Shifts in monsoon transition periods intensify air pollution exposure in Seoul, South Korea

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Background & Objectives

- Fine particulate matter ($PM_{2.5}$) contributes to cardiovascular disease and premature mortality, posing a public health challenge in East Asian cities (WHO, 2024; Sangkham et al., 2024)
- Seoul's air quality has historically followed a seasonal cycle: pollution peaks in dry winter months and clears during the summer monsoon through wet deposition (Yihui & Chan, 2005)
- Emerging evidence suggests climate change is altering monsoon timing, but there were no clear ties to pollution seasonality and population exposure (Katzenberger & Levermann, 2024)
- This study conducts a 36-year temporal analysis (1988–2024) of air quality and precipitation in Seoul to detect shifts in seasonality and quantify changes in cumulative exposure

Data & Methods

- Data sources: hourly $PM_{2.5}$, PM_{10}, SO_2, and NO_2 concentrations from Seoul Open Data Plaza; daily precipitation records from NOAA NCEI (1988–2024)
- Monthly medians used for pollutants (robust to extreme episodes); monthly means used for precipitation (medians returned zero too frequently due to sporadic rainfall)
- Outliers removed via 1.5× IQR rule; values min-max normalized to [0,1] to enable cross-pollutant comparison
- Study period split into early and recent epochs for each variable; peak and trough months identified per period

Relevant Sources

World Health Organization. (2021). WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Www.who.int; World Health Organization. https://www.who.int/publications/i/item/9789240034228

Sangkham, S., Phairuang, W., Sherchan, S. P., Pansakun, N., Munkong, N., Sarndhong, K., Islam, Md. A., & Sakunkoo, P. (2024). An update on adverse health effects from exposure to PM2.5. Environmental Advances, 18, 100603. https://doi.org/10.1016/j.envadv.2024.100603

Katzenberger, A., & Levermann, A. (2024). Consistent increase in East Asian Summer Monsoon rainfall and its variability under climate change over China in CMIP6. Earth System Dynamics, 15(4), 1137–1151. https://doi.org/10.5194/esd-15-1137-2024

Kim, M. J. (2019). The Effects of Transboundary Air Pollution From China on Ambient Air Quality in South Korea. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3361486

