

Short Communication



GEOS-CF Evidence for Regional Near-Neutral and Weak Day–Night Reversal Signals in Surface Ozone

Chao He ¹, Qian Wu ², Yanwen Wang ^{3,4}, Peiyue Tu ^{2,4} and Chaoqing Huang ^{5,*}
¹ School of Artificial Intelligence and Big Data, Wuhan Business University, Wuhan 430056, China

² School of Resource and Environmental Sciences, Wuhan University, Wuhan 430079, China

³ School of Economics and Management, China University of Geosciences, Wuhan 430074, China

⁴ Centre for Integrative Ecology, Deakin University, Melbourne, VIC 3125, Australia

⁵ School of Tourism and Culture, Guangdong Eco-Engineering Polytechnic, Guangzhou 510520, China

* Correspondence: huangchaoqing@whu.edu.cn

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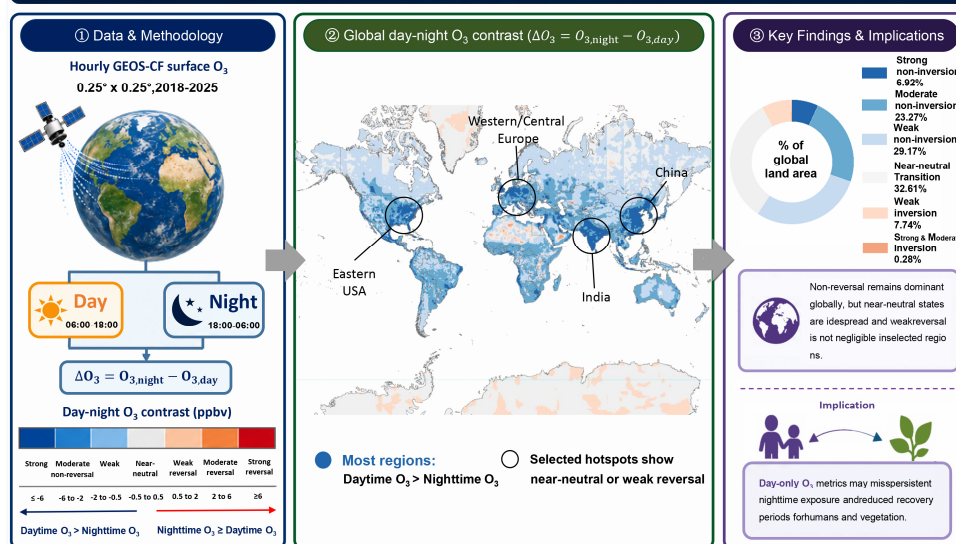
GEOS-CF

Highlights

- GEOS-CF reveals regional near-neutral and weak day–night O_3 reversal signals.
- Non-reversal dominates globally, but reversal covers ~8% of monthly land area.
- Day-only O_3 metrics may underestimate exposure in regions with nocturnal persistence.

Abstract: Traditionally, near-surface ozone (O_3) concentrations are higher during the day than at night. However, analysis of global hourly O_3 reanalysis data from 2018–2025 reveals that a day–night reversal (higher nighttime than daytime concentrations) is emerging in many regions. Globally, the day–night O_3 difference is diminishing, with a notable reversal already evident in parts of India, China, and selected cities in Western Europe. This shift challenges long-held assumptions about O_3 diurnal patterns and has important implications for understanding regional chemistry, air quality assessment, and policy development.

Regional near-neutral and weak day–night O_3 reversal signals from GEOS-CF Global hourly diagnosis, 2018–2025



1. Introduction

Traditionally, near-surface ozone (O_3) concentrations are higher during the day than at night [1]. However, analysis of NASA GEOS-CF hourly O_3 fields at

$0.25^\circ \times 0.25^\circ$ resolution from 2018–2025 indicates that near-neutral or weak day–night reversal signals occur in selected regions, including parts of India, China and Western European cities. Globally, non-reversal remains the dominant condition, but near-neutral and weak-



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reversal states are not negligible in selected regions. These results suggest that day-focused exposure metrics and mitigation strategies may miss persistent nighttime O_3 in some regions. Because the analysis is based on GEOS-CF reanalysis/model fields over an eight-year period, the findings should be interpreted as diagnostic evidence rather than definitive proof of a global regime shift.

Near-surface O_3 is both a key air pollutant and an indicator of regional oxidative capacity and chemical processes [2,3]. Previous site- and region-level studies have reported nocturnal O_3 enhancement under specific meteorological or transport conditions, but a globally consistent hourly diagnosis of this phenomenon remains limited.

