Supplement of Atmos. Chem. Phys., 24, 41–63, 2024
https://doi.org/10.5194/acp-24-41-2024-supplement

Atmospheric Chemistry and Physics
Open Access

Supplement of

Utility of Geostationary Lightning Mapper-derived lightning NO emission estimates in air quality modeling studies

Peiyang Cheng et al.

Correspondence to: Peiyang Cheng (peiyang.cheng@hotmail.com, peiyang.cheng@nsstc.uah.edu)

Table S1: WRF physics, analysis nudging, and dynamics options used in Cheng et al. (2022). Bold texts indicate different dynamics options used in Cheng et al. (2022) as opposed to those of this study.

	Option	Setting
Physics	Microphysics	Morrison 2-moment scheme (Morrison et al., 2009)
	Cumulus	Multiscale Kain-Fritsch (Zheng et al., 2016)
	Radiation	RRTMG (Iacono et al., 2008)
	Surface layer	Pleim (Pleim, 2006)
	Land surface model (LSM)	Pleim-Xiu (Xiu and Pleim, 2001; Pleim and Xiu, 2003)
	Planetary boundary layer (PBL)	ACM2 (Pleim, 2007a,b)
Analysis nudging	Nudging height cutoff	Above the PBL or the ~1.5-km model layer, whichever is higher
	U, V nudging coefficient	3.0×10^{-4} s^{-1}
	T nudging coefficient	3.0×10^{-4} s^{-1}
	Q nudging coefficient	1.0×10^{-5} s^{-1}
Dynamics	Model dynamics	Non-hydrostatic
	Time integration	Runge-Kutta, third order
	Vertical coordinate	**Hybrid**
	Turbulence and mixing	Without vertical correction
	Eddy coefficient	Horizontal Smagorinsky, first order
	Sixth order diffusion	**No up-gradient**
	Upper level damping	**W-Rayleigh**
	Vertical velocity damping	**On (damping coefficient: 0.05)**
	Advection options	**Monotonic**

Table S2: CMAQ science options used in Cheng et al. (2022). Bold texts indicate different dynamics options used in Cheng et al. (2022) as opposed to those of this study (some were due to recent upgrades to the CMAQ model).

Science Option	Setting
Gas phase chemistry solver	CB6r3 (Luecken et al., 2019)
Aerosol chemistry module	**AERO6 (Nolte et al., 2015)**
Dry deposition scheme	M3Dry
In-line biogenic emission module	BEIS3
CTM_OCEAN_CHEM	Y
CTM_WB_DUST	Y
CTM_ERODE_AGLAND	**N**
CTM_WBDUST_BELD	BELD3
CTM_LTNG_NO	N
CTM_WVEL	**Y**
KZMIN	Y
CTM_ILDEPV	**Y**
CTM_MOSAIC	N
CTM_FST	N
CTM_ABFLUX	N
CTM_HGBIDI	N
CTM_SFC_HONO	Y
CTM_GRAV_SETL	Y
CTM_BIOGEMIS	Y
CTM_PT3DEMIS	**N**
CTM_ZERO_PCSOA	**N**

Table S3: Ground-level MDA8 ozone statistics over the model domain and geographic regions for June 2019. Bold numbers indicate better performance for each case. See Fig. 4 for the interpretation of geographical regions.

Region	Case	Record	OBS [ppbv]	MOD [ppbv]	MB [ppbv]	NMB [%]	cRMSE [ppbv]	NME [%]	R
Domain	CNTRL	34128	46.1	47.5	**1.4**	**3.0**	8.4	**14.2**	0.72
	LGTNO	34128	46.1	47.8	1.7	3.7	**8.3**	**14.2**	**0.73**
NE	CNTRL	5358	43.9	47.8	**3.9**	**8.9**	**7.3**	**14.8**	0.72
	LGTNO	5358	43.9	48.1	**4.2**	**9.5**	**7.3**	**14.9**	**0.73**
SE	CNTRL	5871	41.4	44.2	**2.8**	**6.8**	**7.6**	**15.7**	**0.79**
	LGTNO	5871	41.4	44.7	3.3	8.0	**7.6**	16.0	**0.79**
UM	CNTRL	8370	46.1	45.7	-0.4	-0.8	7.5	12.8	0.65
	LGTNO	8370	46.1	46.1	**0.0**	**0.0**	**7.4**	**12.6**	**0.66**
LM	CNTRL	3319	42.8	43.8	**1.0**	**2.2**	9.5	17.2	**0.73**
	LGTNO	3319	42.8	44.2	1.4	3.3	**9.4**	**17.1**	**0.73**
RM	CNTRL	5868	53.1	54.5	**1.4**	**2.6**	8.5	11.9	0.49
	LGTNO	5868	53.1	54.7	1.6	3.0	**8.4**	**11.8**	**0.50**
PC	CNTRL	5342	48.1	48.4	**0.2**	**0.5**	**9.7**	15.7	**0.74**
	LGTNO	5342	48.1	48.4	0.3	0.6	**9.7**	**15.6**	**0.74**

Table S4: Ground-level MDA8 ozone statistics over the model domain and geographic regions for July 2019. Bold numbers indicate better performance for each case. See Fig. 4 for the interpretation of geographical regions.

Region	Case	Record	OBS [ppbv]	MOD [ppbv]	MB [ppbv]	NMB [%]	cRMSE [ppbv]	NME [%]	R
Domain	CNTRL	35158	44.6	45.6	**1.0**	**2.2**	**8.3**	**14.4**	**0.75**
	LGTNO	35158	44.6	46.1	1.4	3.2	**8.3**	14.5	**0.75**
NE	CNTRL	5462	45.6	48.4	**2.8**	**6.2**	**7.7**	**13.9**	**0.78**
	LGTNO	5462	45.6	48.8	3.2	7.1	7.8	14.3	0.77
SE	CNTRL	5975	39.9	44.1	**4.2**	**10.4**	6.9	**15.9**	**0.77**
	LGTNO	5975	39.9	44.9	5.0	12.4	**6.8**	16.8	**0.77**
UM	CNTRL	8618	44.6	44.8	**0.3**	**0.6**	**7.2**	**12.7**	**0.72**
	LGTNO	8618	44.6	45.3	0.7	1.5	**7.2**	**12.7**	**0.72**
LM	CNTRL	3542	38.3	42.4	**4.1**	**10.6**	7.1	**17.3**	0.82
	LGTNO	3542	38.3	42.8	4.5	11.6	**7.0**	17.6	**0.83**
RM	CNTRL	6009	50.2	48.6	-1.6	-3.2	7.9	12.2	0.55
	LGTNO	6009	50.2	49.1	**-1.1**	**-2.2**	**7.7**	**11.8**	**0.57**
PC	CNTRL	5552	46.8	44.7	-2.2	-4.7	**10.3**	**17.0**	**0.80**
	LGTNO	5552	46.8	44.7	**-2.1**	**-4.6**	**10.3**	**17.0**	**0.80**

Table S5: Ground-level MDA8 ozone statistics over the model domain and geographic regions for September 2019. Bold numbers indicate better performance for each case. See Fig. 4 for the interpretation of geographical regions.

