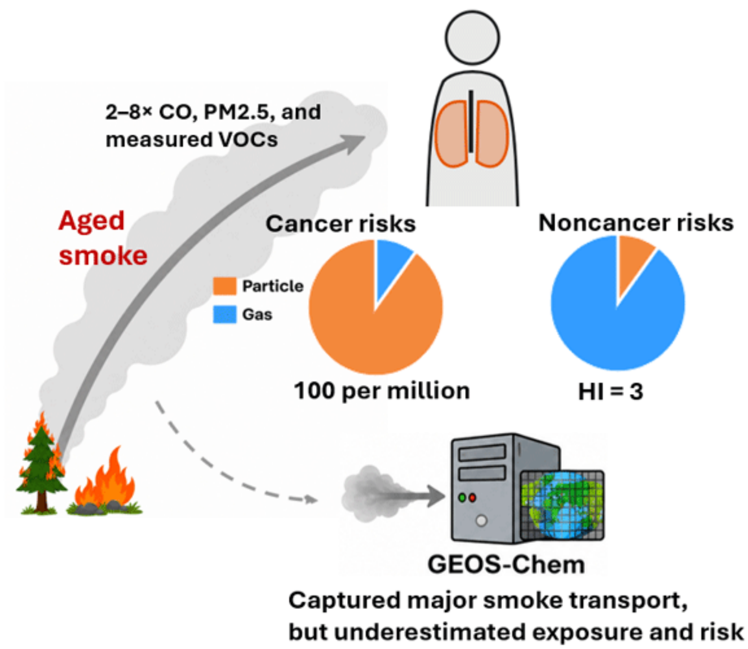
PLAIN-LANGUAGE SUMMARY

More Smoke Does Not Always Mean More Ozone

What happens when wildfire smoke spends days in the atmosphere before reaching a city?

Jin et al. (2026) | Atmospheric Chemistry and Physics



Key visual. Aged wildfire smoke increased particles, carbon monoxide, and measured organic gases; contributed to both cancer and non-cancer health risks; and exposed important limitations in GEOS-Chem.

The study in one minute

Smoke that had traveled for days: Smoke from California and the Pacific Northwest reached Missoula, Montana, after at least three days of transport.

Much higher pollution: Carbon monoxide, PM2.5, and measured organic gases rose by roughly 2-8 times; hourly PM2.5 reached 120 μg/m3.

Ozone did not rise forever: Ozone increased under lighter smoke, then leveled off or declined when PM2.5 exceeded about 30-40 μg/m3.

Particles were not the whole story: Particles dominated the cancer-risk estimate, while gases such as acrolein and formaldehyde dominated chronic non-cancer risk.

01 | FROM FIRES TO A CITY

How does a distant wildfire become a local air-quality problem?

Wildfire smoke can travel hundreds or even thousands of kilometers. In September 2020, large western U.S. fires sent smoke inland and produced three multi-day surface-smoke episodes in Missoula. Much of the smoke had already spent at least three days traveling, mixing, and reacting in the atmosphere.

A smoke layer seen from a satellite does not always reach the air people breathe. PM2.5 alone can also miss gas-rich smoke after rain removes particles more efficiently. The team therefore combined satellite information with ground measurements of PM2.5, carbon monoxide, and chemical tracers such as acetonitrile, furan, and maleic anhydride.

