# Sources of carbonaceous aerosol in a South-East European metropolis

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# What is carbonaceous aerosol?

- Carbonaceous aerosol includes black carbon (BC), organic carbon (OC), inorganic carbon
- BC is operationally defined as elemental carbon (EC) or equivalent black carbon (eBC)
- Major fraction of PM with severe health and climate effects
- New AAQD sets stricter limits for PM and includes BC as a recommended component of monitoring, recommends tracers for biomass burning such as levoglucosan for source apportionment (SA)

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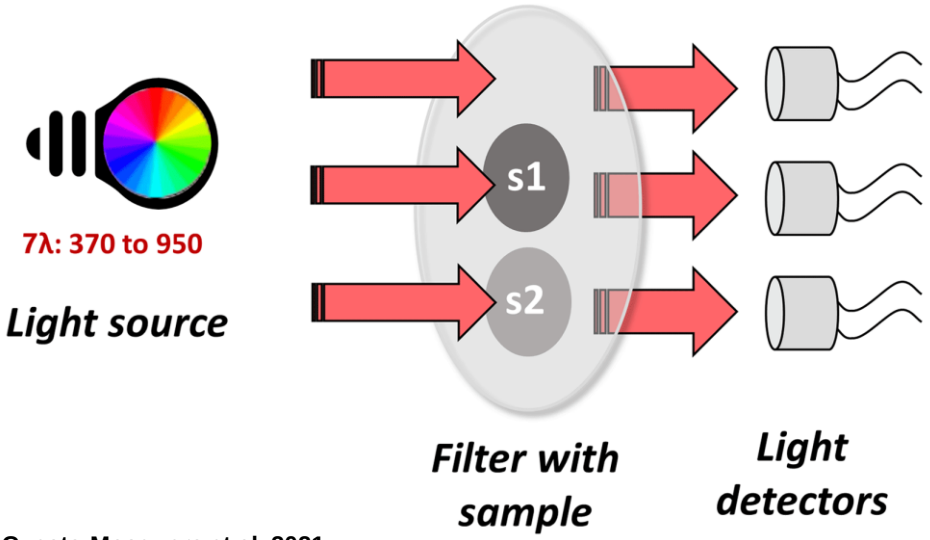
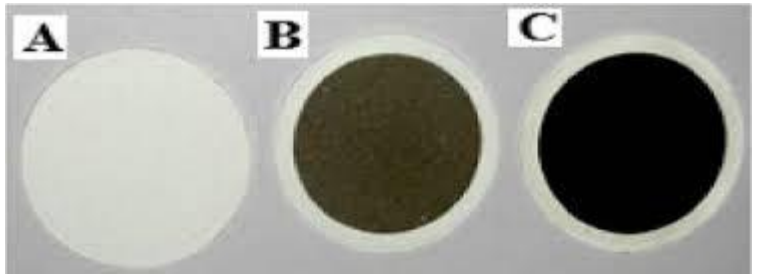
**AAQD defines equivalent black carbon (eBC) as BC measured by absorption**




Andrea Cuesta-Mosquera et al. 2021

**EC and OC, tracers are analysed offline on filters**

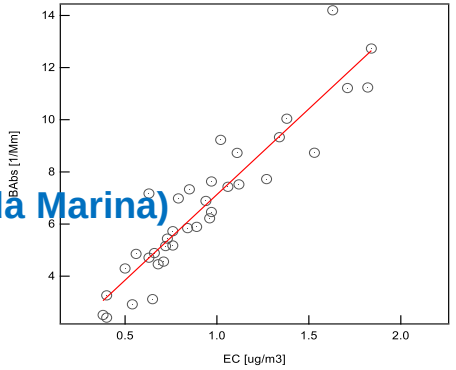



Tiwari et al. 2015

# Why the definition of BC matters

- eBC requires conversion from absorption (BAbs) using the mass absorption cross section (MAC)
- The new AAQD states that default values or normalisation to EC can be used (independant validation)
- Recent work has shown that MAC (hence concentration) varies by **200%** when comparing these approaches (Asmi et al. 2025), combined physical reasons, compounded uncertainty, and reporting errors
- Must consider what MAC is used for large scale assessment or model vs observational studies

