Supplement of Atmos. Chem. Phys., 20, 3373–3396, 2020
https://doi.org/10.5194/acp-20-3373-2020-supplement

Atmospheric Chemistry and Physics
Open Access
EGU

Supplement of

Modeling stratospheric intrusion and trans-Pacific transport on tropospheric ozone using hemispheric CMAQ during April 2010 – Part 1: Model evaluation and air mass characterization for stratosphere–troposphere transport

Syuichi Itahashi et al.

Correspondence to: Syuichi Itahashi (isyuichi@criepi.denken.or.jp)

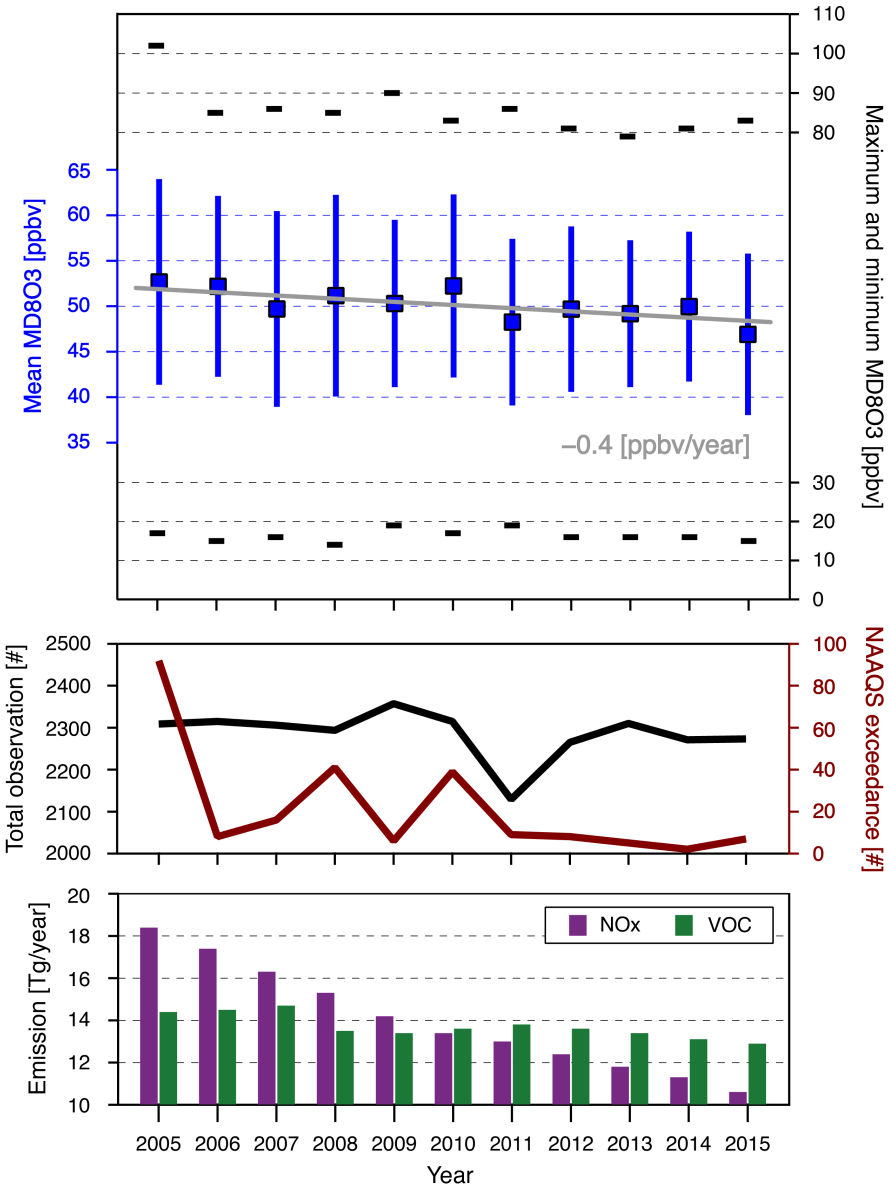

Figure S1. Long-term trends from 2005 to 2015 as before and after 5 years comparison to 2010. (Top) Mean (blue color, left-axis) and maximum