Region	Case	Record	OBS [ppbv]	MOD [ppbv]	MB [ppbv]	NMB [%]	cRMSE [ppbv]	NME [%]	R
Domain	CNTRL	33844	42.8	44.3	**1.6**	**3.6**	7.4	13.7	0.77
	LGTNO	33844	42.8	44.6	1.8	4.2	**7.3**	**13.6**	**0.78**
NE	CNTRL	5263	39.6	42.9	**3.3**	**8.3**	**6.8**	**15.4**	0.79
	LGTNO	5263	39.6	42.9	3.4	8.5	**6.8**	15.5	**0.80**
SE	CNTRL	5706	45.1	46.0	**0.9**	**2.1**	6.6	**11.3**	0.75
	LGTNO	5706	45.1	46.3	1.2	2.6	**6.5**	**11.3**	**0.76**
UM	CNTRL	8488	40.0	41.1	**1.1**	**2.8**	**6.3**	**12.7**	**0.81**
	LGTNO	8488	40.0	41.3	1.3	3.2	**6.3**	**12.7**	**0.81**
LM	CNTRL	3341	42.9	44.0	**1.1**	**2.6**	7.4	14.0	0.74
	LGTNO	3341	42.9	44.5	1.5	3.6	**7.3**	**13.9**	**0.75**
RM	CNTRL	5835	45.6	47.4	**1.8**	**3.9**	7.5	13.3	0.70
	LGTNO	5835	45.6	47.8	2.2	4.9	**7.2**	**13.0**	**0.72**
PC	CNTRL	5211	44.6	45.8	**1.2**	**2.8**	9.5	16.7	**0.77**
	LGTNO	5211	44.6	45.9	1.4	3.0	**9.4**	**16.6**	**0.77**

Table S6: Ground-level daily mean NO_x statistics over the model domain and geographic regions for June 2019. Bold numbers indicate better performance for each case. See Fig. 4 for the interpretation of geographical regions.

Region	Case	Record	OBS [ppbv]	MOD [ppbv]	MB [ppbv]	NMB [%]	cRMSE [ppbv]	NME [%]	R
Domain	CNTRL	10650	7.94	6.75	**-1.19**	**-14.90**	**7.55**	**55.30**	**0.54**
	LGTNO	10650	7.94	6.75	**-1.19**	**-14.90**	**7.55**	**55.30**	**0.54**
NE	CNTRL	1580	10.18	8.27	**-1.92**	**-18.80**	**9.07**	**55.50**	**0.50**
	LGTNO	1580	10.18	8.27	**-1.92**	**-18.80**	**9.07**	**55.50**	**0.50**
SE	CNTRL	1081	10.06	6.93	**-3.12**	**-31.10**	**7.96**	**51.30**	**0.57**
	LGTNO	1081	10.06	6.93	-3.13	**-31.10**	**7.96**	**51.30**	**0.57**
UM	CNTRL	1173	10.12	7.45	**-2.67**	**-26.40**	**7.29**	**46.20**	**0.56**
	LGTNO	1173	10.12	7.45	**-2.67**	**-26.40**	**7.29**	**46.20**	**0.56**
LM	CNTRL	1618	6.93	7.01	**0.08**	1.11	**6.92**	**58.70**	**0.46**
	LGTNO	1618	6.93	7.01	**0.08**	**1.10**	**6.92**	**58.70**	**0.46**
RM	CNTRL	2552	4.30	4.03	**-0.27**	-6.32	**4.24**	**53.40**	**0.74**
	LGTNO	2552	4.30	4.03	**-0.27**	**-6.28**	**4.24**	**53.40**	**0.74**
PC	CNTRL	2646	8.89	7.94	**-0.95**	**-10.70**	**8.92**	**60.80**	**0.41**
	LGTNO	2646	8.89	7.94	**-0.95**	**-10.70**	**8.92**	**60.80**	**0.41**

Table S7: Ground-level daily mean NO_x statistics over the model domain and geographic regions for July 2019. Bold numbers indicate better performance for each case. See Fig. 4 for the interpretation of geographical regions.

Region	Case	Record	OBS [ppbv]	MOD [ppbv]	MB [ppbv]	NMB [%]	cRMSE [ppbv]	NME [%]	R
Domain	CNTRL	10790	7.87	7.15	**-0.72**	**-9.16**	**7.65**	**56.20**	**0.54**
	LGTNO	10790	7.87	7.15	**-0.72**	-9.18	**7.65**	**56.20**	**0.54**
NE	CNTRL	1540	10.04	9.35	**-0.70**	**-6.94**	**8.88**	**57.60**	**0.50**
	LGTNO	1540	10.04	9.34	**-0.70**	-6.98	**8.88**	**57.60**	**0.50**
SE	CNTRL	1067	10.22	7.74	**-2.47**	**-24.20**	**7.83**	**50.50**	**0.54**
	LGTNO	1067	10.22	7.74	-2.48	**-24.20**	**7.83**	**50.50**	**0.54**
UM	CNTRL	1191	9.53	7.25	**-2.28**	**-24.00**	**7.04**	**45.70**	**0.56**
	LGTNO	1191	9.53	7.25	-2.29	**-24.00**	**7.04**	**45.70**	**0.56**
LM	CNTRL	1636	6.04	7.04	**1.00**	16.60	6.75	66.30	**0.43**
	LGTNO	1636	6.04	7.03	**1.00**	**16.50**	**6.74**	**66.20**	**0.43**
RM	CNTRL	2601	4.24	3.88	-0.36	-8.41	3.88	**51.20**	**0.77**
	LGTNO	2601	4.24	3.88	**-0.35**	**-8.36**	**3.87**	**51.20**	**0.77**
PC	CNTRL	2755	9.54	8.79	**-0.75**	**-7.83**	**9.72**	**60.60**	**0.45**
	LGTNO	2755	9.54	8.79	**-0.75**	**-7.83**	**9.72**	**60.60**	**0.45**

Table S8: Ground-level daily mean NO_x statistics over the model domain and geographic regions for September 2019. Bold numbers indicate better performance for each case. See Fig. 4 for the interpretation of geographical regions.

