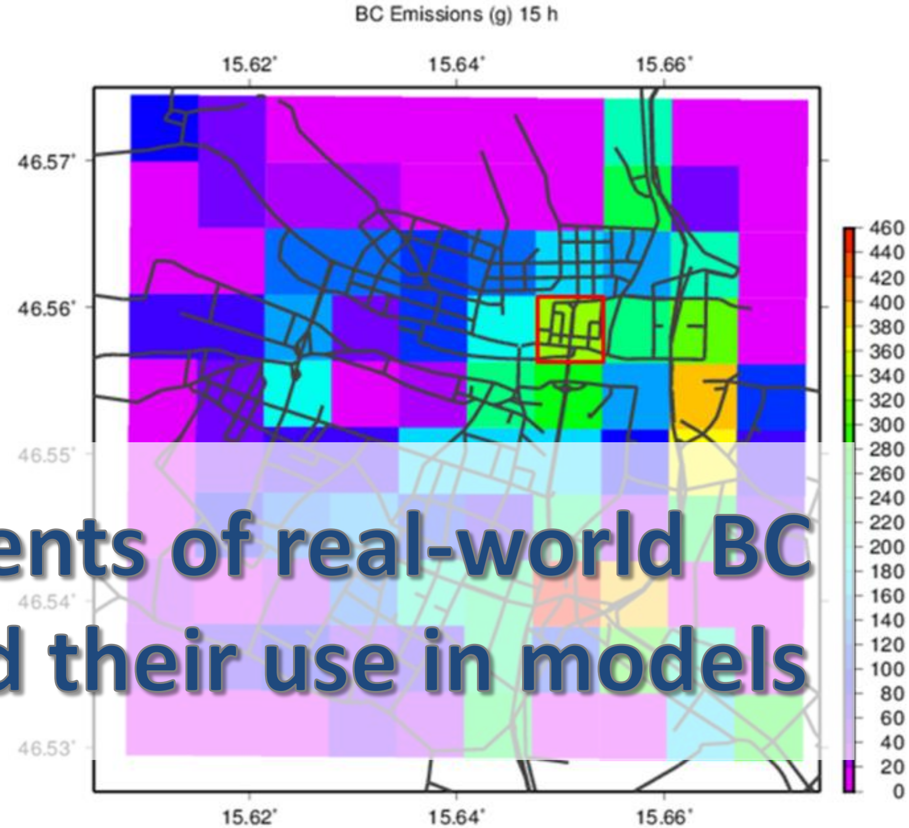

On-road measurements of real-world BC emission factors and their use in models

Training School on Black and Brown Carbon

15. - 17. January 2018, Ljubljana

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Real world EF measurements

- Less precise and repeatable (absence of a standard test cycle, additional sources of variability)

+ validation of EFs gained from laboratory testing

+ identification of gaps in emission models and establish model development priorities.

- **<u>on-road</u>** <u>(chasing)</u>
- remote sensing
- on-board measurements (PEMS)
- tunnel

Le Tunnel Guy Môquet sur l'A86.
© Jean-Claude PATTACINI Institut d'Aménagement et d'Urbanisme Île-de-France

Franco et al., 2013, Atmo. Envir.

Outline

TESTS

- tests of on-road chasing method in controlled conditions, comparison to remote sensing and on-board measurements

MEASURMENT CAMPAIGNS

- Results of two on-road measurement campaigns made in 2011 and 2017.

MODELING

- Modeling BC emission rates in a small city and verification with *in-situ* measurements

ON-ROAD EF MEASUREMENT TESTS

The chasing vs. stationary method measurements

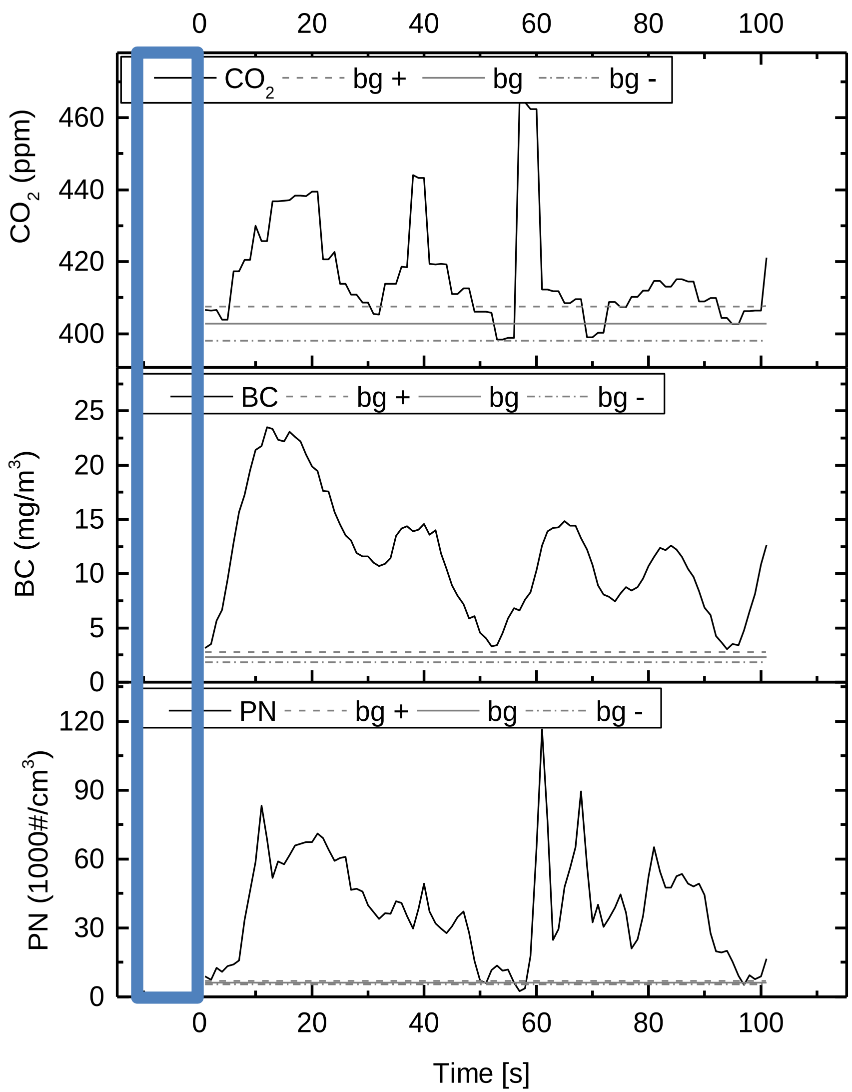
- Comparison of chasing and stationary method for measurement of the same pollutants
- Testing both methods on 5 contemporary cars (three drivers)

Chasing method – measuring exhaust of the vehicle by following it on road (5 laps on the 1.3 km circuit)
Stationary method – immediate increase of pollutants when the vehicle passes the measurement station (several repetitions using different driving regimes)

Instruments:
Aethalometer AE33(BC),
Carbocap (CO_2)
FMPS (PN)

