

# Accuracy of the predictions of modeled emission hotspots based on real-world measured vehicle activity and emissions

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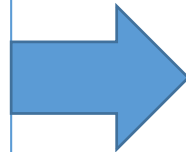
# Research objective

To evaluate the accuracy of a vehicle tailpipe emission model to predict hotspots in comparison to measured hotspots.

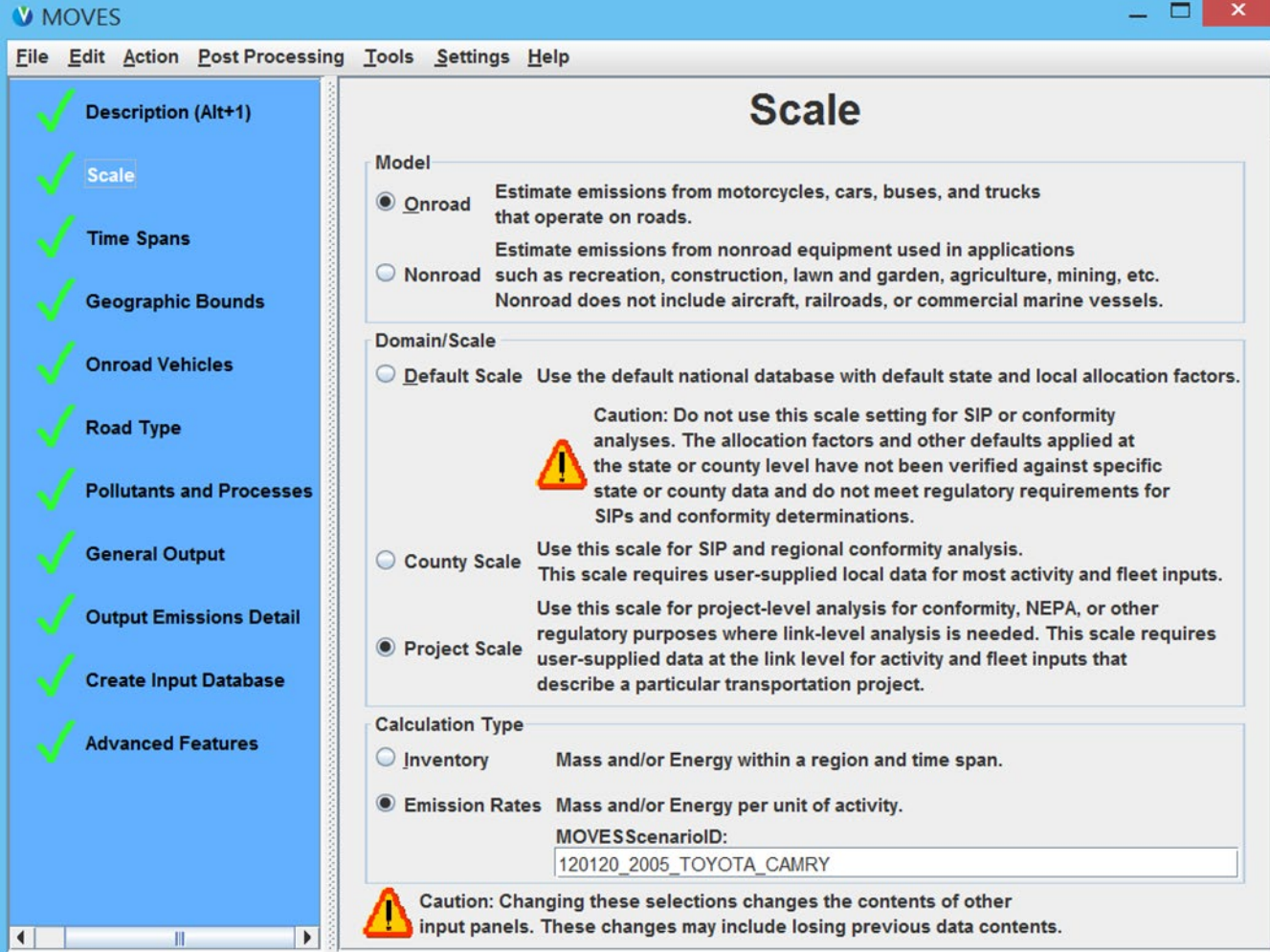
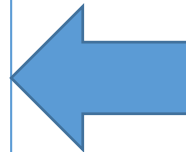
# Methods: On-road vehicles emission model

## US-EPA MOVES 3

Vehicle type (passenger car)  
Vehicle age  
Vehicle activity (1Hz speed profiles and RG)  
Ambient condition



Fleet average segment  
based emission rates



The screenshot shows the MOVES 3 software interface with the 'Scale' panel selected in the left-hand menu. The 'Onroad' model is chosen, and the 'Project Scale' is selected under 'Domain/Scale'. The 'Emission Rates' calculation type is also selected. A caution message at the bottom states: 'Caution: Changing these selections changes the contents of other input panels. These changes may include losing previous data contents.'

**MOVES 3 Scale Settings:**

- Model:**
  - ☒ **Onroad**: Estimate emissions from motorcycles, cars, buses, and trucks that operate on roads.
  - ☐ **Nonroad**: Estimate emissions from nonroad equipment used in applications such as recreation, construction, lawn and garden, agriculture, mining, etc. Nonroad does not include aircraft, railroads, or commercial marine vessels.
- Domain/Scale:**
  - ☐ **Default Scale**: Use the default national database with default state and local allocation factors.  
**Caution:** Do not use this scale setting for SIP or conformity analyses. The allocation factors and other defaults applied at the state or county level have not been verified against specific state or county data and do not meet regulatory requirements for SIPs and conformity determinations.
  - ☐ **County Scale**: Use this scale for SIP and regional conformity analysis. This scale requires user-supplied local data for most activity and fleet inputs.
  - ☒ **Project Scale**: Use this scale for project-level analysis for conformity, NEPA, or other regulatory purposes where link-level analysis is needed. This scale requires user-supplied data at the link level for activity and fleet inputs that describe a particular transportation project.
- Calculation Type:**
  - ☐ **Inventory**: Mass and/or Energy within a region and time span.
  - ☒ **Emission Rates**: Mass and/or Energy per unit of activity.

