Absolute PCA method for emission factors

A mobile monitoring approach

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On-highway vehicle emission factors, and spatial patterns, based on mobile monitoring and absolute principal component score

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What are Emission Factors?

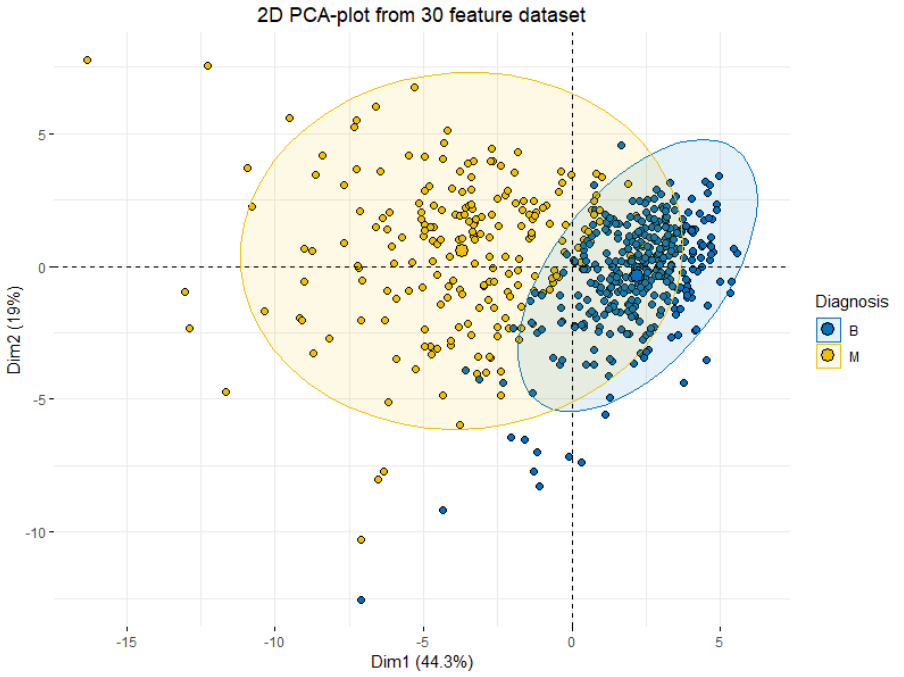
- Pollutant emitted by an actvity
- Expressed as weight of the pollutant divided by a unit weight, volume, distance, or duration of the activity
- Emission factors may differ for petrol- vs. diesel-powered vehicles

What is PCA or Principle Component Analysis?

- Technique to reduce dimensionality
- Replace large set of intercorrleated variables with a smaller number independent variables
- New variables (or dimensions/principle components) are linear combinations of original variables

Remember: Your data stays the same, your frame of reference changes

Example - 2D PCA plot from 30 variables



Mobile Platform

- Ambient-targeted
  - Bangalore study
- Vehicle-targeted
  - Chasing and analyzing exhaust plumes from individual vehicles

Methods

Pollutants

- Measured BC, NOx, CO, CO_2, and PN
- CO_2 is a measure of fuel consumption (traffic volume)
- Diesel trucks are important contributors to NOx, PN, and BC
- petrol vehicles emit more CO than Diesel

Set-up

- petrol powered Buick
- 1 Hz measurements
- Integrated into a database @ 1 record per 10s
  - The information recorded included test time, longitude, latitude and instantaneous speed from the GPS, and 10-s averaged concentrations of NOX, BC, CO, PN, and CO_2 collected simultaneously from five different instruments

Sampling route and set-up

Data Collection

- January 12–18, 2018.
- Routes were covered two to three times each.
- ~30 km/h for busy expressways, ~70 km/h for highways
- ~ one-third of the data were “chase data”
- Chasing Diesel Truck for ~2min and then regular driving looking for next chase
- Chased vehicles were based on convenience
- Total Diesel Trucks chased = 300

Instrumentation

Table 1
Mobile monitoring platform instruments.