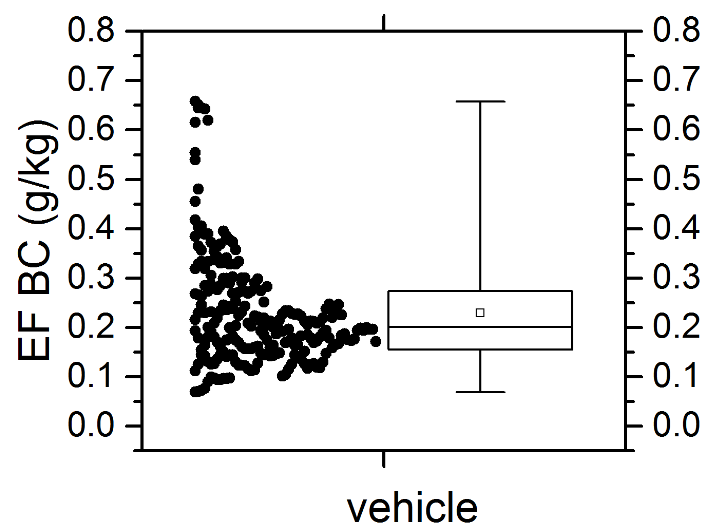
Ježek et al., AMT, 2015

Emission factor (EF) determination

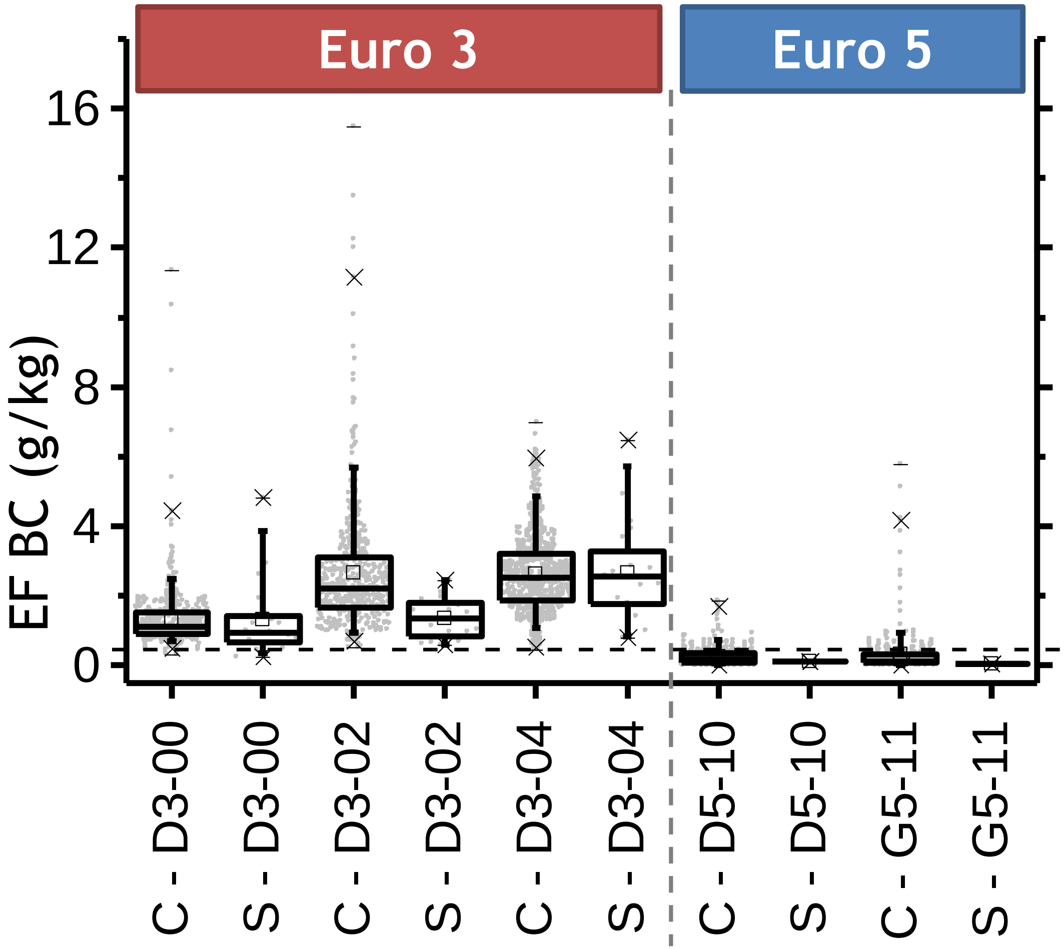


$$EF_P = \frac{\int_{t_1}^{t_2} ([P]_t - [P]_{t_1})dt}{\int_{t_1}^{t_2} ([CO_2]_t - [CO_2]_{t_1})\,dt} \cdot w_c$$

EF distribution for a single chasing event



Results: Comparing EF determined with chasing (C) and stationary (S) method



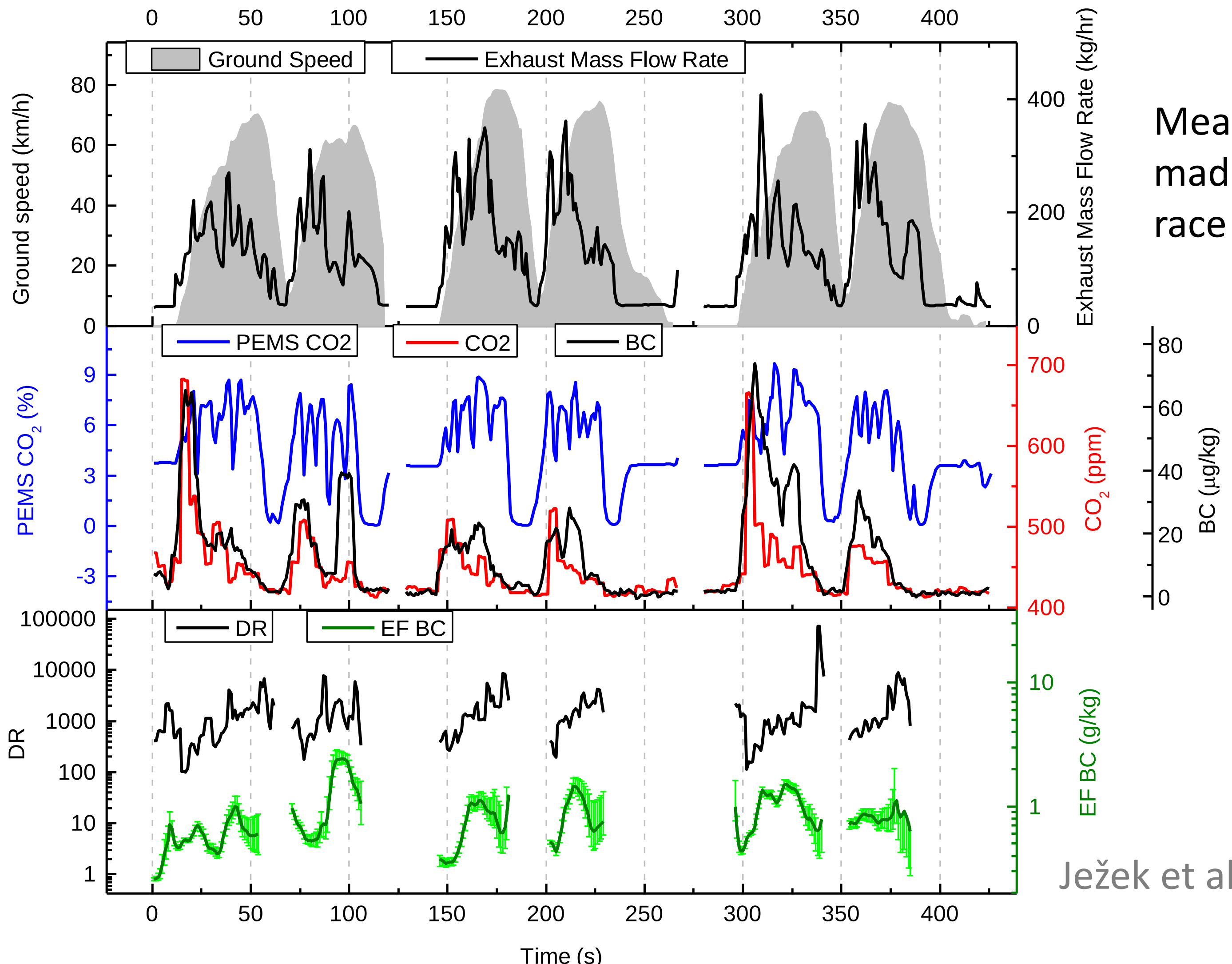
Tested cars:

Acronym	Fuel	Stand.	Year of first registration
D3-00	Diesel	Euro 3	2000
D3-02	Diesel	Euro 3	2002
D3-05	Diesel	Euro 3	2005
D5-10	Diesel	Euro 5	2010
G5-11	Gasoline	Euro 5	2011

Ježek et al., AMT, 2015

- First comparison of the chasing and stationary methods.
- Chasing and stationary EF measurements give similar results.

