

Responses to referee's comments:

We sincerely thank the referee for the careful review and constructive comments, which have helped us improve the manuscript. Our point-by-point responses are provided below in blue.

Referee #2:

Review of “Concurrent Heat and Intense UV Extremes in North America: Divergent Dynamical Drivers and Exacerbated Ozone Pollution” by Bao et al.

This study systematically investigates the compound occurrence of extreme heat and intense surface ultraviolet (UV) radiation over North America, identifying two primary geographic hotspots and elucidating their associated synoptic circulation patterns and surface ozone responses. The topic is highly relevant and contributes valuable insights to the growing field of compound climate–environmental risk assessment. The manuscript is logically structured, and the dynamical mechanisms governing these events are well-articulated.

However, to further strengthen the scientific rigor, methodological reproducibility, and the physical completeness of the analysis, I recommend that the authors address the following major and minor points before publication.

We thank the referee for the constructive comments on event definitions, methodological reproducibility, and interpretation. We have clarified the weighting, temporal scales, thresholds, and spatial interpolation procedures, and strengthened the discussion connecting the regional circulation, land surface conditions, and ozone findings.

Major Comments:

1. The manuscript identifies extreme events based on an “area-weighted spatial mean” over the study regions. Given the substantial latitudinal spans of the two hotspots (e.g., 15° for the southern center and 10° for the northern center), the convergence of meridians means that the influence of latitude on grid-cell area is non-negligible. The authors must explicitly state whether a cosine-latitude weighting (or exact grid-cell area weighting) was applied, and provide the detailed mathematical formulation in the Supplementary Materials to ensure full methodological reproducibility.

We thank the referee for highlighting latitude-dependent grid-cell areas in regional averaging. All regional means used for event identification were calculated using cosine-latitude weights normalized over the study region. The formula is reproduced below as Eq. (S1), together with its notation, and is included in the manuscript Supplement. Section 2.2 now states the weighting procedure.

For a variable X at time t , the regional mean is calculated as follows:

$$\overline{X}(t) = \frac{\sum_{i \in R} X_i(t) \cos(\varphi_i)}{\sum_{i \in R} \cos(\varphi_i)} \quad (S1)$$

Here, R denotes the grid points within the selected hotspot, $X_i(t)$ is the value at grid point i , and φ_i is its latitude. The cosine weights are normalized by their sum over the region. This approach accounts for the latitude-dependent variation in grid-cell area on a regular latitude–longitude grid.

Changes in the manuscript:

We have revised Section 2.2.

Revised text: “Regional means use cosine-latitude weights, normalized by their sum over the study region, following Eq. (S1).”

The weighting formula and notation are included as Eq. (S1) in the Supplement and reproduced above.

2. There is an epistemological gap between the “monthly extreme heat events” used for the composite analyses (Sections 3.1–3.3) and the “daily-scale extreme heat/UV events” utilized for the long-term trend analyses (Section 3.4). The authors are encouraged to add a brief transitional statement at the beginning of Section 3.1 or in the Methods section explaining the rationale behind this dual-scale approach. For instance, clarifying how monthly composites capture persistent synoptic anomalies (like high-pressure ridges) while daily scales better represent transient, high-impact exposure risks would greatly help readers follow the analytical logic.

We appreciate the referee’s suggestion to explain the complementary roles of the monthly and daily analyses. The Methods now introduce how these scales connect the regional meteorological background with the frequency of concurrent heat–UV conditions.

Monthly composites characterize the large-scale circulation background, land surface conditions, and ozone variations associated with unusually warm and high-UV months in each region. The daily analysis resolves the coincidence of heat and intense UV on individual dates and quantifies changes in their annual frequency.

This framework links the meteorological setting of compound months with changes in the annual number of qualifying JJA days. Monthly events are selected using detrended mean $+1\sigma$ thresholds; daily indicators use fixed 90th-percentile thresholds, with frequency trends expressed in days per decade.

Changes in the manuscript:

We have revised Section 2.2.

Revised text: “Monthly composites characterize the circulation and land surface conditions associated with compound months, while daily indicators quantify changes in their annual day counts.”

3. In Section 2.2, “hot days” and “intense UV radiation days” are defined as days exceeding the 90th percentile threshold. However, it is not specified whether this percentile is calculated based on an absolute threshold over the entire historical period (1980–2022) or a relative moving threshold for individual years. This distinction is critical in a non-stationary warming climate. The authors must clarify this definition and briefly discuss how their chosen thresholding method captures the anthropogenic warming signal presented in Section 3.4.

We thank the referee for requesting clarification of the daily thresholds. For each region and variable, the 90th percentile is calculated once from the 1980–2022 JJA reference sample and held fixed for all years. The annual day counts and trend estimates are reproduced in Fig. R1.

1. Fixed daily thresholds and counting

Daily indicators are ERA5 averages of 18:00, 19:00 and 20:00 UTC, representing sampled daytime conditions during JJA 1980–2022. For each region and variable, spatial averaging with cosine-latitude weights precedes estimation of one 90th-percentile threshold from all JJA daily values pooled across the reference period. The undetrended daily indicators are compared with this fixed threshold using a strict exceedance criterion. Compound days satisfy both thresholds on the same date. Each qualifying date contributes one count, and heat and UV counts include compound days.

2. Interpretation of trends under fixed thresholds

Because the daily indicators are not detrended, the fixed historical thresholds retain the influence of background warming on high-temperature exceedance frequency. This provides a common benchmark for assessing changes in extreme-day occurrence. Compound-day counts also depend on UV variability and its co-occurrence with heat. Observed trends can reflect both external forcing and internal variability; quantifying the anthropogenic contribution requires a separate attribution analysis.

Changes in the manuscript:

We have revised Section 2.2.

Revised text: “Daily indicators are regional averages of the three sampled UTC hours. For each variable and region, a fixed 90th percentile is calculated from all undetrended JJA daily values pooled over 1980–2022. Compound days strictly exceed both thresholds on the same date; each qualifying date counts once, and heat and UV counts include compound days.”

We have revised Section 3.4.

Revised text: “Fixed historical thresholds applied to undetrended daily indicators retain the influence of background warming on high-temperature exceedance frequency. Compound-day trends reflect changes in both temperature and UV, as well as their co-occurrence, against this common benchmark.”

