Research

Impact of the 2023 wildfire smoke episodes in Ontario, Canada, on asthma and other health outcomes: an interrupted time-series analysis

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Abstract

Background: During the 2023 wildfire season, Ontario, Canada, had unprecedented wildfire smoke, but the health impact on the population is unknown. We aimed to quantify the acute impact of the wildfire smoke on respiratory and cardiovascular outcomes across Ontario.

Methods: We conducted a quasi-experimental study by leveraging the timing of 2 consecutive wildfire smoke episodes in June 2023. Heavy wildfire smoke blanketed much of Ontario on 2 occasions, in early June and again in late June, causing severely degraded daily air quality. Following the epidemiologic triangulation framework, we collected health data on emergency department visits for 4 outcomes (asthma-related causes, other respiratory causes, ischemic heart disease, and non-cardiorespiratory causes) from Ontario's real-time syndromic surveillance system and the National Ambulatory Care Reporting System. We also employed different epidemiologic methodologies, including interrupted time-series and case–crossover analyses.

Results: After the initial heavy wildfire smoke in early June 2023, daily asthma-related visits increased substantially across Ontario, peaking at a 23.6% increase (95% confidence interval 13.2%–34.9%) at a 1-day lag and lasting up to a lag of 5 days after the start of the smoke episode. The later episode of heavy smoke, despite causing higher exposures, had a reduced effect on asthma-related visits. We did not detect any effect on other outcomes in either episode. These findings were consistent across different methodologies and data sources. Post hoc analysis revealed that asthma-related visits were briefly elevated after the wildfire smoke among children (40% higher), but we observed a more sustained effect among adults (48% higher, lasting 1 week).

Interpretation: The 2023 wildfires substantially increased asthma-related emergency department visits in Ontario, with age and timing of exposure being important factors influencing the impact. As wildfires emerge as one of the fastest-growing environmental risk factors globally, future research should identify and evaluate measures to effectively mitigate the acute health impacts of wildfire smoke.

In Canada, the most destructive wildfire season on record occurred in 2023. Starting in March and intensifying in June, massive fires spread across the country, resulting in 29 megafires,[1] including the largest fire ever recorded in southern Quebec, which consumed 1.2 million acres.[2] These fires displaced thousands of people in Canada, destroyed property, and blanketed vast areas of North America with smoke. The unprecedented wildfires of 2023 are a wake-up call that wildfires — a persistent feature of Canada's landscape — are becoming more intense and prolonged in a changing climate, affecting millions of people.[1]

These large wildfires released substantial amounts of smoke, containing fine particulate matter ($PM_{2.5}$) and other air pollutants, that travelled long distances and deteriorated air quality in densely populated areas.[3] As these events become more common, there is growing interest in the resulting health effects. For example, 2 wildfires in California (2003 and 2007) were found to have significantly increased emergency department visits and hospital admissions for respiratory outcomes (especially asthma) and, to a lesser degree, cardiovascular outcomes.[4–8] Similarly, during British Columbia's 2003 wildfire season, elevated smoke was linked to spikes in daily physician visits and

hospital admissions for respiratory outcomes.[9] These studies and others have consistently linked wildfire smoke to respiratory morbidity, although the evidence for cardiovascular morbidity is mixed.[10–21] More recently, wildfire smoke was found to have a greater impact on respiratory morbidity than emissions from other sources, like traffic.[20]

Most studies on the health effects of wildfire smoke have either focused on specific wildfire events or used time-series and case–crossover methods to assess average effects of daily variations in wildfire-specific $PM_{2.5}$ over several years.[4–10,12–21] These studies generally overlooked the timing of wildfire events. By assuming that health effects depend solely on exposure levels, these studies may not differentiate risks for individuals with the same average exposure but different exposure histories, which could be problematic since the timing of exposure is likely important. In addition, although findings on respiratory outcomes are relatively consistent, the results on other outcomes, especially cardiovascular diseases, remain mixed. To prepare communities and health care systems for future wildfires, elucidating how wildfire smoke affects health is crucial.

In June 2023, heavy smoke descended on much of Ontario — first in early June and then again in late June — resulting in some of the world's worst daily air quality.[22] Although the health impact of the first episode was assessed in some regions of the United States,[23,24] little is known about its effects, or those of the second episode, in the province of Ontario (home to around 40% of Canada's population). Unlike western Canada and the Prairies, which regularly face wildfires,[9] Ontario has rarely experienced severe wildfire smoke in its population centres. Therefore, we aimed to assess the acute impact of the wildfire smoke on health across Ontario.

Methods

Setting

An unusually dry spring season in 2023 led to 155 simultaneous fires across Quebec as of June 4.[2] The largest, formed by the merging of 19 smaller fires, occurred in the Lebel-sur-Quévillon area of southern Quebec.[2] This massive fire emitted large amounts of smoke that travelled southwestward, along with smoke from several large fires in northeastern Ontario, affecting much of Ontario on 2 occasions in June (Figure 1).[2] These 2 episodes triggered air-quality advisories and the closure of outdoor recreational activities.