**MOVES Scenario ID:** 120120\_2005\_TOYOTA\_CAMRY

# Case study: 10 Tier 2 gasoline sedan Passenger Cars

Vehicle	Model inputs		Vehicle characteristics that are not modeled			
	Model Year	Age when measured (years)	Rated HP	Curb weight (lb)	RFE (mpg)	Mileage (mi*1000)
Toyota Camry	2005	7	160	3164	25	106
Toyota Camry	2012	0	178	3240	28	19
Kia Forte	2013	0	156	2791	29	9
Honda Accord	2012	2	185	3279	26	30
Ford Fusion	2016	0	175	3431	26	0.2
Toyota Corolla	2009	7	132	2745	30	174
Hyundai Elantra	2010	7	132	2747	29	74
Mazda 6	2006	12	160	3166	23	173
Honda Civic	2011	7	140	2831	29	63
Hyundai Sonata	2009	10	175	3266	25	143



# Methods: Activity and emission measurements



Portable Emission Measurement System (PEMS):  $\text{CO}_2$ , CO, HC,  $\text{NO}_x$

On-Board Diagnostic scantool (OBD):  
1Hz vehicle activity data (e.g. speed)



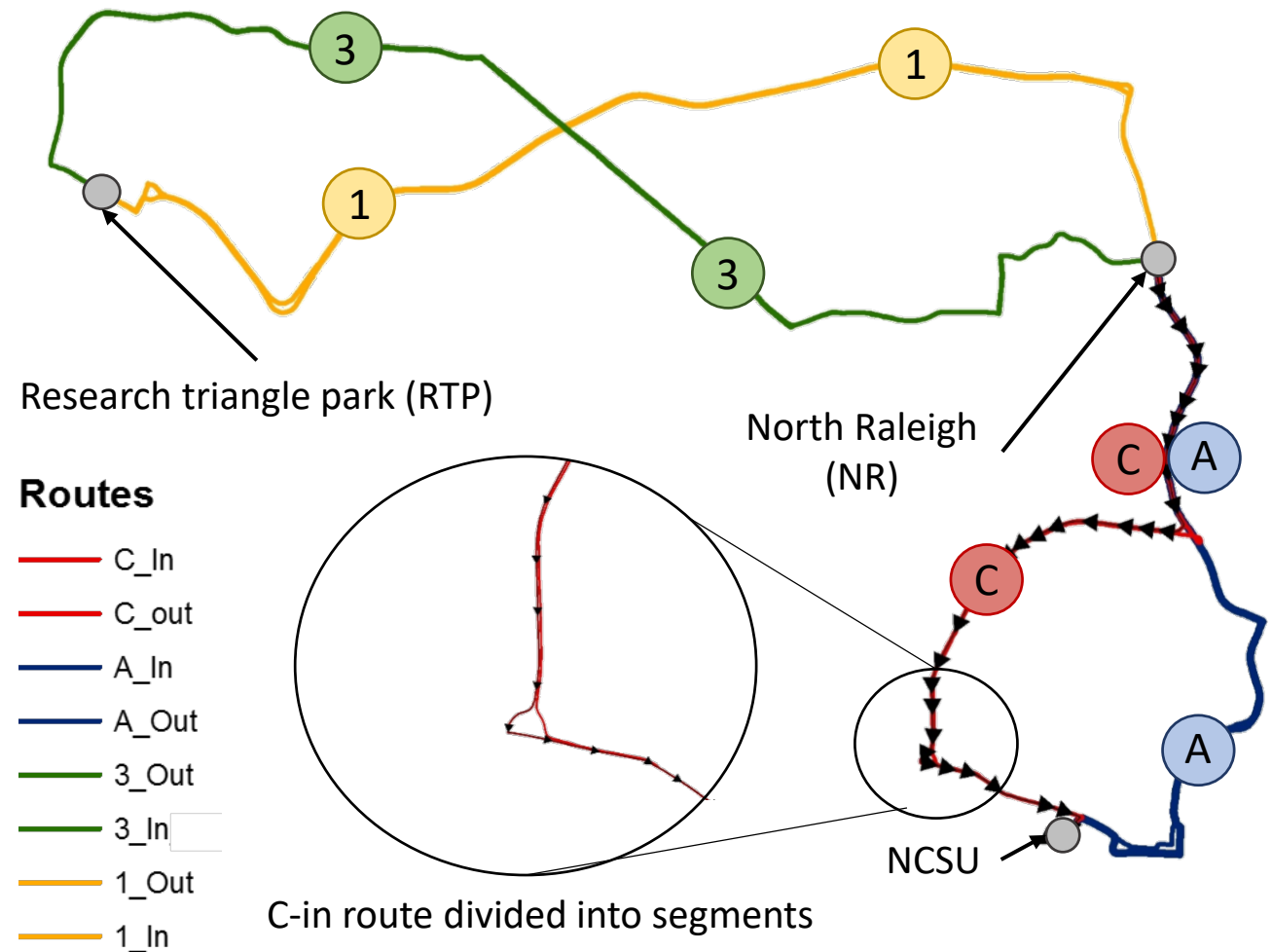
Global positioning system (GPS) with  
barometric altimeter.



Road Grade (RG) estimation based on  
linear regression of elevation versus  
distance. Ranging from -5.3 to 5.7%