A widely accepted assumption has been that daytime O_3 levels exceed nighttime levels, underpinning interpretations of observed diurnal cycles and evaluations of model performance [4,5]. Here, using hourly O_3 data from the NASA GEOS-CF v1 reanalysis (January 2018–December 2025, uniformly converted to ppbv), we diagnose global spatial patterns of day–night O_3 contrast and identify regional near-neutral and weak-reversal signals. Hourly O_3 data were obtained from the NASA GEOS-CF v1 reanalysis [6]. UTC was converted to longitude-based local solar time for each pixel. Consistent with the operational day–night separation adopted by Shan et al. [7], daytime and nighttime were defined as 06:00–18:00 and 18:00–06:00 local time, respectively. We calculated daytime and nighttime means separately for each grid cell and computed $\Delta O_3 = O_{3, \text{night}} - O_{3, \text{day}}$. We identified reversal where $\Delta O_3 > 0$. We further classified ΔO_3 into seven categories (strong, moderate, and weak non-reversal; near-neutral transition; weak, moderate, and strong reversal) using zero-centred strength intervals, and tracked spatiotemporal changes by computing monthly areal coverage globally and for sub-regions.

2. Methods

Monthly daytime and nighttime near-surface O_3 tendencies at global and regional scales were quantified using Theil–Sen slope estimation combined with the Mann–Kendall test, with statistical significance defined as $p < 0.05$ [8]. Hourly UTC data were converted to local time by grid-cell longitude. The baseline daytime and nighttime windows were defined as 06:00–18:00 and 18:00–06:00 local time, respectively. This fixed local-time definition was used as a globally consistent diagnostic baseline rather than a strict solar-radiation-based definition of photochemical day/night; its influence was assessed using alternative day–night windows in the Supplementary Materials, and high-latitude results should be interpreted with additional caution. We calculated $\Delta O_3 = O_{3, \text{night}} - O_{3, \text{day}}$ for each land grid cell,

where $\Delta O_3 > 0$ indicates day–night reversal. To describe reversal strength, ΔO_3 was classified into seven zero-centred regimes using symmetric thresholds, with a ± 1 ppbv near-neutral buffer to avoid over-interpreting small differences around zero; the exact thresholds are provided in Table S2. Monthly areal extents of each regime were calculated using grid-cell areas for global and regional summaries. Sensitivity tests using alternative day–night windows and data-completeness criteria, together with ground-station validation of GEOS-CF O_3 , are provided in the Supplementary Materials.

3. Results and Discussion

Spatiotemporal statistics indicate that, from 2018 to 2025, the global land-mean daytime O_3 concentration was approximately 26.9 ppbv, with monthly means ranging from about 24.1 to 29.6 ppbv, and increased only slightly over this period (at an annual rate of $0.070 \text{ ppbv yr}^{-1}$; Figure 1a). This magnitude is broadly consistent with published global surface- O_3 assessments, while the weak positive tendency agrees in direction with reported tropospheric-column ozone increases for 2005–2020 [9]. Most regions still show lower nighttime O_3 than daytime O_3 ($\Delta O_3 < 0$), but apparent reversal signals ($\Delta O_3 > 0$) are identified in parts of India, China, and selected Western European cities; after aggregation, non-reversal, near-neutral transition, and reversal categories account for 59.36%, 32.61%, and 8.02% of the monthly land-grid area, respectively (Figure 1b).

Examination of 12 key regions reveals clear intra-annual cycles in monthly ΔO_3 . Given the eight-year period, we refer to the Theil–Sen estimates [8] as 2018–2025 monthly tendencies rather than long-term trends (Figures 2c and S1). These tendencies were calculated from monthly ΔO_3 series derived from the underlying hourly GEOS-CF fields. Negative ΔO_3 tendencies indicate stronger daytime dominance relative to nighttime O_3 , whereas positive tendencies indicate movement toward weaker daytime dominance or nighttime enhancement. Significant negative ΔO_3 tendencies were found in the United States ($-0.027 \text{ ppbv yr}^{-1}$; $p < 0.05$), Middle East ($-0.031 \text{ ppbv yr}^{-1}$; $p < 0.05$), Russia and Northern Europe ($-0.005 \text{ ppbv yr}^{-1}$; $p < 0.05$), Greenland and Canada ($-0.007 \text{ ppbv yr}^{-1}$; $p < 0.05$), North Africa (excluding Egypt) ($-0.011 \text{ ppbv yr}^{-1}$; $p < 0.05$), East Africa ($-0.020 \text{ ppbv yr}^{-1}$; $p < 0.05$), and Southern Africa ($-0.043 \text{ ppbv yr}^{-1}$; $p < 0.05$). In contrast, China exhibits a near-neutral monthly tendency ($-0.002 \text{ ppbv yr}^{-1}$; $p = 0.884$), while Southeast Asia shows a weak increase ($0.016 \text{ ppbv yr}^{-1}$; $p = 0.124$) that does not reach conventional significance. Western and Central Europe ($-0.022 \text{ ppbv yr}^{-1}$; $p = 0.090$), South Asia ($-0.018 \text{ ppbv yr}^{-1}$; $p = 0.190$), and Mexico ($-0.016 \text{ ppbv yr}^{-1}$; $p = 0.134$) are primarily governed by seasonal and inter-monthly variability, with limited evidence of monotonic change over this short