Parameter	Instrument	Manufacturer	Measurement range
Black carbon (BC)	AE33 880 nm channel	Magee	0.01–100 μg/m^3
Particle number concentration (PN)	CPC 3007	TSI, Inc.	0.01–1 μm; 0–100,000 #/cm^3
NO_X	CLD 66	Eco Physics AG, Switzerland.	50–25,000 ppb
CO	Series 7100FM	SIGNAL USA	0–1000 ppm
CO_2	LI-820	LI-COR, Inc.	0–20,000 ppm
Position and real-time tracking	Hemisphere GPS		Accuracy ±5 m

Data Processing

Smoothing

- Moving block average of consecutive observations in a 70-s interval centered on each 10-s observation

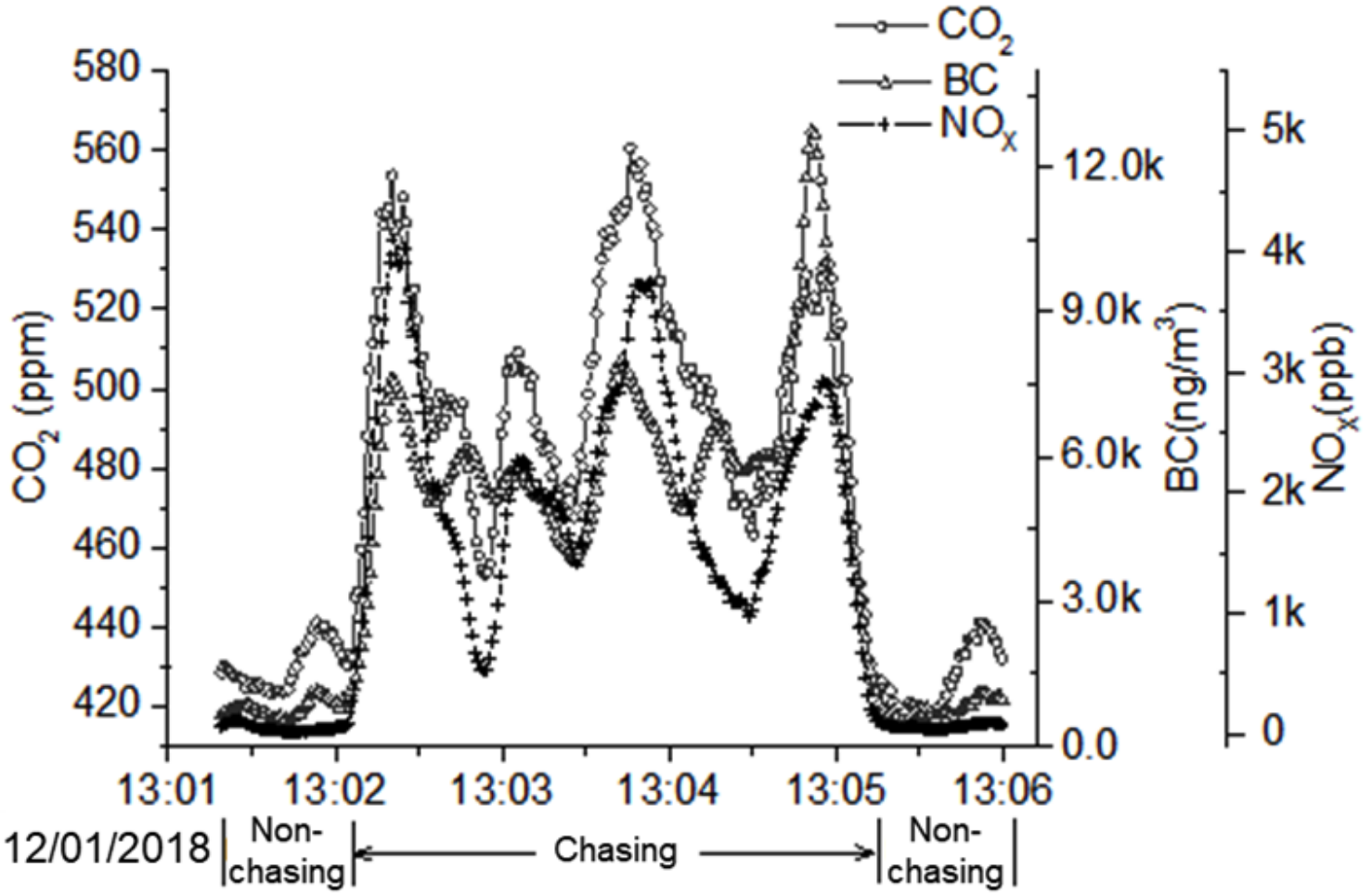
Removing background values

- Estimated bg concentrations with each 10s observation and substracted this bg value from the 70s avg

