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Report

State of China's atmospheric environment in 2025

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ABSTRACT

The year 2025 experienced appreciable improvements in both $PM_{2.5}$ and O_3 air quality over China but with strong regional differences. Relative to 2022–2024, the national $PM_{2.5}$ concentration in 2025 was decreased by ~1 μg m^{-3} due to the spatially opposite changes of a 4–8 μg m^{-3} decrease in the North China Plain (NCP) and a 2–4 μg m^{-3} increase in southern China and northeastern China. In contrast, the MDA8 O_3 concentration in 2025 was decreased by 3.4 μg m^{-3}, with extensive decreases in most cities. High-impact air pollution extremes, dust, fire, persistent pollution episodes, and compound events were also reported. The severe $PM_{2.5}$ (O_3) pollution was 5–8 days in 28 cities (1–3 days in 6 cities) over northern China. Three major dust episodes were identified, in which the November dust event propagated southeastward and strongly affected southern China. The annual fire $PM_{2.5}$ emissions ranked the lowest level in the past two decades. Persistent $PM_{2.5}$ pollution episodes accounted for 17% in the NCP and 10% in the Sichuan Basin of total exceedance days and the fraction of persistent O_3 pollution was more pronounced. The frequency of $PM_{2.5}$–O_3 pollution compound events (heatwave–O_3 compound events) showed a decreasing (increasing) tendency in 2025. With stricter air quality standards being implemented, significant challenges remain in achieving sustained air quality improvement in China.

摘要

本文系统报道了2025年我国的大气环境状况.对比2022–2024年, 2025年全国$PM_{2.5}$浓度下降约1 μg m^{-3}, 主要是由于不同地区$PM_{2.5}$变化存在相反的趋势; O_3浓度则在大多数城市呈现一致的下降. 针对高影响的极端事件: 2025年北方28个城市经历了5天以上的重度$PM_{2.5}$污染; 识别出了三次重大沙尘天气, 能够长距离传输影响东南沿海地区; 火灾源$PM_{2.5}$排放处于较低水平; 在超标总天数中, 持续性$PM_{2.5}$污染事件在华北平原占比17%, 而持续性O_3污染事件占比更高; $PM_{2.5}$与O_3复合污染的发生频率呈现出下降态势, 但热浪-O_3复合事件的发生频率呈上升趋势.

1. Introduction

The major ambient air pollutants in China are fine particulate matter ($PM_{2.5}$) and surface ozone (O_3). $PM_{2.5}$, primarily originating from industrial emissions, coal combustion, and secondary chemical formation, poses severe risks to human health and affects climate change both locally and globally (Pozzer et al., 2023; Li et al., 2022a). Surface ozone, formed through complex photochemical reactions involving NO_x (nitrogen oxides) and VOCs (volatile organic compounds), is detrimental to human health, food security, and climate warming (Feng et al., 2022). In addition, high-impact air pollution events can also be triggered by natural processes, including dust storms and fires, which are strongly dependent on climate variability and climate warming (Gui et al., 2022).

China has witnessed significant improvement in its atmospheric environment over the past decade. The Chinese government has promulgated several phases of air pollution controls (Lu et al., 2020). These policies have evolved from initially shifting towards structural reforms in the energy, industrial, and transportation sectors, to form a more comprehensive strategy that combines air pollution control with carbon emission mitigation (Liu et al., 2025). With stricter air quality standards being implemented (MEE, 2026), significant challenges remain in achieving sustained air quality improvement in China. As such, analyzing current atmospheric environment changes would offer timely scientific support for control strategies.

This report provides a comprehensive assessment of China's atmospheric environment in 2025. We focus on the current levels and changes

