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Supplement of

Surface and tropospheric ozone over East Asia and Southeast Asia from observations: distributions, trends, and variability

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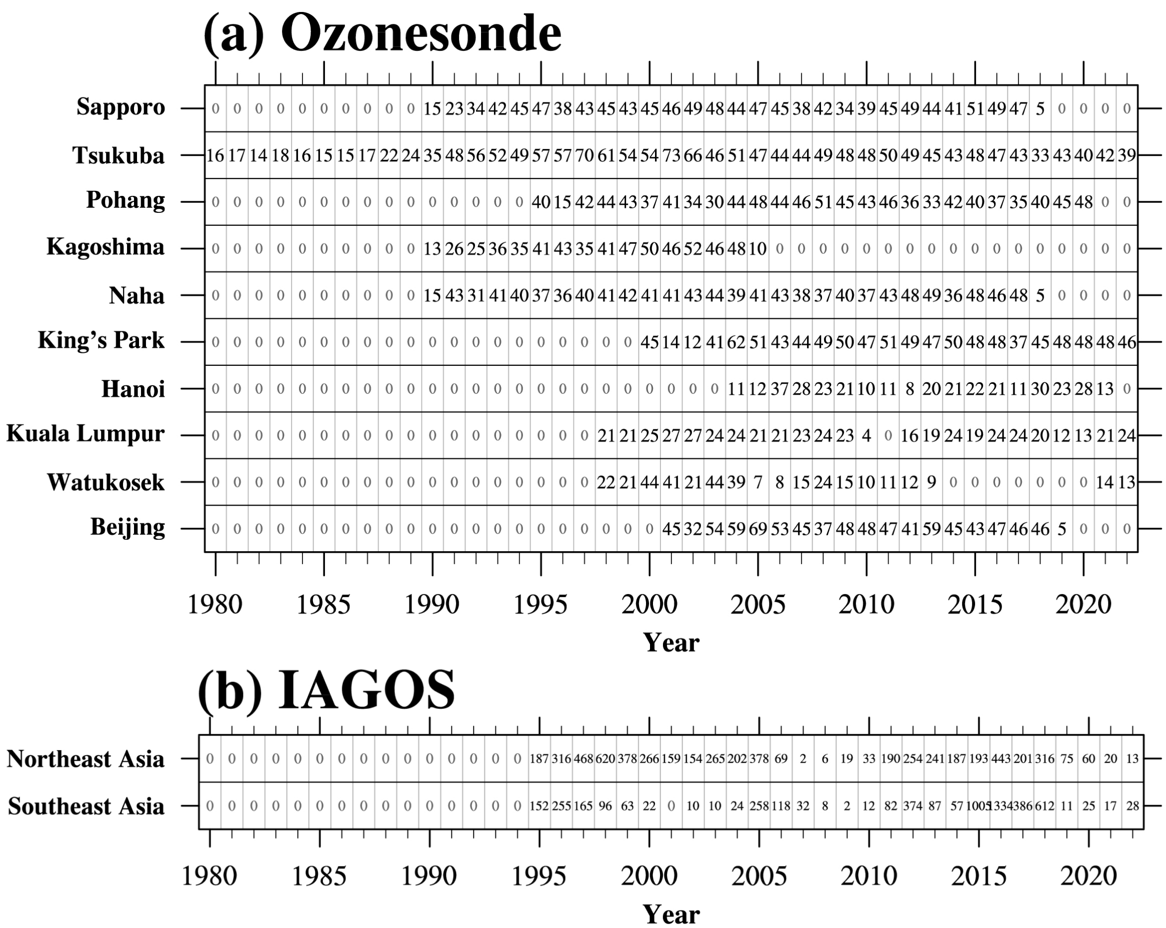

Figure S1. The number of all (a) ozonesonde and (b) IAGOS data used in this study.

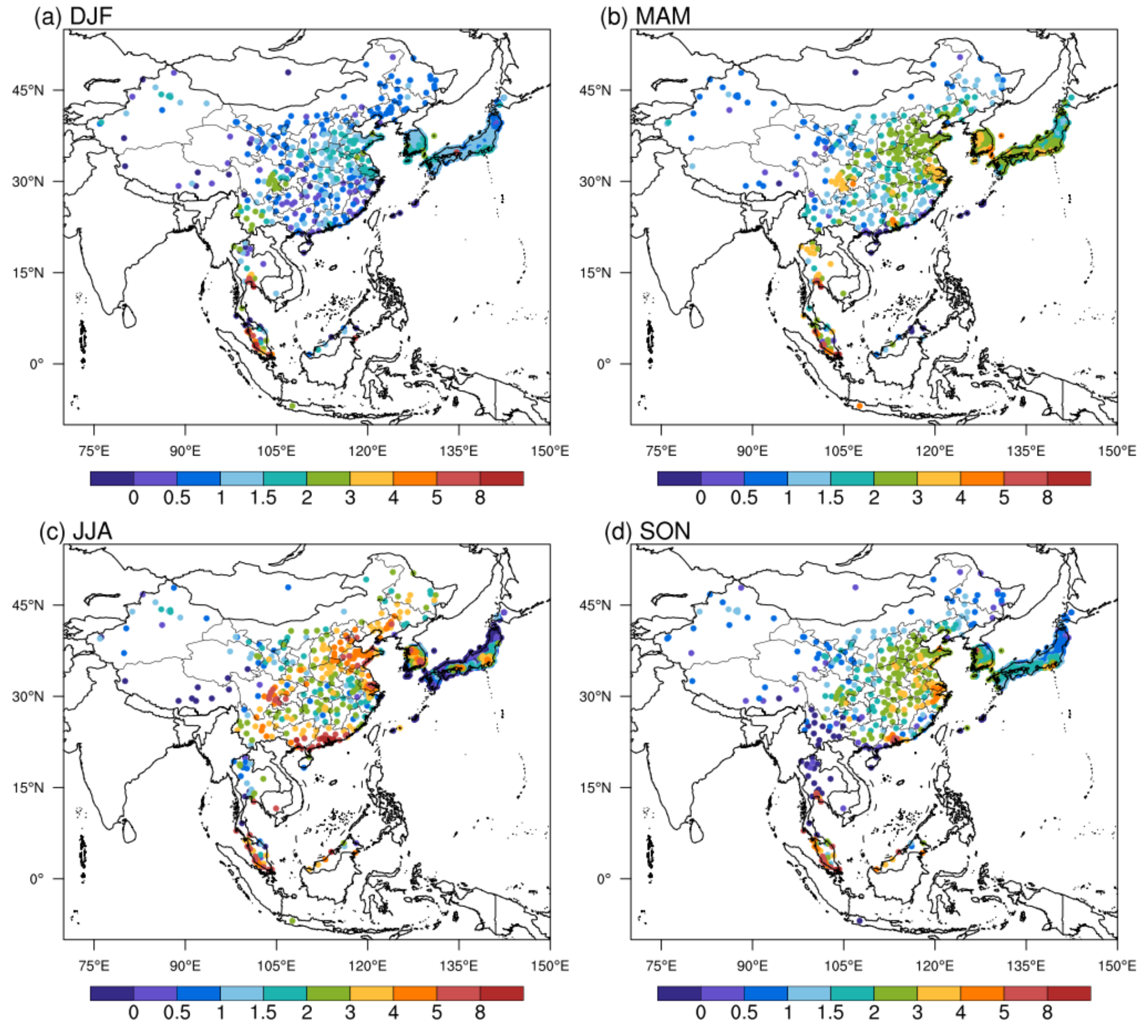

Figure S2. The observed 95th percentile regression slope (nmol mol^{-1} °C^{-1}) between daily surface MDA8 ozone and daily maximum 2-m air temperature (Tmax) in (a) DJF, (b) MAM, (c) JJA, and (d) SON averaged over 2017-2021.

