

Characterizing Postfire Fine and Ultrafine Particles in the 2025 Eaton Fire Burn Zone and Nearby Areas

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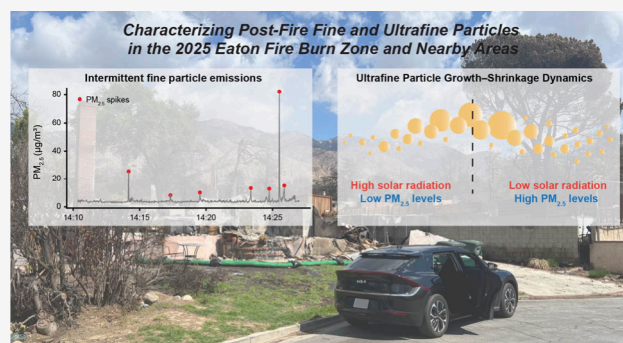
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Supporting Information

ABSTRACT: Particle emissions may persist in wildland–urban interface (WUI) fire burn zones during the postfire period, yet their characteristics remain poorly understood. Following full containment of the 2025 Eaton Fire, we conducted aerosol measurements to characterize the spatial variability and temporal dynamics of fine and ultrafine particles within and around the burn zone. We found that the burn zone (inside the fire perimeter) exhibited slightly lower median $PM_{2.5}$ concentrations than locations >1000 m outside the perimeter (11.1 vs 12.0 $\mu\text{g}/\text{m}^3$) but more frequent transient $PM_{2.5}$ concentration peaks (2.8 vs 2.2 peaks/km) with greater prominence (9.0 vs 6.0 $\mu\text{g}/\text{m}^3$) and shorter durations (2.9 vs 7.5 s). These results indicate intermittent and intense $PM_{2.5}$ emissions that were not captured by time-integrated measurements. In addition, particle number concentrations within the burn zone were higher than the urban background measured ~ 23 km downwind (1.2×10^4 vs 9.5×10^3 particles/ cm^3). Distinct aerosol dynamics were observed within the burn zone that may contribute to elevated particle number concentrations, including (1) formation and growth of ultrafine particles and (2) shrinkage and disintegration of submicron particles. Together, these observations demonstrate that the postfire period represents an active and evolving phase of WUI particle emissions with important implications for human exposure and health.

KEYWORDS: Wildland–Urban Interface (WUI) Fires, Postfire Airborne Particles, Particle Size Distributions, Particle Formation and Growth, Particle Shrinkage and Disintegration



1. INTRODUCTION

In January 2025, a series of destructive wildfires swept across the wildland–urban interface (WUI) of the Los Angeles (LA) metropolitan area, among which the Eaton Fire and the Palisades Fire were particularly devastating.^{1,2} In addition to the immediate toll on lives and property, these fires substantially degraded regional air quality, as wildfire smoke comprises a complex mixture of air pollutants, including particulate matter (PM), carbon monoxide, volatile organic compounds, etc.^{3–5} WUI fires further amplify public health impacts due to the combustion of both natural vegetation and synthetic materials, combined with their close proximity to densely populated communities.^{6–11} Studies have shown that WUI fires contribute disproportionately to annual global premature mortality relative to their share of total fire emissions.¹² During the 2025 LA fires, daily average fine particulate matter ($PM_{2.5}$) concentrations exceeded 100 $\mu\text{g}/\text{m}^3$ at multiple downwind locations across LA County.^{13,14} A total of 440 excess deaths in LA County were associated with the

2025 LA fires.¹⁵ Another study estimated that 14 excess deaths were attributable to acute smoke exposure.¹⁶

Although regional air quality typically returns to prefire levels following WUI fire containment, communities within and near the burn zone may continue to face potential exposure risks during the postfire period as emergency response, reoccupation, and rebuilding activities progress. For instance, even 6 months after the Marshall Fire in 2021, returning residents reported symptoms including watery eyes, headache, and dry cough that were associated with self-reported exposure to smells and ash.^{17,18} Postfire air monitoring therefore remains essential for assessing commun-