period (Figure 2c and Figure S1). Overall, we find that seasonal cycles and monthly perturbations—rather than strong, consistent long-term drift—dominate detectable changes in day–night differences from 2018 to 2025.

Globally, the “sign-strength” composition of ΔO_3 states is dominated by weak non-reversal (29.17%), followed by near-neutral transition (32.61%) and moderate non-reversal (23.27%), with strong non-reversal only 6.92%. Reversal categories occupy 8.02% of the monthly area, almost entirely from weak reversal (7.74%); moderate (0.26%) and strong (0.02%) reversals are rare globally. In selected regions, the United States, Western and Central Europe exhibit large, repeatable seasonal swings among strong/moderate/weak non-reversal and near-neutral categories, with reversal occurring thinly and intermittently. China and South Asia show relatively stable compositions, with non-reversal persistently dominant and reversal contributions narrow (Figures 2a,b and S2). Thus, non-reversal and near-

neutral states form the continuous background of global O_3 variability. In contrast, reversal manifests as scattered, localised patches rather than a pervasive background. The high proportion of near-neutral transition implies that many grid cells frequently hover near $\Delta O_3 \approx 0$, so even modest perturbations can drive substantial areal redistribution between weak non-reversal and near-neutral categories without necessarily expanding strong reversal.

We interpret ΔO_3 as a diagnostic indicator of day–night contrast rather than direct evidence of net nocturnal O_3 production. Positive or near-neutral ΔO_3 can arise from suppressed daytime O_3 , weakened nighttime loss or titration, stable boundary-layer conditions, and vertical or horizontal transport of O_3 -rich air. Conversely, a negative ΔO_3 tendency indicates stronger daytime dominance. Full chemical attribution is beyond the scope of this commentary and requires process-based modelling.

