June smoke, two different footprints

Timing and persistence of urban $PM_{2.5}$ departures during two June 2023 Canadian wildfire smoke episodes

Abstract

Two Canadian wildfire smoke episodes crossed the eastern United States in June 2023. Using 810 local-day observations at 27 fixed outdoor $PM_{2.5}$ sites, we compared four Great Lakes and four Atlantic urban county groups across both episodes. The mean of daily corridor medians was 74.1 $\mu g\,m^{-3}$ higher in the Atlantic corridor on June 6–8 and 69.1 $\mu g\,m^{-3}$ higher in the Great Lakes corridor on June 27–29, relative to site-specific June 20–22 medians. The reversal persisted with an alternate reference and after sequential omission of each site or urban group. Seven of eight urban groups were at least 20 $\mu g\,m^{-3}$ above reference on June 29, after all four Great Lakes group peaks. Runs at or above that level lasted up to three days around the early episode and four around the late episode. A fixed-site daily panel distinguishes days of broad geographic overlap from the sequence of local peaks.

Introduction

NOAA satellite observations documented a plume over the Great Lakes on June 5, over New York and southern New England on June 6 and farther south in the Mid-Atlantic on June 7–8 [1]. At the end of June, NOAA reported another period of smoke around the Great Lakes, eastern Ohio and Pittsburgh [2]. Analyses of that season mapped surface $PM_{2.5}$ and ozone over the Upper Midwest and documented both June events [3]. Those records establish the timing and geographic context for a comparison of monitor departures.

A broad regional footprint can encompass urban groups with different local peak dates and durations. We ask how the geographic distribution of above-reference $PM_{2.5}$ changed between the two June episodes, and which days combined sustained local departures with concurrent elevation elsewhere. We follow the same instruments on every June day so that those differences can be evaluated without changes in the reporting panel.

Methods

Coverage. We streamed the US EPA annual AirData archive for daily parameter 88101 [4,5], which contains Federal Reference Method and Federal Equivalent Method measurements. We defined two corridors using counties along the Great Lakes urban arc (Milwaukee, Cook, Wayne, Cuyahoga and Erie, NY) and Atlantic urban corridor (Suffolk, MA, New York City's five borough counties, Philadelphia, Baltimore City and the District of Columbia). These are specified county groupings. The fixed June panel retained no stream in Erie County, NY, or Baltimore City, leaving four groups per corridor.

Canonical daily records. We used the arithmetic mean on local dates for 24-hour block averages or integrated 24-hour samples in micrograms per cubic metre at local conditions. We selected the archive's PM25 24-hour 2012 summary, retained event-inclusive and no-event records, and required observation percent of at least 75% for block averages or 100% for integrated daily samples. We keyed candidate instrument streams by physical site, duration, parameter occurrence code (POC), and method. Within stream and day we ranked duplicates by percent, observation count, and event-inclusive status, stopping on inconsistent equal-ranking values. Among streams complete for all 30 days, we selected a single stream per physical site by hourly block preference, highest summed percent, lowest POC and stable method-code ordering. All selected streams were hourly-derived 24-hour block averages. The monitor map uses reported NAD83 and WGS84 positions treated as equivalent at the display scale; group names are connected to the average position by leader lines.

Local departures. For site i and local day t, we calculated the difference between the daily mean x_{it} and the site median on June 20–22. This Tuesday–Thursday reference matches the days of week of both comparison windows. The designation describes an internal comparison period. For each day, we took the median site departure within each urban group, then the median of the four group values in each corridor. The difference between the two corridors is Atlantic minus Lake. Our event summary is its mean across the three dates of each event window.

Timing and persistence. To capture changes around the window edges, we found the earliest day of the highest group departure in June 4–10 and June 25–30. Within each neighborhood we counted the maximum run of consecutive days with departure at or above $+20\ \mu\mathrm{g\,m^{-3}}$ in each group and the number of groups jointly reaching that level each day. The cutoff applies to the group median of site-level differences from the June reference. Each group's absolute concentration on threshold days depends on its site baselines. We repeated the run calculation at $+10$ and $+30\ \mu\mathrm{g\,m^{-3}}$.

Sensitivity. We recalculated both contrasts after removing each site and each urban group in turn. An alternate reference pooled June 1–3 with June 23–25 at each site. Ranges across omission runs describe design sensitivity. We report descriptive estimates for the panel and its two selected events. Spatial and day-to-day dependence among observations limits variance estimation from simple resampling of site-days.

Results

The selection reduced 4,256 June county-group records to 2,287 canonical 24-hour rows before excluding four summaries that removed event observations. Fifty-six physical sites had eligible instrument rows during June and 27 offered a complete 30-day stream. The retained Lake groups were Milwaukee (2), Chicago (4), Detroit (6) and Cleveland (3). The Atlantic groups were Boston (4), New York (2), Philadelphia (3) and Washington (3).