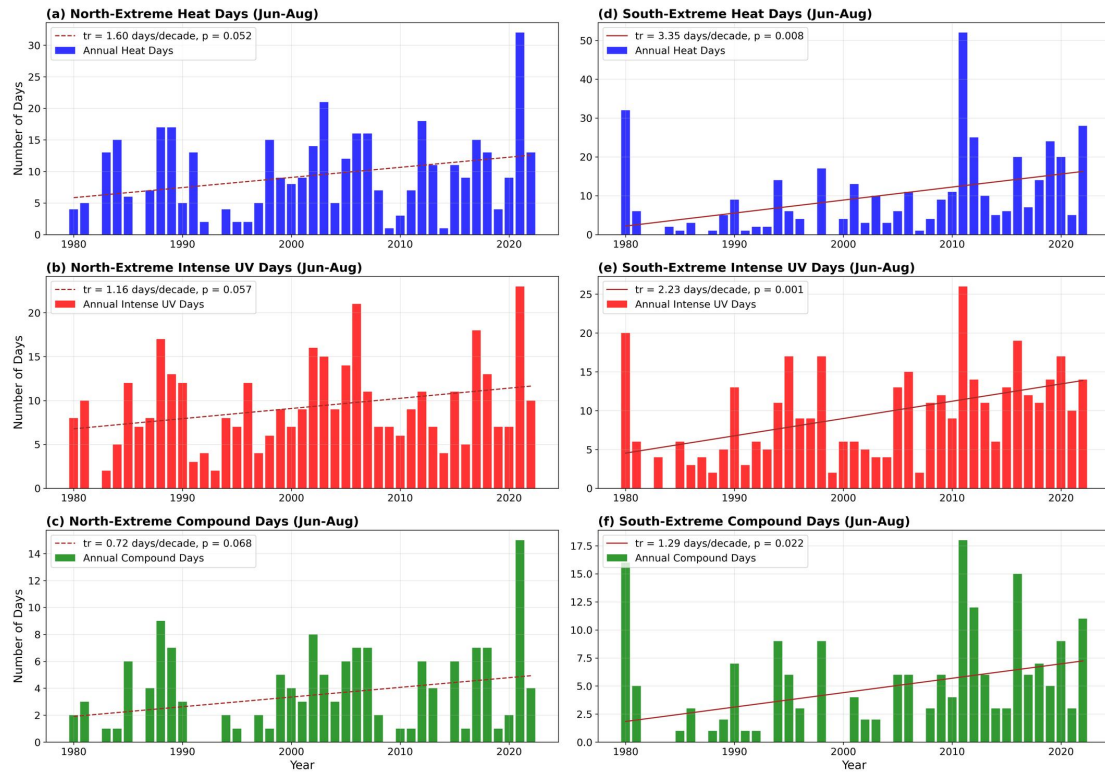


Figure R1. Updated replacement for original manuscript Fig. 7. Annual JJA counts of heat, intense UV, and compound days during 1980–2022 in the Northern Center (left) and Southern Center (right). Heat and UV counts include compound days. tr is the linear trend in days per decade. Two-sided p -values test a zero slope; solid and dashed trend lines denote $p < 0.05$ and $p \geq 0.05$, respectively.

4. In discussing the fiercely coupled heat–drought feedback loop (Sections 3.1 & 3.2), the analysis relies exclusively on surface volumetric soil water content (SWC). While SWC is a robust proxy for desiccation, the actual physical driver amplifying near-surface temperatures is the altered partitioning of surface energy fluxes (i.e., a drastic shift from latent to sensible heat flux). To provide a more complete thermodynamic picture of the land–atmosphere feedback, the authors should consider briefly examining composite anomalies of surface sensible and latent heat fluxes during these extreme events, or at minimum, incorporate this energy partitioning perspective into the discussion.

We thank the referee for highlighting surface energy partitioning as a physical link between soil moisture availability and near-surface warming. We have incorporated this perspective into the discussion of the SWC and temperature composites.

The co-occurrence of reduced SWC and elevated temperature identifies land surface conditions consistent with soil moisture limitation of evaporative cooling. This provides a physical basis for discussing how moisture availability may contribute to warming during compound events.

The revised discussion connects these observed patterns with a potential shift in available energy from latent to sensible heating, providing an interpretation of land–

atmosphere coupling during compound conditions. The revised conceptual schematic (replacing original manuscript Fig. 8) retains the label “Coupled Heat–Drought Feedback,” with the intensity qualifier removed. The updated schematic is reproduced as Fig. R2 here.

Changes in the manuscript:
We have revised Section 3.2.

Revised text: “The warm and dry composite conditions are consistent with soil moisture limitation of evaporative cooling and a shift towards sensible heating, providing a physical basis for coupled heat–drought feedback (Seneviratne et al., 2010; Miralles et al., 2014).”

Section 4 and the conceptual-schematic caption retain coupled heat–drought feedback as a physical interpretation of the warm and dry composites.

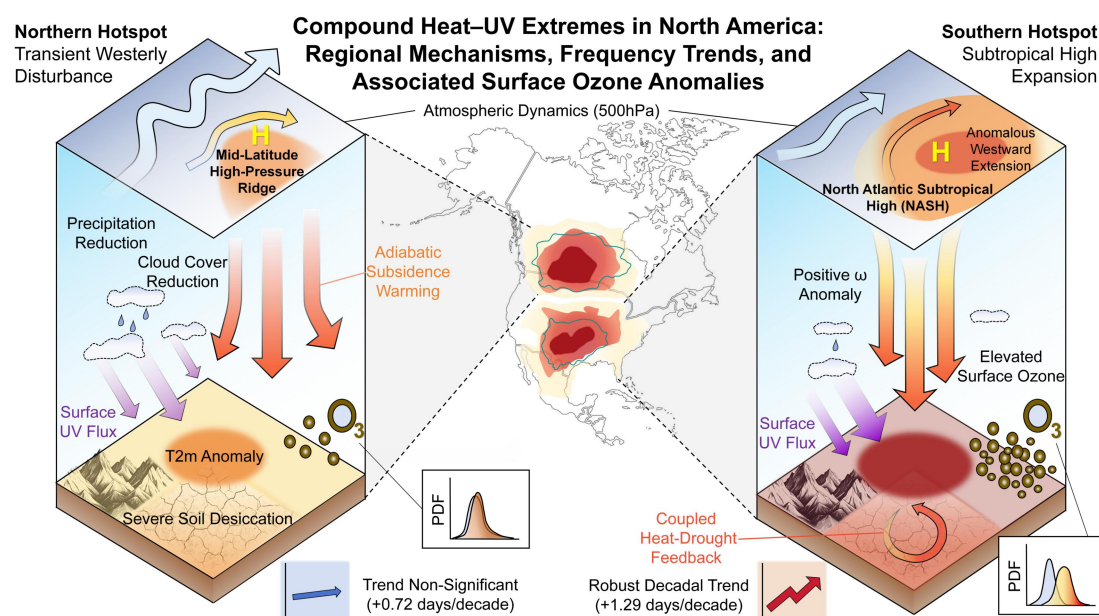


Figure R2. Updated replacement for original manuscript Fig. 8. Conceptual synthesis of regional circulation, land surface conditions, frequency trends and associated surface ozone during compound heat–UV extremes. Circulation pathways represent physical interpretations of the composite patterns; the southern westward-extension label refers to the 500-hPa ridge pattern. Ozone symbols and inset density curves are qualitative. Trend labels show changes in annual JJA compound-day counts during 1980–2022.

5. The captions for Figures 2 and 3 state that the “dark cyan contour outlines areas where the mean values during hot years exceed ± 1 standard deviation of the climatological mean”. Yet, this key graphical feature is largely ignored in the main text. The authors should add a brief description in Section 3.2 addressing the spatial alignment between these $\pm 1\sigma$ regions and the central anomaly centers, clarifying whether these contours serve as an objective metric for delineating the “core impact zones” of the compound extremes.

We thank the referee for requesting this clarification. In the meteorological composite panels, dark cyan contours identify where the event-year mean anomaly exceeds one climatological standard deviation in magnitude. The climatological mean and standard deviation retain the full-period calendar-month reference after detrending. Stippling is based on two-sided Welch comparisons between event and non-target years. Surface ozone composite maps show anomalies without significance stippling or $\pm 1\sigma$ contours. These conventions are distinguished in the revised captions. The revised Northern and Southern composites are reproduced as Figs. R5–R6 (replacing original manuscript Figs. 2–3).

The hotspot boxes define the study regions, while the $\pm 1\sigma$ contours provide an objective reference for anomaly strength and spatial extent within and around them. In Northern June, the $+1\sigma$ T2m and UV regions overlap substantially within the study box, with portions extending beyond its boundaries (Fig. R5a, d). In Northern August, the SWC-deficit region extends south and southeast of the main warm-anomaly centre (Fig. R5c, i). We have added these examples to Section 3.2 to clarify how the variable- and month-specific contours complement the fixed boxes used for event selection.

Tables R1–R2 document the monthly samples used in these composites: the ERA5 categories are identified over 1940–2022, and the SWC compound years are independently identified over 1950–2022. The catalogues are included as Supplement Tables S1 and S2. The updated T2m and newly added UV time series illustrate the joint monthly thresholds (Figs. R3–R4 below; Supplement Figs. S1–S2).

Changes in the manuscript:

We have revised Section 3.2.

