Source Apportionment of Carbonaceous Aerosols and Other Pollutants in Central Europe

Spatial and temporal variations of black carbon, carbonaceous aerosols and co-emitted pollutants depend on the sources – results of Central European campaigns

Duisburg, 5 March 2013

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Aerosol

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MGRT(MVZT)/EUREKA Eurostars E!4825, FC Aeth

MGRT (MVZT) JR-KROP 3211-11-000519

Mestna občina Maribor, Nova Gorica, Celje, Klagenfurt, PMinter - SI-AT 2007-2013

CEA-ARRS, bilateral project BI-FR/CEA/10-12-006.

Aerosol

Investing in your future
OPERATION PART FINANCED BY THE EUROPEAN UNION
European Social Fund

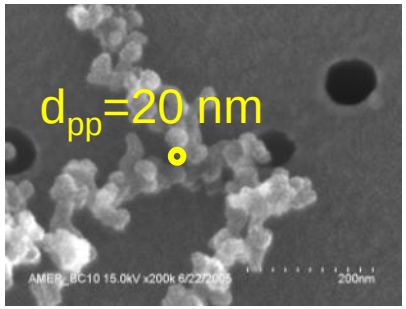
Aerosol Black Carbon

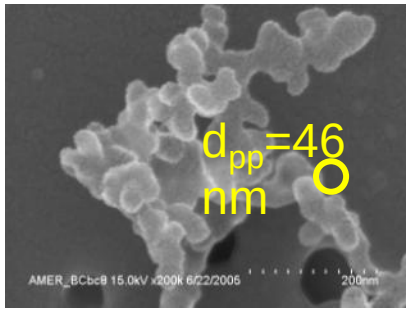
- BC is a **primary** product of incomplete **combustion**
- BC not automatically related to CO_2 emission
- BC emissions can not be predicted:

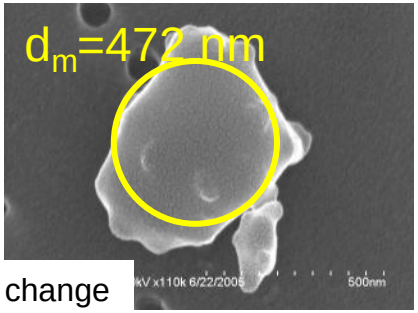
  must be measured

- BC particles from different sources can have different characteristics that produce different effects in the atmosphere:

  (Coal/Diesel/Biomass, USA/Asia/Europe)







Note change in scale

Aerosol

Advantages / Attributes of Optical Analysis

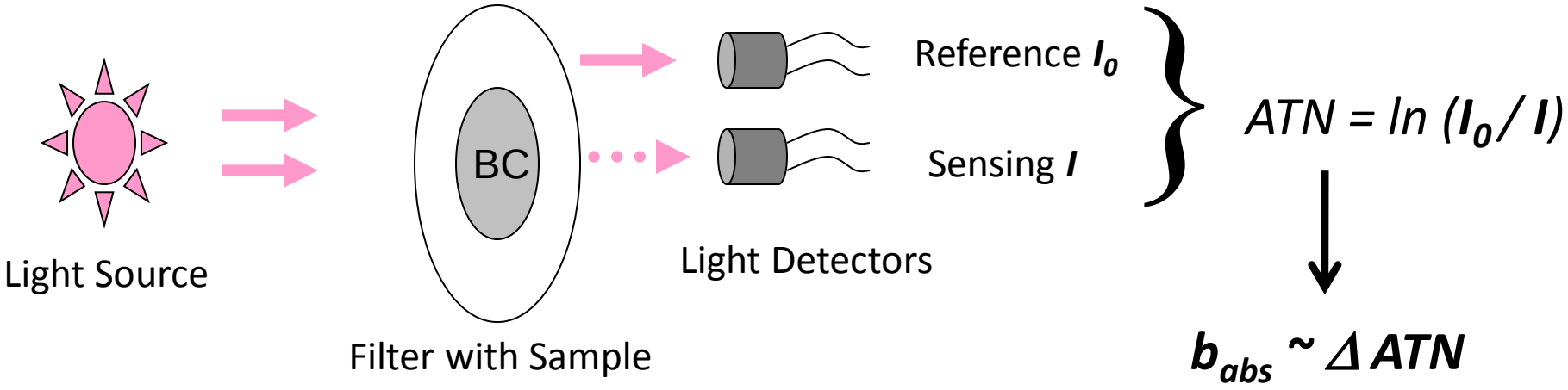
Typical **chemical speciation** time resolution – hours, **day**!

Optical methods – minute!

- Instantaneous
- Non-destructive
- Mobile / Portable
- Added dimension - *time*
- Added dimension – *wavelength*

Aerosol

Analytical Instrument : Aethalometer™

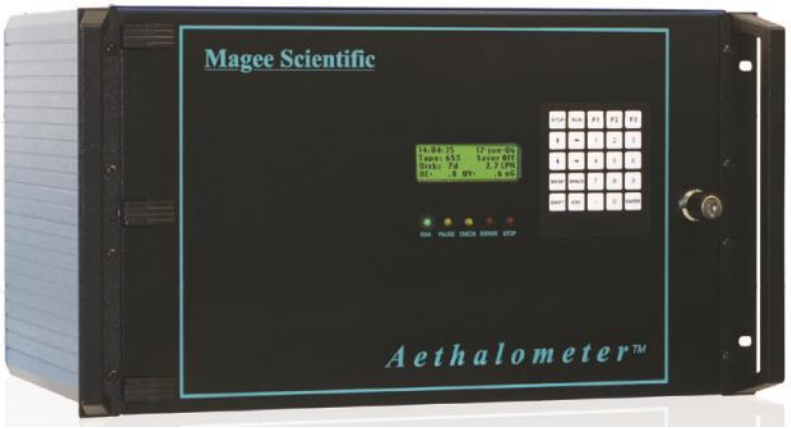


- Collect sample **<u>continuously</u>**.
- ***Optical absorption*** ~ change in ATN.
- Measure optical absorption <u>continuously</u> : λ = 370 to 950 nm.
- Convert ***optical absorption*** to ***concentration of BC:***

$$BC\ (t) = b(t) / \sigma$$

- Real-time data: **5 minutes**
  - *<u>Dynamical, real-time measurement, updated each period</u>*

Aethalometer – Continuous rack mount instruments



AE31 Spectrum – Ambient Air Quality Monitoring

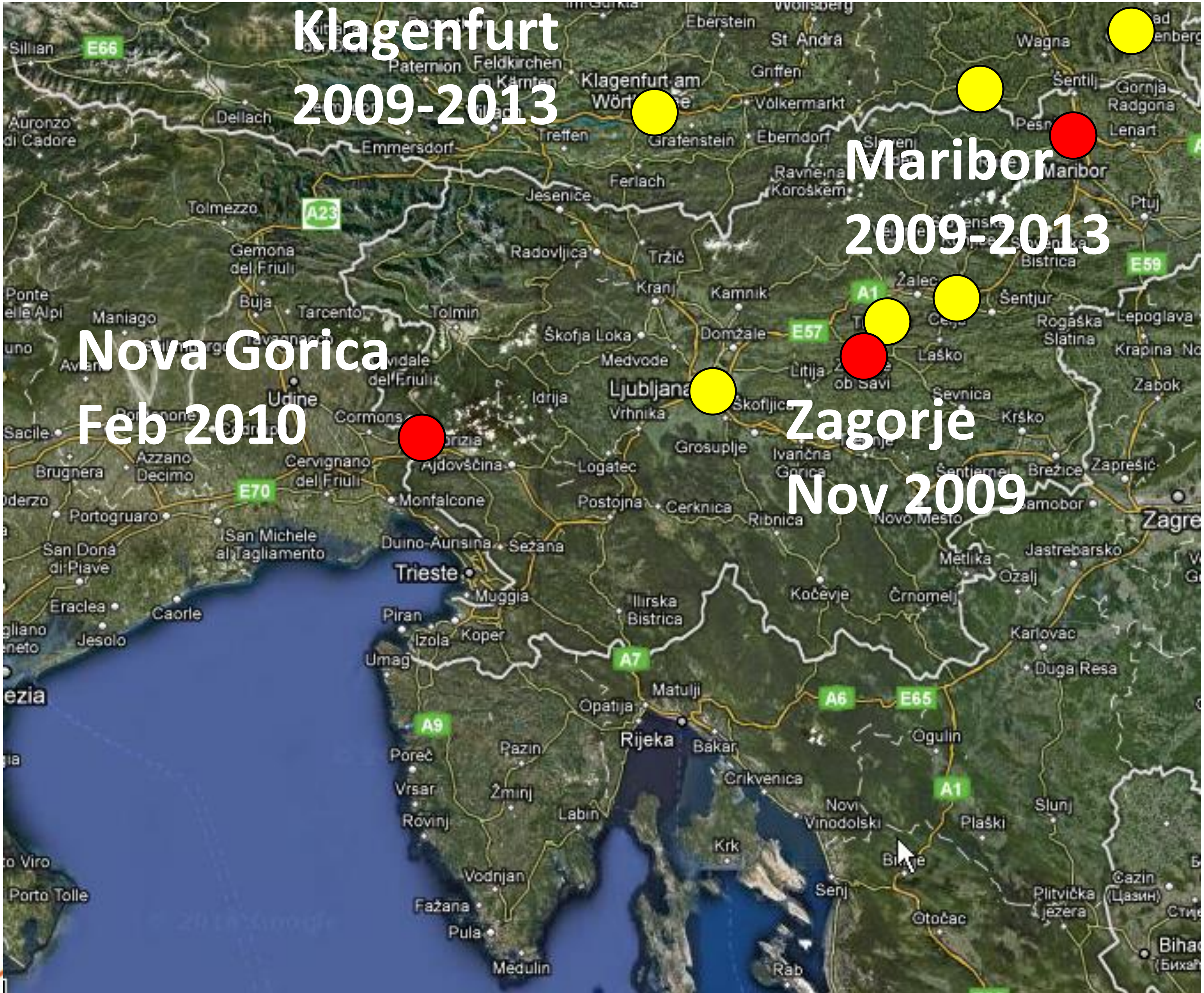
- ✓ ***Seven wavelength (370, 470, 520, 590, 660, 880, and 950 nm)***
- ✓ ***Local source identification***
- ✓ ***Regional, Continental, Global Atmospheric studies***
- ✓ ***Particle size distribution, radiative transfer***
- ✓ ***Climate change, albedo, cloud modification***

Aerosol

The Aethalometer Model AE33

EUREKA/Eurostars FC Aeth E!4825

The Eurostars Programme is powered by
EUREKA and the European Community


Klagenfurt
2009-2013
Maribor
2009-2013
Nova Gorica
Feb 2010
Zagorje
Nov 2009

Site and instrumentation

Aerosol light absorption:
Aethalometer AE31-ER

- 7 wavelengths: 370, 470, 520, 590, 660, 880, 950 nm
- flow 4 LPM
- absorption coefficient b_{abs} - compensation for loading and scattering
- Angstrom exponent α from $b_{abs}(\lambda)$

5 min time resolution

OC / EC filter analysis:
Sunset T-O Carbon Aerosol analyzer

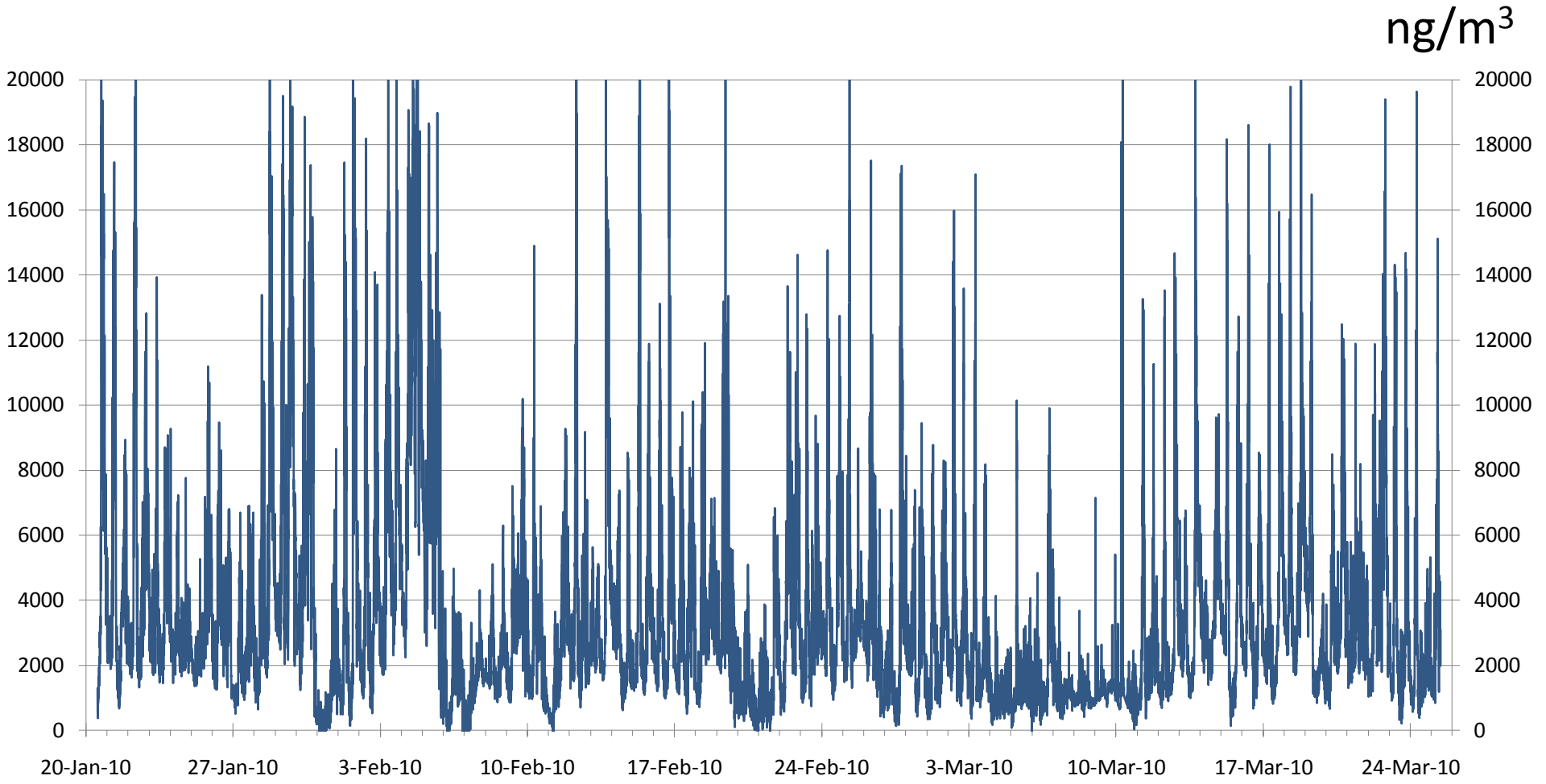
- 24 h quartz filters, 16,7 LPM
- EUSAAR-2 protocol

PM10:
EN 12341
reference gravimetric method

1 day time resolution

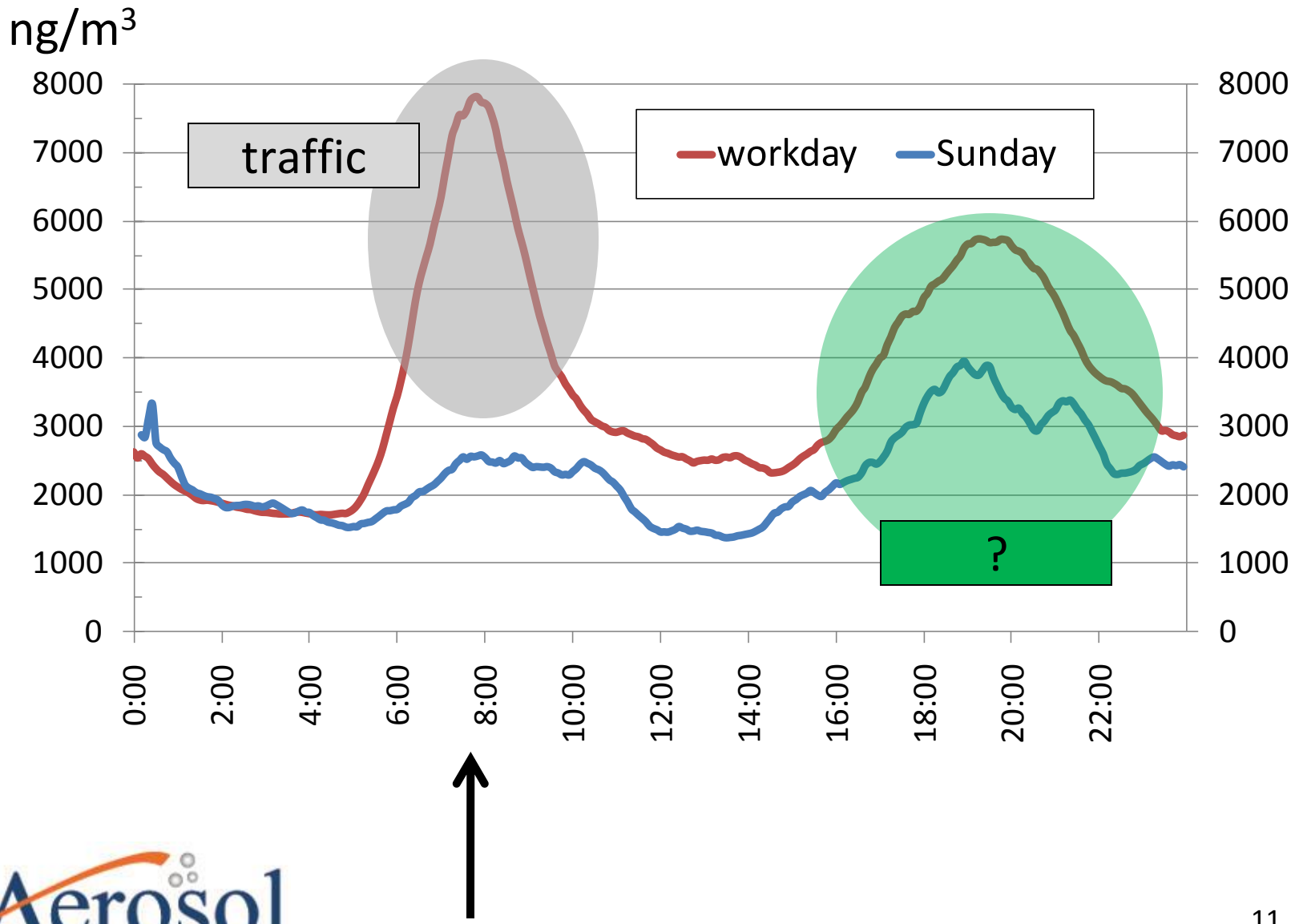
Aerosol

BC time-series, Nova Gorica



Aerosol

BC in Nova Gorica – diurnal variation



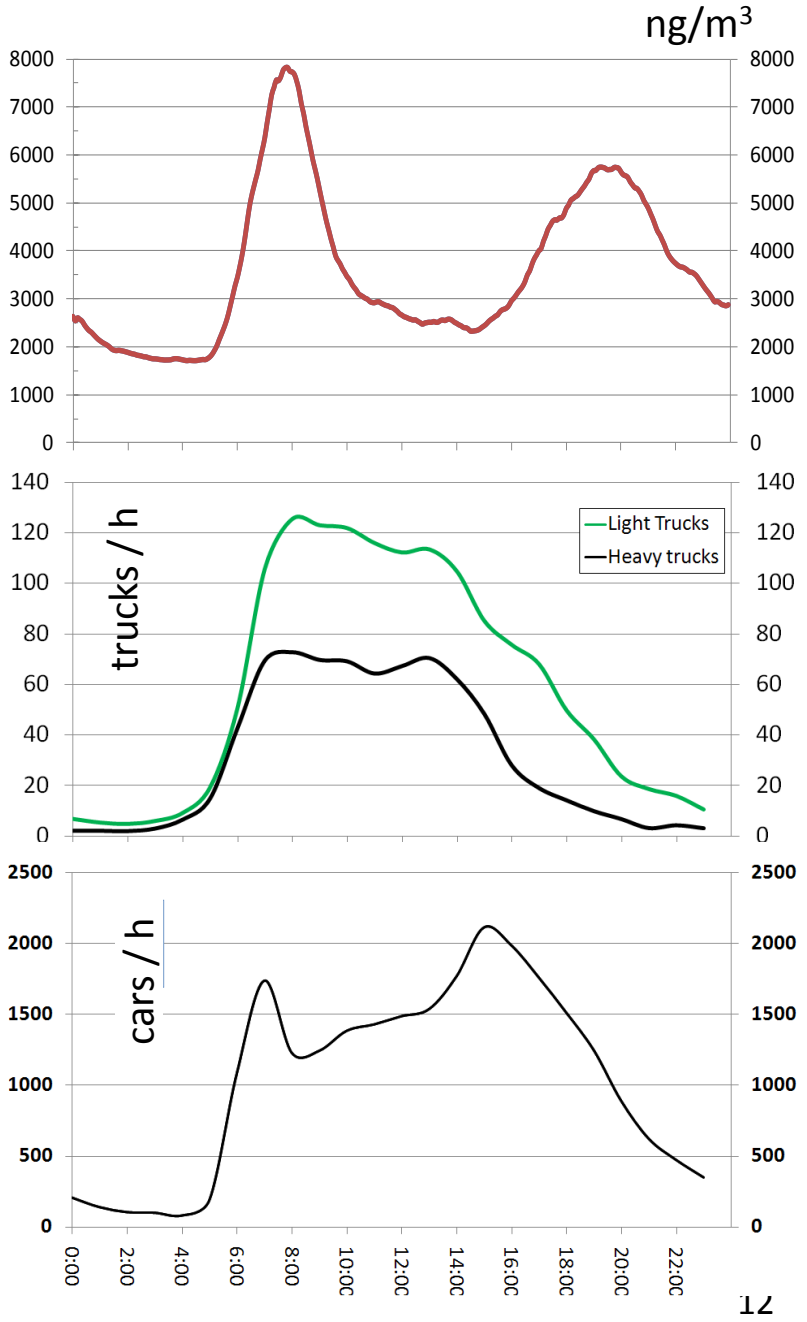
Traffic

Does traffic diurnal pattern match the BC pattern?