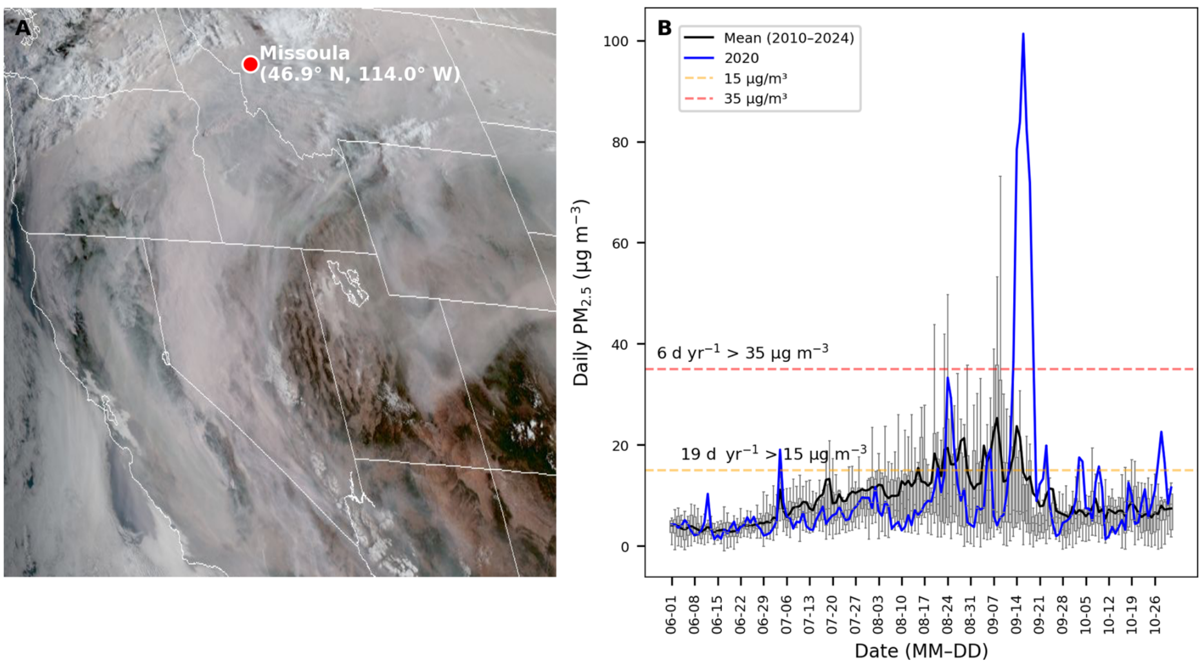


Figure 1. Satellite smoke over the western United States on 15 September 2020, together with Missoula's 2020 daily PM2.5 compared with the 2010-2024 climatology.

> **Takeaway:** To understand public exposure, researchers need more than a satellite image or a single particle measurement.

02 | A MOVING CHEMICAL REACTOR

The smoke was still there, but it was no longer the same smoke

Aging did not make the smoke disappear. Compared with urban background conditions, average PM2.5 rose by a factor of 6.7, carbon monoxide by 2.5, and the total of 75 measured organic gases by 2.3. Nitrogen oxides showed almost no increase. Distant smoke was not simply 'more of everything.'

A smoke plume behaves like a moving chemical reactor. Some gases emitted directly by a fire are consumed on the way, while oxygen-containing compounds such as formaldehyde and acetaldehyde can continue to form. Fifteen of the 75 measured gases are classified by the U.S. EPA as hazardous air pollutants, and together they made up about half of the measured organic gases. PM2.5 alone cannot describe the full mixture that reaches a community.