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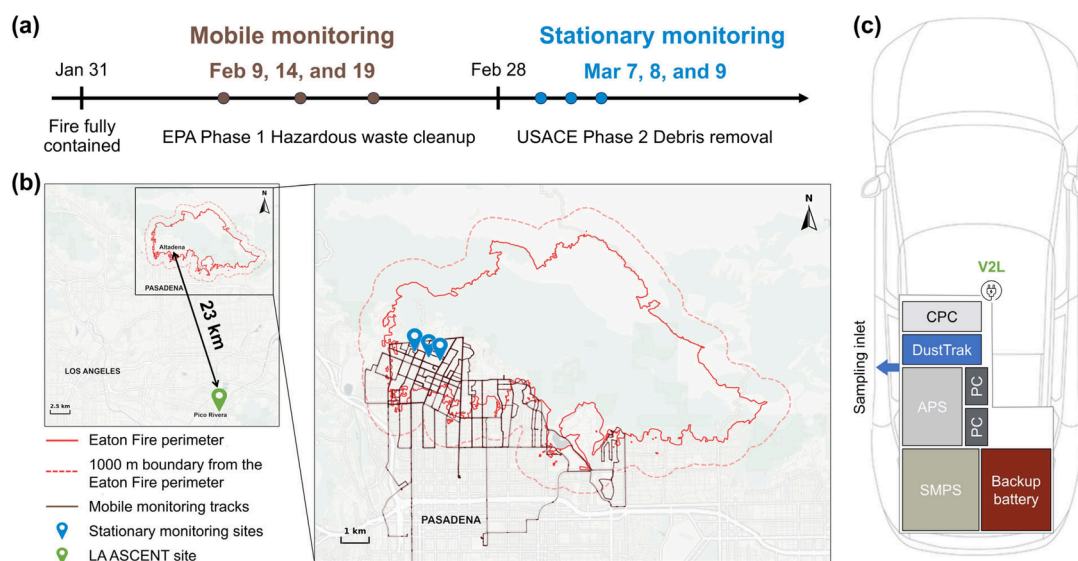


Figure 1. Postfire monitoring of airborne particles in the Eaton Fire burn zone and nearby areas. (a) Mobile and stationary monitoring of airborne particles in the burn zone and nearby areas was conducted in February and March, coinciding with the U.S. EPA-led Phase 1 hazardous waste cleanup and the U.S. Army Corps of Engineers (USACE)-led Phase 2 debris removal under the federally coordinated postfire recovery program.³¹ (b) Illustration of the mobile monitoring tracks and stationary monitoring sites in the Eaton Fire burn zone (inside the fire perimeter) and proximal (0–1000 m) and distal (>1000 m) areas outside the perimeter and the location of the LA ASCENT site in Pico Rivera. (c) EV-based airborne particle monitoring platform.

ity-level air quality and for communicating potential exposure risks arising from recovery and rebuilding activities. In response to the 2025 LA fires, several regulatory agencies and research entities such as the South Coast Air Quality Monitoring District¹⁹ and the LA Fire HEALTH Study²⁰ consortium conducted comprehensive postfire air-quality monitoring in the fire-impacted areas. For example, levels of hexavalent chromium (Cr^{6+}) in nanoparticles were found to exceed the U.S. Environmental Protection Agency (EPA) screening levels in the debris cleanup zones around the Eaton and Palisades Fires.²¹

As WUI wildfires become increasingly frequent worldwide,^{22–24} it is also critical to characterize the physicochemical properties of airborne particles within the postfire landscapes, which are substantially reshaped by combustion and often retain ash, debris, and residual emissions. Previous studies have shown that wind erosion of wildfire-burned soils can contribute substantial amounts of airborne particles.^{25–27} Studies of active wildfires have demonstrated highly dynamic fine and ultrafine particle processes, including intense new particle formation (NPF), condensational growth, and evaporation, primarily mediated by semivolatile and intermediate-volatility organic compounds from biomass-burning emissions.^{28–30} However, far less is known about how fine and ultrafine particles behave, transform, and evolve after fire containment, when active combustion has ceased but fire-altered materials such as ash, debris, and residuals remain and are subject to disturbance from cleanup activities.

In this study, following full containment of the Eaton Fire, we conducted mobile and stationary aerosol measurements to characterize the spatial variability and temporal dynamics of fine and ultrafine particles within and around the burn zone. Our observations reveal distinct postfire aerosol behavior, including intermittent particle emissions and growth–shrinkage dynamics, highlighting postfire recovery as an active and evolving phase of air pollution with implications for human exposure and health.