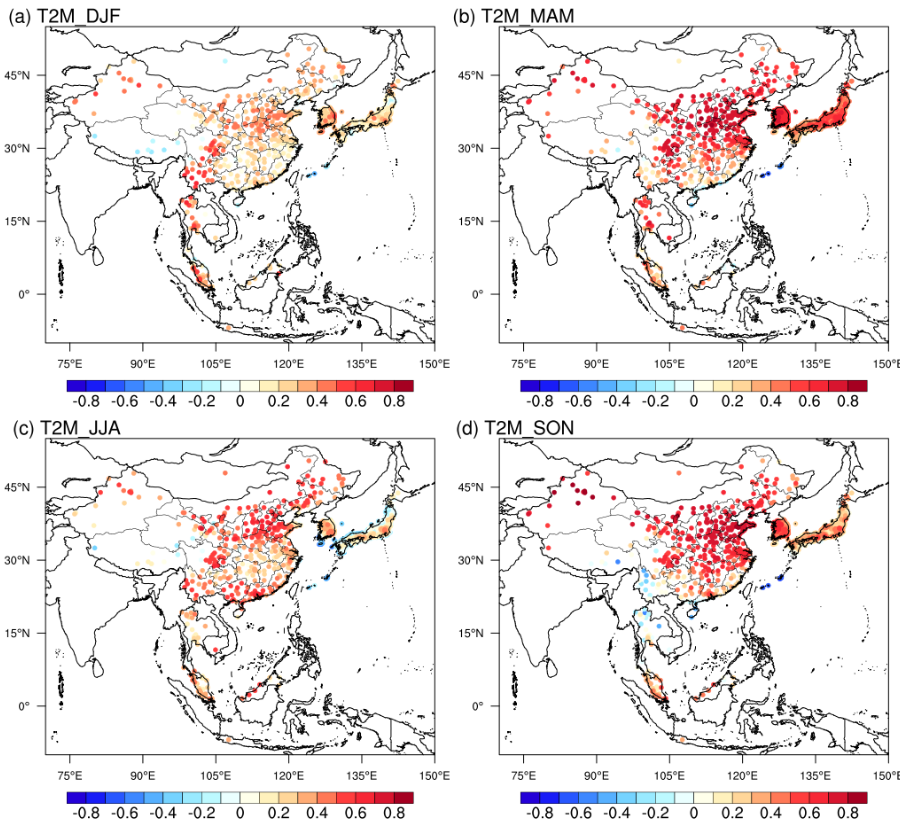

Figure S3. The correlation coefficients between observed daily surface MDA8 ozone and daily maximum 2-m air temperature in (a) DJF, (b) MAM, (c) JJA, and (d) SON averaged over 2017-2021.

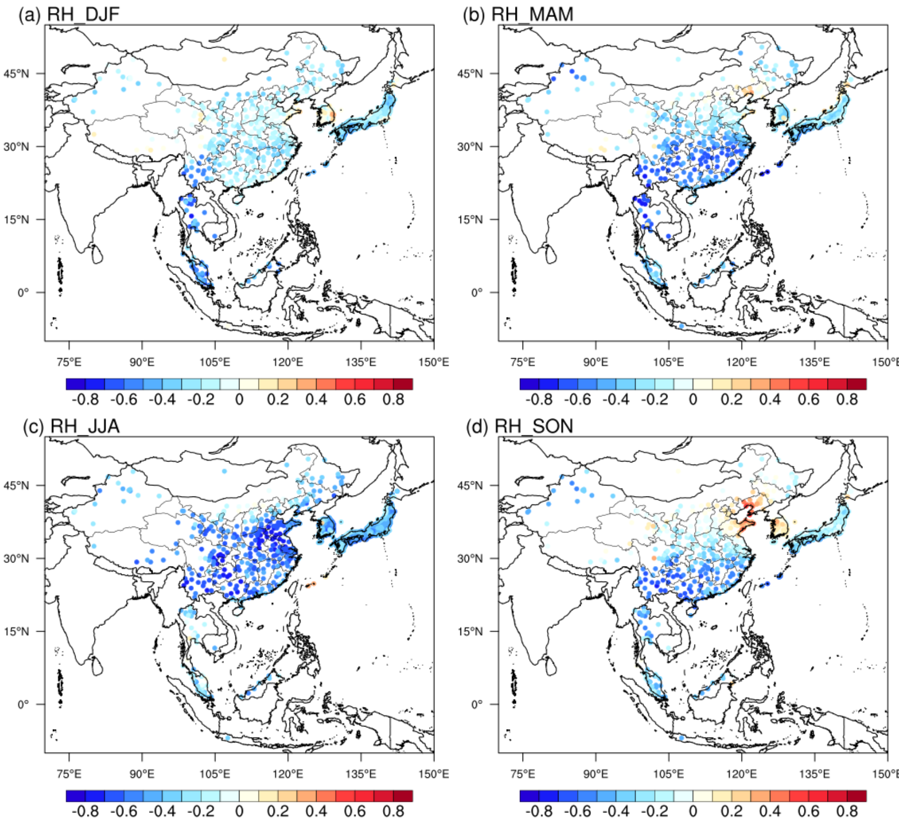

Figure S4. Same with Figure S3, but for relative humidity (RH).

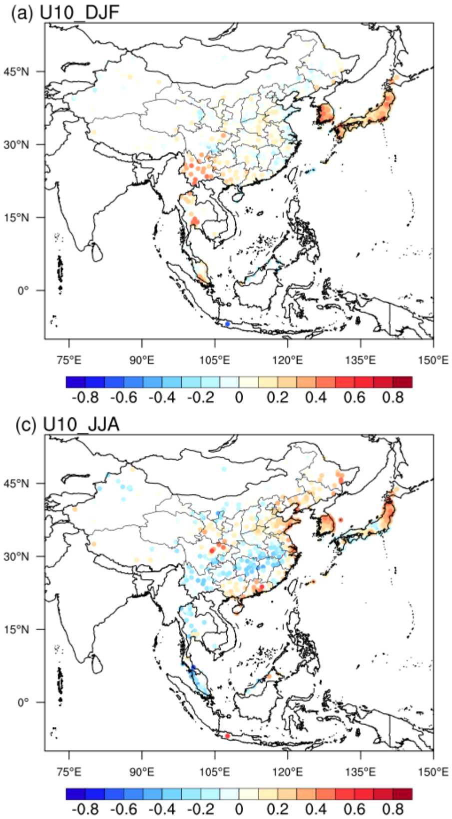

Figure S5. Same with Figure S3, but for 10-m zonal wind (U10).