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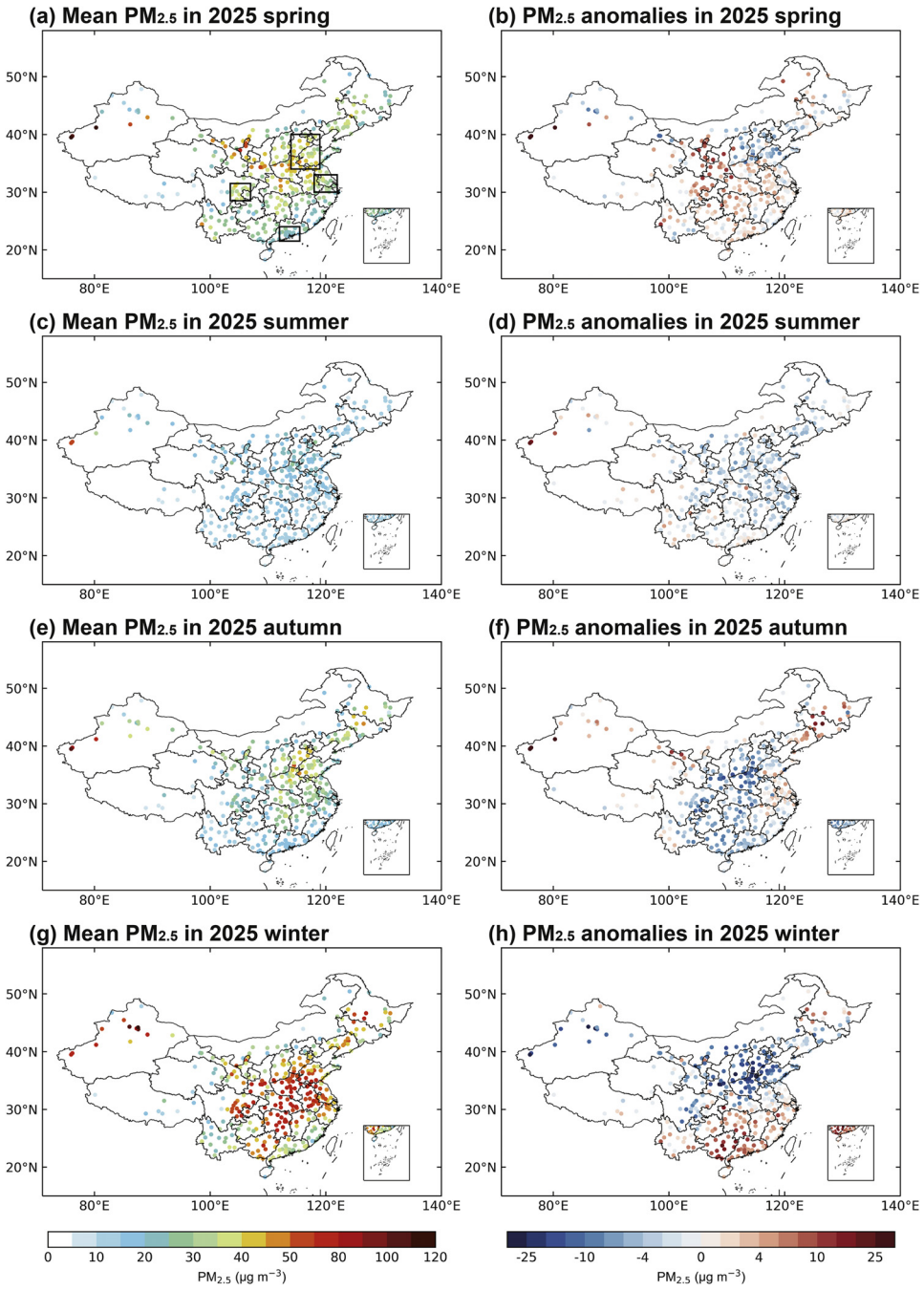


Fig. 1. Seasonal mean $PM_{2.5}$ in 2025 (left) and its anomalies relative to 2022–2024 (right). The units of $PM_{2.5}$ concentration are μg m^{-3}. Note that we did not exclude the impact of dust events. The air quality observation data do not include Taiwan, Hong Kong, or Macau. The hourly surface air quality measurements were obtained from the Chinese Ministry of Ecology and Environment (MEE) website. The domain of city clusters is also given for the NCP (34°–40°N, 114°–119°E), YRD (30°–33°N, 118°–122°E), PRD (21.5°–24°N, 112°–115.5°E), and SCB (28.5°–31.5°N, 103.5°–107°E).

of $PM_{2.5}$ and O_3 concentrations, as well as high-impact air pollutant events and compound events in 2025. By integrating data from the surface air quality network from the Chinese Ministry of Ecology and Environment (MEE) website, which reports hourly concentrations of $PM_{2.5}$ and O_3, along with satellite observations and meteorological reanalysis, this analysis aims to offer insights into the atmospheric challenges and achievements in 2025, informing future policy and scientific research.

2. $PM_{2.5}$ air quality in 2025

Annual mean $PM_{2.5}$ concentrations in China ranged from 4.7 to 91.1 μg m^{-3} across ~330 cities, with a national average of 29.5 μg m^{-3}. High-concentration regions were mainly located in the North China Plain (NCP), the Fenwei Plain, parts of the middle and lower reaches of the Yangtze River, and the Sichuan Basin (SCB). The annual mean $PM_{2.5}$ concentration in the NCP reached 38.6 μg m^{-3}. In addition, Northwest China also experienced high levels of $PM_{2.5}$ concentrations of over 50 μg m^{-3}. From a seasonal perspective, pollution levels were relatively low in summer and autumn, while winter remained the most polluted season of the year, with localized high-value areas exceeding 80 μg m^{-3} (Fig. 1).

Compared with the three-year mean (2022–2024), the national mean $PM_{2.5}$ concentration in 2025 was decreased by approximately 1 μg m^{-3}, which can be explained by the fact that the city-level $PM_{2.5}$ decrease