# Methods: Measured routes

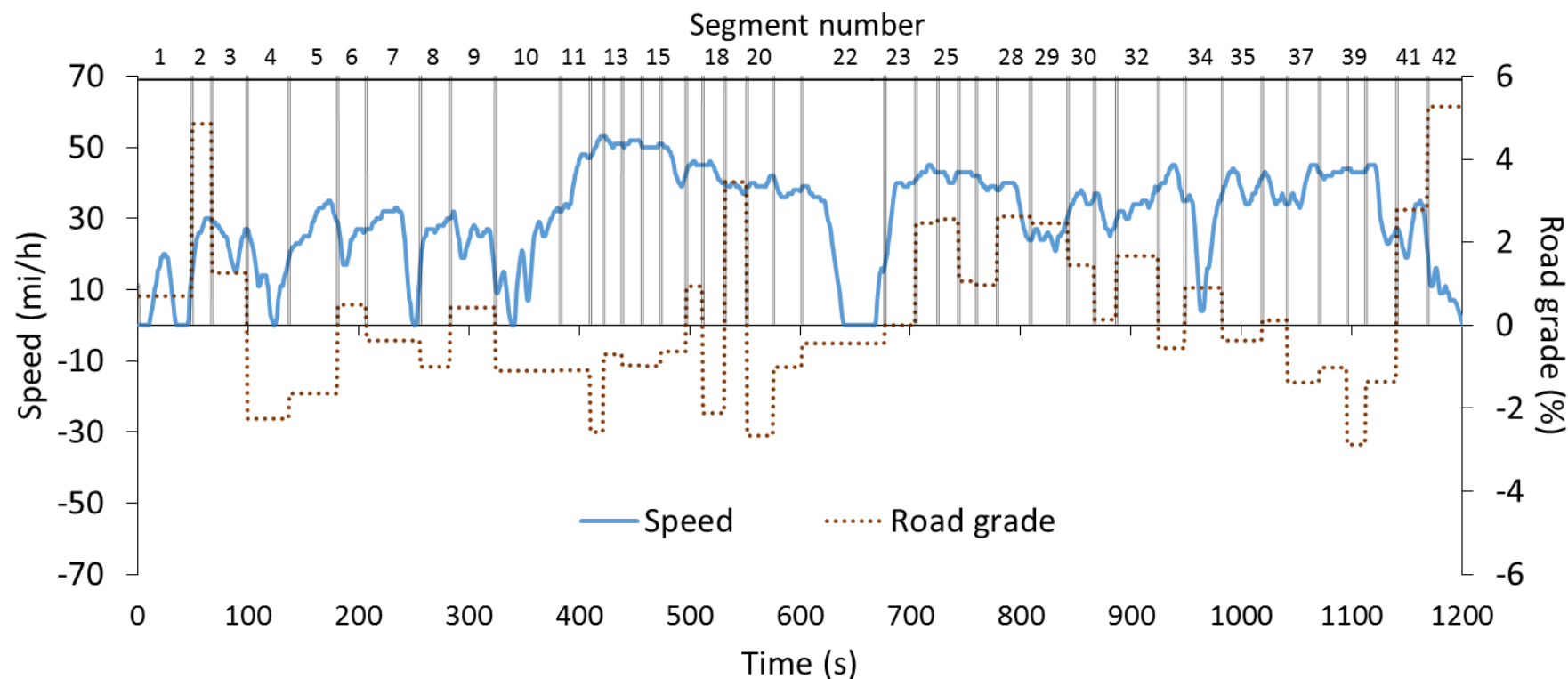
- 8 one-way routes:
  - 4 out routes from NCSU to NR and from NR to RTP
  - 4 in routes from RTP to NR and from NR to NCSU
- Broad coverage of road types, speed limits and RG
- Total distance 110 mi
- 450 segments, based on:
  - constant RG
  - speed limits
  - road types
- Average length of 0.25 mi (0.005-0.49 mi)



# Methods: segmented trajectories

Example segmented trajectory for Ford Fusion vehicle over route A-out with 42 segments

- Second by second vehicle speed
- Segment average road grade



# Methods: Hotspots definition

Emission **hotspots** are defined as segments within the top 10% ( $\geq 90^{\text{th}}$  percentile) of segments average emission rates for each pollutant.



# Methods: Model hotspot prediction accuracy

- Confusion matrix: summary of prediction results per pollutant:

450 segments per pollutant	Modeled +	Modeled -
Measured +	True positive (TP)	False negative (FN)
Measured -	False positive (FP)	True negative (TN)

- Model accuracy (Acc) predicting hotspots and non-hotspots per pollutant:

$$Acc\ (\%) = \left( \frac{N_{TP} + N_{TN}}{N_{AP} + N_{AN}} \right) \times 100$$

Where:

- $N_{TP}$  =count of predicted true positives (exact matching of top 10% of segments)
- $N_{TN}$  =count of predicted true negatives
- $N_{AP}$  =count of actual positives, i.e. hotspot segments in the measurements (n=45)
- $N_{AN}$  =count of actual negatives, i.e. non-hotspot segments in the measurements (n=405)

# Methods: Model hotspot prediction precision

- Model precision (P) identifying hotspot segments:

$$P (\%) = \left( \frac{N_{TP}}{N_{AP}} \right) \times 100$$

Where:

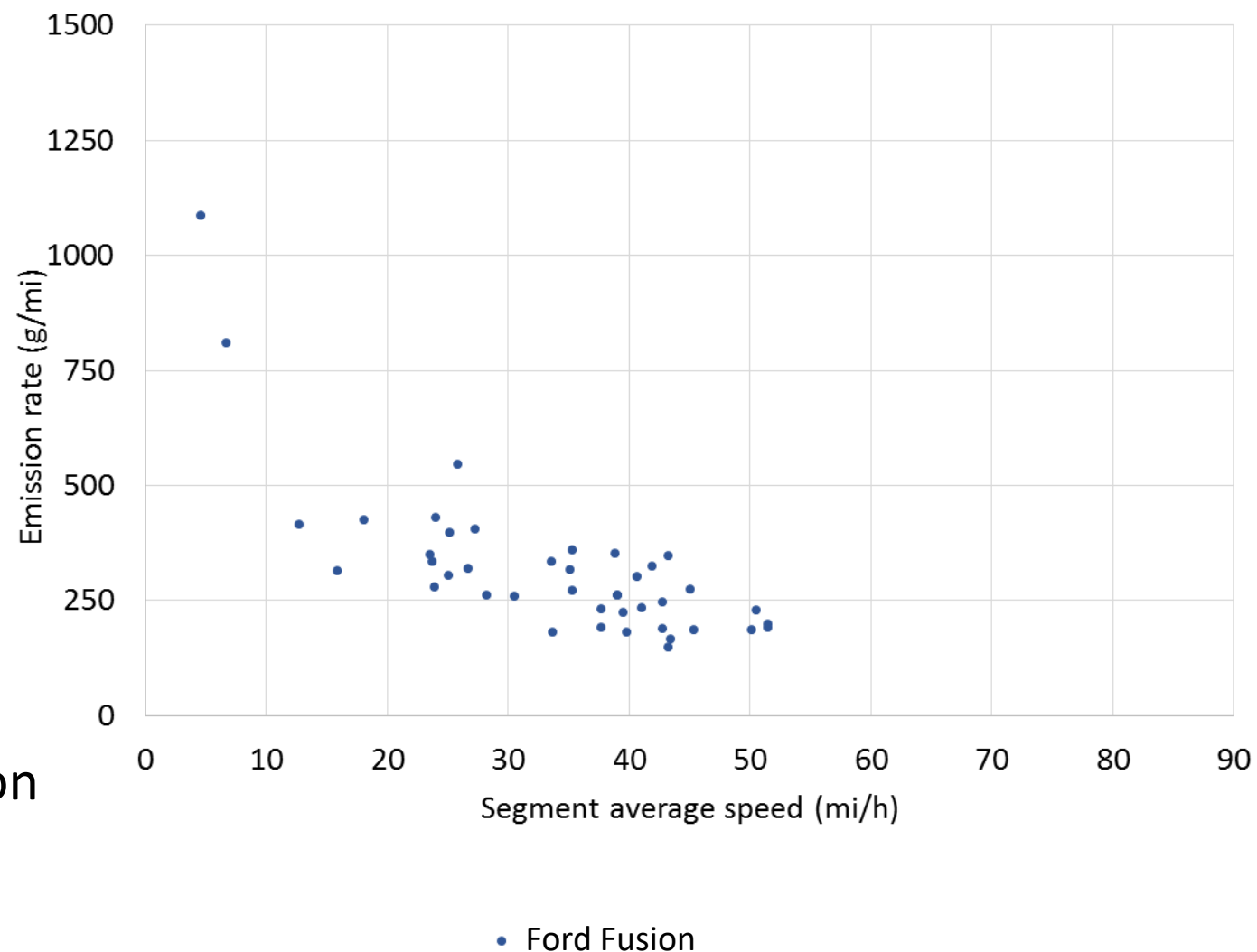
- $N_{TP}$  =count of predicted true positives (exact matching of top 10% of segments)
- $N_{AP}$  =count of actual positives, i.e. hotspot segments in the measurements (n=45)
- **Near misses** of measured hotspots: segments which have segment average modeled emission rates that are below the top 10%, but are in the top 20% ( $\geq 80^{\text{th}}$  percentile).



