

Table S1 Model configurations. A detailed model information on the simulation domain, period, resolution, meteorological and chemical schemes, initial and boundary fields, and emission inventory. The spin-up time is 2 days.

Domain	
Period of baseline simulation	July, 2022
Size	200 grids × 200 grids
Center	120.0°E, 31.2°N
Horizontal resolution	6 km × 6 km
Vertical resolution	A flexible vertical interval, 35 vertical levels, spacing ranging from 50 m near the surface, 500 m at 2.5 km above the ground level, and more than 1 km above 14 km
Meteorology	
Microphysics scheme	WSM 6-class graupel microphysics scheme (Hong & Lim, 2006)
Boundary layer scheme	Mellor-Yamada-Janji planetary boundary layer scheme (Janjić, 2002)
Surface layer scheme	Monin-Obukhov surface layer scheme (Janjić, 2002)
Land-surface scheme	Noah land-surface model (Chen & Dudhia, 2001)
Longwave radiation scheme	Goddard (Dudhia, 1989)
Shortwave radiation scheme	Goddard (Dudhia, 1989)
Dry deposition	Wesely (1989)
Wet deposition	CMAQ by the U.S. EPA (Byun & Ching, 1999)
Chemistry	
Gas phase chemistry	SAPRC99 chemical mechanism (Binkowski and Roselle, 2003)
Inorganic aerosols	ISORROPIA version 1.7 (Nenes et al., 1998), SO ₂ heterogeneous reaction on aerosol surface (G. Li et al., 2017)
Secondary organic aerosol	Non-traditional VBS parametrization (G. Li, Zavala, et al., 2011), NO ₂ heterogeneous reaction (Li et al., 2010)
Photolysis rates	FTUV radiation transfer model (Tie et al., 2003; G. Li, Bei, et al., 2011)
Initial and boundary conditions	
Meteorological	NCEP FNL 6-hr 1° × 1°
Chemical	CAM-chem 6-hr outputs
Emission inventory	
Anthropogenic	MEIC (M. Li et al., 2017)
Biogenic	MEGAN (Guenther et al., 2006)

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23 **Table S2** Setup of model experiments.

Experiment	Anthropogenic emission	Meteorology	Cloud-radiation interactions
BS Exp.	Emission 2022	Meteorology 2022	Yes
			No
CTRL Exp.1	Emission 2022	Meteorology 2021	Yes
			No
CTRL Exp.2	Emission 2021	Meteorology 2022	Yes
BG Exp.	No	Meteorology 2022	Yes

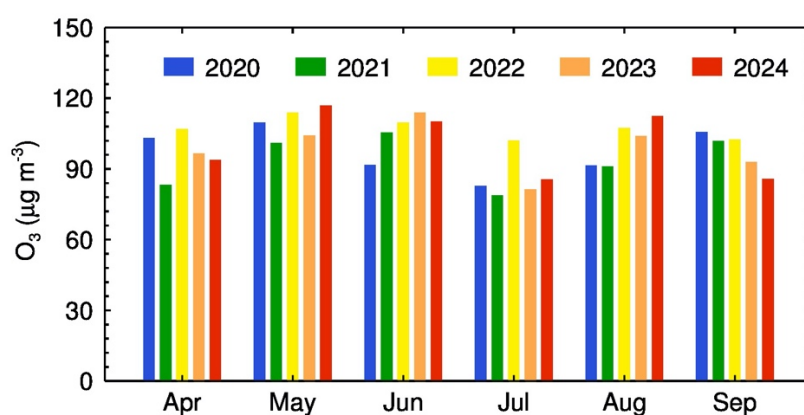
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25 **Table S3** Climate models and variables. A total of 41 models from CMIP6 are used,
 26 and each model name and variables therein are listed.