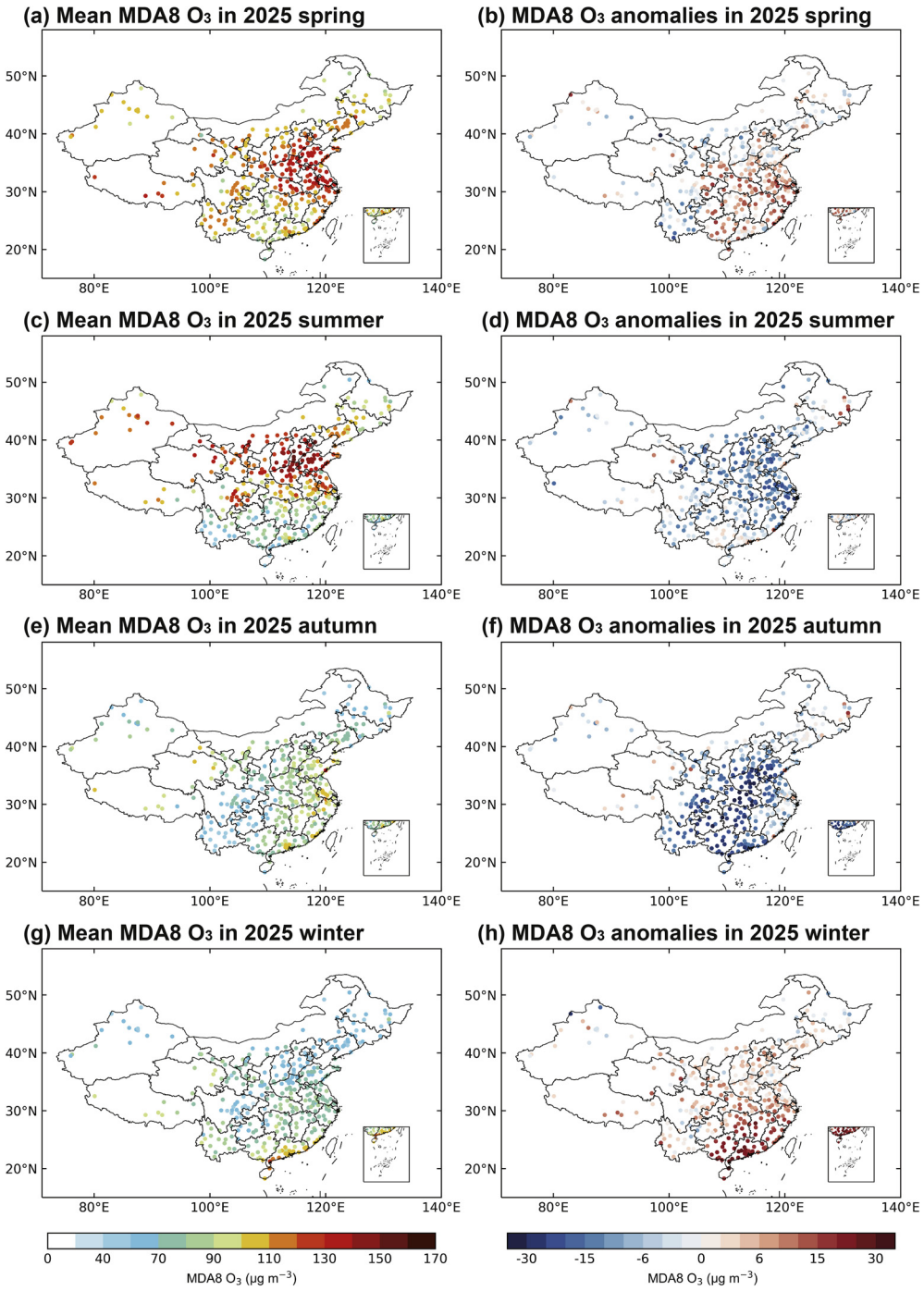


Fig. 2. Seasonal mean MDA8 O_3 in 2025 (left) and its anomalies relative to 2022–2024 (right). The units of O_3 concentration are μg m^{-3}. The air quality observation data do not include Taiwan, Hong Kong, or Macau.

of 4–8 μg m^{-3} over the NCP sites was offset by the $PM_{2.5}$ increase of 2–4 μg m^{-3} in southern China and northeastern China. This is particularly evident in the seasonal $PM_{2.5}$ anomalies. In spring, widespread positive anomalies occurred across eastern China except the NCP, with $PM_{2.5}$ increases reaching up to 10 μg m^{-3}. In contrast, summer showed a slight but consistent decrease in $PM_{2.5}$ concentrations across different regions of China. In autumn, $PM_{2.5}$ levels declined in most regions, while $PM_{2.5}$ increases were observed in parts of Northeast China and Northwest China. In winter, the spatial distribution of $PM_{2.5}$ anomalies exhibited a strong north–south contrast. $PM_{2.5}$ pollution in North China was decreased by over 8 μg m^{-3} relative to 2022–2024, whereas significantly positive anomalies of 4–10 μg m^{-3} emerged in southern China.

3. O_3 air quality in 2025

The annual concentrations of maximum daily 8-hour average (MDA8) O_3 in China ranged from 63.9 to 120 μg m^{-3}, with a national average of 93.5 μg m^{-3}. Most cities exhibited MDA8 O_3 levels below 100 μg m^{-3}, while 27% of cities exceeded 100 μg m^{-3}. From a seasonal perspective (Fig. 2), O_3 pollution was very severe in the summer and spring seasons due to strong photochemistry, whereas low O_3 concentra-