# Results: MOVES3 modeled emission rates per segment

## CO<sub>2</sub>

- Fleet results based on Ford Fusion vehicle data
- Route A-out
- 42 segments (points)

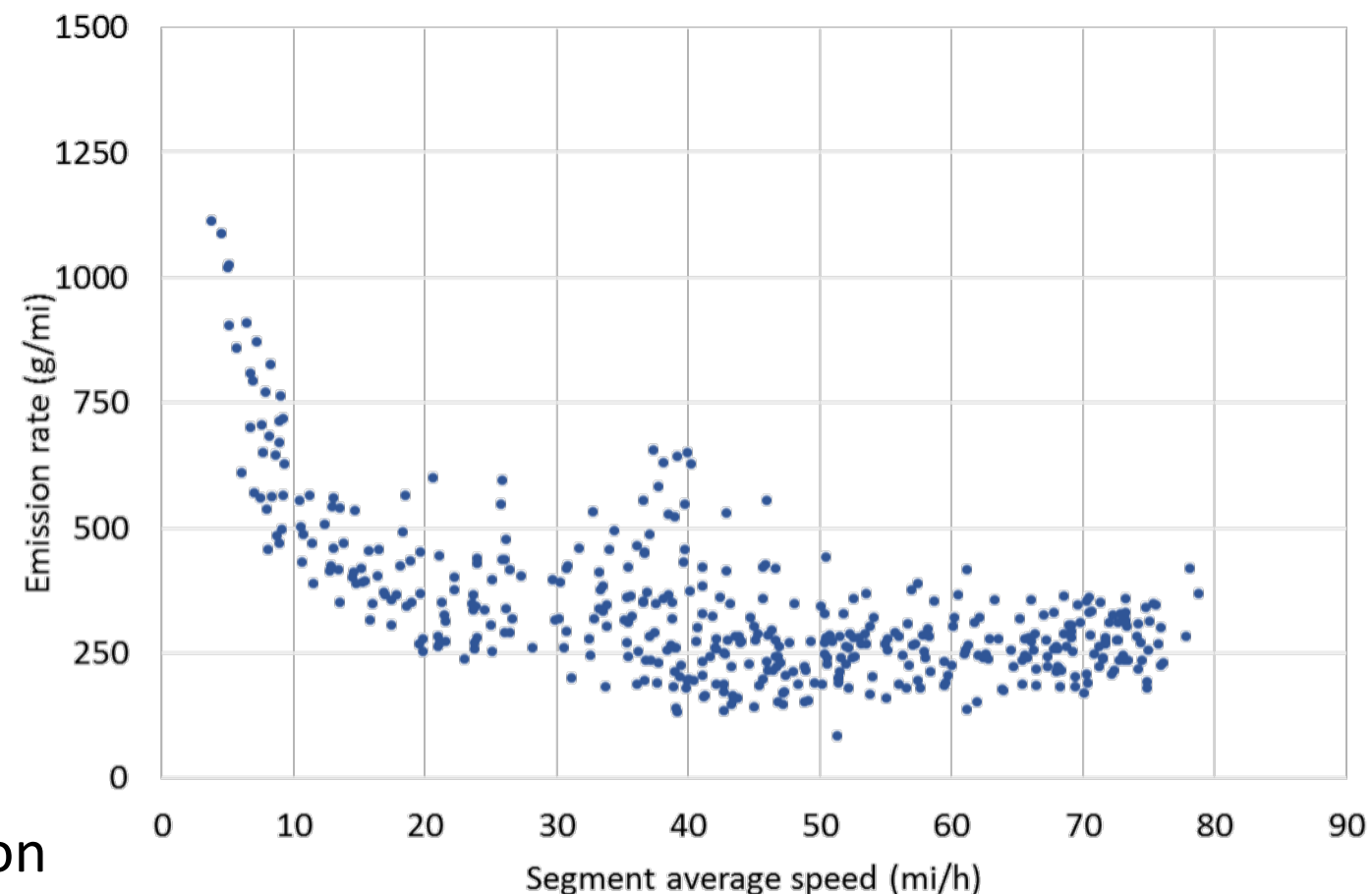




# Results: MOVES3 modeled emission rates per segment

## CO<sub>2</sub>

- Fleet results based on Ford Fusion vehicle data
- All routes
- 450 segments (points)