and minimum (black color, right-axis) MD8O3 on April. (Center) Number of total observations (black color, left-axis) and exceedance of NAAQS (dark red color, right-axis; 75 ppbv is used as a criterion as 2010) on April. (Bottom) Annual NO_x (purple) and VOCs (green) emissions in the U.S.A. except wildfire (https://www.epa.gov/air-emissions-inventories/air-pollutant-emissions-trends-data).

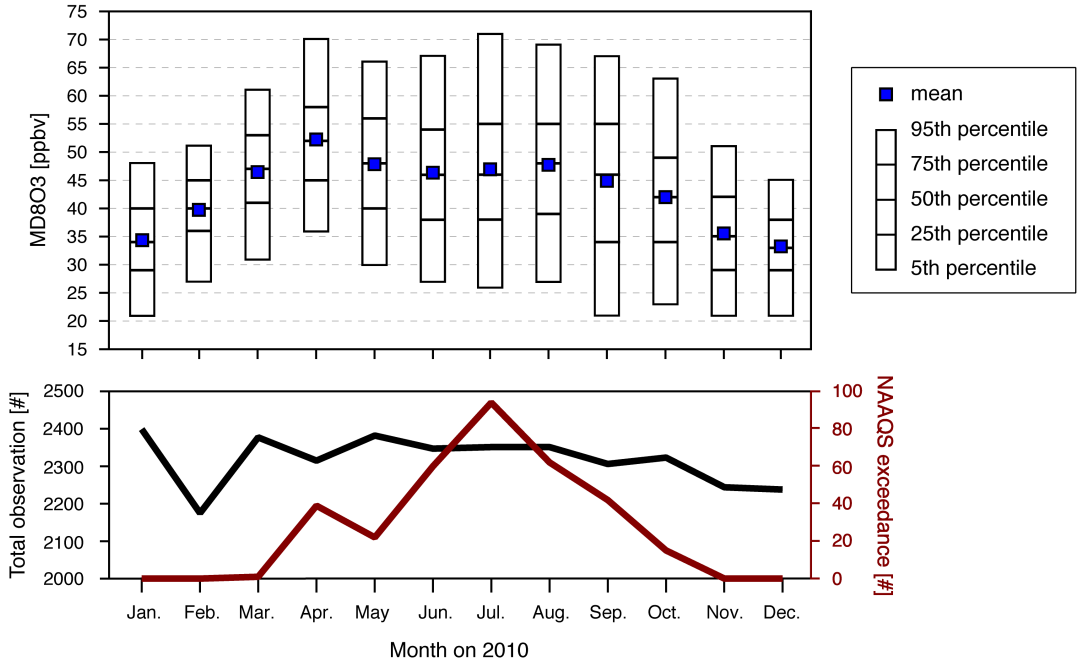

Figure S2. (Top) Monthly mean and percentiles of MD8O3 on 2010. (Bottom) Number of total observations (black color, left-axis) and exceedance of NAAQS (dark red color, right-axis; 75 ppbv is used as a criterion as 2010) on 2010.