2. MATERIALS AND METHODS

2.1. Postfire Monitoring of Airborne Particles in the Eaton Fire Burn Zone and Nearby Areas

As illustrated in Figure 1a,b, following full containment (January 31, 2025) of the Eaton Fire, we conducted mobile and stationary monitoring of airborne particles within the burn zone (inside the fire perimeter) and in proximal (0–1000 m) and distal (>1000 m) areas outside the perimeter over 6 days in February and March 2025. To investigate postfire particle emissions and capture the spatial variability in the burn zone and nearby areas, mobile monitoring was conducted by driving across the fire perimeter at a speed of 20–30 km/h, as shown in Figure 1b. To further characterize the temporal dynamics of airborne particles in the burn zone, stationary monitoring was conducted at central locations within the burn zone. During the monitoring period, no active fire, reignition, or visible smoldering hotspots were reported or observed.

As shown in Figure 1c, a mobile measurement platform was built inside an electric vehicle (2024 KIA EV6) and equipped with a suite of real-time aerosol monitoring instruments, which were powered by the EV battery via a vehicle-to-load (V2L) function. A scanning mobility particle sizer (SMPS, Model 3936, TSI, Inc., USA) measured particles from 13 to 445 nm (electrical mobility diameter) and an aerodynamic particle sizer (APS, Model 3321, TSI, Inc., USA) measured particles from 0.54 to 20 μm (aerodynamic diameter). Both instruments were synchronized at 1 min resolution. In parallel, a DustTrak photometer (Model 8534, TSI, Inc., USA) with a $\text{PM}_{2.5}$ sampling inlet and a portable condensation particle counter (CPC, Model 3007, TSI, Inc., USA) provided 1-s-resolution readings of $\text{PM}_{2.5}$ mass concentrations and particle number concentrations (PNCs), respectively. Other measurements included temperature and relative humidity, measured using a Q-Trak XP air-quality monitor (Model 7585, TSI, Inc., USA). The sampling port was mounted on the vehicle roof at approximately 1.5 m above the ground.

2.2. Data Analysis and Quality Assurance/Quality Control

Before each monitoring session, aerosol instruments were synchronized for the clock time and zero-checked by using HEPA-filtered air. The DustTrak is sensitive to the composition and size distribution of airborne particles, leading to notable measurement bias for different