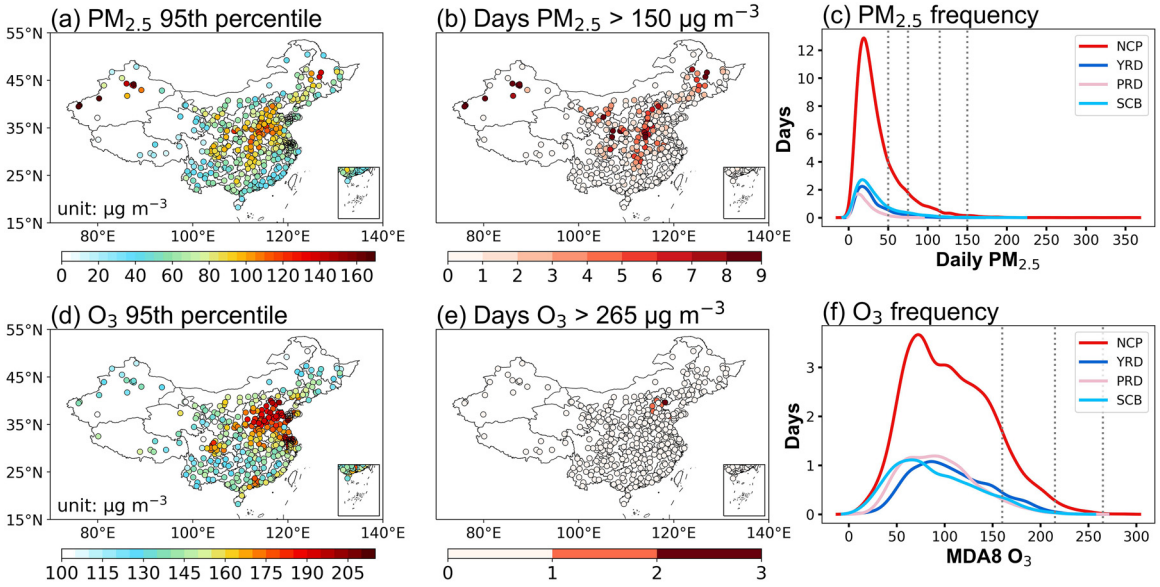


Fig. 3. $PM_{2.5}$ and O_3 pollution extremes in 2025: (a) annual 95th percentile $PM_{2.5}$ concentration; (b) severe $PM_{2.5}$ pollution days; (c) frequency distribution of annual average $PM_{2.5}$ concentrations. Panels (d–f) are the same as (a–c) but for MDA8 O_3. The dashed lines in (c) represent the thresholds for $PM_{2.5}$ of 50, 75, 115, and 150 μg m^{-3}, respectively, and dashed lines in (f) represent the thresholds for MDA8 O_3 of 160, 215, and 265 μg m^{-3}, respectively. Note that the air quality standard for daily $PM_{2.5}$ was revised from 2026. Severe $PM_{2.5}$ or O_3 pollution (i.e., air quality index equal to 200) was identified by the threshold of 150 μg m^{-3} for daily $PM_{2.5}$ and 265 μg m^{-3} for MDA8 O_3.

tions of <100 μg m^{-3} prevailed in autumn and winter. The mean MDA8 O_3 concentrations over the NCP were able to reach over 160 μg m^{-3} in summer. In addition, high MDA8 O_3 levels of 110 μg m^{-3} were observed in the Pearl River Delta (PRD) during the autumn and winter seasons and in the Yangtze River Delta (YRD) during autumn (Fig. 3).

Compared with the three-year mean (2022–2024), the national mean MDA8 O_3 concentrations in 2025 decreased by 3.4 μg m^{-3}. Most observed sites featured negative anomalies, suggesting an extensive improvement in O_3 pollution. Increases of annual MDA8 O_3 concentrations were only observed in parts of southern China and northeastern China. Seasonally, notable nationwide decreases in MDA8 O_3 were found in summer and autumn. The highly polluted regions (e.g., NCP and YRD) saw a decline of over 6 μg m^{-3} in MDA8 O_3 in summer. Instead, the MDA8 O_3 increased over central China and South China in winter and spring. This is particularly evident in South China in winter and the mean MDA8 O_3 in the PRD in 2025 increased by 22.4 μg m^{-3} relative to 2022–2024. These observed large negative/positive anomalies cannot be explained by anthropogenic emission controls alone, in which the interannual variability of meteorology could also play an important role (Li et al., 2025).

4. High-impact events in 2025

4.1. Air pollution extremes

Relative to the mean pollution levels, the 95th percentile values can identify the hotspots over the major urban clusters in China. For example, the regional mean 95th percentile MDA8 O_3 levels are comparable (i.e., 182.6 μg m^{-3} for NCP, 179.2 μg m^{-3} for YRD, 160.5 μg m^{-3} for PRD, and 167.3 μg m^{-3} for SCB). In addition, we also calculated the days with severe $PM_{2.5}$ or O_3 pollution (i.e., air quality index equal to 200). Similar to the spatial pattern of the 95th percentile values, severe $PM_{2.5}$ pollution mainly occurred in northern China, with the highest frequency of >8 days in several cities. Compared to $PM_{2.5}$, severe O_3 pollution only occurred over the NCP, with 1–3 days. In terms of the frequency distribution of pollutant concentrations, at the high-concentration end, the NCP and SCB have a much higher frequency of $PM_{2.5}$, but for O_3, the difference among the four regions is much smaller. If the threshold for severe $PM_{2.5}$ pollution is tightened from 150 to 115 μg m^{-3}, the frequency of severe pollution will be greatly increased.

4.2. Dust events

In 2025, China was affected by several intense dust storm events despite the overall long-term decline in dust concentration (Fig. 4(a)) and dust storm frequency (Li et al., 2022b). The MODIS dust optical depth (DOD) was calculated from the MODIS aerosol optical depth (AOD) at 550 nm using the Pu and Ginoux (2018) parameterization based on the Ångström exponent. Three major dust episodes occurred in late March, mid-April, and late November (Fig. 4(b)), with spring events showing markedly higher PM_{10} and the November event exhibiting distinct transport pathways. The March episode exhibited the highest DOD over the Taklamakan Desert, while the April episode was dominated by exceptionally high DOD over the Gobi Desert, indicating a strong Mongolian source; the November event also originated from the Gobi but with much weaker dust loading (Fig. 4(c)). The March and November dust plumes propagated southeastward, affecting the NCP and, particularly for November, extending farther south to the YRD (Fig. 4(d)). The April dust storm recorded the most spatially extensive dust event in the past decade. Under the influence of anomalously strong synoptic-scale winds with a more westward and southward transport pathway, dust impacts extended across nearly the whole of central and eastern China. The dust plumes penetrated southward across the Qinling Mountains into the SCB and further reached southern China (including Hainan).