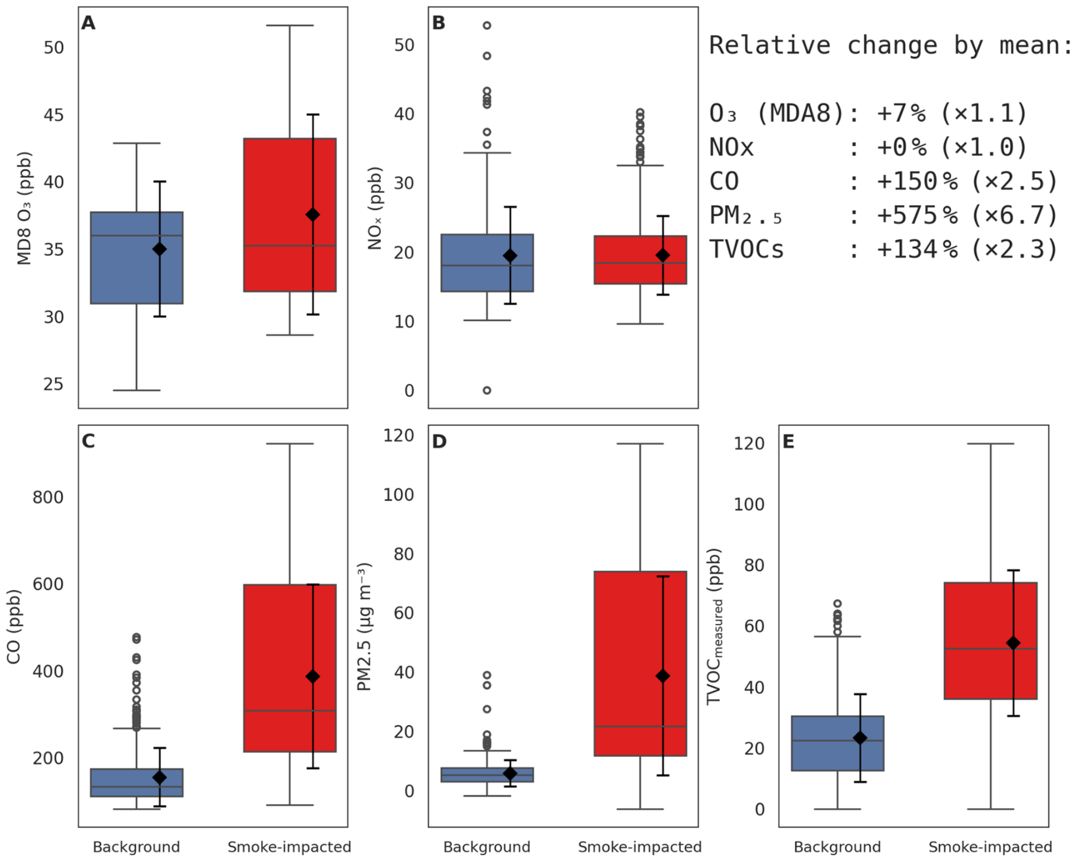


Figure 2. Aged smoke strongly increased PM2.5, carbon monoxide, and measured organic gases, while nitrogen oxides changed little and ozone increased only modestly on average.

Source: Jin et al. (2026), Fig. 4, CC BY 4.0.

> **A useful analogy:** Aged smoke is not an inert cloud of dust. It is a small chemical reactor moving with the wind.

03 | A COUNTERINTUITIVE RESULT

Why did more smoke not always produce more ozone?

Ozone is not emitted directly by a fire. It forms through sunlight-driven reactions involving organic gases and nitrogen oxides. It may therefore seem reasonable to expect ozone to keep rising as smoke becomes thicker, but the observations did not follow a simple straight line.

Under lighter smoke, the maximum daily 8-hour average ozone increased. Once PM2.5 exceeded roughly 30-40 µg/m3, ozone leveled off or declined. During one intense episode, surface ozone fell by as much as about 15 parts per billion while incoming shortwave radiation dropped by around 50%. Weaker sunlight, little change in nitrogen oxides, and altered boundary-layer mixing likely acted together.

GEOS-Chem and the regional AIRPACT forecast system both continued to predict increasing ozone as smoke thickened. They captured smoke, but missed an important turning point in its chemistry.

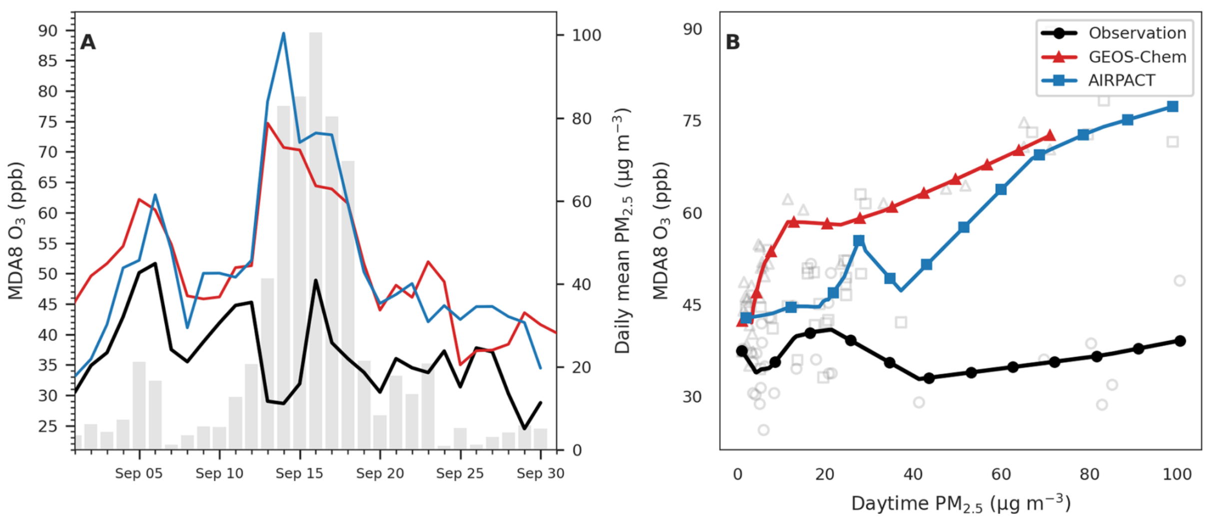


Figure 3. Observed ozone increased under lighter smoke but flattened or declined at high PM2.5. GEOS-Chem and AIRPACT continued to predict rising ozone.

Source: Jin et al. (2026), Fig. 6, CC BY 4.0.

Takeaway: The heaviest smoke does not necessarily produce the highest surface ozone. Forecasts must represent sunlight, nitrogen chemistry, and smoke aging together.