**Site specific MAC can be determined as slope of Babs vs EC (Ada Marina)**



# Research objectives and knowledge gaps

Limited year-round, accessible data on carbonaceous aerosol in Western Balkans

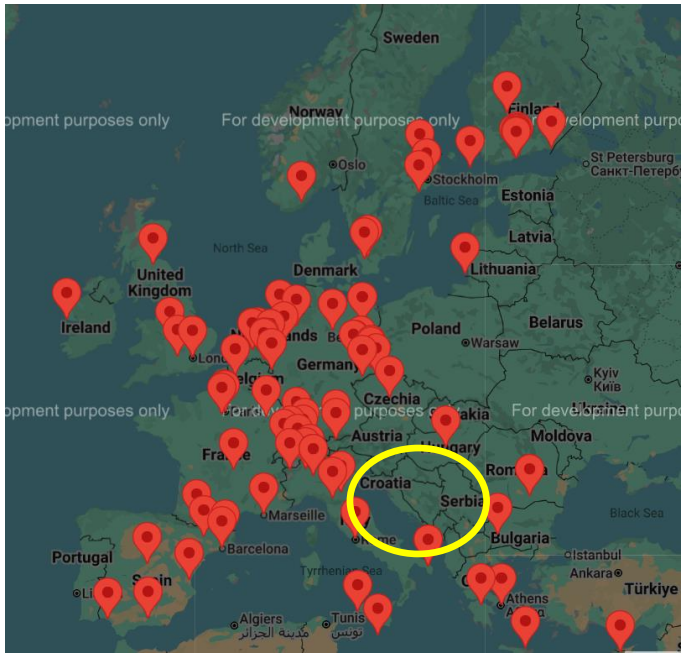
Need:

- High time resolution data
- Source apportionment (SA) studies in Western Balkan region to inform mitigation
- Multi-method validation

Objective:

- Identify dominant sources of carbonaceous aerosol
- Compare SA approaches
- Link to transport