4.3. Fire events

Climatologically, $PM_{2.5}$ emissions from fire activities are primarily located in the border regions of northeastern China, followed by southeastern and southwestern China (Fig. 5(a)), where vegetation fuels are abundant. Over the past two decades (2001–2025), fire-emitted $PM_{2.5}$

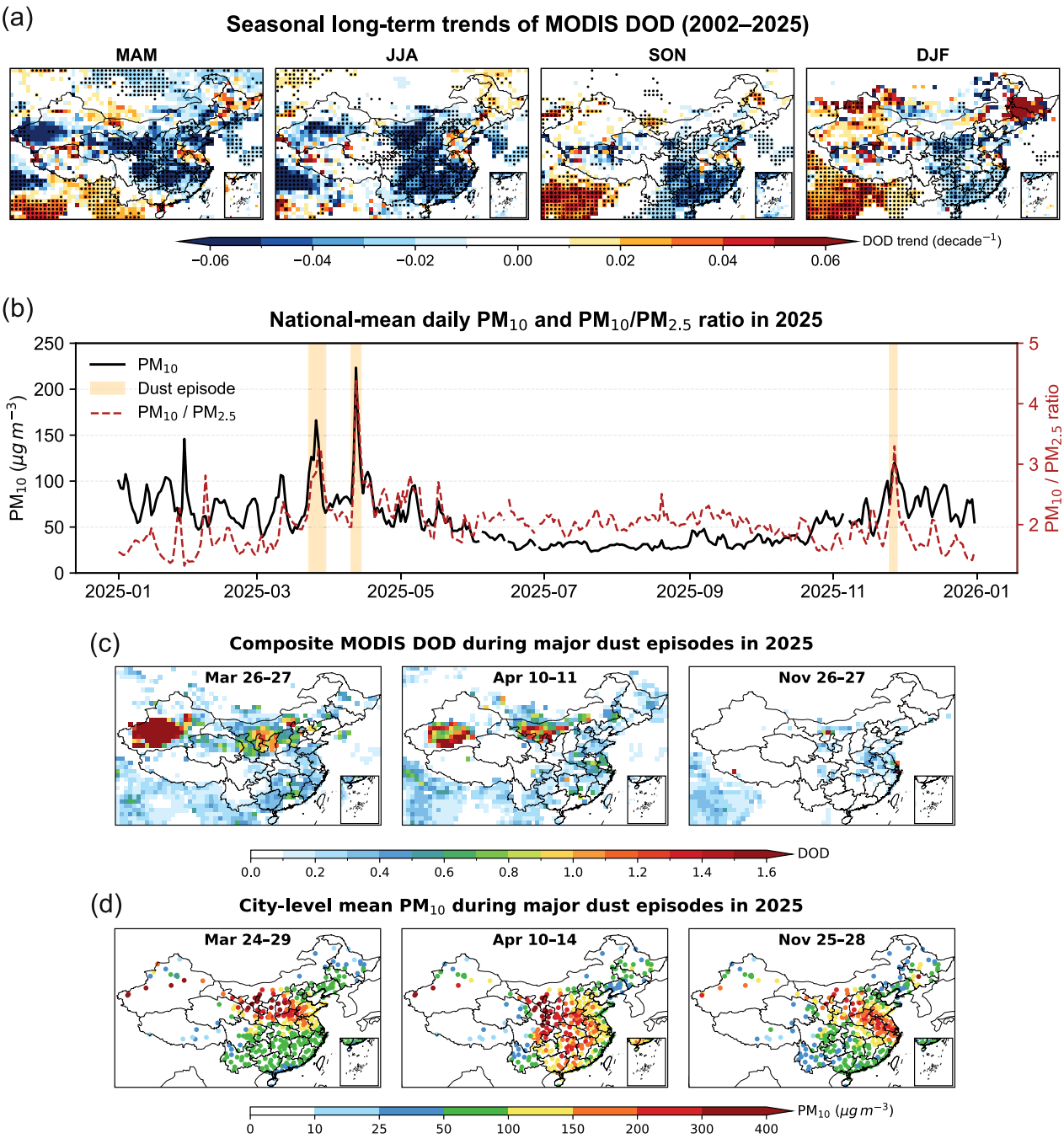


Fig. 4. Spatiotemporal characteristics of dust activity and major dust episodes over China. (a) Seasonal long-term trends of MODIS dust optical depth (DOD) during 2002–2025, with stippling indicating statistically significant trends ($p < 0.05$). (b) Observed national mean daily PM_{10} concentration (black solid) and $PM_{10}/PM_{2.5}$ ratio (red dashed) in 2025. (c, d) MODIS DOD and city-level PM_{10} concentrations during the three dust episodes in 2025, respectively. MODIS AOD data were obtained from https://search.earthdata.nasa.gov.

in China has exhibited an overall decreasing trend except for northeastern China (Fig. 5(c)). Consistent with this trend, in 2025, total pyrogenic $PM_{2.5}$ emissions amounted to only 1.62 Tg yr^{-1}, ranking among the lowest annual levels recorded since 2001. Notably, fire activity anomalies in 2025 showed pronounced spatial heterogeneity (Fig. 5(b)). While fire emissions in fire-prone areas were substantially lower than the multi-year mean, central and southern parts of northeastern China experienced elevated fire activities. Seasonally, China typically exhibits two fire peaks, in early spring (March–April) and mid-autumn (October). In 2025, fire-related $PM_{2.5}$ emissions remained below the climatological mean during both peak seasons (Fig. 5(d)).