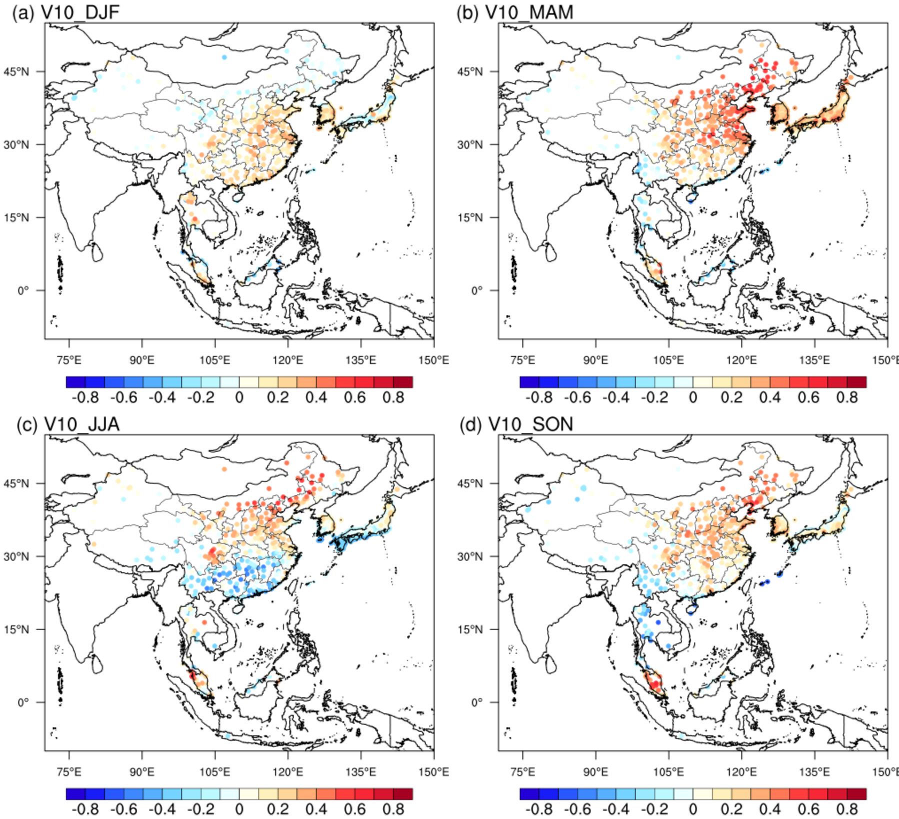

Figure S6. Same with Figure S3, but for 10-m meridional wind (V10).

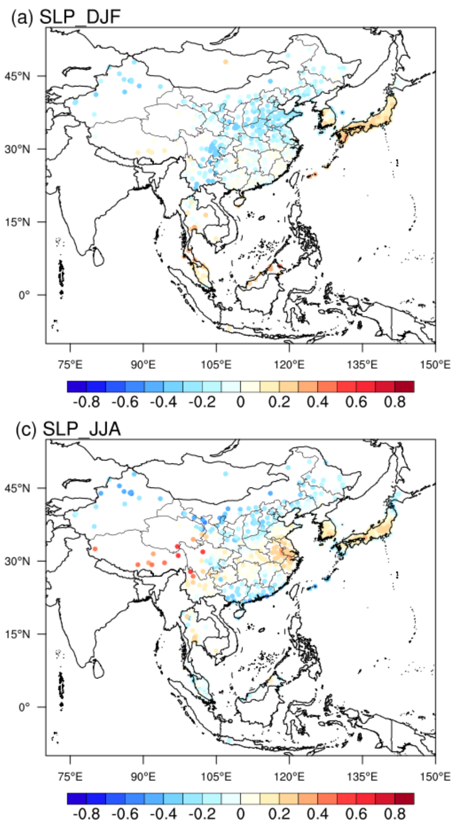

Figure S7. Same with Figure S3, but for sea level pressure (SLP).

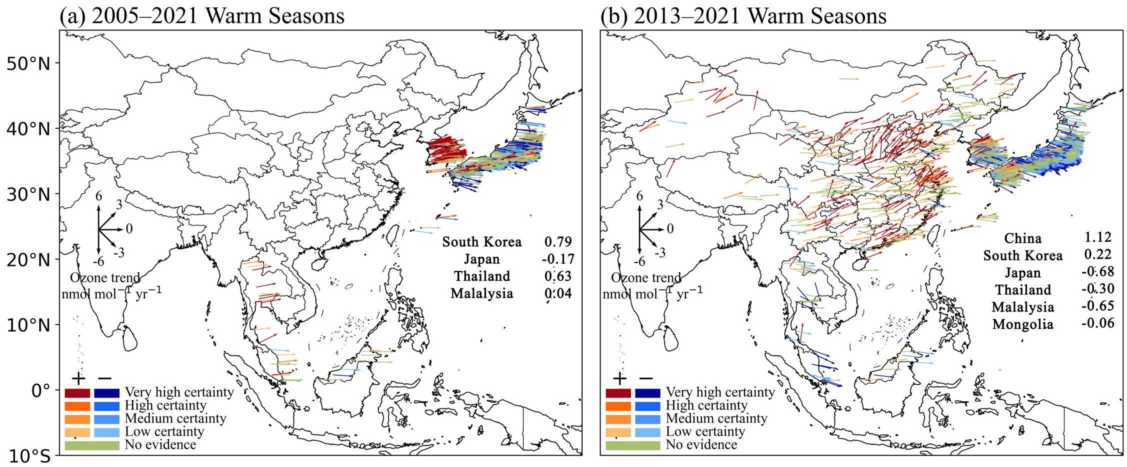

Figure S8. The observed ozone trends during warm seasons (April to September) over 2005-2021 (left) and 2013-2021 (right) over East Asia and Southeast Asia. It is noted that national surface ozone data in China is not available before 2013.