The tailpipe measurements performed with the portable emission measurement system (PEMS)



Measurements made on Monza race track

Ježek et al., AMT, 2015

The BC EF does not show any significant dependence on the DR, and the uncertainty of EF (light green) increases when the CO_2 emissions are low.

TESTS - Conclusions

- Chasing and stationary EF measurements give similar results.
- The BC EF does not show any significant dependence on the dilution ratio.
- The uncertainty of EF increases when the CO_2 emissions are low.

ON-ROAD EF MEASUREMENTS

Fast response instruments
Aethalometer AE33 – BC (1s)
Vaisala Carbocap GMP343 – CO_2 (2s)
2B Technologies NOx monitor (10s)
or Eco Physics CLD 86 – NOx (1s)
TSI FMPS – PN (1s)

3 x 100 Ah batteries

Ministry of infrastructure RS
provided data on vehicles.

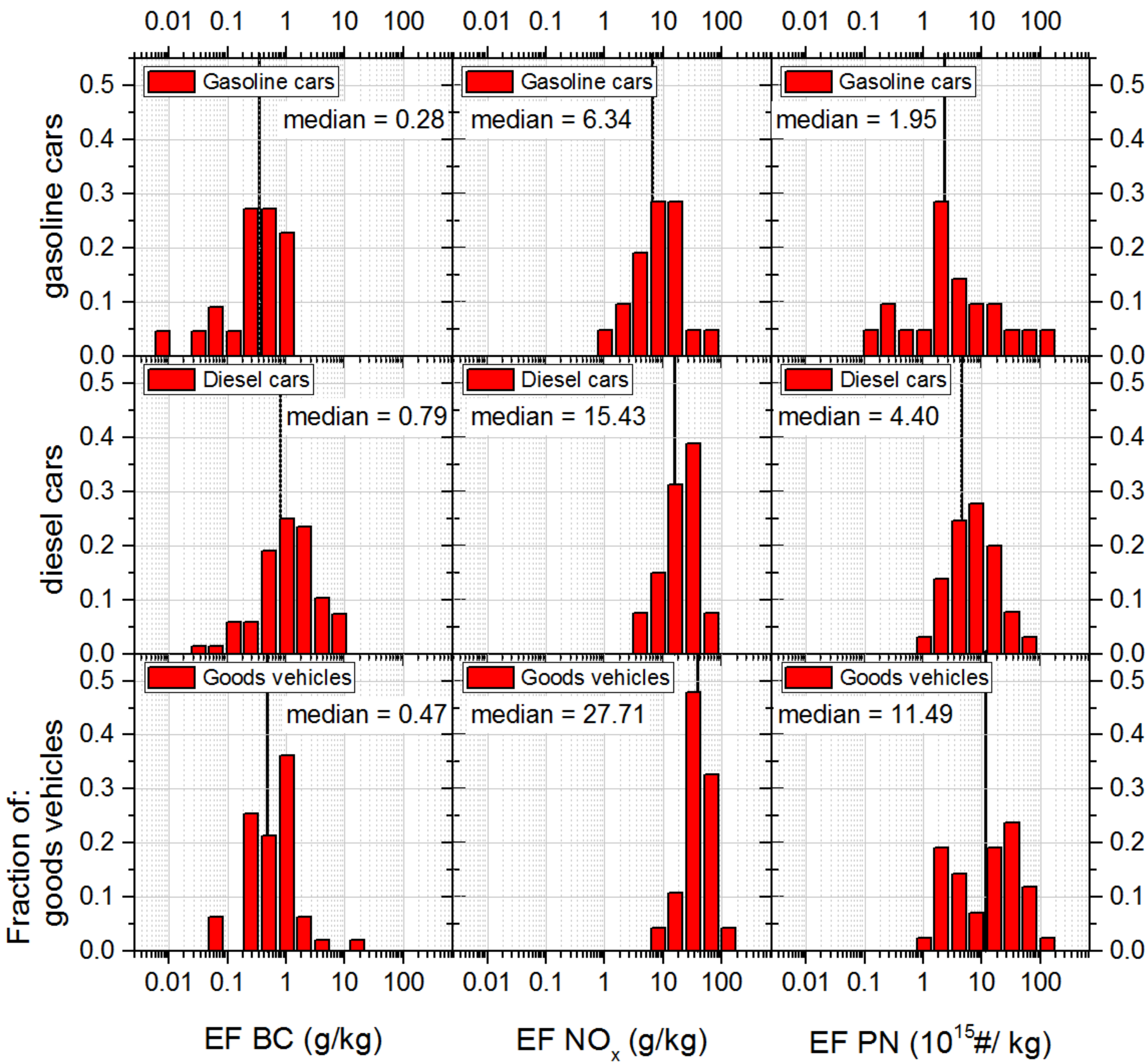
ON-ROAD EF MEASUREMENTS

- 1st in December 2011 (results published in ACP, Ježek et al., 2015)
- 2nd in March 2017 (preliminary results)

Category	Vehicle type	# in 2011	# in 2017
Gasoline cars	Gasoline cars (M1)	24	113
Diesel cars	Diesel cars (M1)	51	119
	Light goods vehicles (N1)	17	41
Heavy Goods Vehicles (HGV)	Light goods vehicles (N2)	8	12
	Mini bus (M2)	1	0
	Buses (M3)	6	14
	Heavy goods vehicles (N3)	32	81
Total		**139**	**380**

Results 2011

The **first reported BC EF for individual diesel cars** measured in real driving conditions.