Trucks are all diesel and emit more than other vehicles.

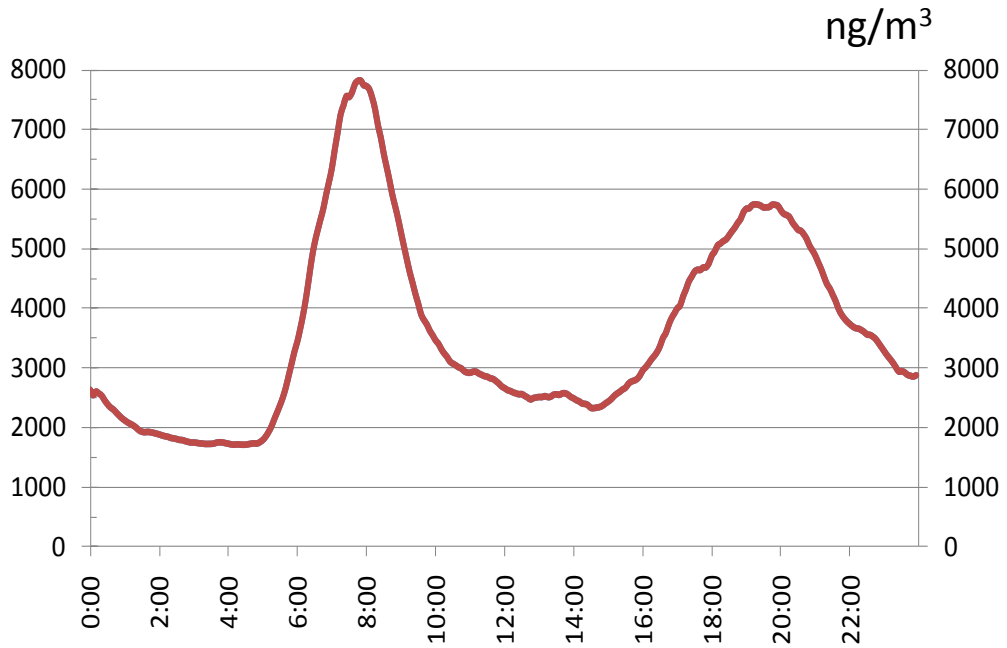
What about cars?

Note the change in scale!

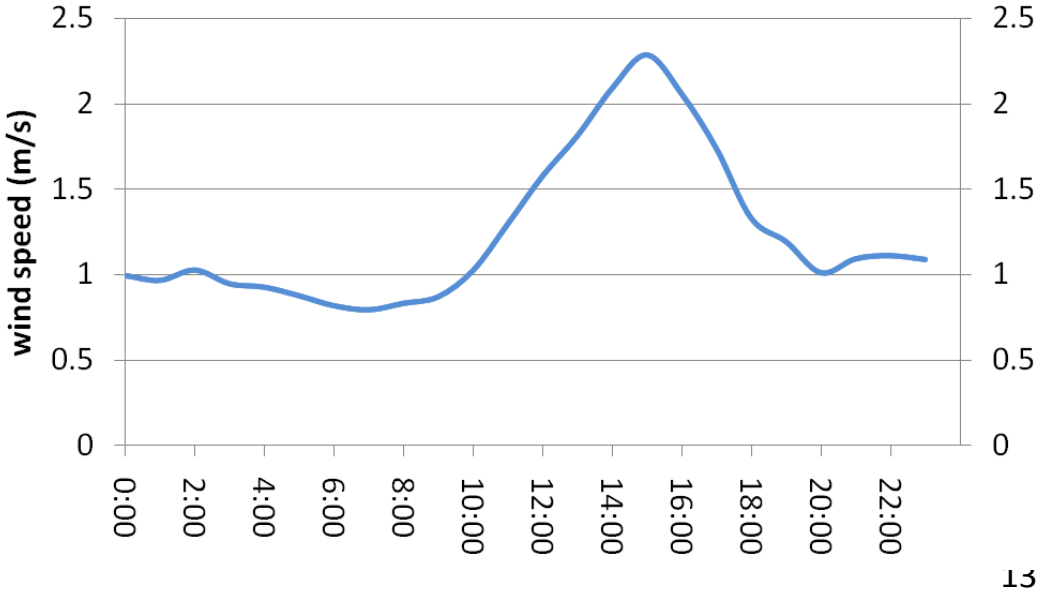


Wind

Does the wind diurnal pattern influence the BC pattern?

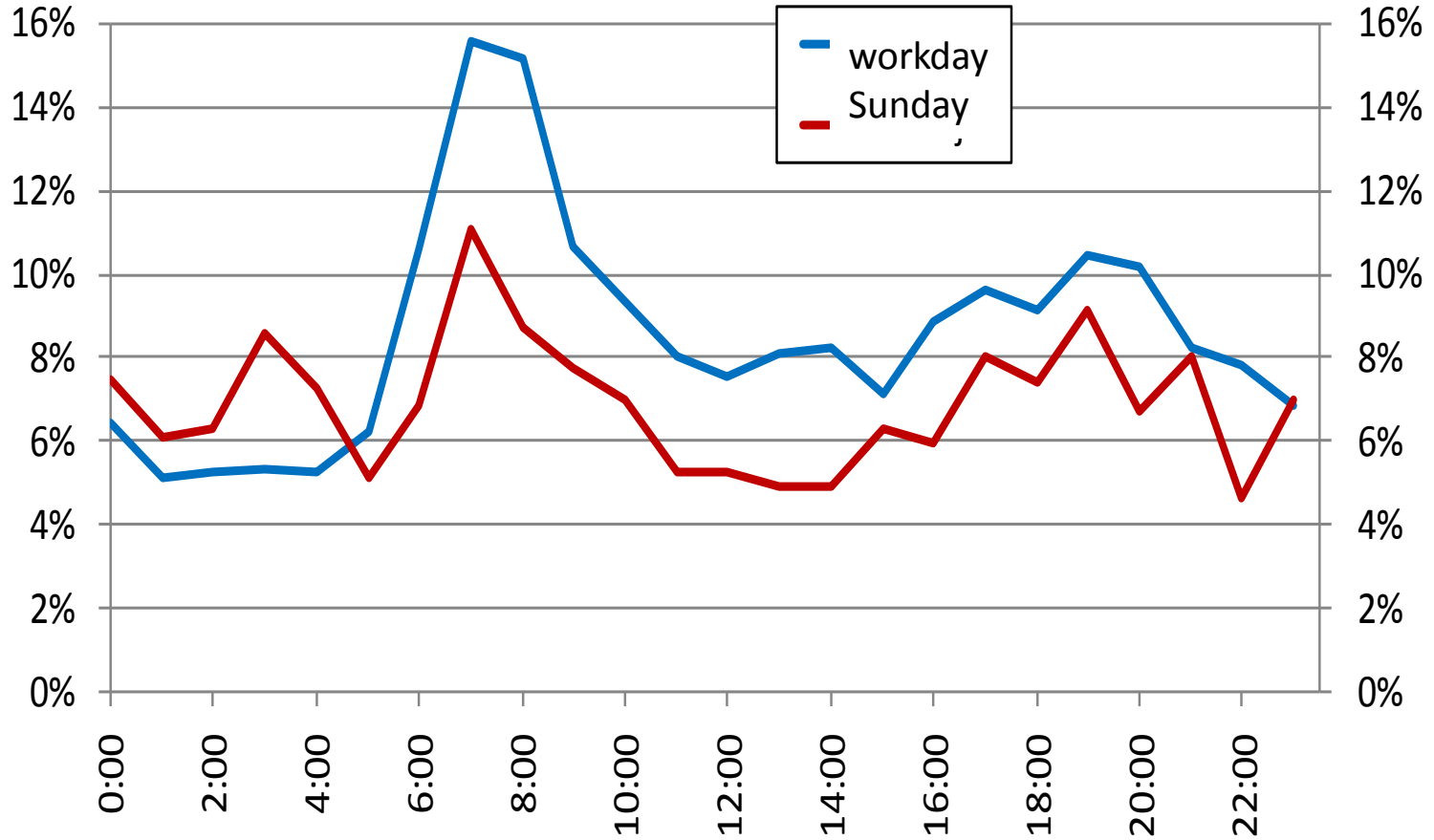


Wind does disperse the primary air pollution!



Aerosol

Composition of PM10 changes during the day!



Aerosol

Biomass is globally a major energy source

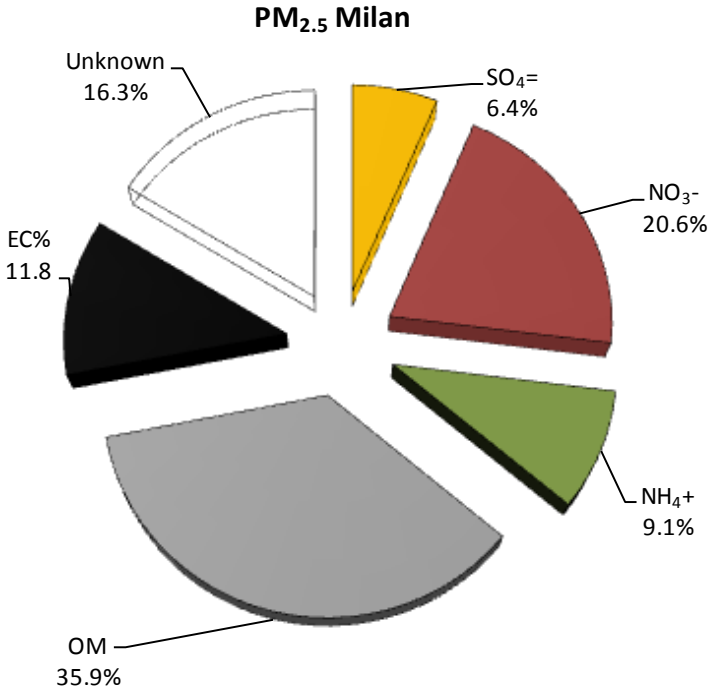
Woodsmoke in cities?!

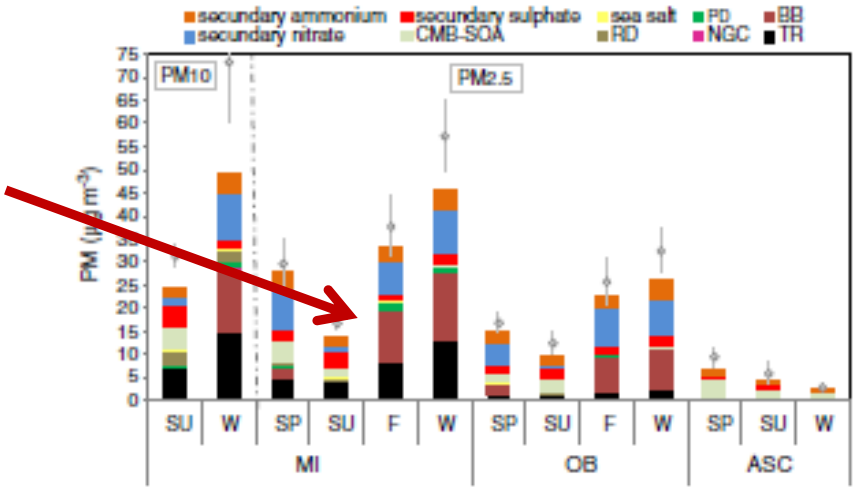
PM2,5		
Paris, winter	20%	Favez 2009
Grenoble, winter	35%	Favez 2010

similar for Vienna, Graz, Salzburg (Caseiro 2009),
Zurich (Lanz 2008, Szidat 2006)...

and also:

Milano, fall	30%	Perrone 2012
Milano, winter	25%	Perrone 2012





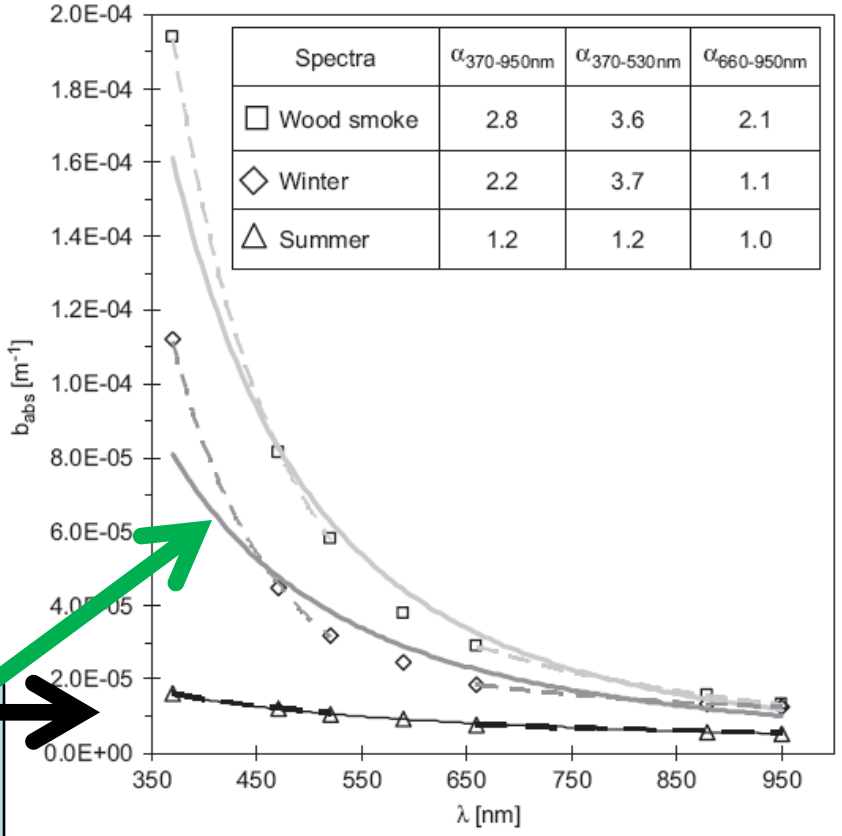
Biomass-smoke vs. diesel - 7λ

- measure attenuation with the Aethalometer
- absorption coefficient - b_{abs}
- for pure black carbon: $b_{abs} \sim 1/\lambda$
- generalize **Angstrom exponent**:

$$b_{abs} \sim 1/\lambda^{\alpha}$$

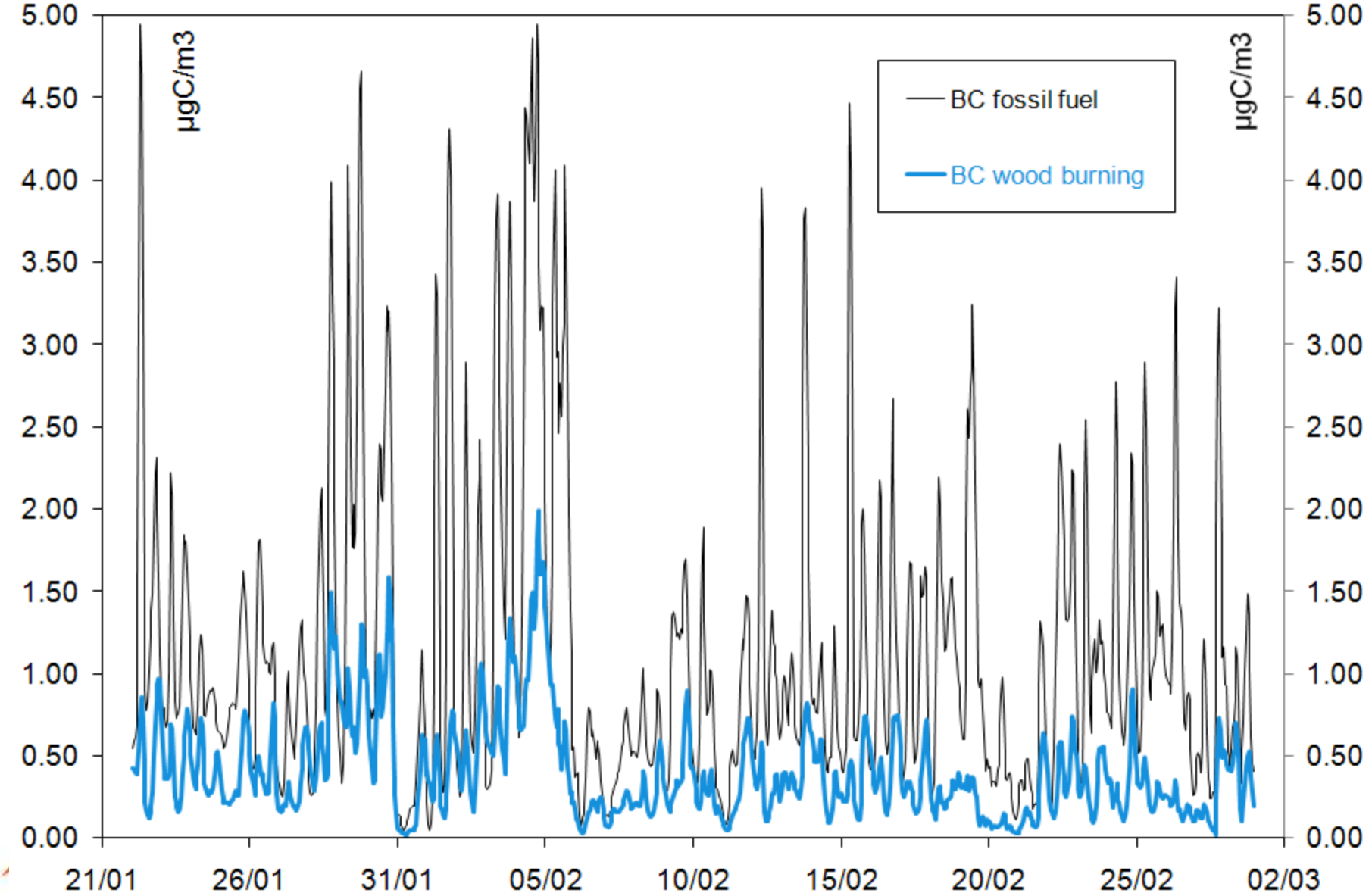
diesel: $\alpha \approx 1$

biomass-smoke: $\alpha \approx 2$ and higher

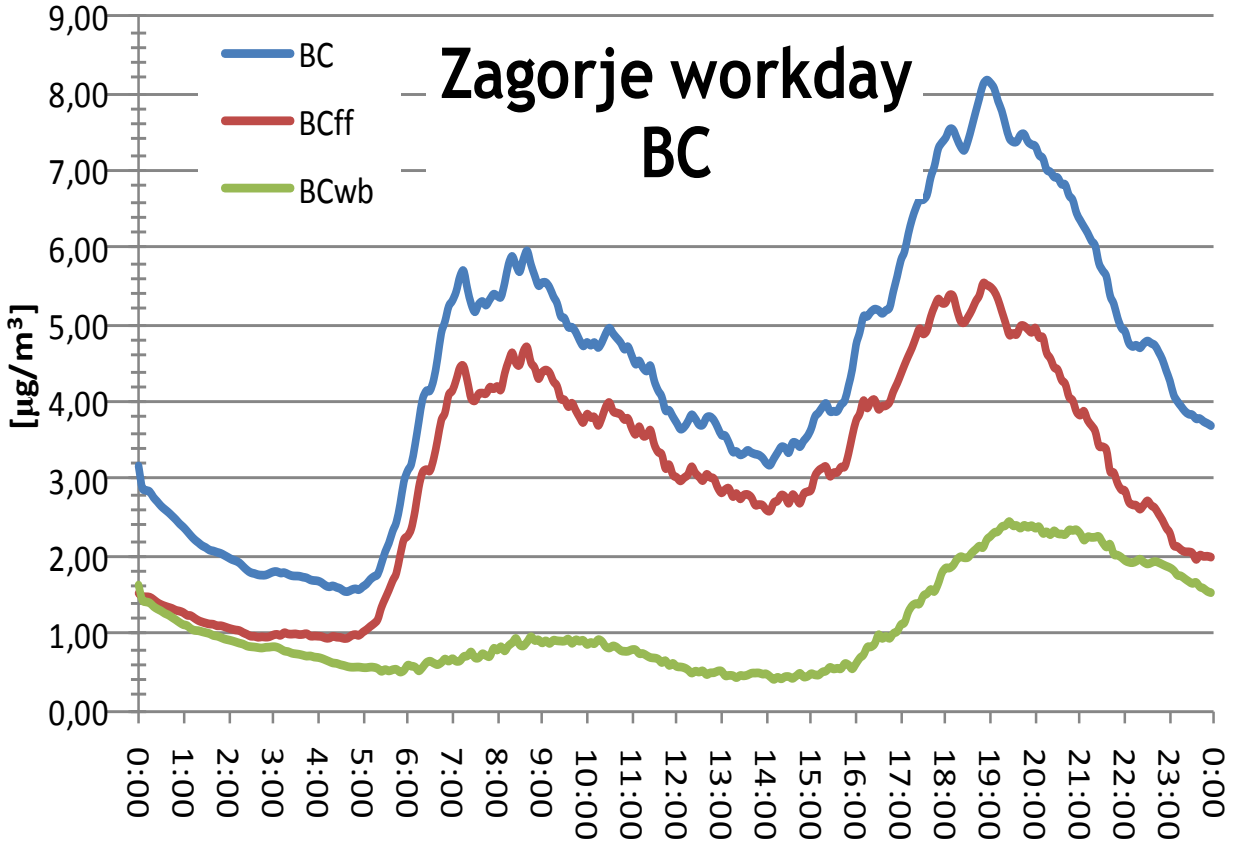


J. Sandradewi et al., A study of wood burning and traffic aerosols in an Alpine valley using a multi-wavelength Aethalometer, Atmospheric Environment (2008) 101–112

BC_{ff}, BC_{wb} time series, Nova Gorica



Source apportionment: which sources to regulate?



traffic

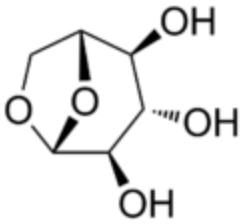
73% ± 8%

27% ± 8%

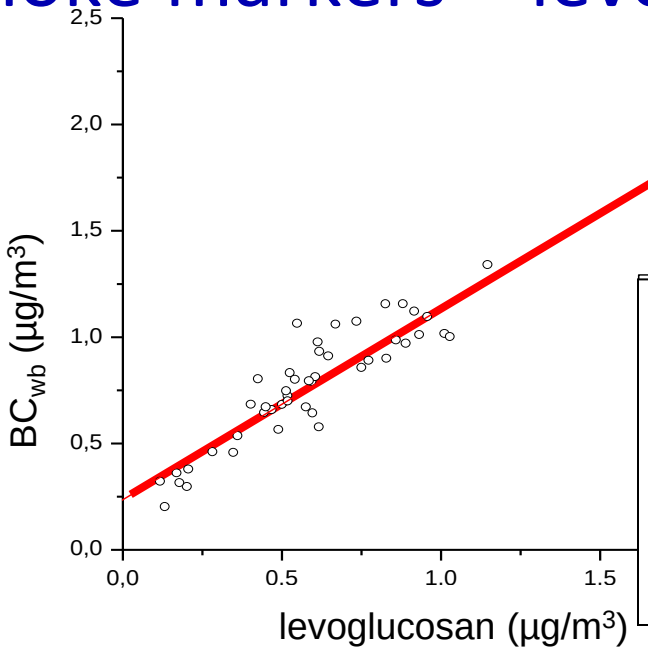
wood combustion

Aerosol

Wood-smoke markers – levoglucosan



Nova Gorica

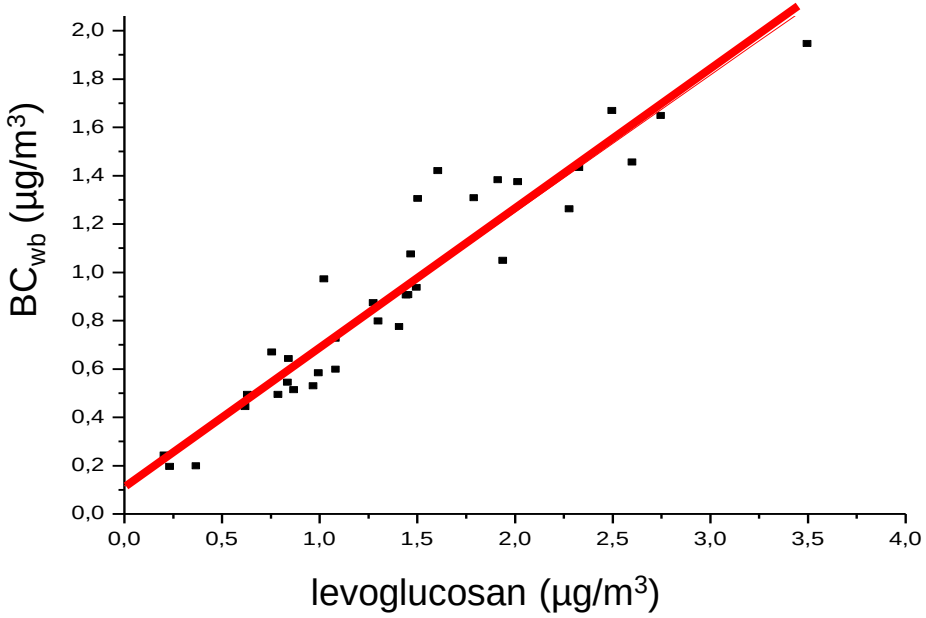


Different slopes

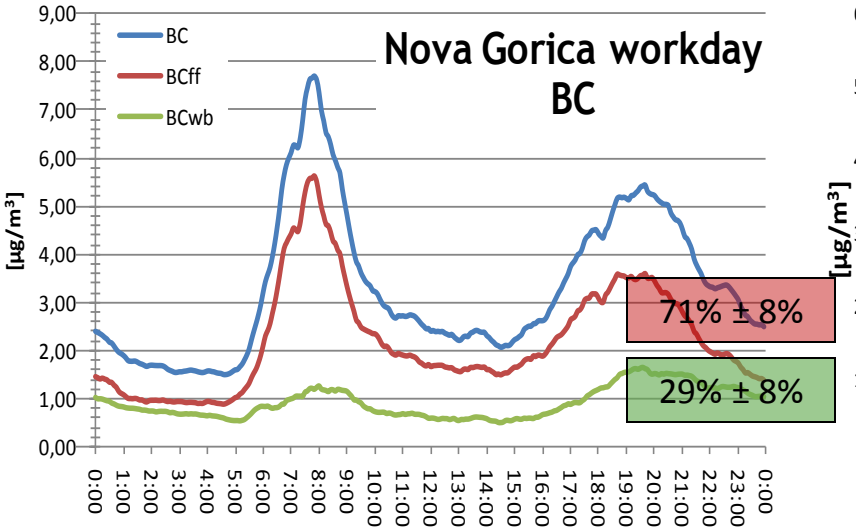
-> **different fuels**:

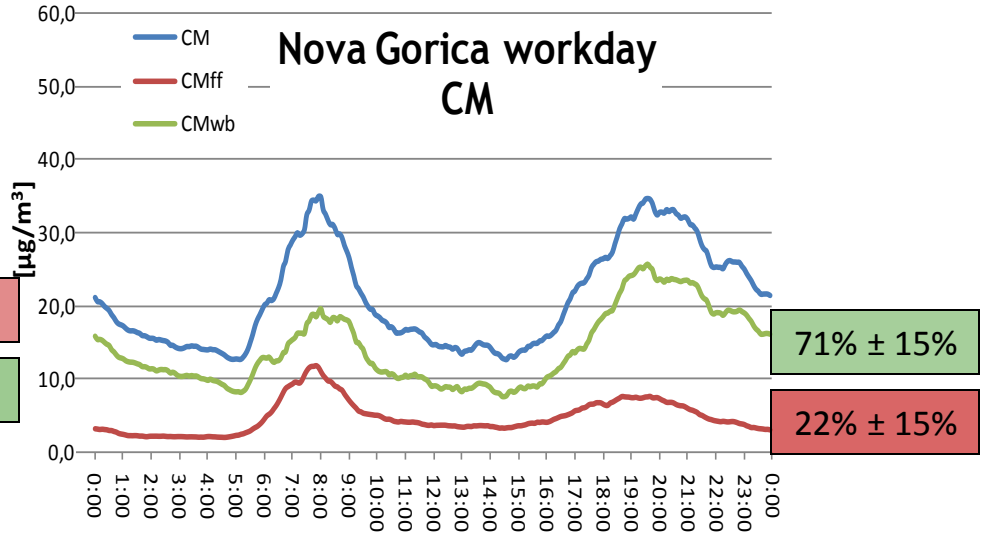
log wood vs. Chips, pellets

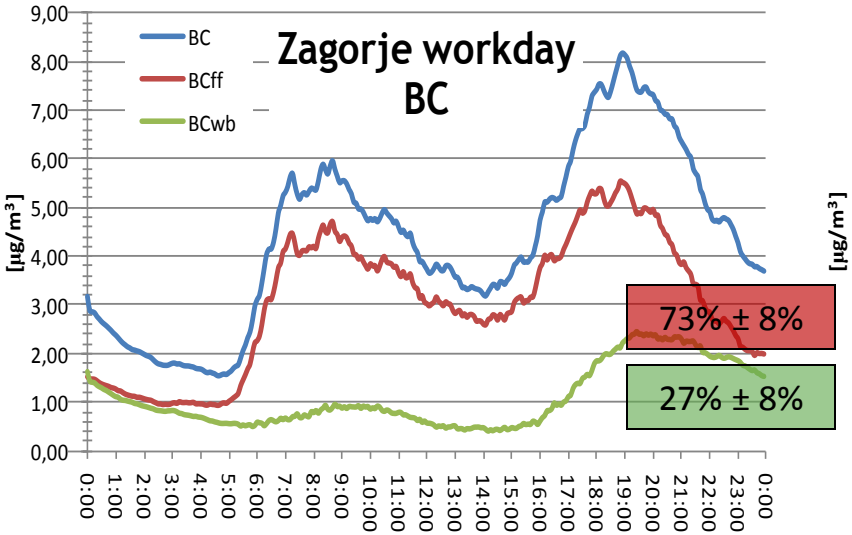
Zagorje

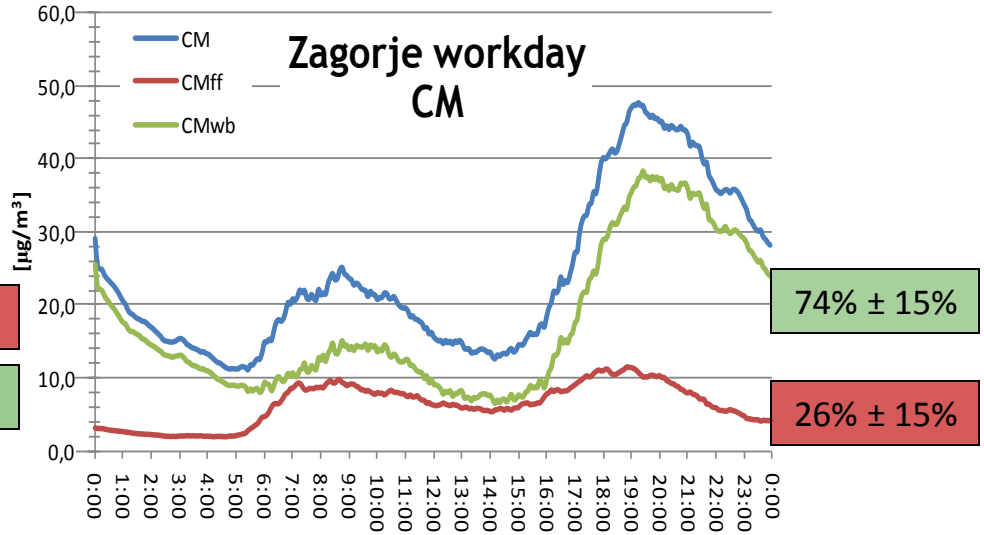


Levoglucosan - ion chromat. EARS


Nova Gorica workday
BC
BC
BCff
BCwb
[µg/m³]
71% ± 8%
29% ± 8%


Nova Gorica workday
CM
CM
CMff
CMwb
[µg/m³]
71% ± 15%
22% ± 15%

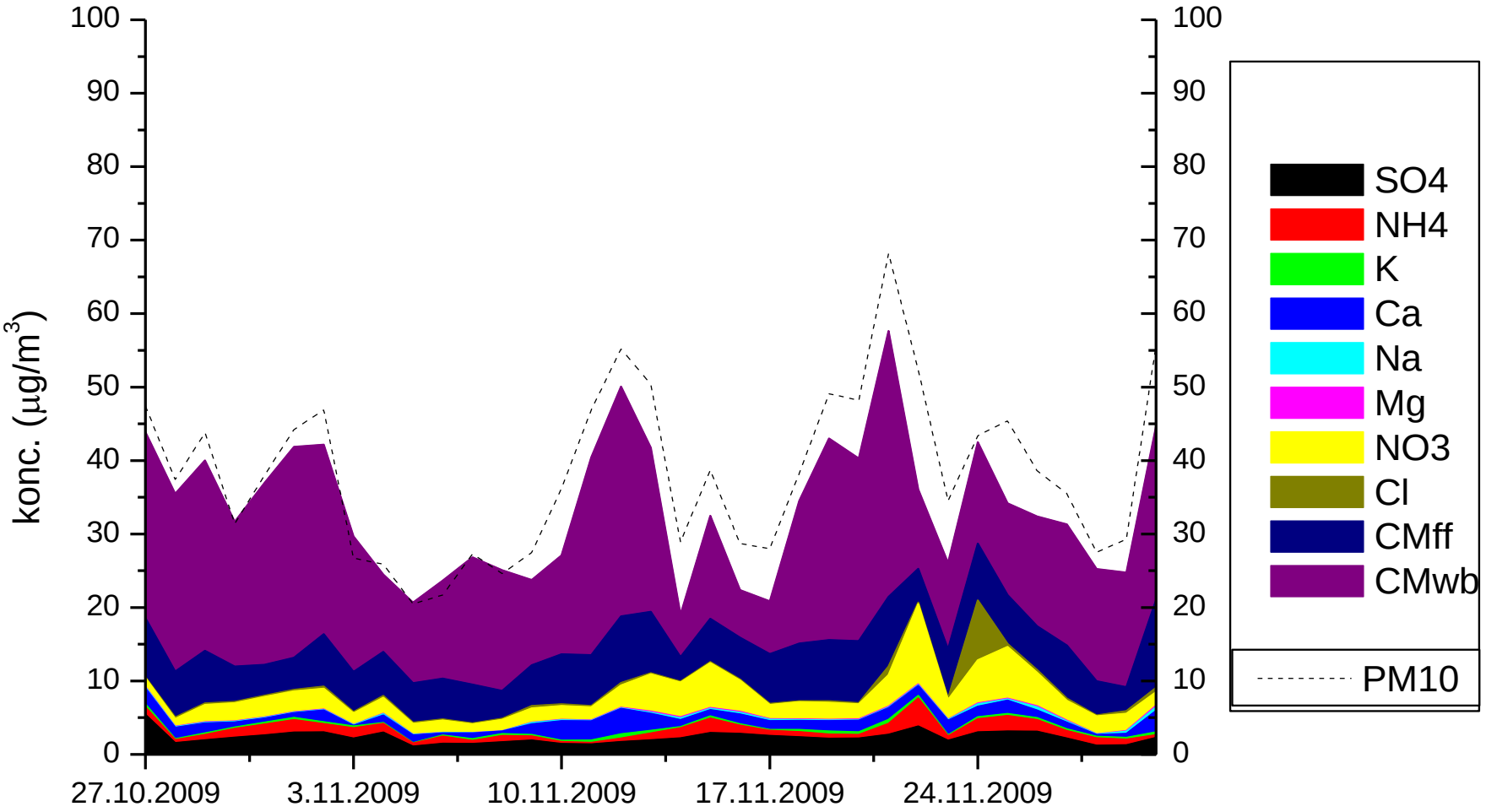

Zagorje workday
BC
BC
BCff
BCwb
[µg/m³]
73% ± 8%
27% ± 8%

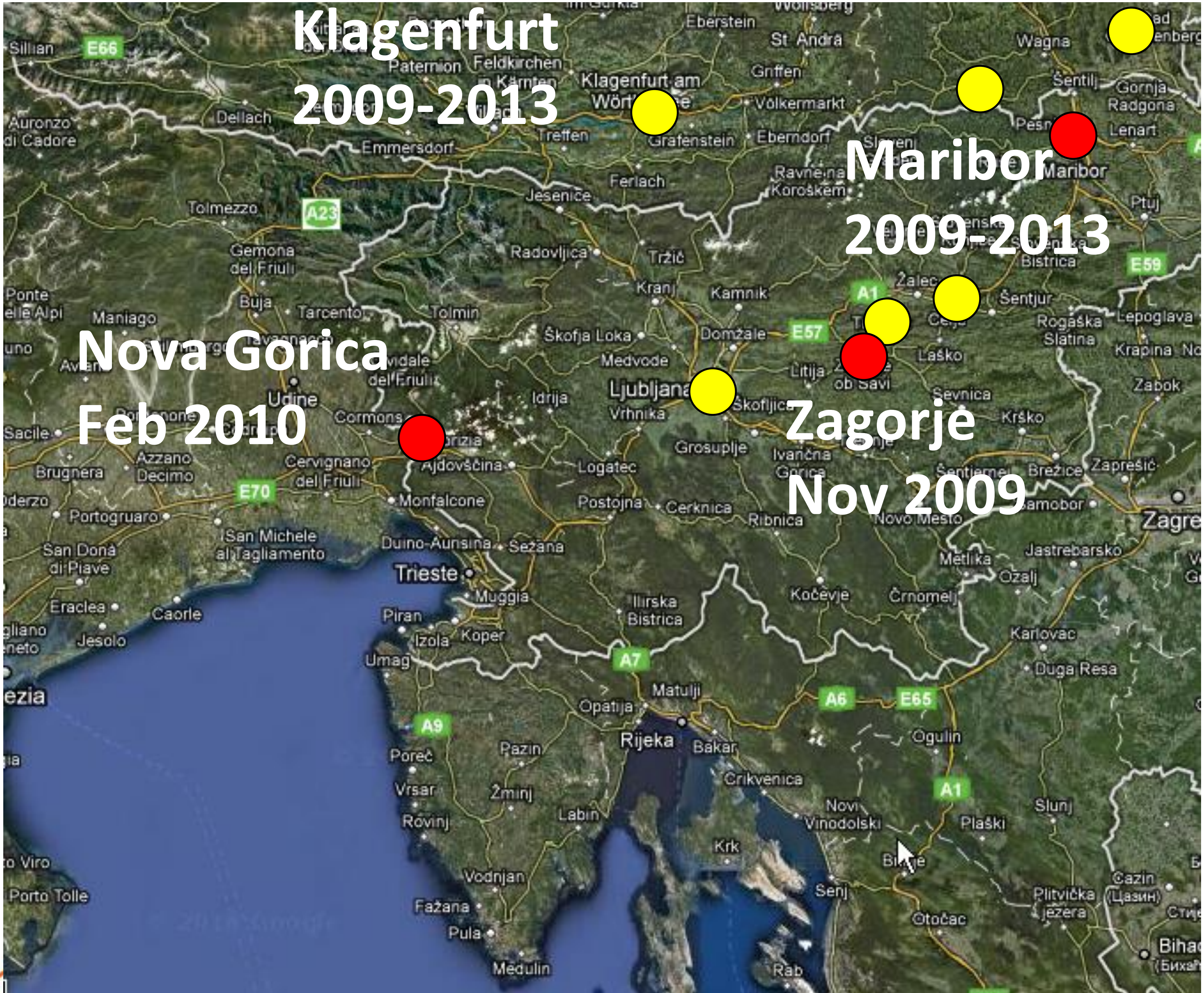

Zagorje workday
CM
CM
CMff
CMwb
[µg/m³]
74% ± 15%
26% ± 15%

Aerosol

Mass closure - Zagorje

Filter chemical analysis- EARS



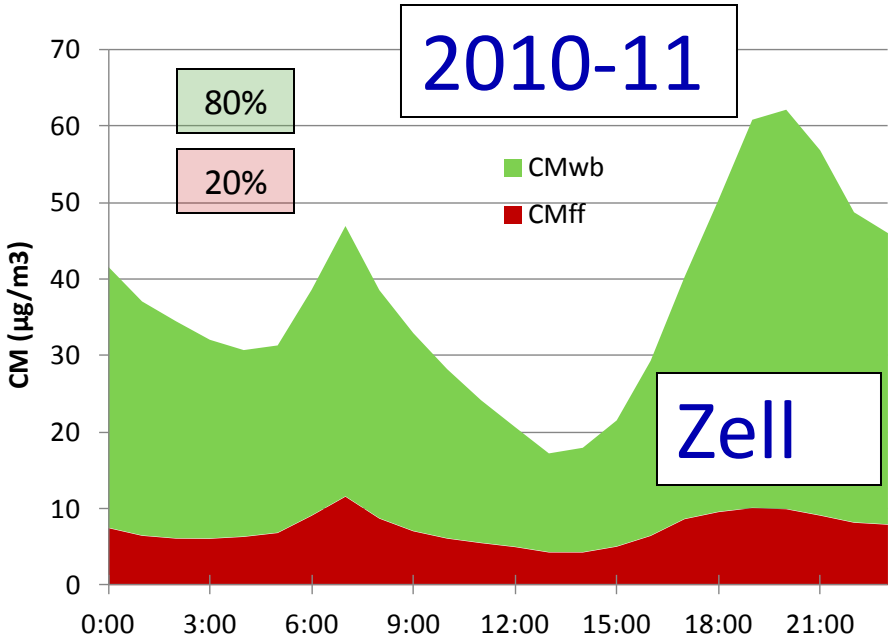

Klagenfurt
2009-2013
Maribor
2009-2013
Nova Gorica
Feb 2010
Zagorje
Nov 2009

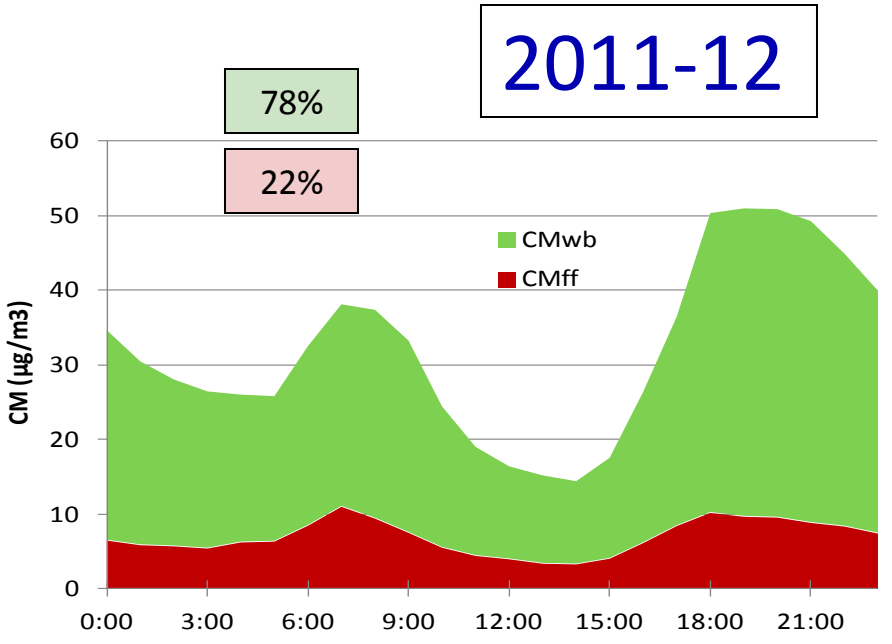
Wood-smoke vs. Fossil fuel – regionally AT-SI

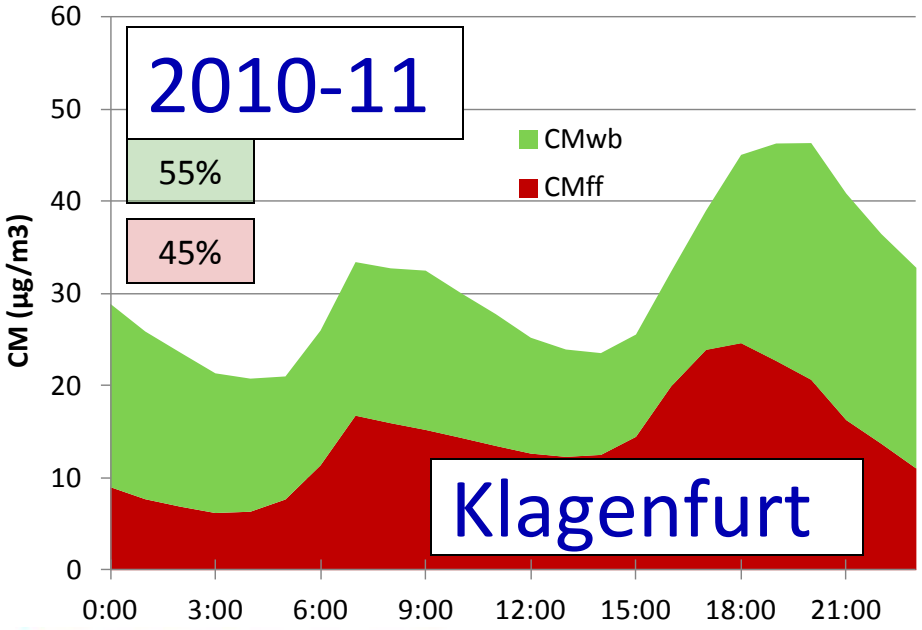
	ug/m3			%	
	CM	CMff	CMwb	CMff	CMwb
Maribor, SI	22,9	8,9	13,9	39%	61%
Vrbanski plato	23,8	3,5	20,3	15%	85%
Leibnitz, AT	35,5	10,7	24,7	30%	70%
Arnfels	6,4	1,1	5,2	18%	82%
Klagenfurt, AT Voelkermktstr	33,8	15,9	17,9	47%	53%
Limmersdorf	21,8	5,7	16,2	26%	74%
Zell	37,0	7,3	29,7	20%	80%

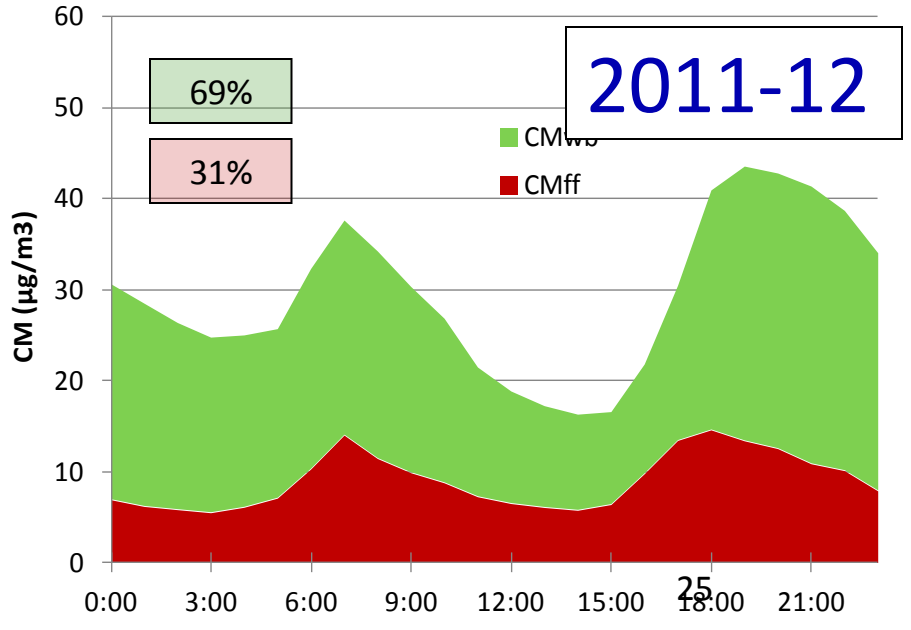
PMinter 2011-2012

Aerosol

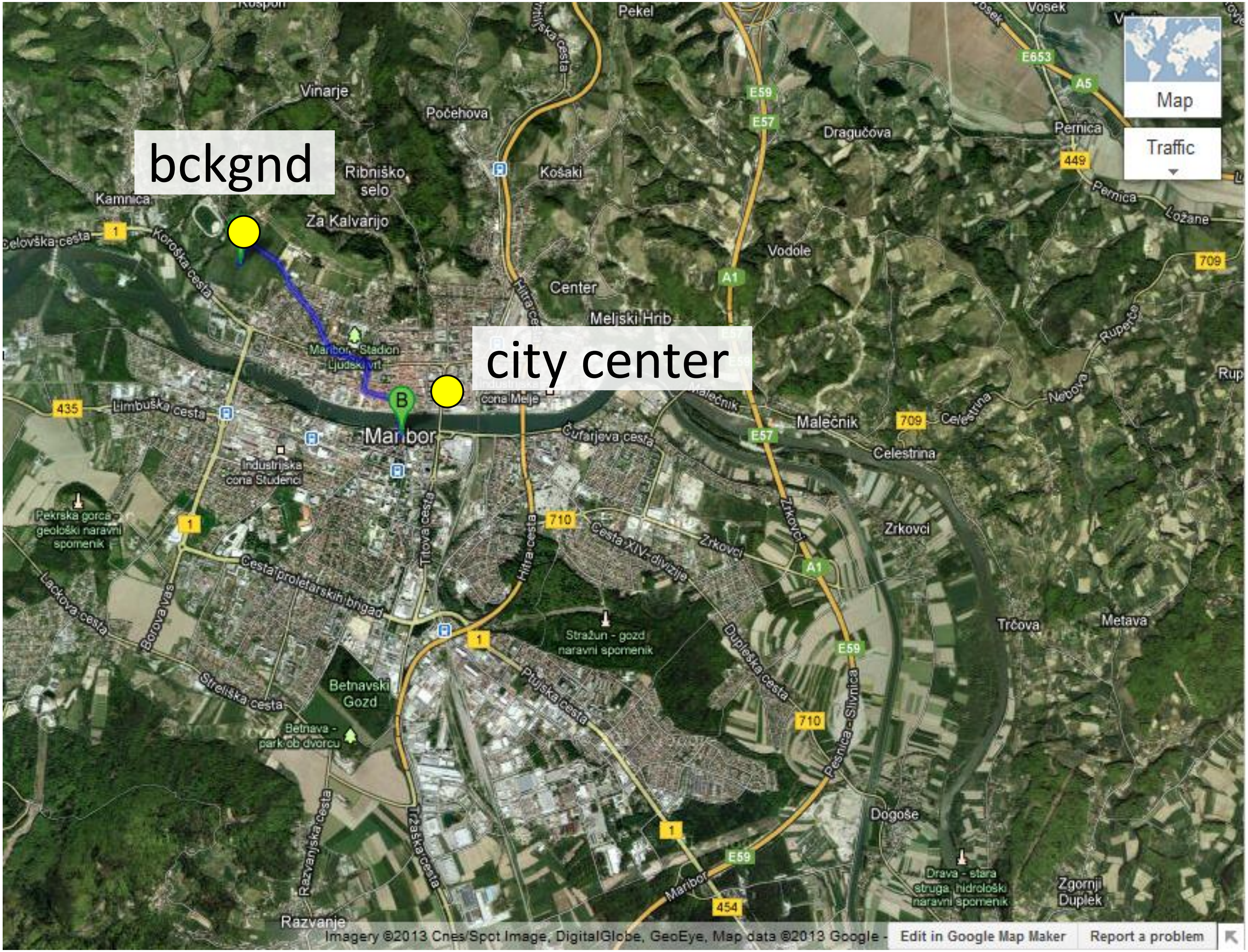

2010-11
80%
20%
CMwb
CMff
Zell
CM (µg/m3)
0
10
20
30
40
50
60
70
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00

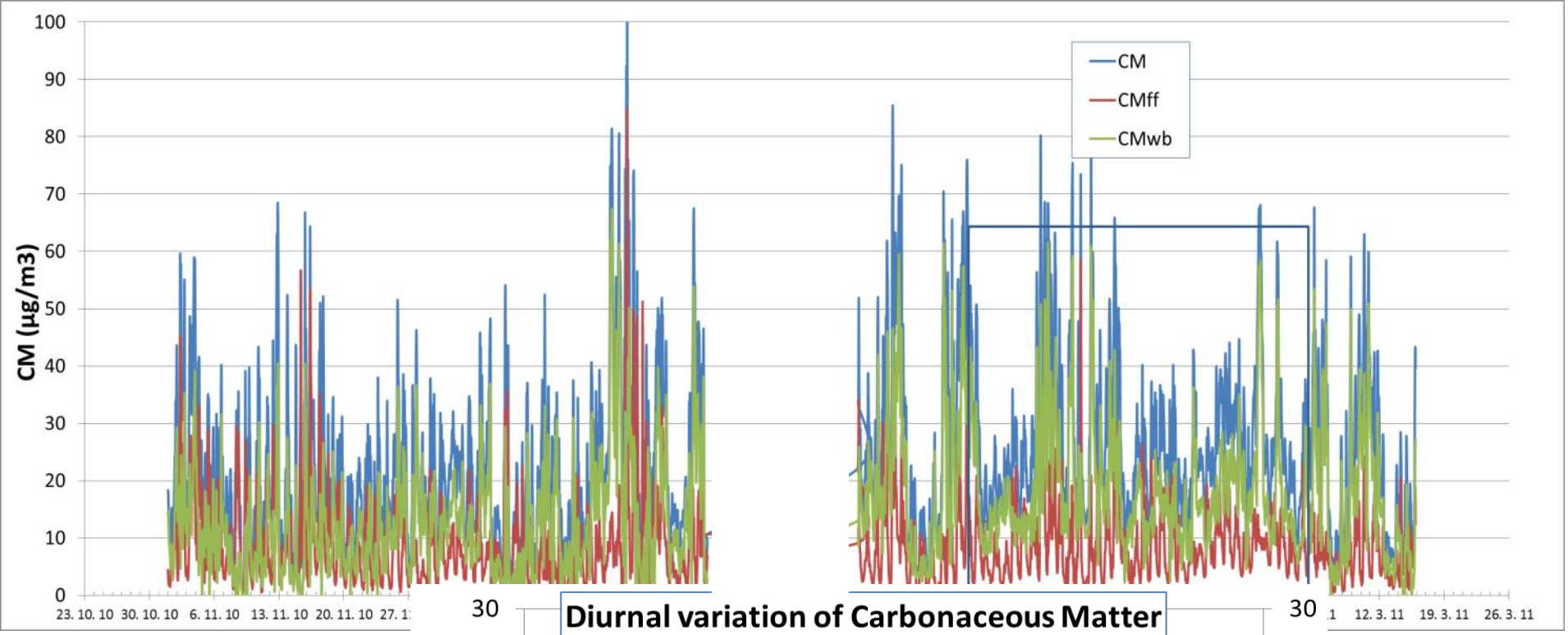

2011-12
78%
22%
CMwb
CMff
CM (µg/m3)
0
10
20
30
40
50
60
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00

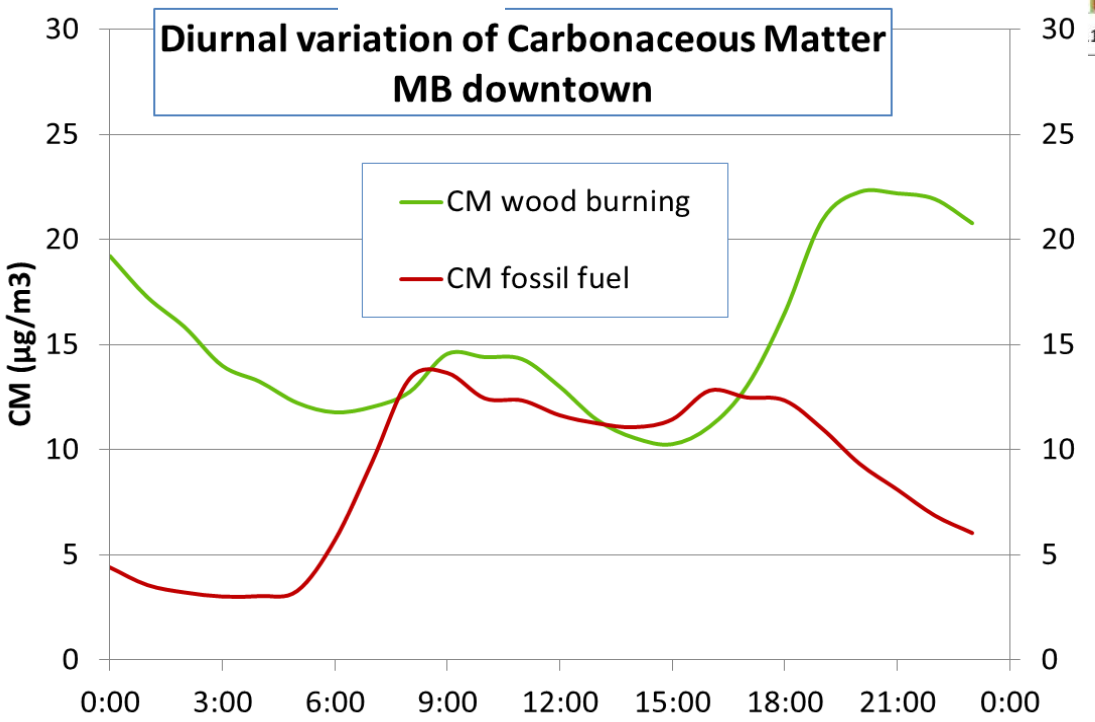

2010-11
55%
45%
CMwb
CMff
Klagenfurt
CM (µg/m3)
0
10
20
30
40
50
60
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00


2011-12
69%
31%
CMwb
CMff
CM (µg/m3)
0
10
20
30
40
50
60
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00