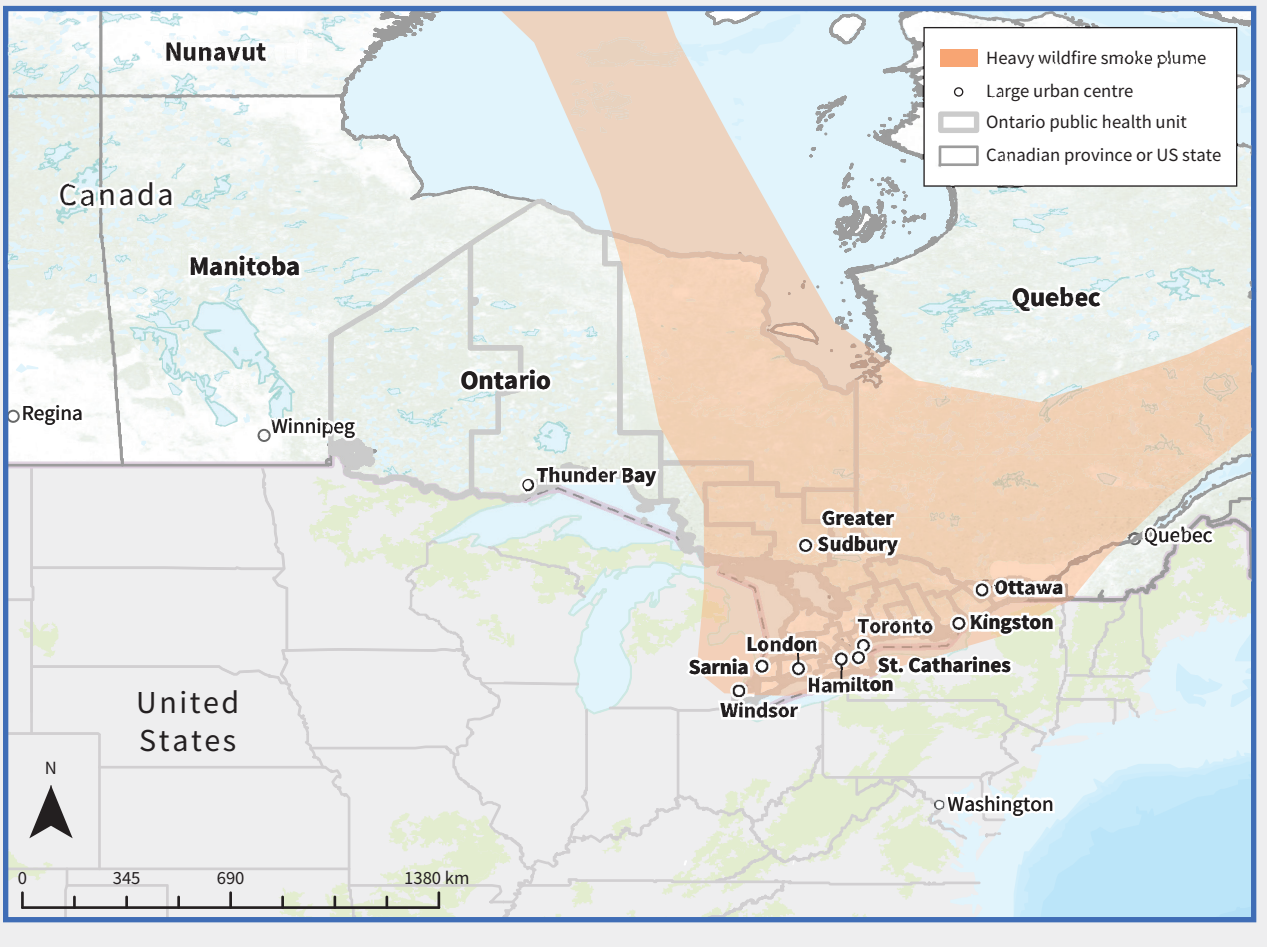

Figure 1: Map of the 2023 Canadian wildfire smoke as of June 5, 2023. Map created by H. Chen using data sourced from the Province of Ontario, TomTom, Garmin, Food and Agriculture Organization, National Oceanic and Atmospheric Administration, United States Geological Survey, US Environmental Protection Agency, US Fish and Wildlife Service, Parks Canada, Natural Resources Canada, and Esri.

Study design and data sources

These 2 episodes of heavy wildfire smoke enabled us to conduct a quasi-experimental study of the period from Apr. 1, 2023 (around 8 weeks before the first episode), to July 31, 2023 (4 weeks after the second episode), including all reported emergency department visits in Ontario. To strengthen causal inference on the impact of these wildfire episodes, we employed the triangulation framework, using different epidemiologic methodologies and data sources.[25] To identify emergency department visits, we used data from Kingston, Frontenac, and Lennox & Addington Public Health's Acute Care Enhanced Surveillance (ACES) and from the Canadian Institute of Health Information's National Ambulatory Care Reporting System (NACRS). The ACES database is a syndromic surveillance system developed to identify public health emergencies in Ontario through near real-time monitoring of patient triage registration records from emergency departments (and inpatient records) at more than 95% of Ontario's acute care hospitals (Appendix 1, available at www.cmaj.ca/lookup/doi/10.1503/cmaj.241506/tab-related-content).[26] The NACRS database collects administrative, clinical, and service-specific data for visits to all emergency departments in Ontario.[27] Data from NACRS are routinely used to assess the acute impact of environmental factors (e.g., extreme heat),[28] but are delayed by several months, limiting their usefulness for timely decision-making. We linked NACRS data sets using unique encoded identifiers and analyzed the data at ICES.

Exposures, outcomes, and covariates

We ascertained daily smoke exposure for each of Ontario's 34 public health units (PHUs) using air-quality monitoring data from the Ministry of the Environment, Conservation, and Parks[29] and satellite-based smoke plume information from the US National Oceanic and Atmospheric Administration's Hazard Mapping System.[30] We classified days as "smoke days" if PHU-specific daily mean $PM_{2.5}$ concentrations exceeded the maximum daily concentrations recorded from Jan. 1, 2022, to May 31, 2023, and if a heavy smoke plume intersected with the PHU polygon centroid on the Ontario Ministry of Health Public Health Unit Boundary map. Previous work covering several years of wildfires showed that heavy smoke plume was highly correlated with wildfire-related $PM_{2.5}$.[31] All other days were defined as "non-smoke days."

We ascertained daily emergency department visits for 4 outcomes, defined a priori[9,20,23,24]: asthma-related causes, other respiratory causes, ischemic heart disease, and non-cardiorespiratory causes. We used visits for non-cardiorespiratory causes as a control outcome, as we did not expect these to show associations with wildfire smoke.[32] We defined non-cardiorespiratory outcomes as all emergency department visits excluding those for respiratory conditions (asthma and non-asthma) and cardiovascular conditions (including ischemic heart disease). In ACES, these outcomes were classified as syndromes using a validated algorithm that analyzes text in triage records,[26,33,34] an approach that is increasingly applied in wildfire health research.[24] These predefined ACES syndromes have been validated against NACRS and shown to have strong alignment (e.g., Pearson correlation coefficients of 0.98 for the respiratory syndrome and 0.74 for the asthma syndrome).[26,33,34] Conversely, in NACRS, these outcomes were ascertained using primary diagnostic codes (Appendix 1).

We considered PHU-specific daily mean temperature, relative humidity, ozone (O_3), and nitrogen dioxide (NO_2) levels as potential time-varying confounders.[4–10,12–20] We obtained temperature and humidity data from Environment and Climate Change Canada's weather stations in Ontario.[35] Considered as surrogates for air pollution unrelated to wildfire smoke, O_3 and NO_2 data were obtained from the Ministry of the Environment, Conservation and Parks. We adjusted for weekdays and holidays. To account for the potential impact of COVID-19 on Ontario's health care system, we obtained weekly COVID-19 cases for each PHU from Public Health Ontario.[36] This variable is relevant because we included data from 2022 as a control series in the quasi-experimental analysis.

Statistical analysis

Capitalizing on the random timing of the 2 wildfire smoke episodes as a natural experiment, we employed interrupted time-series analysis to quantify the impact of wildfire smoke by comparing daily cause-specific emergency department visits before, during, and after these episodes. To minimize potential confounding by latent concomitant events and seasonal patterns, we included the same period in 2022 as a control series.[37] To perform this analysis, we used a conditional quasi-Poisson regression model, stratified by PHU of residence and adjusted for long-term time trends, temperature, and humidity using a natural spline function with 3 degrees of freedom; for NO_2, O_3, and weekly COVID-19 cases, we used a natural spline with 2 degrees of freedom.[4–10,12–20] We also included indicators for weekdays and holidays, as well as an indicator for calendar year and its interaction with long-term time trends. To account for potential autocorrelation, we followed the method by Brumback and colleagues.[38,39] Separate models were fitted to study the effect of each episode. For the first episode, the model included outcomes that occurred before the second episode (Apr. 1 to June 25), and for the second episode, it excluded outcomes that occurred during the first episode. For both episodes, we focused on level changes following the smoke episode, given the acute nature of its effect. To explore the lag structure of the association, we repeated the analysis on outcomes for same-day exposure (lag 0) and for outcomes lagged by up to 7 days after the smoke episode (lag 7). We repeated the analyses for each outcome and data source. In all analyses, we confirmed the absence of autocorrelation by examining the plots of residuals and the partial autocorrelation function.[40]

To control for time-varying confounding (e.g., seasonality and long-term trends) through study design rather than statistical adjustments, we employed a time-stratified case–crossover design as an alternative methodology.[41] Specifically, we matched up to 4 referent periods (when the outcome did not occur) with the case period (when the outcome occurred) on the same weekday within the same month, thus effectively controlling for seasonality and long-term trends by design.[41] In addition, since each case served as its own control, this approach eliminated known and unknown confounding factors that change slowly over time.

To conduct this analysis, we followed the approach from Armstrong and colleagues[36] by using a conditional quasi-Poisson model, adjusting for PHU, temperature, humidity, NO_2, O_3, weekly COVID-19 cases, and holidays, parameterized similarly to the controlled interrupted time-series analysis.

For both approaches, we expressed the effect of smoke episodes as a percentage change compared with anticipated emergency department visits, calculated as the exponential of the Poisson partial regression coefficient minus 1, with the result multiplied by 100. We did statistical analyses with R (version 4.3.0). Analytic code is provided in Appendix 1.