No.	Model name	T_max	TCC	SSRD
1	ACCESS-CM2	√	√	√
2	AWI-CM-1-1-MR	√	√	√
3	BCC-CSM2-MR	√	√	√
4	CAMS-CSM1-0	√	√	√
5	CanESM5	√	√	√
6	CanESM5-CanOE	×	√	√
7	CESM2	√	√	√
8	CESM2-WACCM	√	×	×
9	CIESM	×	×	√
10	CMCC-CM2-SR5	×	√	√
11	CMCC-ESM2	√	√	√
12	CNRM-CM6-1	√	√	√
13	CNRM-CM6-1-HR	√	√	√
14	CNRM-ESM2-1	√	√	√
15	E3SM-1-1	×	√	√
16	EC-Earth3	√	√	×
17	EC-Earth3-CC	√	√	√
18	EC-Earth3-Veg	√	√	×
19	EC-Earth3-Veg-LR	√	√	√
20	FGOALS-f3-L	×	×	√
21	FGOALS-g3	√	√	√
22	FIO-ESM-2-0	×	×	√
23	GFDL-ESM4	√	√	√
24	GISS-E2-1-G	×	√	√
25	HadGEM3-GC31-LL	×	√	√
26	HadGEM3-GC31-MM	×	√	√
27	IITM-ESM	×	√	√

28	INM-CM4-8	√	√	√
29	INM-CM5-0	√	√	√
30	IPSL-CM6A-LR	√	√	√
31	KACE-1-0-G	√	√	√
32	KIOST-ESM	√	√	√
33	MIROC6	√	√	√
34	MIROC-ES2L	√	√	√
35	MPI-ESM1-2-LR	√	√	√
36	MRI-ESM2-0	√	√	√
37	NESM3	√	√	√
38	NorESM2-LM	√	√	√
39	NorESM2-MM	√	√	√
40	UKESM1-0-LL	√	√	√
41	TaiESM1	×	√	√

27 Note: The number of models for projecting T_max, TCC, and SSRD varies significantly by the SSP,
 28 of which the number of models is the fewest under SSP1-1.9, with 12 models for T_max, 9 models
 29 for TCC, and 10 models for SSRD. Correspondingly, under SSP2-4.5, the number of models is 15,
 30 31 and 33, respectively. Under SSP5-8.5, the number of models is 24, 34 and 37, respectively. “√”
 31 represents the variable is projected in the model, while “×” represents the variable is not projected.
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35 **Figure S1** Warm-season O₃ variations. Interannual variation in monthly mean daytime

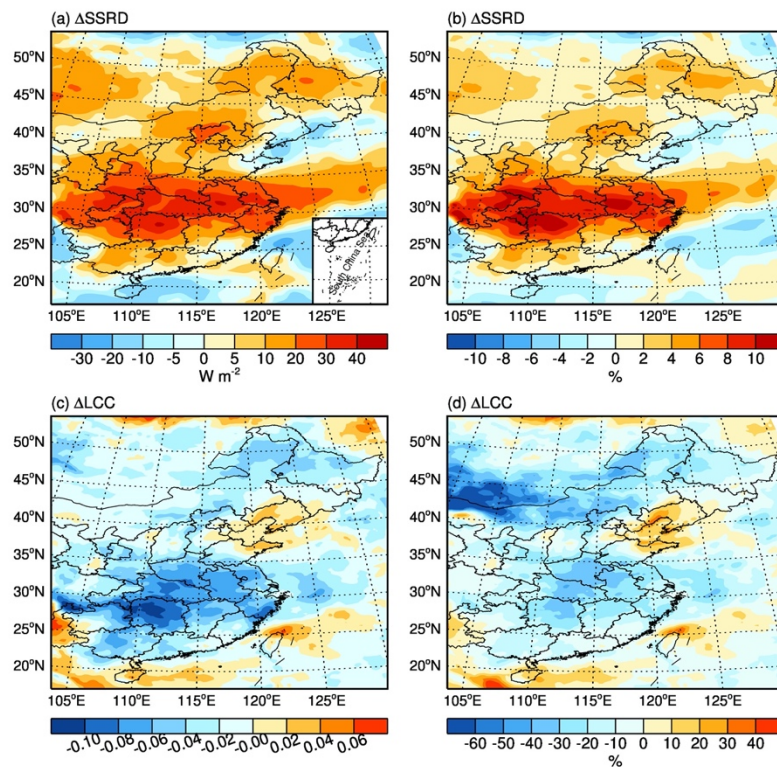
36 (07:00 - 18:00, BJT) O₃ concentration from April to September during 2020-2024.

