Source Apportionment of Optical Properties of Carbonaceous Aerosols between Urban and Suburban areas in the Republic of Korea, spring 2022

EGU25-7495

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Introduction

❖ **Light-Absorbing Carbonaceous Aerosols (LACs)**

- Light-absorbing carbonaceous aerosols (LACs), primarily composed of black carbon (BC) and brown carbon (BrC), are key drivers of climate change due to their strong solar radiation absorption and reduction of surface albedo.

❖ **Optical Complexity of LACs**

- The optical properties of LACs vary by emission source, atmospheric processing, and secondary formation. However, differentiating the light-absorption characteristics of LACs by source remains a significant challenge.
- Instruments like the Aethalometer enable source apportionment (e.g., fossil fuel vs. biomass burning). However, reliance on empirical parameters such as the Absorption Ångström Exponent (AAE) introduces estimation uncertainties.
- Receptor models such as Positive Matrix Factorization (PMF) and the Multilinear Engine (ME-2) reduce this uncertainty by integrating chemical composition and absorption data to quantify source-specific contributions (Wang et al., ACP, 2020).

Study Area

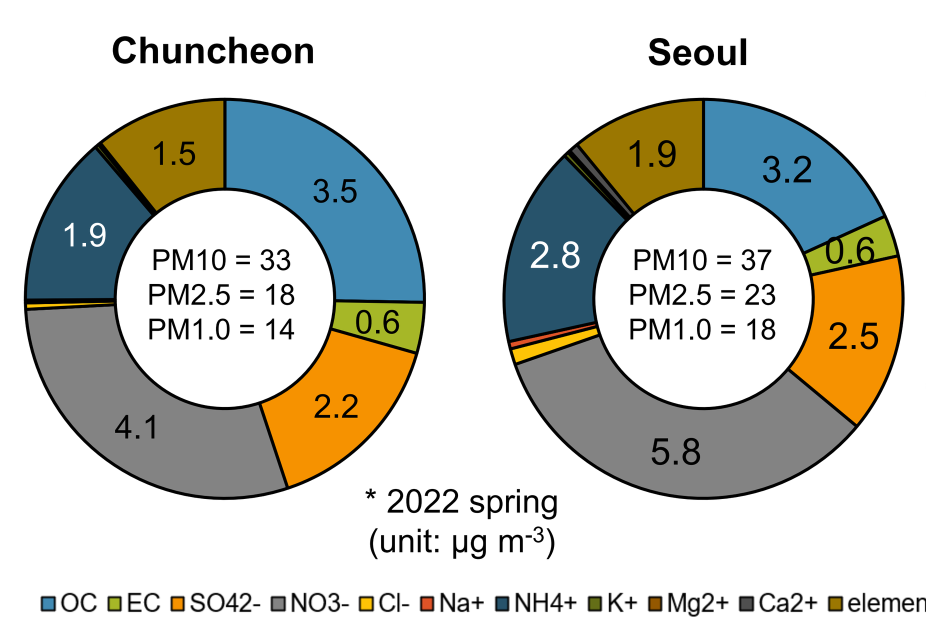

Figure 1. Chemical composition and PM mass concentration in Chuncheon and Seoul (Spring 2022).

- **Chuncheon**: Small inland city with substantial biomass burning influence (Choi et al., APR, 2022).
- **Seoul**: Large megacity dominated by traffic emissions.

Objectives of This Study

In this study, we applied the PMF model to quantify and compare source-specific optical properties of LACs in Chuncheon and Seoul during Spring 2022.

- Identify the sources of LACs in Chuncheon and Seoul.
- Quantify the contribution of each source to total absorption.
- Calculate optical parameters by sources such as the Absorption Ångström Exponent (AAE) and Mass Absorption Cross-section (MAC).
- Compare regional differences in optical properties and emission characteristics of LACs.