OC/EC TUW


bckgnd
city center
Vinarje
Počehova
Pekel
Ribniško selo
Kamnica
Za Kalvarijo
Košaki
Dragučova
Pernica
Vodole
Center
Meljski Hrib
Map
Traffic
Maribor
Industrijska cona Melje
Industrijska cona Studenci
Limbuška cesta
Koroška cesta
Malečnik
Celestrina
Čufarjeva cesta
Pekrska gorca - geološki naravni spomenik
Cesta proletarskih brigad
Titova cesta
Hitra cesta
Cesta XIV. divizije
Zrkovci
Stražun - gozd naravni spomenik
Betnavski Gozd
Betnava - park ob dvorcu
Streliška cesta
Lackova cesta
Borova vas
Ptujska cesta
Dupleška cesta
Pesnica - Slivnica
Trčova
Metava
Dogoše
Drava - stara struga, hidrološki naravni spomenik
Zgornji Duplek
Razvanje
Razvanjska cesta
Tržaška cesta
Imagery ©2013 Cnes/Spot Image, DigitalGlobe, GeoEye, Map data ©2013 Google -
Edit in Google Map Maker
Report a problem





Maribor, SI

2010-2011

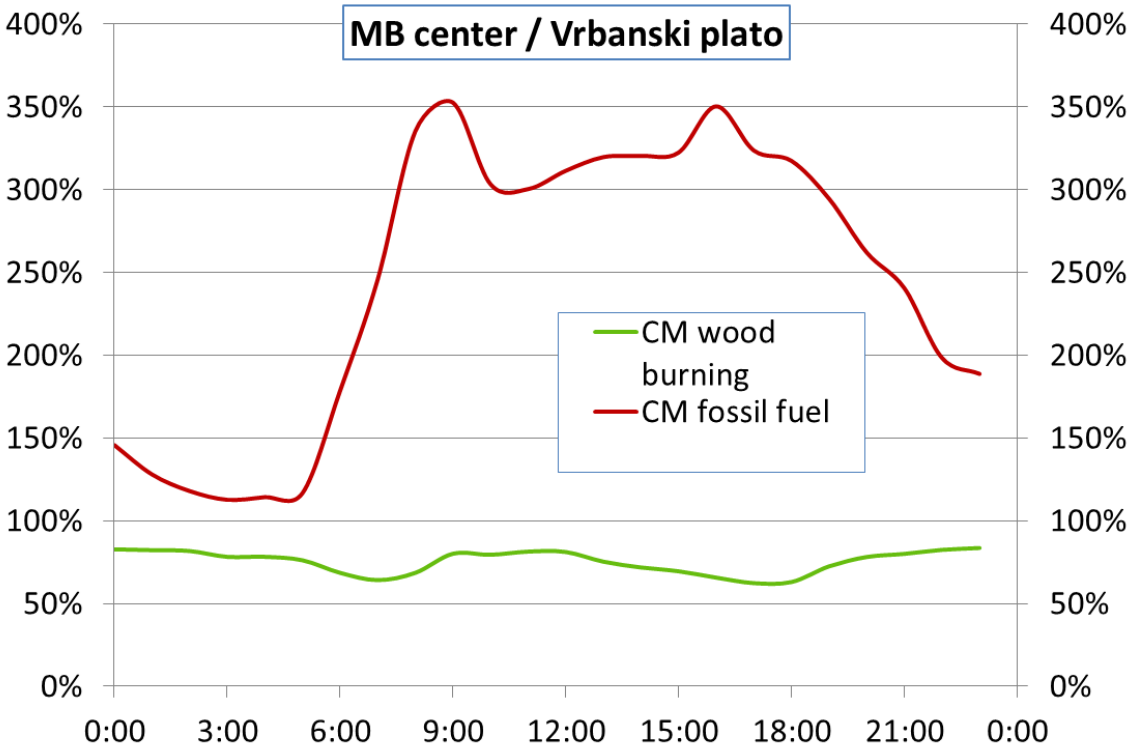
OC/EC TUW

Aerosol

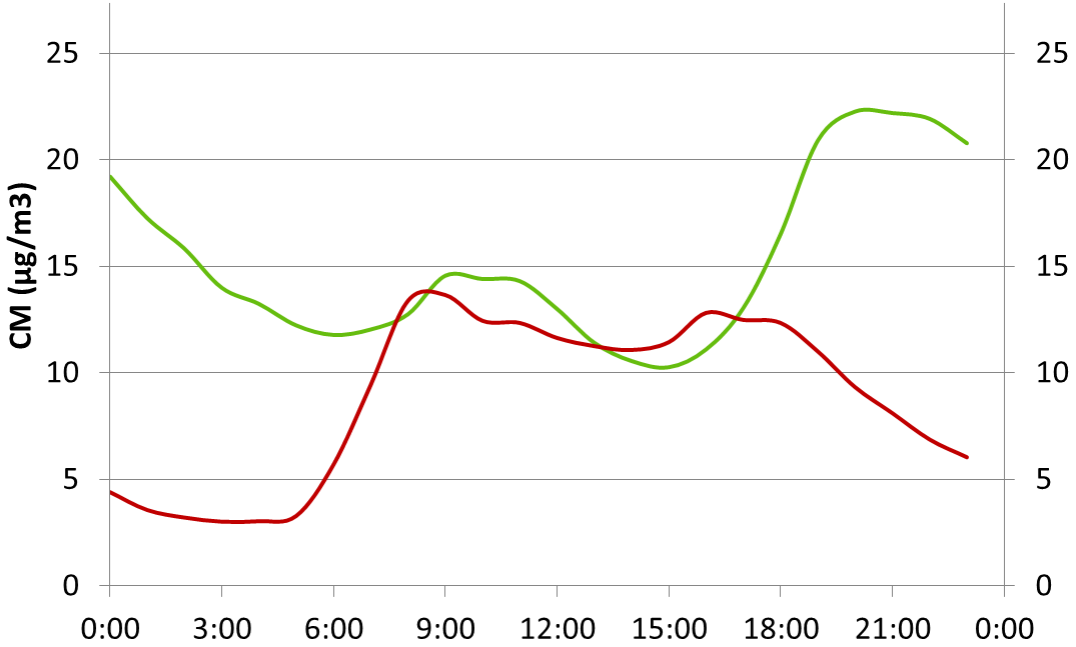
63% ± 16%

37% ± 16%

Ratio:
city / background

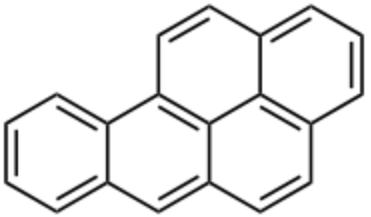


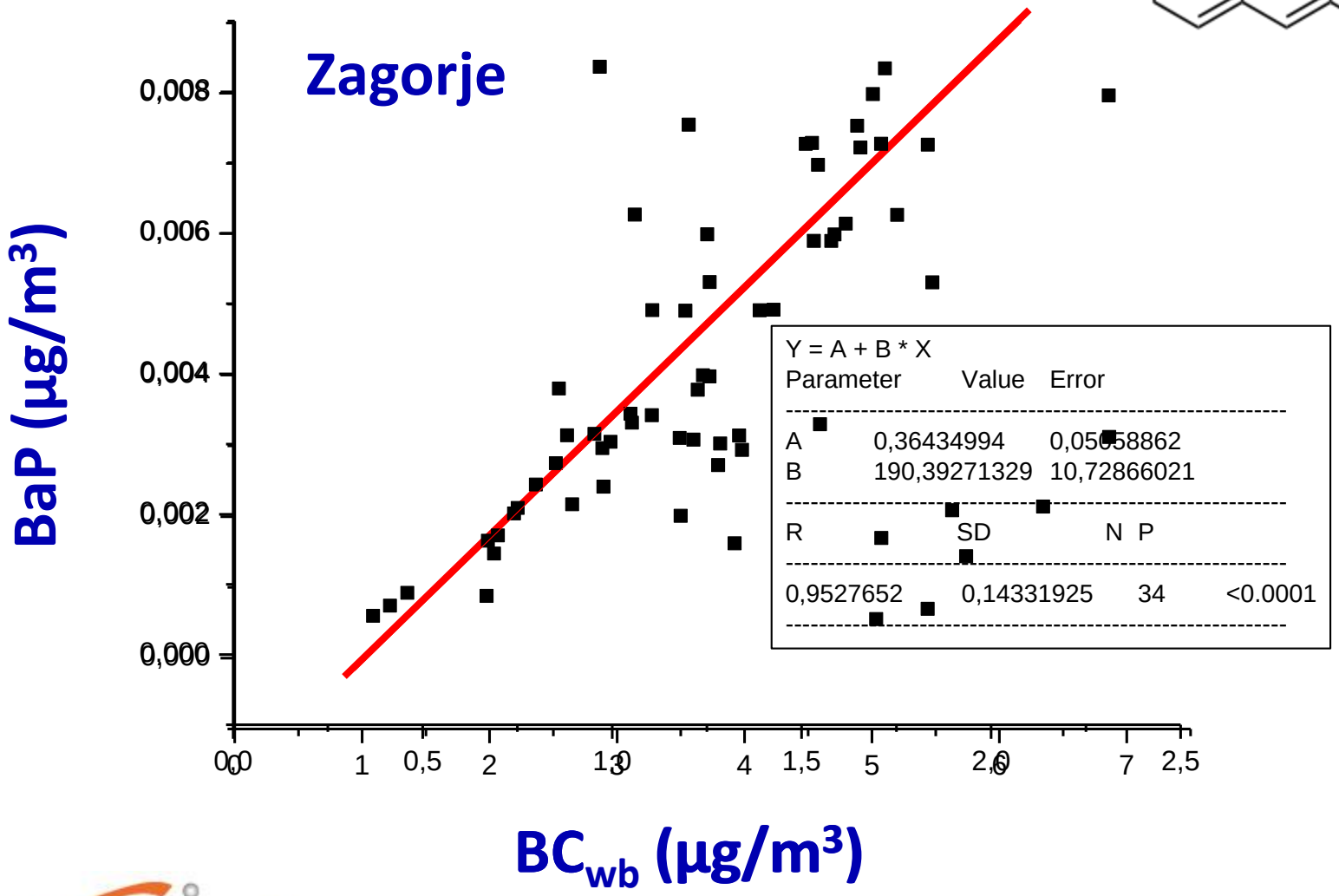
Maribor, SI



Aerosol

PAH – what is the source?

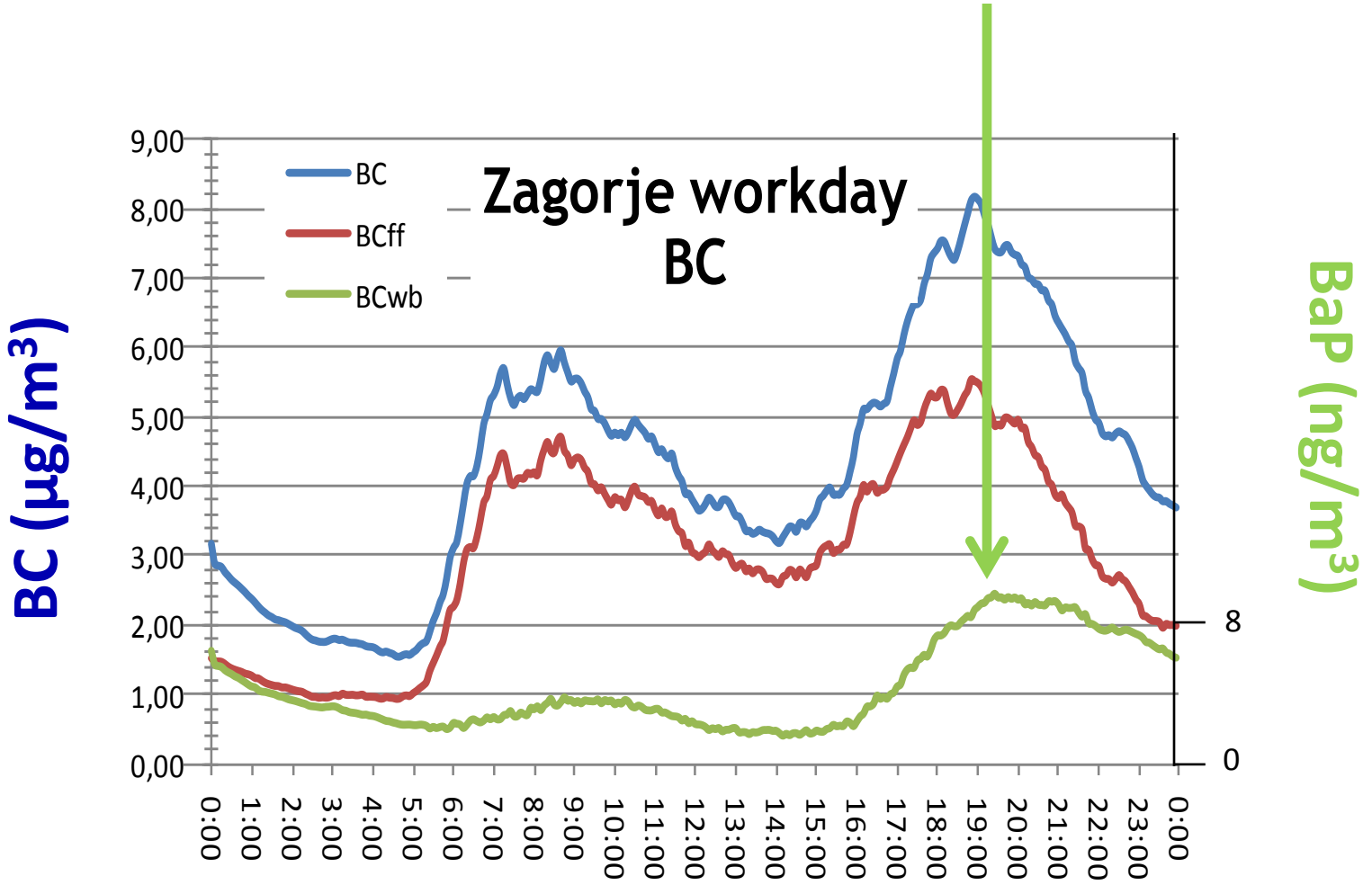




Aerosol

BaP by GC-MS - EARS

Diurnal variation of BC_{wb} = BaP



Aerosol

Conclusions

- we can measure **Black Carbon** from **Fossil Fuel** and **Biomass** combustion with the Aethalometer
- time resolution is **1 min**
- we can investigate **time evolution** of BC and biomass smoke during the day, excellent correlation with markers, PAH source
- **quantitative biomass smoke determination** – 24 h TC, but Aethalometer high time resolution - minutes
- monitoring station pair: **regional and local behaviour**
- **woodsmoke is a regional pollutant**

Aerosol

Thank you for your attention!
Questions?

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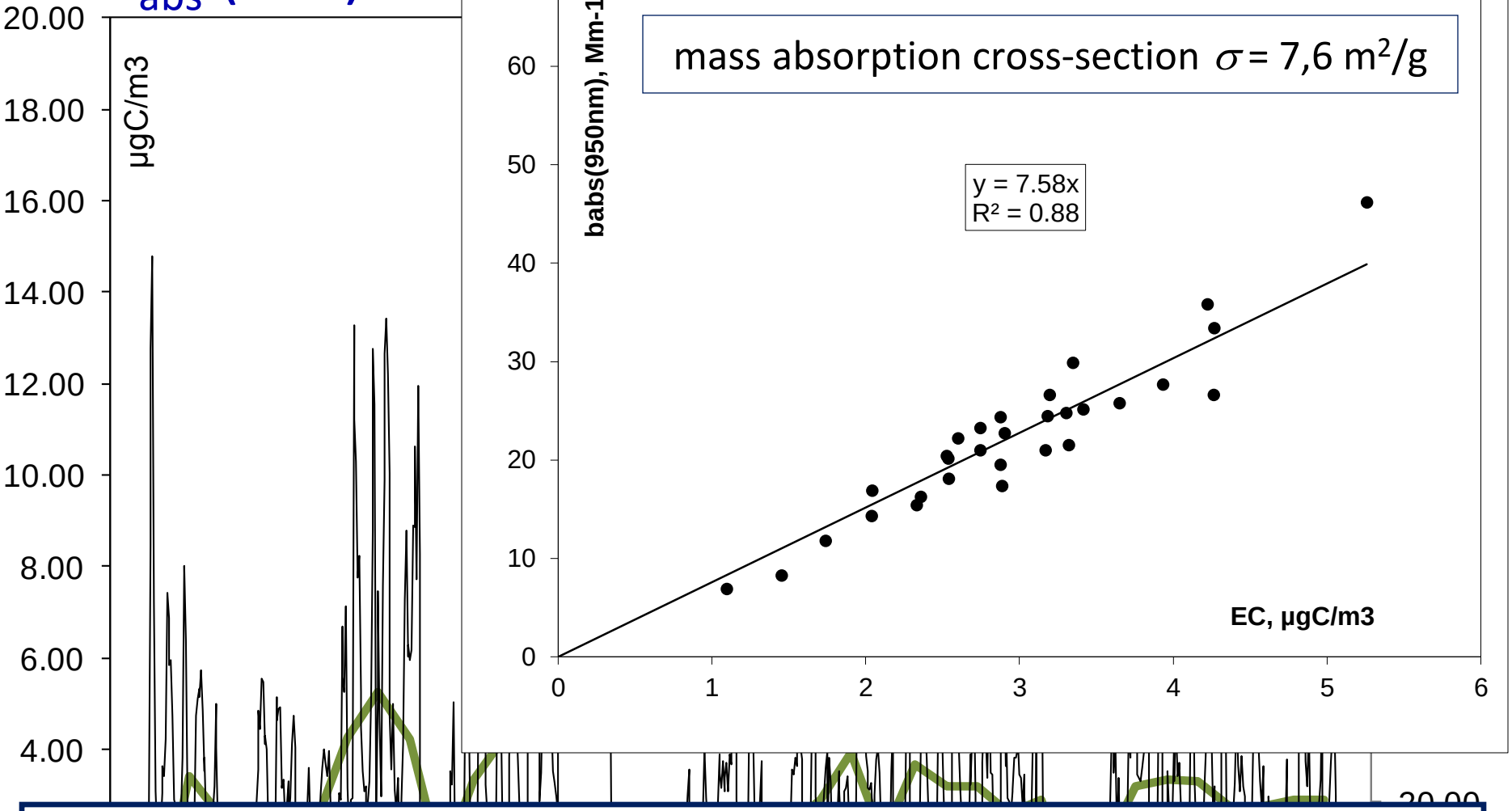
fax: +386 59 191 221

grisa.mocnik@aerosol.si

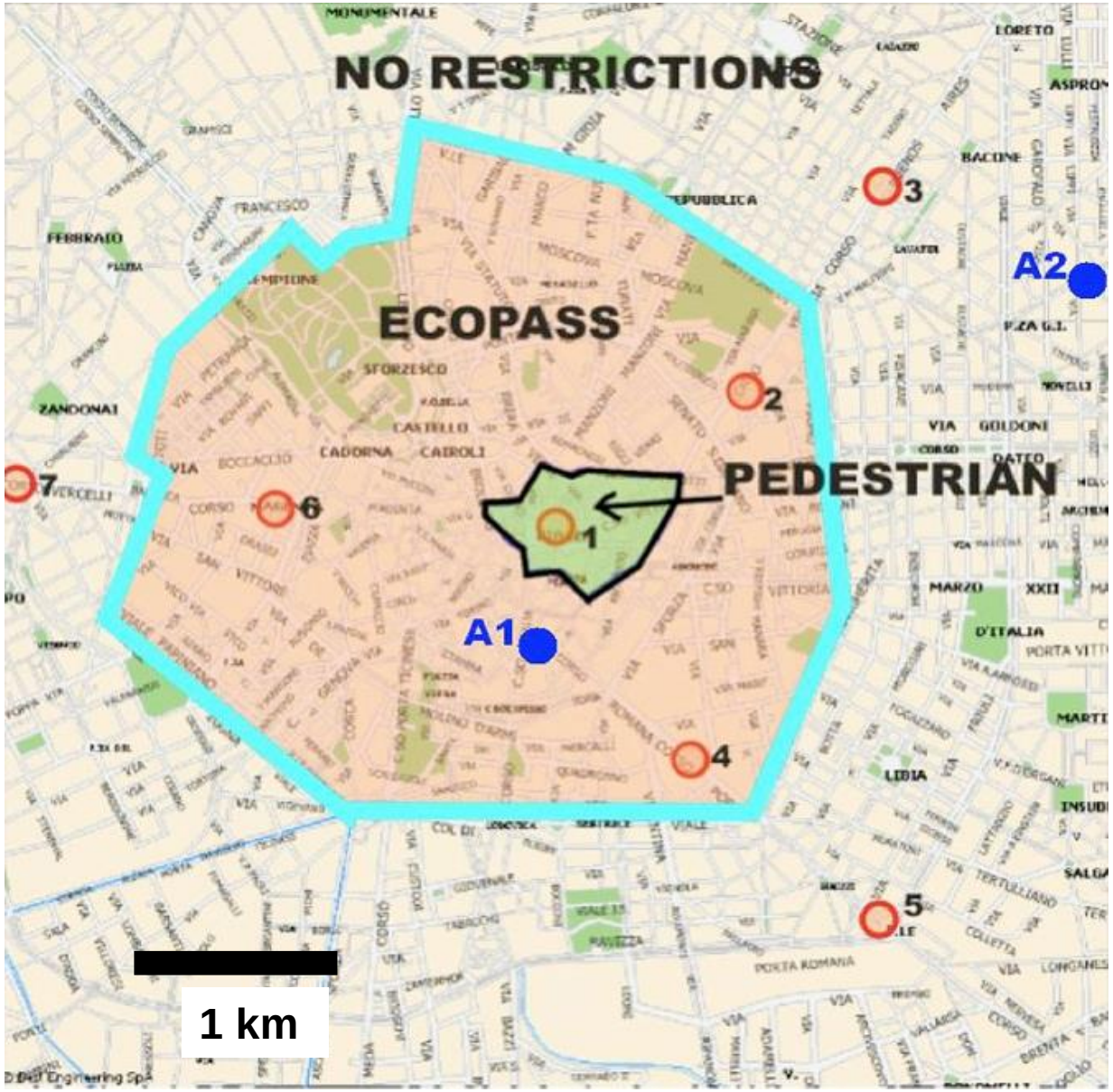
b_{abs} (950) ~ B



Good agreement between thermal EC and optical BC!

