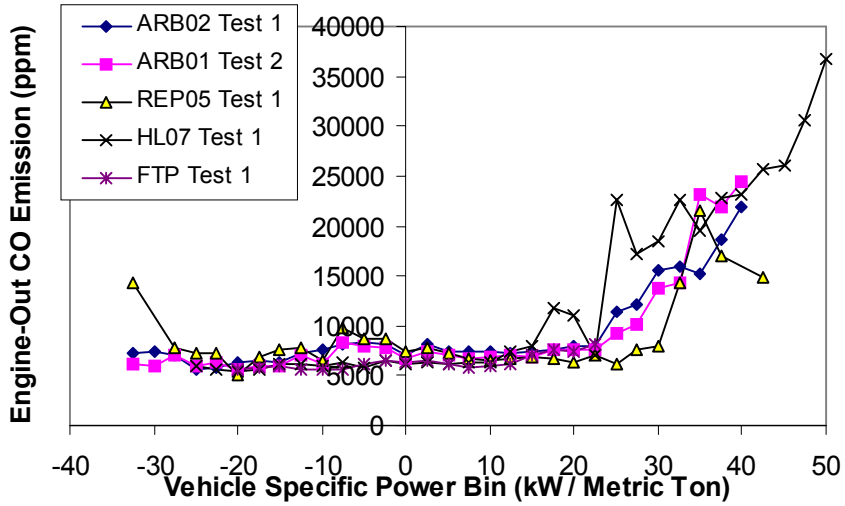
Emissions vs. VSP (1 Vehicle)

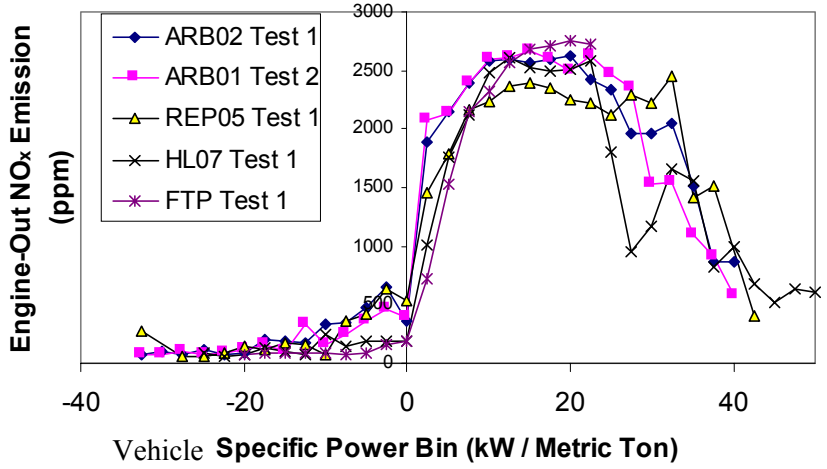


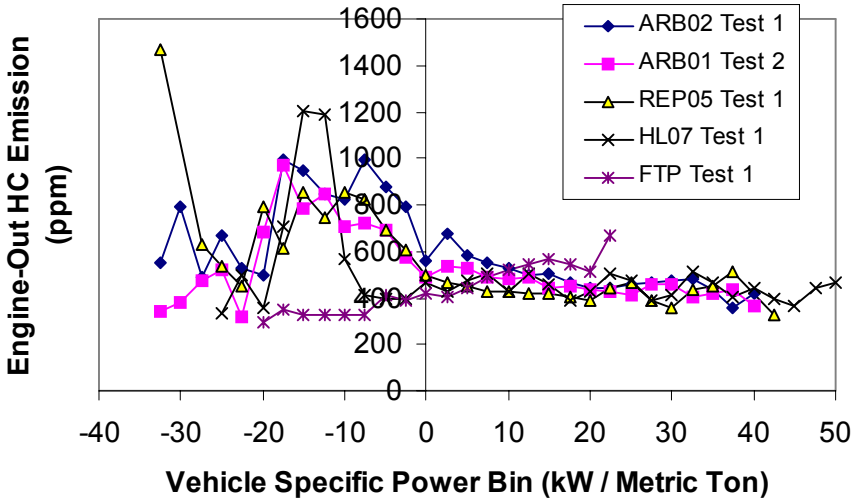
Sec-by-sec data for a 1994 Jeep Cherokee in HL07 dyno cycle, from SFTP CD-ROM (Haskew et al., 1994)

Emissions vs. VSP (1 Vehicle)