Revised text: “In Northern June, the $+1\sigma$ regions of T2m and UV overlap substantially within the box, with portions extending beyond its boundaries (Fig. 3a, d). In Northern August, the SWC-deficit region extends south and southeast of the main warm-anomaly center (Fig. 3c, i). The $\pm 1\sigma$ contours delineate variable- and month-specific areas of pronounced anomalies, complementing the boxes used for regional event selection.”

The anomaly reference and Welch comparison groups are defined in Section 2.2; the revised captions identify stippling and the $\pm 1\sigma$ contours. The updated time series are provided in Supplement Figs. S1–S2.

Table R1. Monthly event years by category, 1940–2022.

Region	Month	Compound years (n)	Heat-only years (n)	UV-only years (n)	Normal years (n)
Northern	Jun	1955, 1956, 1961, 1970, 1987, 1988, 2021 (7)	1941, 1995, 2006 (3)	1962, 1972, 1974, 1979, 1986 (5)	Remaining years (68)
Northern	Jul	1947, 1960, 1989, 2006, 2007, 2021 (6)	1941, 1964, 1975, 2002, 2012 (5)	1943, 1957, 1959, 1967, 2017 (5)	Remaining years (67)
Northern	Aug	1940, 1955, 1961, 1969, 1971, 1983, 1998, 2001, 2003 (9)	1949, 1973, 1981, 1984, 1991, 2022 (6)	1967, 1970, 1996, 2006, 2008, 2011, 2012 (7)	Remaining years (61)
Southern	Jun	1948, 1952, 1953, 1954, 1956, 1990, 1998, 2008, 2011, 2012 (10)	1958, 1980, 1994, 2010, 2018 (5)	1960, 1964, 1974, 2005, 2020 (5)	Remaining years (63)
Southern	Jul	1954, 1957, 1980, 2001, 2011, 2016, 2022 (7)	1951, 1953, 1963, 1964, 1966, 1969, 1998, 2020 (8)	1956, 1962, 1965, 1995, 2000, 2019 (6)	Remaining years (62)
Southern	Aug	1943, 1948, 1952, 1962, 2000, 2010, 2011, 2019, 2020 (9)	1944, 1951 (2)	1950, 1954, 1956, 1958, 2009, 2012, 2015 (7)	Remaining years (65)

Note: Parentheses give selected-year counts; Remaining years exceed neither threshold.

Table R2. Compound years for SWC composites, 1950–2022.

Region	Month	Compound event years	n
Northern	Jun	1956, 1961, 1987, 1988, 2021	5
Northern	Jul	1957, 1960, 1989, 2006, 2007, 2021	6
Northern	Aug	1955, 1961, 1969, 1971, 1983, 2001, 2003	7
Southern	Jun	1952, 1953, 1954, 1956, 1990, 1998, 2008, 2011, 2012	9
Southern	Jul	1954, 1957, 1980, 2001, 2011, 2016, 2022	7
Southern	Aug	1952, 1958, 1962, 2000, 2010, 2011, 2019, 2020	8

Note: n gives selected-year counts.

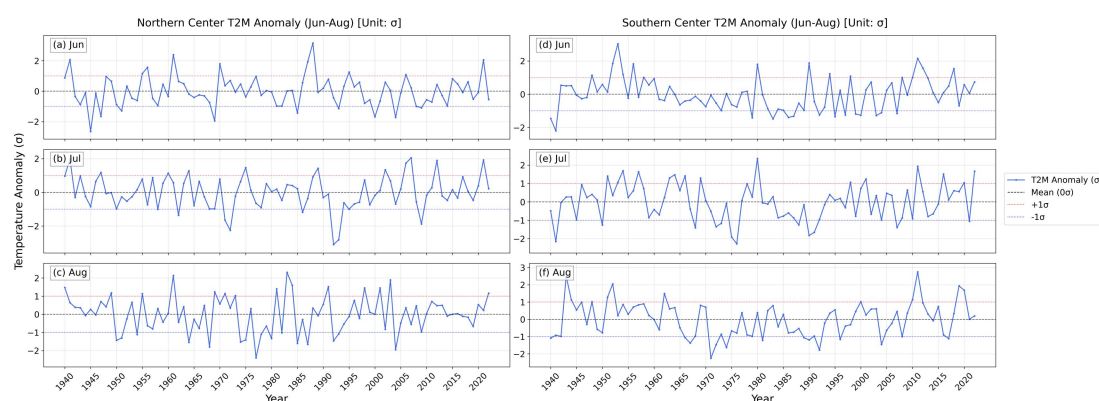


Figure R3. Time series of standardized monthly T2m anomalies during 1940–2022 in the Northern Center (a–c) and Southern Center (d–f), based on ERA5. Rows show June–August. Black dashed lines denote the climatological means; red and blue dotted lines mark +1 and -1 standard deviation, respectively. Series are linearly detrended before standardization. Event categories use the joint T2m and UV criteria in Table S1.

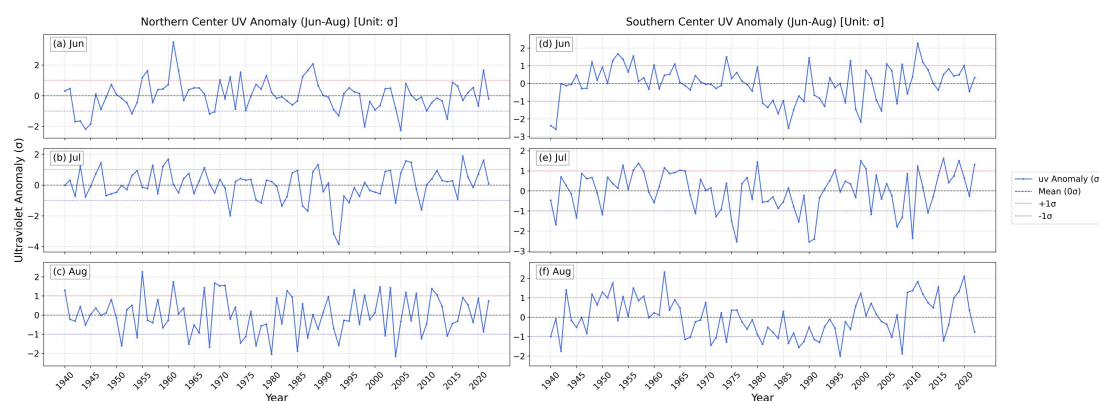


Figure R4. Time series of standardized monthly UV anomalies during 1940–2022 in the Northern Center (a–c) and Southern Center (d–f), based on ERA5. Rows show

June–August. Black dashed lines denote the climatological means; red and blue dotted lines mark $+1$ and -1 standard deviation, respectively. Series are linearly detrended before standardization. Event categories use the joint T2m and UV criteria in Table S1.