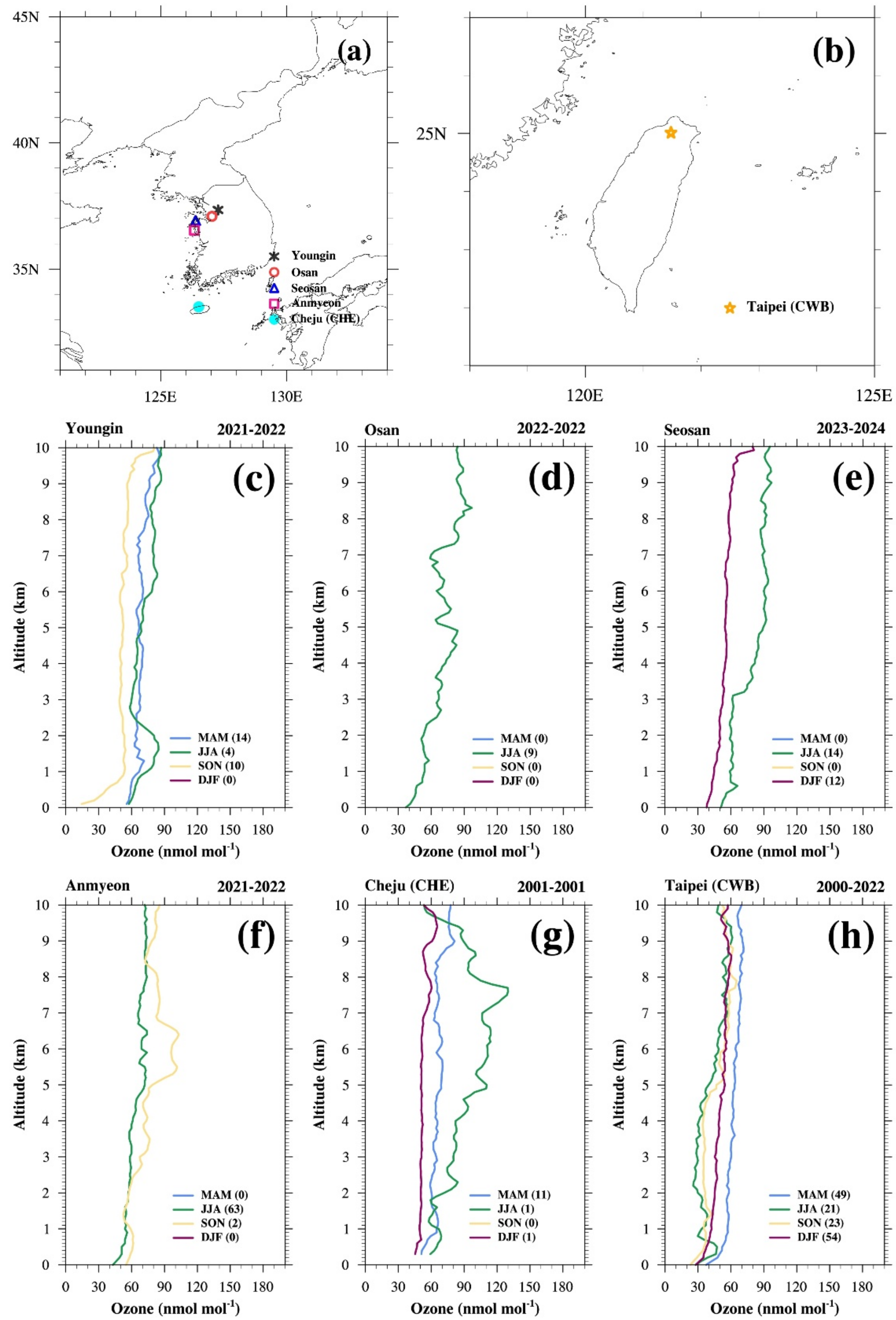

Figure S9. The location of (a) 5 ozonesonde sites in South Korea and (b) 1 site in Taiwan, not having measurements in continuous 10 years. Seasonal mean vertical ozone profiles at (c) Yongin, (d) Osan, (e) Seosan, (f) Anmyeon, (g) Cheju, and (h) Taipei were also provided in a same style of Figure 12.

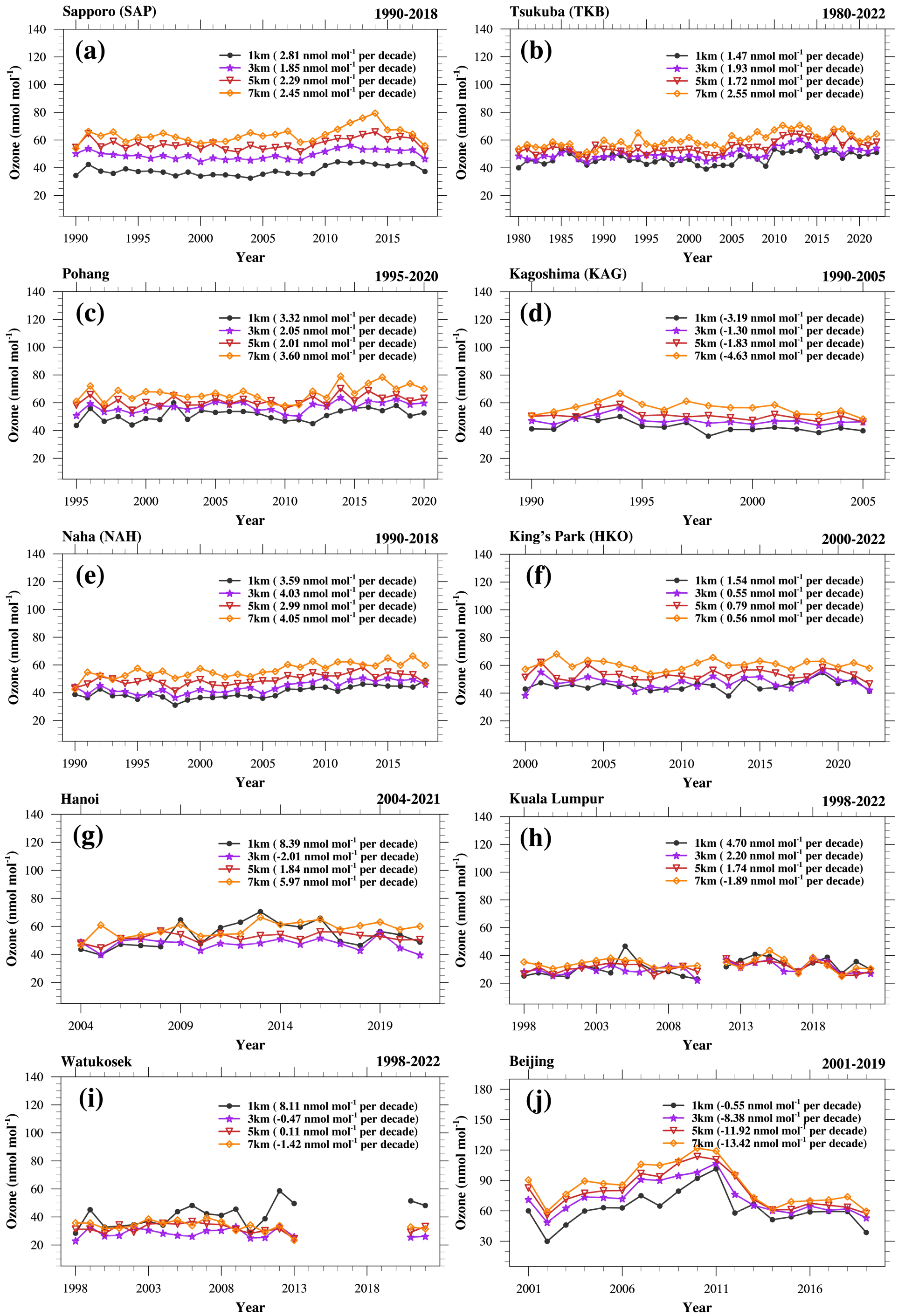

Figure S10. Annual median ozone variation of 1-km (black), 3-km (purple), 5-km (red), and 7-km (orange) altitudes at (a) Sapporo, (b) Tsukuba, (c) Pohang, (d) Kagoshima, (e) Naha, (f) King's park, (g) Hanoi, (h) Kuala Lumpur, (i) Watukosek, and (j) Beijing site.