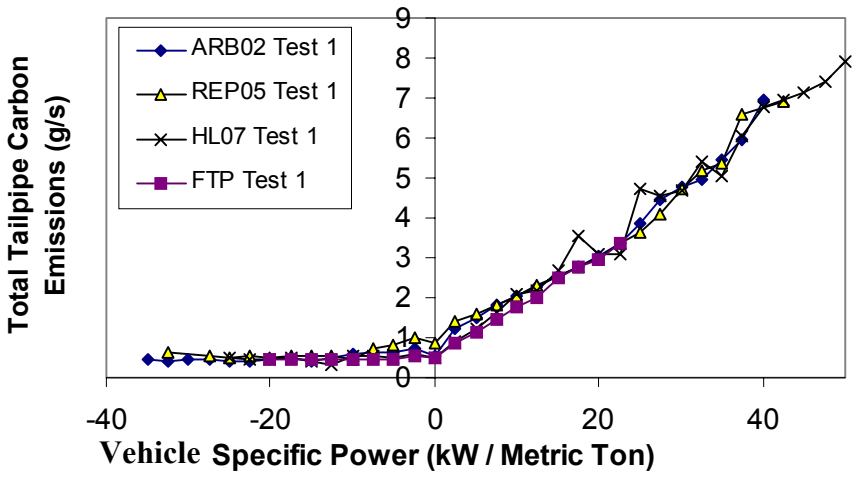


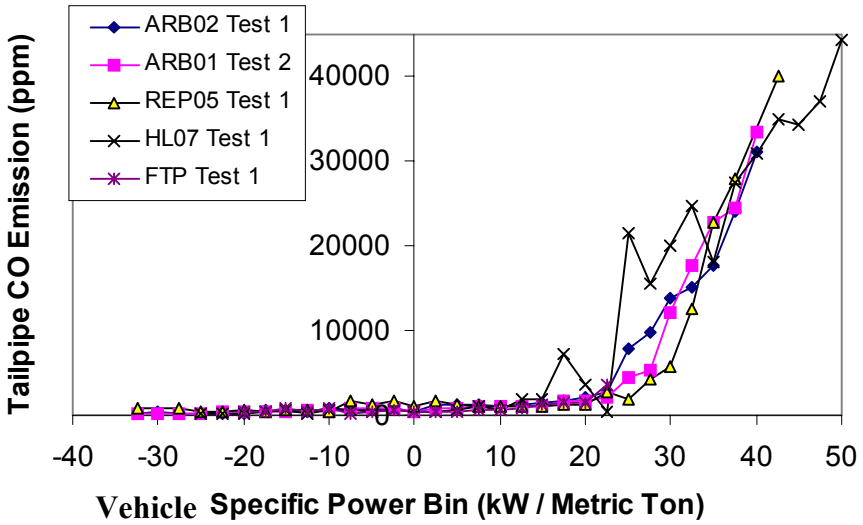


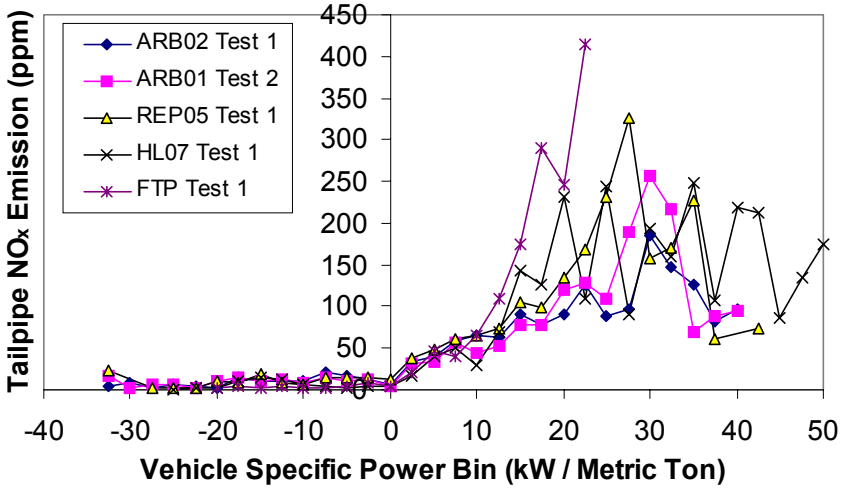


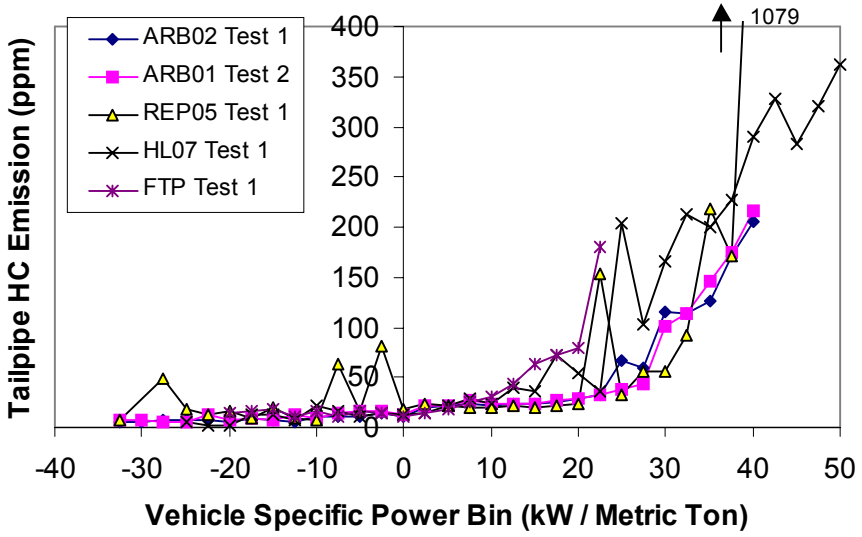
Binned Sec-by-sec data for a 1994 Jeep Cherokee, from SFTP CD-ROM (Haskew et al., 1994)

Emissions vs. VSP (1 Vehicle)