To check the robustness of our findings, we performed an array of secondary analyses. We visually examined population-weighted daily ACES emergency department syndromes and NACRS emergency department visits for all selected outcomes across Ontario (per 100 000 people) to identify underlying trends and variations before, during, and after both episodes. We performed standard interrupted time-series analyses for 2022 and 2023, respectively, with 2022 serving as a placebo test for visual comparison.[35] We defined either days with more moderate smoke exposure in June 2023 or the entire month of June 2023 as smoke days to capture the potential impact of moderate smoke exposure. We used a more specific definition of asthma emergency department visits based on NACRS data (Appendix 1, page 7). Additionally, we performed post hoc analyses to assess whether the impact of wildfire smoke on asthma visits varied by age (0–4 yr, 5–17 yr, 18–64 yr, and ≥ 65 yr) using syndromic data. As a sensitivity analysis, we further restricted the youngest age group to 3–4 years, given a concern about the difficulty of distinguishing asthma from bronchiolitis in the group aged 0–2 years. Finally, we conducted post hoc analyses on ACES and NACRS emergency room visits for ischemic heart disease, examining lags up to 14 days.

Ethics approval

Use of ICES data in the present study was authorized under section 45 of the *Personal Health Information Protection Act* of Ontario, which does not require review by a research ethics board. The use of ACES syndromic data in its aggregate format is similarly exempt from research ethics board review.

Results

After excluding PHUs with missing exposure, this study included 30 PHUs, representing around 95% of Ontario's population. From Apr. 1, 2023, to July 31, 2023, there were 1 860 061 recorded ACES emergency department syndromes and 1 979 531 NACRS emergency department visits for all causes. For specific causes, the average daily counts were 553 ACES emergency department syndromes and 317 NACRS emergency department visits for asthma; 1036 ACES emergency department syndromes and 1354 NACRS emergency department visits for other respiratory causes; 765 ACES emergency department syndromes and 78 NACRS emergency department visits for ischemic heart disease; and 12 493 ACES emergency department syndromes and 11 864 NACRS emergency department visits for non-cardiorespiratory causes. Similar numbers were recorded in 2022 (Appendix 1, Table S1).

Analysis of daily smoke exposure data yielded 2 episodes, each comprising 3 smoke days on average (range 1–6 d, depending on PHU) (Figure 2). Although satellite imagery also identified heavy smoke plumes in July, they did not materially degrade ground-level $PM_{2.5}$ concentrations, likely because they remained high in the atmosphere; therefore, they were not considered smoke episodes. During the 2 smoke episodes in June 2023, daily mean $PM_{2.5}$ concentration surged across Ontario, reaching 53.2 μg/m^3 and 65.3 μg/m^3, respectively, from 7.4 μg/m^3 in the pre-smoke period (Apr. 1 to May 31) (Figure 2). These smoke episodes were marked by heavy smoke plumes. Conversely, daily O_3 levels remained stable throughout and temperatures gradually increased. No discernible difference between the various periods was noted for these factors in 2022.

Our interrupted time-series analysis of data from ACES, adjusted for all confounders and using 2022 as a control, showed increases in daily asthma-related emergency department syndromes during the first episode, peaking at a 2-day lag (21.7%, 95% confidence interval [CI] 12.9%–31.1%) and remaining elevated for up to a 6-day lag (Figure 3). No increases were observed for other respiratory syndromes, while emergency department visits for ischemic heart disease syndromes decreased during smoke days but increased significantly after lags of 5–7 days. As expected, there was no discernible increase in non-cardiorespiratory syndromes in this episode. In contrast, the second episode showed no consistent impact on asthma or other emergency department syndromes.

Similarly, our analysis using data from NACRS showed that daily asthma-related emergency department visits surged during the first episode, peaking at a 1-day lag (23.6%, 95% CI 13.2%–34.9%) and lasting up to a lag of 5 days (Figure 4). We observed no significant increase in asthma visits during the second episode and no consistent associations for other causes in either episode.

Our case–crossover analysis similarly revealed a significant increase in asthma syndromes and emergency department visits during the first episode, with daily cases increasing by 12.0%–23.2%, depending on lag and data source (Appendix 1, Figure S1 and Figure S2). This effect diminished in the second episode. We did not observe associations for other emergency department outcomes in either episode.

Standard interrupted time-series analyses, conducted separately for 2022 (serving as a placebo test) and 2023, confirmed that the spikes in daily asthma syndromes and emergency department visits were specific to the first episode in 2023, with no similar increase during the same period in 2022 (Figure 5 and Figure 6). There was no increase in other emergency department outcomes in either year. For the second episode, we did not observe strong evidence of increases in asthma, ischemic heart disease, and non-cardiorespiratory emergency department visits in either 2022 or 2023 (Figure 7 and Figure 8). We observed similar increases in other respiratory syndromes and emergency department visits in both years, underscoring the importance of leveraging 2022 as a control.

Our visual checks further revealed a noticeable jump in daily asthma syndromes and emergency department visits during the

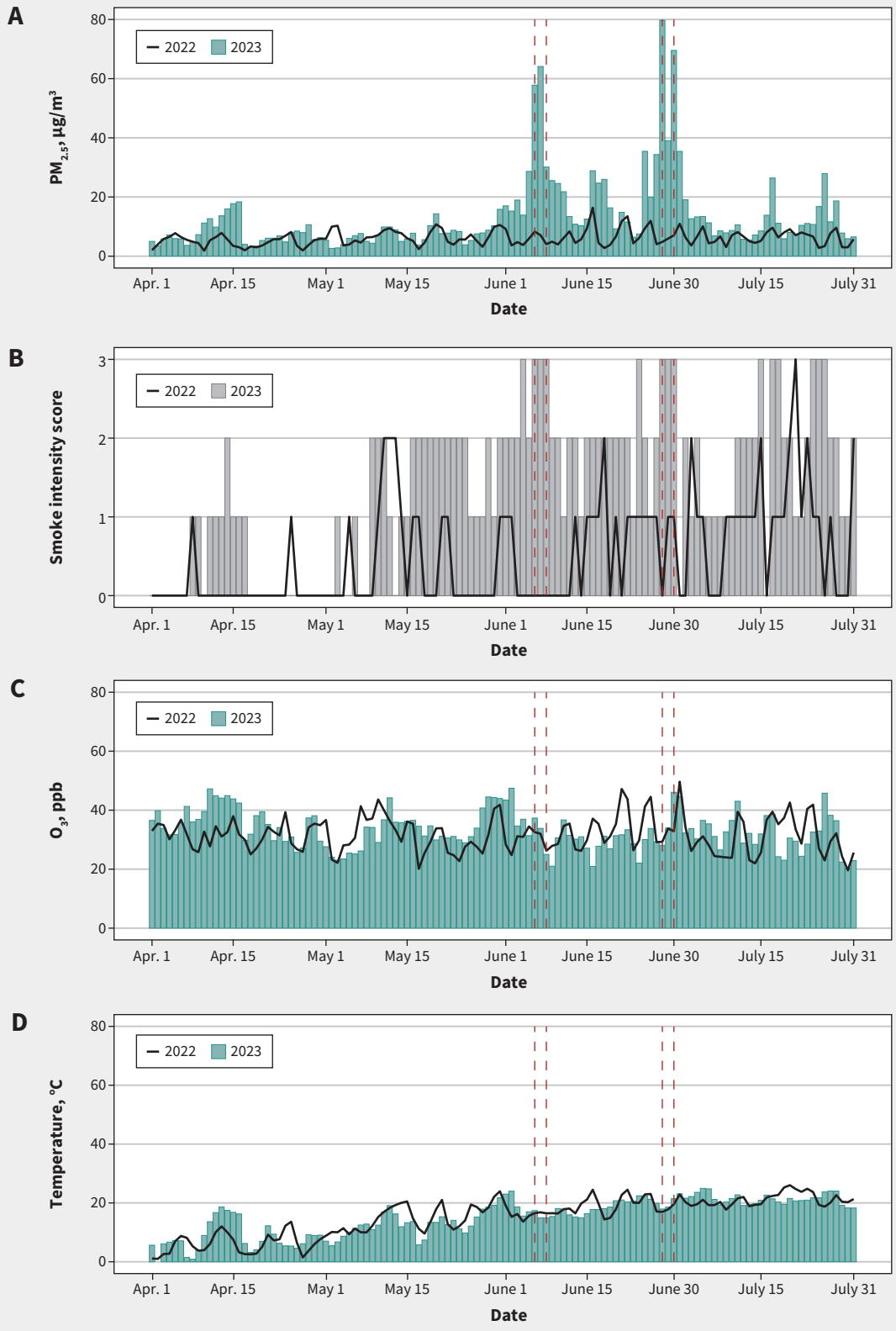

Figure 2: Population weighted daily mean of (A) fine particulate matter ($PM_{2.5}$) concentration, (B) smoke plume intensity score (0 = no smoke, 1 = light smoke, 2 = medium smoke, 3 = heavy smoke), (C) O_3 levels, and (D) temperature across 30 public health units in Ontario, from Apr. 1 to July 31 in 2022 and 2023, respectively. Vertical dashed lines denote wildfire episodes in early and late June 2023). During these 2 episodes, mean $PM_{2.5}$ concentrations surged to 53.2 µg/m³ and 65.3 µg/m³, respectively, from 7.4 µg/m³ in the pre-wildfire period (Apr. 1 to May 31); episodes were also marked by heavy smoke plumes.