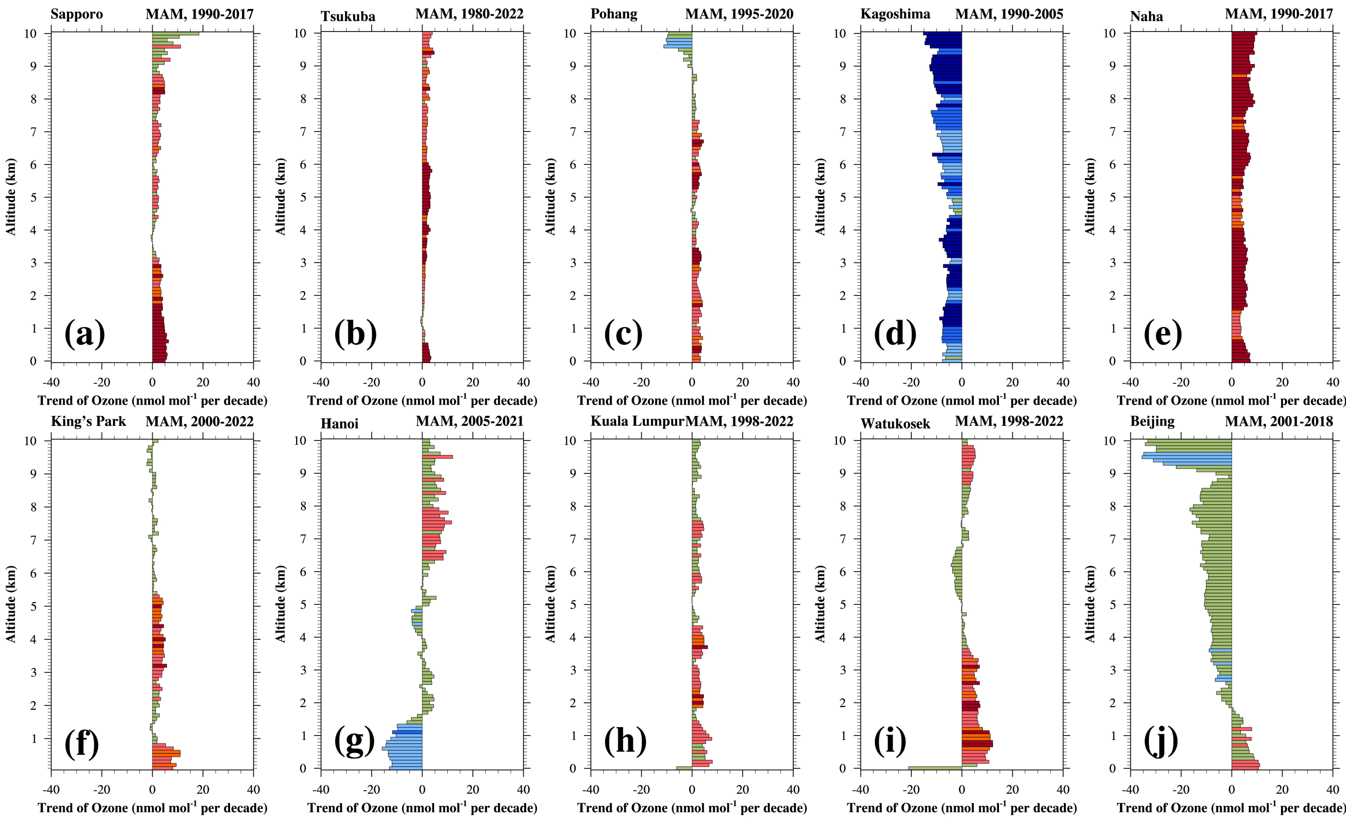

Figure S11. Long-term trends of spring (MAM) median ozone per 100-m range from 0 to 10 km altitude at (a) Sapporo, (b) Tsukuba, (c) Pohang, (d) Kagoshima, (e) Naha, (f) King's park, (g) Hanoi, (h) Kuala Lumpur, (i) Watukosek, and (j) Beijing site. Dark red color means positive trend values with p-value <= 0.05 (high certainty), orange color means positive trend values with 0.05 < p-value <= 0.10 (medium certainty), light orange color means positive trend values with 0.10 < p-value <= 0.33 (low certainty), light olive green color means positive/negative trend values with p-value > 0.33 (no evidence), light blue means negative trend values with 0.10 < p-value <= 0.33 (low certainty), median blue color means negative trend values with 0.05 < p-value <= 0.10 (medium certainty), and dark blue color means negative trend values with p-value <= 0.05 (high certainty).

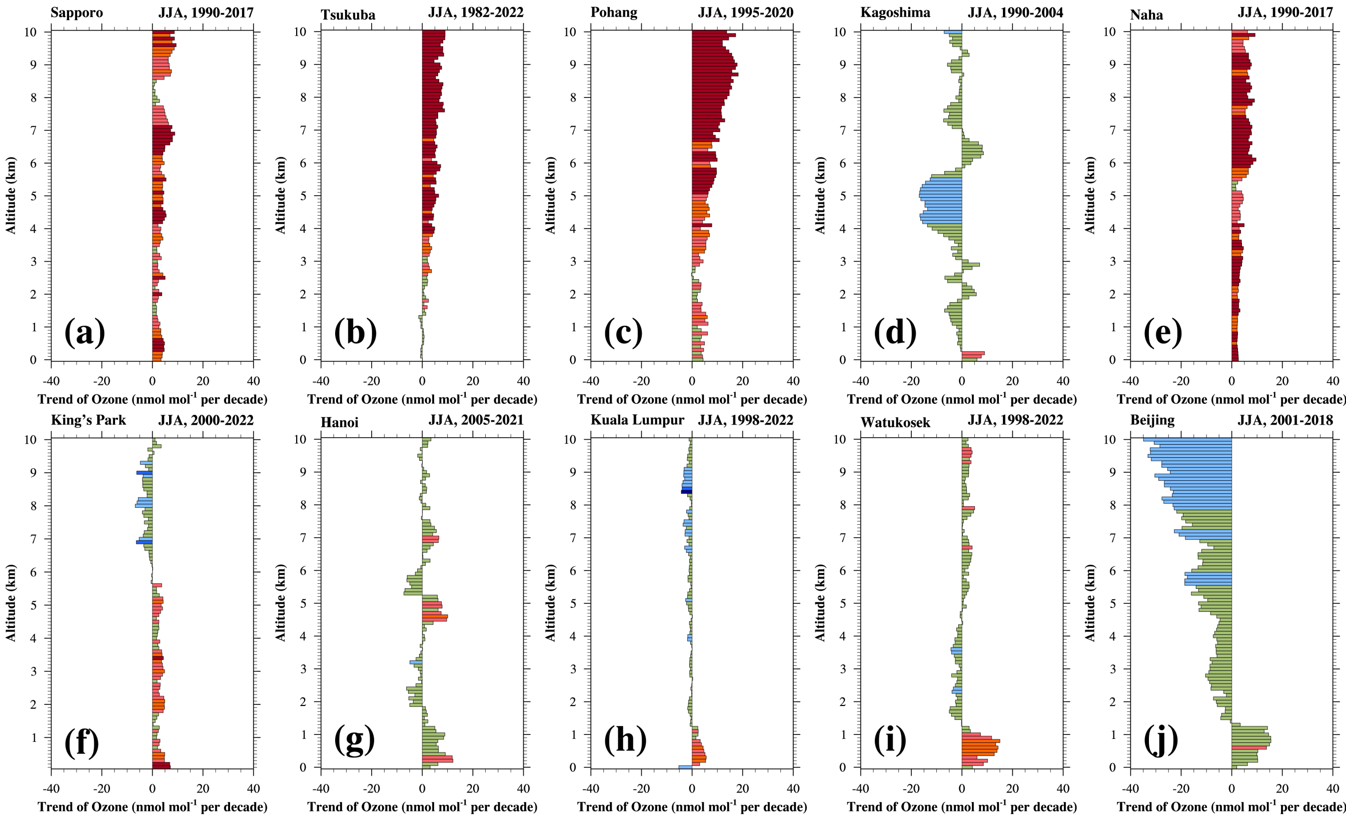

Figure S12. Same as Figure S11 but for long-term trends of summer (JJA) mean ozone.