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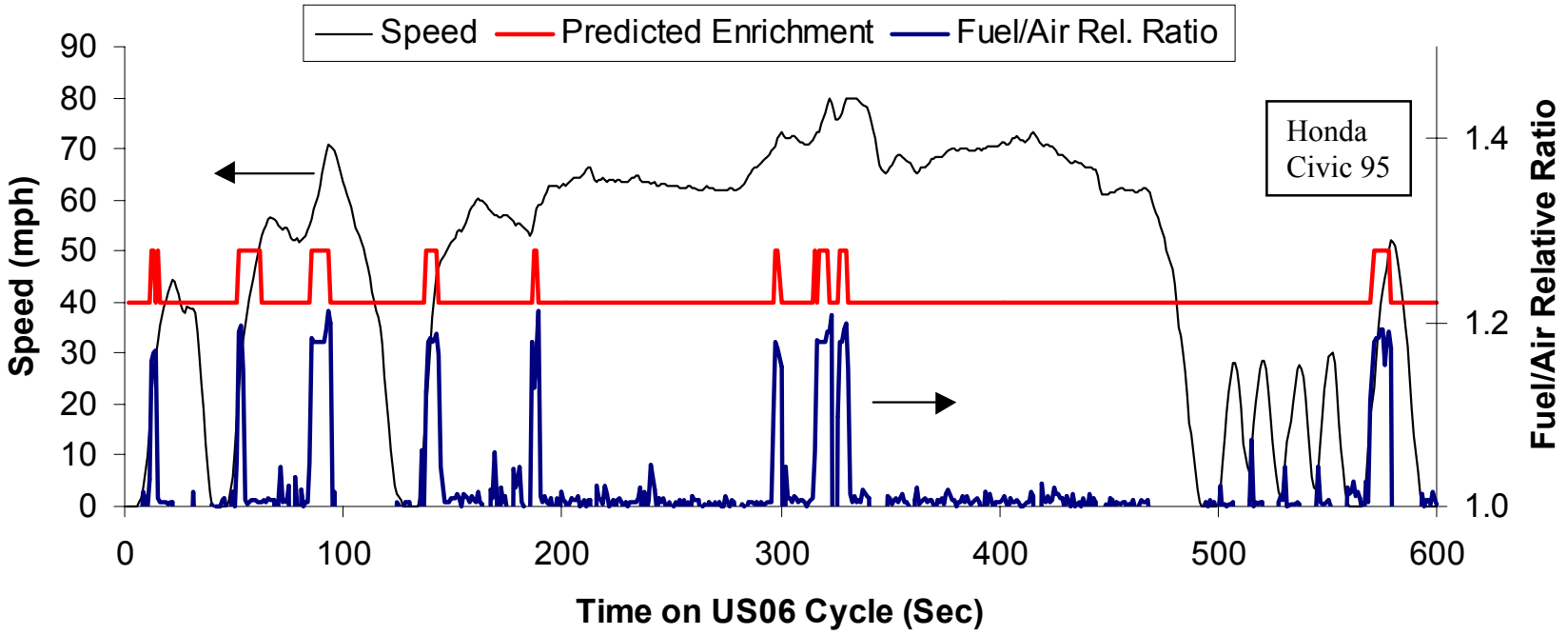
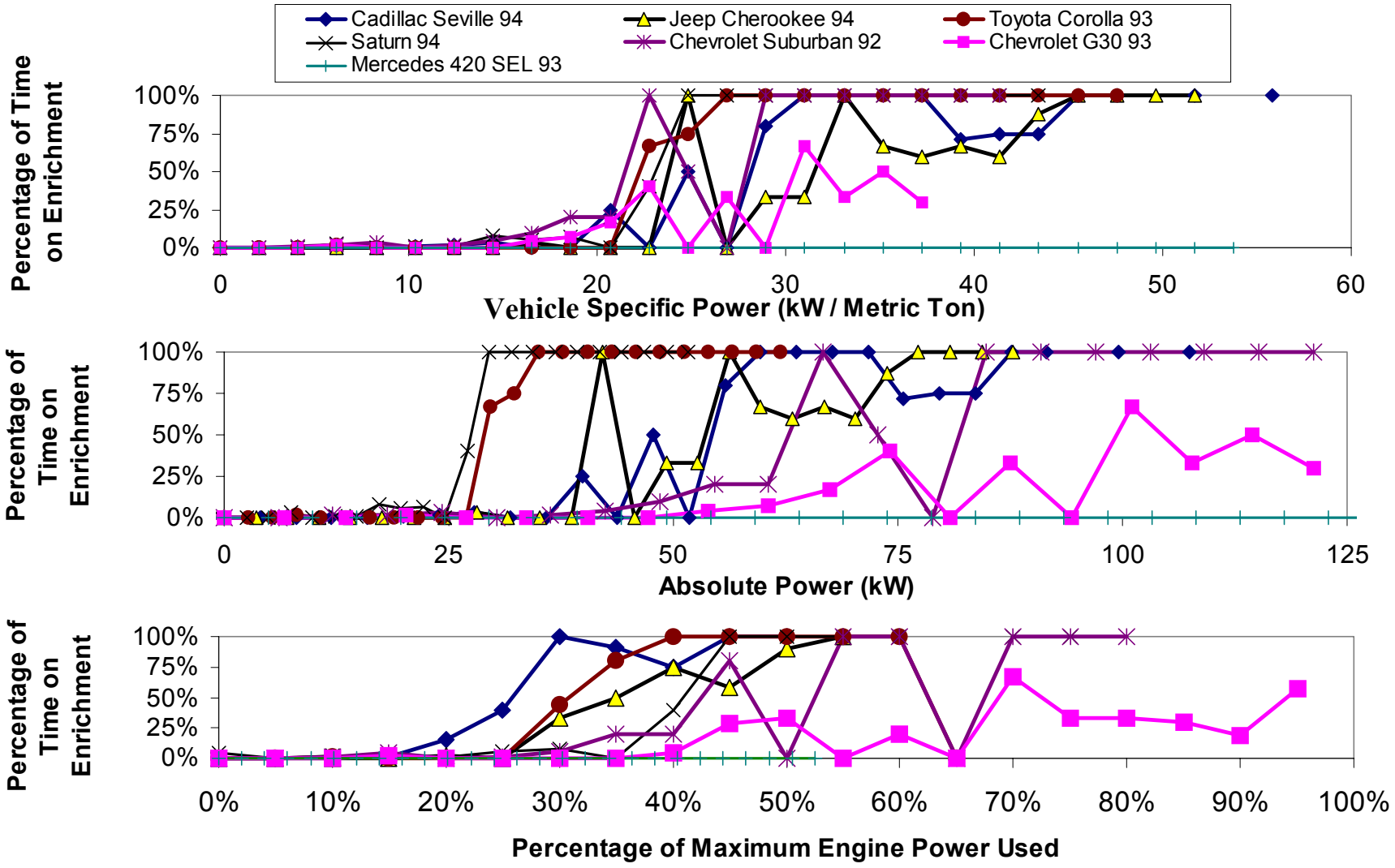
Prediction of Commanded Enrichment



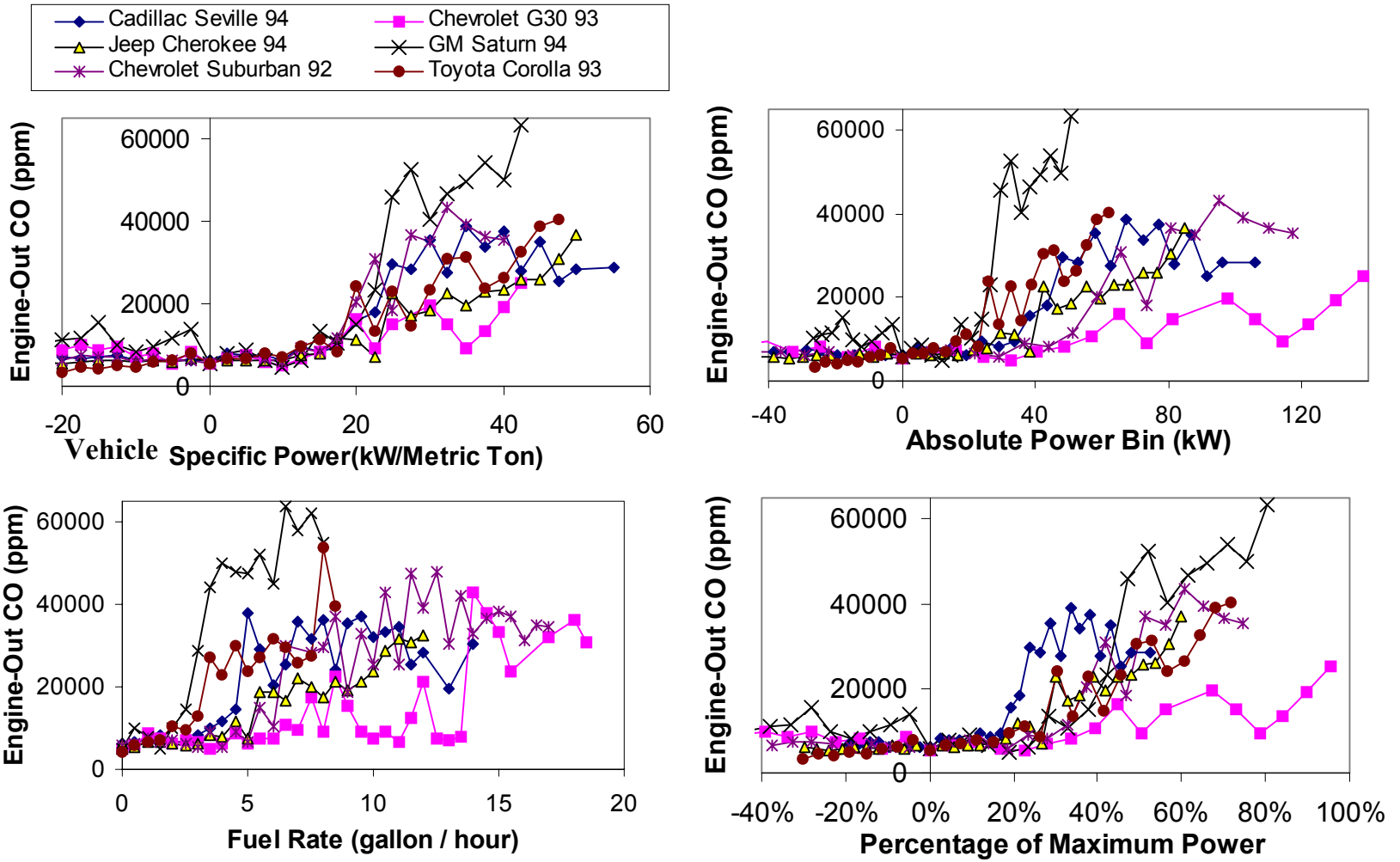
VSP > Max. VSP on FTP is good predictor of enrichment