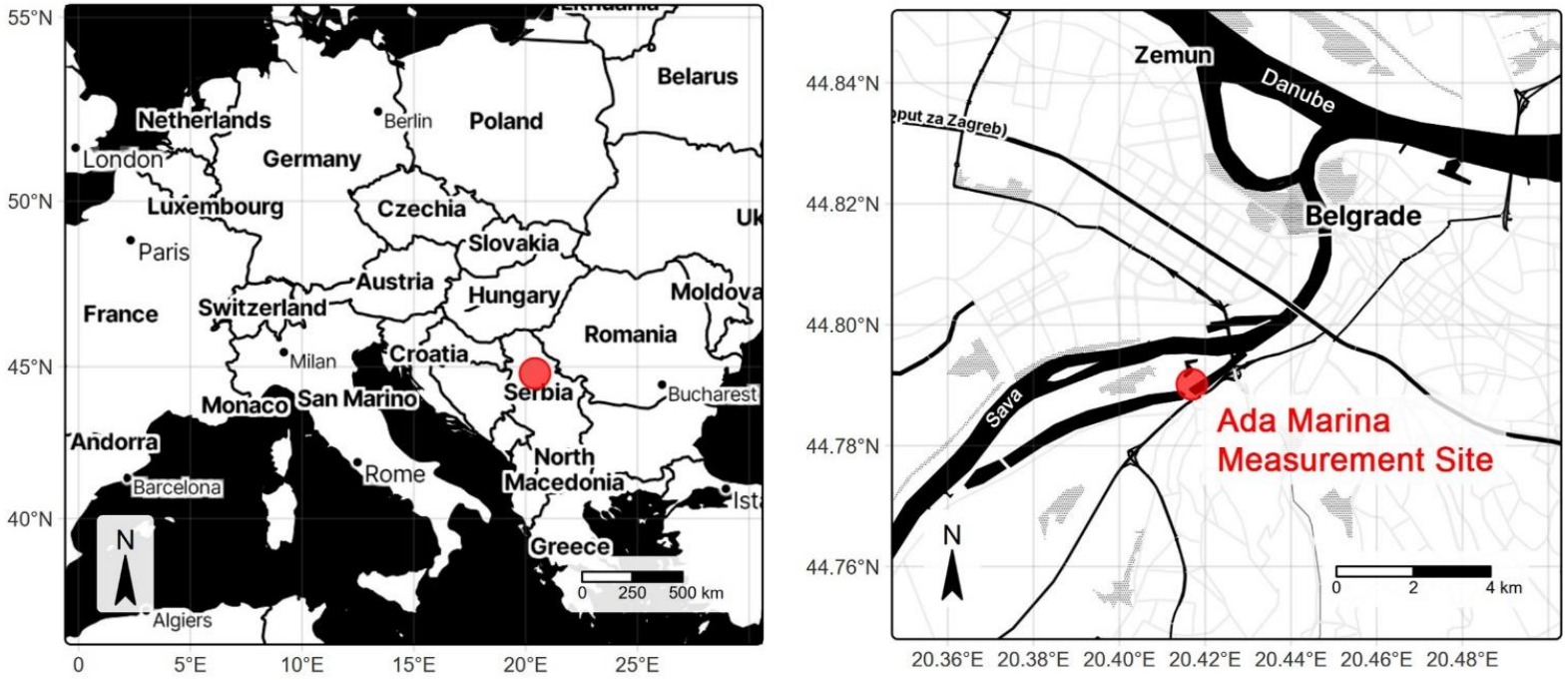
**EBAS: eBC data until 2022**



# Sources of carbonaceous aerosol in a South-East European metropolis

- Ada Marina, Belgrade (urban background)
- 2023 to 2025 dataset
- Multi-method source apportionment (SA)
- NILU + Serbian and Slovenian partners in WeBaSOOP (https://webasoop.org/)

**Ada Marina location from Platt et al. Submitted**



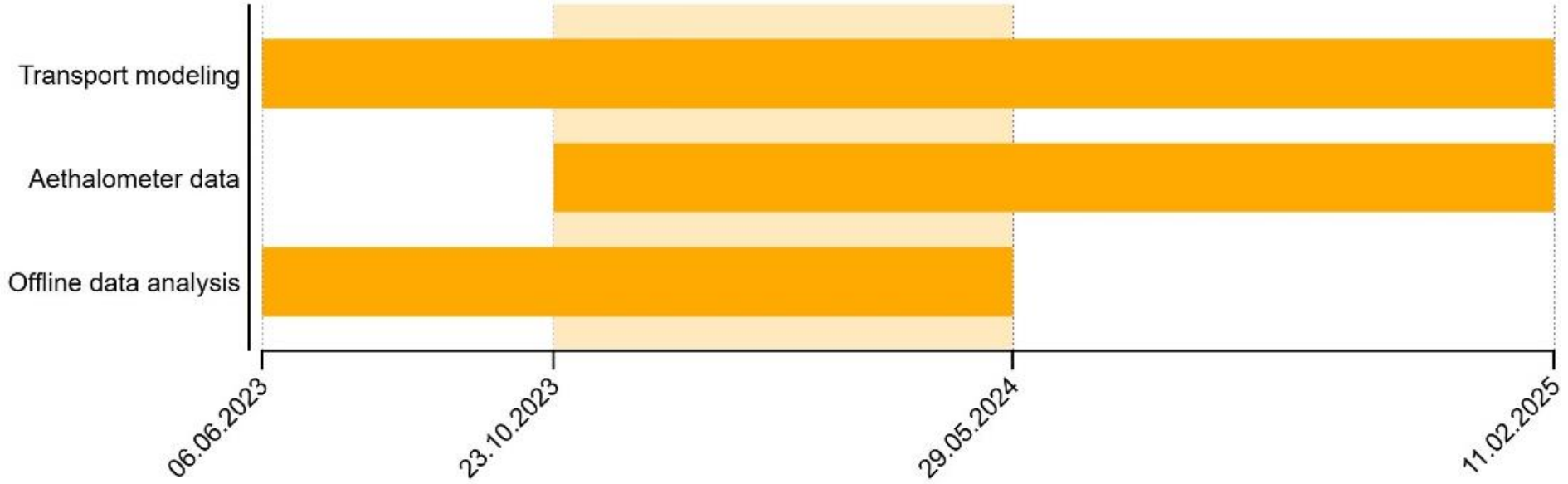
# Measurement strategy

**Online:**
- AE33 (multi-wavelength absorption) for eBC and online source apportionment

**Offline**:
- OC/EC + tracers (levoglucosan etc.) for offline source apportionment
- FLEXPART modelling, combined with gridded emissions for model concentrations of EC and OC