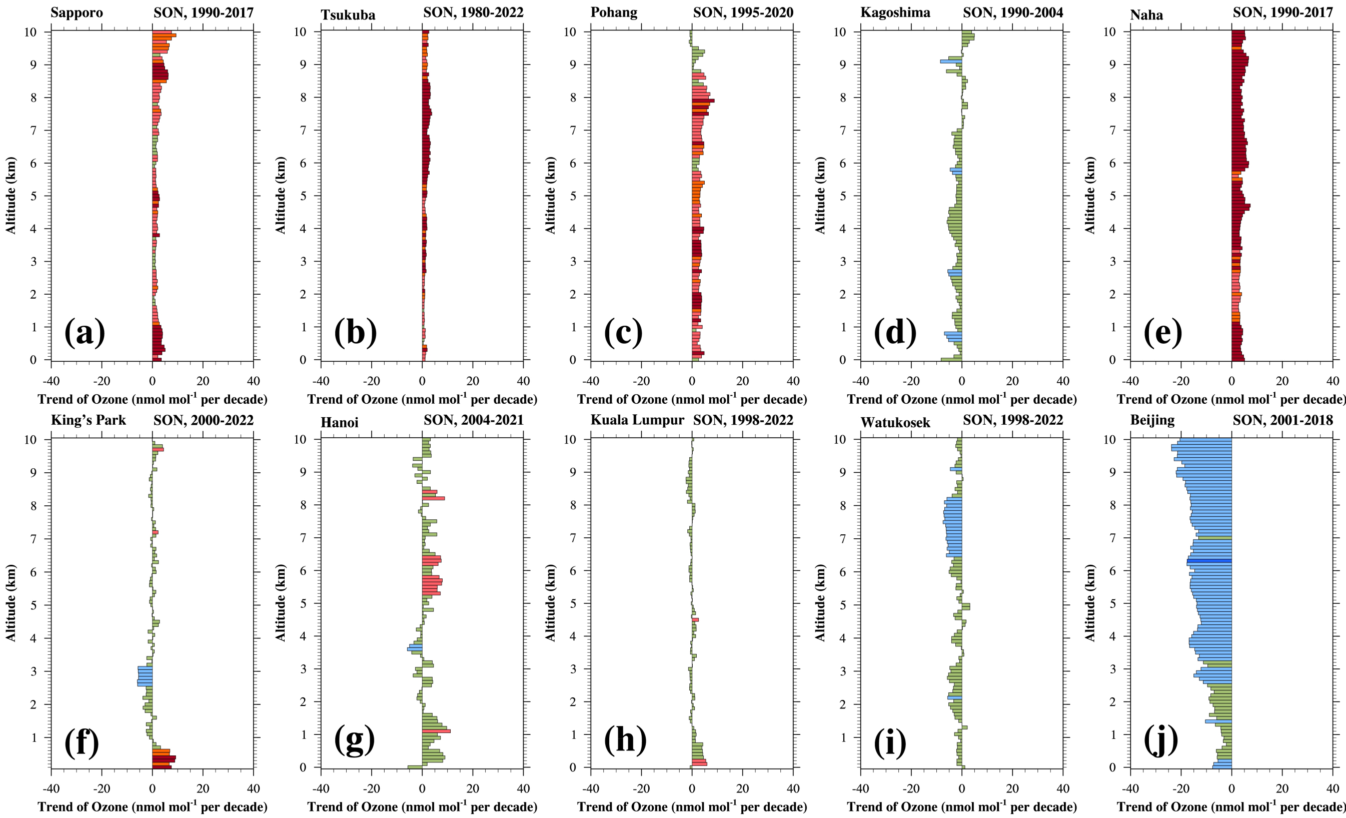

Figure S13. Same as Figure S11 but for long-term trends of autumn (SON) mean ozone.

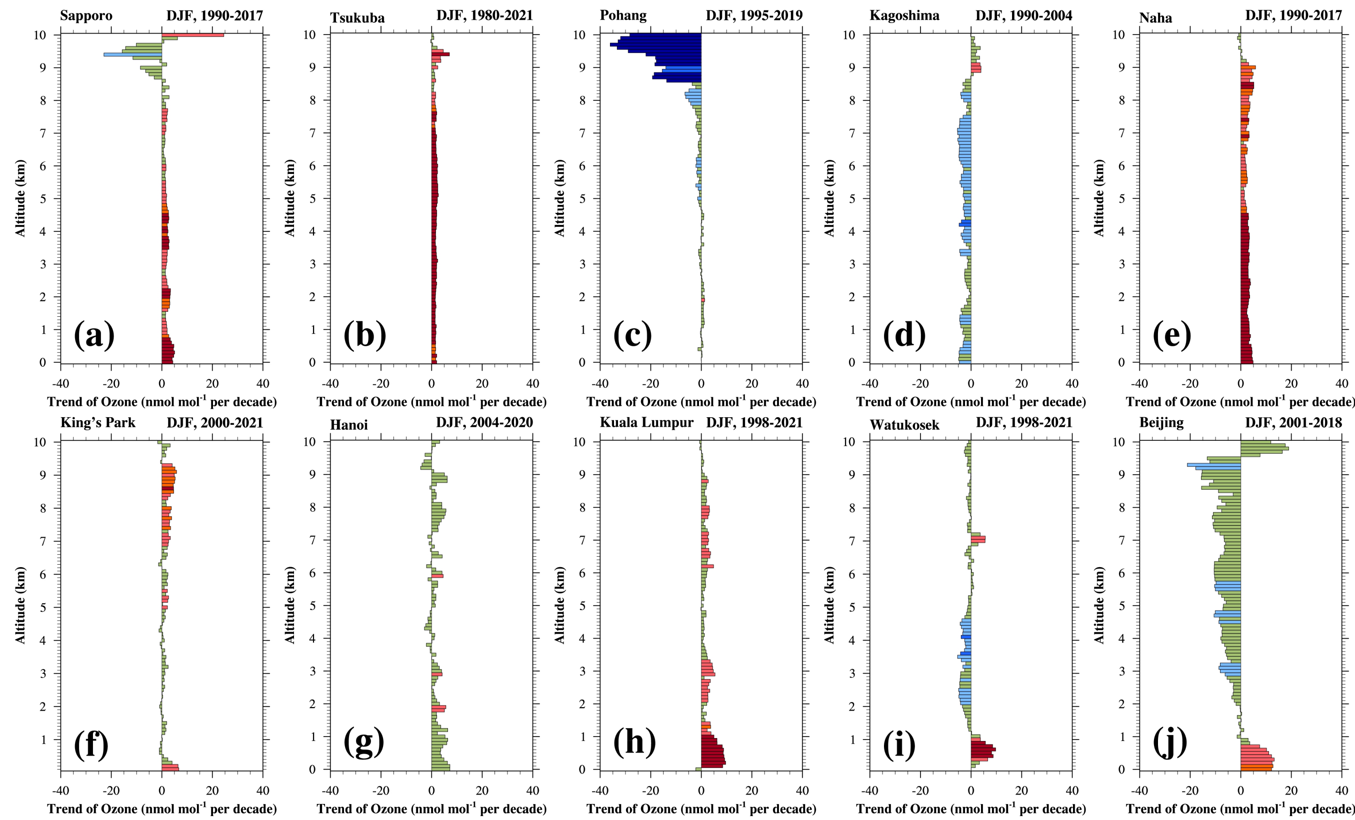

Figure S14. Same as Figure S11 but for long-term trends of winter (DJF) mean ozone.