Methods

Method 1: Identifying the secondary source of Abs(λ)

$$Abs(\lambda) = Abs(\lambda)_{pri} + Abs_{sec,BrC}(\lambda)$$

$$Abs_{pri}(\lambda) = \left(\frac{Abs(\lambda)}{BC}\right)_{pri} \times [BC]$$

$$Abs_{sec,BrC}(\lambda) = Abs(\lambda) - \boxed{\left(\frac{Abs(\lambda)}{BC}\right)_{pri}} \times [BC]$$

Minimum R-squared (MRS) method
(Wu et al., ACP, 2016; Wu et al., ACP, 2018)

Table 1. $\left(\frac{Abs(\lambda)}{BC}\right)_{pri}$ values from MRS.

λ	Chuncheon	Seoul
370 nm	20.9	16.1
470 nm	15.3	12.8
520 nm	13.5	11.2
590 nm	11.6	10.0
660 nm	10.3	8.9
880 nm	7.6	6.9
950 nm	7.1	6.4

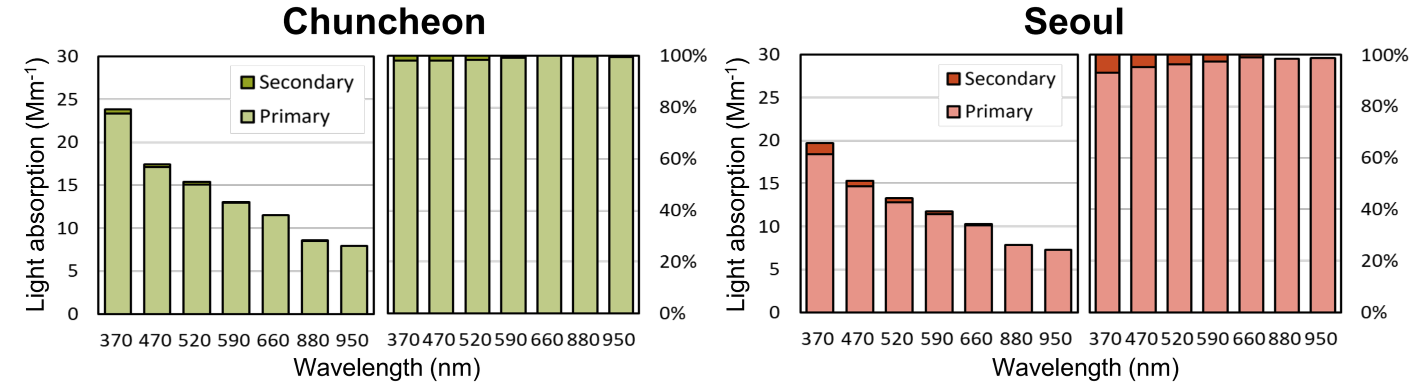

Figure 2. Contribution of secondary vs. primary light absorption.

- Contribution of secondary brown carbon ($Abs_{BrC,sec}(\lambda)$) to total light absorption was minor (< 5%) at both sites.

Method 2: Identifying the primary source of Abs(λ)

❖ **Positive Matrix Factorization (PMF)** ver. 5.0 (Norris et al., EPA, 2014)

$$X_{ij} = \sum_{k=1}^{p} G_{ik}F_{kj} + Eij$$

$$Q = \sum_{i=1}^{m}\sum_{j=1}^{n}\left(\frac{E_{ij}}{\sigma_{ij}}\right)^2$$

- X_{ij}: observed concentration of the j[th] species in the i[th] sample
- G_{ik}: source contribution of the k[th] factor to the i[th] sample
- F_{kj}: factor profile of the j[th] species in the k[th] factor
- E_{ij}: the residual concentration for each data point
- Q: scaled residue
- σ_{ij}: uncertainty for each data point provided by the user

$$\sigma_{ij} = \begin{cases} \sqrt{(error\ fraction \times concentration)^2 + (0.5 \times MDL)^2} & (if\ concentration > MDL) \\ \frac{5}{6} \times MDL & (if\ concentration \le MDL) \end{cases}$$

* MDL: Method detection limit
c.f. Replace with 1/2 of the minimum value of the species concentration if MDL information is unavailable.