Removing outliers

- CO_2 concentration < 5ppm (Instrument precision limit)
- Concentration value is above the 95th daily percentile value for each pollutant

Results - Chase & non-chase data



Results - Mean/median concentrations

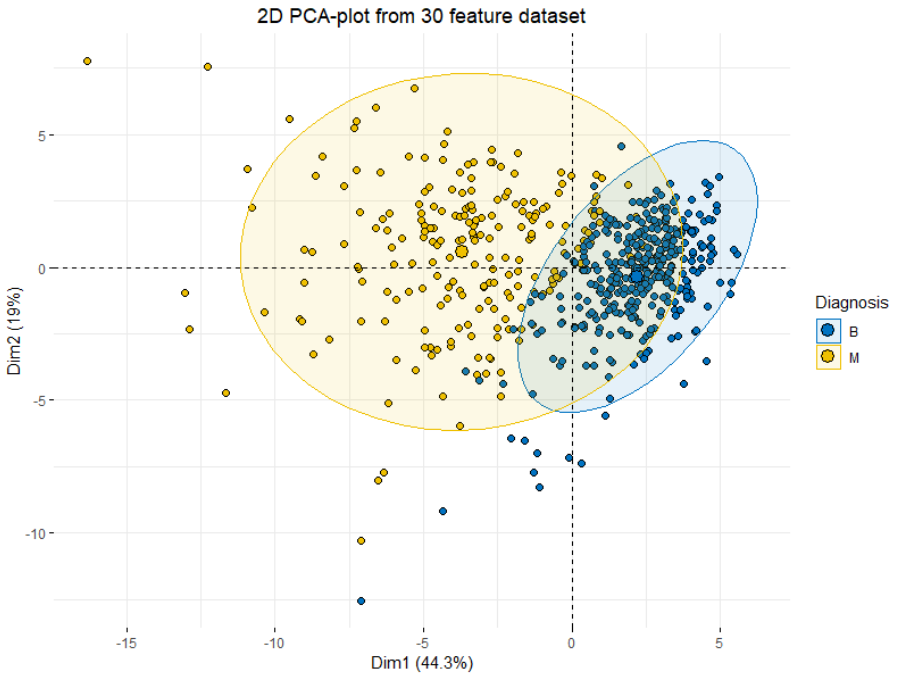
Table 2
Summary of trimmed, adjusted concentrations of non-chase and chase data.

	Non-chase data	Chase data
# of observations	4749	2290
PN median (mean) [#/cm^3]	16,965 (22,442)	34,484 (44,398)
NO_X median (mean) [ppbv]	118 (207)	451 (643)
BC median (mean) [ng/m^3]	3342 (4028)	4645 (6520)
CO median (mean) [ppmv]	0.71 (0.88)	0.61 (0.87)
CO_2 median (mean) [ppmv]	440 (508)	549 (721)

Principle Component Analysis

Technique to reduce dimensions

Your data stays the same, your frame of reference changes



Results - PCA for non-chase data

- PN, NOx and BC have high values in first principle component
- CO has higher values in second principle component
- the two components account for 67% of the variance of the non-chase data.

Table 3
Loadings, eigenvalues and proportion variances of two principal components from PCA for the non-chase data.

Pollutants	PN-NO_X-BC-rich feature	CO-rich feature
PN	0.829	0.031
NO_X	0.834	0.008
BC	0.789	0.112
CO	0.020	0.849
CO_2	0.244	0.750
Eigenvalues	2.18	1.19
Proportion variances	0.413	0.261

Results - PCA for chase data (Diesel Truck)

- NOx has high values in first principle component
- PN and BC have higher values in second principle component
- the two components account for 65% of the variance of the non-chase data.