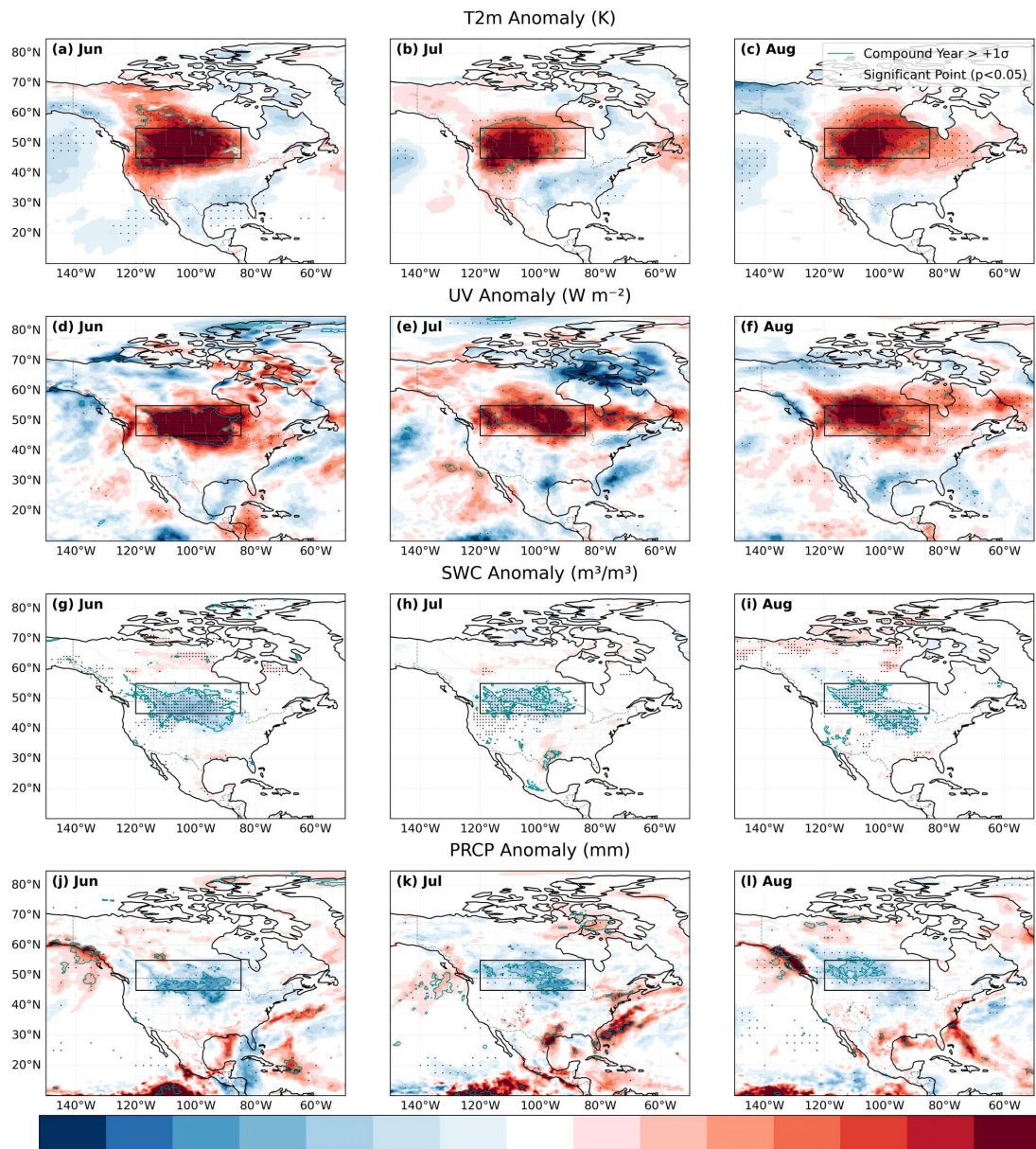


Figure R5. Updated replacement for original manuscript Fig. 2. Spatial distributions of composite anomalies during compound heat–UV months in the Northern Center for June–August. Colour scale ranges are ± 2.4 K for T2m (a–c), ± 2.4 W m^{-2} for UV (d–f), ± 0.16 $\text{m}^3 \text{m}^{-3}$ for SWC (g–i), and ± 2.4 mm for precipitation (j–l). ERA5 fields cover 1940–2022 and SWC covers 1950–2022. Blue and red denote negative and positive anomalies; white denotes near-zero anomalies. Stippling marks $p < 0.05$; dark cyan contours outline anomalies exceeding one climatological standard deviation in magnitude.

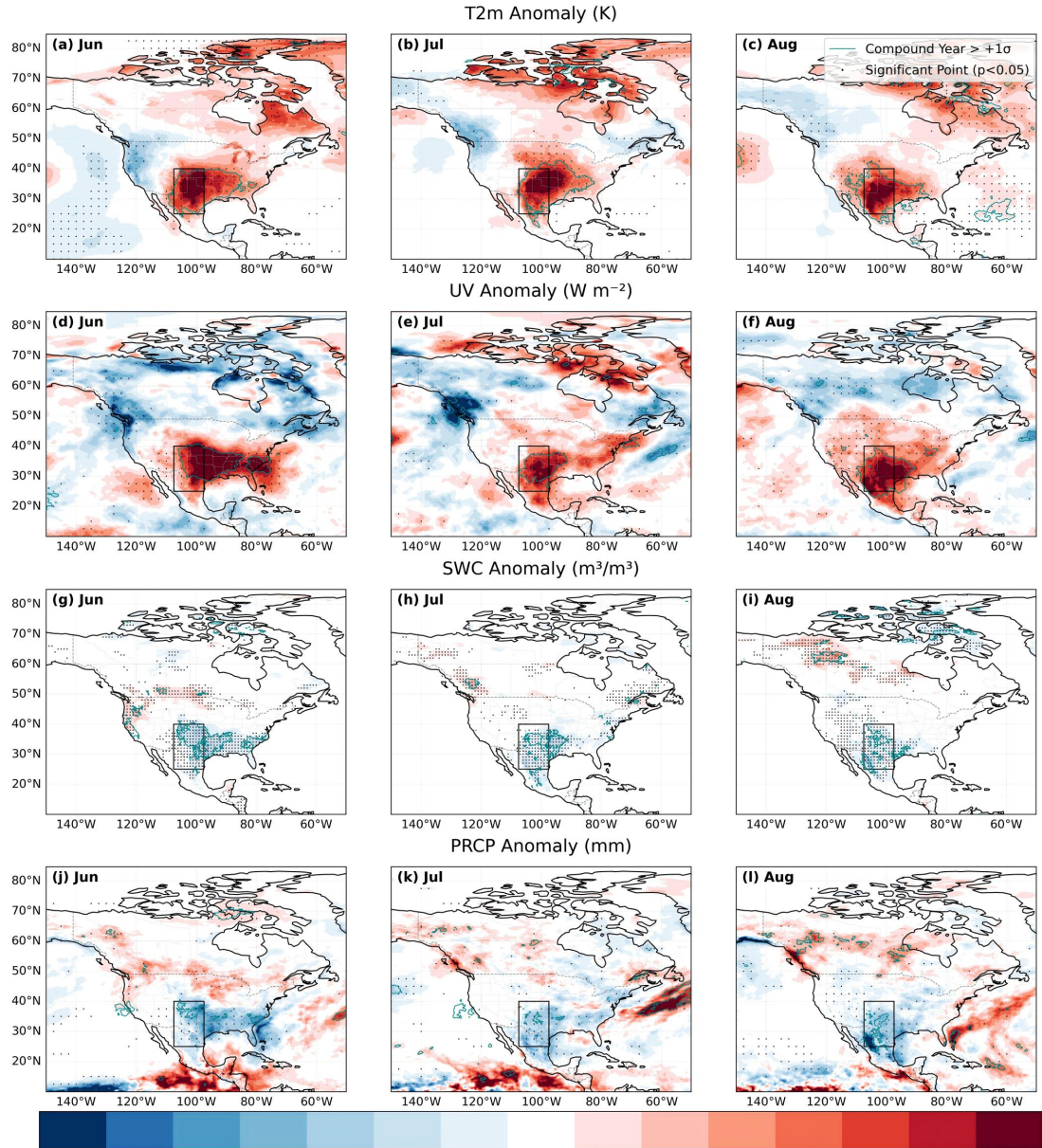


Figure R6. Updated replacement for original manuscript Fig. 3. Spatial distributions of composite anomalies during compound heat–UV months in the Southern Center for June–August. Colour scale ranges are ± 2.4 K for T2m (a–c), ± 2.4 W m^{-2} for UV (d–f), ± 0.16 $\text{m}^3 \text{m}^{-3}$ for SWC (g–i), and ± 2.4 mm for precipitation (j–l). ERA5 fields cover 1940–2022 and SWC covers 1950–2022. Blue and red denote negative and positive anomalies; white denotes near-zero anomalies. Stippling marks $p < 0.05$; dark cyan contours outline anomalies exceeding one climatological standard deviation in magnitude.