Region	Case	Record	OBS [ppbv]	MOD [ppbv]	MB [ppbv]	NMB [%]	cRMSE [ppbv]	NME [%]	R
Domain	CNTRL	10545	9.21	7.99	**-1.22**	**-13.20**	**8.53**	**53.60**	**0.57**
	LGTNO	10545	9.21	7.99	**-1.22**	**-13.20**	**8.53**	**53.60**	**0.57**
NE	CNTRL	1552	11.14	10.20	**-0.94**	**-8.43**	**9.69**	**56.20**	**0.51**
	LGTNO	1552	11.14	10.20	**-0.94**	-8.44	**9.69**	**56.20**	**0.51**
SE	CNTRL	999	11.55	7.93	**-3.62**	**-31.40**	**9.15**	**52.20**	**0.60**
	LGTNO	999	11.55	7.93	**-3.62**	**-31.40**	**9.15**	**52.20**	**0.60**
UM	CNTRL	1153	11.04	8.86	**-2.18**	**-19.80**	**8.31**	**45.50**	**0.57**
	LGTNO	1153	11.04	8.85	**-2.18**	**-19.80**	**8.31**	**45.50**	**0.57**
LM	CNTRL	1709	7.27	8.76	**1.49**	**20.50**	**7.18**	**62.40**	**0.51**
	LGTNO	1709	7.27	8.75	**1.49**	**20.50**	**7.18**	**62.40**	**0.51**
RM	CNTRL	2563	5.15	4.39	**-0.77**	**-14.90**	**5.83**	**51.70**	**0.72**
	LGTNO	2563	5.15	4.39	**-0.77**	**-14.90**	**5.83**	**51.70**	**0.72**
PC	CNTRL	2569	11.63	9.37	**-2.26**	**-19.40**	**10.00**	**53.30**	**0.52**
	LGTNO	2569	11.63	9.37	**-2.26**	-19.50	**10.00**	**53.30**	**0.52**

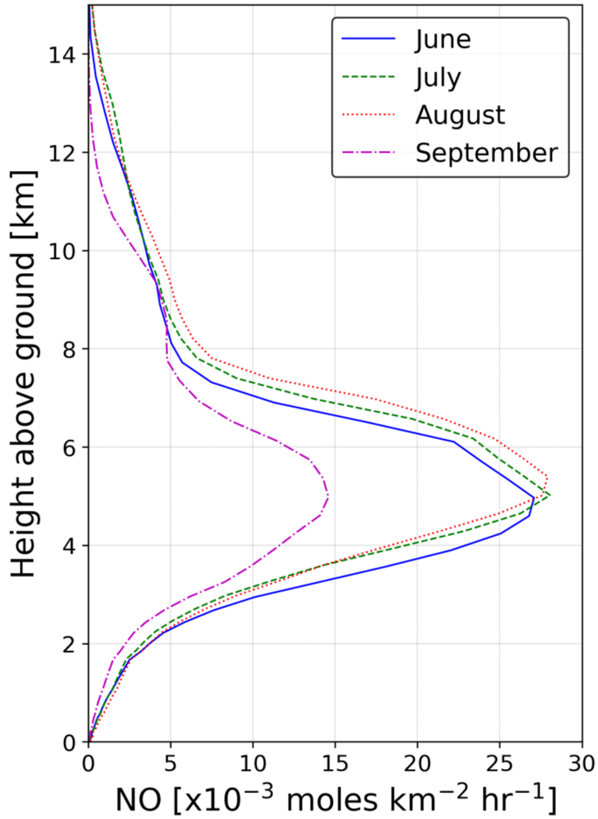

Figure S1: Vertical distribution of monthly mean LNO emission profiles produced by the LNO emission model for June through September 2019 across the entire CONUS model domain.