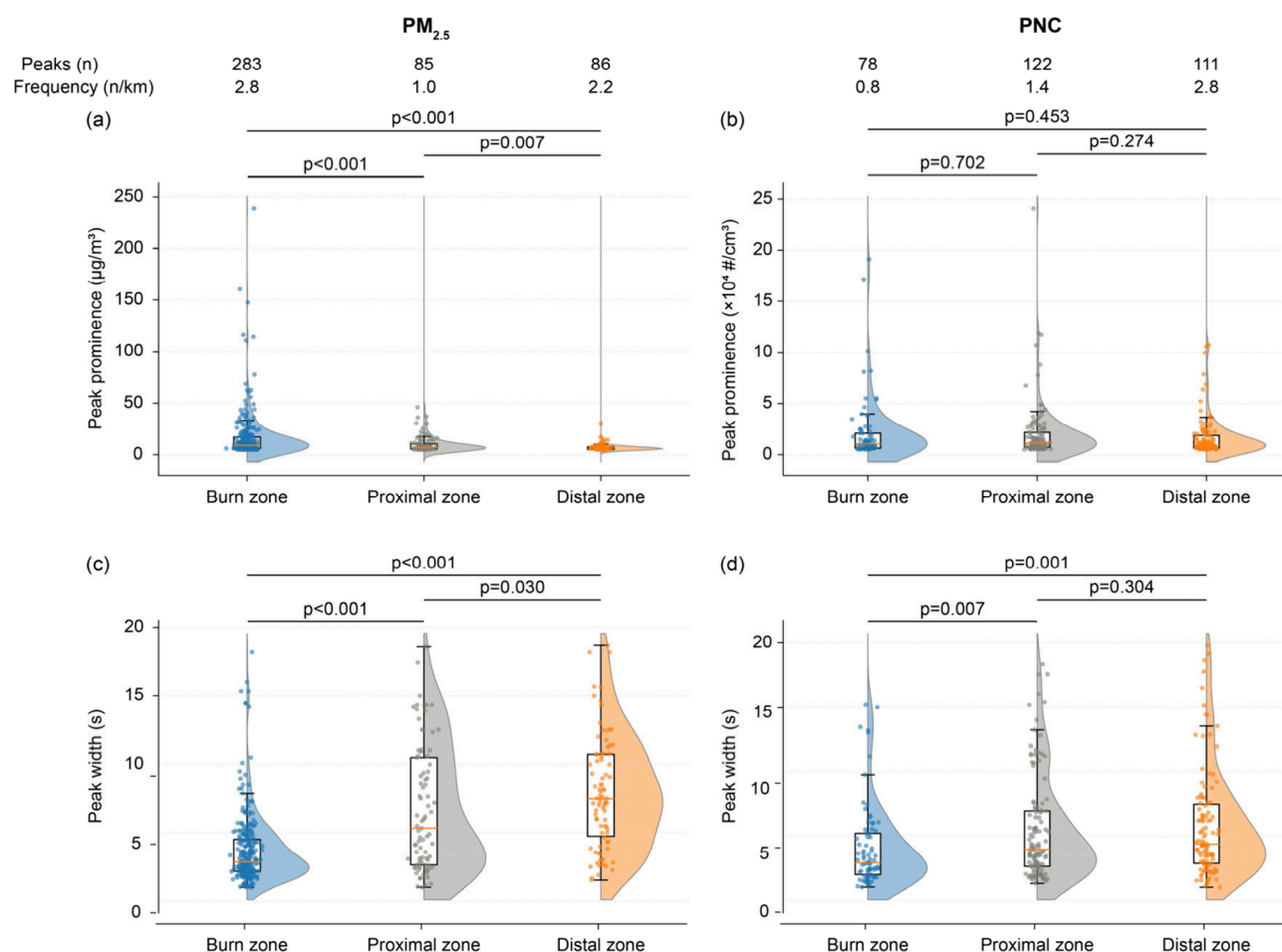


Figure 2. Characteristics of PM_{2.5} and PNC spikes across three distance-based zones of the Eaton Fire. Spikes of PM_{2.5} and PNC were identified along the mobile monitoring route and classified into three groups based on the distance of each measurement location relative to the fire perimeter: the burn zone (within the fire perimeter), the proximal zone (0–1000 m from the fire perimeter), and the distal zone (>1000 m from the fire perimeter). The total number (*n*) and frequency of peaks per distance driven (*n*/km) were calculated for each zone. Raincloud plots show (a and b) peak prominence and (c and d) peak width, with differences between zones assessed using Mann–Whitney U tests.

aerosols.^{32–35} Therefore, we applied a correction factor of 0.5 based on published gravimetric calibration studies for ambient aerosols.³⁶

Real-time PM_{2.5} and PNC data were aggregated to 1 min averages, and descriptive statistics, including the arithmetic mean, median, and interquartile range, were generated. To identify emission spikes encountered during mobile monitoring, peaks in the time series were identified using SciPy's `find_peaks` function.^{37–39} Examples of identified PM_{2.5} and PNC peaks are shown in Figure S1. Summary statistics of the particle size distributions, including the mode diameter, geometric mean, and geometric standard deviation, were calculated separately for SMPS and APS measurements. Total PNCs and total particle mass concentrations (PMCs) over the full-size range (13 nm to 20 µm) were calculated with the assumption of spherical particles with a density of 1.65 g/cm³, as widely reported and used for ambient particles.⁴⁰