4.4. Persistent pollution episodes

We also calculated persistent pollution episodes, which are defined as pollutant concentrations exceeding the air quality standard for five or more consecutive days (i.e., 75 μg m^{-3} for daily $PM_{2.5}$ and 160 μg m^{-3} for MDA8 O_3). In 2025, in the NCP and SCB with relatively severe pollution, persistent $PM_{2.5}$ pollution episodes accounted for approximately 17% and 10% of the total polluted days, respectively. In the YRD, persistent $PM_{2.5}$ pollution episodes accounted for approximately 5% of the total polluted days in the year, while no persistent $PM_{2.5}$ pollution events were observed in the PRD. However, if the thresh-

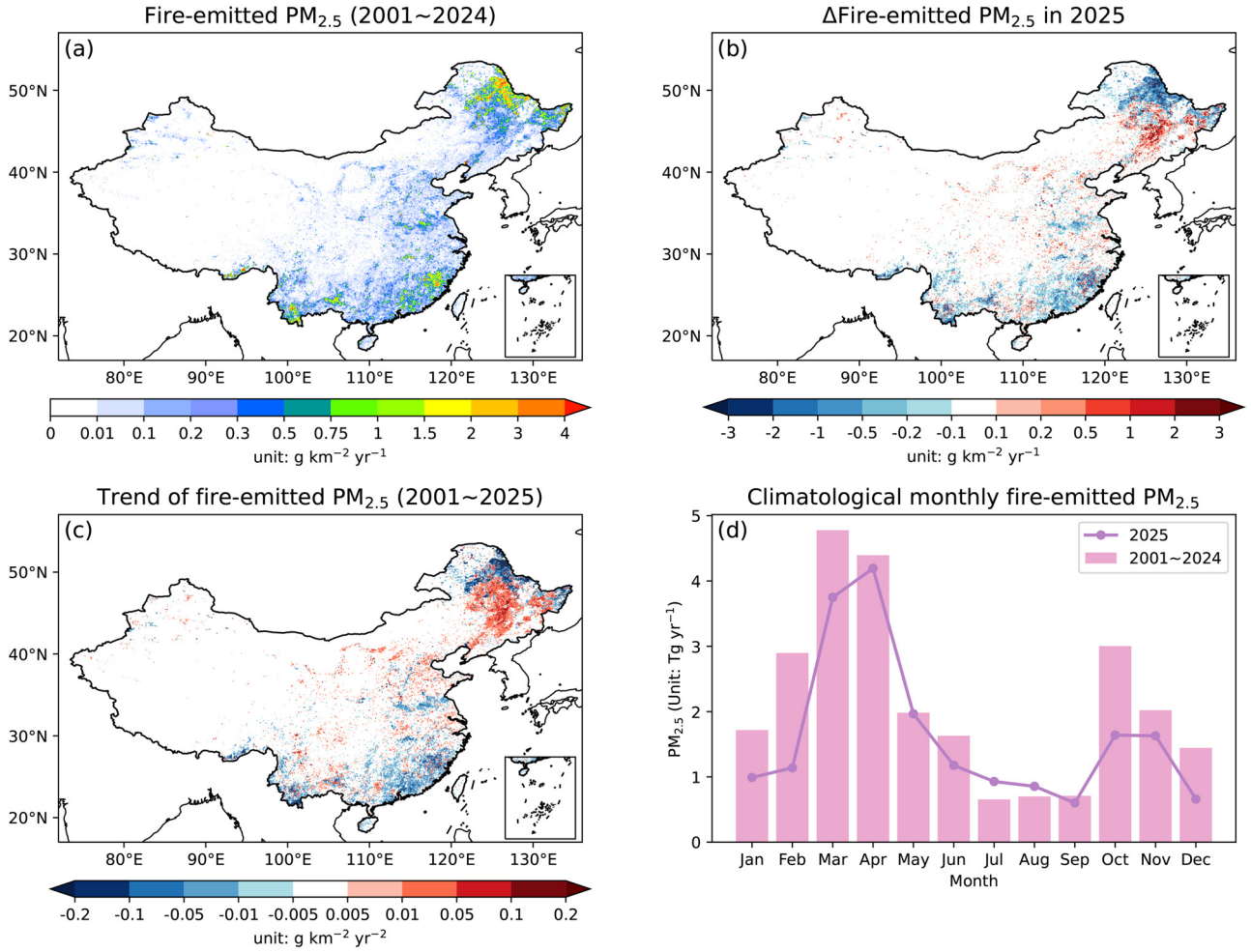


Fig. 5. Spatiotemporal patterns of fire-emitted $PM_{2.5}$ in China: (a) climatological annual fire-emitted $PM_{2.5}$ emissions (units: g km^{-2} yr^{-1}) averaged over 2001–2024; (b) $PM_{2.5}$ emission anomalies in 2025 relative to 2001–2024; and (c) linear trend of annual fire-emitted $PM_{2.5}$ (units: g km^{-2} yr^{-2}) over 2001–2025. (d) National monthly fire-emitted $PM_{2.5}$ in 2025 overlaid on the 2001–2024 means. The daily fire-emitted $PM_{2.5}$ data were obtained from the Quick Fire Emissions Dataset (QFED, v2.6r1) with a 0.1° × 0.1° spatial resolution (Koster and Darmenov, 2015).