6. The study integrates datasets with varying spatial resolutions: ERA5 (0.25°), ERA5-Land (0.1°), and CAMS EAC4 (0.75°). It is not explicitly stated whether the authors pre-interpolated all datasets onto a common grid prior to performing the composite analyses and regional averaging. Please clarify the interpolation scheme (e.g., bilinear interpolation, conservative remapping) in the Data section, and briefly comment on whether remapping from coarser grids (like EAC4) to finer grids introduces any spatial smoothing biases in extreme peak values.

We thank the referee for requesting this clarification. Composite analyses and regional averaging use each dataset's native grid. Cross-dataset calculations that require matched locations, such as grid-point T2m–SWC correlations, use interpolation to the ERA5 grid. The updated correlation maps are reproduced as Fig. R7.

1. Spatial matching for correlation analysis

For T2m–SWC correlations, monthly ERA5-Land SWC fields are interpolated from 0.1° to the 0.25° ERA5 grid using `xarray.DataArray.interp` with `method="linear"` in latitude and longitude. This is applied to each monthly field before grid-point detrending and correlation calculation.

T2m–SWC correlations use the common 1950–2022 period. Interpolated SWC fields are interpreted at the ERA5 target resolution; the composites and regional means retain their native grids. Section 2.1 also clarifies the ERA5-Land replay driven by ERA5 atmospheric forcing.

2. Surface ozone on the native grid

The ozone composites, regional means and concentration distributions use model level 60, the lowest CAMS EAC4 model layer, on the native 0.75° grid. Ozone mass mixing ratios are converted to ppbv as $q \times 10^9 \times (28.97/48.00)$. All ozone figures and statistics have been recomputed consistently using this surface layer.

Changes in the manuscript:

We have revised Section 2.1.

Revised text: “Composites and regional averages retain each dataset's native grid. For grid-point T2m–SWC correlations, monthly SWC fields are bilinearly interpolated to the ERA5 grid before detrending and correlation analysis.”

Revised text: “To examine the association of concurrent extreme heat and intense ultraviolet radiation with surface ozone, monthly mean surface ozone from model level 60, the lowest model layer of the CAMS atmospheric composition reanalysis (EAC4), was used for the period 2003–2022 at a horizontal resolution of $0.75^\circ \times 0.75^\circ$.”

Section 2.1 also distinguishes ERA5 data assimilation from the ERA5-Land replay; the CAMS access platform is corrected in Code and data availability.

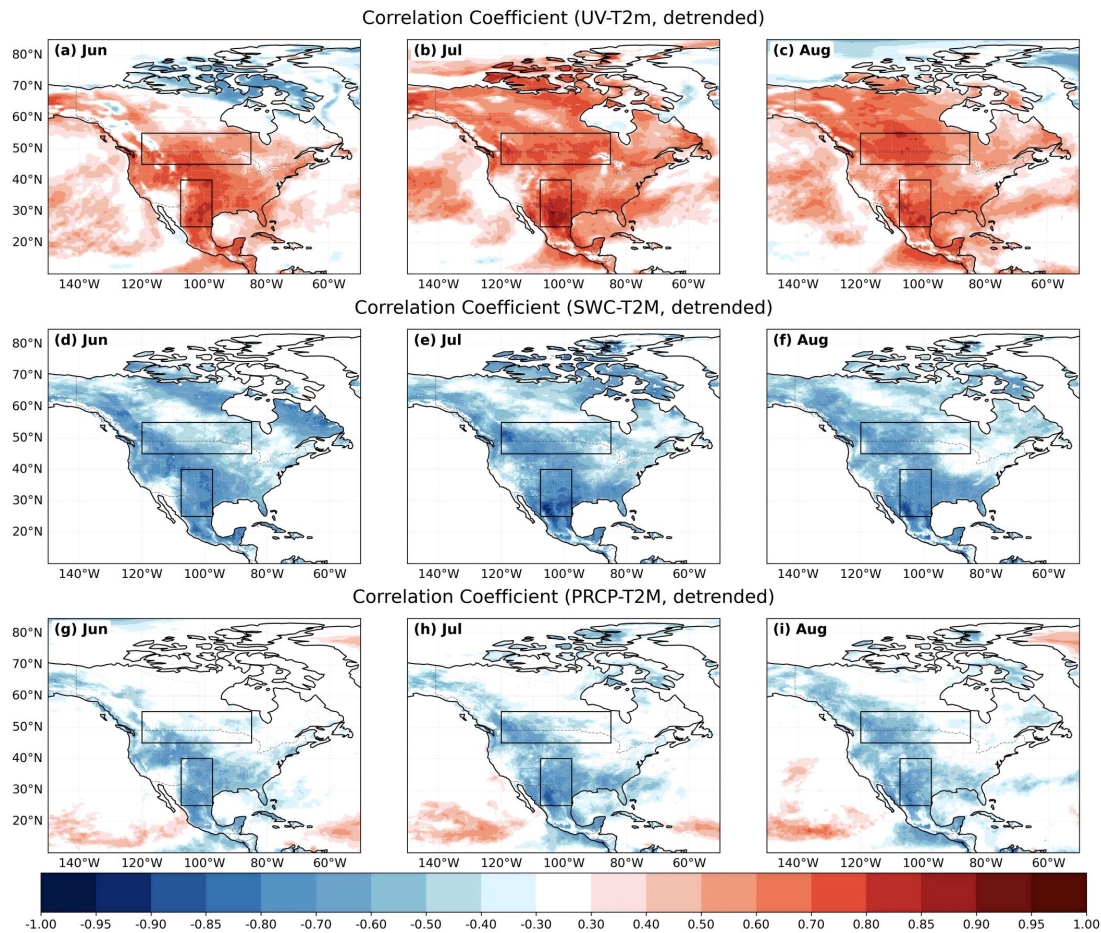


Figure R7. Updated replacement for manuscript Fig. 1. Spatial correlations of T2m with UV (a–c), SWC (d–f) and precipitation (g–i) for June–August. T2m–UV and T2m–precipitation cover 1940–2022; T2m–SWC covers 1950–2022. Red and blue indicate positive and negative correlations, respectively. Black boxes mark the two study regions.

7. Figure 6 presents the PDFs of surface ozone concentrations for “Hot Years” and “Normal Years”. Because the temperature sensitivity and the specific years identified as “hot” likely differ between the northern and southern centers, the exact sample sizes are ambiguous. Please report the sample sizes (e.g., $n = 15$) for both categories in each region and month, either in the figure captions or the main text, to allow readers to evaluate the statistical robustness of the PDF estimations.

We thank the referee for this suggestion. The revised ozone concentration distributions (Fig. R8 here) replace original manuscript Fig. 6 and include selected-year counts in each panel. The curves distinguish normal, pooled single-extreme and compound categories; single extremes combine heat-only and UV-only years. Classification uses independently identified 2003–2022 events (Table R3 here; manuscript Supplement Table S3), and ozone uses CAMS EAC4 model level 60.

The panel counts follow the legend colors in the order normal, single extremes, and compound, and refer to event years. Each panel partitions the 20-year record. The Northern August compound sample contains one year (2003), which is now explicit in the figure and caption.

We have revised Section 3.3 and the caption of original manuscript Fig. 6, and added the event catalogue in the Supplement.

Revised text: “Single extremes combine heat-only and UV-only years; panel n values give selected-year counts.”