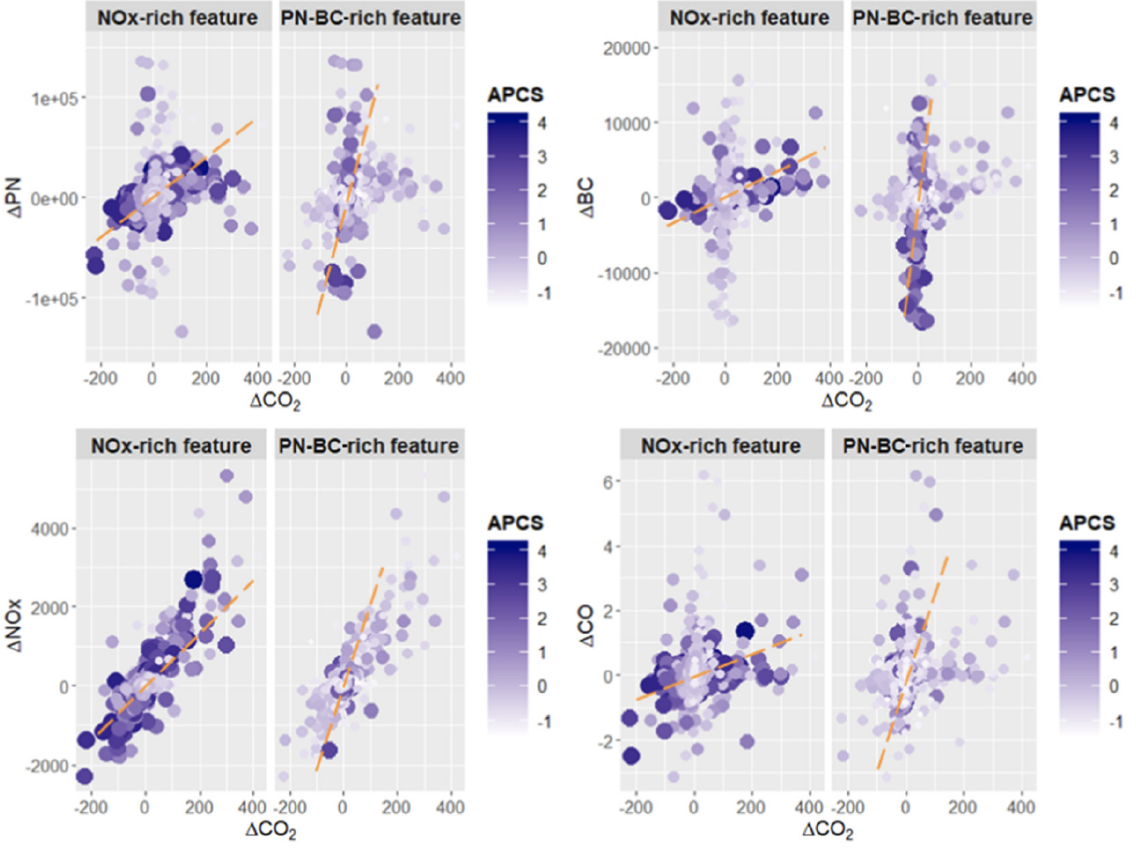
Table 4
Loadings, eigenvalues and proportion variances of two principal components for the chase data for HDDT plumes.

Pollutants	NO_X-rich feature	PN-BC-rich feature
PN	0.335	0.775
NO_X	0.910	0.160
BC	−0.116	0.877
CO	0.132	0.002
CO_2	0.941	0.008
Eigenvalues	1.97	1.29
Proportion variances	0.371	0.280

Results - PCA for chase data (Diesel Truck)

How does pollutant concentration change with change in traffic volume?

- Slope indicates (relative) emission factor
- Higher emitters have higher slopes



Reminder

NOx-rich feature refers to NOx being a strong component of that feature. It does not necessarily mean that (NOx)emission factor is higher for that feature than for other feature (PN-BC rich feature).