Overlap period for validation (light orange)

**Schematic of the measurement period for each analysis type**



# Source apportionment

1. Aethalometer model spectral fingerprint (absorption Aangstroem exponent, AAE)-based:  Liquid fuel vs solid fuel split

2. Non negative matrix factorisation NNMF (novel application)

3. Tracer-based: Levoglucosan OC/EC ratios, representative ratios for fossil and biomass OC, sugar alcohols for primary biological aerosol (PBAP), secondary organic carbon (SOC) as residual OC mass

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**AI generated representation of solid fuel (left) and liquid fuel (right) soot:**

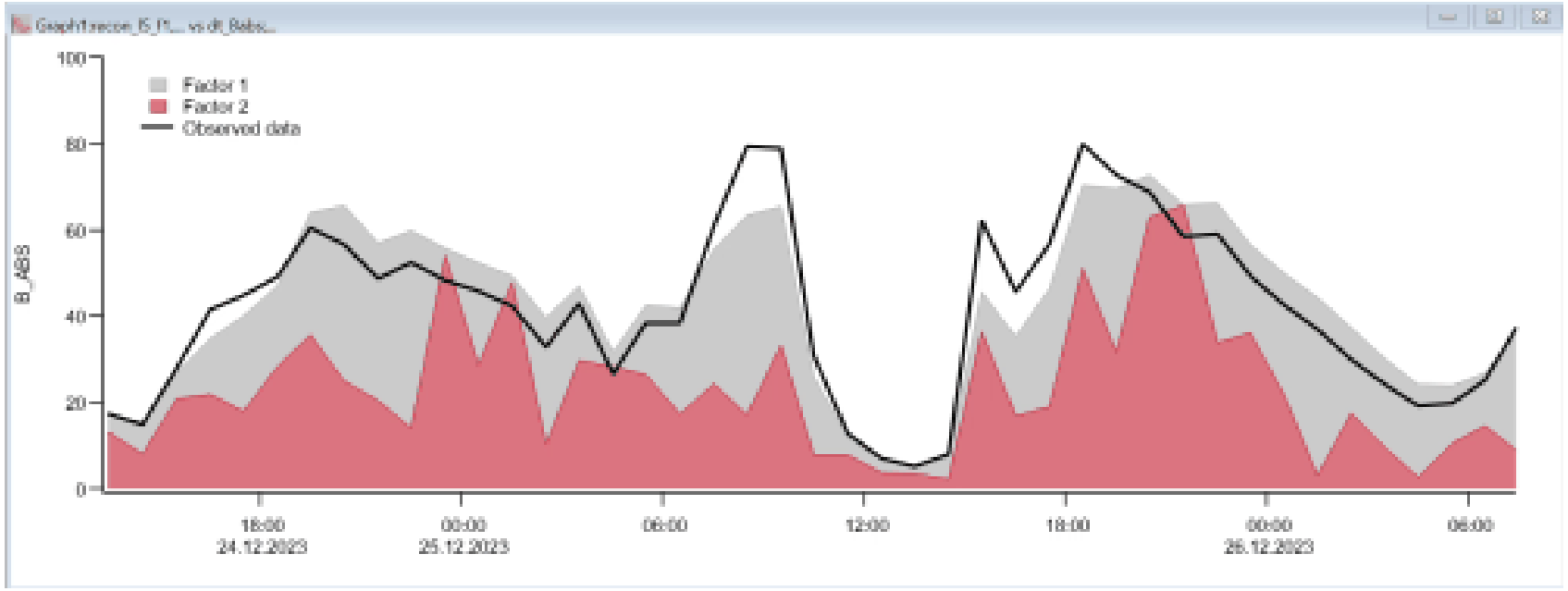
Presence of additional incomplete combustion products (so called chromophores) in solid fuel combustion yields a different AAE:

- A priori assumed AAE used in the aethalometer model
- High uncertainty, inflexible fixed values, negative concentrations

# Non negative matrix factorisation

- Choose number of factors
- Here two factors: liquid fuel (grey) and solid fuel (red), though we did investigate three
- Iteratively adapt by turns the spectrum (H≈AAE) then the time series (W) of each factor to match more closely the original data (V, black)
- Data driven best fit

NNMF iterative algorithm fitting two factors (liquid and solid fuel) to the original observation




$$H^{n+1} \leftarrow H^n \odot \left( \frac{(W^n)^T V}{(W^n)^T W^n H^n} \right),$$

$$W^{n+1} \leftarrow W^n \odot \left( \frac{V(H^{n+1})^T}{W^n H^{n+1} (H^{n+1})^T} \right)$$

# Results: concentrations

eBC annual average : **1.42 ± 1.40 µg m⁻³**

$PM_{10}$ annual average (black): **27.7 µg m⁻³**

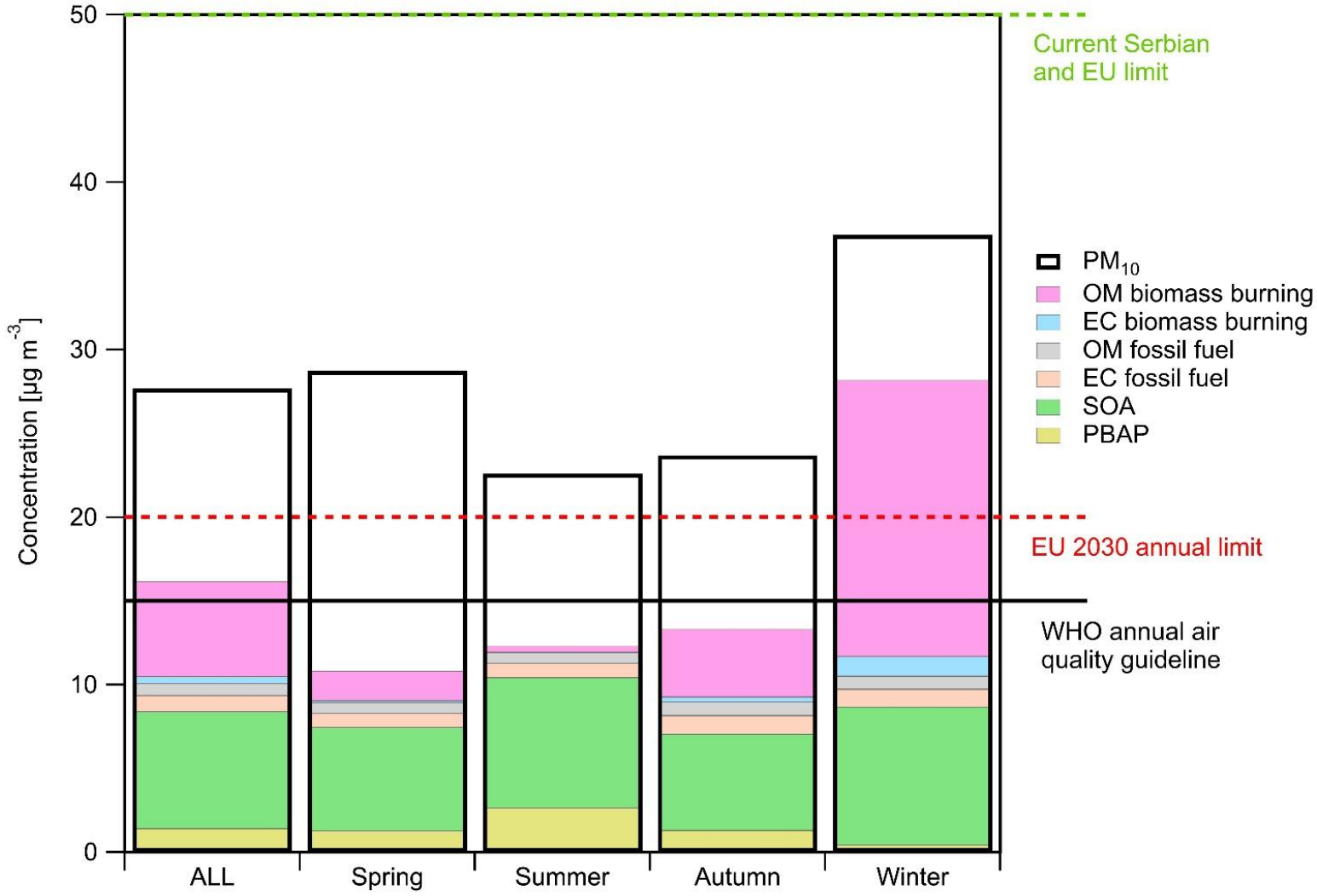
Below EU limits, above WHO and upcoming EU