Aerosol data from mobile monitoring were classified into three groups based on the distance of each measurement location relative to the fire perimeter: the burn zone (within the fire perimeter), the proximal zone (0–1000 m from the fire perimeter), and the distal zone (>1000 m from the fire perimeter). The 1000 m threshold was chosen to differentiate areas adjacent to the burn zone from more distant areas where the influence of burn-zone sources is expected to be limited by atmospheric dispersion and dilution under the observed meteorological conditions. The SMPS data from stationary monitoring were compared with measurements from an urban site within the Atmospheric Science and Chemistry mEasurement NeTwork (ASCENT) in Pico Rivera (hereafter referred to as the LA ASCENT

site), located approximately 23 km south of the burn zone. The LA ASCENT site has been characterized as a representative urban site within the Los Angeles basin and is influenced by emissions from the Los Angeles urban core.⁴¹ During the active Eaton Fire, the LA ASCENT site captured elevated lead levels in PM_{2.5} on January 8–11, which returned to prefire levels by the evening of January 11.⁴² During our monitoring period, prevailing wind fields indicated that the LA ASCENT site was generally downwind of the Eaton Fire burn zone (Figure S2). Therefore, measurements at the LA ASCENT site provide a regional urban reference for comparison with stationary monitoring inside the Eaton Fire burn zone. The details about the SMPS configuration at the LA ASCENT site were described previously.⁴¹ The aerosol statistics were calculated for the overlapping size range (13–445 nm) and aggregated to 20 min averages to accommodate differences in the time resolution of the instruments. The temporal coverage of our data sets is provided in Figure S3.

Because none of our aerosol measurement data follow a normal distribution, the differences among three distance-based zones during mobile monitoring and between the Eaton Fire burn zone and the LA ASCENT site during stationary monitoring were assessed using the Mann–Whitney U test and Wilcoxon Signed-Rank test paired in time, respectively. Data analysis and visualization were performed using Python (version 3.11.7) within JetBrains DataSpell (version 2025.2.3).

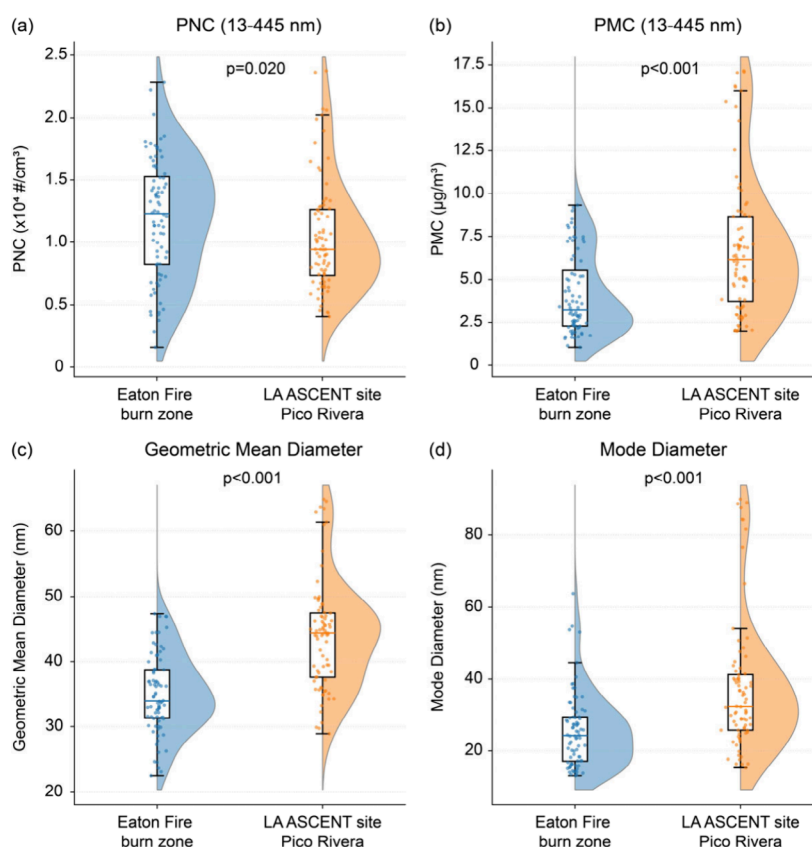


Figure 3. Characteristics of postfire airborne particles in the Eaton Fire burn zone: (a) PNCs, (b) PMCs, (c) geometric mean diameters, and (d) mode diameters were calculated for the overlapping SMPS size range between measurements collected in the Eaton Fire burn zone and at the LA ASCENT site in Pico Rivera. Differences were assessed by using time-paired Wilcoxon Signed-Rank tests.