Onset of Enrichment



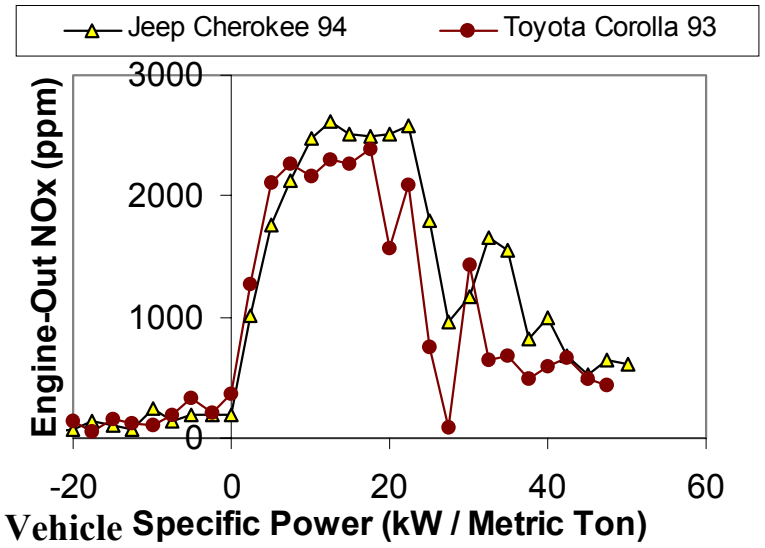
Binned Sec-by-sec data from chassis dynamometer tests of SFTP CD-ROM (Haskew et al., 1994)

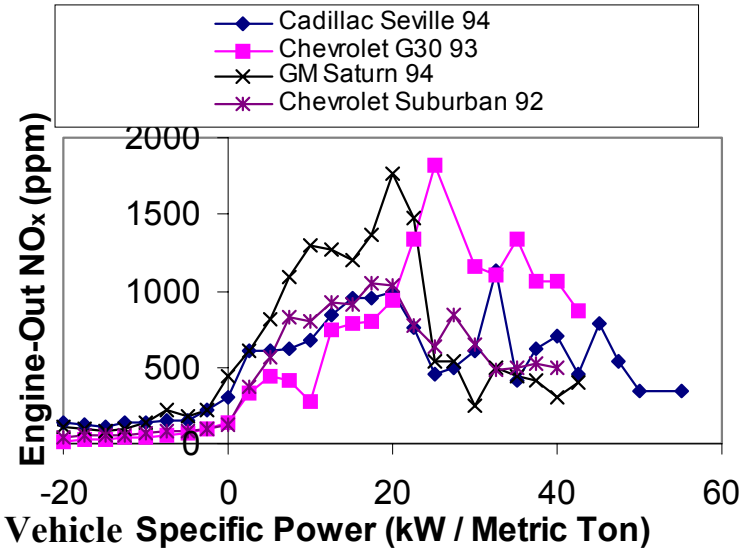
CO Emissions vs. Several Parameters (6 Vehicles)

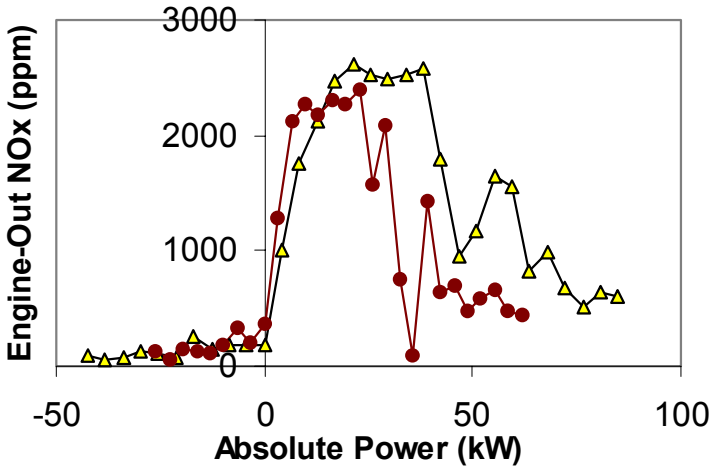


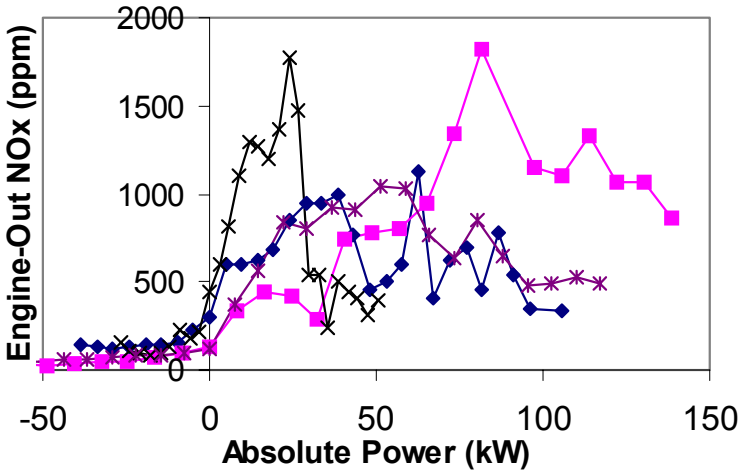
Binned Sec-by-sec data from chassis dynamometer tests of SFTP CD-ROM (Haskew et al., 1994)