Strong contribution from biomass burning in winter according to the tracer method (pink), secondary organic aerosol all year (green)

Moderate pollution, still health relevant

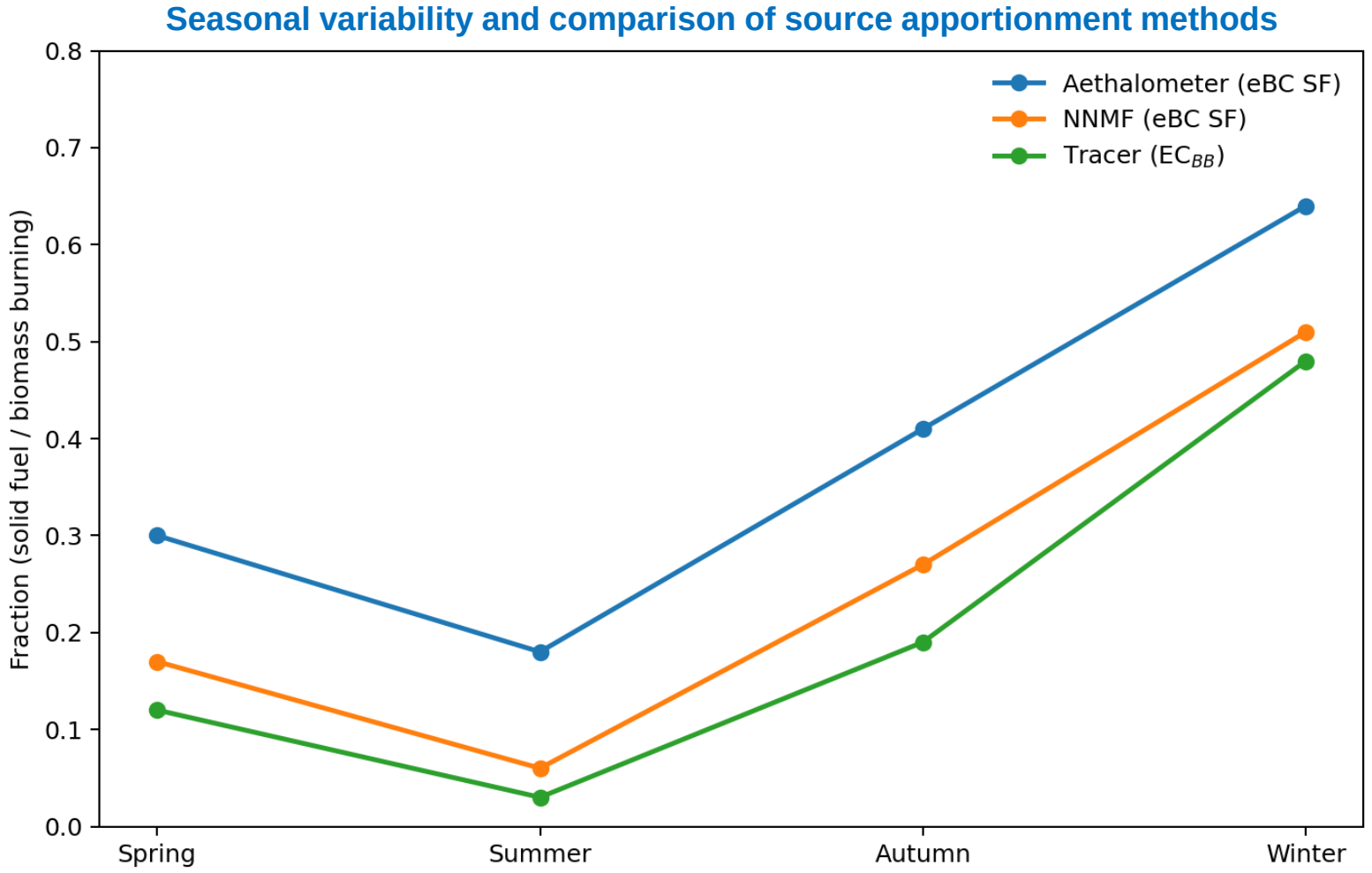
Wood burning has strong mitigation potential (if economic and societal factors are not considered)