Results - Spatial variation - non chase

Diesel trucks are prohibited from entering the arterial roads in main urban area so they are mainly seen on the ring roads

CO rich feature

PN-NOx-BC-rich feature

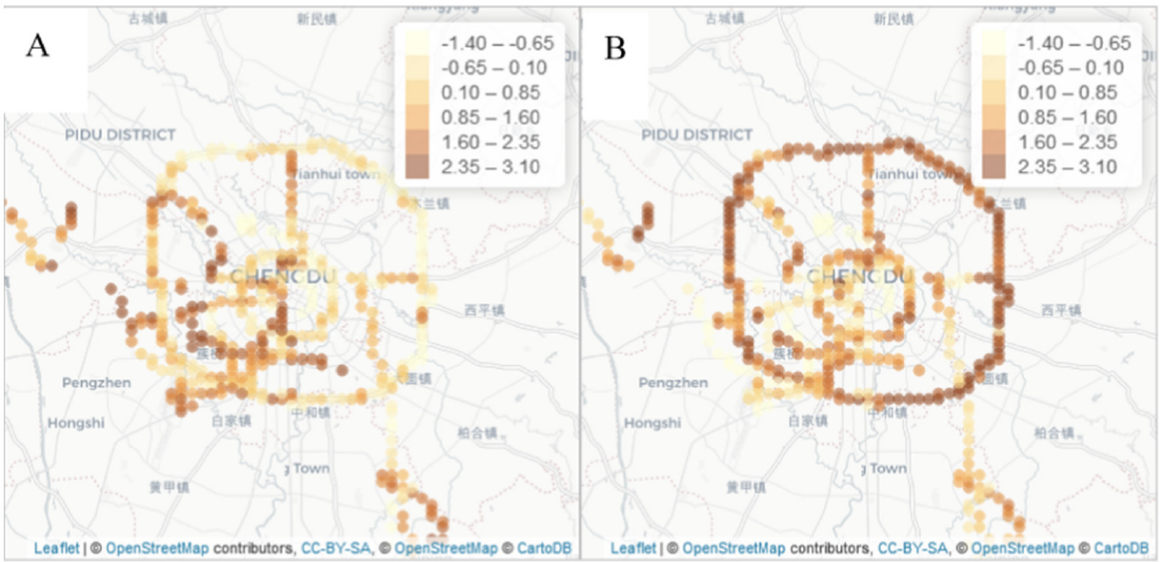


Fig. 3. Spatial distribution of the Varimax-rotated features for non-chase data. (A) CO-rich feature; (B) PN-NO_X-BC-rich feature. Color is proportional to relative significance of the feature at that location.

Results - Spatial variation - chase (Diesel Truck)

- NOx-rich(normal emitting) is prominent in second-ring road
- High emitting is prominent in fourth ring road
- In 2018 non-compliant vehicles could not enter the area within 3rd RR