37 Interannual variation in mean daytime O₃ concentration in July is highly consistent with

38 the interannual variation in warm-season mean O₃ concentration, with the maximum in

39 2022.

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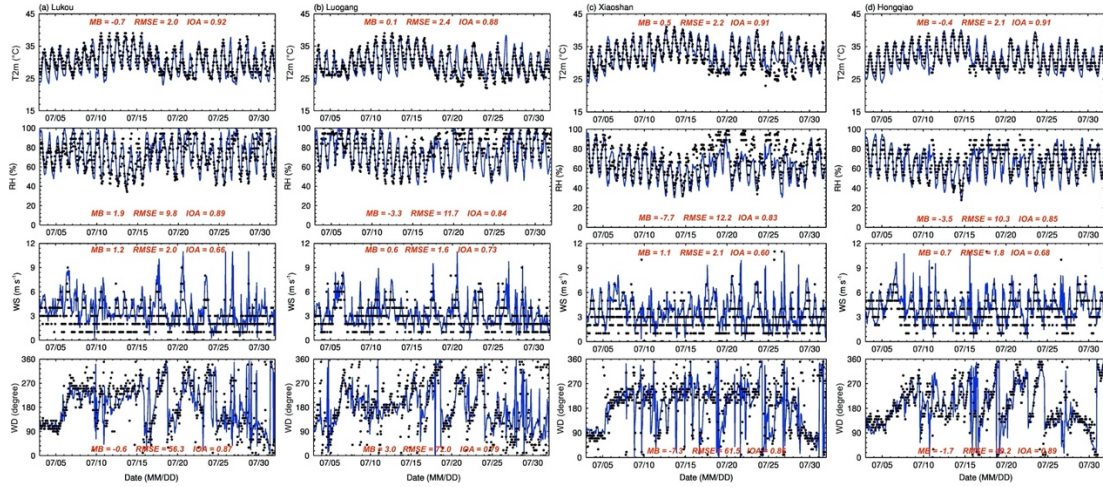


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43 **Figure S2** Observed anomaly in solar radiation for O₃ formation. (a) SSRD anomaly
 44 during the warm season of 2022 relative to the past decade (2014-2024). (b) Same as
 45 (a), but for the percentage change in SSRD. (c) LCC anomaly. (d) Same as (c), but for
 46 the relative percentage change in LCC. During the warm season of 2022, more SSRD
 47 and less LCC are observed in most of China, particularly in the region between 25°N
 48 and 35°N, where the YRD is located, with an anomalously more SSRD and less LCC.
 49 This is highly favorable for O₃ formation.

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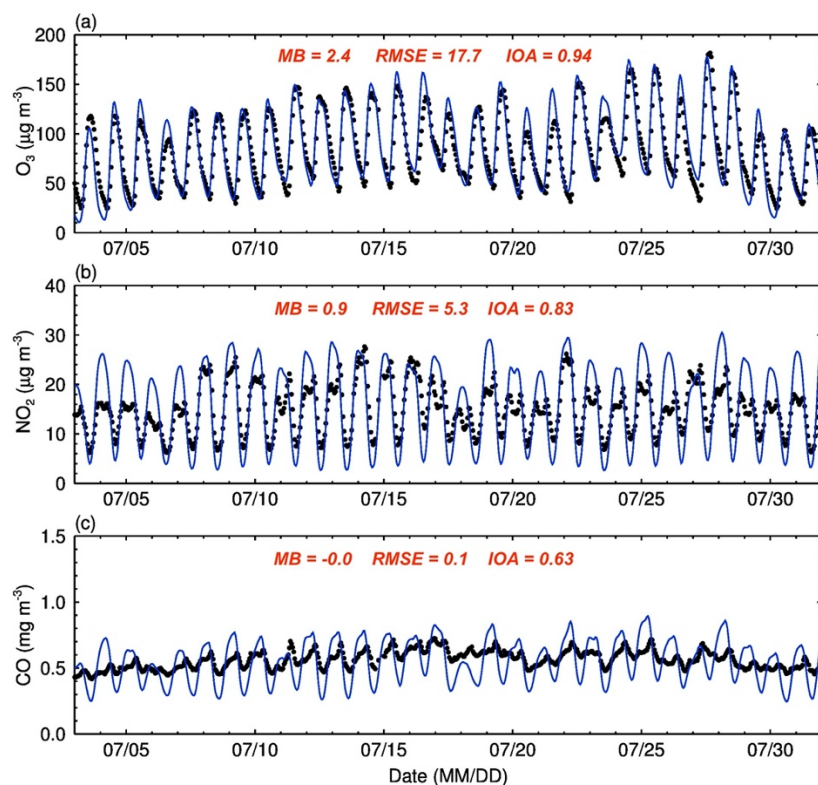