Ježek et al., ACP, 2015

Comparing our results to other on-road studies

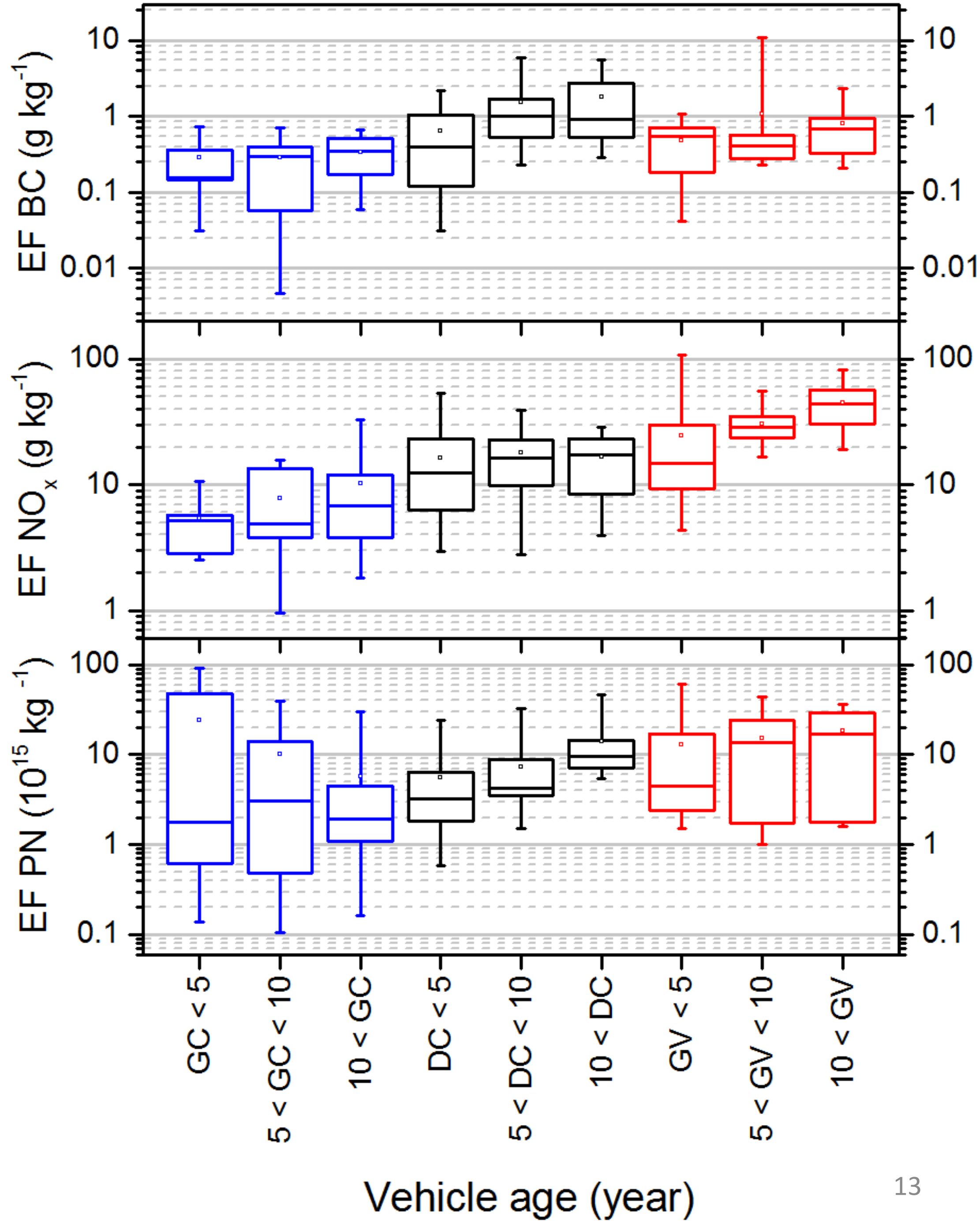
Study	Study type	Vehicle type	EF BC (g kg^{-1})	EF NO_X (g kg^{-1})
Shorter et al., 2005	Chasing [a]	Diesel buses		34.5 (8.1 – 117.1)
		CRT		27.8 (±6.3)
Wang et al.,2012	Chasing [b]	HGV Beijing	0.4 (0.2-0.8)	47.3 (38.1 - 62.5)
		HGV Chongqing	1.1 (0.7-1.6)	40.0 (31.7-48.1)
Dallmann et al., 2011	Remote s. [c]	HGV (2009)	1.07 ± 0.18	25.9 ± 1.8
		HGV (2010)	0.49 ± 0.08	15.4 ± 0.9
Dallmann et al., 2013	Remote s. [c]	HGV	0.62 ± 0.17	
Carslaw and Rhys-Tyler, 2013	Remote s. [d]	Gasoline cars		5.34 (1.15 - 26.83)
		Diesel cars		16.37 (14.82 – 20.65)
		Van		18.1 (16.87 – 23.59)
		HGV (all)		37.88 (35.13 – 48.37)
Chasing 2011 (Ježek et. al., 2015)	Chasing [b]	Gasoline cars 2011	0.28 (0.005–1.52)	6.74 (3.3 – 13.16)
		Diesel cars 2011	0.92 (0.03–5.87)	15.47 (9.15 – 23.28)
		LGV 2011	0.56 (0.05–5.24)	20.25 (11.84 – 28.22)
		HGV 2011	0.45 (0.04–11.01)	29.6 (23.18 – 48.67)

Ježek et al., ACP, 2015

Effect of vehicle age 2011 campaign

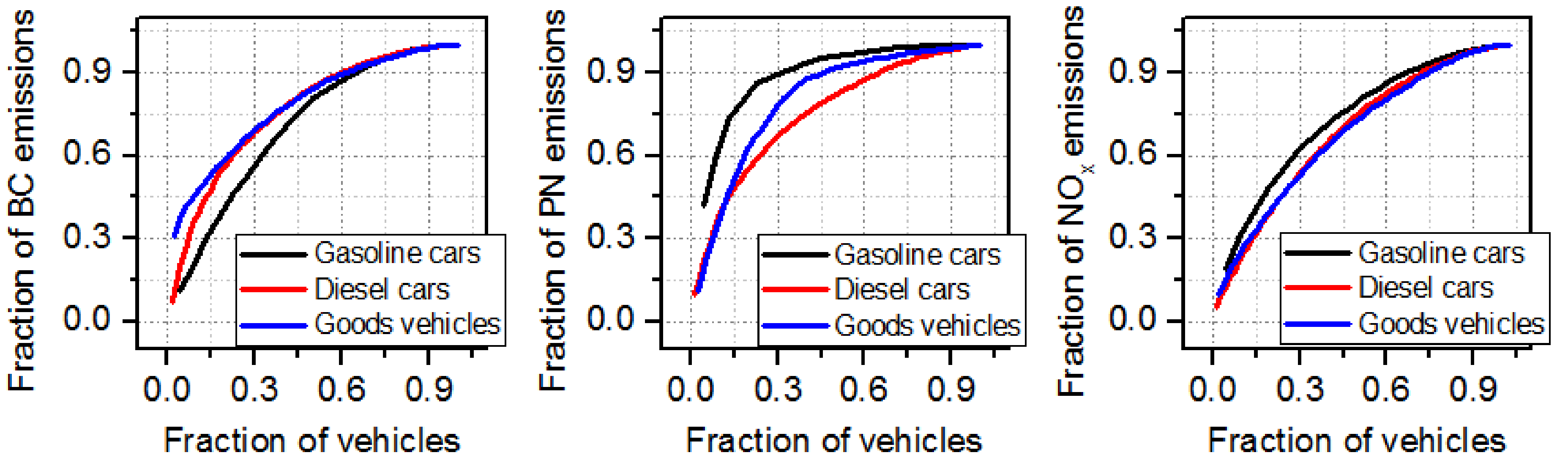
Less than 5 years ≈ Euro 4 and 5
Between 5 and 10 ≈ Euro 3
10 and more ≈ Euro 2 or less

- The median BC EF of diesel cars that were in use for less than 5 years was **reduced by a 60%** compared to those in use for 5 – 10 years.
- **No decrease** in median BC EF of the goods vehicles.
- PN and NO_x EF of goods vehicles were **reduced by 52% and 67%,** respectively



Ježek et al., ACP, 2015

„Super emitters“ contributions to total fleet emissions 2011



- Contribution of super emitters: 25% of vehicles was found to disproportionately contribute to the total fleet emissions 47% to 87%.
- 25% of emitting diesel cars contributed 63%, 47% and 61% of BC, NO_x and PN.

Ježek et al., ACP, 2015

On-road EF measurements Conclusions

- The **first reported BC EF for individual diesel** cars measured in real driving conditions in 2011
- Good agreement with the results of previous studies.
- Follow-up study with a larger fleet sample in 2017
- **Reduction BC EF of diesel cars and HGV** with introduction of new technology.
- **No decrease in median NOx EF of diesel cars.** There was a **reduction in median NOx EF for gasoline cars** and **HGV.**
- Simple and efficient methodology for monitoring emissions of the in-use vehicle fleet