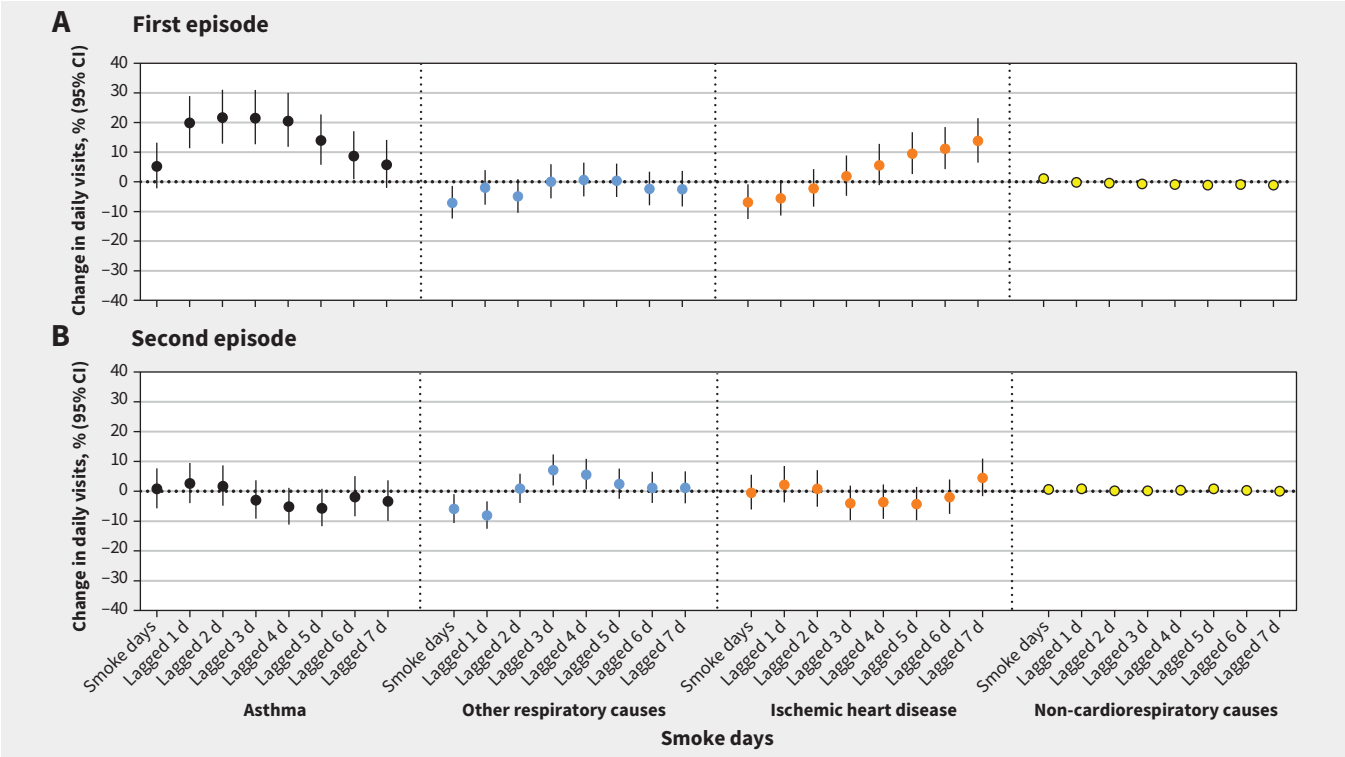

Figure 3: Associations between (A) the first and (B) second wildfire smoke episodes in 2023 and daily Acute Care Enhanced Surveillance emergency department syndromes for asthma, other respiratory causes, ischemic heart disease, and non-cardiorespiratory causes across 30 public health units in Ontario using controlled interrupted time-series analysis, by episode. Daily emergency department syndromes for asthma during the first episode peaked at a 2-day lag and stayed elevated up to a 6-day lag. Note: CI = confidence interval.

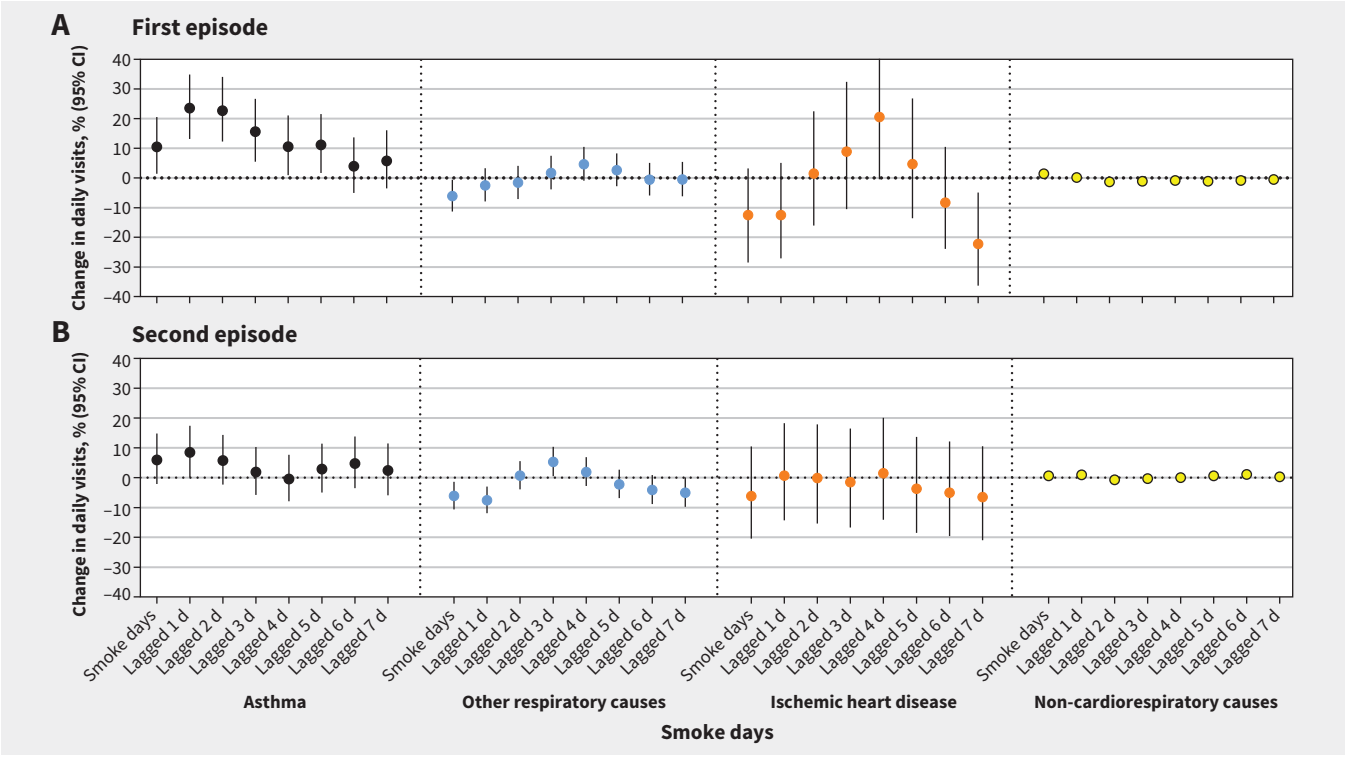

Figure 4: Associations between (A) the first and (B) second wildfire smoke episodes in 2023 and daily National Ambulatory Care Reporting System emergency department visits for asthma, other respiratory causes, ischemic heart disease, and non-cardiorespiratory causes across 30 public health units in Ontario using controlled interrupted time-series analysis, by episode. Daily emergency department visits for asthma during the first episode peaked at a 1-day lag and lasted up to a lag of 5 days. Note: CI = confidence interval.