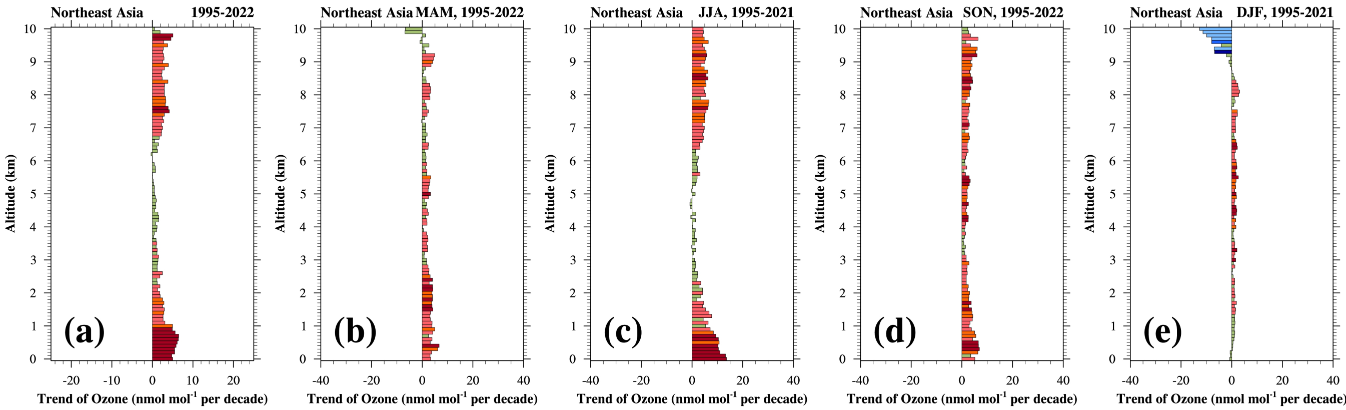

Figure S15. Long-term trends of (a) annual, (b) MAM, (c) JJA, (d) SON, and (e) DJF median ozone in Northeast Asia obtained from the IAGOS aircraft measurement. The period of used data is from 1995 to 2022. Dark red color means positive trend values with p-value <= 0.05, orange color means positive trend values with 0.05 < p-value <= 0.10, light orange color means positive trend values with 0.10 < p-value <= 0.33, light olive green color means positive/negative trend values with p-value > 0.33, light blue means negative trend values with 0.10 < p-value <= 0.33, median blue color means negative trend values with 0.05 < p-value <= 0.10, and dark blue color means negative trend values with p-value <= 0.05.

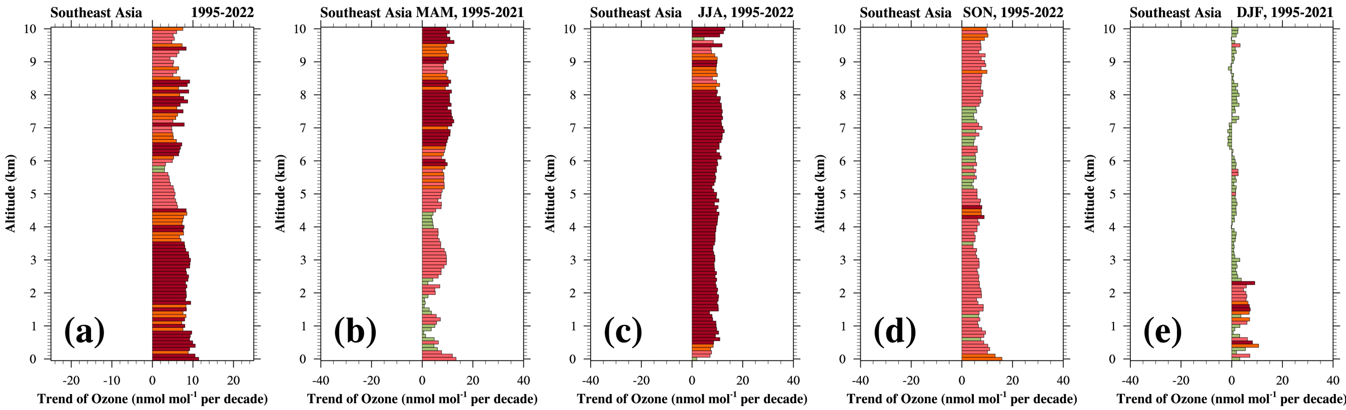

Figure S16. Same as Figure S15 but for long-term trends of Southeast Asia.