Milano, Italy

- largest city in N Italy, in a valley
- 1.3 M inhabitants
- one of the most polluted cities in Europe
- major traffic in the Po valley
- traffic: 89,000 vehicles in the city center every day
- traffic restriction in place since Jan 2008



Radial measurements

Each site:

- **PM10, PM2.5, PM1**
- **Black Carbon**
- RH, T

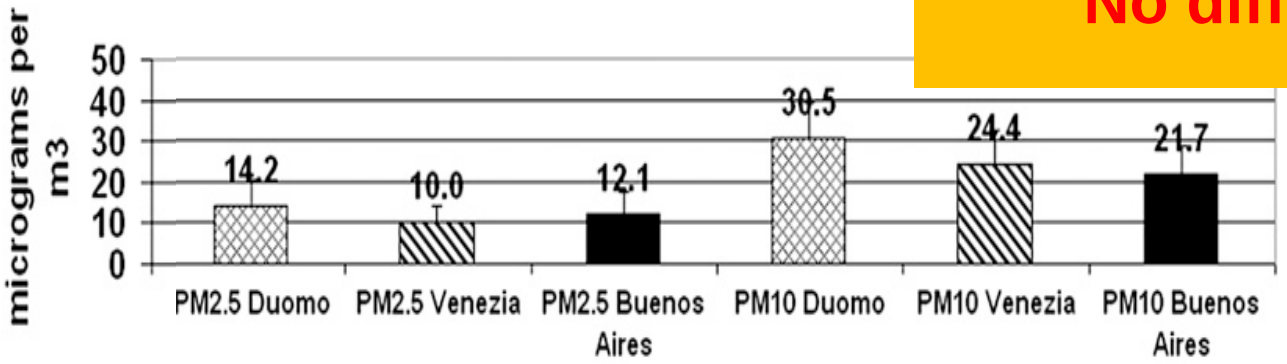
08:30 – 19:30

Summer:
July 2010

T = 30 C

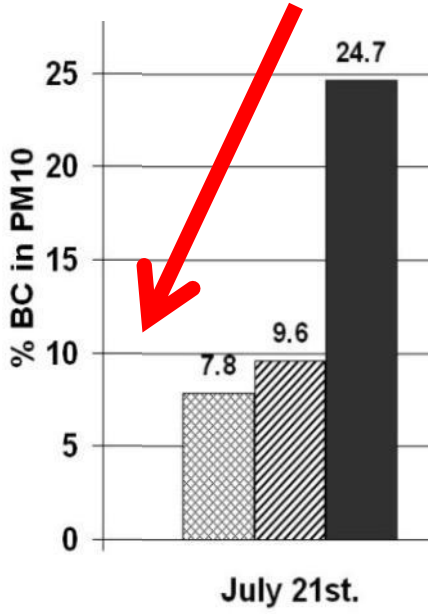
Results

No difference!

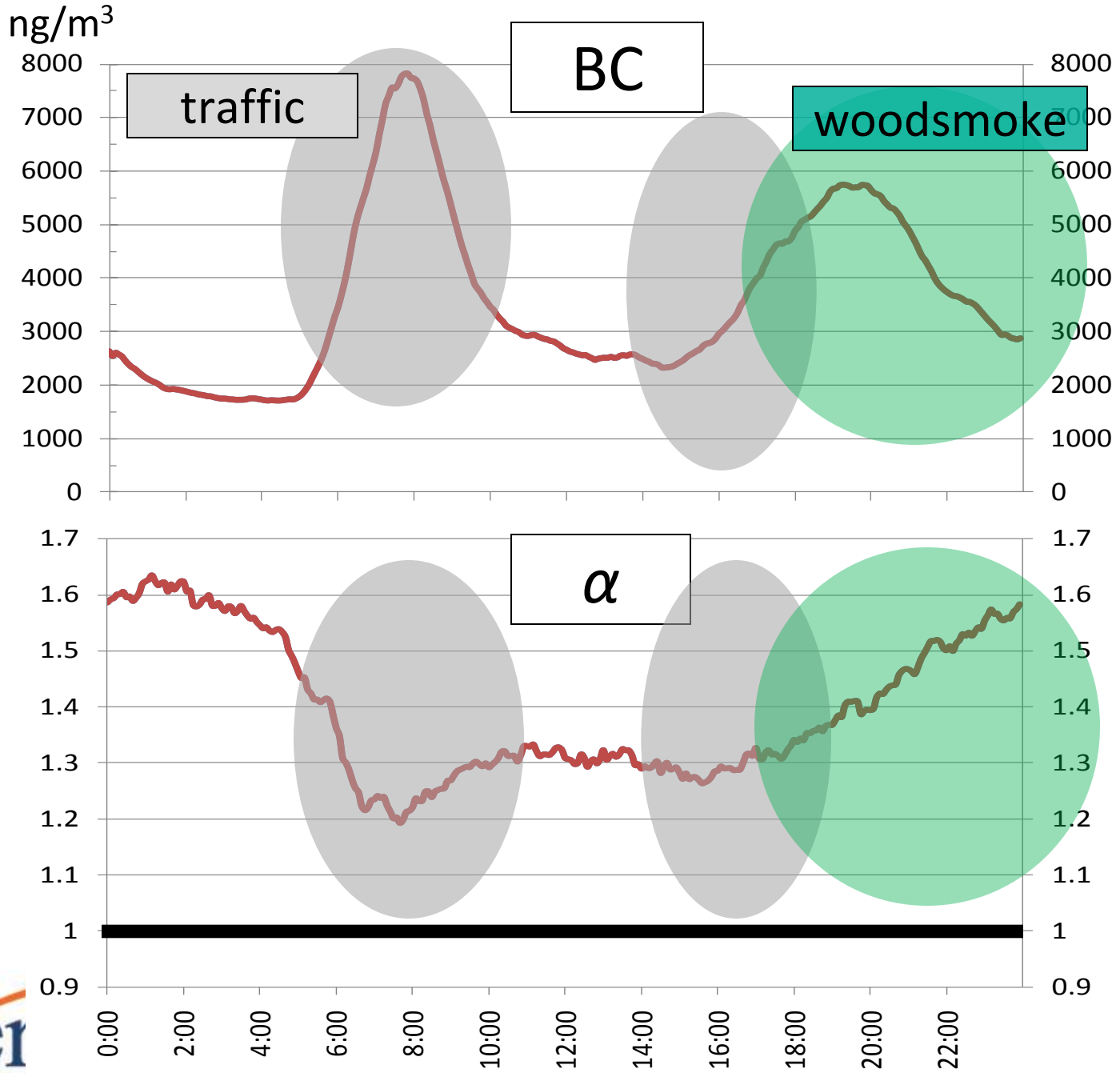


PM

Big difference!



BC/PM


ng/m3
BC
traffic
woodsmoke
8000
7000
6000
5000
4000
3000
2000
1000
0
α
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00

Quantification

$b(\lambda) = b_{wb}(\lambda,\text{wood}) + b_{ff}(\lambda,\text{fossil})$ $\lambda = 470\ nm,\ 950\ nm$

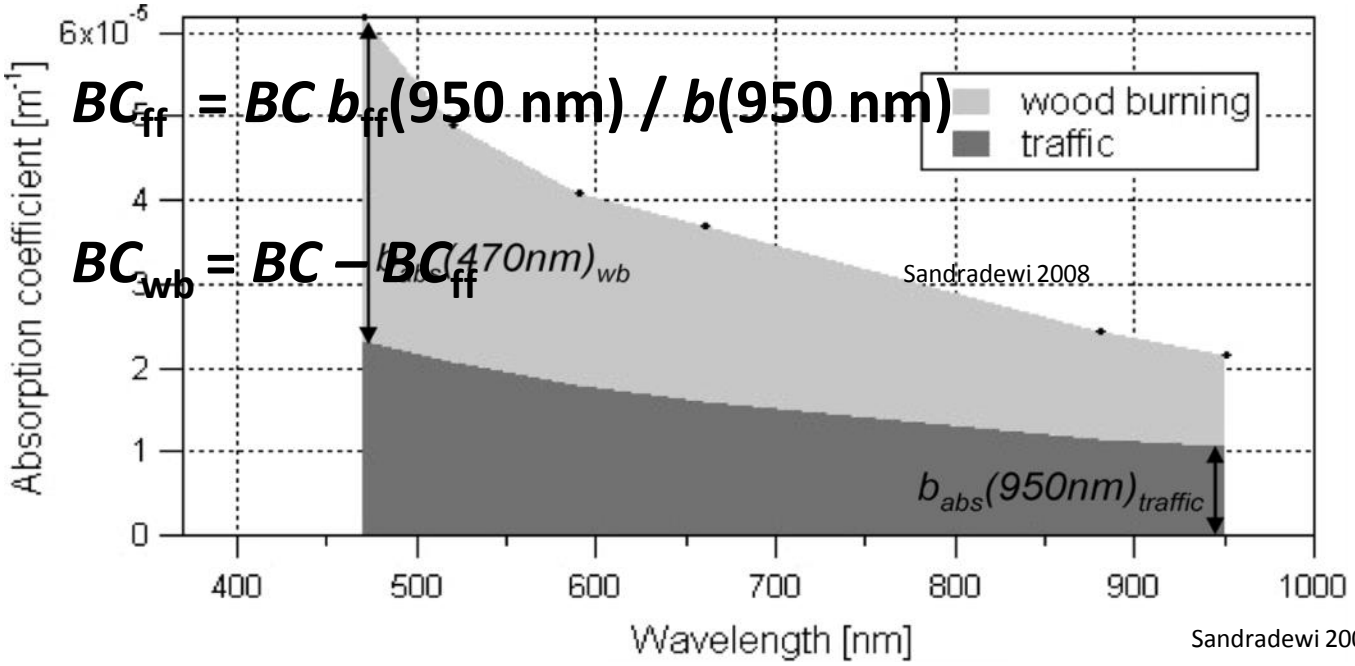
$b_i(470\ nm) / b_i(950\ nm) = (470\ nm / 950\ nm)^{-\alpha}$

$\alpha = 1{,}0 \pm 0{,}1$ (fossil) Bond & Bergstrom 2004 .

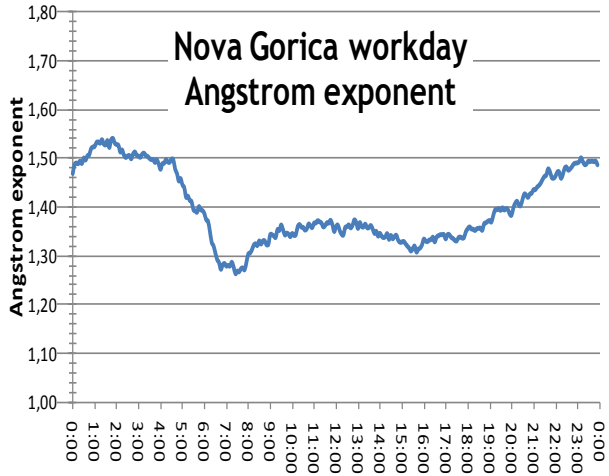
$\alpha = 2{,}0\ -0{,}5/+1{,}0$ (wood) Kirchstetter 2004, Day 2006, Lewis 2008

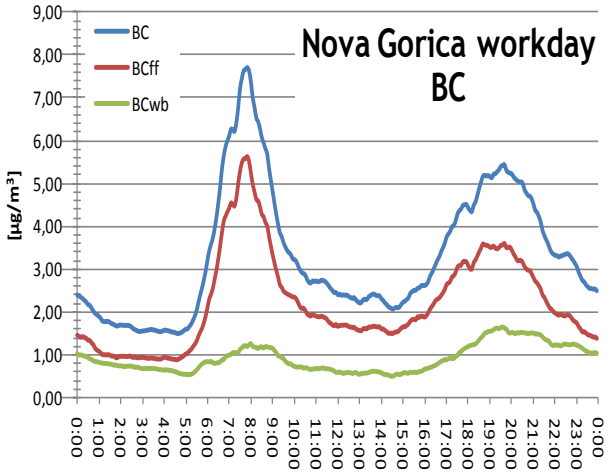
$BC_{ff} = BC\ b_{ff}(950\ nm) / b(950\ nm)$

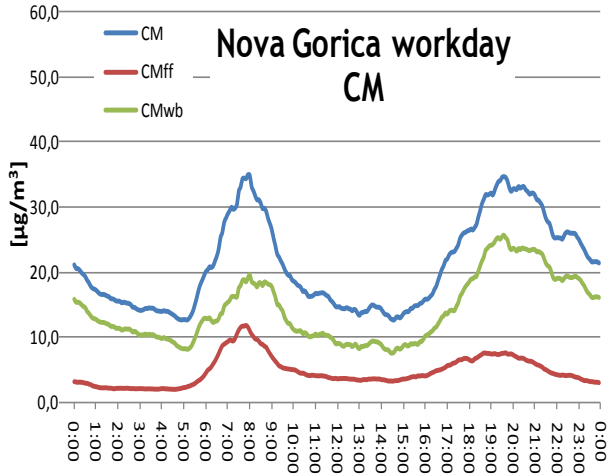
$BC_{wb} = BC - BC_{ff}$

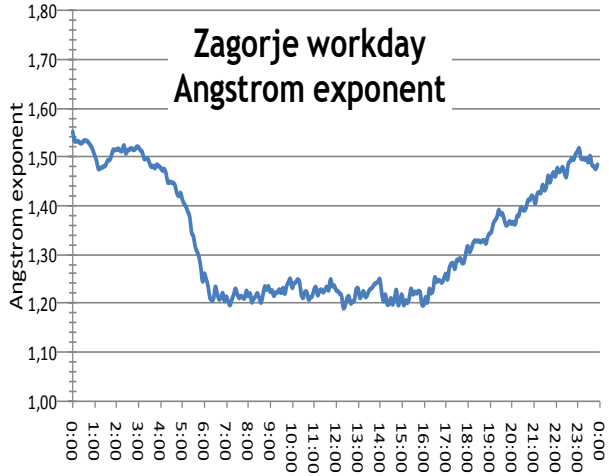


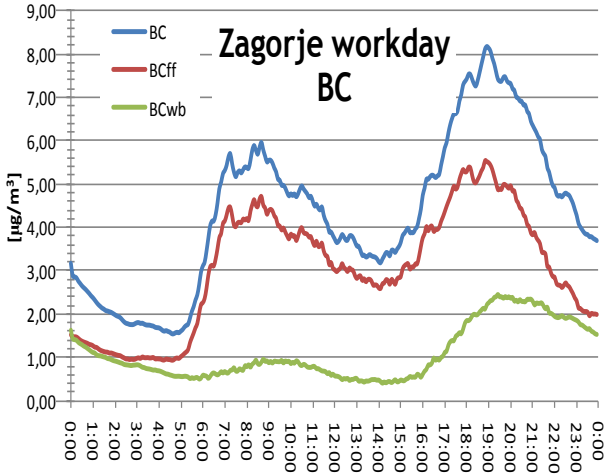
Sandradewi 2008

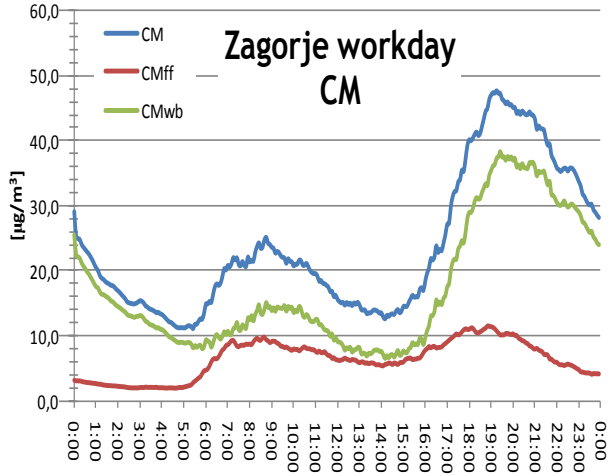

Nova Gorica workday
Angstrom exponent
Angstrom exponent


Nova Gorica workday
BC
BC
BCff
BCwb
[µg/m³]


Nova Gorica workday
CM
CM
CMff
CMwb
[µg/m³]


Zagorje workday
Angstrom exponent
Angstrom exponent


Zagorje workday
BC
BC
BCff
BCwb
[µg/m³]


Zagorje workday
CM
CM
CMff
CMwb
[µg/m³]