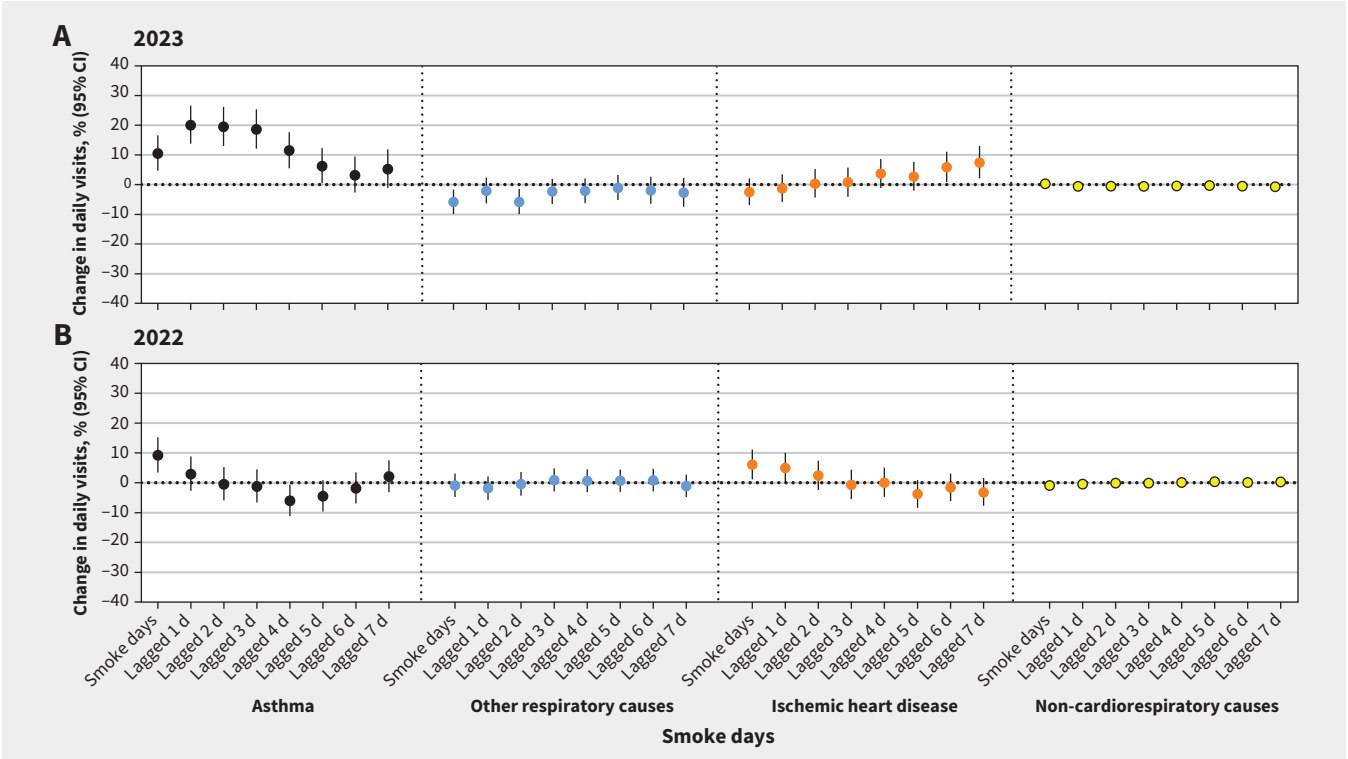

Figure 5: Associations between (A) the first wildfire episode in 2023 and (B) the same period in 2022 (placebo test) and daily Acute Care Enhanced Surveillance emergency department syndromes for asthma, other respiratory causes, ischemic heart disease, and non-cardiorespiratory causes across 30 public health units in Ontario using standard interrupted time-series analysis, by year. This placebo test showed that spikes in daily asthma syndromes were specific to the first episode in 2023. Note: CI = confidence interval.

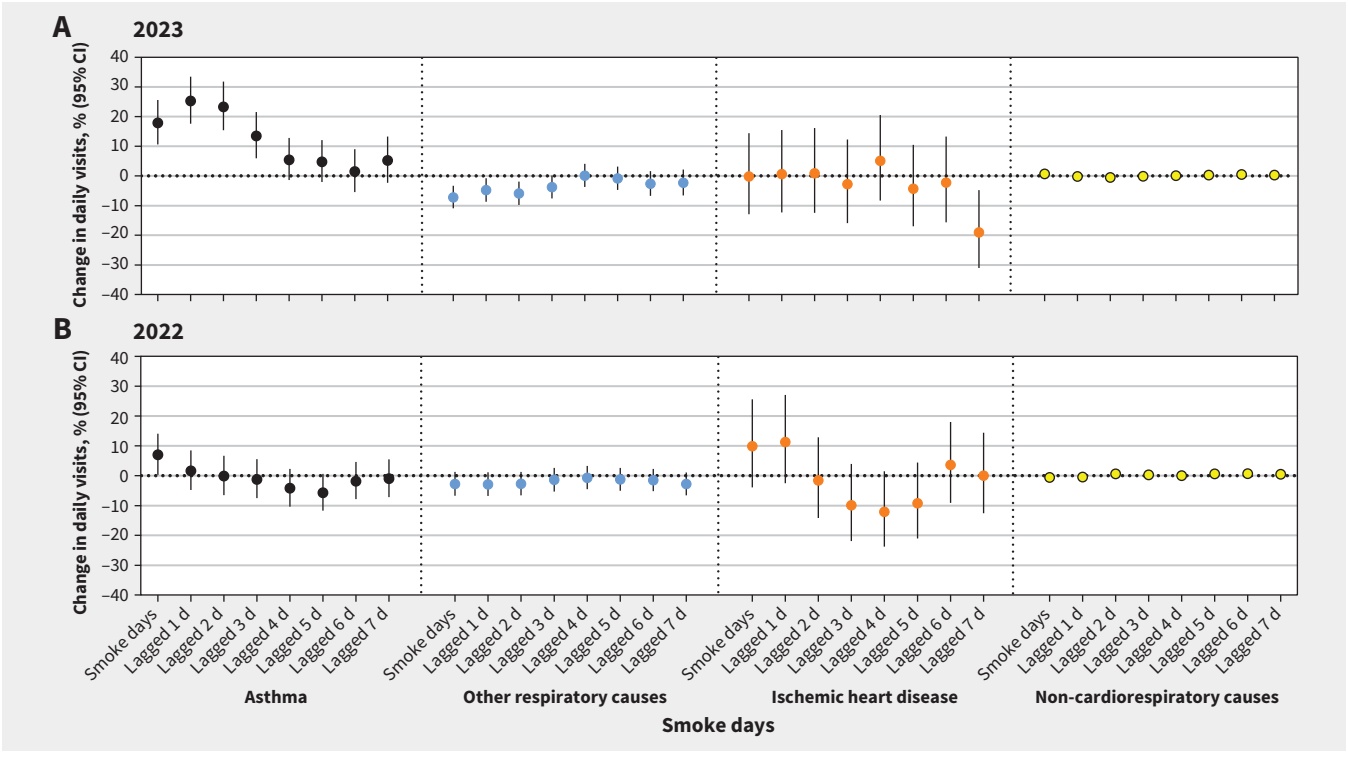

Figure 6: Associations between the (A) first wildfire episode of 2023 and (B) the same period in 2022 (placebo test) and daily National Ambulatory Care Reporting System emergency department visits for asthma, other respiratory causes, ischemic heart disease, and non-cardiorespiratory causes across 30 public health units in Ontario using standard interrupted time-series study analysis, by year. This placebo test showed that spikes in daily asthma emergency department visits were specific to the first episode in 2023. Note: CI = confidence interval.