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53 **Figure S3** Observed and simulated meteorology for model performance. Observations
54 data on T2m, RH, WS, and WD at four weather stations are from four international
55 airports. (a) Lukou in Nanjing, Jiangsu. (b) Luogang in Hefei, Anhui. (c) Xiaoshan in
56 Hangzhou, Zhejiang. (d) Hongqiao in Shanghai. The hourly simulations (blue curves)
57 of four meteorological parameters are generally in good agreements with observations
58 (black dots) at four airport weather stations in the YRD in July 2022. The MBs, RMSEs,
59 and IOAs are shown in the margin.

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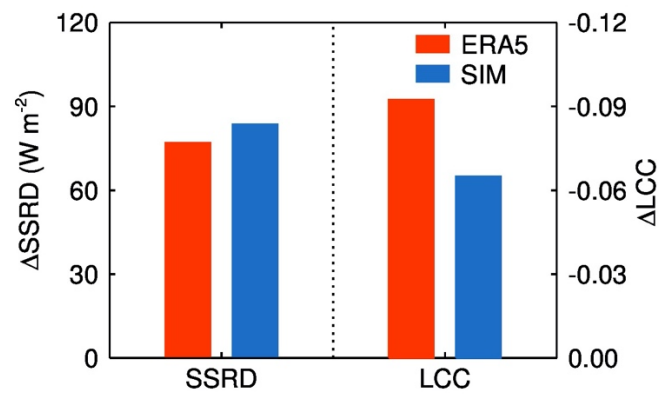
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63 **Figure S4** Model validation for pollutants. Comparison between observed (blue curves)
 64 and simulated (black dots) mass concentrations of pollutants. The model well
 65 reproduces temporal variations in O₃, NO₂, and CO in the YRD in July 2022. The MBs,
 66 RMSEs, and IOAs are shown in the top margin.

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70 **Figure S5** The simulated and observed interannual differences in SSRD and LCC.

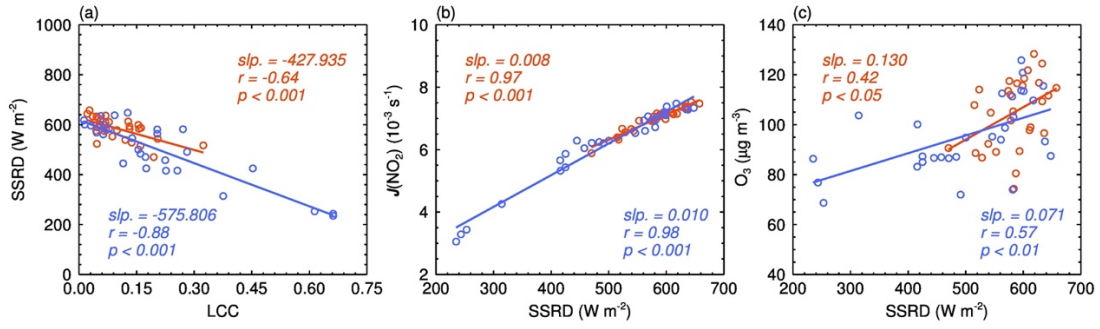
71 Differences in SSRD and LCC in July between 2021 and 2022 calculated by the model

72 (the blue histograms) are highly closed to ECMWF ERA5 reanalysis data (the red

73 histograms), showing a better performance of the model on the solar radiation change.