Aerosol

Carbonaceous matter

measure Total Carbon – 24 h resolution

TC = OC + EC → *carbonaceous matter CM*

$$CM = C_1\, b(\text{fossil},950\text{ nm}) + C_2\, b(\text{wood},470\text{ nm}) + C_3$$

fossil fuel combustion BrC containing – wood combustion non-combustion sources

$$CM = BC + OM$$

C_1, C_2, C_3 determination – some hand-waving

- C_1 is less variable than C_2 and C_3 and fixed to 290.000
- C_2 and C_3 determined from (CM-CM_{ff}) vs. CM
- determine CM_{ff} from

$$CM_{ff} = BC_{ff} + OM_{ff}$$

$$BC_{ff} / OC_{ff} = 1$$

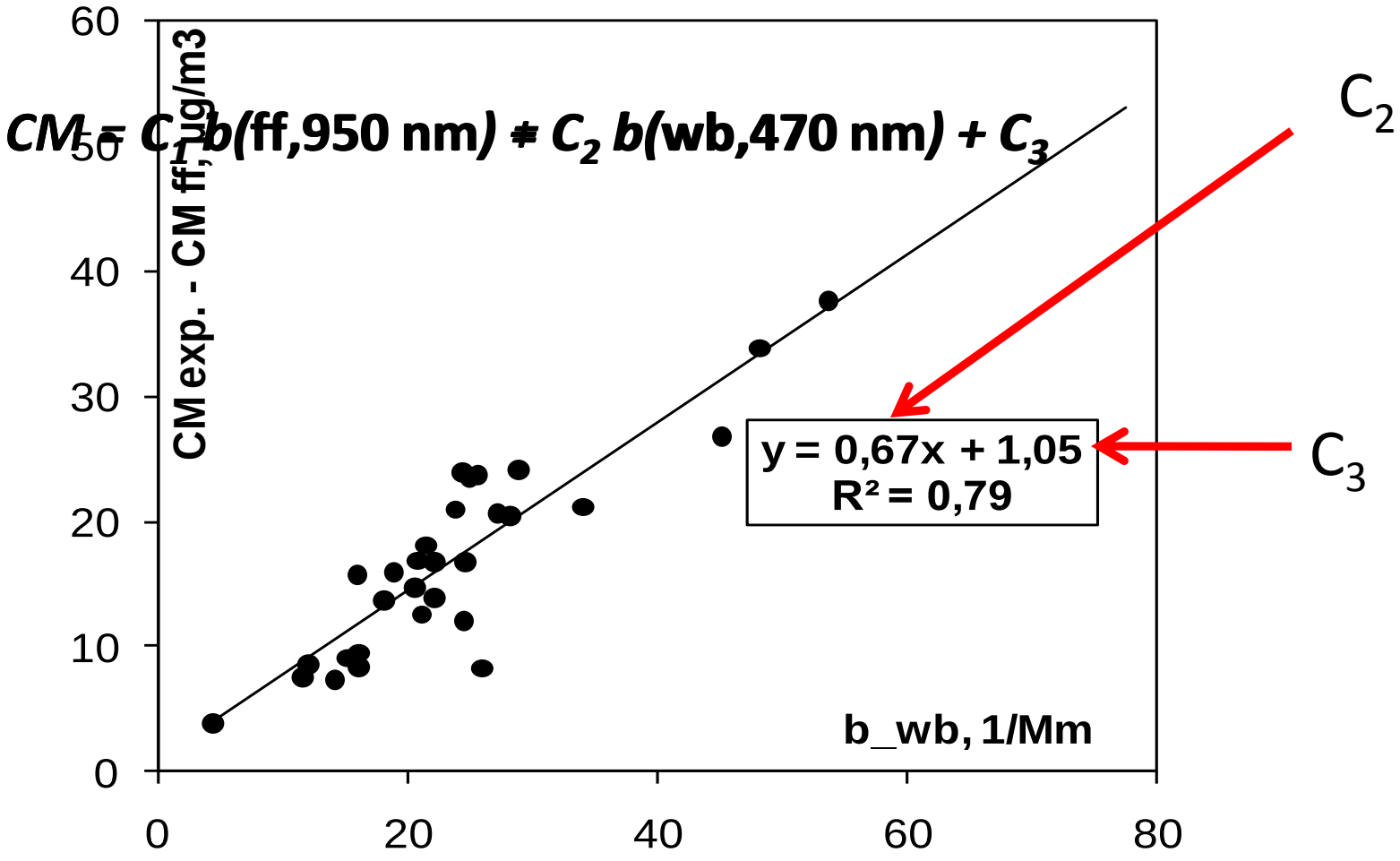
$$OM_{ff} = 1{,}8\ OC_{ff}$$

} supported by ambient and emission studies, WSOC measured

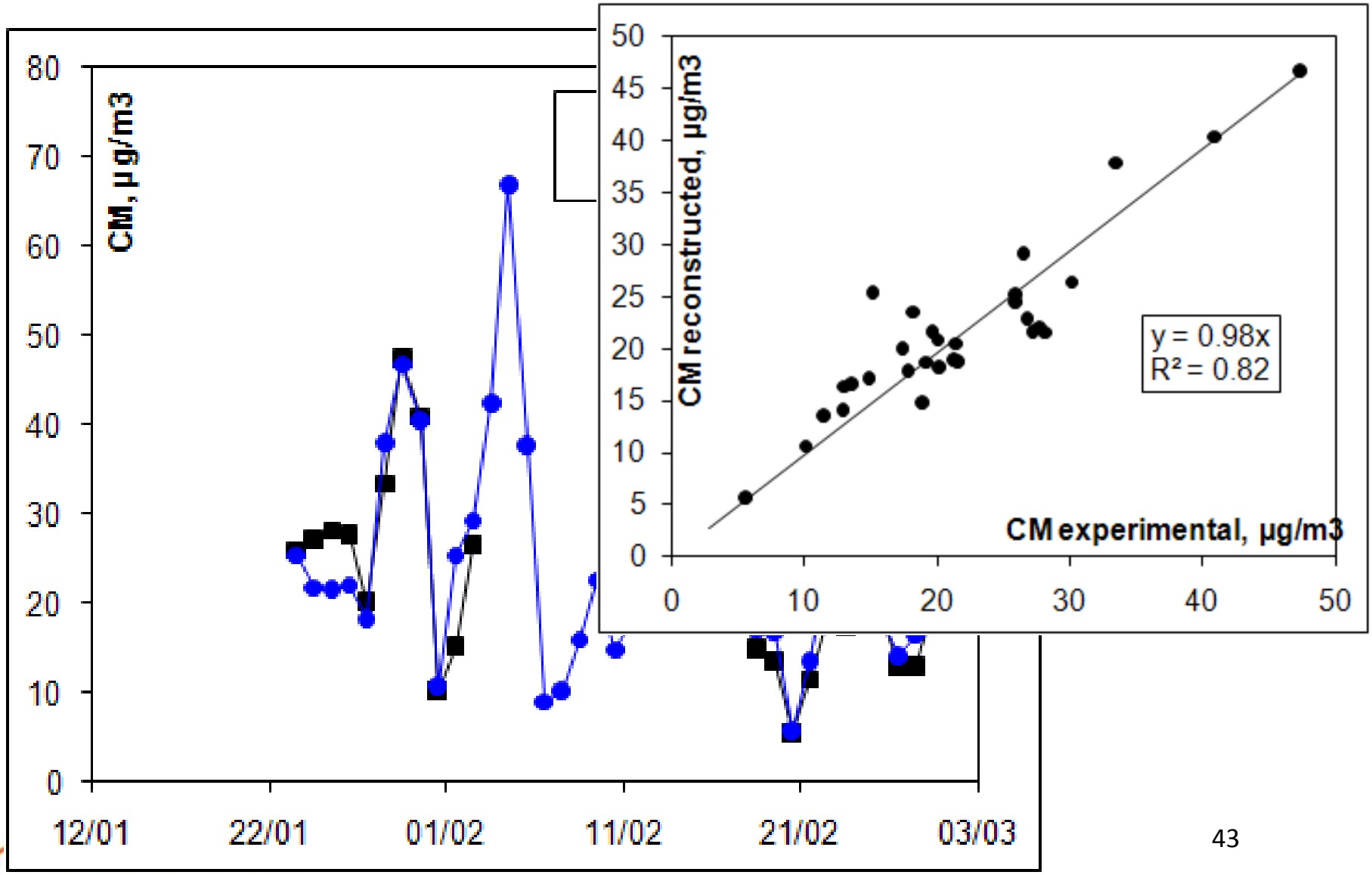
Sandradewi 2008, Favez 2010

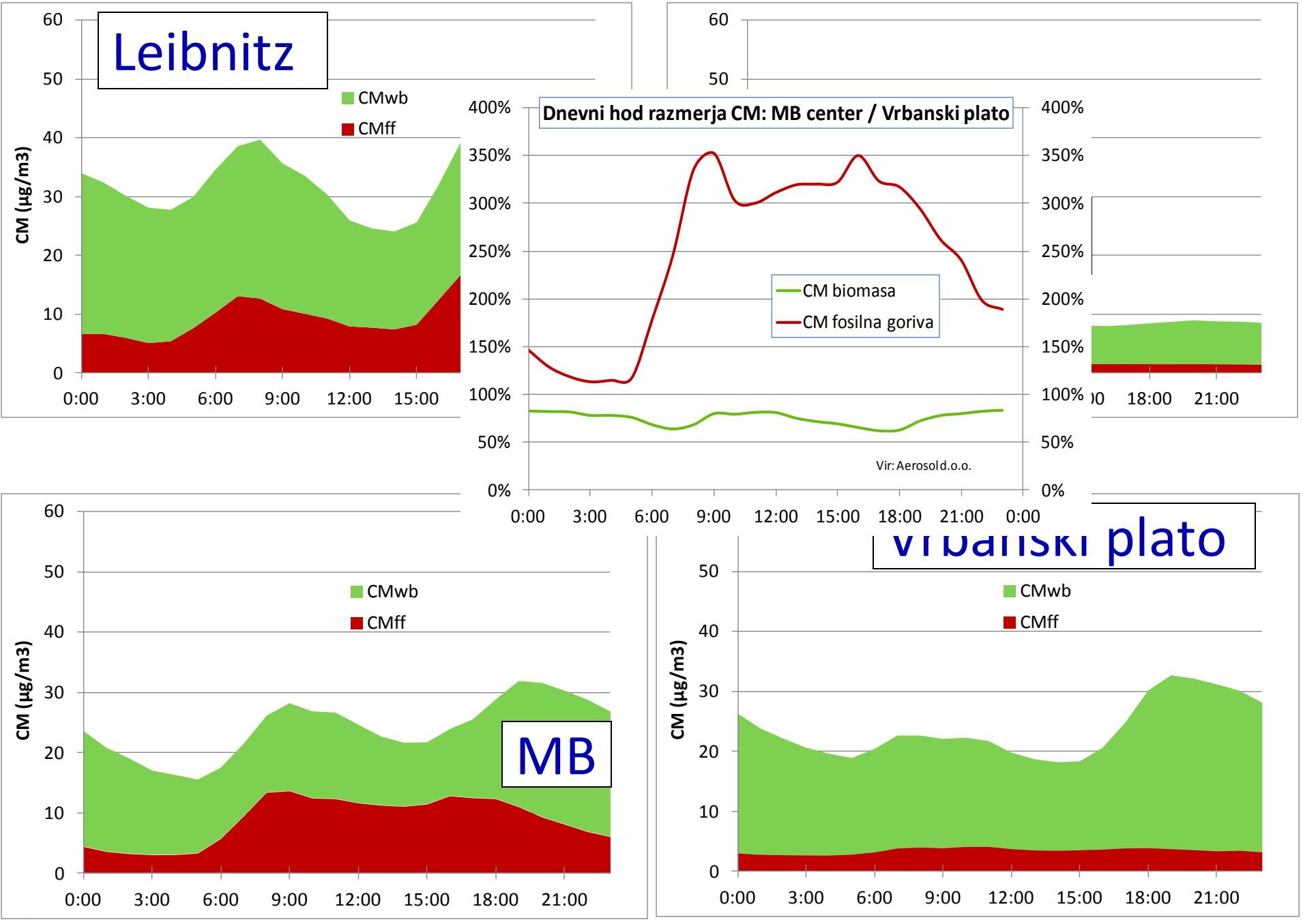
Aerosol

C_2, C_3 determination (2) – Nova Gorica



CM reconstruction using C_i – Nova Gorica



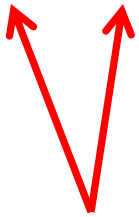

Leibnitz
CMwb
CMff
CM (µg/m3)
0
10
20
30
40
50
60
0:00
3:00
6:00
9:00
12:00
15:00
Dnevni hod razmerja CM: MB center / Vrbanski plato
CM biomasa
CM fosilna goriva
Vir: Aerosol d.o.o.
0%
50%
100%
150%
200%
250%
300%
350%
400%
18:00
21:00
MB
Vrbanski plato

Wood-smoke vs. Fossil fuel

	Aethalometer model ug/m3			%		TUW
	CM	CMff	CMff	CMff %	CMwb%	CMwb%
Maribor	22,9	8,9	13,9	39%	61%	75%*
Vrbanski plato	23,8	3,5	20,3	15%	85%	82%
Leibnitz	35,5	10,7	24,7	30%	70%	62%
Arnfels	6,4	1,1	5,2	18%	82%	43%**
Voelkermktstr	33,8	15,9	17,9	47%	53%	54%
Limmersdorf	21,8	5,7	16,2	26%	74%	69%
Zell	37,0	7,3	29,7	20%	80%	77%

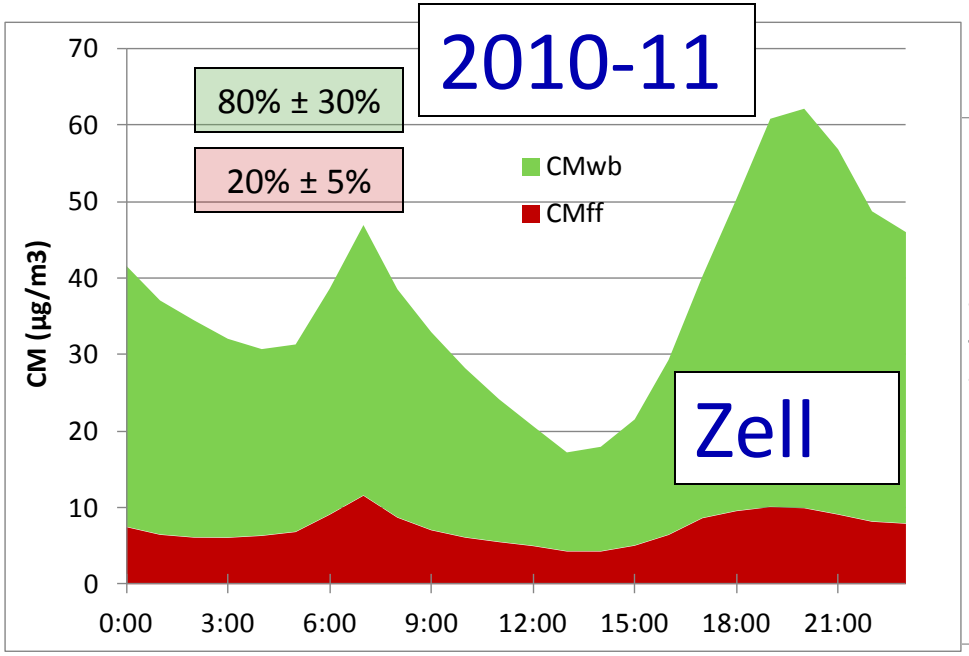
* reanalysis

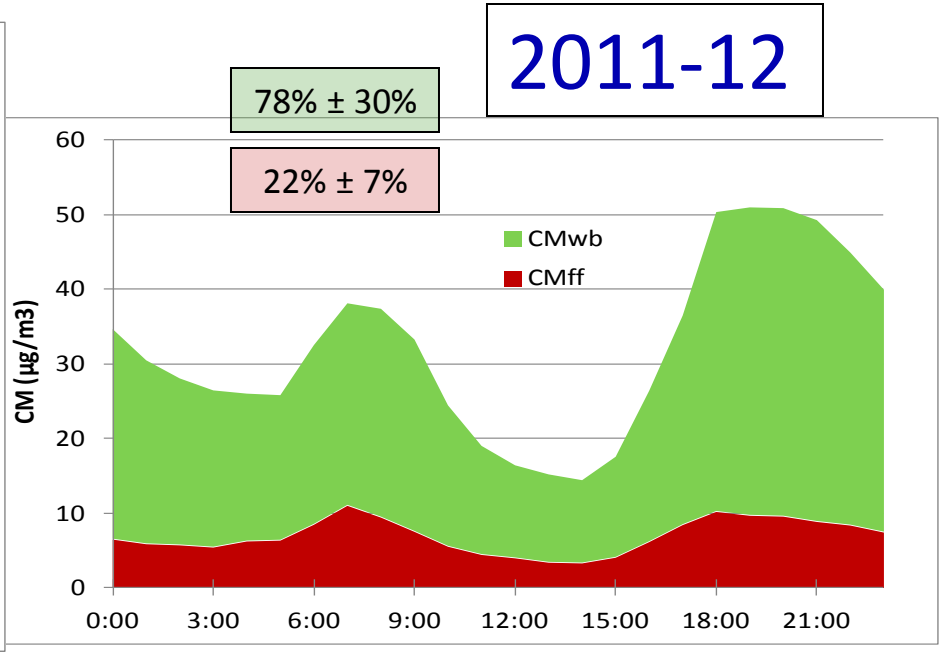
** 31% other OM!

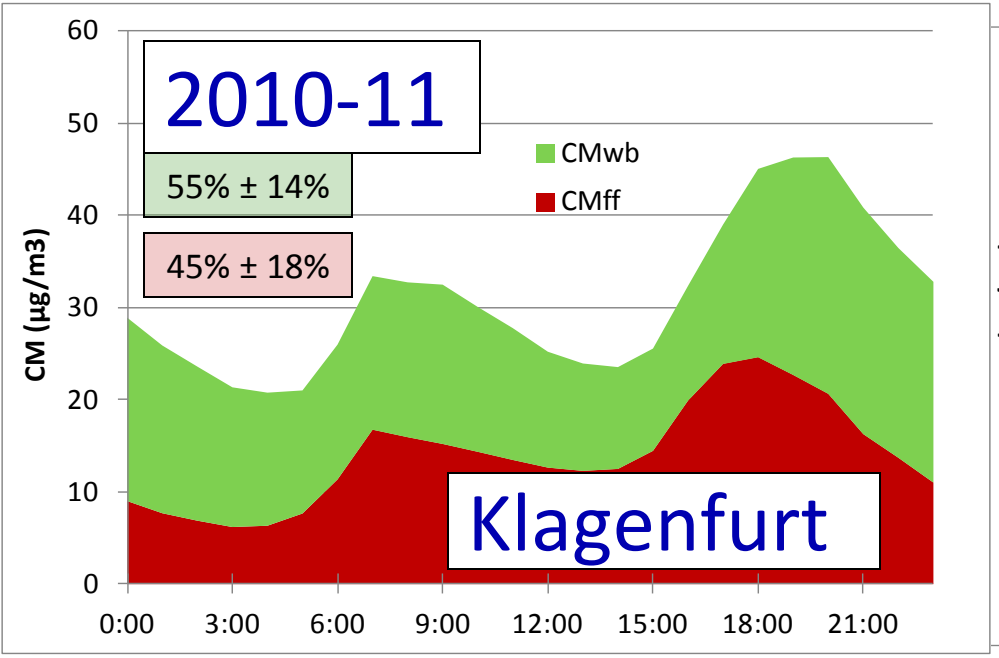


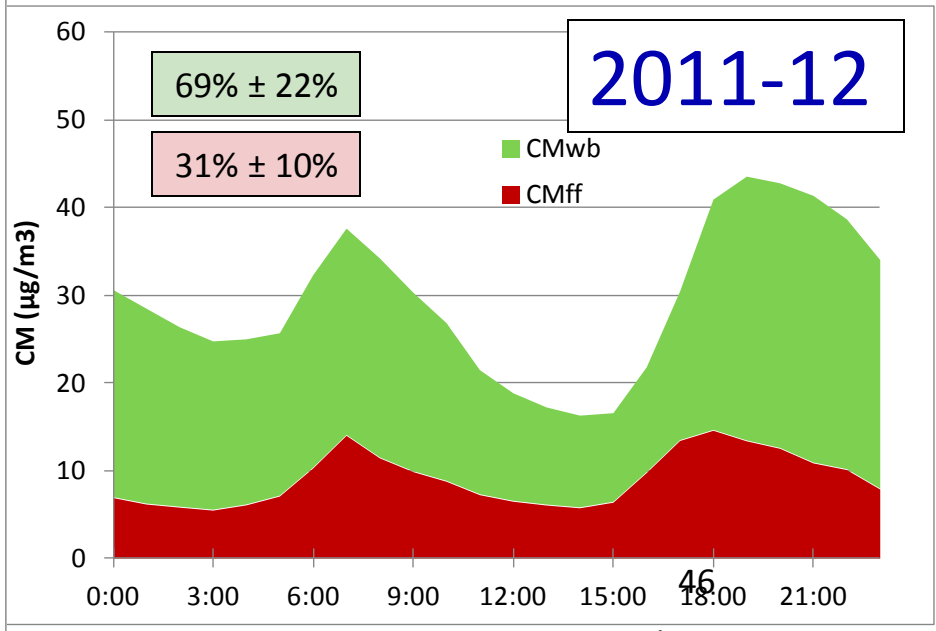
Good agreement!