old for $PM_{2.5}$ is tightened from 75 to 50 μg m^{-3} as regulated by the new air quality standard (MEE, 2026), the fractions of persistent pollution episodes in total polluted days are 48%, 37%, 15%, and 67% for the NCP, YRD, PRD, and SCB, respectively. In contrast to $PM_{2.5}$, the persistent O_3 pollution was more pronounced. All four city clusters experienced persistent O_3 pollution episodes, with the highest fraction of 35% in the NCP, followed by the PRD (18%), YRD (12%), and SCB (10%). Therefore, the high fraction of persistent pollution episodes in city clusters should be paid more attention in current air pollution controls.

5. Compound events in 2025

5.1. $PM_{2.5}$–O_3 pollution compound events

A $PM_{2.5}$–O_3 compound event is defined if a day has $PM_{2.5}$ > 50 μg m^{-3} and MDA8 O_3 > 160 μg m^{-3}. The national average for $PM_{2.5}$–O_3 co-polluted days in 2025 was 1.7 days, with frequent co-pollution mainly occurring over the major four city clusters and Hubei Province (Fig. 6). The frequency of $PM_{2.5}$–O_3 compound events in 2025 was lower than the average of 2022–2024 (2.3 days). Focusing on the four city clusters, $PM_{2.5}$–O_3 compound pollution in 2025 amounted to 3.6, 2.9, 3.7, and 2.8 days for the NCP, YRD, SCB, and PRD, respectively. Although $PM_{2.5}$–O_3 compound events show a remarkable decreasing trend in the past decade, a flat trend is also clear in recent years (Fig. 6(b)). For example, an anomalous decrease in 2025 relative to the mean of 2022–2024 can only be found in the NCP (−5.4 days), due to the rapid decline of O_3 concentrations (Fig. 2). In contrast, there is a slight increasing tendency in $PM_{2.5}$–O_3 pollution compound events in the SCB after 2021, while there is improvement in $PM_{2.5}$ and O_3 levels over 2022–2025.

5.2. Heatwave–O_3 compound events

We also focus on compound heatwave–O_3 extreme (CHOE) events during the warm season (May–September). The definition of a CHOE follows that of Wang et al. (2022). A heatwave day is defined as a day on which Tmax exceeds its climatological 95th percentile value, and then a day is identified as the CHOE if the MDA8 O_3 exceeds 160 μg m^{-3} during a heatwave day. High numbers of CHOE days are mainly concentrated in eastern and central China, with particularly strong hotspots over the NCP, YRD, and SCB. In contrast, western China and parts of southern China experience relatively fewer CHOE days. In 2025, the YRD and SCB recorded the highest annual mean CHOE days (i.e., 17 days and 15 days) among the four urban clusters. In contrast, the CHOE days in the NCP decreases in 2025 relative to the preceding years, suggesting a recent improvement in compound heatwave–O_3 conditions. Historically, a statistically significant increasing trend of CHOE days in the past decade is observed in the NCP, YRD and SCB, indicating a rapid intensification of CHOE occurrence risks in these regions. In addition, it is also noted

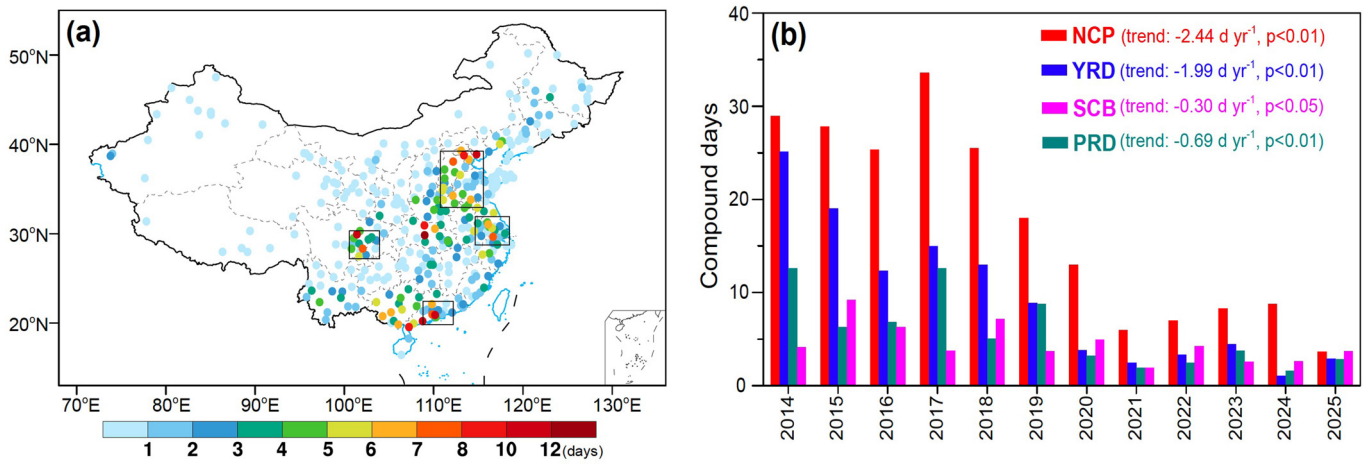


Fig. 6. (a) Spatial distribution of $PM_{2.5}$–O_3 compound days in 2025, identified if a day had $PM_{2.5}$ > 50 μg m^{-3} and MDA8 O_3 > 160 μg m^{-3}. (b) Time series of the frequency of $PM_{2.5}$–O_3 compound pollution from 2014 to 2025 averaged over the NCP (red), YRD (blue), SCB (pink), and PRD (cyan).