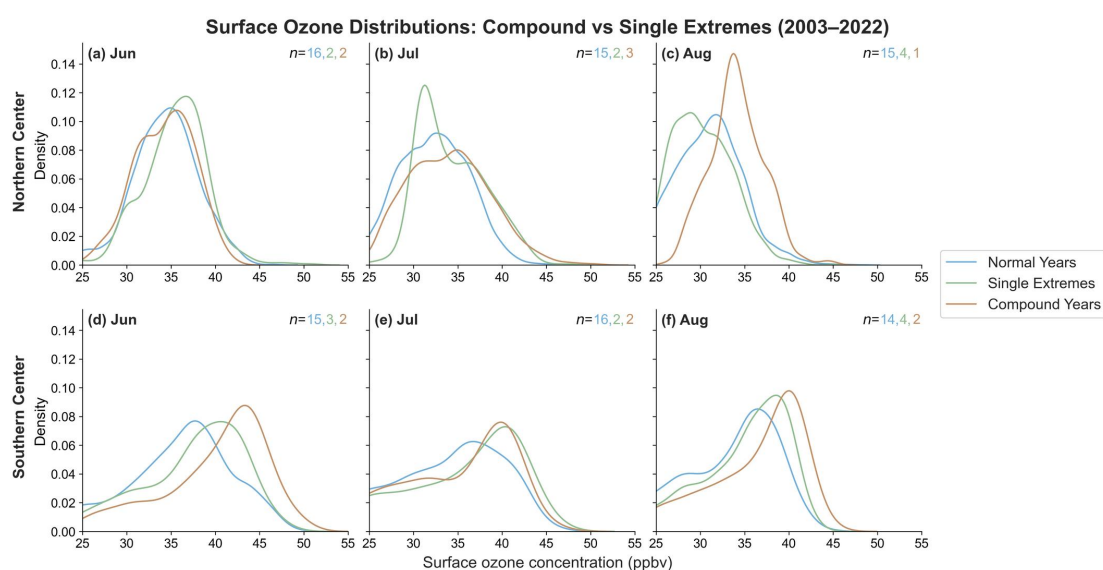


Figure R8. Updated replacement for original manuscript Fig. 6. Monthly surface ozone concentration distributions (ppbv) during June–August 2003–2022 in the Northern (a–c) and Southern (d–f) Centers. Blue, green and orange curves denote normal, pooled single-extreme and compound years, respectively. Single extremes combine heat-only and UV-only years; panel n values give selected-year counts.

Table R3. Event years for the CAMS EAC4 ozone analysis, 2003–2022.

Region	Month	Compound years (n)	Heat-only years (n)	UV-only years (n)	Normal years (n)
Northern	Jun	2006, 2021 (2)	None (0)	2003, 2015 (2)	Remaining years (16)
Northern	Jul	2006, 2007, 2021 (3)	2012 (1)	2017 (1)	Remaining years (15)
Northern	Aug	2003 (1)	2022 (1)	2006, 2008, 2011 (3)	Remaining years (15)
Southern	Jun	2011, 2012 (2)	2018 (1)	2005, 2008 (2)	Remaining years (15)
Southern	Jul	2011, 2016 (2)	2022 (1)	2003 (1)	Remaining years (16)
Southern	Aug	2011, 2020 (2)	2019 (1)	2009, 2010, 2015 (3)	Remaining years (14)

Note: Event categories are identified independently for 2003–2022. Parentheses give selected-year counts; Remaining years exceed neither threshold.

Minor Comments:

1. P5, Fig. 1 Caption: The panel reference currently reads “(g–h)”, but it should be “(g–i)” as Figure 1 contains panels a through i. Please correct this typographical error.

We thank the referee for noting this typographical error. The panel reference in the Fig. 1 caption is corrected to (g–i).

2. P11, Fig. 4 Caption: The specific parameters used for the “Gaussian smoothed” climatological geopotential height are missing. Please specify the standard deviation (σ) or filter window size in the caption to ensure the figure is fully reproducible.

We thank the referee for pointing out this omission. The caption of original manuscript Fig. 4 (Fig. R9 here) now specifies a Gaussian filter with $\sigma = 1$ grid point for the climatological Z500 contours.

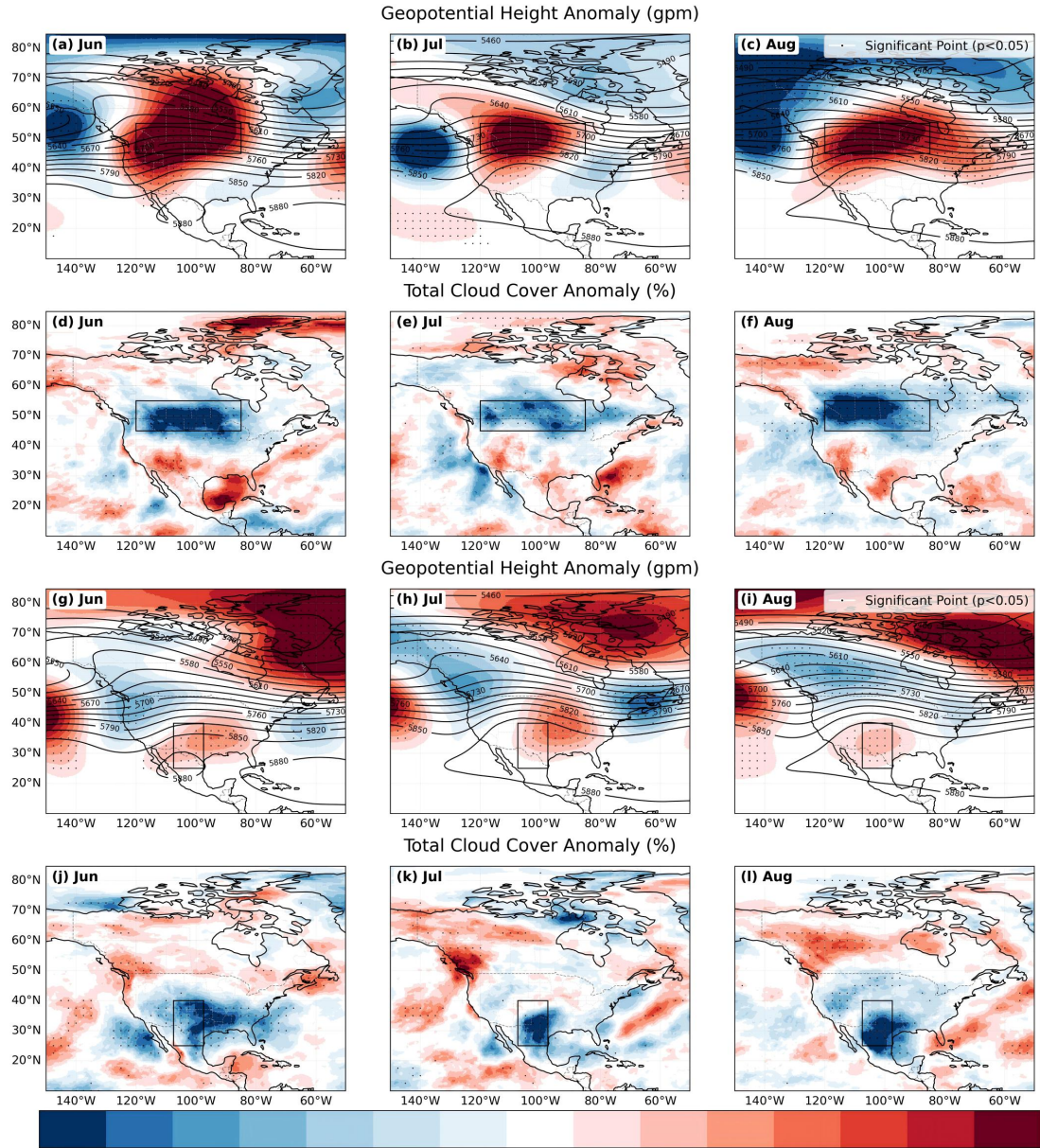


Figure R9. Updated replacement for original manuscript Fig. 4. Spatial distributions of Z500 and total-cloud anomalies during compound months in the Northern and Southern Centers for June–August 1940–2022. Panels (a–c) and (g–i) show Z500; (d–f) and (j–l) show total cloud cover. Colour scales are limited to ± 40 gpm for Z500 and ± 12 percentage points for total cloud cover; extrema reported in the text are calculated from the composite fields within the study boxes. Blue and red denote negative and positive anomalies; white denotes near-zero anomalies. Black contours show climatological Z500 from 5460 to 5880 gpm at 30-gpm intervals, Gaussian-smoothed with $\sigma = 1$ grid point. Stippling marks $p < 0.05$.