**Tracer analysis speciated PM concentrations from Platt et al. Submitted**



# Results: seasonal variability

- Strong winter dominance of solid fuel eBC or $EC_{BB}$, i.e. residential wood combustion (RWC)
- Consistent across all methods (higher agreement for NNMF vs tracers):
  1. Aethalometer model: 64% winter vs 18% summer
  2. NNMF: 51% vs 6%
  3. Tracers: 48% vs 3%



# Results: method comparison

- Strong agreement between all approaches especially BC (red); aethalometer model left, NNMF, right
- Note the correlation between biomass burning / solid fuel and secondary OC (green)

Correlation matrix of source apportionment approaches LF= eBC liquid fuel, SF=eBC solid fuel, analogous to EC from fossil fuel ($EC_{FF}$) and EC from biomass burning ($EC_{BB}$)

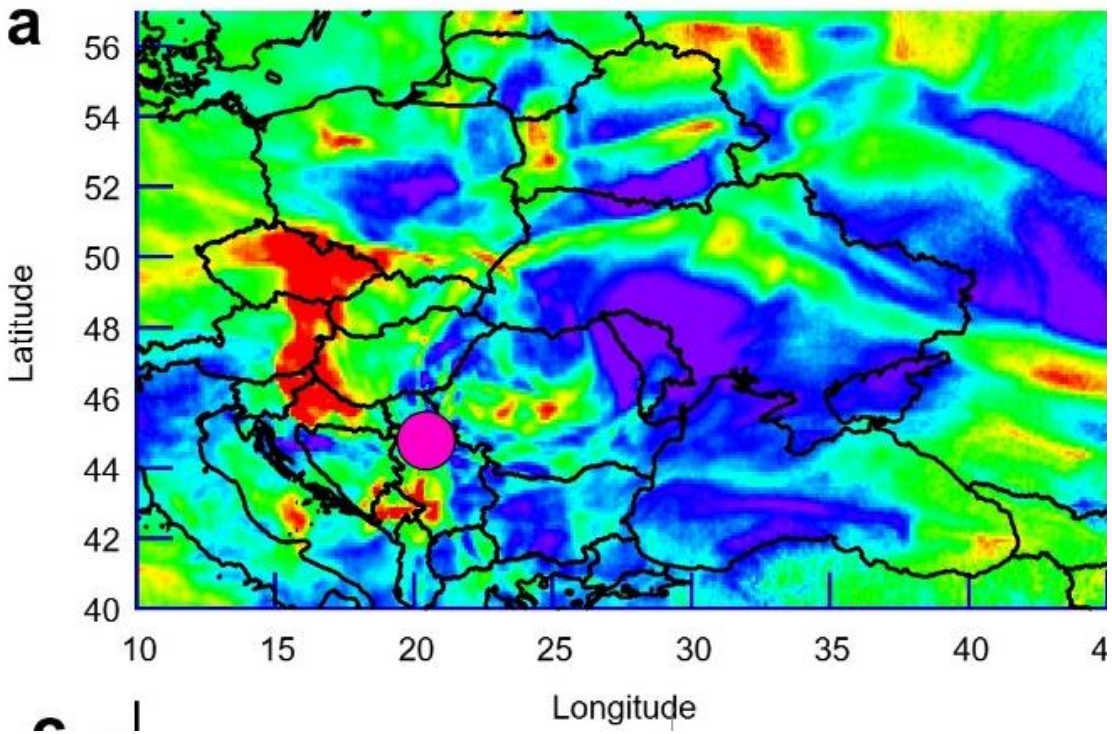
| | | Aethalometer model | | | | | | | NNMF | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | LF | SF | $EC_{FF}$ | $EC_{BB}$ | $OC_{FF}$ | $OC_{BB}$ | SOC | LF | SF | $EC_{FF}$ | $EC_{BB}$ | $OC_{FF}$ | $OC_{BB}$ | SOC |
| Online solid fuel, liquid fuel | LF | 1.00 | 0.68 | 0.89 | 0.64 | 0.89 | 0.64 | 0.46 | 1.00 | 0.75 | 0.87 | 0.77 | 0.87 | 0.77 | 0.53 |
| | SF | | 1.00 | 0.53 | 0.99 | 0.51 | 0.99 | 0.74 | | 1.00 | 0.47 | 0.99 | 0.45 | 0.99 | 0.76 |
| EC and OC from fossil fuel (FF) biomass burning (BB), secondary organic carbon (SOC) | $EC_{FF}$ | | | 1.00 | 0.41 | 1.00 | 0.41 | 0.36 | | | 1.00 | 0.41 | 1.00 | 0.41 | 0.36 |
| | $EC_{BB}$ | | | | 1.00 | 0.38 | 1.00 | 0.48 | | | | 1.00 | 0.38 | 1.00 | 0.48 |
| | $OC_{FF}$ | | | | | 1.00 | 0.38 | 0.35 | | | | | 1.00 | 0.38 | 0.35 |
| | $OC_{BB}$ | | | | | | 1.00 | 0.48 | | | | | | 1.00 | 0.48 |
| | SOC | | | | | | | 1.00 | | | | | | | 1.00 |