❖ **PMF Model Input Data**

- **Sites**: Gangwon (Chuncheon) and Seoul air quality monitoring stations
- **Period**: March 14 to April 13, 2022
- **Data**: 1 hour resolution, 24 species
  - 1 Ionic
  - 2 Carbonaceous
  - 14 Elemental
  - 7-wavelength absorption coefficient

Table 2. PMF input species concentration (Conc.) (avg ± SD), signal-to-noise ratio (S/N), and category (Cat.).

Species	Unit	Chuncheon			Seoul		
		Conc.	S/N	Cat.	Conc.	S/N	Cat.
K^+	μg m-3	0.04±0.04	8.6	Strong	0.07±0.05	8.9	Strong
OC	μg m-3	3.5±2.4	8.9	Strong	3.2±1.6	8.8	Strong
EC		0.6±0.5	8.7	Strong	0.6±0.4	8.7	Strong
Si	ng m-3	134.9±198.5	7.8	Weak	134.9±183.8	7.8	Strong
S		1061.9±738.5	8.9	Strong	1147.5±701.2	8.9	Strong
Ca		66.1±58.0	8.9	Strong	87.8±63.9	8.8	Strong
Ti		8.8±6.7	9.0	Strong	8.2±5.7	8.9	Strong
Cr		0.4±0.4	7.4	Strong	0.9±1.0	8.4	Strong
Mn		3.9±3.4	7.9	Strong	6.4±5.3	8.5	Strong
Fe		118.9±81.9	9.0	Strong	159.6±93.7	8.8	Strong
Ni		0.5±0.4	8.7	Strong	0.6±0.7	7.7	Strong
Cu		3.3±2.3	9.0	Strong	3.7±4.8	8.4	Weak
Zn		20.9±14.3	9.0	Strong	34.6±32.6	9.0	Strong
As		2.7±2.3	9.0	Strong	3.7±3.2	9.0	Strong
Se		0.6±0.6	7.9	Strong	0.6±0.6	8.3	Strong
Br		4.6±3.0	8.9	Strong	5.2±3.5	8.9	Strong
Pb		7.3±5.7	8.2	Strong	7.1±8.1	8.1	Strong
Abs (370 nm)	Mm-1	21.6±14.9	8.7	Strong	19.7±11.7	8.9	Strong
Abs (470 nm)		15.8±10.5	8.8	Strong	15.3±8.9	8.9	Strong
Abs (520 nm)		13.9±9.2	8.8	Strong	13.3±7.7	8.8	Strong
Abs (590 nm)		11.9±7.9	8.8	Strong	11.7±6.8	8.8	Strong
Abs (660 nm)		10.5±6.9	8.8	Strong	10.3±6.0	8.8	Strong
Abs (880 nm)		7.7±5.2	8.7	Strong	7.8±4.6	8.8	Strong
Abs (950 nm)		7.2±4.8	8.7	Strong	7.2±4.3	8.8	Strong

Results

Result 1: Source apportionment of primary Abs(λ)