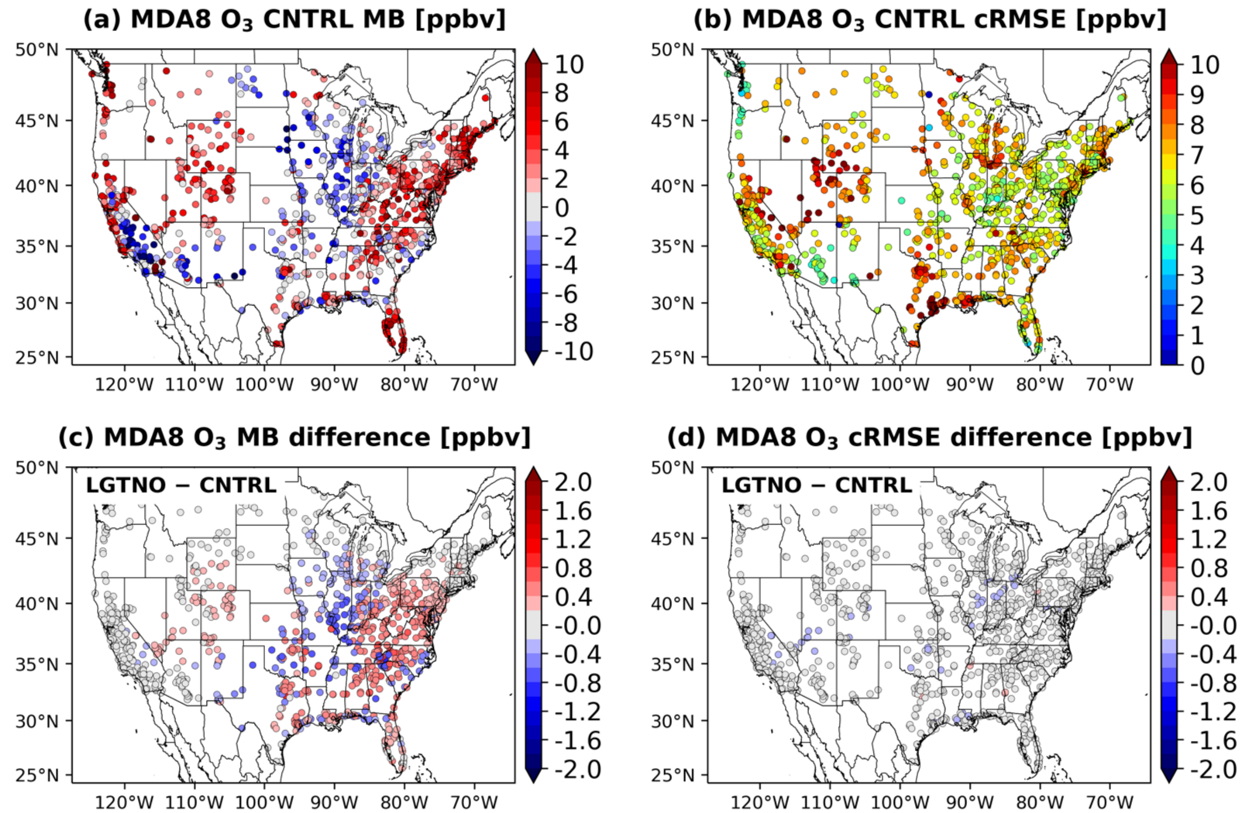

Figure S2: Spatial distribution of ground-level MDA8 ozone statistics for June 2019. (a) Mean bias of the CNTRL; (b) centered RMSE of the CNTRL; (c) absolute mean bias difference between the LGTNO and the CNTRL; (d) centered RMSE difference between the LGTNO and the CNTRL. In (c) and (d), negative and positive values represent improved and degraded statistics when including lightning NO emission, respectively.

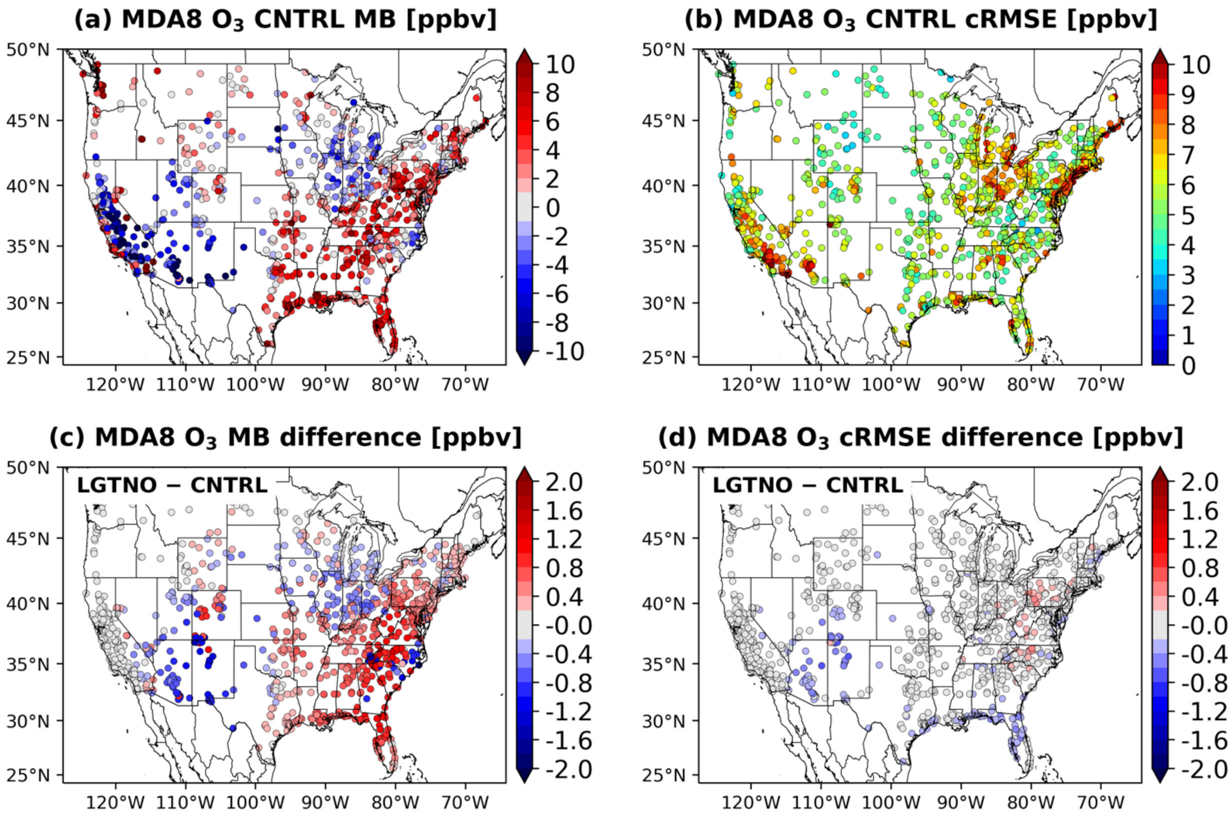

Figure S3: Spatial distribution of ground-level MDA8 ozone statistics for July 2019. (a) Mean bias of the CNTRL; (b) centered RMSE of the CNTRL; (c) absolute mean bias difference between the LGTNO and the CNTRL; (d) centered RMSE difference between the LGTNO and the CNTRL. In (c) and (d), negative and positive values represent improved and degraded statistics when including lightning NO emission, respectively.