3. RESULTS AND DISCUSSION

3.1. Characteristics of Postfire Airborne Particles across Three Distance-Based Zones of the Eaton Fire

As shown in Figure S4a,b, median $\text{PM}_{2.5}$ concentrations and PNCs during mobile monitoring across the three distance-based zones of the Eaton Fire ranged from 10 to $12 \mu\text{g}/\text{m}^3$ and from 1.0 to 1.4×10^4 particles/ cm^3 , respectively, which are within the typical ranges previously observed in the LA area.^{43,44} $\text{PM}_{2.5}$ concentrations within the fire perimeter and in the proximal zone (0–1000 m from the fire perimeter) were significantly lower than those observed in the distal zone (>1000 m from the fire perimeter) (pairwise Mann–Whitney U tests). In contrast, PNCs within the burn zone and in the proximal zone were significantly higher than those measured in the distal zone (pairwise Mann–Whitney U tests). In addition, geometric mean diameters measured by the SMPS and APS showed a gradual decrease in the submicrometer particle size from inside the fire perimeter to outside areas while both the burn and proximal zones exhibited smaller ultrafine particles than the distal zone (Figure S4c,d). Collectively, these results suggest that although the burn and proximal zones exhibit lower $\text{PM}_{2.5}$ levels, they are characterized by distinct particle emissions and may represent important sources of ultrafine particles.

As shown in Figure 2, peak analysis revealed that the burn zone exhibited the highest frequency of $\text{PM}_{2.5}$ emission spikes, which were also characterized by the greatest peak prominence and the shortest peak widths (pairwise Mann–Whitney U tests). These results indicate that $\text{PM}_{2.5}$ emissions in the burn

zone were more transient and intense, which may not be reflected in time-integrated $\text{PM}_{2.5}$ measurements. In contrast, PNC spikes likely reflected traffic-related emissions along the mobile monitoring route, where peak frequency and width increased from inside the fire perimeter to outside areas, consistent with the observed reduced vehicular activity within the burn zone, while peak prominence remained relatively constant. These spatial contrasts for $\text{PM}_{2.5}$ and PNC spikes are further illustrated by the mobile monitoring map shown in Figure S5. Collectively, these results reveal distinct characteristics of airborne particle emissions associated with the postfire landscape and recovery activities in the Eaton Fire burn zone and nearby areas.

3.2. Postfire Aerosol Dynamics in the Eaton Fire Burn Zone

Postfire airborne particles were further characterized using stationary monitoring at central locations within the burn zone, and the results were compared with measurements at the urban background LA ASCENT site. As shown in Figure 3, for particles in the 13–445 nm range, the Eaton Fire burn zone exhibited higher PNCs (median: 1.2×10^4 vs 9.5×10^3 particles/ cm^3) but lower PMCs (median: 3.2 vs $6.2 \mu\text{g}/\text{m}^3$) associated with smaller particle sizes compared to those measured at the LA ASCENT site (paired Wilcoxon Signed-Rank tests). These results are consistent with the contrasts observed between the burn and distal zones in the mobile monitoring data (Figure S4).

These results are likely due to (1) formation and growth of ultrafine particles and (2) shrinkage and disintegration of submicron particles inside the burn zone. As shown in Figure