NOx rich feature

PN-BC-rich feature

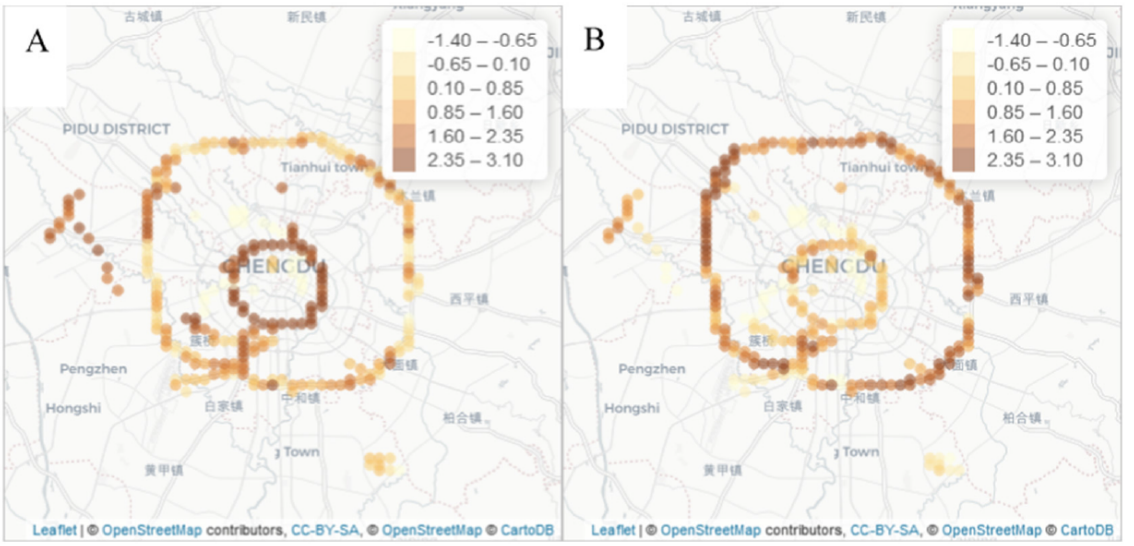
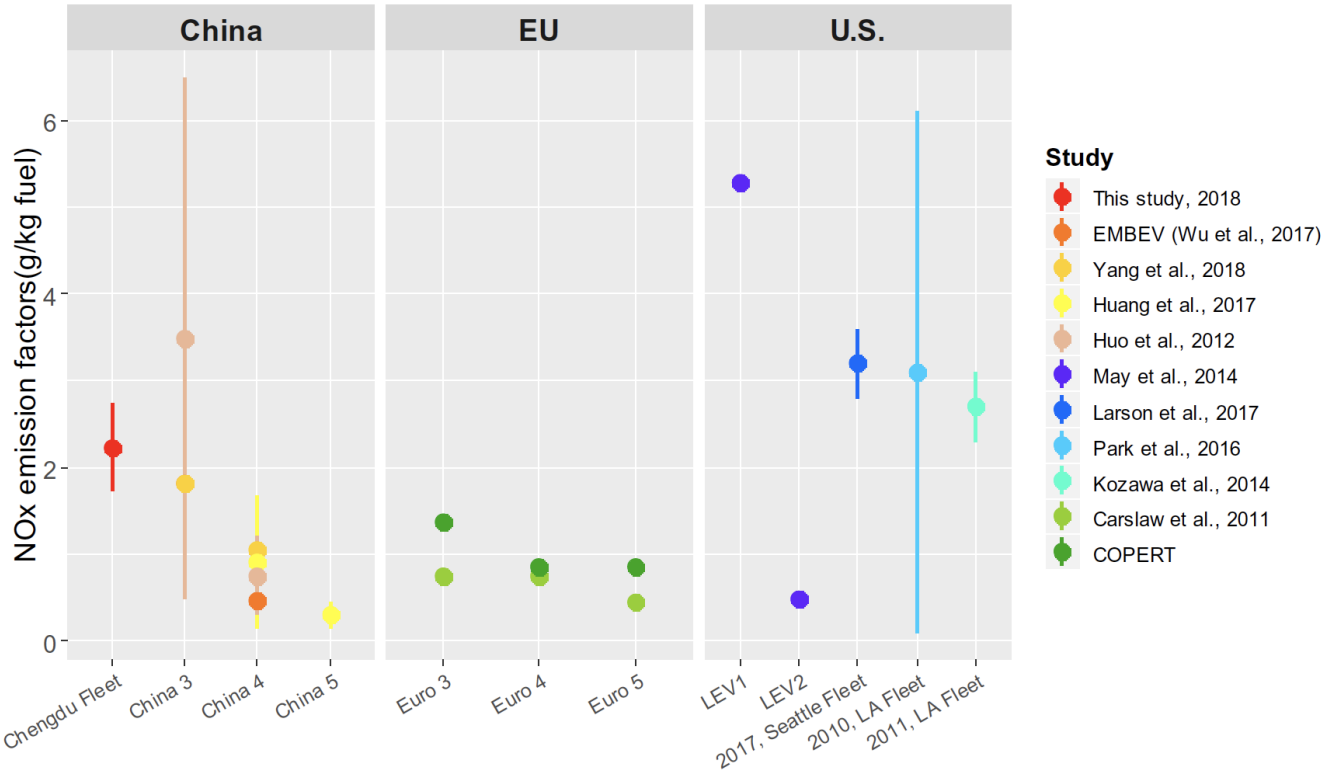
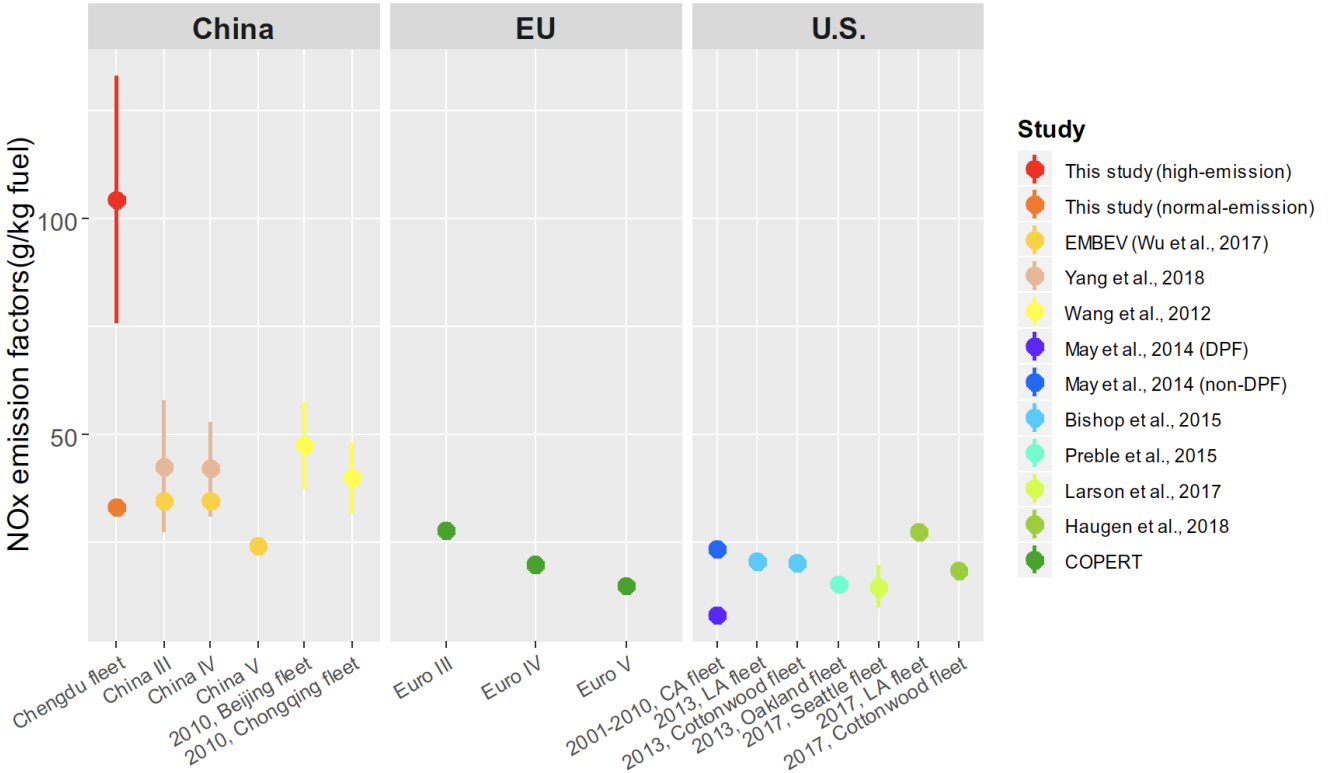


Fig. 4. Spatial distribution of the Varimax-rotated features for HDDTs' chase data. (A) NO_X-rich feature; (B) PN-BC-rich feature.

Results - NOx Emission factor - Petrol



Results - NOx Emission factor - Diesel



Summary

- APCA approach can differentiate between diesel and petrol vehicles
- High-emitting diesel trucks are 3–13 times dirtier than normal
- Removing high emitters can reduce emissions by half
- Identifying and removing a small fraction of vehicles from a fleet can have significant reductions in emissions

Thanks!

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