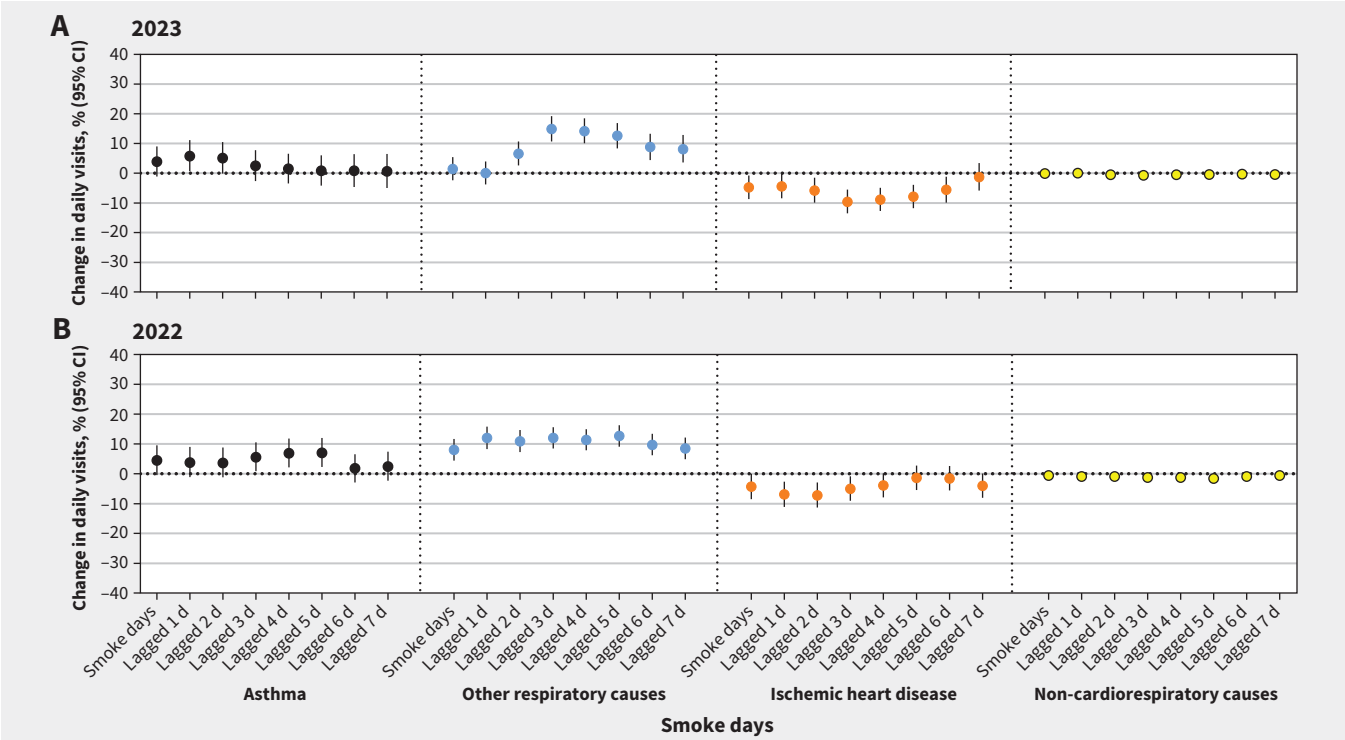

Figure 7: Associations between (A) the second wildfire episode in 2023 and (B) the same period in 2022 (placebo test) and daily Acute Care Enhanced Surveillance syndromes for asthma, other respiratory causes, ischemic heart disease, and non-cardiorespiratory causes across 30 public health units in Ontario using standard interrupted time-series analysis, by year. No strong evidence of increases in asthma, ischemic heart disease, and non-cardiorespiratory syndromes was found in either 2022 or 2023. Note: CI = confidence interval.

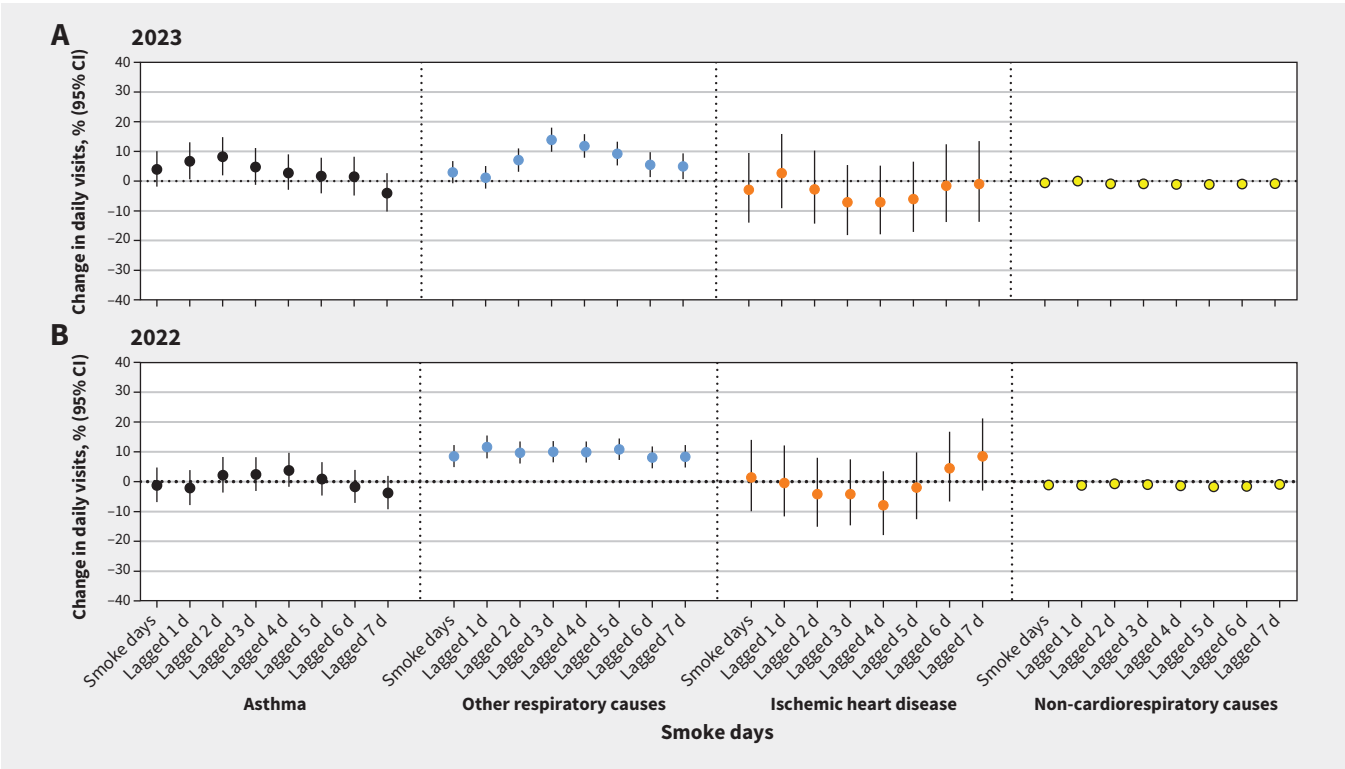

Figure 8: Associations between (A) the second wildfire episode in 2023 and (B) the same period in 2022 (placebo test) and daily National Ambulatory Care Reporting System emergency department visits for asthma, other respiratory causes, ischemic heart disease, and non-cardiorespiratory causes across 30 public health units in Ontario using standard interrupted time-series analysis, by year. No strong evidence of increases in asthma, ischemic heart disease, and non-cardiorespiratory emergency department visits was found in either 2022 or 2023. Note: CI = confidence interval.

first episode in 2023, which was absent in the second episode. In 2022, these 2 outcomes were stable throughout. For all other outcomes, daily cases remained stable during both episodes in both years (Figure 9).