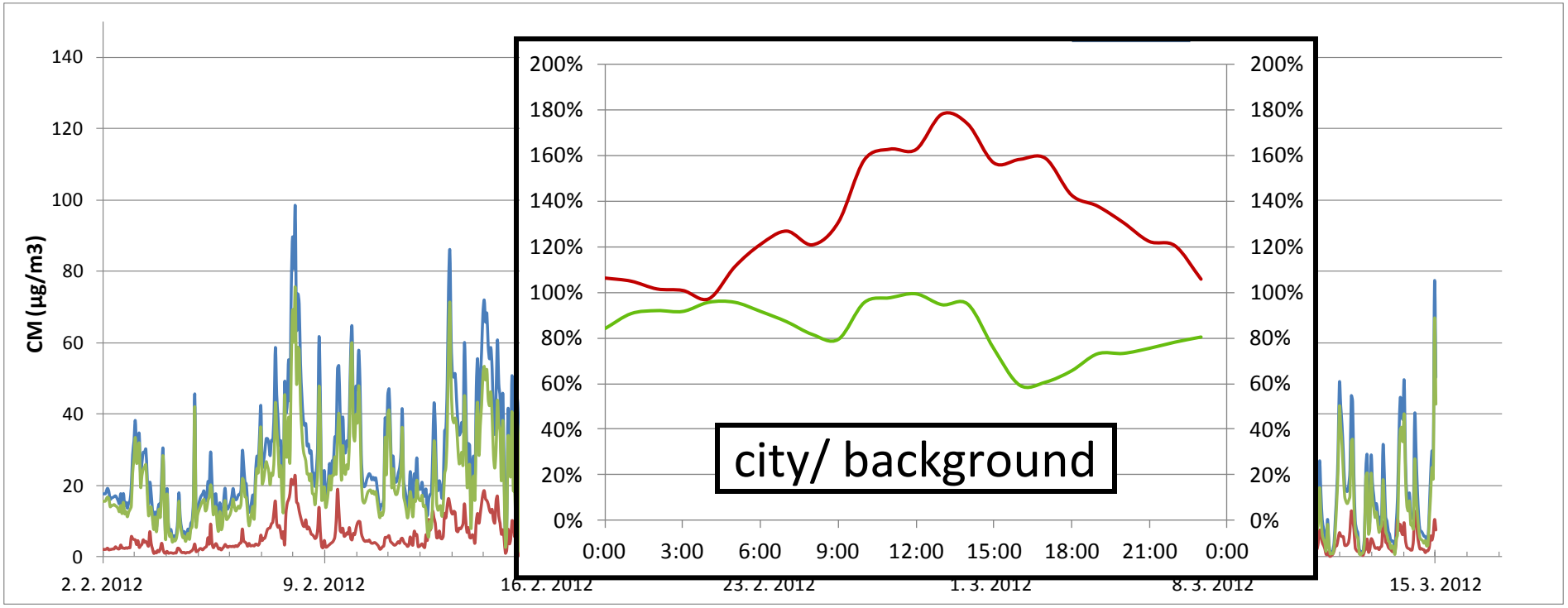
Preliminary!


2010-11
80% ± 30%
20% ± 5%
CMwb
CMff
CM (µg/m3)
Zell
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00


2011-12
78% ± 30%
22% ± 7%
CMwb
CMff
CM (µg/m3)
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00


2010-11
55% ± 14%
45% ± 18%
CMwb
CMff
CM (µg/m3)
Klagenfurt
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00

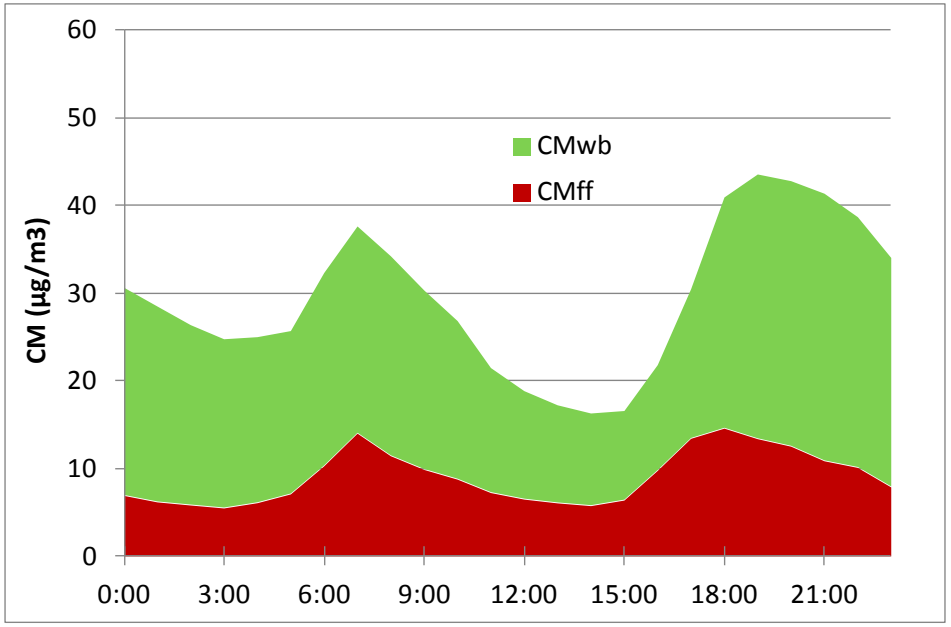

2011-12
69% ± 22%
31% ± 10%
CMwb
CMff
CM (µg/m3)
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00



Klagenfurt

OC/EC TUW

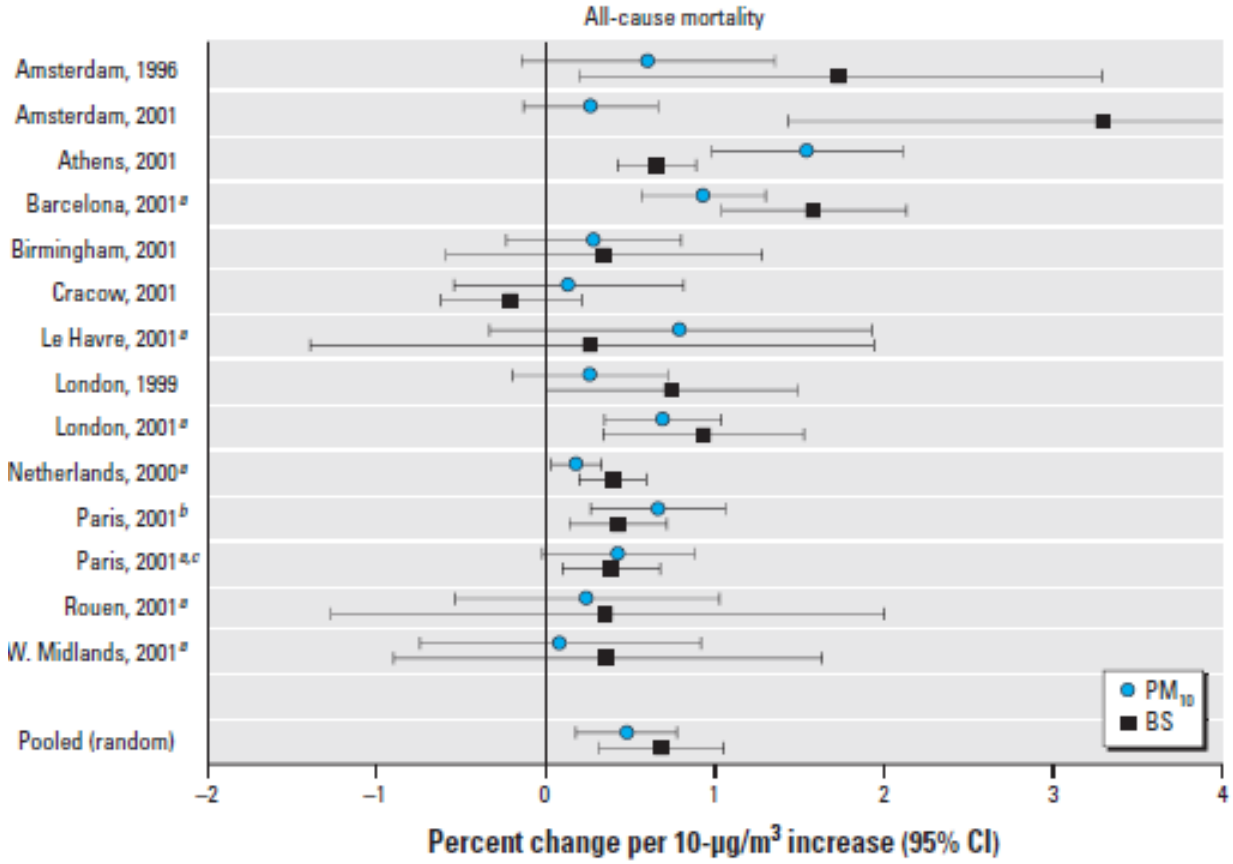
Aerosol



69% ± 22%

31% ± 10%

Health Effects



Dockery et al., *N. Engl. J. Med.* 329: 1753 (1993)

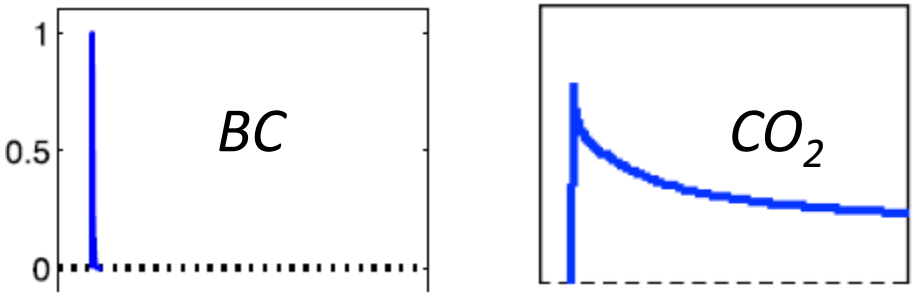
	Mortality Ratio
	Highest *vs.* Lowest PM
All causes	1.26
Lung cancer	1.37
Other cardiopulmonary	1.37
Non-cardiopulmonary	1.01

Two-pollutant models in time-series studies suggested that the effect of BCP was more robust than the effect of PM mass. The estimated increase in life expectancy associated with a hypothetical traffic abatement measure was four to nine times higher when expressed in BCP compared with an equivalent change in PM2.5 mass. Jansen et al, 2011 EHP

Climate Change Effects of Aerosols: BC vs. CO_2

What is the big deal with BC?
C mass emitted as BC is 0.1% of C mass emitted as CO_2!

... and its lifetime is small!



Bond 2012

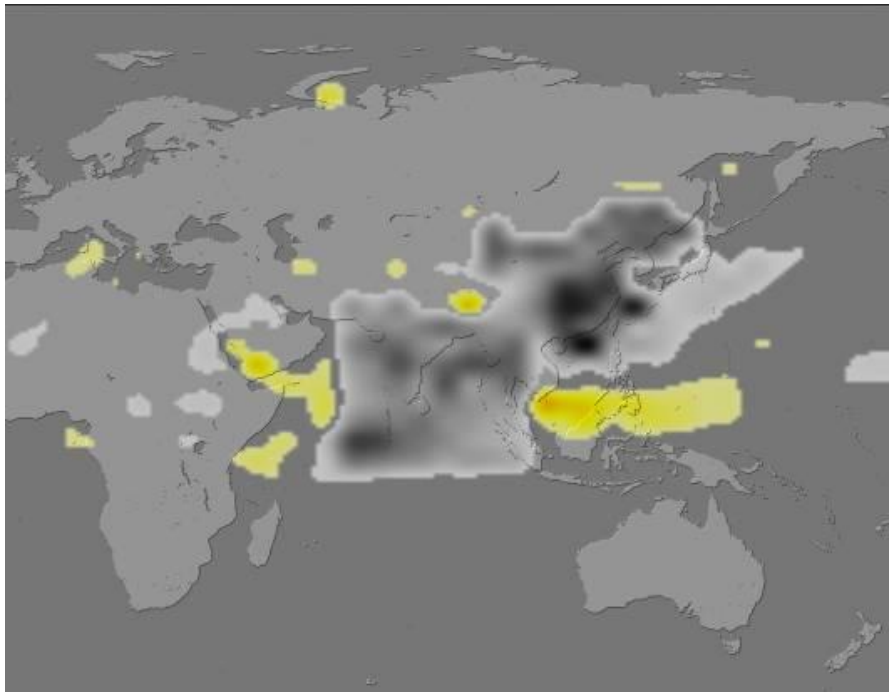
BUT... BC absorbs sunlight extremely efficiently:

1 g of BC absorbs as much as ~10 umbrellas!

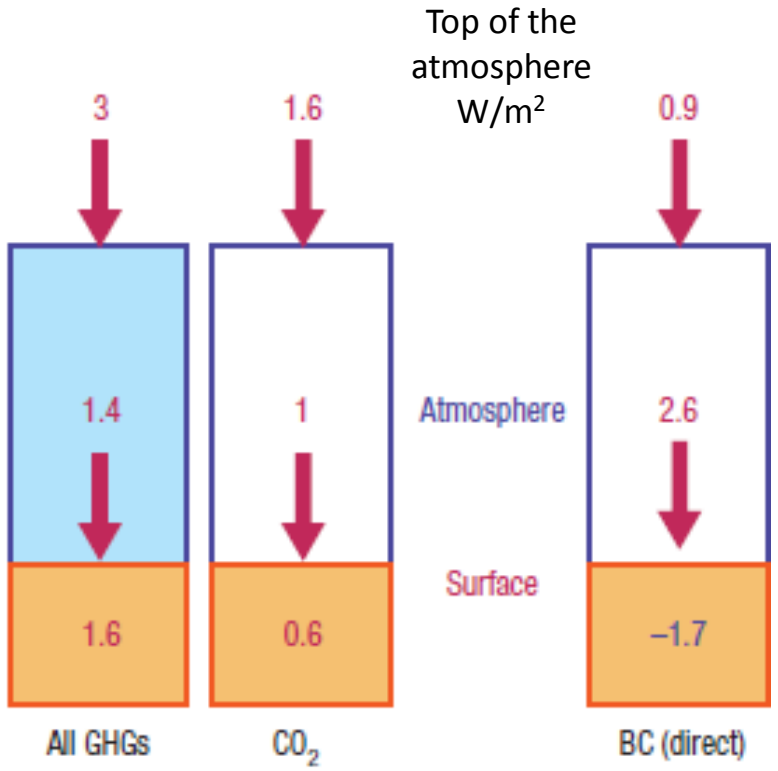
truck: EF=10 g/kg → 1 umbrella/100 m

Climate Change Effects of Aerosols

Total BC forcing: direct + indirect
1,1 W/m²
(Bond et al 2013)



S. Menon, J. Hansen et al. *Science* (2002) 2250

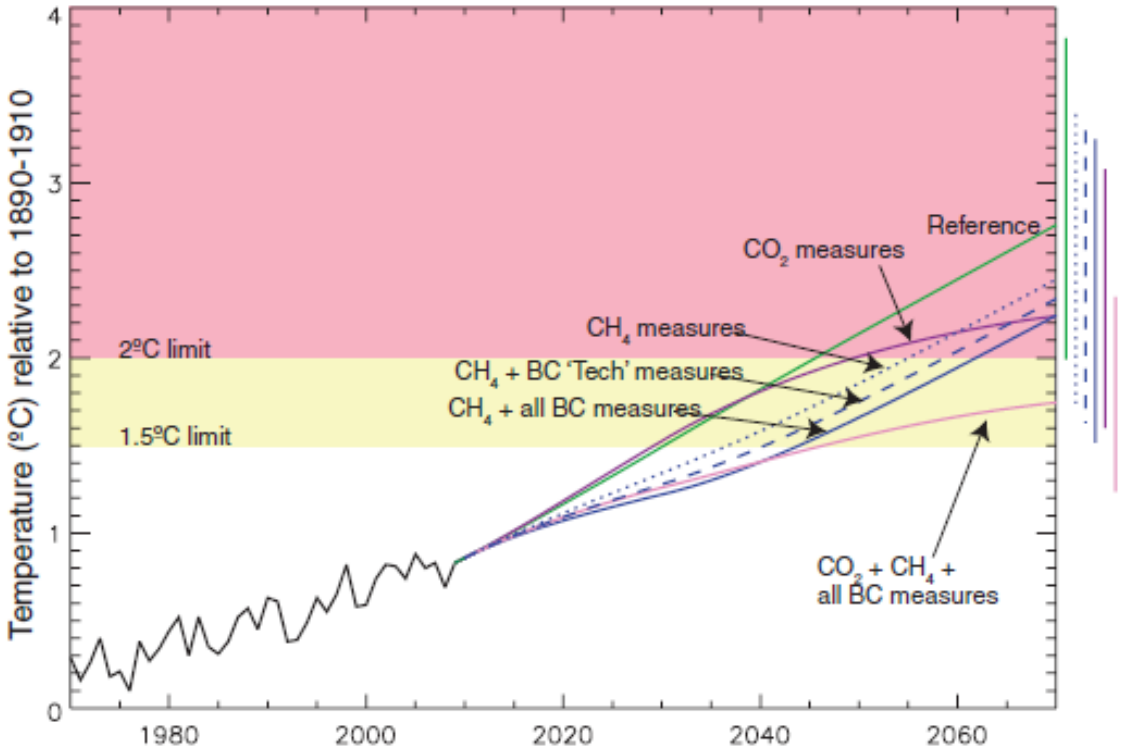


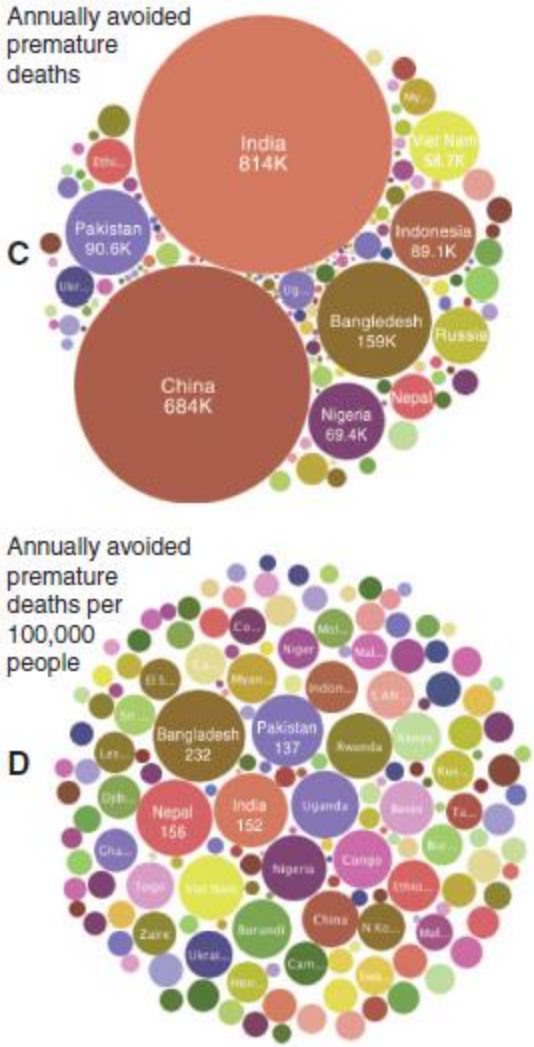
V. Ramanathan, G. Charmichael, Nature Geosci (2008) 221

Haze over Asia: up to 40% of sunlight absorbed. Crop yields reduced ; local rainfall changed.

BC forcing is almost 1/3 of the total TOA GHG forcing!
Heat redistribution → weather

Climate & health!





Drew Shindell, *et al.*
Simultaneously Mitigating Near-Term Climate Change and Improving Human Health and Food Security
Science ***335, 183 (2012);***

Aerosol

Installations in monitoring stations

- fixed measurement sites
- analysis of **temporal** trends
- **source apportionment**

London, UK

Austria

China

Aethalometer Model AE33

- **Multiple wavelengths**: absorption: UV-IR, quantitative source aportionment: fossil fuel vs. wood-smoke – BC and CM.
- **Dynamic loading compensation** eliminates filter loading artifacts.
- **Automated QA/QC** with zero, optical span checks and flow calibration.
- **Improved performance**: low noise, fast time resolution.
- Easily integrates into **networks**: ease of communication and maintenance.

Aerosol

From Black&White to Color

Aerosol