NO_x Emissions vs. VSP and Power (6 Vehicles)



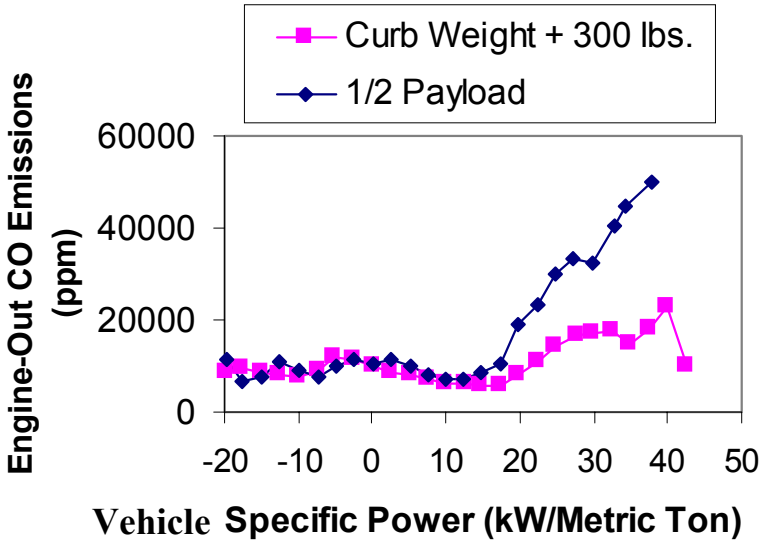


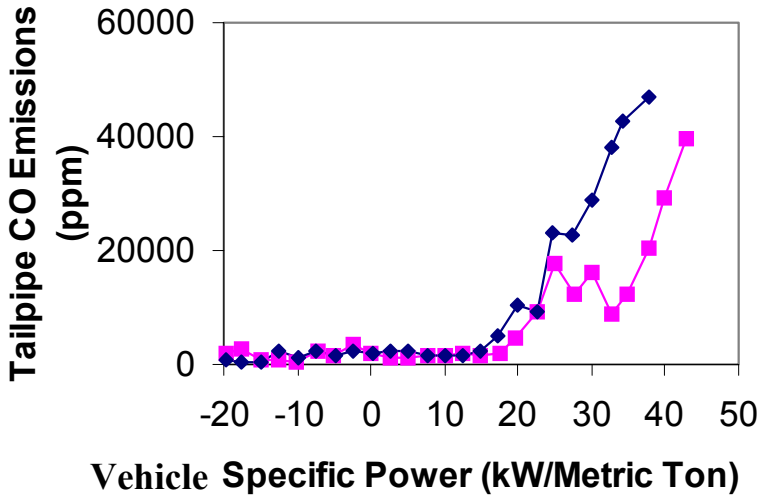


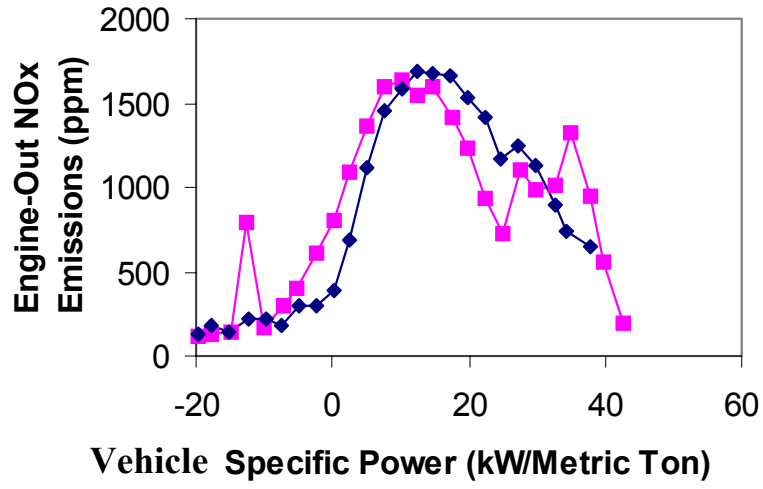


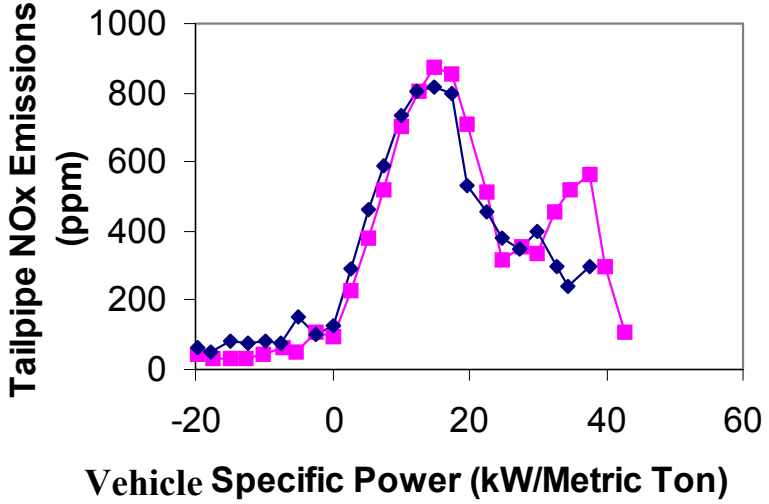
Binned Sec-by-sec data from chassis dynamometer tests of SFTP CD-ROM (Haskew et al., 1994)