Our analysis of days with more moderate smoke exposure in June 2023 found no evidence of a significant increase in daily emergency department syndromes or emergency department visits compared with non-smoke days for all outcomes examined (Appendix 1, Table S2). However, when treating the entire month of June as smoke days, we observed an average 3% increase in daily ACES asthma syndromes (95% CI 0%–7%) and a 6% increase in daily NACRS emergency department visits for asthma (95% CI 2%–11%) compared with May and July 2023. No evidence of increases was found for other emergency department outcomes. Using a more specific definition of asthma emergency department visits, we noted stronger associations between these and wildfire smoke (Appendix 1, Figure S3).

A post hoc analysis of associations by age subgroup showed a brief spike in daily asthma visits among children (up to 40% higher at a 1- to 2-day lag) but a more sustained increase among adults (48% higher, lasting 1 week) during the first episode (Figure 10). No similar increases were observed for any age group during the second episode. Restricting the youngest age group to those aged 3–4 years did not materially alter these results (Appendix 1, Figure S4). Finally, there was no strong evidence of increased emergency department visits for ischemic heart disease in either ACES or NACRS data, even after extending the analysis to a 14-day lag.

Interpretation

In this quasi-experimental study, we observed a substantial increase in asthma-related emergency department visits across Ontario following heavy wildfire smoke in early June 2023. A subsequent episode of heavy smoke in late June, however, produced a diminished impact on asthma visits, despite causing higher exposures. We observed no compelling evidence of increases in other outcomes during either episode. Further post hoc analysis revealed that asthma visits among children were briefly elevated after the wildfire smoke, but a more sustained effect was observed among adults. A key strength of this study is our use of diverse methodologies and data sources within the epidemiologic triangulation framework. The consistency in results across different methodologies and data sources strengthened the causal inference.

Ontario's population was unaccustomed to heavy wildfire smoke episodes and was therefore unlikely to have adopted anticipatory measures or behaviours that could confound associations with health outcomes. Our results align with previous studies of the 2023 Canadian wildfires and asthma emergency department visits in the US.[23,24] For example, Chen and colleagues[24] found a 44% increase in daily emergency department syndromes for asthma in New York during a wildfire smoke event from June 6 to 8, 2023, compared with 2 adjacent, non-smoke periods. The increase was highest among people aged 18–64 years (increased by 52%), followed by those aged 5–17 years (32%), and those aged 65 years or older (24%).[24] Another study using data from several US states found a 17% increase in emergency department visits for asthma in association with the 2023 Canadian wildfires.[23] Our findings are further supported by studies linking wildfire smoke to increased emergency department visits and hospital admissions for asthma in past wildfire seasons, especially among adults.[7–9,12,14] Previous studies also reported increased daily emergency department visits and hospital admissions for all respiratory causes from wildfire smoke.[4,7,13,21] In the present study, we observed no appreciable increase in daily emergency department visits for non-asthma respiratory causes. Asthma often constitutes a substantial portion of total respiratory emergency department visits (e.g., around 20% in this cohort) and may be a major factor linking wildfires to total respiratory outcomes. Our study also found no clear evidence of an increase in emergency department visits related to ischemic heart disease during either episode. Although all-source $PM_{2.5}$ is a known risk factor for cardiovascular morbidity, the evidence for wildfire-specific $PM_{2.5}$ remains mixed.[10–21] It is plausible that the impact of wildfire smoke on cardiovascular morbidity involves a longer exposure window. However, we found no association even after extending to a 14-day lag.

The occurrence of 2 episodes in quick succession in Ontario in June 2023 provided a unique opportunity to study the health impact of both history and level of exposure to wildfire smoke. Unlike the first episode, the second wave of heavy smoke was not associated with a comparable increase in asthma emergency department visits, despite causing higher exposures. Although the exact reason is unknown, possible explanations include extended protective effects of preventive medications prescribed during the first episode, increased supply and use of medications (e.g., caregiver administration of maintenance medication to children), or improved behavioural adaptations to minimize exposure in keeping with air-quality advisories, such as staying indoors and using air filters. We have previously shown that air-quality advisories reduced asthma-related emergency department visits in Toronto, Ontario.[42]

Consistent with previous studies,[24] our study showed a more modest and delayed increase in daily asthma visits among people aged 65 years and older, compared with adults aged 18–64 years, in the first episode. This difference may partly be attributed to potential alternative primary diagnoses owing to pre-existing multimorbidity among older adults. Alternatively, pre-existing multimorbidity could influence daily activities and, consequently, exposure to wildfire smoke. Older adults tend to spend more time indoors, whereas younger adults might choose to continue daily activities such as work, school, or errands, despite wildfire warnings during this episode.

Finally, although harmful effects from heavy wildfire smoke in 2023 have been clearly shown, our exploratory analysis showed no associations with moderate smoke exposure. Compared with heavy smoke days, moderate smoke days are often influenced by $PM_{2.5}$ emissions from non-wildfire sources, making it more difficult to isolate the causal effects of wildfire smoke. In addition, the extended protective effects of preventive medications prescribed during the first episode or adaptive behaviours may have played a role in reducing the effects. Future research on more moderate exposure could benefit from using a longer time series and wildfire-specific $PM_{2.5}$ data.