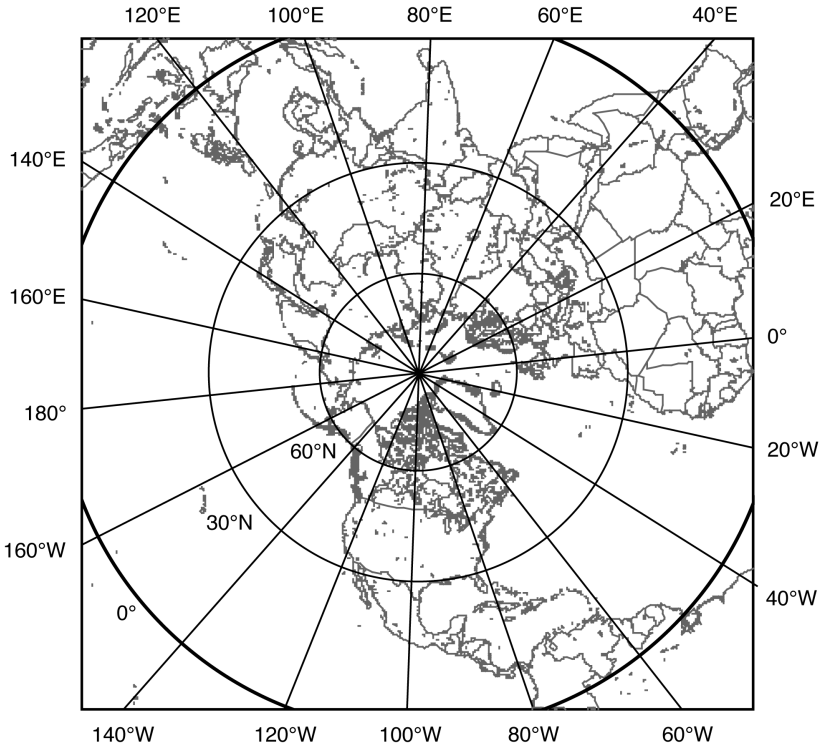

Figure S3. The information of longitude and latitude in H-CMAQ modelling system.

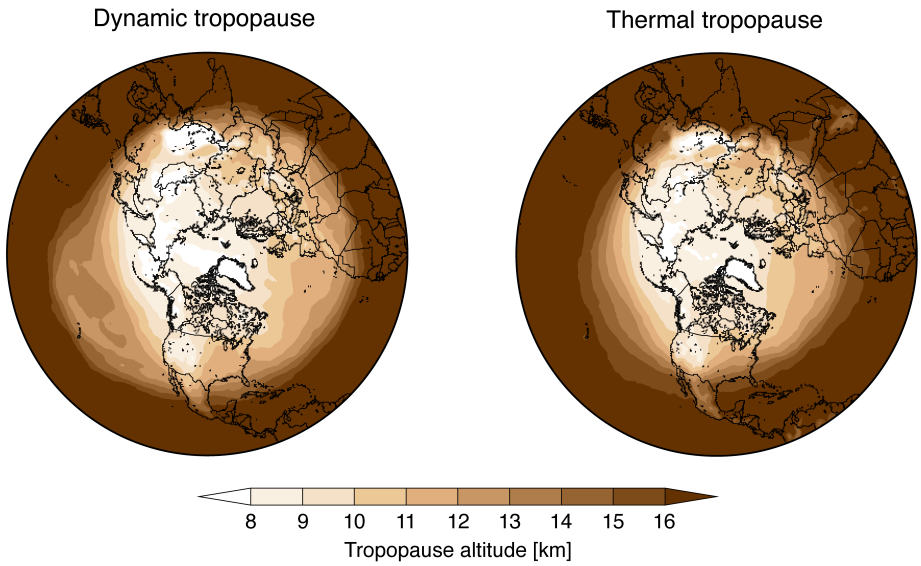

Figure S4. Estimated tropopause altitude averaged over April 2010 by (left) the dynamic approach using PV in this work and (right) the thermal approach using the lapse rate.