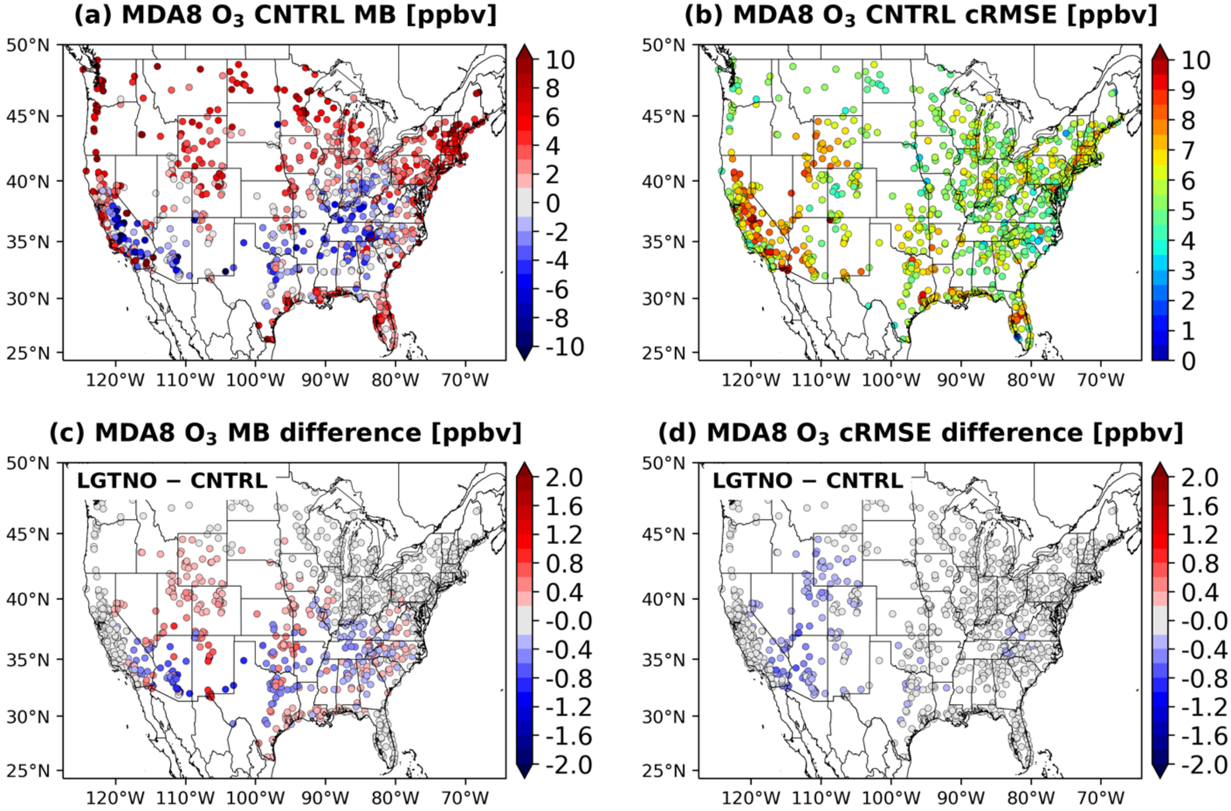

Figure S4: Spatial distribution of ground-level MDA8 ozone statistics for September 2019. (a) Mean bias of the CNTRL; (b) centered RMSE of the CNTRL; (c) absolute mean bias difference between the LGTNO and the CNTRL; (d) centered RMSE difference between the LGTNO and the CNTRL. In (c) and (d), negative and positive values represent improved and degraded statistics when including lightning NO emission, respectively.

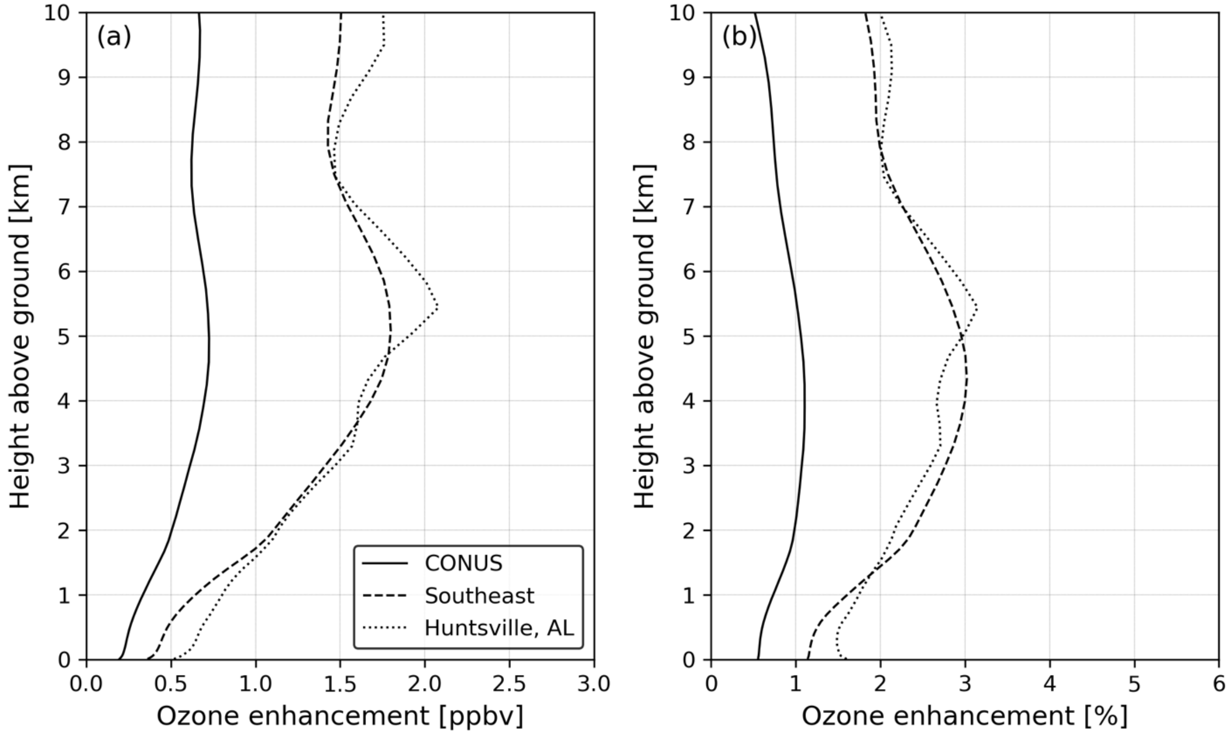

Figure S5: Vertical distribution of average ozone enhancement due to lightning NO emission during June 2019 for the CONUS, the southeast U.S. (arbitrarily selected 25–40°N, 75–95°W for computation), and Huntsville, AL. (a) Ozone enhancement in ppbv; (b) ozone enhancement in percent.