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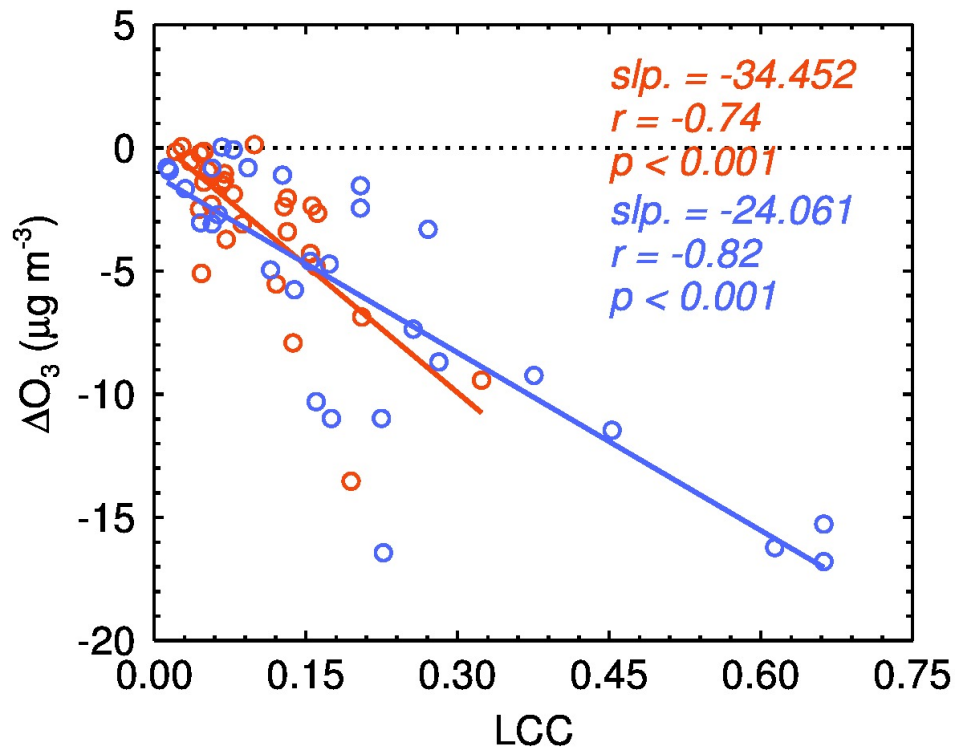
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77 **Figure S6** Simulated linkage between O_3 and LCC through SSRD. (a) A significantly
 78 negative correlation between SSRD and LCC, with confidence levels exceeding 99.9%.
 79 Consistent with observations in Figure 2a, SSRD is strongly modulated by the LCC.
 80 The more the LCC, the more SSRD is weakened. (b) The photolysis rates strongly
 81 depend on SSRD, and are mostly controlled by the SSRD, with the correlation
 82 coefficient highly close to 1.0, i.e., $r = 0.98$ (2021) and $r = 0.97$ (2022). For every 100
 83 W m^{-2} increase in SSRD, the photolysis rate $J(\text{NO}_2)$ rises by $1.0 \times 10^{-3} \text{ s}^{-1}$. (c)
 84 Relationship between O_3 and SSRD, O_3 concentration is significantly positively
 85 correlated with SSRD, with confidence levels exceeding 95%. The colored circles
 86 represent the simulations for July 2021 (blue) and July 2022 (red), respectively. The
 87 colored lines represent the linear fits corresponding to the circles of the same color.

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91 **Figure S7** Same as Figure S6, but for relationship between ΔO_3 due to CRI and LCC.

92 The ΔO_3 is significantly negatively correlated with LCC, with confidence levels

93 exceeding 99.9%. The impact of LCC on ΔO_3 through CRI mechanism is more

94 significant in the initial stage of clouds occurrence.

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