3. P13, Fig. 6 & Section 3.3: The manuscript describes a qualitative “rightward shift” in the ozone PDF distributions. This visual observation should be supported by a robust quantitative statistical test. The authors are advised to apply a Two-Sample Kolmogorov–Smirnov (K–S) test and annotate the corresponding p-values on the panels to objectively confirm the significance of this distributional shift.

We thank the referee for requesting quantitative support for the ozone distributions. A conventional K–S test assumes independent observations, whereas the density curves pool spatially dependent grid-cell concentrations. We therefore complement the concentration distributions (Fig. R8) with comparisons of regional monthly ozone anomalies (Fig. R10), which quantify spatially integrated mean contrasts. The updated surface ozone composites are also reproduced below (Fig. R11, replacing original manuscript Fig. 5).

For JJA 2003–2022, we compare detrended and deseasonalized, area-weighted CAMS EAC4 model level 60 ozone anomalies across four categories. Table R5 reports category means and both monthly and distinct-year sample counts; Table R4 gives mean contrasts and exploratory exact monthly-label permutation p-values. Table R6 reports whole-year bootstrap intervals, and Table R7 and Fig. R12 show leave-one-year-out sensitivity. Bootstrap resampling uses 20,000 whole-year draws (seed 20261012), keeping each year’s three JJA observations together and refitting the ozone trend and calendar-month means. Event labels remain fixed; draws with an empty comparison group are excluded, with valid-draw counts reported.

Compound-minus-heat-only and compound-minus-UV-only mean differences are +1.47 and +0.85 ppbv in the Northern Center and +0.91 and +1.08 ppbv in the Southern Center, respectively (Table R4). All four remain positive in all 20 leave-one-year-out analyses (Fig. R12), indicating consistency in direction across the sampled years. The exploratory 95% intervals span zero (Table R6) and permutation p-values exceed 0.05, so the text describes a tendency toward higher regional ozone anomalies under compound conditions.

Changes in the manuscript:

We have revised Section 2.2.

Revised text: “Separately, regional monthly ozone anomalies are calculated from area-weighted CAMS EAC4 surface ozone after removing a linear trend from the 60 JJA monthly values for 2003–2022 and subtracting calendar-month means. Four-category comparisons use the 2003–2022 event catalogue. Compound-minus-control mean contrasts are assessed using exploratory monthly-label permutation comparisons. Uncertainty and sensitivity are evaluated using whole-year bootstrap and leave-one-year-out analyses, retaining each year’s three JJA observations together when resampling or omitting years. Permutation comparisons, category summaries, bootstrap intervals and individual-year sensitivity are reported in Tables S5, S6, S7 and S8,

respectively.”

We have revised Section 3.3.

Revised text: “Compound months have mean regional ozone anomalies of 1.31 ppbv in the Northern Center and 2.04 ppbv in the Southern Center (Fig. 8). The higher Southern mean reflects positive regional compound anomalies in all three summer months, while the Northern enhancement is concentrated in July and August. Compound-minus-heat-only and compound-minus-UV-only differences are +1.47 and +0.85 ppbv in the north and +0.91 and +1.08 ppbv in the south. These positive contrasts are consistent with temperature-sensitive chemistry and enhanced photolysis acting together in the warm, high-radiation environment of compound events (Jacob and Winner, 2009; Madronich et al., 2023).”

Revised text: “All four contrasts remain positive in all 20 individual-year removal analyses (Fig. S15; Table S8), showing that the higher regional mean ozone under compound conditions persists after omitting any single year. Exploratory 95 % whole-year bootstrap intervals span zero, and monthly-label permutation p-values exceed 0.05 (Tables S5 and S7).”

Revised text: “Probability density function (PDF) analysis further reveals month-dependent shifts towards higher surface ozone concentrations during compound conditions, particularly in Southern June and August and Northern August (Fig. 7). In the Southern Center, the dominant concentration peak shifts from approximately 38 to 43 ppbv in June and from 36 to 40 ppbv in August. These rightward shifts indicate that higher ozone concentrations become more characteristic of compound conditions, extending the ozone association beyond a change in the regional mean alone.”

The sample summaries and full uncertainty and sensitivity results are provided in Supplement Tables S5–S8 and Fig. S15.

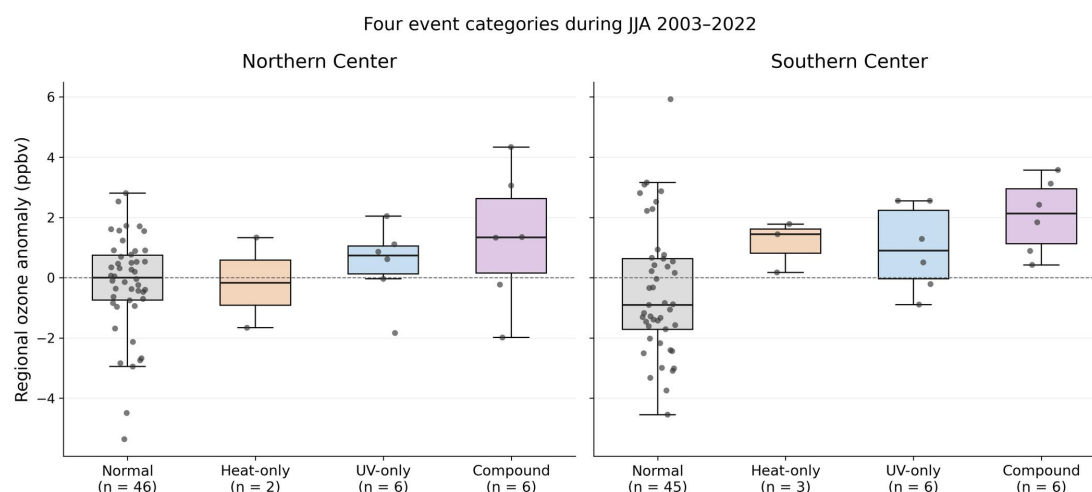


Figure R10. Regional monthly surface ozone anomalies (ppbv) during JJA 2003–2022 in the Northern (left) and Southern (right) Centers for four event categories. Boxes show the interquartile range and median; whiskers extend to observations within 1.5 times the interquartile range. Points show year–month observations, and n gives their count.

Table R4. Regional mean ozone contrasts and permutation comparisons.

Region	Control	ΔO_3 (ppbv)	p(one-sided)	p(two-sided)
Northern	Heat-only	1.47	0.286	0.571
Northern	UV-only	0.85	0.223	0.446
Northern	Single (pooled)	1.01	0.163	0.326
Southern	Heat-only	0.91	0.143	0.286
Southern	UV-only	1.08	0.093	0.186
Southern	Single (pooled)	1.02	0.067	0.133

Note: ΔO_3 is the compound-minus-control mean (ppbv); Single (pooled) combines heat-only and UV-only observations. Exact monthly-label permutation p-values are exploratory because allocations do not preserve within-year dependence. The one-sided alternative is a higher compound mean.