Modeling traffic emission rates

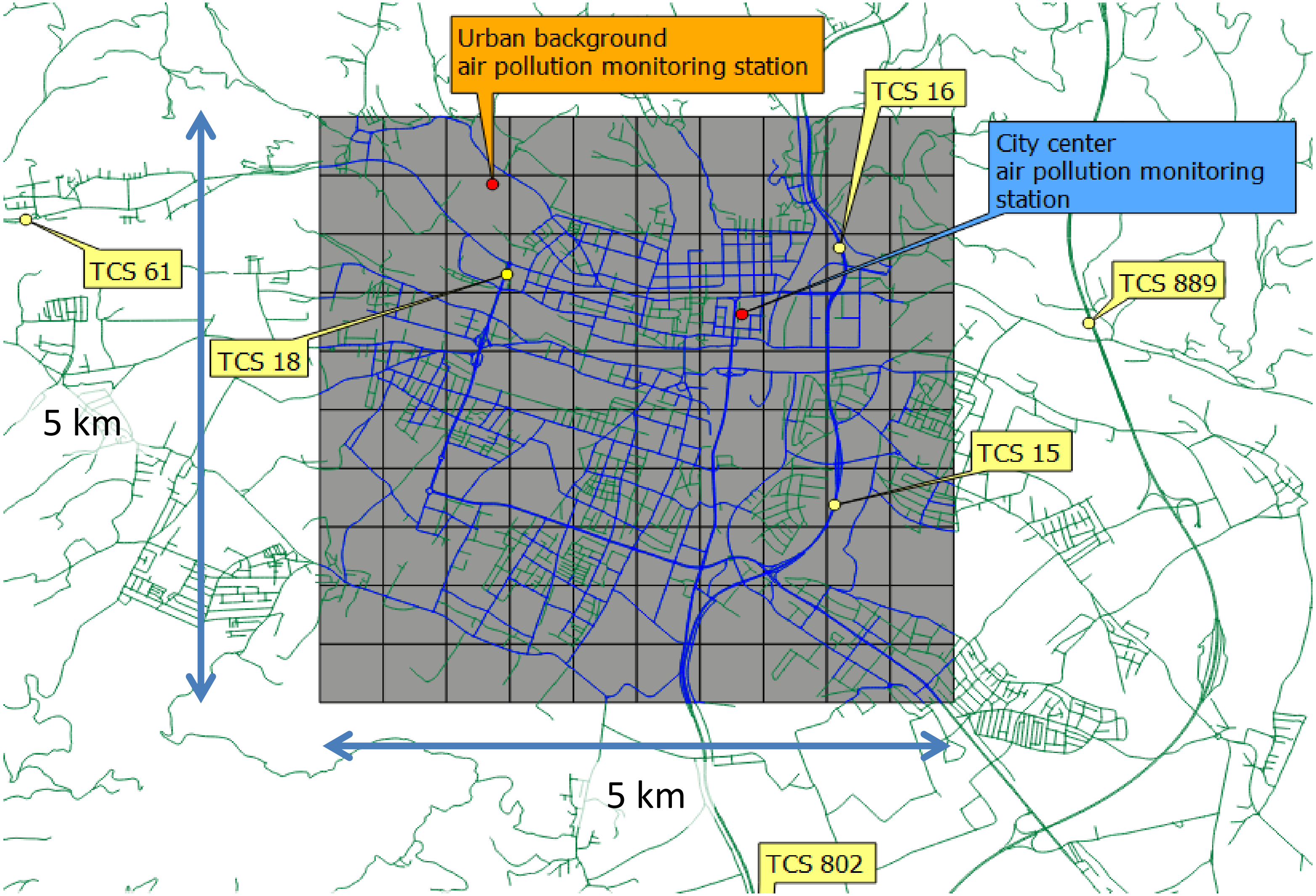
Modeling BC and NO_x traffic emission rates with EMISENS model

$$Q_{ip}(x,y,t) = \sum_{Ie}^{NIe} \bar{e}_{ip,Ie} \, A_{Ie}(x,y,t)$$

- Emission reduction scenarios
- Model validation with in-situ measurements
  - In-situ BC measurements apportioned to traffic with the Aethalometer model
  - Empirical diffusion model

*Modeled BC concentrations = diffusion * BC emission rates*

Study area – Maribor, Slovenia



Ambient measurement periods of BC winters: 2010/11, 2011/12, 2012/13

Road map from a noise study (Drev et al., 2009) in blue.

INPUT DATA:
Emission factors and vehicle categories

Category	Subcat. I	Subcat. II	EF BC g/km	EF NO_x g/km	Weight factor α	
LV (< 3.5 t)	CARS	Gasoline cars	0.022	0.560	**0.63**	**0.94**
		Diesel cars	0.072	1.036	**0.36**	
	LT		0.066	2.222	/	**0.06**
HV (> 3.5 t)			0.237	7.917	/	

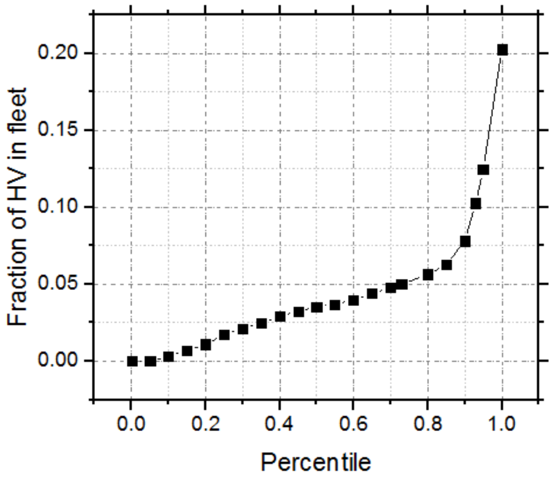
Emission factors measured with on-road chasing method (Ježek et al., 2015, ACP)

Fuel consumption (EMEP/EEA guidebook 2013)

Traffic count data

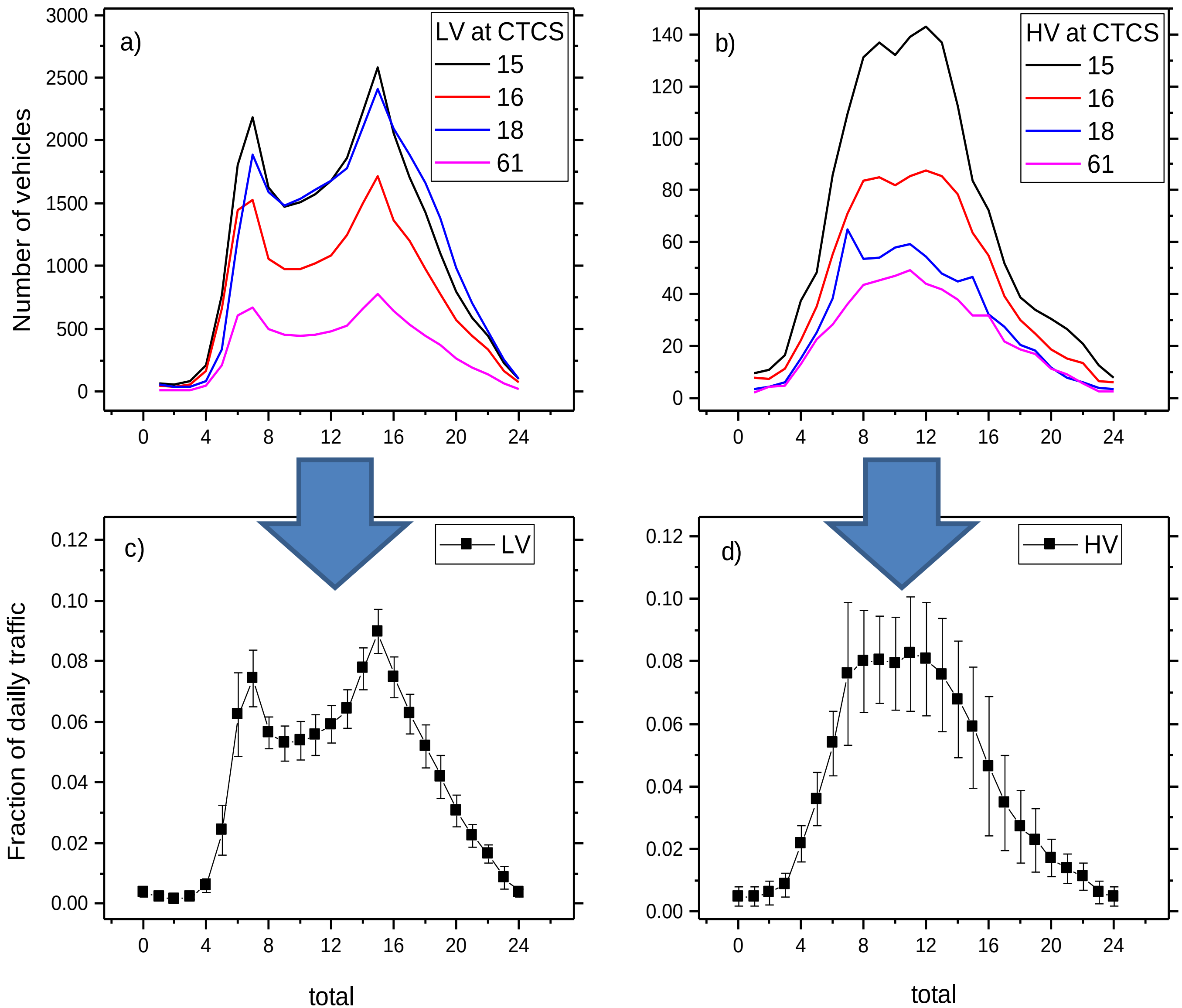
- used to investigate fleet composition

Sites	CAR	LT	HV
15, 16, 18, 61	86 – 93%	4 – 7%	2– 7%
802, 889	81– 56%	10 – 12%	19 – 34%