Results

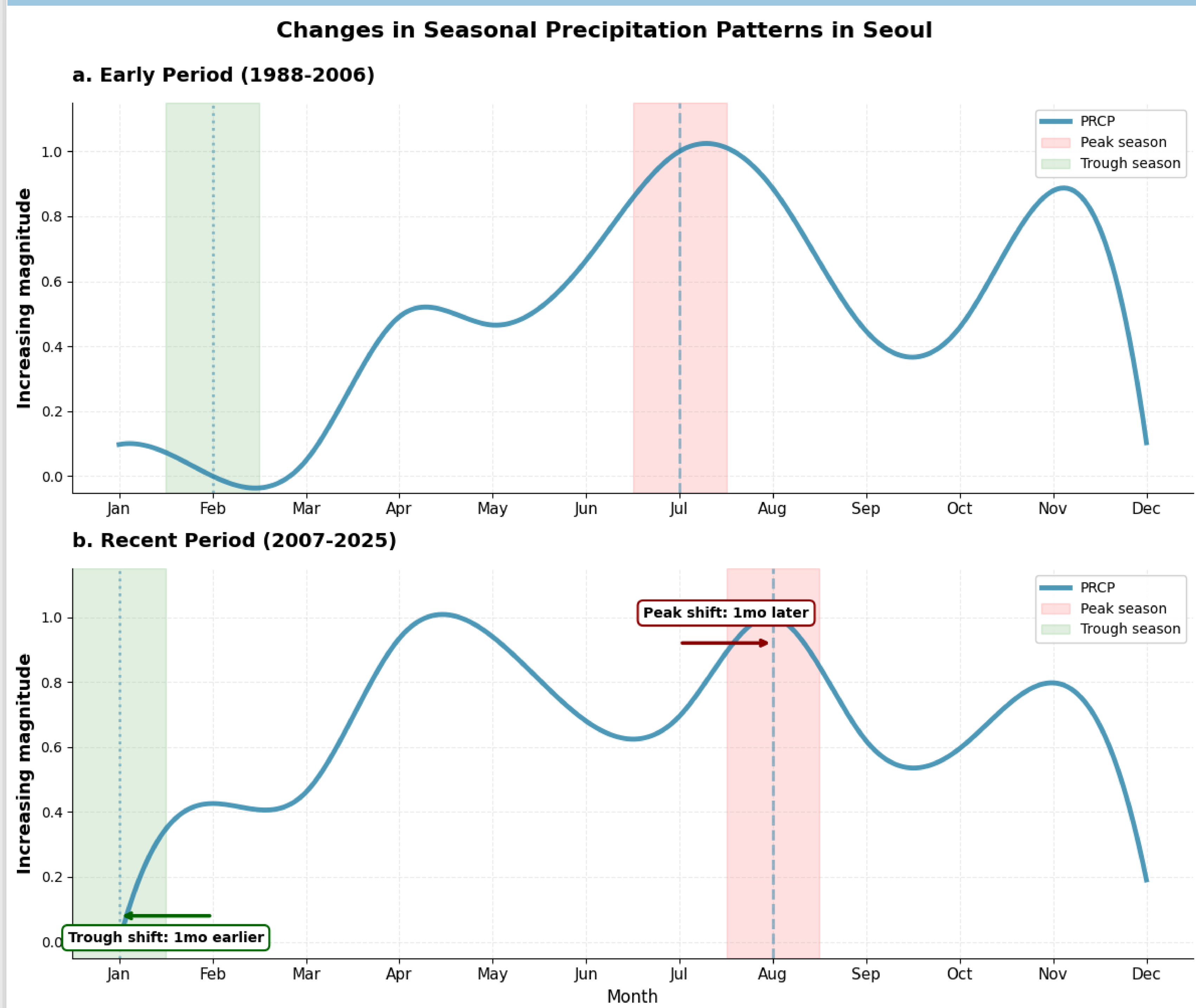

Figure 1. Monsoon peak precipitation shifted 1 month later (July → August) and the dry trough shifted 1 month earlier (February → January), with a modest but significant increasing trend in annual rainfall ($p < 0.05$)

- The other gaseous pollutants examined (SO_2 and NO_2) showed no significant timing shifts, despite changing meteorological patterns