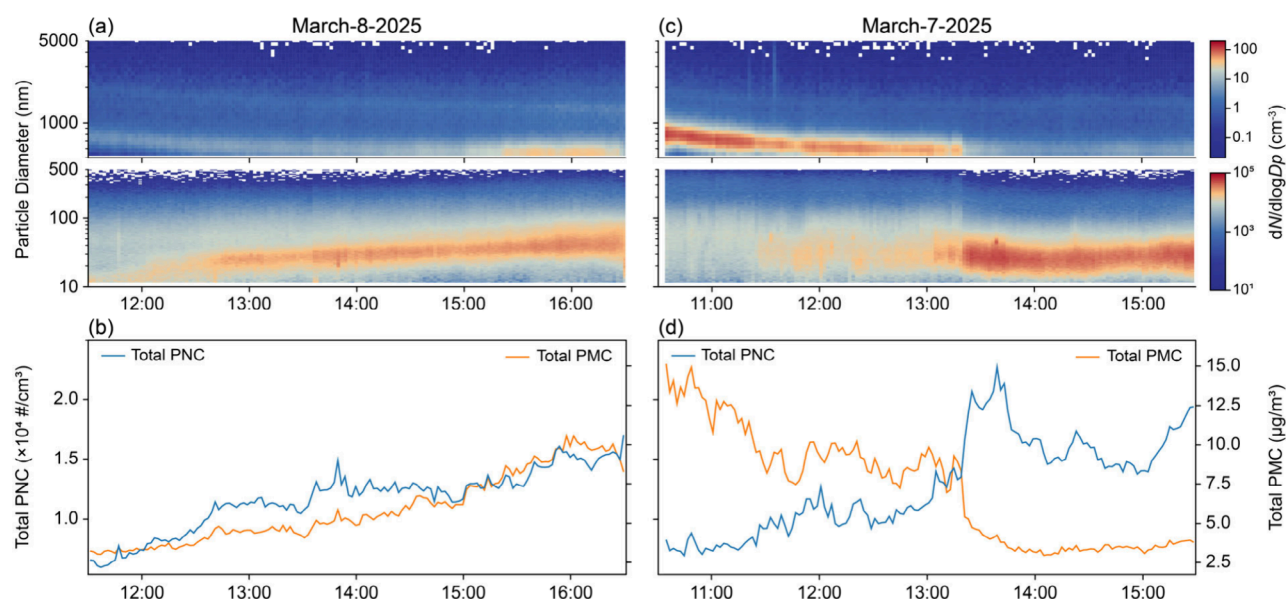


Figure 4. Temporal dynamics of airborne particles in the Eaton Fire burn zone. Events of (a and b) formation and growth of ultrafine particles and (c and d) shrinkage of submicron particles are shown in (a and c) number-based particle size distributions measured by the SMPS (lower panels) and APS (upper panels) and (b and d) total PNCs and PMCs.

4a, a particle growth event was observed on March 8, where small particles (~ 13 nm, mode diameter) started to grow at around noon to larger particles (43 nm, mode diameter) in the afternoon. The APS captured the submicrometer particles resulting from this particle growth event. The temporal evolution of the particle size distribution exhibited the characteristic “banana” shape and could be classified as a Class I NPF event according to the Dal Maso scheme (2005).⁴⁵ A similar event was also observed the next day on March 9 (Figure S6), and the particle growth rates of the two events were 5.9 and 8.1 nm/h, within the range of previously reported regional NPF events in different environments.⁴⁶ Because our instrument does not detect particles smaller than 10 nm, we were unable to directly observe the initial nucleation mode required to confirm a full NPF event under the modified NPF classification scheme by Buenrostro Mazon et al. (2009).⁴⁷ However, as shown in Figure 4b, the concurrent increase in total PNCs along with the increasing total PMCs from particle growth over hours indicates that we most likely captured the growth phase of an NPF event rather than a quasi or tail event as described by Buenrostro Mazon and colleagues.⁴⁷ In contrast, measurements at the LA ASCENT site in Pico Rivera showed only a weak growth signal on March 8 and no event on March 9 (Figure S7). The wind field also suggests that the weak growth in Pico Rivera on March 8 might resemble a tail event that was possibly transported from the Eaton Fire burn zone (Figure S2).

We also observed a particle shrinkage process on March 7. As shown in Figure 4c, at the beginning of the late-morning measurements, airborne particles exhibited a bimodal size distribution with a primary ultrafine mode at 40–60 nm (SMPS mode diameter) and a secondary submicrometer mode centered at $0.78 \mu\text{m}$ (APS mode diameter). This bimodal distribution was characterized by relatively low total PNCs but high PMCs. Over time, the submicron particles gradually shrank toward smaller sizes and subsequently disintegrated into ultrafine particles. This shrinkage process resulted in a decrease in the level of PMCs and was accompanied by a

concurrent increase in the level of PNCs, as shown in Figure 4d. A possible underlying mechanism is that particle shrinkage reduces the ability to retain electric charge (e.g., approaching the Rayleigh limit for liquid droplets),⁴⁸ and upon reaching this charge stability limit, one submicron particle may break into multiple smaller particles. The shrinkage of postfire airborne particles could be due to evaporation of water or volatile/semivolatile organic components. To evaluate the role of water evaporation, we examined both relative humidity and precipitation conditions during the observation period, as well as during a similar event observed on February 9 during mobile monitoring (Figure S6). While localized precipitation was reported at a nearby monitoring station on March 8 (representing the previous 24 h accumulation; Table S1), no precipitation was observed during our field measurements. Additionally, neither event was accompanied by a substantial decrease in the ambient relative humidity (Figure S8), suggesting that the observed size reduction is unlikely due to hygroscopic drying. In contrast, evaporation of volatile or semivolatile organic components remains a plausible explanation, although this mechanism warrants further investigation by measuring the particle chemical composition and electric charge in future studies.