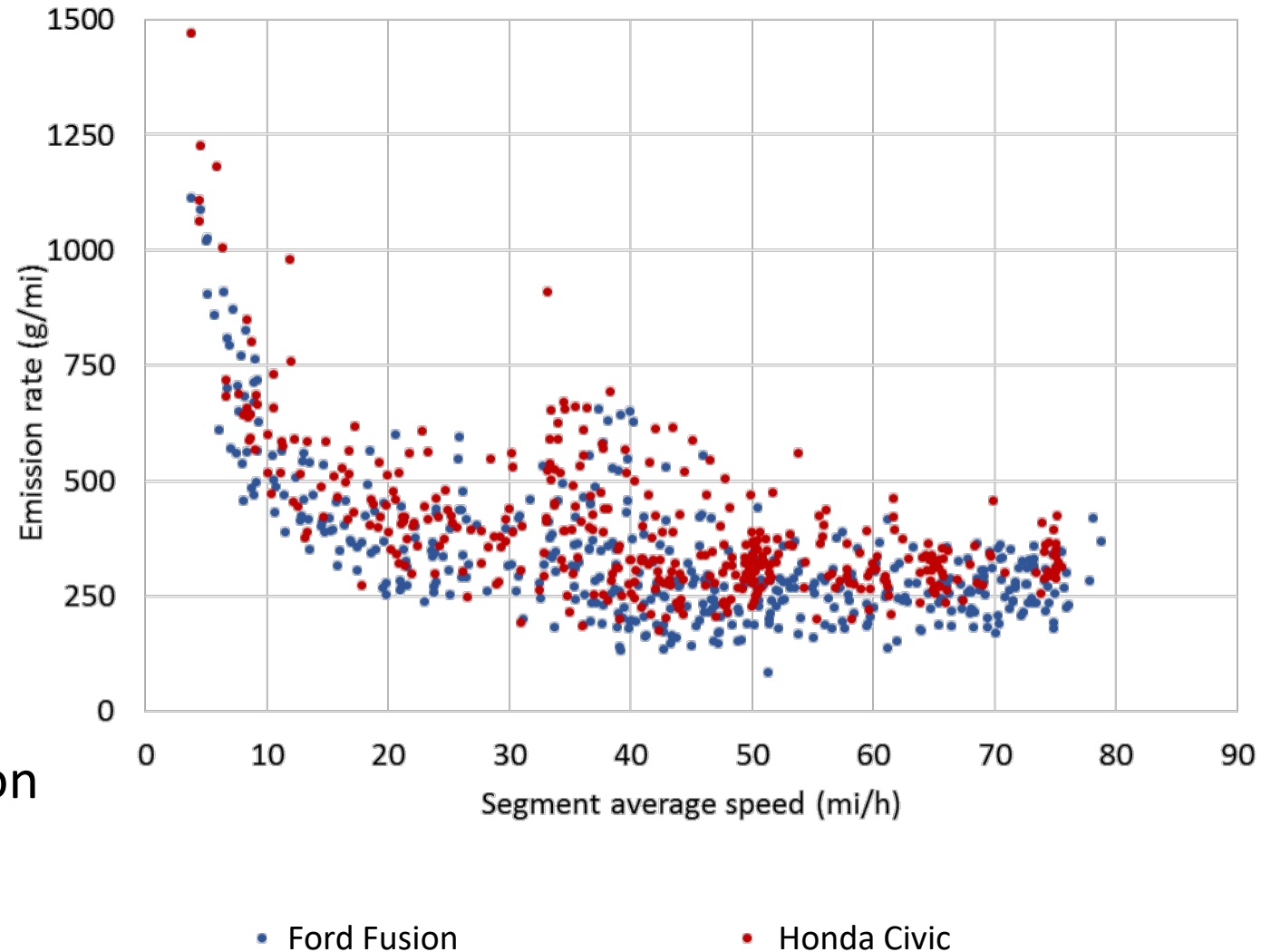
• Ford Fusion



# Results: MOVES3 modeled emission rates per segment

## CO<sub>2</sub>

- Fleet results based on Ford Fusion and Honda Civic vehicle data
- All routes
- 450 segments (points)