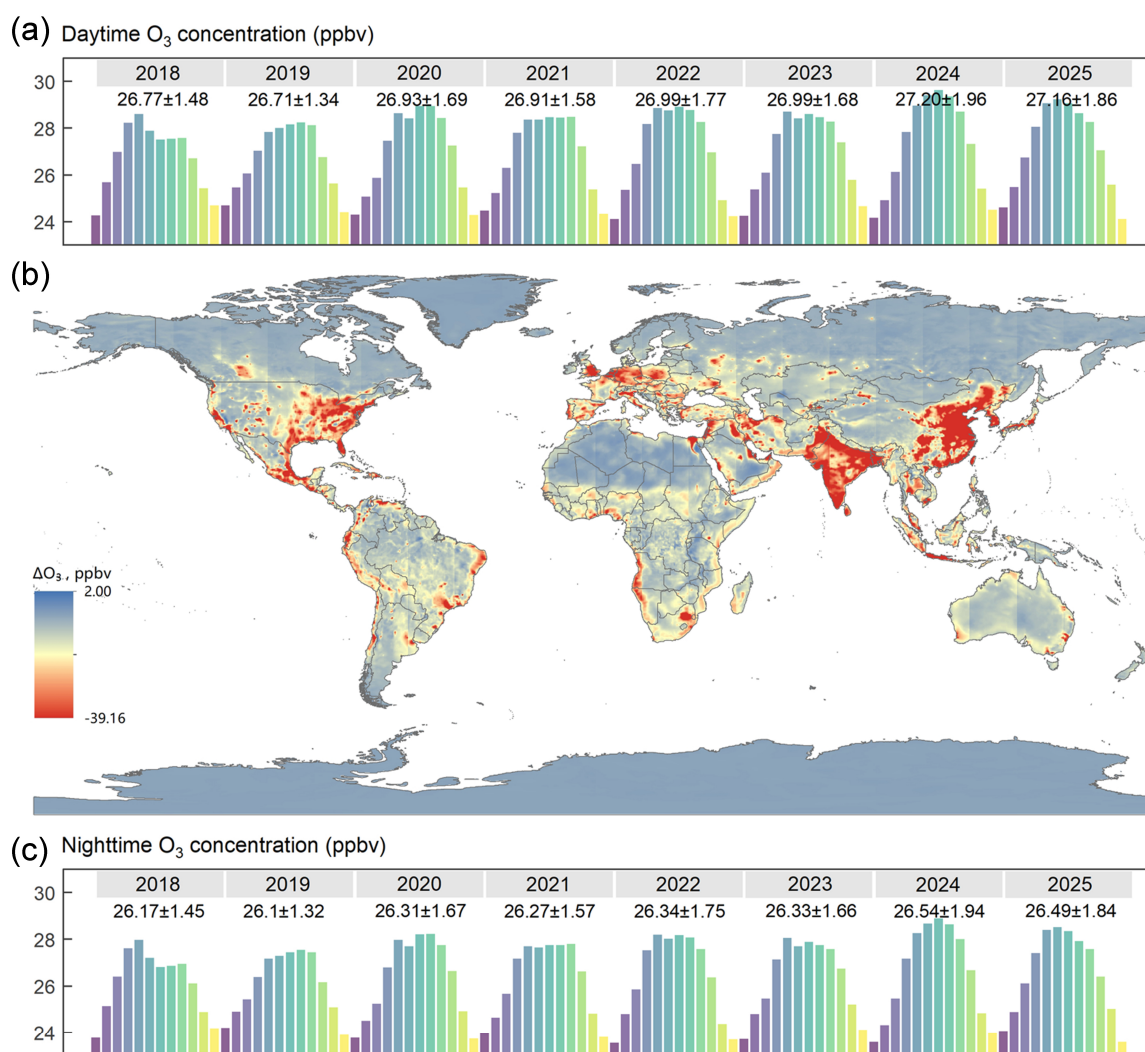


Figure 1. Global daytime and nighttime surface O_3 variability from GEOS-CF. (a) Monthly mean daytime O_3 concentration over global land from 2018 to 2025. (b) Multi-year mean day–night O_3 contrast, $\Delta O_3 = O_3, \text{night} - O_3, \text{day}$, over global land. Positive values indicate higher nighttime O_3 than daytime O_3 . (c) Monthly mean nighttime O_3 concentration over global land. O_3 is shown in ppbv. Additionally, each colored bar in Figures 1a,c corresponds to the mean monthly O_3 concentration for that specific year.