❖ **Factor Profile and Source Contribution**

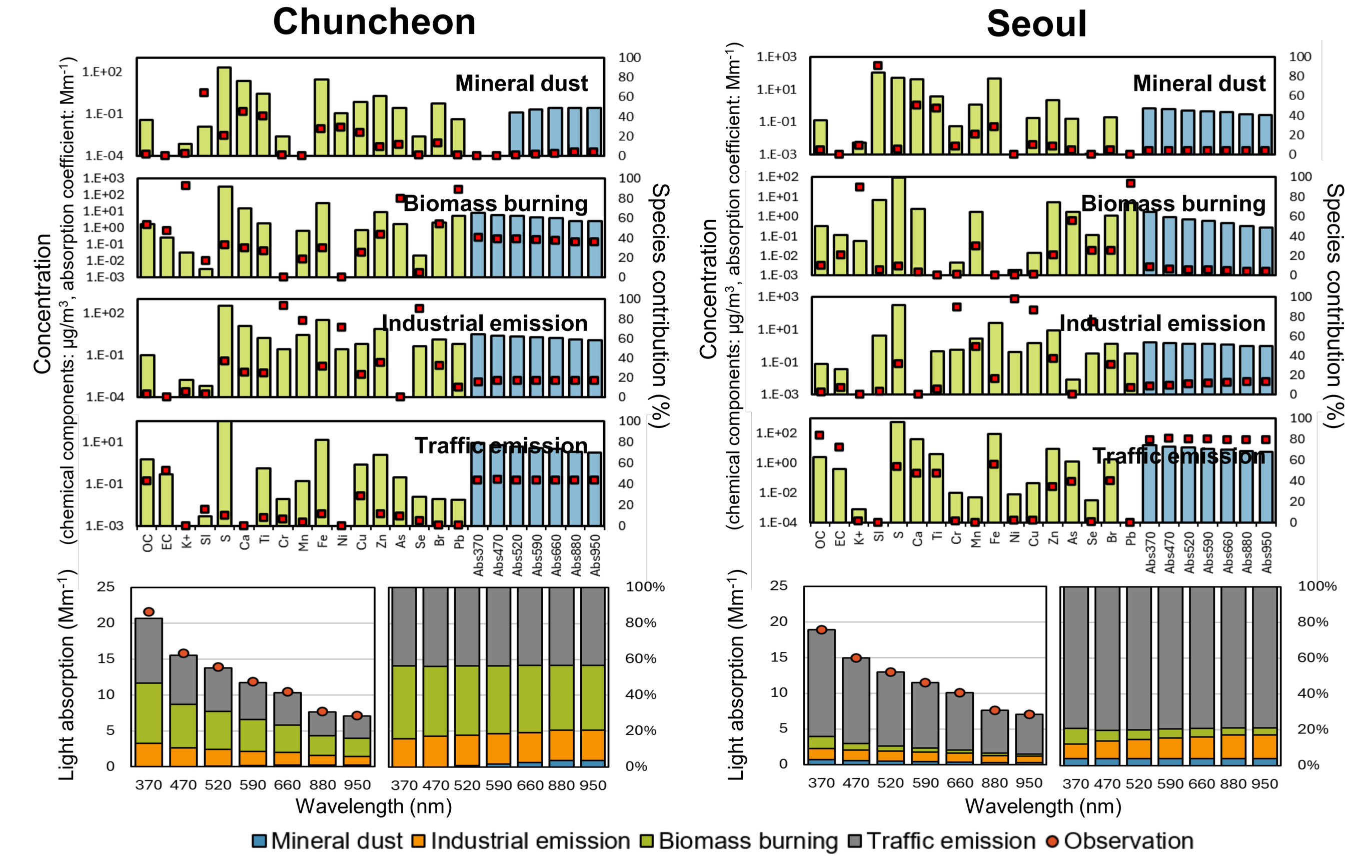

Figure 3. PMF-derived source profiles and contributions.

- PMF identified 4 major sources - Traffic emissions, Biomass burning, Industrial emissions, Mineral dust
- In Chuncheon, biomass burning and traffic emissions were major contributors, while in Seoul, traffic emissions were the dominant source of light absorption.