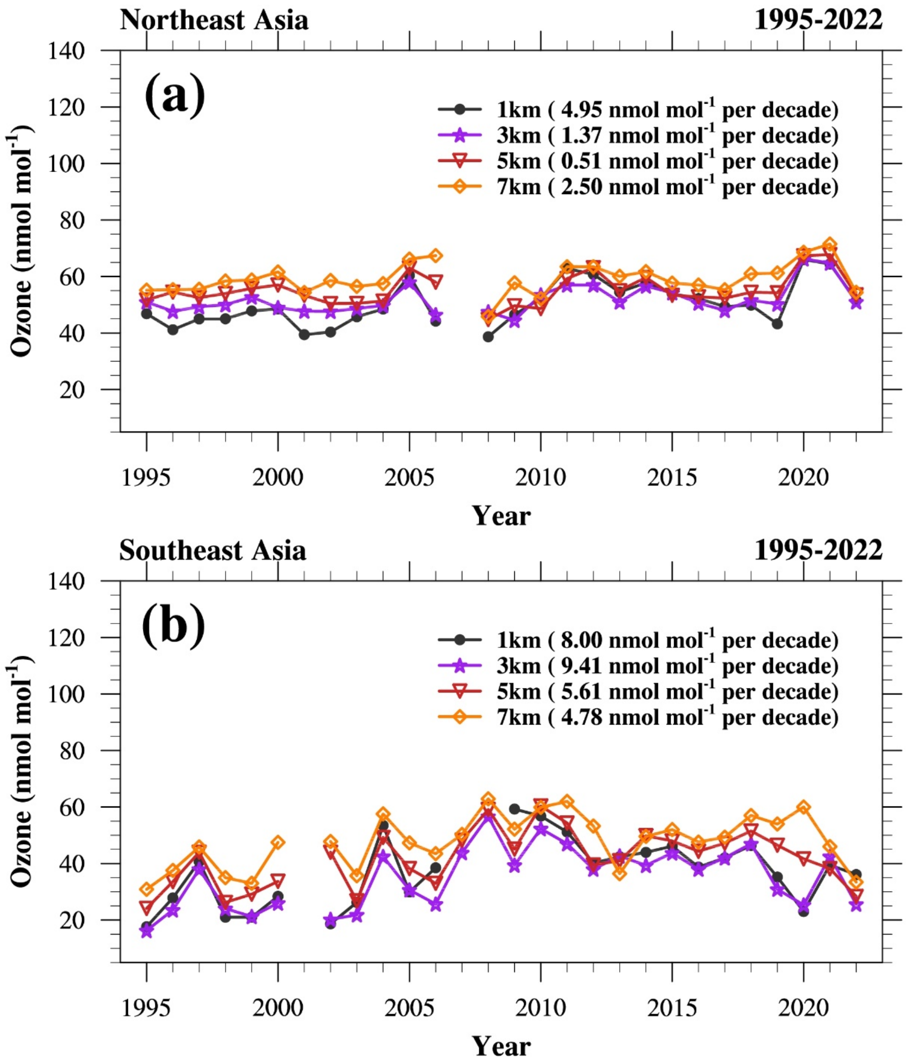

Figure S17. Annual median ozone variation of 1-km (black), 3-km (purple), 5-km (red), and 7-km (orange) altitudes in the (a) Northeast and (b) Southeast Asia, based on the analysis of IAGOS measurements from 1995 to 2022.

Table S1. The observed ozone trends (nmol mol^{-1} yr^{-1}) in 11 long-term sites over China. The * denotes *p*-value less than 0.1, and ** denotes *p*-value less than 0.01. The *p*-value is also given in the bracket.

Site	Metric	Spring	Summer	Autumn	Winter
Mt. Waliguan	MDA8	0.56±0.56* (0.06)	0.37±0.52 (0.14)	0.33±0.64 (0.26)	0.15±0.29 (0.27)
	24h mean	0.51±0.51* (0.07)	0.32±0.41 (0.19)	0.32±0.42 (0.20)	0.15±0.21 (0.23)
Shangdianzi	MDA8	0.85±0.97* (0.09)	0.73±0.92 (0.12)	0.26±0.95 (0.58)	0.32±0.35* (0.07)
	24h mean	0.55±0.67 (0.11)	0.64±0.73* (0.09)	0.05±0.62 (0.88)	0.23±0.34 (0.17)
Lin'an	MDA8	-0.16±1.48 (0.82)	0.06±0.88 (0.88)	-0.55±1.31 (0.40)	0.52±0.77 (0.18)
	24h mean	-0.27±1.02 (0.60)	0.02±0.58 (0.94)	-0.31±0.93 (0.50)	0.44±0.68 (0.19)
Longfengshan	MDA8	-1.67±0.79** (0.00)	-0.25±1.18 (0.67)	0.35±0.95 (0.44)	-1.24±0.65** (0.00)
	24h mean	-1.41±0.63** (0.00)	-0.24±0.86 (0.57)	0.24±0.62 (0.43)	-0.95±0.57** (0.00)
Xianggelila	MDA8	0.00±0.73 (0.99)	0.26±0.98 (0.59)	1.23±1.08** (0.03)	0.17±0.58 (0.55)
	24h mean	-0.20±0.67 (0.54)	0.06±0.81 (0.89)	0.53±0.89 (0.23)	0.00±0.63 (0.99)
Akedala	MDA8	-1.46±1.07** (0.01)	-3.65±0.89** (0.00)	-1.73±2.15 (0.1)	-0.88±1.65 (0.27)
	24h mean	-1.84±1.06** (0.00)	-2.90±0.91** (0.00)	-1.68±1.27** (0.01)	-0.44±1.71 (0.59)
Mt. Tai	MDA8	N.A.	0.83±1.98 (0.35)	N.A.	N.A.
	24h mean	N.A.	0.76±1.79 (0.35)	N.A.	N.A.
Gucheng	MDA8	0.89±2.06 (0.38)	0.89±1.40 (0.20)	-0.23±2.12 (0.82)	-0.12±0.76 (0.75)
	24h mean	0.26±1.30 (0.68)	0.46±0.99 (0.35)	-0.31±0.97 (0.52)	-0.20±0.41 (0.32)
Xunjuahui	MDA8	1.61±0.76** (0.00)	1.02±0.87** (0.02)	1.26±0.70** (0.00)	1.48±0.49** (0.00)
	24h mean	1.47±0.50** (0.00)	1.04±0.52** (0.00)	1.30±0.54** (0.00)	1.20±0.40** (0.00)
Guangzhou	24h mean	0.48±0.80 (0.24)	0.59±0.43** (0.01)	-0.37±0.69 (0.29)	0.29±0.48 (0.23)
Hong Kong	24h mean	0.41±0.42* (0.05)	0.45±0.33** (0.01)	-0.19±0.60 (0.52)	0.04±0.31 (0.82)

Table S2. The national air quality standard for MDA8 and MDA1 ozone over East Asia and Southeast Asia.

Country	MDA1 ozone ($\mu g\ m^{-3}$)	MDA8 ozone ($\mu g\ m^{-3}$)	Reference
China	160	100	https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/dqhjbh/dqhjzlbz/201203/t20120302_224165.shtml
Japan	120		https://www.env.go.jp/air/kijun/index.html
South Korea	200	120	https://www.airkorea.or.kr/eng/contents/contentView/?pMENU_NO=160&cntnts_no=16
Singapore	N.A.	120	https://www.nea.gov.sg/our-services/pollution-control/air-pollution/air-quality
Myanmar	N.A.	100	https://www.myanmar-responsiblebusiness.org/pdf/2015-12-29-National-Environmental-Quality_Emission_Guidelines_en.pdf
Indonesia	235	N.A.	http://www.brigc.net/zcyj/bgxz/2021/202112/P020211217480996607271.pdf
Vietnam	200	120	
Thailand	200	140	
Laos	200	100	
Malaysia	180	N.A.	
Cambodia	200	N.A.	http://www.epiac.org/uploadfile/2021/0820/20210820032403319.pdf
Philippine	N.A.	60	He et al., 2024

Table S3. Summary of ozonesonde sites used in this study.

Site ID	GAW platform ID	Site name	Country	Latitude	Longitude
SAP	12	Sapporo	Japan	43.06 °N	141.33 °E
TKB	14	Tsukuba	Japan	36.05 °N	140.13 °E
POH	332	Pohang	Korea	36.03 °N	129.38 °E
KAG	7	Kagoshima	Japan	31.55 °N	130.55 °E
NAH	190	Naha	Japan	26.20 °N	127.68 °E
HKO	344	King's park	China	22.31 °N	114.17 °E
AAR	330	Hanoi	Vietnam	21.02 °N	105.80 °E
SEP	443	Sepang Jaya	Malaysia	2.73 °N	101.70 °E
WAT	437	Watukosek	Indonesia	7.5 °S	112.65 °E
Beijing	N.A.	Beijing	China	39.8 °N	116.47 °E

Reference

He, J., Wang, Z., Guo, M., Gu, Y., Jiang, M., Hu J., Wu X., and Chai, F.: Research on global ambient air quality standards and future prospects of China's standards[J]. Res. Environ. Sci. (in Chinese), 37(9), 1897-1910, https://doi.org/10.13198/j.issn.1001-6929.2024.07.07, 2024.