# Results: transport analysis

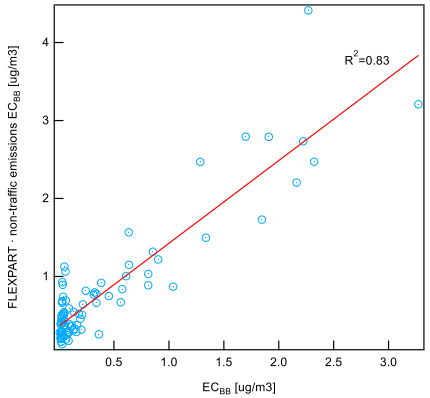
FLEXPART:

- Regional transport linked to elevated pollution (Serbia + Pannonian Basin)
- Strong seasonal wood burning component when using transport model combined with gridded emissions (LRTAP, CAMS GFAS)
- High model skill at estimating non traffic emissions (cna model miigation strategies, demonstrates representitivness of Ada Marina site

**Footrpint during episodes >80th percentile eBC concentrations**




**Model emissions of non-traffic BC vs $EC_{BB}$ (tracer based)**



# Conclusions

Provided data and  source apportionment in a data-sparse region (Western Balkans)

Residential wood combustion dominates winter carbonaceous aerosol at Ada Marina

- Consistent across all methods (aethalometer, NNMF, tracers)
- May be even more important due to association with SOC and brown carbon (BrC)

Multi-method agreement strengthens source attribution

- Independent approaches converge on the same seasonal pattern

NNMF provides a flexible, data-driven alternative

- No a priori assumptions on spectral behaviour
- Captures real variability in aerosol properties

Aethalometer model is limited by fixed AAE assumptions

- Spectral assumptions influence source apportionment results

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# Data availability

- Results presented in Platt et al., *Sources of carbonaceous aerosol in a South-East European metropolis* submitted to ACP
- NNMF and eBC SA scripts: *Source apportionment of multi-wavelength aerosol absorption using NNMF and aethalometer-based methods (Igor Pro code)* https://zenodo.org/records/19221205
- Raw data at ebas.nilu.no (WeBaSOOP framework)
- FLEXPART products at https://atmo-access.nilu.no/AdaMarina_SRB.py

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