Effect of Payload



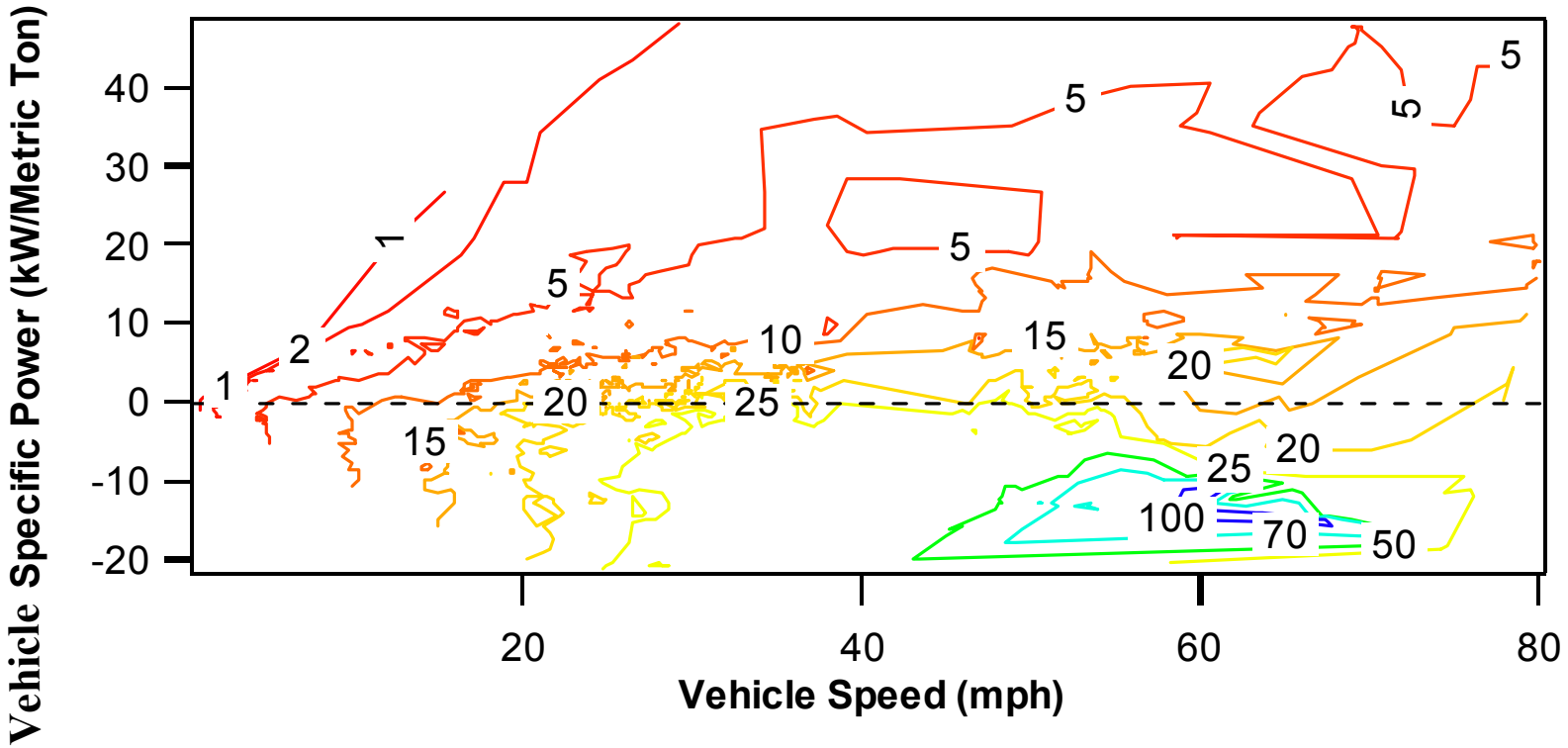






Binned Sec-by-sec data from chassis dynamometer tests of SFTP CD-ROM (Haskew et al., 1994) for a 1993 Ford 250

Residence Time in Exhaust System

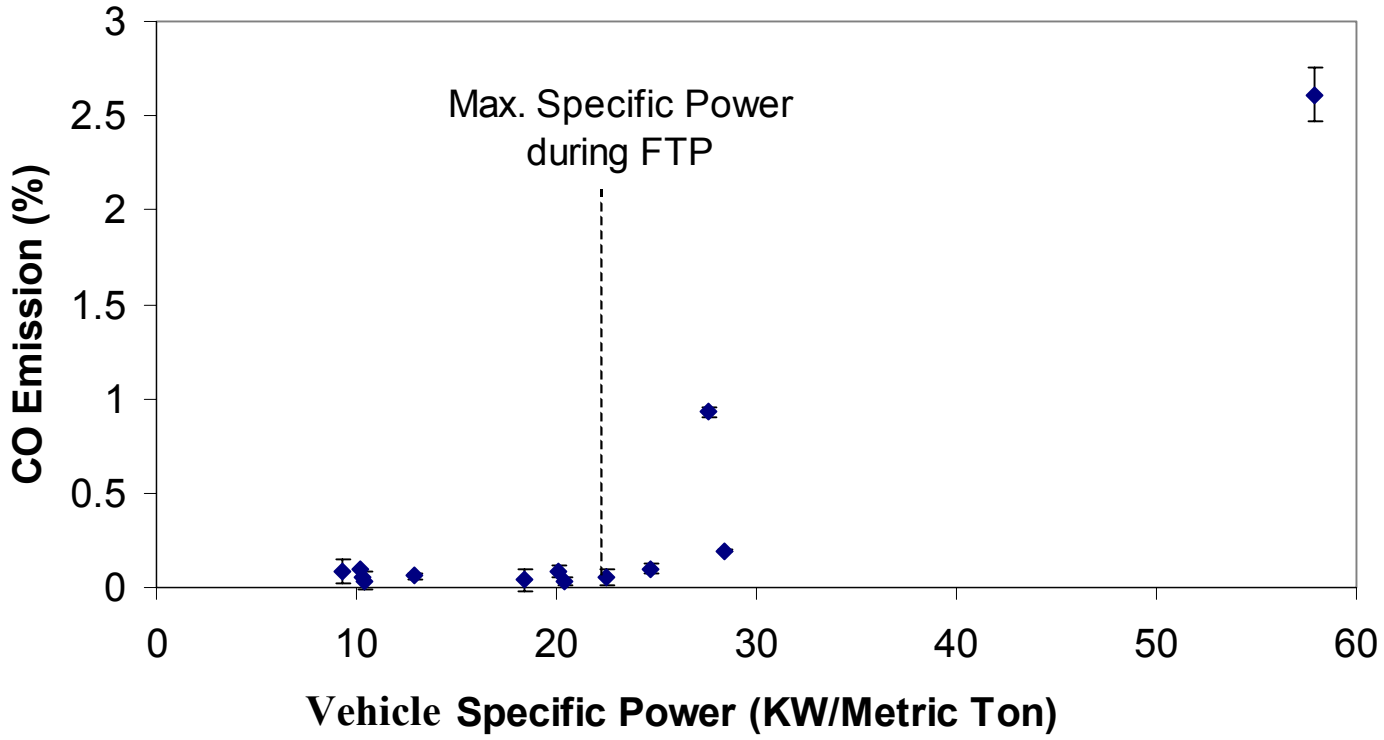


- Exhaust that leaves the tailpipe at the remote sensor was generated in the engine 1-25 meters before (when VSP>0)
  - Avoid decelerations at high speed