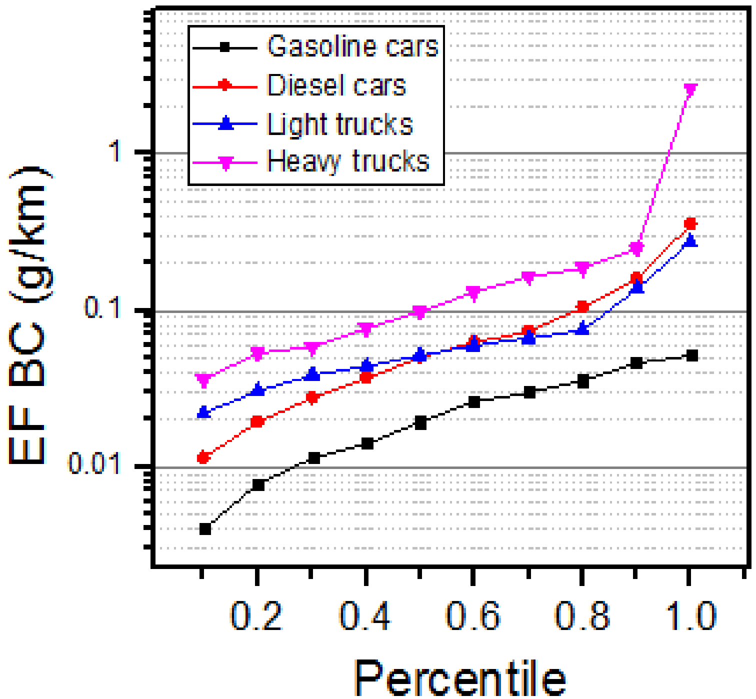
- verify the Annual Average Daily Traffic on the road map
- calculate the diurnal traffic flux profiles for light vehicles LV (<3.5 t) and heavy vehicles HV (> 3.5t)
- calculate the weights for light trucks (LT) and cars in LV category

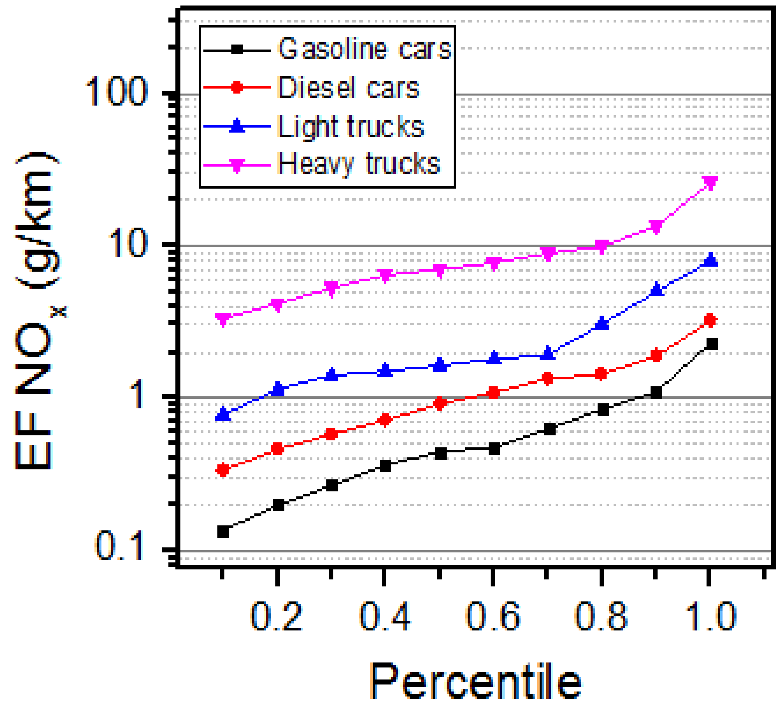
INPUT DATA: Diurnal traffic flux profiles



Emission reduction scenarios

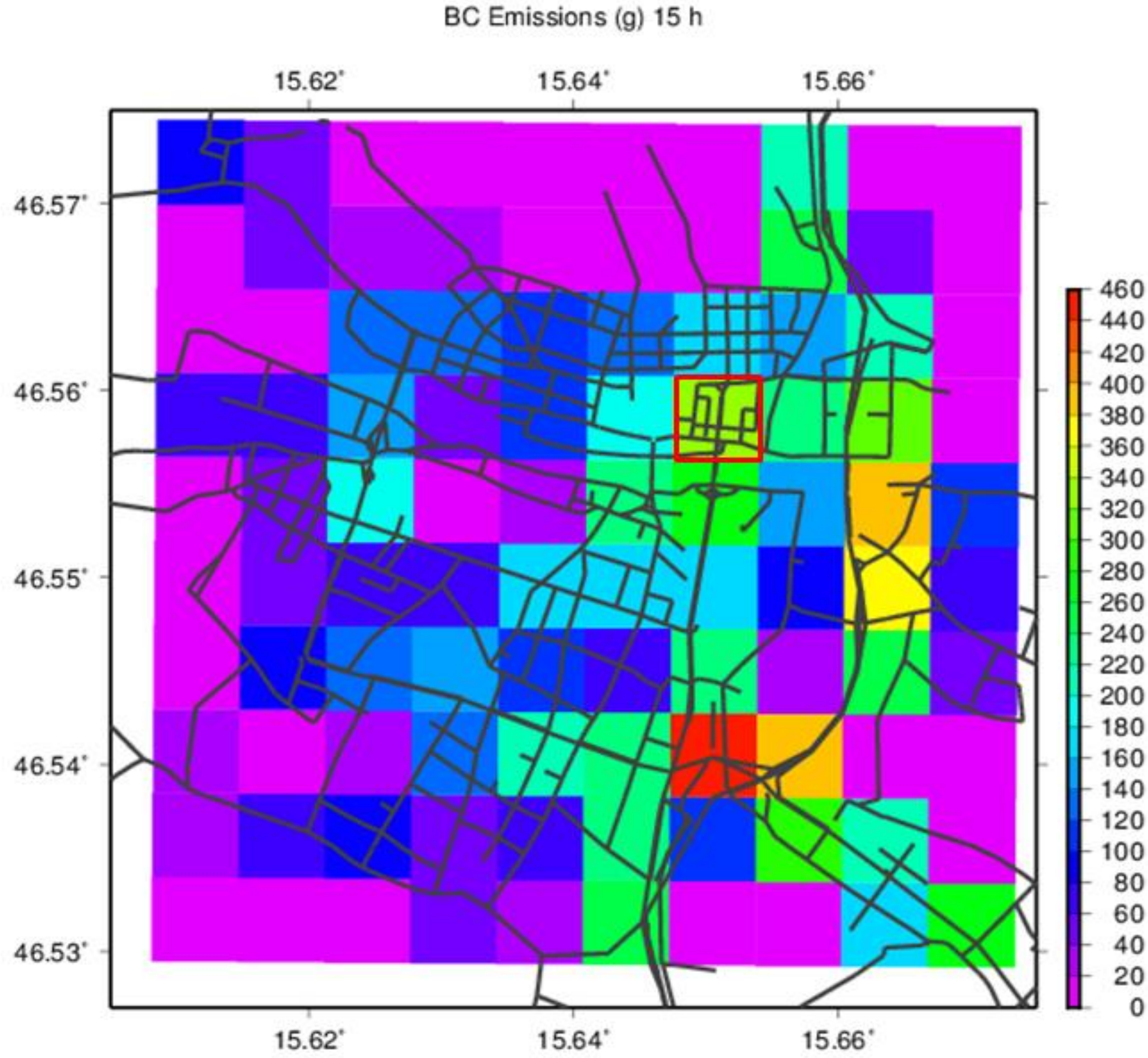
a) replacing HV with LT
b) excluding vehicles older than 15 years (10%)
c) excluding 10% of highest BC emitters
d) excluding 10% of highest NO_x emitters