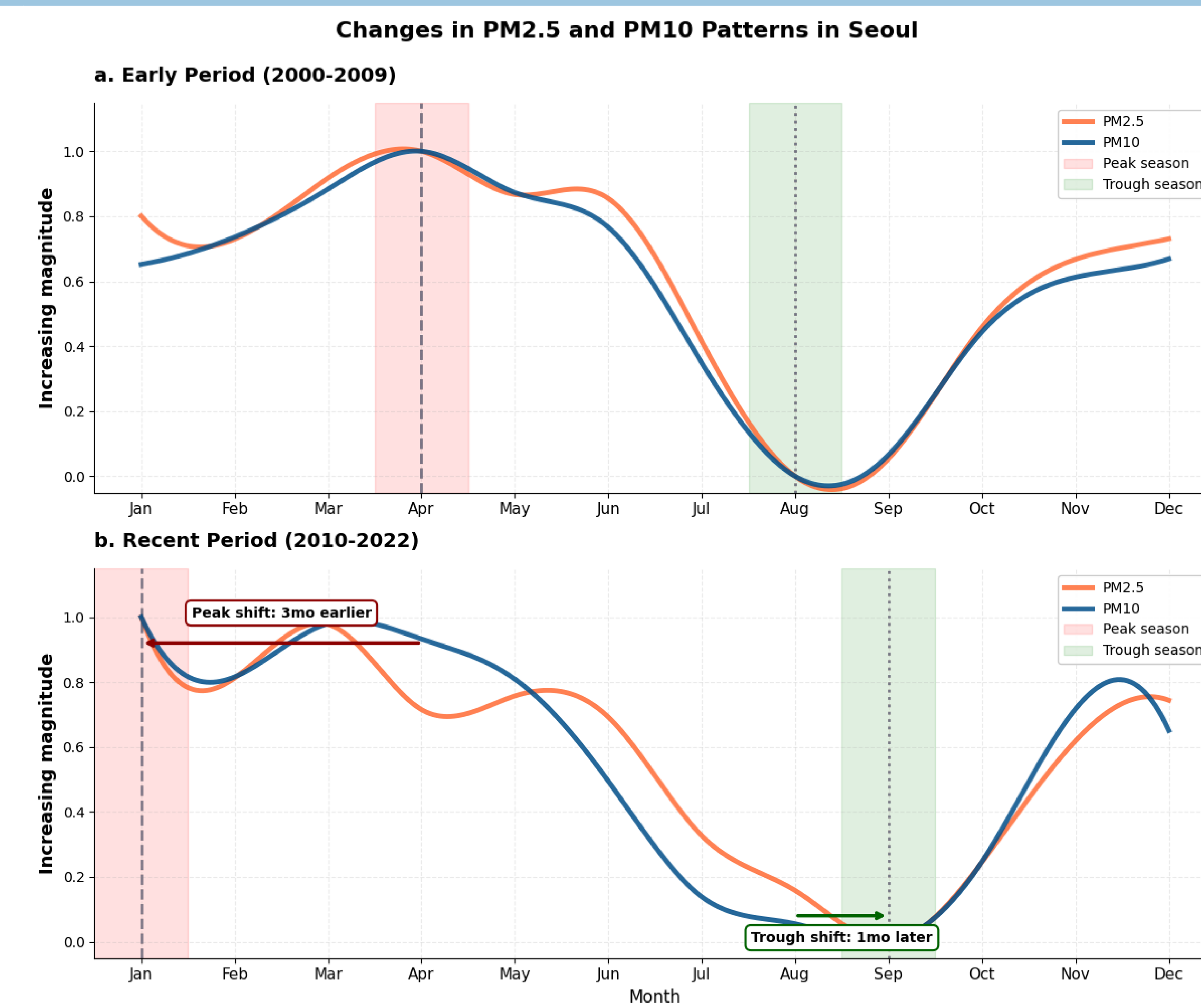

Figure 2. $PM_{2.5}$ and PM_{10} peak concentrations shifted 3 months earlier: from April in 2000–2009 to January in 2010–2023; trough timing delayed 1 month (August → September)

- Cumulative $PM_{2.5}$ exposure increased 50.7% during the peak-to-trough window, while PM_{10} exposure remained stable (1.9% reduction)

Discussion

- The earlier $PM_{2.5}$ peak likely results from enhanced wintertime atmospheric stagnation, increased transboundary transport from outside the country, and potentially greater heating emissions, rather than changes in gaseous pollutant sources, as they remained stable (Ho et al., 2021)
- The shift in monsoon trough (August → September) aligns with the delayed peak rainfall, delaying the wet deposition effect and extending the window of elevated pollution (Hien et al., 2011)
- Stable SO_2 and NO_2 patterns confirm that gaseous pollutant chemistry and emission sources have not changed, isolating meteorological forcing as the primary driver of particulate matter seasonality shifts (Ho et al., 2021)
- The divergence between $PM_{2.5}$ (50.7% exposure increase) and PM_{10} (no significant change) suggests fine particles are more sensitive to weather shifts and combustion patterns, while coarse particles are driven by year-round mechanical sources such as road dust and construction (Tucker, 2000)
- **Future research directions**:
  - Coupling air quality models with regional climate projections to assess whether observed trends align with expected climate change
  - Public health studies linking the $PM_{2.5}$ exposure increase to health outcomes (mortality, hospitalizations, respiratory disease) to quantify population health burdens and drive policy direction