VSP: Implications for Emission Research

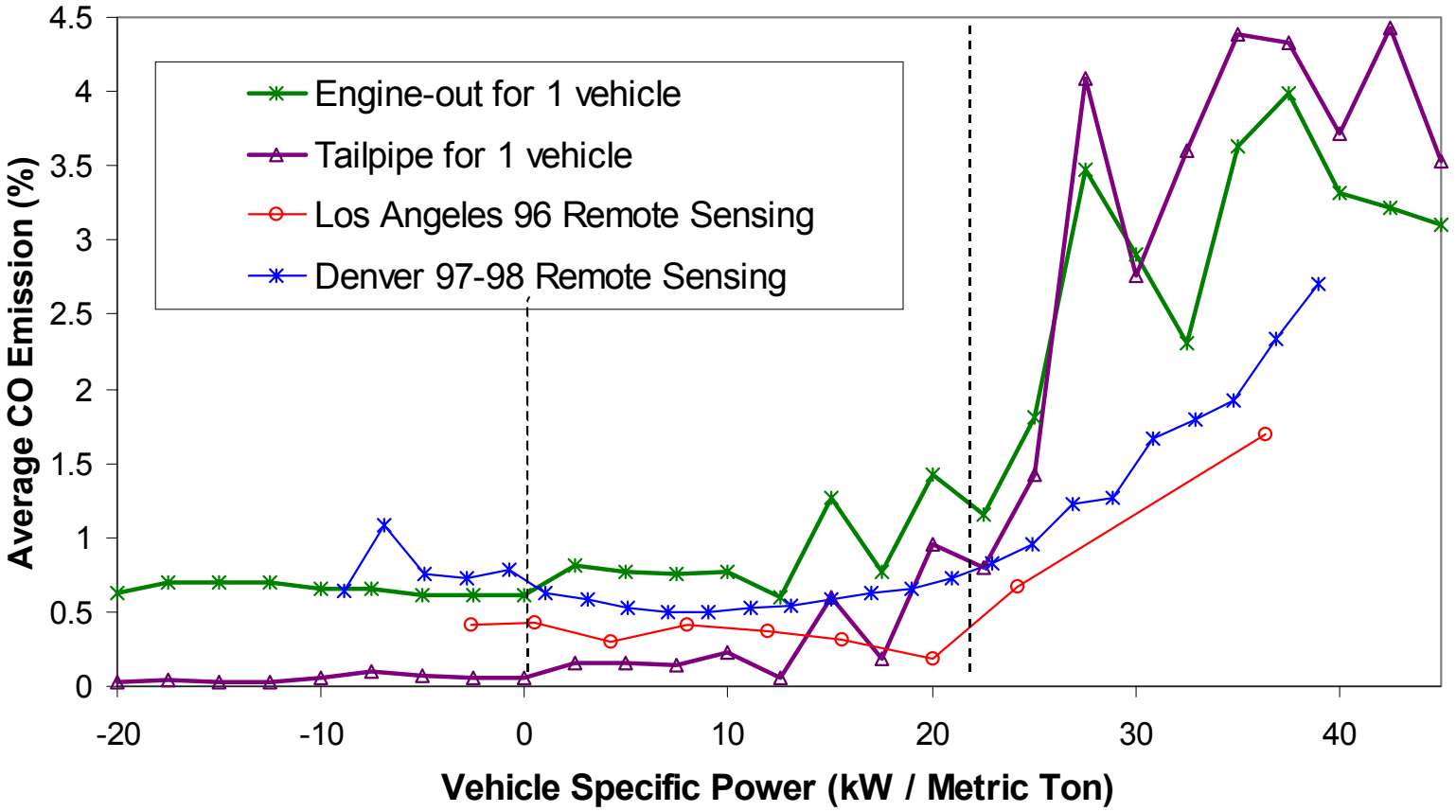
- Remote Sensing:
  - Improve clean screen and high emitter detection
    - Valid if 3 kW/t <VSP < 22 kW/t
    - E.g. LA 96: 26% high CO emitters are suspect of enrichment
  - Relate RS results to I/M test results
  - Quantify real emissions at high power levels
- Compare results of:
  - RS sites
  - Dynamometer tests
  - Emission models
- Better representation of power in models
  - Use VSP distribution