❖ **Diurnal Pattern of Each Source**

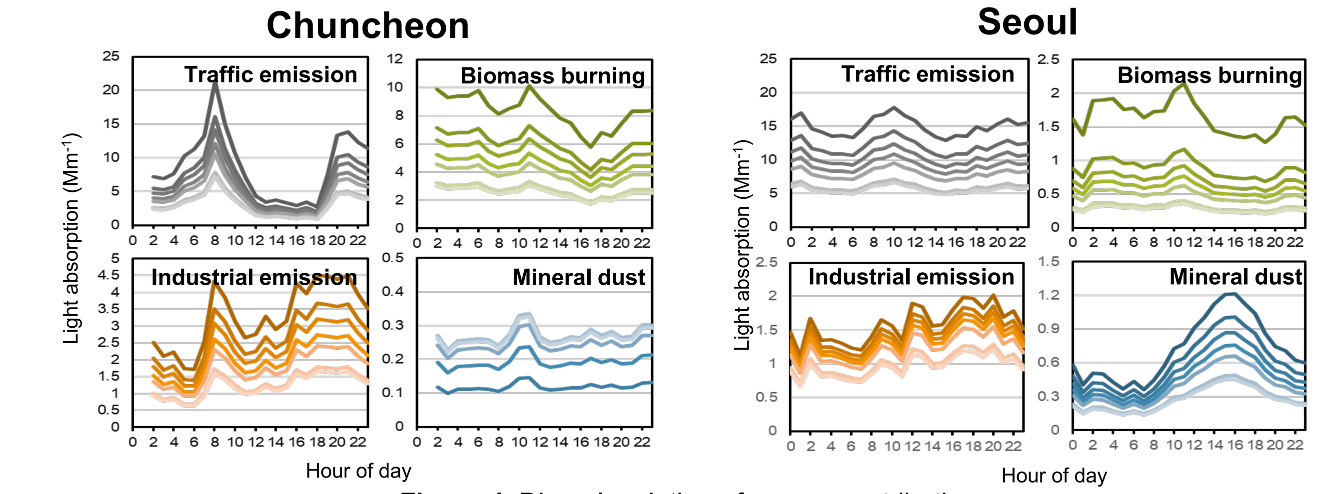

Figure 4. Diurnal variation of source contributions.

Result 2: Source-dependent optical properties

❖ **Absorption Ångström Exponent (AAE)**

$Abs(\lambda) = C \times \lambda^{-AAE}$ (Andreae and Gelenscér, ACP, 2006)

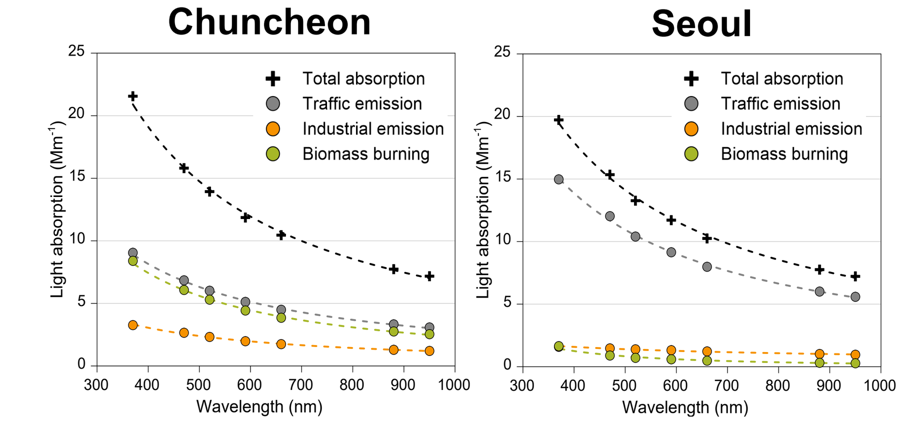

Figure 5. Power-law fitting of light absorption by source.

Table 3. Source-specific AAE values.

Source	Chuncheon	Seoul
Traffic	1.15	1.06
Industry	1.09	0.89
Biomass	1.48	1.82
Total	**1.16**	**1.07**

- AAE was slightly higher in Chuncheon (1.16) than in Seoul (1.07), reflecting enhanced short-wavelength absorption from biomass burning in Chuncheon.