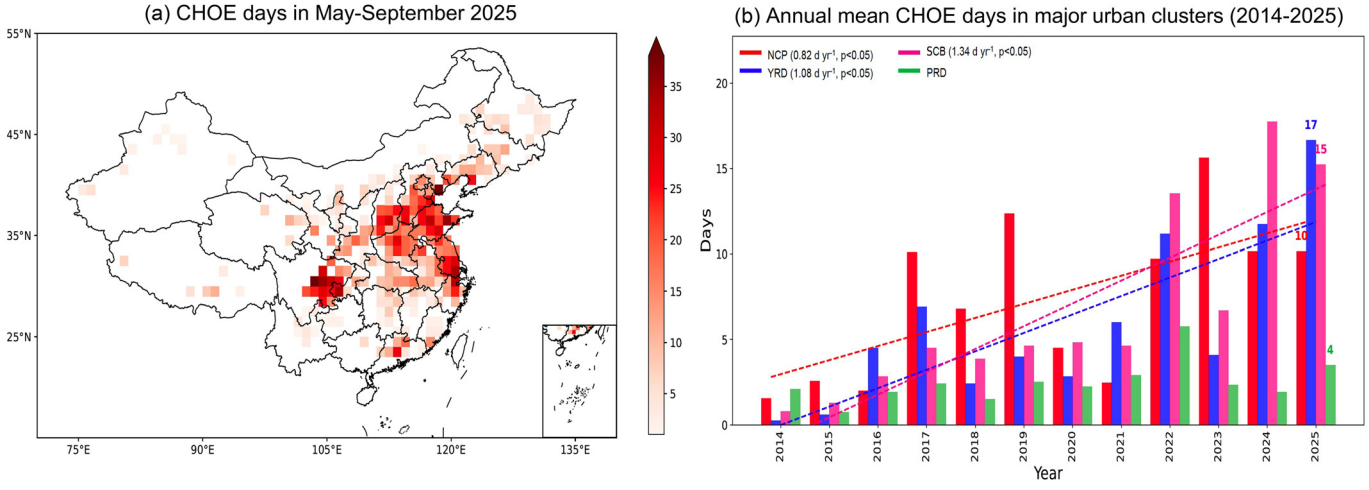


Fig. 7. (a) Spatial distributions of CHOE days in China during May–September in 2025. (b) Changes of CHOE days in major urban clusters of China from 2014 to 2025. The observed surface O_3 concentrations are interpolated onto a 1° × 1° grid and daily maximum temperature (Tmax). A heatwave day is defined as a day on which Tmax exceeds the corresponding its climatological 95th percentile value, and then a day is identified as the CHOE if the MDA8 O_3 concentration exceeds 160 μg m^{-3} during a heatwave day. The climatological (1961–1990) 95th percentile value of Tmax during May–September over the NCP, YRD, SCB, and PRD is 30 °C, 33 °C, 29 °C, and 32 °C, respectively. The temperature data were obtained from the ERA5-Land reanalysis at 0.1° × 0.1° spatial resolution.

that there is a strong regional difference in the evolution of CHOE days at the interannual scale (Fig. 7).

6. Summary

In 2025, there were notable improvements in both $PM_{2.5}$ and O_3 air quality over China but with strong regional differences. The annual mean $PM_{2.5}$ concentrations ranged from 4.7 to 91.1 μg m^{-3} across ~330 cities and MDA8 O_3 concentrations ranged from 63.9 to 120 μg m^{-3}. Compared with the 2022–2024 mean level, the national $PM_{2.5}$ concentration in 2025 was decreased by ~1 μg m^{-3} due to the fact that the large decrease of 4–8 μg m^{-3} over northern China was partially offset by increases in southern China and northeastern China. In contrast, the national mean MDA8 O_3 concentrations in 2025 decreased by 3.4 μg m^{-3}, featuring extensive decreases in most cities.

We also summarized the high-impact air pollution extremes, dust, fire, persistent pollution episodes, and compound events in 2025. Severe $PM_{2.5}$ pollution amounted to 5–8 days in several cities across the northern part of China, and severe O_3 pollution of 1–3 days only occurred over the NCP. Three major dust episodes were identified, in which the November dust event propagated southeastward and strongly affected the YRD, and the April dust storm recorded the most spatially extensive event in the past decade. The annual fire $PM_{2.5}$ emissions ranked at the lowest level in the past two decades, but central and southern parts of northeastern China experienced elevated fire activities. Persistent $PM_{2.5}$ pollution episodes accounted for 17% in the NCP and 10% in the SCB of the total exceedance days, while persistent O_3 pollution was more pronounced and with the highest fraction of 35% in NCP, but 10%–18% in other city clusters. As for $PM_{2.5}$–O_3 pollution compound events, the national mean of co-pollution was 1.7 days in 2025, which was lower than the average (2.3 days) over 2022–2024. As for heatwave–O_3 compound events, the YRD and SCB recorded the highest annual mean heatwave–O_3 compound days (i.e., 17 days and 15 days) and there was a statistically significant increasing trend in the past decade over most of China. More research is strongly needed to understand the chemical and physical drivers of these high-impact events.

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