Previous studies have shown that NPF events at continental sites commonly occur under conditions of low concentrations of preexisting particles, high solar radiation, and low relative humidity (RH).^{47,49} Our observations are consistent with these conditions. As summarized in Table S1, the formation and growth of ultrafine particles occurred when the $\text{PM}_{2.5}$ concentrations were relatively low ($\sim 2\text{--}6 \mu\text{g}/\text{m}^3$), whereas particle shrinkage tended to occur when the initial $\text{PM}_{2.5}$ levels were much higher ($>12 \mu\text{g}/\text{m}^3$). Stronger solar radiation and lower RH were observed during particle growth compared with particle shrinkage (Table S1). In addition, previous studies have reported more frequent NPF during spring and summer due to enhanced emissions of biogenic organic compounds and their oxidation products, which contribute to NPF processes.⁵⁰ Taken together, these results suggest a plausible

mechanism in the postfire environment: (1) the burned landscape emits a mixture of volatile and semivolatile organic compounds (VOCs and SVOCs); (2) these compounds contribute to the formation of ultrafine particles and support their subsequent growth, and (3) the formed submicrometer particles may readily evaporate under relatively dry, high-insolation conditions and may even undergo disintegration, producing more ultrafine particles. These coupled processes may collectively explain the higher ultrafine particle concentrations observed in the Eaton Fire burn zone. Such particle formation and evolution processes mediated by VOCs and SVOCs have been widely documented in wildfire-influenced environments, although observations during the postfire period remain limited.^{28–30} However, our measurements captured only discrete segments of aerosol dynamic events and were limited in their temporal coverage. In addition, our measurements were conducted in a postfire landscape containing mixed fire residues (e.g., ash and debris from both natural vegetation and built structures). Therefore, the current data set does not allow separation of particle characteristics associated with vegetation fuels versus those originating from structural or synthetic materials. More comprehensive and longer-term monitoring campaigns are therefore needed to fully characterize the temporal evolution of particle formation and loss processes in postfire atmospheres and to identify the key controlling factors governing postfire aerosol dynamics.

Overall, our mobile monitoring of airborne particles within and around the burn zone revealed intermittent fine particle emissions characterized by high intensity but short duration, suggesting that such transient events may not be effectively captured by conventional time-averaged PM monitoring. Stationary measurements within the burn zone further revealed distinct aerosol growth–shrinkage dynamics that may contribute to elevated ultrafine particle concentrations in postfire environments. Together, these observations demonstrate that the postfire period represents an active and evolving phase of WUI particle emissions, with important implications for human exposure and health.

■ ASSOCIATED CONTENT

SI Supporting Information

The Supporting Information is available free of charge at <https://pubs.acs.org/doi/10.1021/acs.estlett.6c00123>.

Summary of observed postfire aerosol dynamics in the Eaton Fire burn zone (Table S1), time series of PM_{2.5} and PNC with peaks identified from mobile monitoring on February 14, 2025 (Figure S1), wind field in the study region during the stationary monitoring period (Figure S2), temporal coverage of data sets from both the mobile and stationary monitoring and the reference data from the Pico Rivera ASCENT site (Figure S3), comparison of airborne particle characteristics across three distance-based zones of the Eaton Fire (Figure S4), mobile monitoring tracks showing the locations of PM_{2.5} spikes (upper panel) and PNC spikes (lower panel) (Figure S5), number-based particle size distributions in the Eaton Fire burn zone and nearby areas measured during the mobile and stationary monitoring (Figure S6), contour plots of number-based particle size distributions observed in the Eaton Fire burn zone and at the Pico Rivera ASCENT site (Figure S7), and temperature and relative humidity during the observed

particle shrinkage events in the burn zone of Eaton fire (Figure S8) (PDF)

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Notes

The authors declare no competing financial interest.

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