❖ **Mass Absorption Cross-section (MAC)**

$$MAC_{BC}(\lambda) = \frac{Abs_{BC}(\lambda)}{[EC]}$$

$$MAC_{BrC}(\lambda) = \frac{Abs_{BrC}(\lambda)}{[OM]}$$

※ [OM] = 1.8 x [OC].

- In Chuncheon, BC from biomass burning and traffic contributed to strong absorption, producing MAC levels comparable to those observed in Seoul.
- This suggests that even in a suburban environment, biomass-related emissions can yield light-absorbing properties similar to those in megacities.

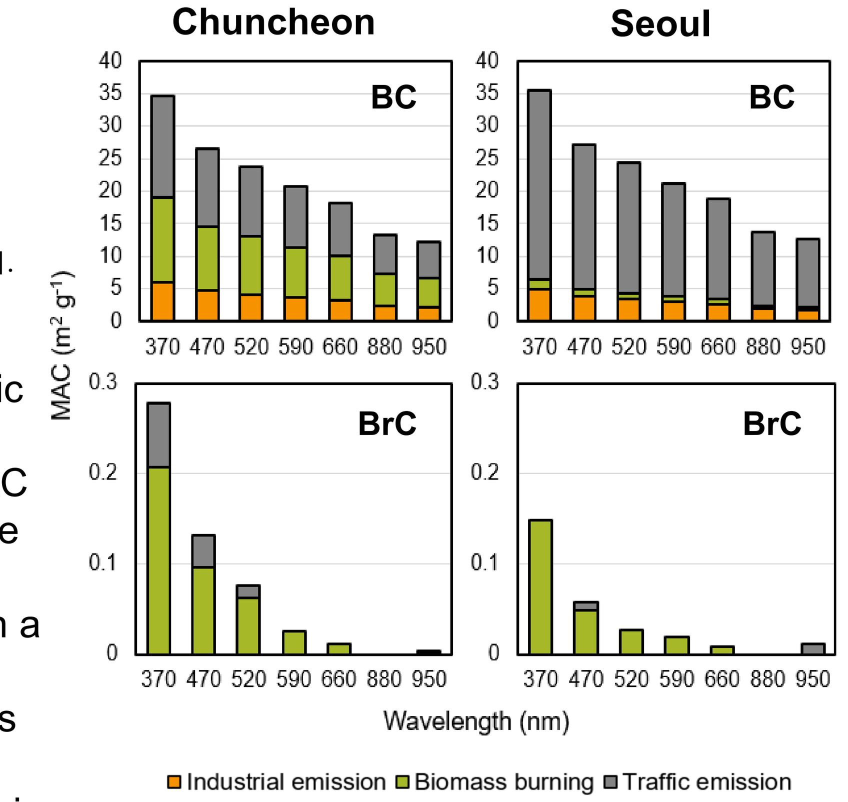

Figure 6. Source-specific MAC values for BC and BrC.

Conclusion

➢ Despite **similar PM concentrations and chemical composition**, Chuncheon and Seoul exhibited **distinct optical properties** of carbonaceous aerosols.

➢ In Seoul, light absorption was primarily driven by traffic-related BC, whereas **Chuncheon exhibited a distinct optical profile characterized by biomass burning**, particularly evident at shorter wavelengths (higher AAE).

➢ **Chuncheon had a similar light absorption capacity** (MAC) **to Seoul despite its lower urban activity**, reflecting the significant impact of residential biomass burning.

➢ These results highlight **the role of suburban regions** like Chuncheon in understanding **regional aerosol radiative effects** and support the need for emission control strategies for local source characteristics.

Abstract QR code

EGU25-7495

This research was supported by the National Institute of Environmental Research (NIER), Republic of Korea (NIER-2024-01-01-004).