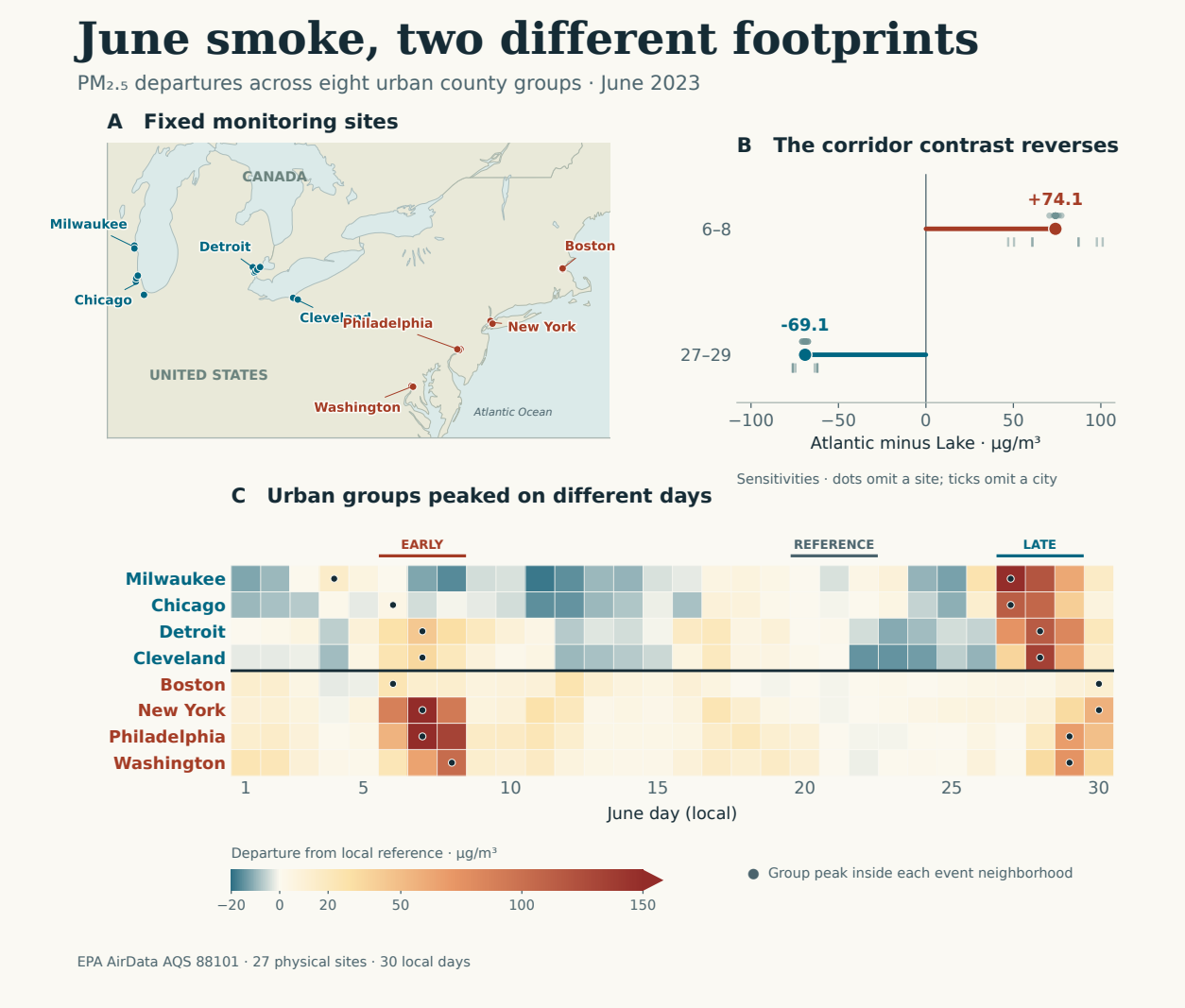


Figure 1. Urban departures across two June smoke episodes. (A) Retained EPA physical site locations, grouped by corridor. Natural Earth provides the geographic outlines. (B) Three-day Atlantic-minus-Lake contrasts with one-site (dots) and one-group (ticks) omission results. (C) Group medians of site departures over all 30 local days. Dots mark each group's neighborhood peak, with the earlier date used for ties. Colors on group names connect the heatmap to the map; the cell color measures departure. The arrow at the upper end of the scale groups values above 150 $\mu g\,m^{-3}$.