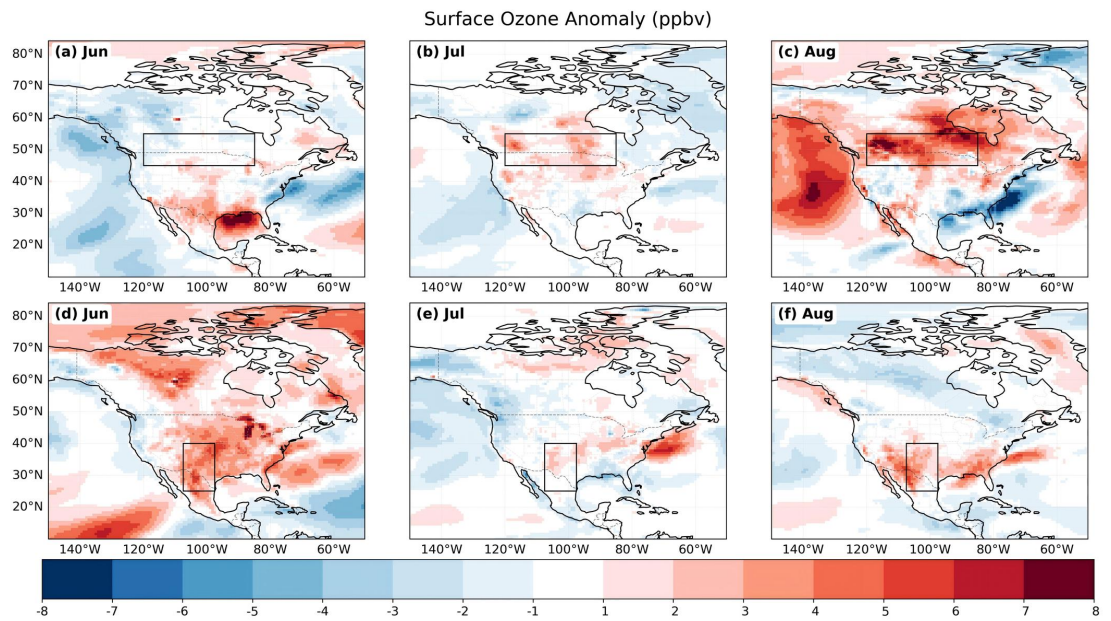


Figure R11. Updated replacement for original manuscript Fig. 5. Spatial distributions of monthly surface ozone composite anomalies (ppbv) during compound months in the Northern (a–c) and Southern (d–f) Centers for June–August 2003–2022, based on CAMS EAC4. Blue and red denote negative and positive anomalies; white denotes near-zero anomalies.

Table R5. Regional ozone anomaly summaries, JJA 2003–2022.

Region	Category	Year–month observations	Distinct years	Mean (ppbv)	SD (ppbv)
Northern	Normal	46	19	−0.22	1.66
Northern	Heat-only	2	2	−0.17	2.12
Northern	UV-only	6	6	0.46	1.31
Northern	Compound	6	4	1.31	2.26
Southern	Normal	45	19	−0.48	2.16
Southern	Heat-only	3	3	1.13	0.85
Southern	UV-only	6	6	0.96	1.43
Southern	Compound	6	4	2.04	1.24

Note: Counts distinguish year–month observations from distinct years; a year can contribute to more than one category when its monthly labels differ.

Table R6. Ozone mean contrasts and exploratory uncertainty intervals.

Region	Control	ΔO_3 (ppbv)	95 % bootstrap interval (ppbv)	p (two-sided)	Valid draws
Northern	Heat-only	1.47	[−1.02, 4.30]	0.571	17217
Northern	UV-only	0.85	[−1.07, 3.18]	0.446	19753
Northern	Single extremes (pooled)	1.01	[−0.83, 3.25]	0.326	19764
Southern	Heat-only	0.91	[−1.02, 2.48]	0.286	18982
Southern	UV-only	1.08	[−0.63, 2.52]	0.186	19738
Southern	Single extremes (pooled)	1.02	[−0.52, 2.31]	0.133	19758

Note: Intervals are exploratory 95% whole-year bootstrap percentiles; valid draws are out of 20,000. Two-sided monthly-label permutation p-values are exploratory because allocations do not preserve within-year dependence. Pooled single extremes combine heat-only and UV-only observations.

Table R7. Sensitivity of ozone contrasts to individual-year removal.

Region	Control	Minimum (ppbv)	Maximum (ppbv)	Positive analyses
Northern	Heat-only	0.04	3.08	20/20
Northern	UV-only	0.13	1.27	20/20
Southern	Heat-only	0.33	1.31	20/20
Southern	UV-only	0.76	1.38	20/20

Note: Each analysis excludes all JJA observations from one year and refits the ozone trend and calendar-month means, with event labels fixed.

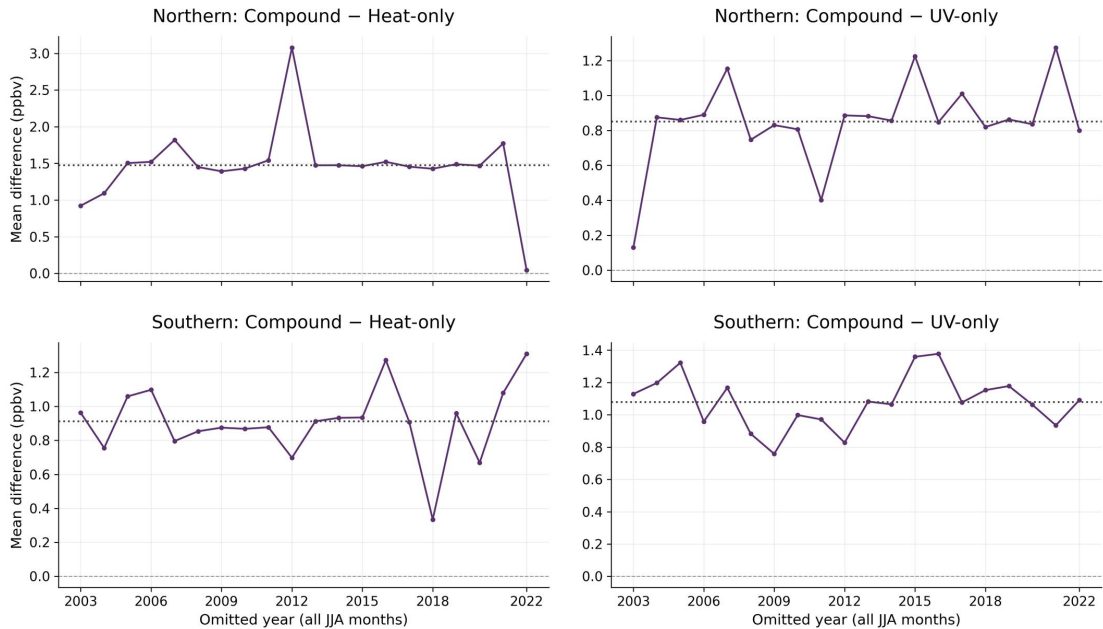


Figure R12. Leave-one-year-out sensitivity of regional ozone mean contrasts during JJA 2003–2022. Rows show the Northern and Southern Centers; columns compare compound with heat-only and UV-only events. Each point excludes all JJA observations from the indicated year. Dotted lines show full-sample contrasts and dashed lines mark zero. Panel vertical scales differ.

References

Jacob, D. J. and Winner, D. A.: Effect of climate change on air quality, *Atmos. Environ.*, 43, 51–63, <https://doi.org/10.1016/j.atmosenv.2008.09.051>, 2009.

Madronich, S., Sulzberger, B., Longstreth, J. D., Schikowski, T., Andersen, M. S., Solomon, K. R., and Wilson, S. R.: Changes in tropospheric air quality related to the protection of stratospheric ozone in a changing climate, *Photochem. Photobiol. Sci.*, 22, 1129–1176, <https://doi.org/10.1007/s43630-023-00369-6>, 2023.

Miralles, D. G., Teuling, A. J., Van Heerwaarden, C. C., and Vilà-Guerau de Arellano, J.: Mega-heatwave temperatures due to combined soil desiccation and atmospheric heat accumulation, *Nat. Geosci.*, 7, 345–349, <https://doi.org/10.1038/ngeo2141>, 2014.

Seneviratne, S. I., Corti, T., Davin, E. L., Hirschi, M., Jaeger, E. B., Lehner, I., Orlowsky, B., and Teuling, A. J.: Investigating soil moisture-climate interactions in a changing climate: A review, *Earth-Sci. Rev.*, 99, 125–161, <https://doi.org/10.1016/j.earscirev.2010.02.004>, 2010.