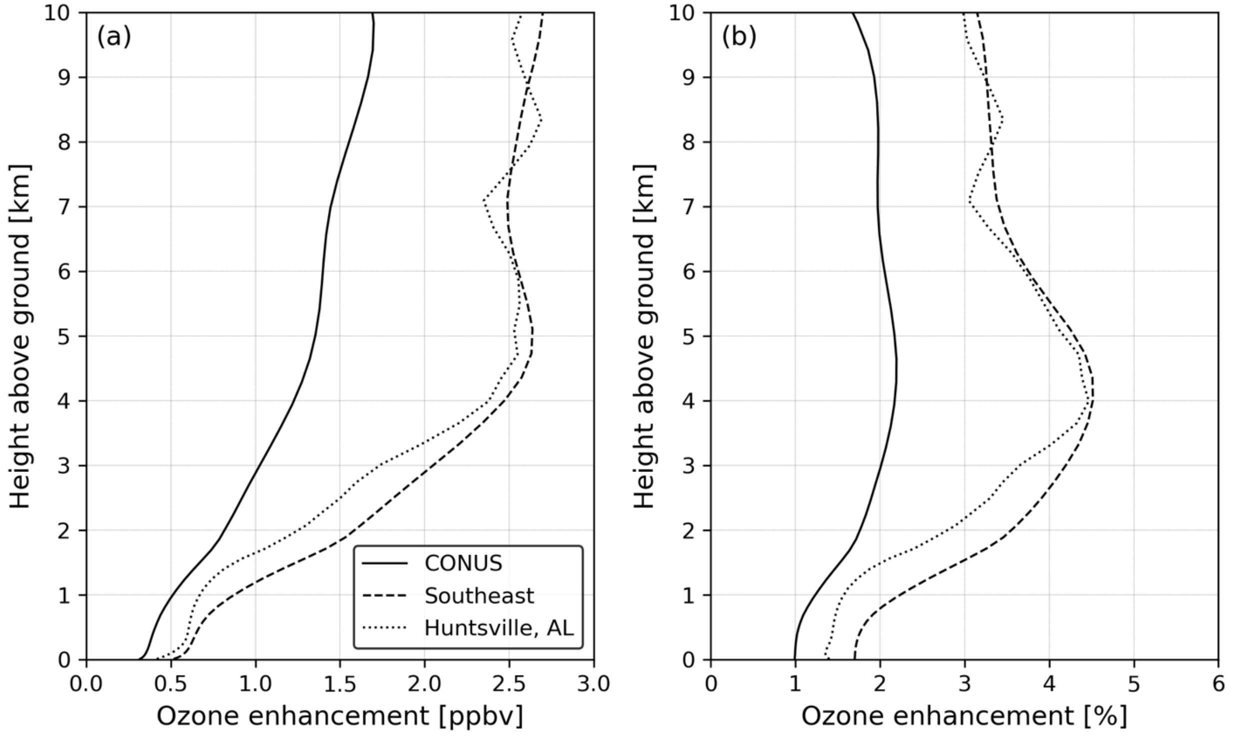

Figure S6: Vertical distribution of average ozone enhancement due to lightning NO emission during July 2019 for the CONUS, the southeast U.S. (arbitrarily selected 25–40°N, 75–95°W for computation), and Huntsville, AL. (a) Ozone enhancement in ppbv; (b) ozone enhancement in percent.

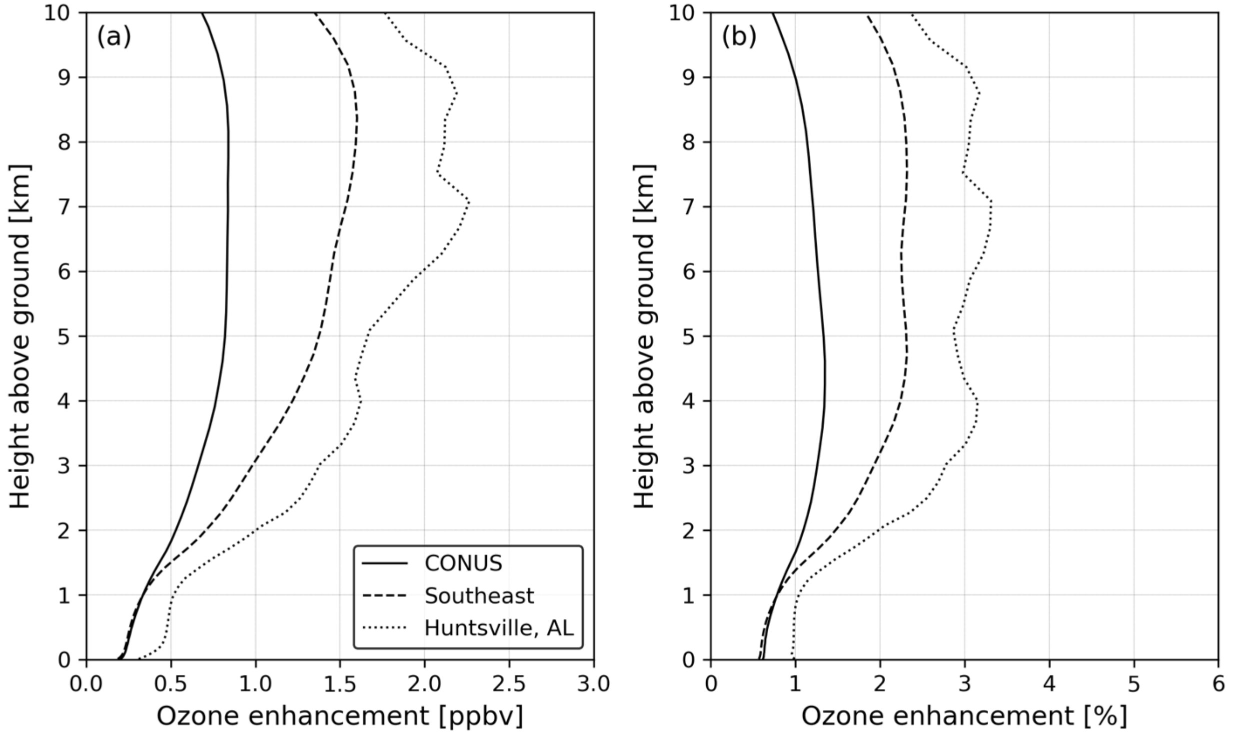

Figure S7: Vertical distribution of average ozone enhancement due to lightning NO emission during September 2019 for the CONUS, the southeast U.S. (arbitrarily selected 25–40°N, 75–95°W for computation), and Huntsville, AL. (a) Ozone enhancement in ppbv; (b) ozone enhancement in percent.