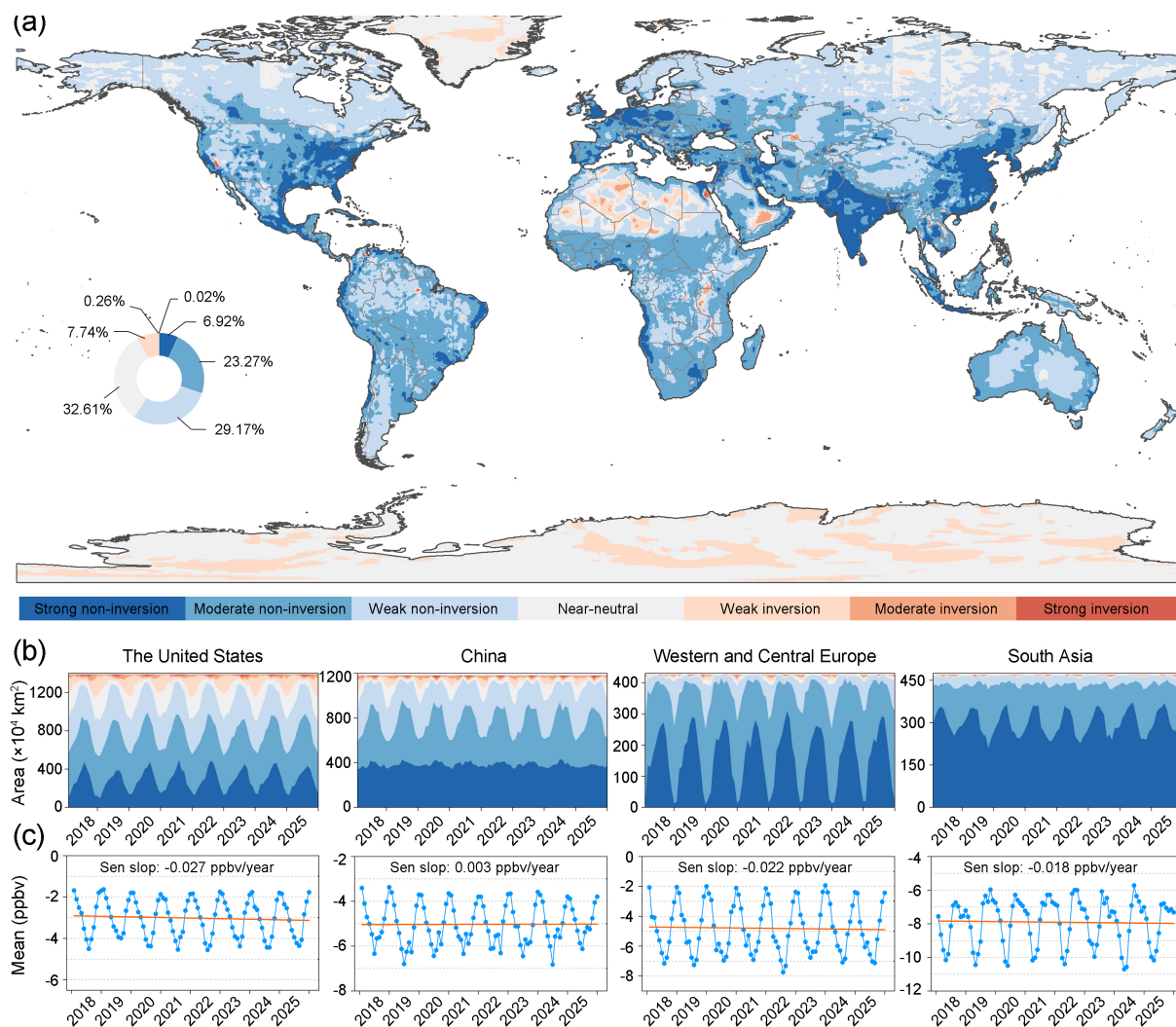


Figure 2. Global patterns and regional variability of day–night O_3 contrast regimes. (a) Seven-class ΔO_3 regime map and global area composition based on the multi-year mean ΔO_3 over land. ΔO_3 is expressed in ppbv. (b) Monthly areal evolution of ΔO_3 regimes in selected focus regions, with area expressed as 10^4 km^2 . (c) Regional monthly ΔO_3 time series and Theil–Sen tendencies from 2018 to 2025. Solid lines indicate monthly ΔO_3 , and reported p values are from the Mann–Kendall test.

These findings imply that day-only O_3 metrics may underestimate total exposure and overlook reduced nocturnal recovery periods for humans and vegetation, highlighting the need to consider full diurnal O_3 behaviour in exposure assessment and air-quality management.

In summary, GEOS-CF hourly O_3 fields from 2018–2025 indicate that near-neutral and weak day–night reversal signals are not negligible in selected regions, although non-reversal remains the dominant global state. Station comparisons show moderate agreement at most sites but weaker performance at Dingling, supporting cautious interpretation of GEOS-CF-derived hourly O_3 variability.

Supplementary Materials

The additional data and information can be downloaded at: <https://media.scilit.com/articles/others/2607171029115688/GES-26020134-SI.pdf>. Figure S1: Regional time series and trends of mean ΔO_3 in

other focus regions (2018–2025). Figure S2: Seasonal evolution of regime areas in major focus regions (stacked monthly areas, seven classes). Figure S3: Validation of GEOS-CF hourly surface O_3 against collocated ground-based observations at four representative sites. Figure S4: Sensitivity of station-based monthly ΔO_3 reversal agreement to daytime/nighttime definition. Table S1: Sensitivity of station-based ΔO_3 validation to daytime/nighttime definitions and data-completeness thresholds. Table S2: Thresholds used to classify the seven ΔO_3 regimes. References [10] are cited in the Supplementary Materials.

Author Contributions

C.H. (Chao He): conceptualization, methodology, writing—original draft preparation; Q.W.: data curation, software, visualization; Y.W.: investigation; P.T.: supervision, validation; C.H. (Chaoqing Huang): conceptualization, writing—reviewing and editing. All

authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Hourly time-averaged near-surface O₃ fields at 0.25° × 0.25° spatial resolution were obtained from the NASA GEOS-CF v1 replay product for January 2018–December 2025. The data were accessed through the Google Earth Engine collection NASA/GEOS-CF/v1/rpl/tavg1hr: https://developers.google.com/earth-engine/datasets/catalog/NASA_GEOS-CF_v1_rpl_tavg1hr (accessed on 24 May 2026.). We used the O₃ band, reported as dry-air mol fraction, and converted it to ppbv by multiplying by 10⁹. All spatial analyses were restricted to global land grid cells. The codes to reproduce the analyses presented in this study are available upon request from the corresponding author (huangchaoqing@whu.edu.cn).

Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

During the preparation of this work, the authors used DeepSeek to assist with English language polishing. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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