Ultra Low Emissions Vehicle



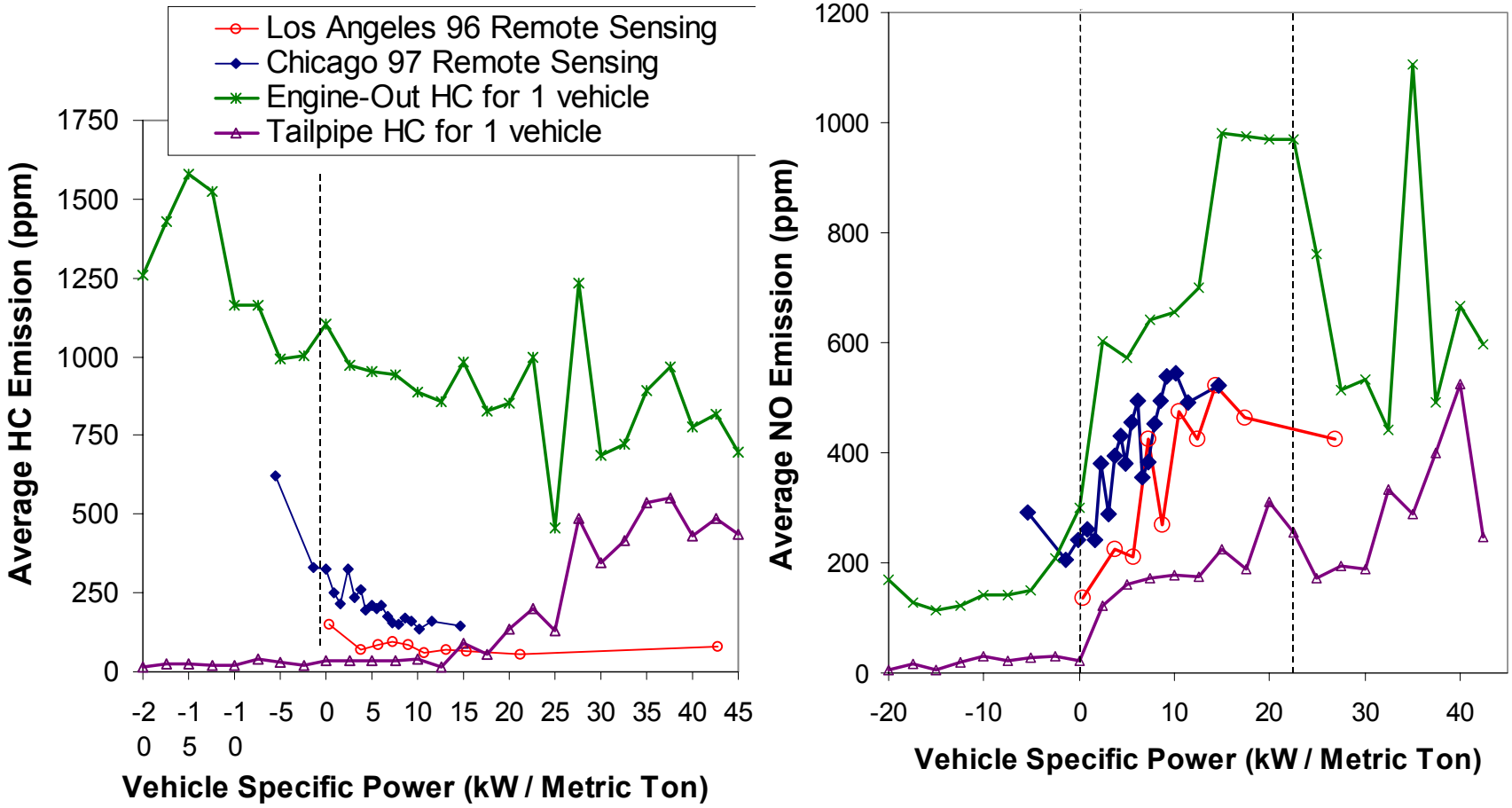
Can screen out power enrichment in RS

Remote Sensing and Dyno Data vs. VSP

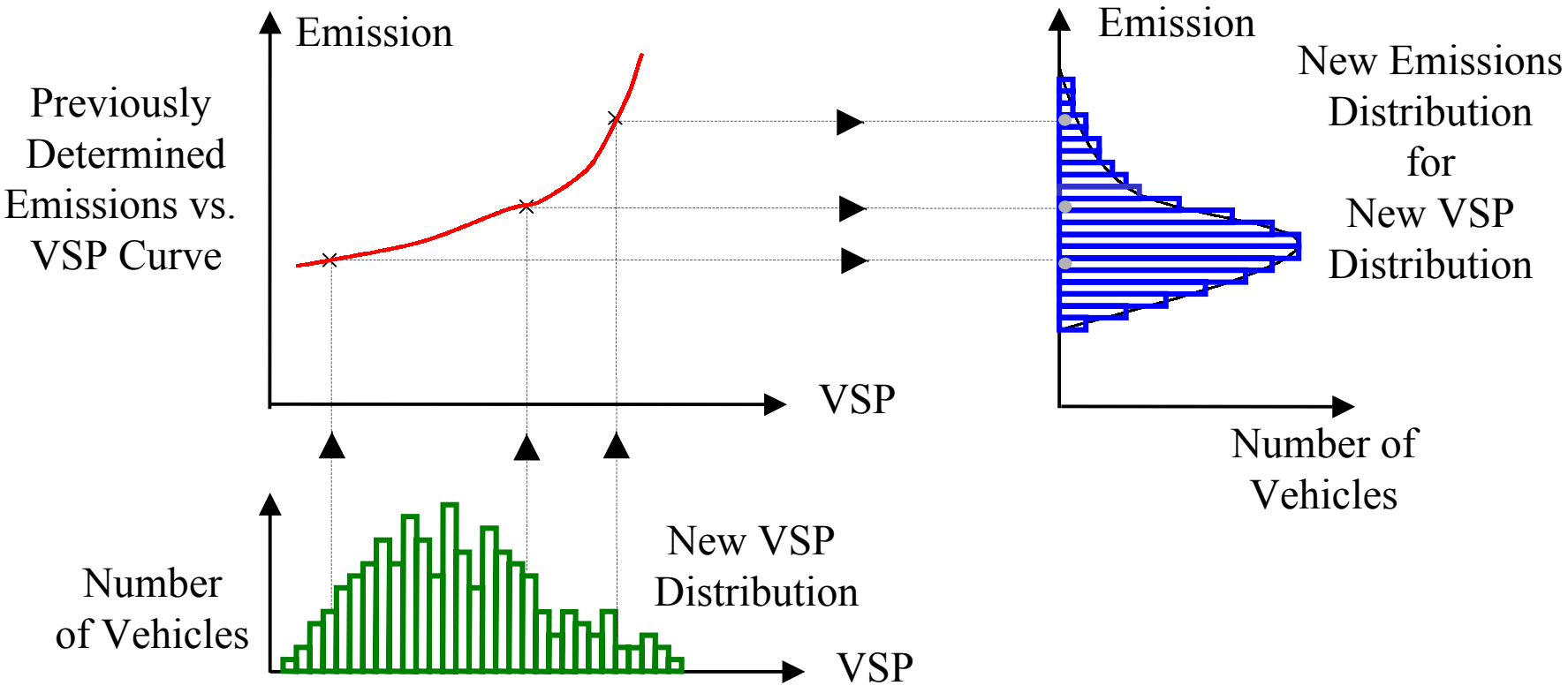


Allows Comparison and Interpretation

Remote Sensing and Dyno Data vs. VSP (II)



Correction for Power Demand



- Allows comparison of results of different methods and conditions
  - IM240 and remote sensing
  - Model different cities & road types

Conclusions

- Vehicle Specific Power (VSP)
  - Captures dependence of emissions on power
    - Specified in driving cycles
  - Roadside measurable
  - One dimensional, physically meaningful
- Applications
  - Improve low and high emitter detection on RSD
  - Common metric for emission studies
    - Compare RS, I/M tests, dyno cycles, models
  - Improve emission models