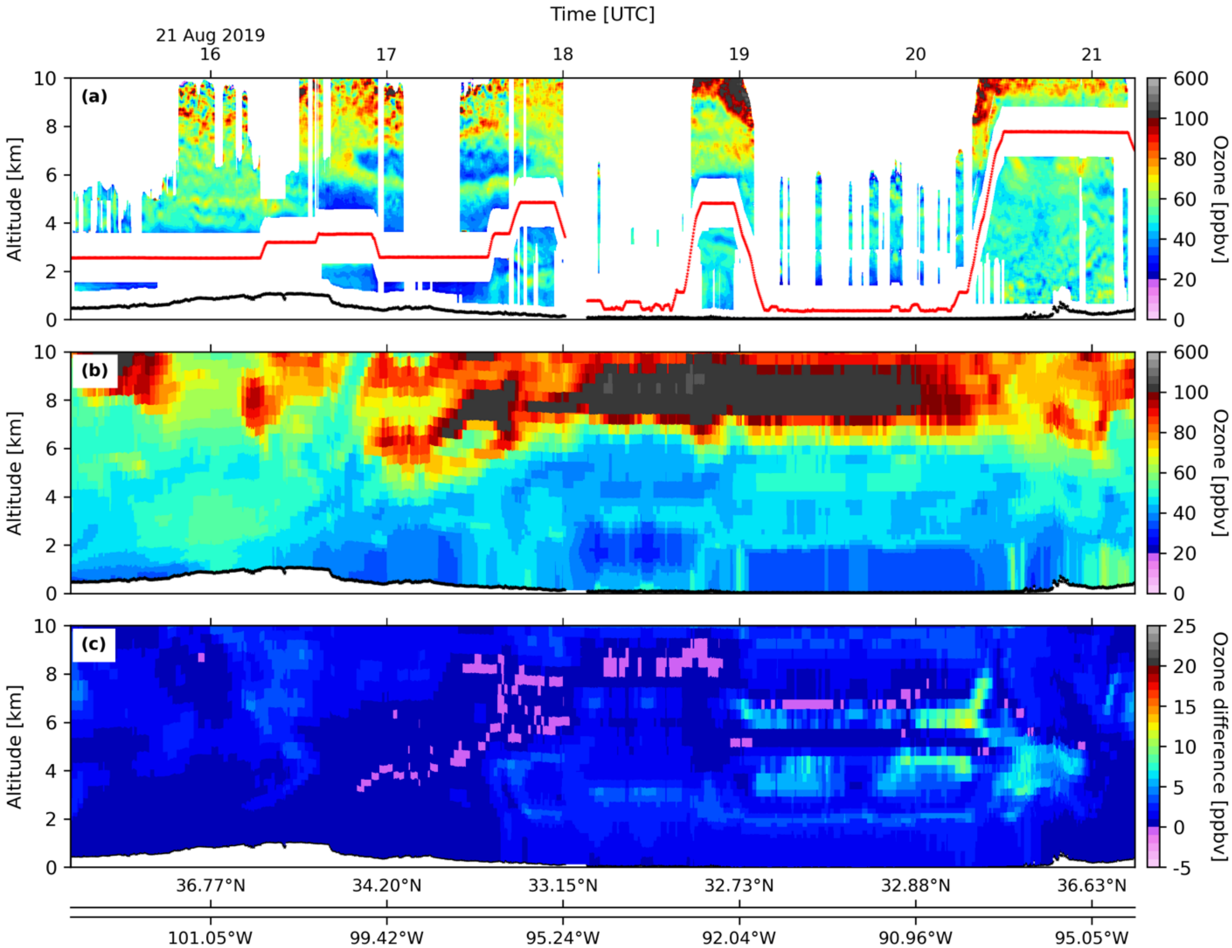

Figure S8: Time-height cross sections of lidar-measured and model-simulated ozone mixing ratio along the FIREX-AQ flight track on 21 August 2019. (a) Lidar-measured ozone profiles; (b) simulated ozone mixing ratio by the CNTRL model run; (c) ozone difference between the LGTNO and the CNTRL.