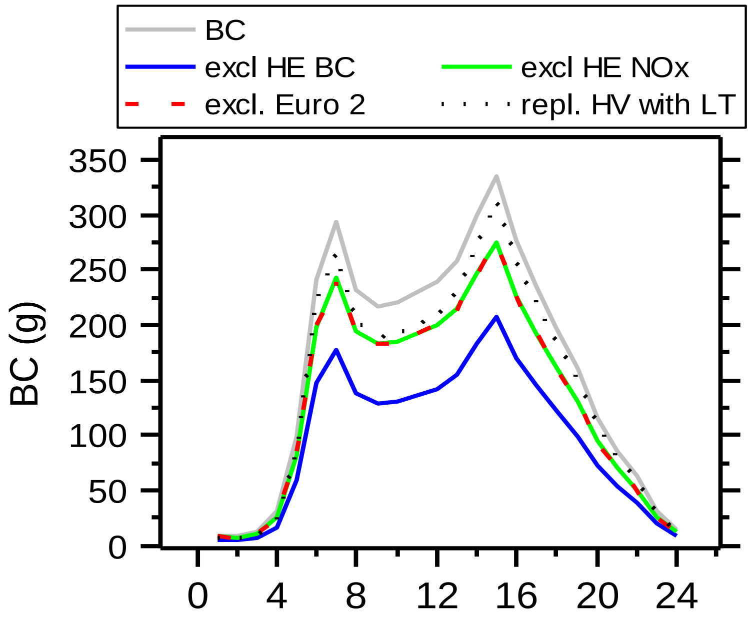
RESULTS

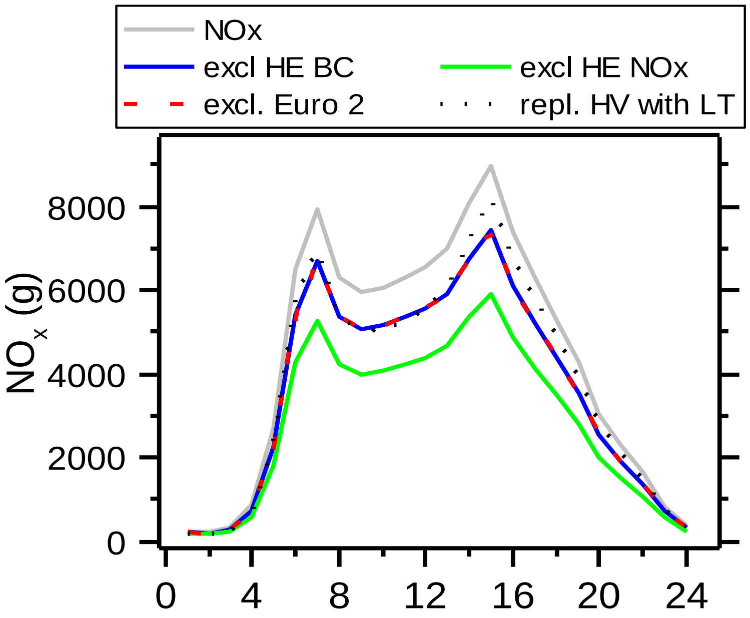
Spatial variation of emissions



RESULTS

Diurnal variation of emissions and emission reduction scenarios





	Total daily emissions (g)	Replace HV with LT	Restricting up to Euro 2 veh.	Restricting BC HE	Restricting NO_x HE
BC	3907.9	9%	18%	**39%**	17%
NO_x	105451.8	12%	16%	16%	**33%**

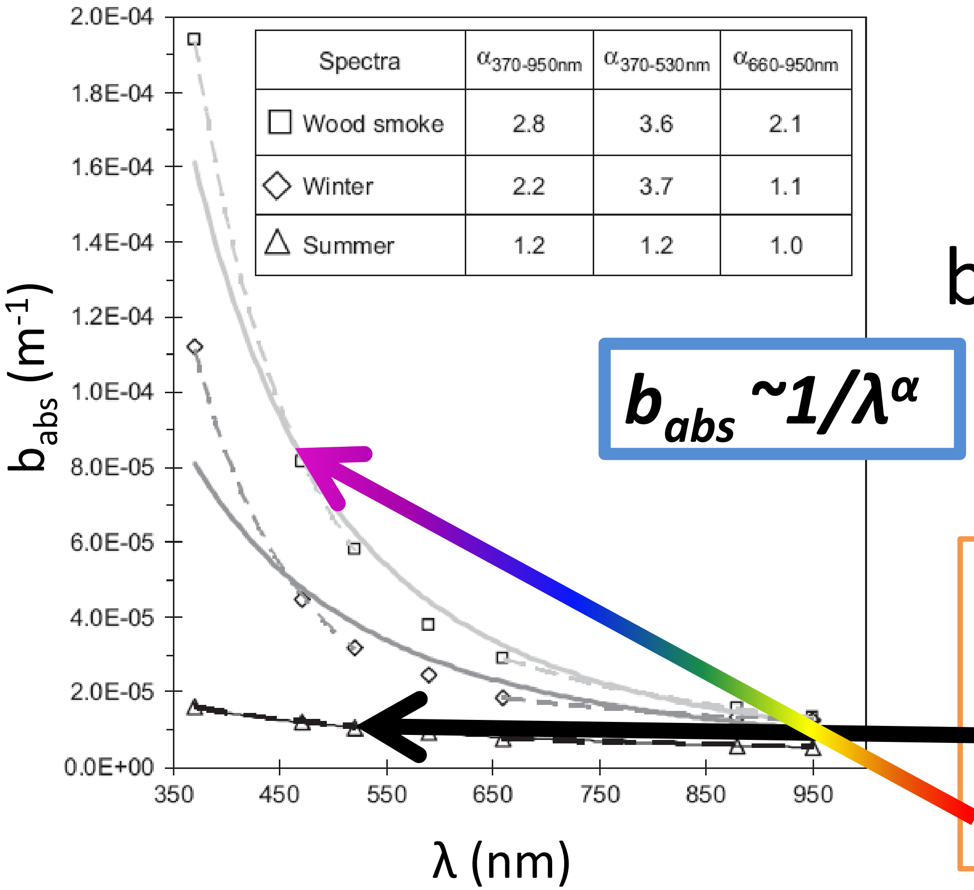
Model validation with in-situ measurements

Modeled BC concentrations = diffusion * emission rate

$$C[BCmodel] = D \cdot Q_{BC} = \frac{C[NO_x\ traffic]}{Q_{NO_x}} Q_{BC}$$

$$C[NO_x\ traffic] = C[NO_x\ urban] - C[NO_x\ background]$$

In-situ source apportionment of BC



Spectra	$\alpha_{370\text{-}950nm}$	$\alpha_{370\text{-}530nm}$	$\alpha_{660\text{-}950nm}$
□ Wood smoke	2.8	3.6	2.1
◇ Winter	2.2	3.7	1.1
△ Summer	1.2	1.2	1.0