04 | PARTICLES AND TOXIC GASES

Two kinds of pollutants shaped risk, but the model missed one of them

The health analysis used an upper-bound screening scenario: a season with the intensity of 2020 was assumed to recur every year over a 70-year lifetime. This comparison is not a count of illnesses caused by one smoke event and is not a clinical prediction for an individual.

In that scenario, the smoke-attributable excess lifetime cancer risk was about 100 additional cases per million people, with roughly 90% attributed to PM2.5. The chronic non-cancer hazard index, or HI, was about 3, with roughly 90% driven by gas-phase hazardous air pollutants, especially acrolein and formaldehyde. An HI above 1 signals a need for closer evaluation; an HI of 3 does not mean illness is certain or three times more likely.

GEOS-Chem captured the arrival of the major smoke events but underestimated many pollutants by about 30%-90%. It estimated 63 rather than 100 excess cancer cases per million and produced a chronic HI of about 0.3 rather than 3.

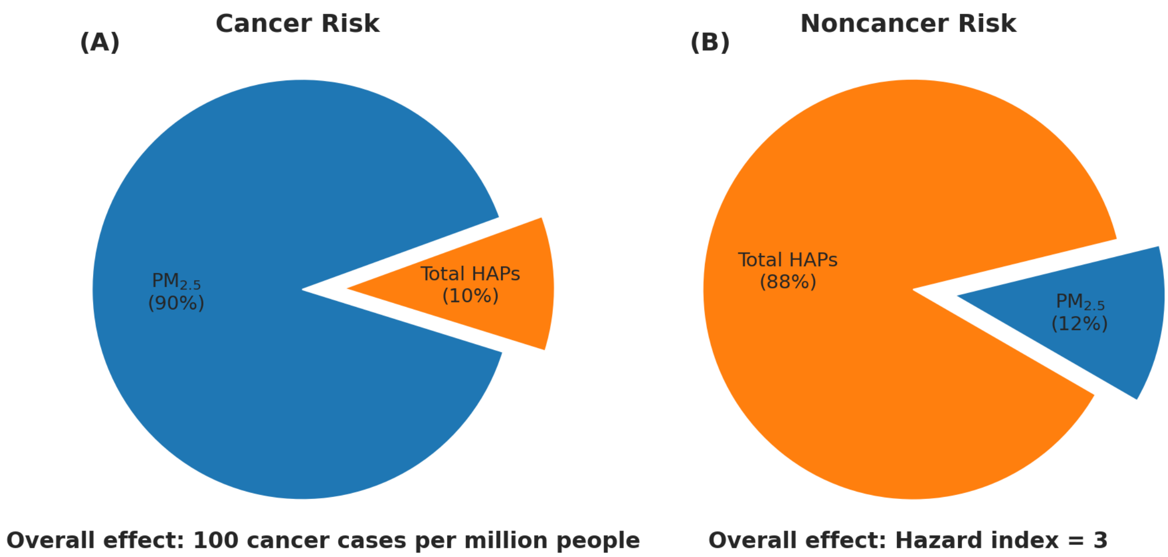


Figure 4. PM2.5 dominated the cancer-risk estimate, while hazardous organic gases dominated the chronic non-cancer hazard index. Source: Jin et al. (2026), Fig. 7, CC BY 4.0.

How to read these numbers: Particle filtration matters, but it cannot remove every hazardous gas. Monitoring, models, and indoor protection need to consider both particles and gases.

WHY THIS MATTERS

Forecasts should tell us not only where smoke goes, but what people breathe

This study connects fire emissions, several days of chemical change, community-level exposure, health screening, and model evaluation in one evidence chain. It shows why visible haze or PM2.5 alone cannot represent the full mixture in an aged smoke plume.

To serve communities better, air-quality models need more than accurate estimates of how much a fire emits. They also need improved organic-gas chemistry, secondary oxygenated pollutants, smoke effects on sunlight, and high-potency toxic gases. Forecasting should move from 'Will smoke arrive?' toward 'What will be in it when it gets here, and how large might the exposure be?'

This is a case study of one city and one exceptional fire season, so its numbers should not be transferred directly to every fire or location. Its value is the unusually detailed, hourly evidence it provides about what aged smoke can contain when it reaches the ground.

> **What the model missed:** GEOS-Chem captured major smoke intrusions but underestimated carbon monoxide, PM2.5, and organic gases by 30%-90%. Tripling all fire emissions improved some gases but could not correct gases and particles at the same time.

Explore the study

Paper: Jin et al. (2026), Atmospheric Chemistry and Physics
Data: Zenodo
Analysis code: GitHub
Archived code: Zenodo

> **Note:** Prepared from the formally published article. See the ACP article and Supplement for methods and full context.