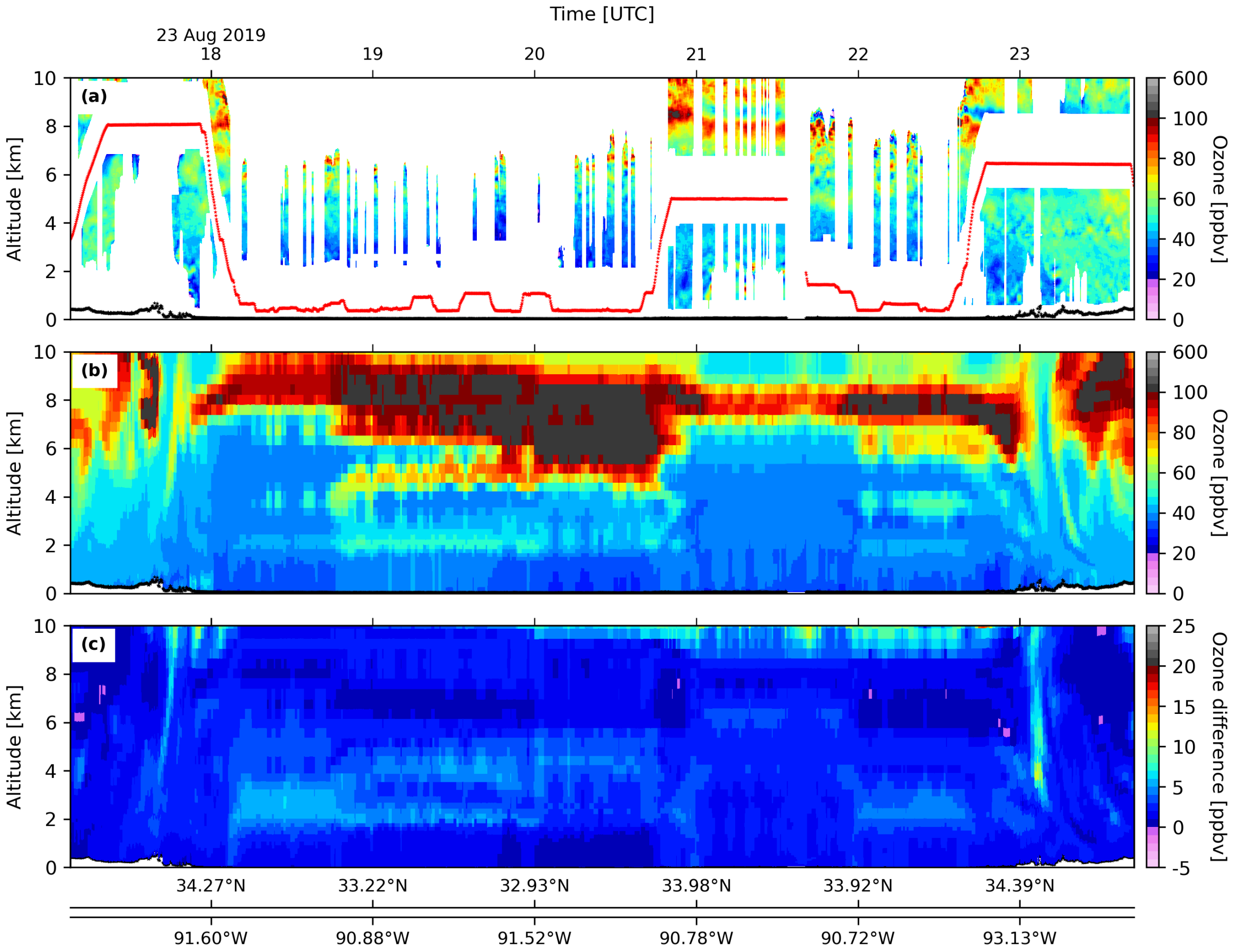

Figure S9: Time-height cross sections of lidar-measured and model-simulated ozone mixing ratio along the FIREX-AQ flight track on 23 August 2019. (a) Lidar-measured ozone profiles; (b) simulated ozone mixing ratio by the CNTRL model run; (c) ozone difference between the LGTNO and the CNTRL.

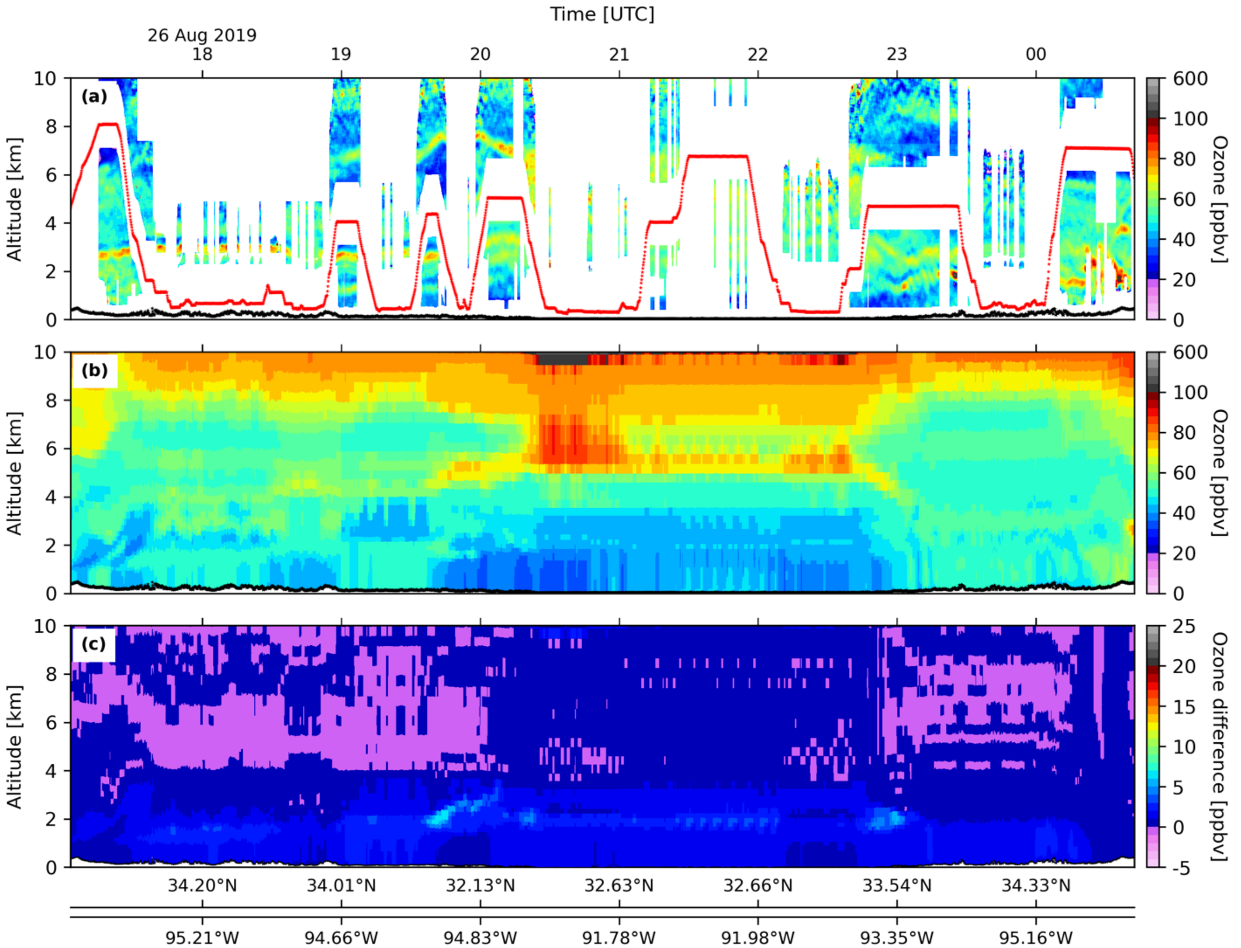

Figure S10: Time-height cross sections of lidar-measured and model-simulated ozone mixing ratio along the FIREX-AQ flight track on 26 August 2019. (a) Lidar-measured ozone profiles; (b) simulated ozone mixing ratio by the CNTRL model run; (c) ozone difference between the LGTNO and the CNTRL.