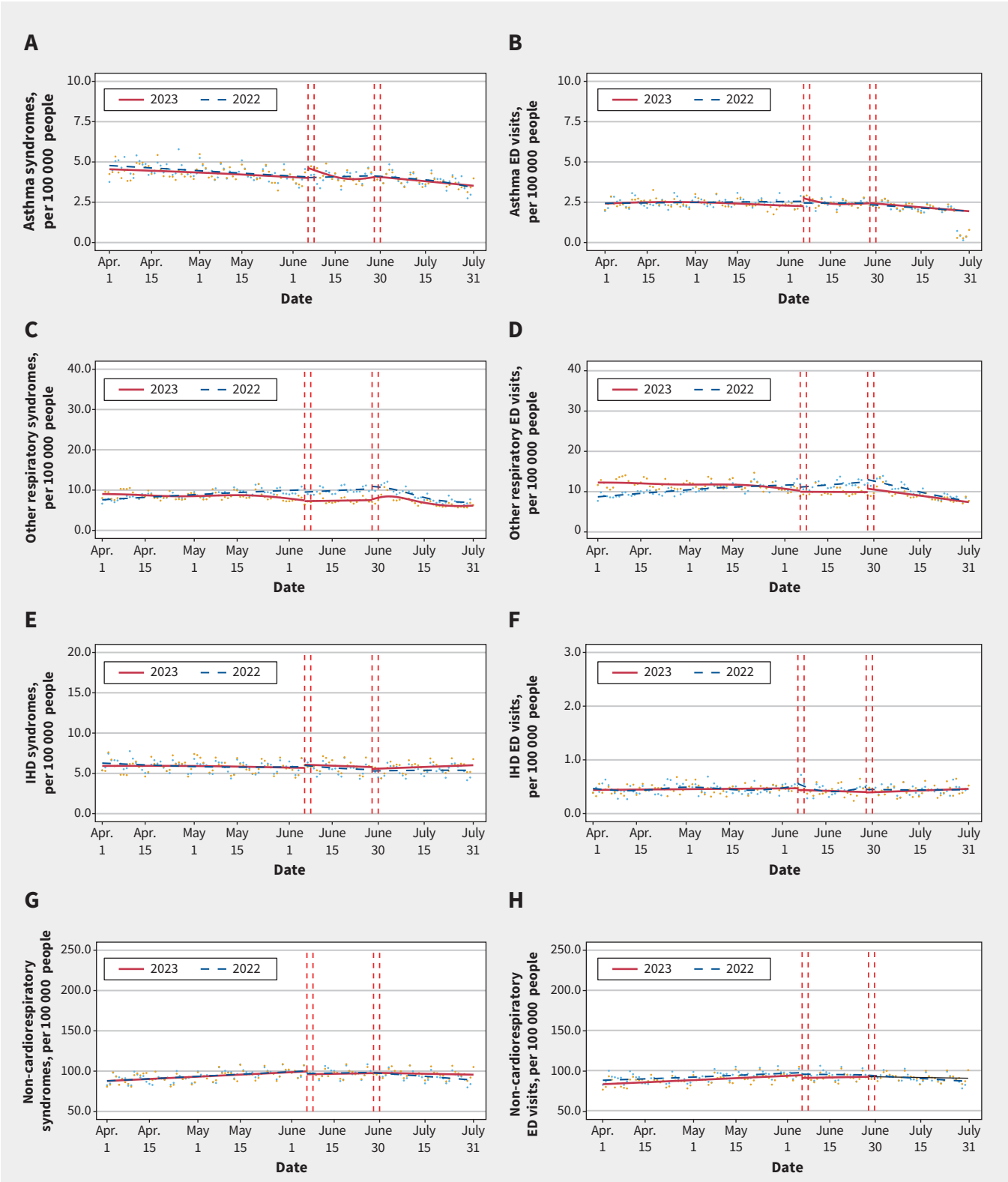

Figure 9: Daily incidence rate of (A) Acute Care Enhanced Surveillance (ACES) syndromes for asthma, (B) National Ambulatory Care Reporting System (NACRS) emergency department (ED) visits for asthma, (C) ACES syndromes for other respiratory causes, (D) NACRS ED visits for other respiratory causes, (E) ACES syndromes for ischemic heart disease (IHD), (F) NACRS ED visits for IHD, (G) ACES syndromes for non-cardiorespiratory causes, and (H) NACRS ED visits for non-cardiorespiratory causes, per 100 000 people across 30 public health units in Ontario (Apr. 1–July 31 in 2022 and 2023). For each outcome, the blue dashed line and red solid line denote smooth trendline of daily incidence rate for 2022 and 2023, respectively, using p spline. Daily asthma syndromes and emergency department visits spiked during the first wildfire episode in 2023, but not the second episode. In 2022, these outcomes were stable. Vertical red dashed lines denote 2 wildfire smoke episodes.

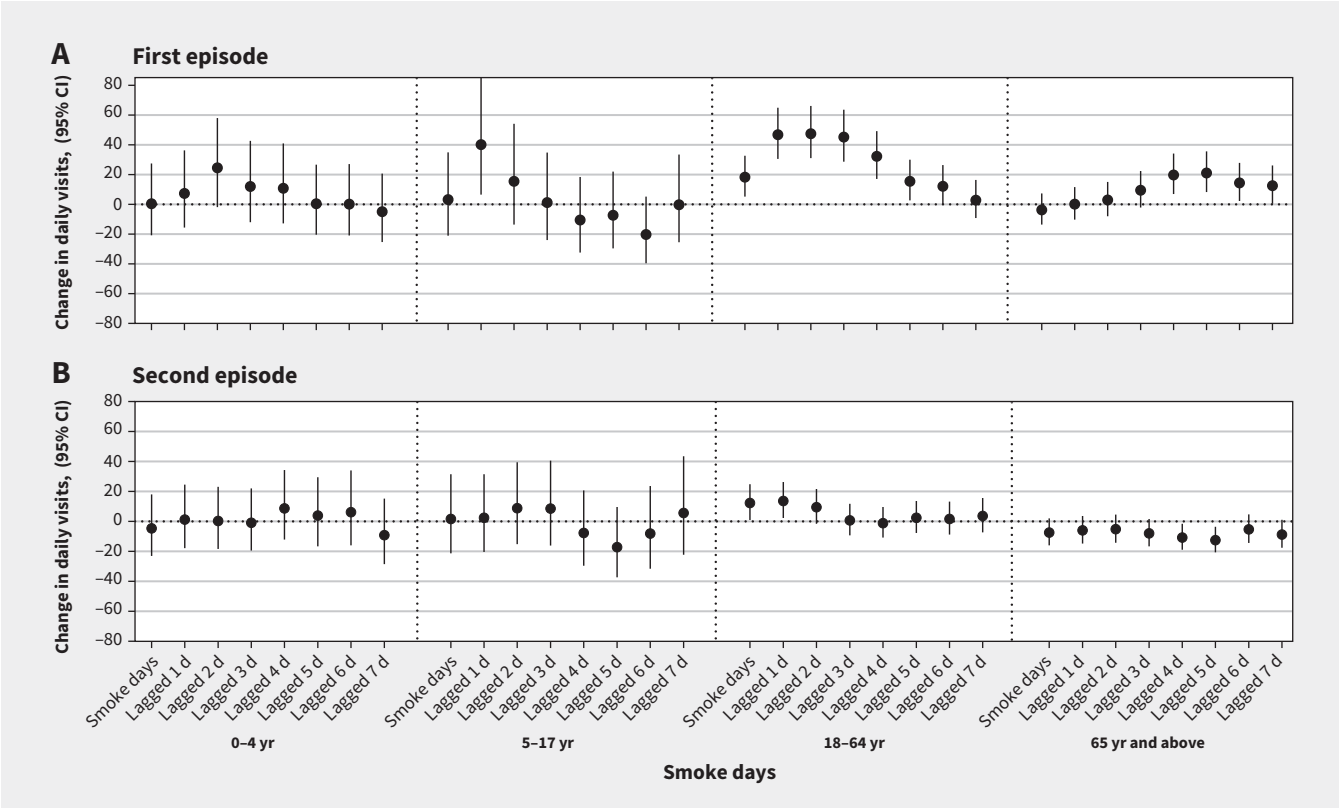

Figure 10: Associations between (A) the first and (B) second wildfire smoke episodes in 2023 and daily Acute Care Enhanced Surveillance emergency department syndromes for asthma across 30 public health units in Ontario using controlled interrupted time-series analysis, by age group and episode (for both episodes, average percentage of cases by age group are 8% for 0–4 yr, 7% for 5–17 yr, 41% for 18–64 yr, and 42% for ≥ 65 yr). During the first episode, daily asthma visits increased briefly among children, but adults showed a more sustained increase. Note: CI = confidence interval.

Limitations

A main limitation of this study is the potential for exposure misclassification related to the imperfect delineation of ground-level smoke plumes using satellite imagery[5] and the reliance on area-level air-pollution data as a proxy for individual-level exposure. Additionally, although certain respiratory conditions like chronic obstructive pulmonary disease may have been exacerbated by wildfire smoke,[8] we could not assess these associations because of limited data. Other limitations involve not accounting for longer lagged effects (e.g., ≥ 1 mo) and potential for outcome misclassification in syndromic data, which is likely less accurate in ascertaining certain outcomes than NACRS data.[26] However, our findings from syndromic data and gold-standard NACRS data were largely consistent, suggesting that syndromic data hold potential for real-time public health surveillance with future wildfires.

Conclusion

The 2023 Canadian wildfires led to a substantial increase in asthma-related emergency department visits across Ontario, with important heterogeneity by age and timing of exposure. As wildfires emerge as one of the fastest-growing environmental risk factors globally, future research is needed to better understand the dose–response relationship, especially in relation to moderate wildfire exposure, and to identify and evaluate measures to effectively mitigate the acute health effects of wildfire smoke.

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