Regional contrast and concurrent elevation

The Atlantic corridor had the higher departures in the early window. On June 7, three of its four groups (New York, Philadelphia and Washington) were at least 20 μg m^{-3} above reference; Boston had reached that level on June 6. Five or more groups across both corridors reached the threshold on each of June 6–8, with six on June 6. Five groups reached the threshold for three consecutive days. No group reached it on June 9 or 10.

The Lake corridor had the higher departures in the late window. All four Lake groups peaked on June 27–28. Philadelphia and Washington peaked on June 29, and Boston and New York peaked on June 30. On June 29 all four Lake groups and three Atlantic groups (New York, Philadelphia and Washington) jointly reached the departure threshold. The four runs still underway on June 30 were Detroit, New York, Philadelphia and Washington. Their observed durations (four, two, two and three days, respectively) are lower bounds. Milwaukee's four-day run ended on June 29.

	June 6–8	June 27–29
Lake corridor mean departure, μg m^{-3}	13.3	91.3
Atlantic corridor mean departure, μg m^{-3}	87.4	22.3
Atlantic minus Lake, μg m^{-3}	$+74.1$	-69.1
Site omission range, μg m^{-3}	$+70.6$ to $+77.5$	-70.7 to -67.4
Group omission range, μg m^{-3}	$+47.0$ to $+101.1$	-76.1 to -62.0
Alternate reference contrast, μg m^{-3}	$+63.3$	-79.8
Max coincident groups at $+20$ μg m^{-3}	6 (June 6)	7 (June 29)
Max run at $+10$ / $+20$ / $+30$ μg m^{-3}, days	5 / 3 / 3	5 / 4 / 3

Table 1. Contrast uses the core dates in the column heads. Counts and runs use the June 4–10 and June 25–30 neighborhoods.

The sign of each regional contrast survived all omissions and the alternate reference. Single-group omission moved the early contrast by up to 27.0 μg m^{-3} from its full-panel value. Reducing the persistence threshold from 20 to 10 μg m^{-3} extended the longest run in both neighborhoods to five days. Increasing it to 30 μg m^{-3} yielded a three-day maximum in both. Boston contributes an informative spatial exception. It briefly reached the primary threshold early in June and stayed below it in the second neighborhood.

Discussion

The two episodes exchanged corridor dominance, and the late episode combined strong same-day overlap with a west-to-east progression in peak dates across the sampled corridors. A summary based solely on the number of groups above a reference threshold would have obscured that timing. Conversely, a display of local peaks alone would have missed the day when seven groups remained elevated together. The patterns can inform selection of daily windows in subsequent investigations of these two smoke episodes.

Interpretation and scope

The early pattern aligns with NOAA's account of an episode that moved from the Great Lakes toward New York and the Mid-Atlantic [1]. NOAA's account of the late event showed vertically integrated smoke forecasts around the Great Lakes and eastern Ohio [2]. Cooper et al. mapped smoke, $PM_{2.5}$ and ozone in the Upper Midwest and identified notable events on June 6 and 28 [3]. Their daily maps track the regional episodes. Following a fixed set of instruments and giving county groups equal weight resolves a different comparison: which corridor had larger typical departures, when groups peaked, and when their departures overlapped.

The EPA archive provides bulk mass measurements and does not distinguish smoke particles from other sources. We use the independent event documentation for context. The reference can contain residual smoke, local emissions, and meteorological variation. Equal weighting controls the relative contribution of group medians to each corridor, but groups differ in monitor density, siting and area. Completeness criteria kept the day-to-day panel fixed at the cost of broader county coverage, notably for New York City and two entirely excluded planned groups. Descriptive persistence is sensitive to the chosen threshold and the late observation boundary. The inferred ordering uses local dates and has daily resolution. The estimates describe monitor departures in June 2023; personal exposure, regulatory metrics and source-apportioned concentrations would require different designs.

Data and code

The EPA source archive is available through AirData [4]. The reproducibility package provides the analysis source, filter ledger, county definitions, eligible site values, figure sources and reported estimates. The archive SHA-256 is recorded in the package. Natural Earth supplied release-independent map outlines; a geographic subset used to render the figure is retained with the code.

References

[1] NOAA NESDIS (2023). *NOAA satellites tracked historic levels of harmful smoke, impacting millions in the Eastern U.S.* NOAA satellite account.

[2] NOAA Air Resources Laboratory (2023). *Canadian wildfire smoke continues across US.* June 29 account and animation.

[3] Cooper, O. R., et al. (2024). Early season 2023 wildfires generated record-breaking surface ozone anomalies across the U.S. Upper Midwest. *Geophysical Research Letters*, 51, e2024GL111481. doi:10.1029/2024GL111481.

[4] US EPA. *AirData pre-generated files: daily parameter 88101 archive, 2023.* Annual archive.

[5] US EPA. *AirData download files documentation.* Daily file fields.