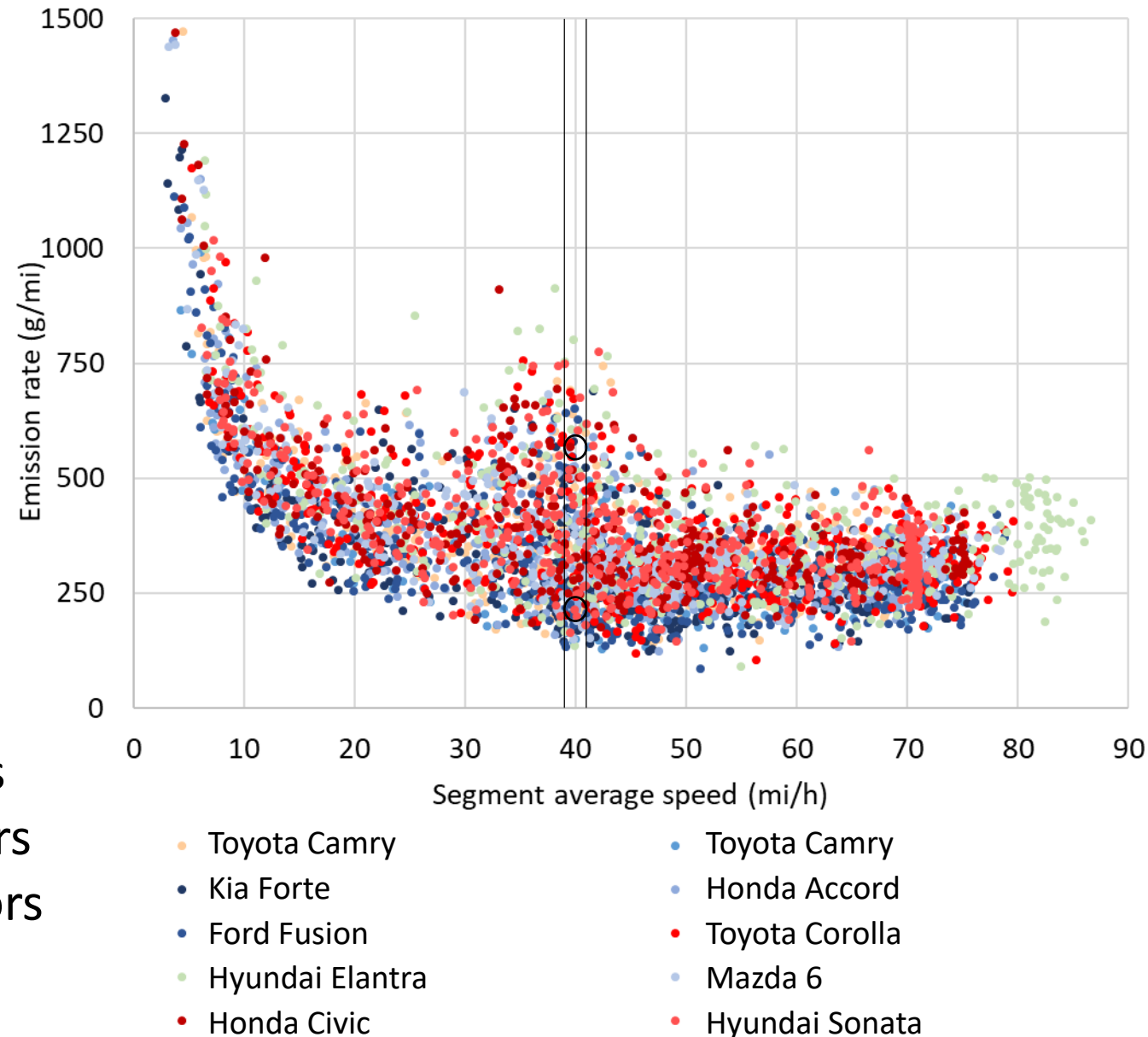




# Results: MOVES3 modeled emission rates per segment

## CO<sub>2</sub>

4201 segments (points) over 8 routes  
Higher avg emission rates in **red** colors  
Lower avg emission rates in **blue** colors



# Results: Modeled emission rates variability for similar average speed

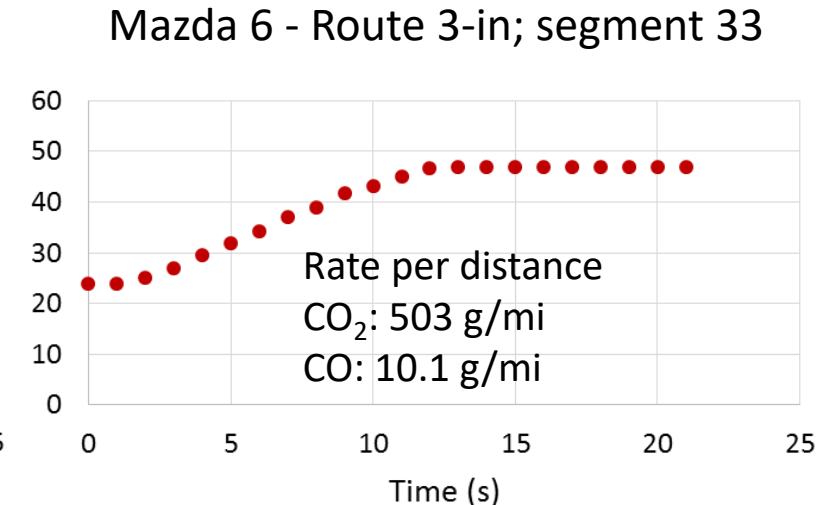
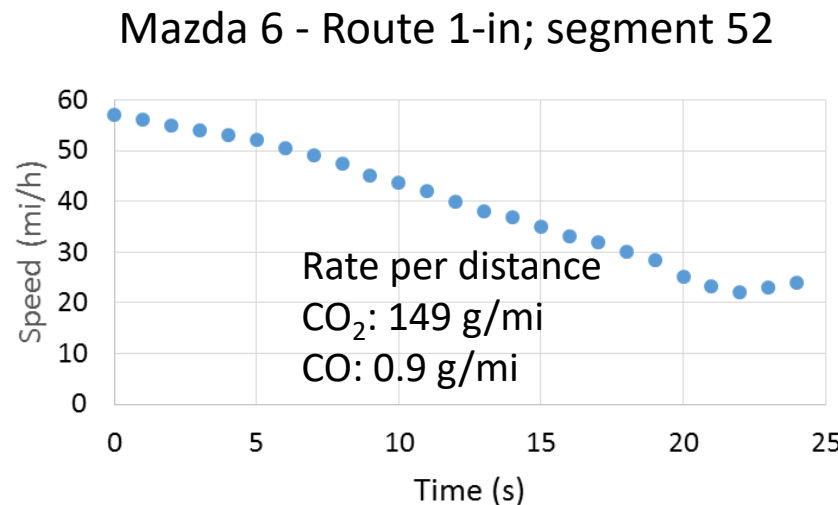
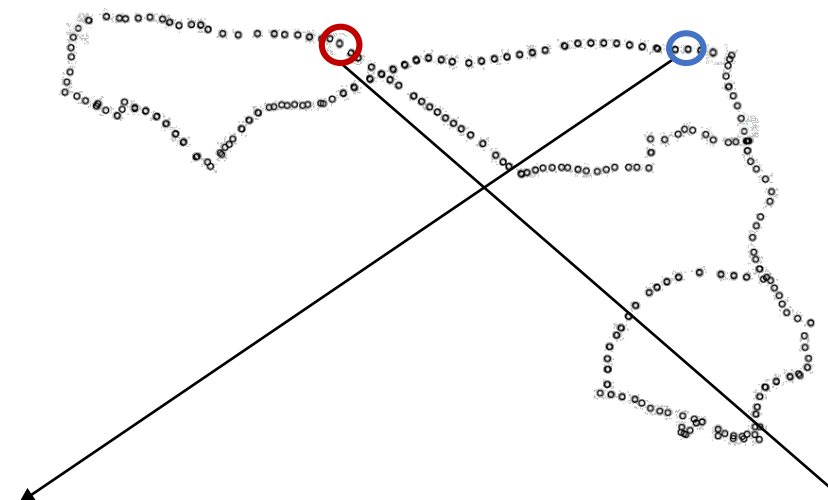
As an example:

- Average speed around 40 mi/h (39.5 - 40.5 mi/h)

Emission rates:

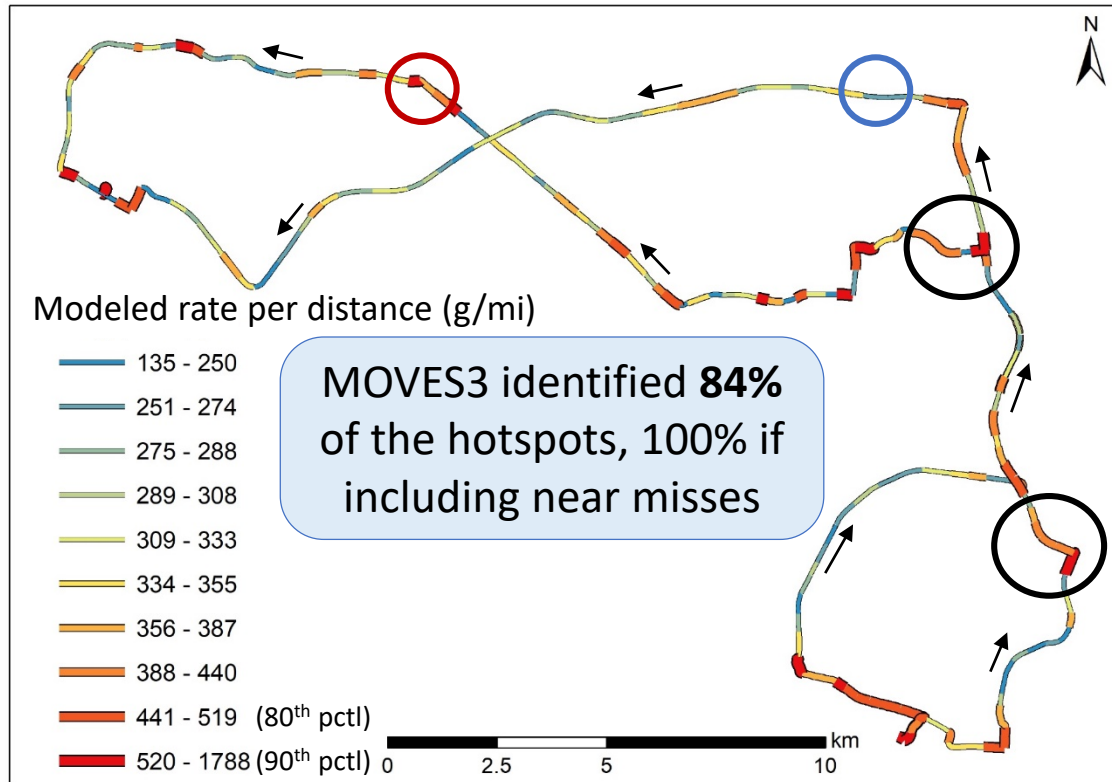
- Lower emission rates for deceleration patterns.
- Higher emission rates for acceleration patterns.