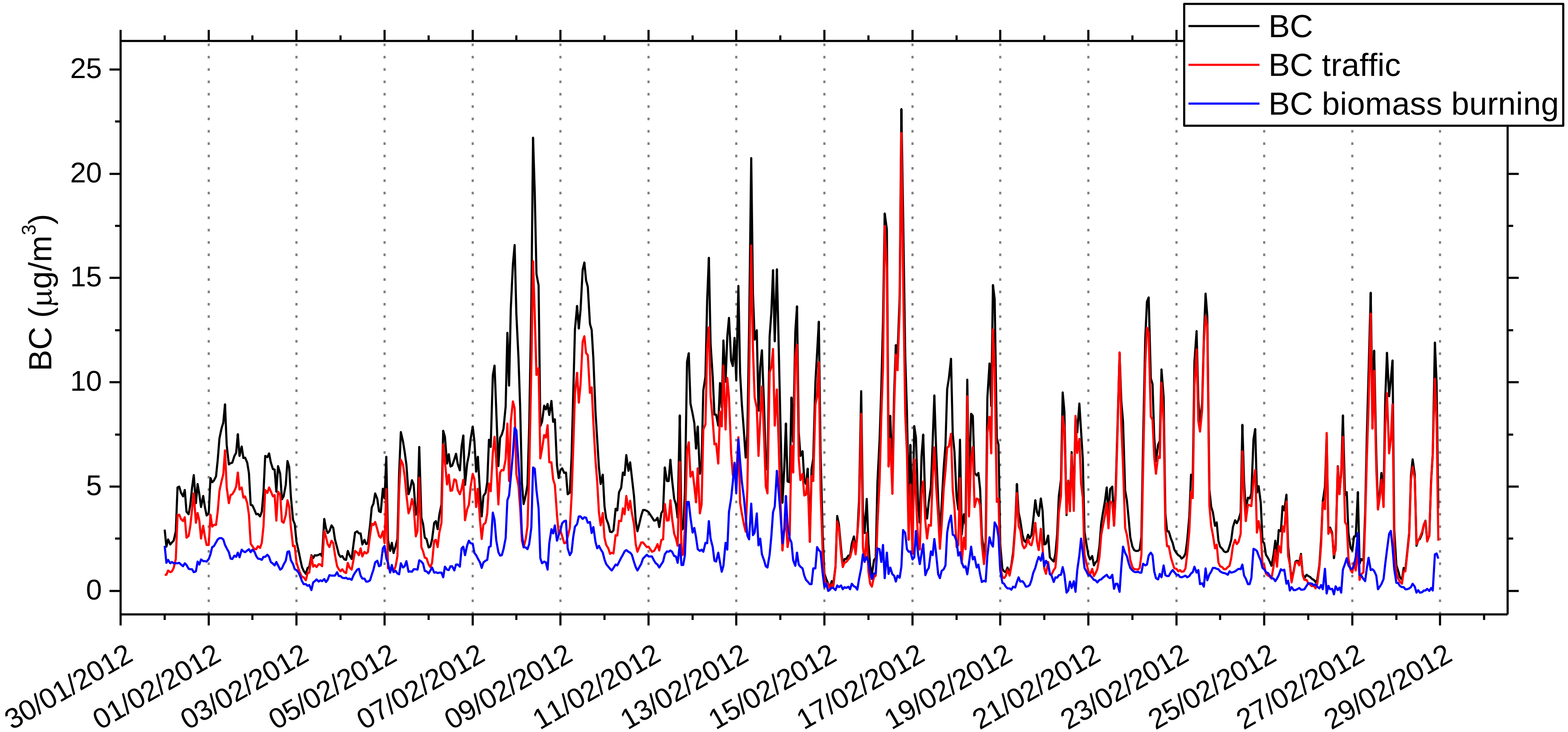
<u>The Aethalometer model</u> discriminates between sources based on aerosol light absorption properties

Angstrom exponent α
is source specific
Traffic α = 1 ± 0.1
Wood burning α = 2 -0.5/+1.0

J. Sandradewi et al., A study of wood burning and traffic aerosols in an Alpine valley using a multi-wavelength Aethalometer, Atmospheric Environment (2008) 101–112

Bond & Bergstrom 2004
Kirchstetter 2004,
Day 2006,
Lewis 2008

Aethalometer model BC source apportionment example



Maribor city center

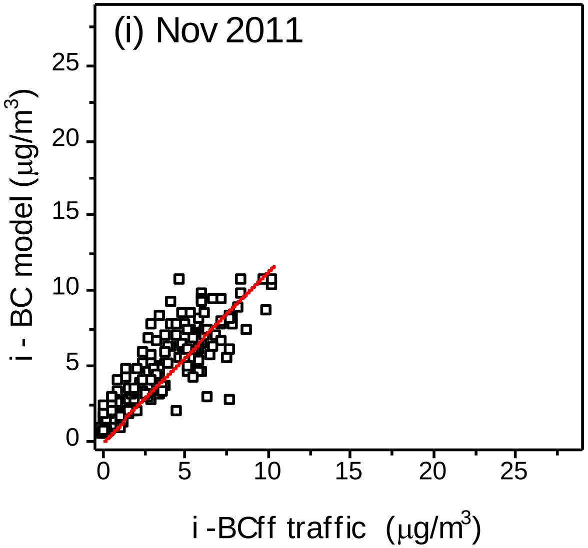
RESULTS

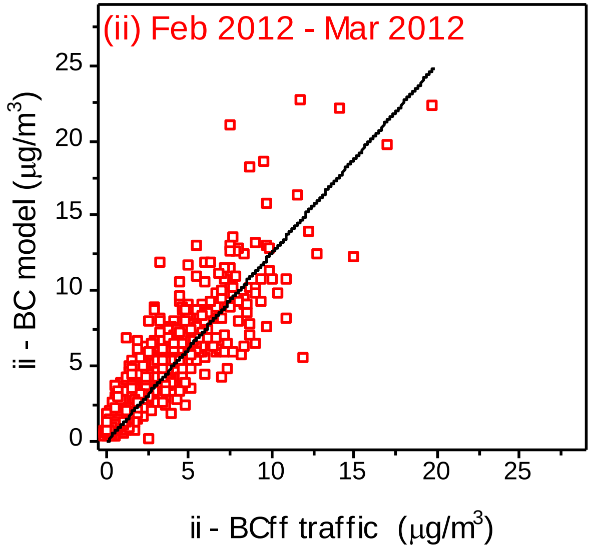
Model validation

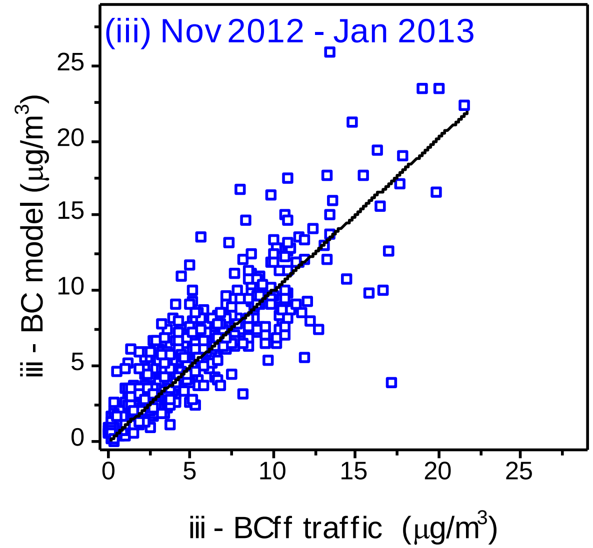
Linear fit (i) Nov 2011	
Pearson's r	0.95
Adj. R-Square	0.91
Slope	1.13
Intercept	0.00
Bias	0.26
Root mean square	1.88

Linear fit (ii) Feb 2012 - Mar 2012	
Pearson's r	0.95
Adj. R-Square	0.90
Slope	1.25
Intercept	0.00
Bias	1.13
Root mean square	2.08

Linear fit (iii) Nov 2012 - Jan 2013	
Pearson's r	0.96
Adj. R-Square	0.91
Slope	1.01
Intercept	0.00
Bias	0.85
Root mean square	1.59







Conclusions

- **detailed methodology** to determine traffic emissions in a city and a simple method to verify the emission models results.
- **Real-world EF** measurements were successfully included in traffic emission model
- **Excluding super emitters** is more efficient than excluding vehicles according their age or type in reducing traffic emissions
- **good agreement between the two independent approaches** was found, with the modelled BC concentrations overestimating the measured BC by 13%, 25% and 1% in three different winter time periods

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Literature

Testing and chasing 2011 results were published in

- Ježek et al., 2015 a, Atmos. Meas. Tech., 8, 43–55, 2015, www.atmos-meas-tech.net/8/43/
- Ježek et al., 2015 b, Atmos. Chem. Phys., 15, 11011–11026, 2015

www.atmos-chem-phys.net/15/11011/2015/

doi:10.5194/acp-15-11011-2015

Modeling results were submitted for publication in Atmospheric Environment.