Selected segments second-by-second speed profiles

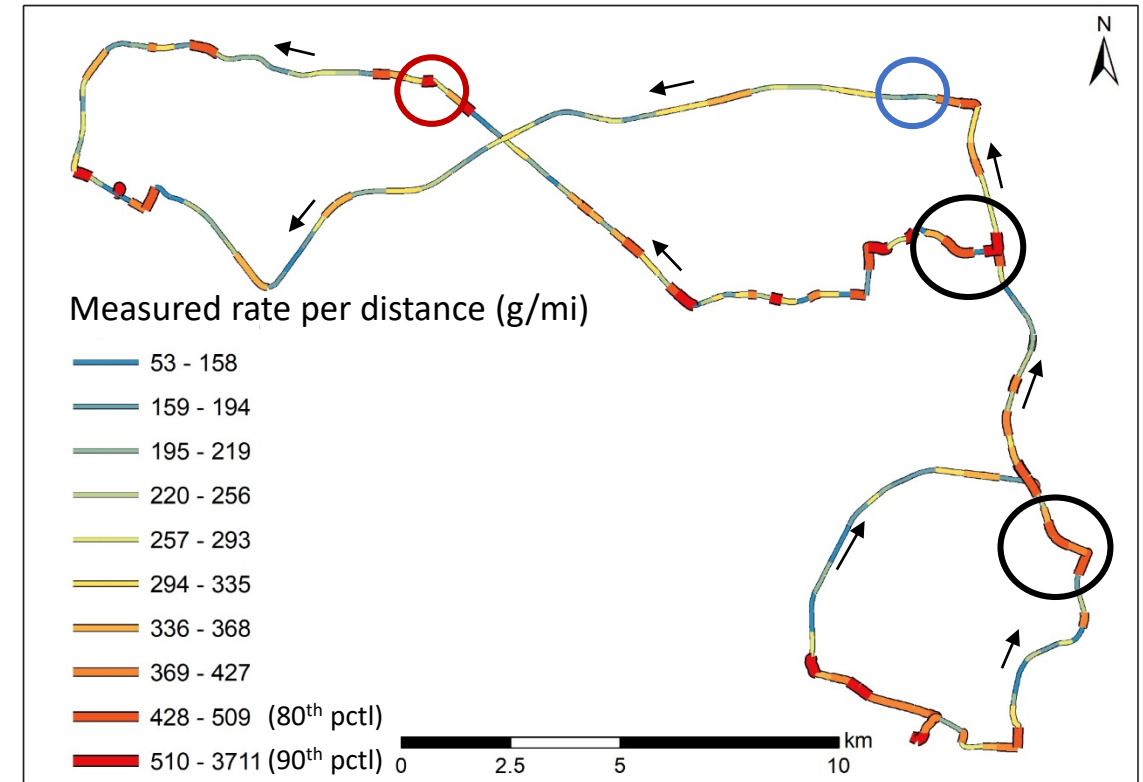


# Results: MOVES3 modeled and measured emission rates per segments – average for 10 vehicles - CO<sub>2</sub>

## Model predicted hotspots



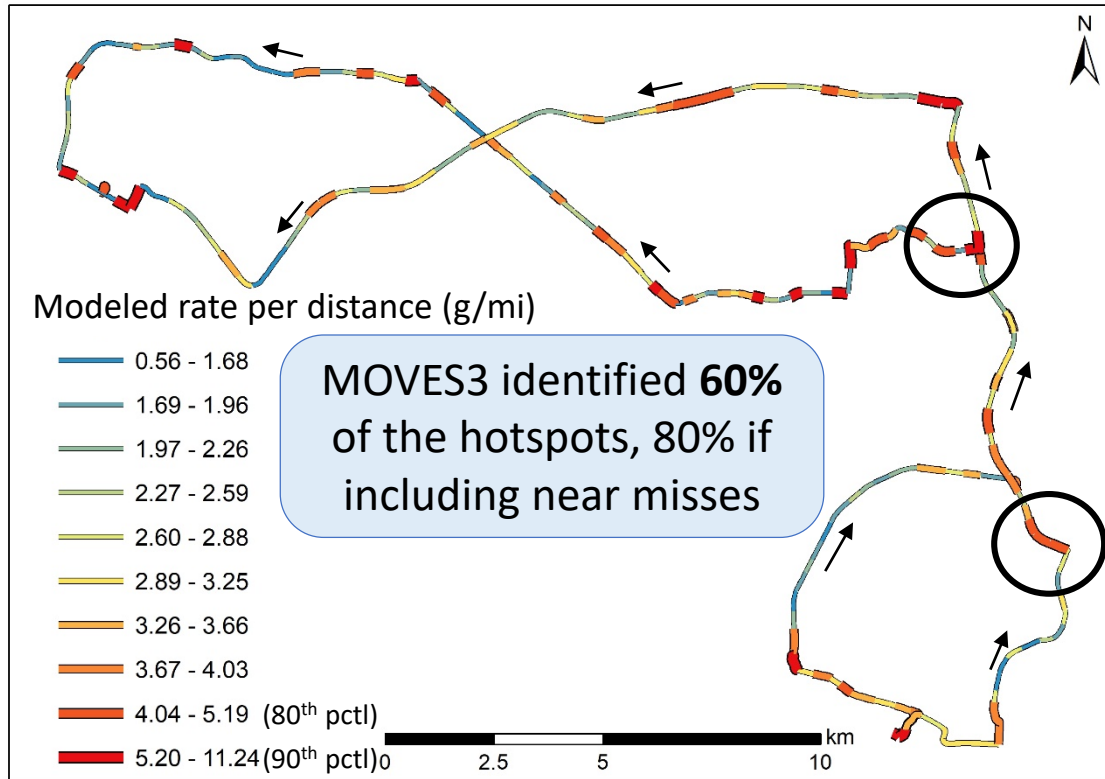
## Measured hotspots



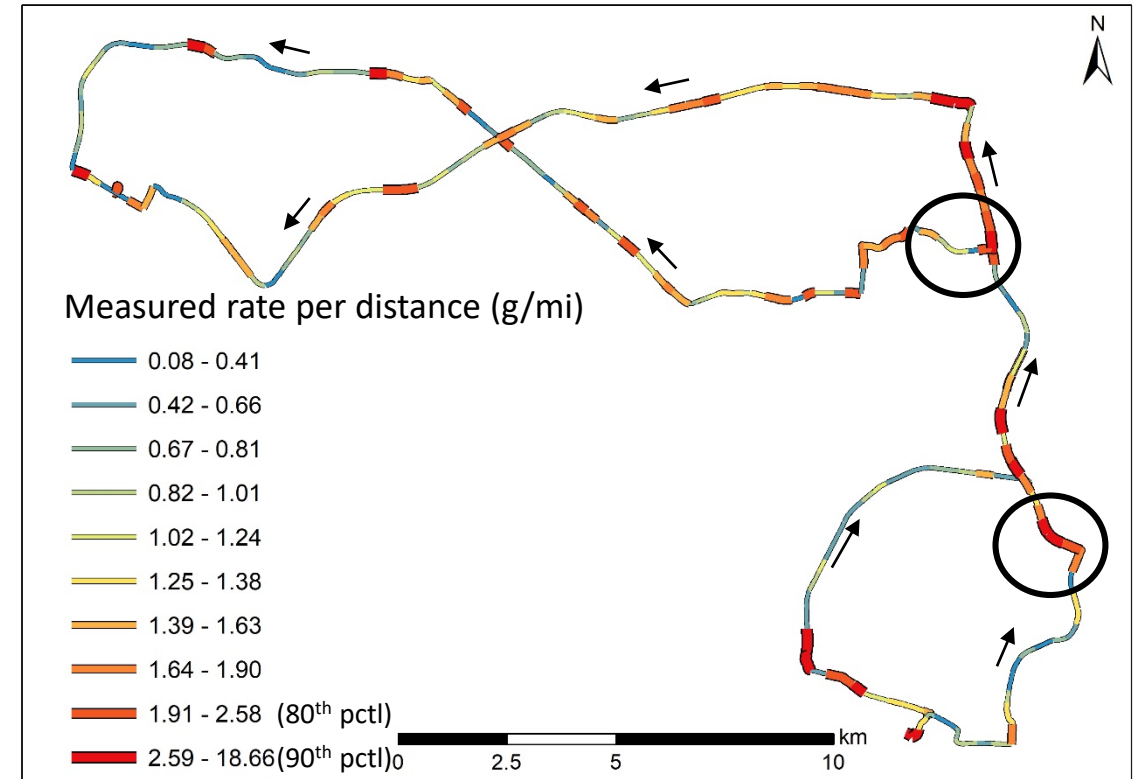


# Results: MOVES3 modeled and measured emission rates per segments – average for 10 vehicles - CO

## Model predicted hotspots



## Measured hotspots



# Results: Model accuracy predicting hotspots and non-hotspots for several pollutants

CO <sub>2</sub> 450 segments	Modeled +	Modeled -
Measured +	38	7
Measured -	7	398

CO 450 segments	Modeled +	Modeled -
Measured +	27	18
Measured -	18	387

NO <sub>x</sub> 450 segments	Modeled +	Modeled -
Measured +	13	32
Measured -	32	373

HC 450 segments	Modeled +	Modeled -
Measured +	26	19
Measured -	19	386

Accuracy and precision per pollutant

	CO <sub>2</sub>	CO	NO <sub>x</sub>	HC
Precision	84%	60%	29%	58%
Accuracy	97%	92%	86%	92%

Results are based on a sample of 10 vehicles



# Results: Model accuracy predicting hotspots and non-hotspots for several pollutants – including near misses

CO <sub>2</sub> 450 segments	Modeled +	Modeled -
Measured +	45	0
Measured -	7	398

CO 450 segments	Modeled +	Modeled -
Measured +	36	9
Measured -	18	387

NO <sub>x</sub> 450 segments	Modeled +	Modeled -
Measured +	23	22
Measured -	32	373

HC 450 segments	Modeled +	Modeled -
Measured +	34	11
Measured -	19	386

## Accuracy and precision per pollutant

	CO <sub>2</sub>	CO	NO <sub>x</sub>	HC
Precision	100%	80%	51%	76%
Accuracy	98%	94%	88%	93%

Results are based on a sample of 10 vehicles

# Conclusions


- The model is highly accurate, at 86% to 97% across pollutants, in locating the measured hotspots and non-hotspots (88 % to 98% including near misses).
- The precision of the model in identifying hotspots, based on the exact matching of the top 10% of segments, depends on the pollutant. The lower precision estimation for NO<sub>x</sub> can be related to the sample size.

# Future steps

- Expand the analysis to a bigger fleet based on a dataset of up to 232 vehicles covering emission standards from tier 1 to tier 3.

# Thank you!

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