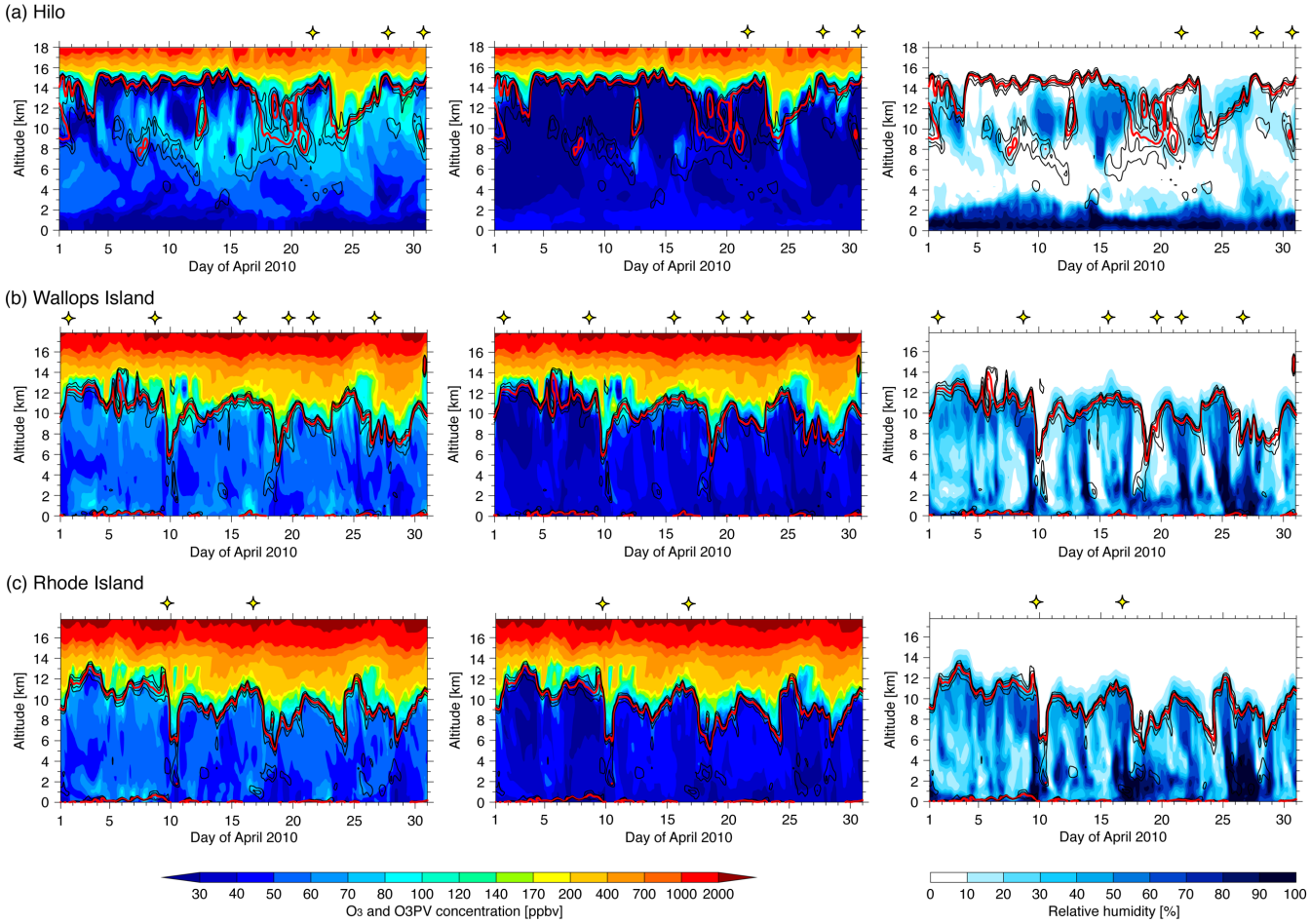

Figure S5. Curtain plots of modeled (left) O_3, (center) O3PV, and (right) RH at U.S. ozonesonde sites of (a) Hilo (HI), (b) Wallops Island (VA), and (c) Rhode Island (RI). during April 2010. Yellow stars indicate the time of available ozonesonde measurements. Contour lines of modeled PV are also inserted for contours of 1.0, 1.5, 2.0, 2.5, and 3.0 PVU with thick red lines denoting the 2.0 PVU contour as an index to diagnose the tropopause. See also Figure 4.

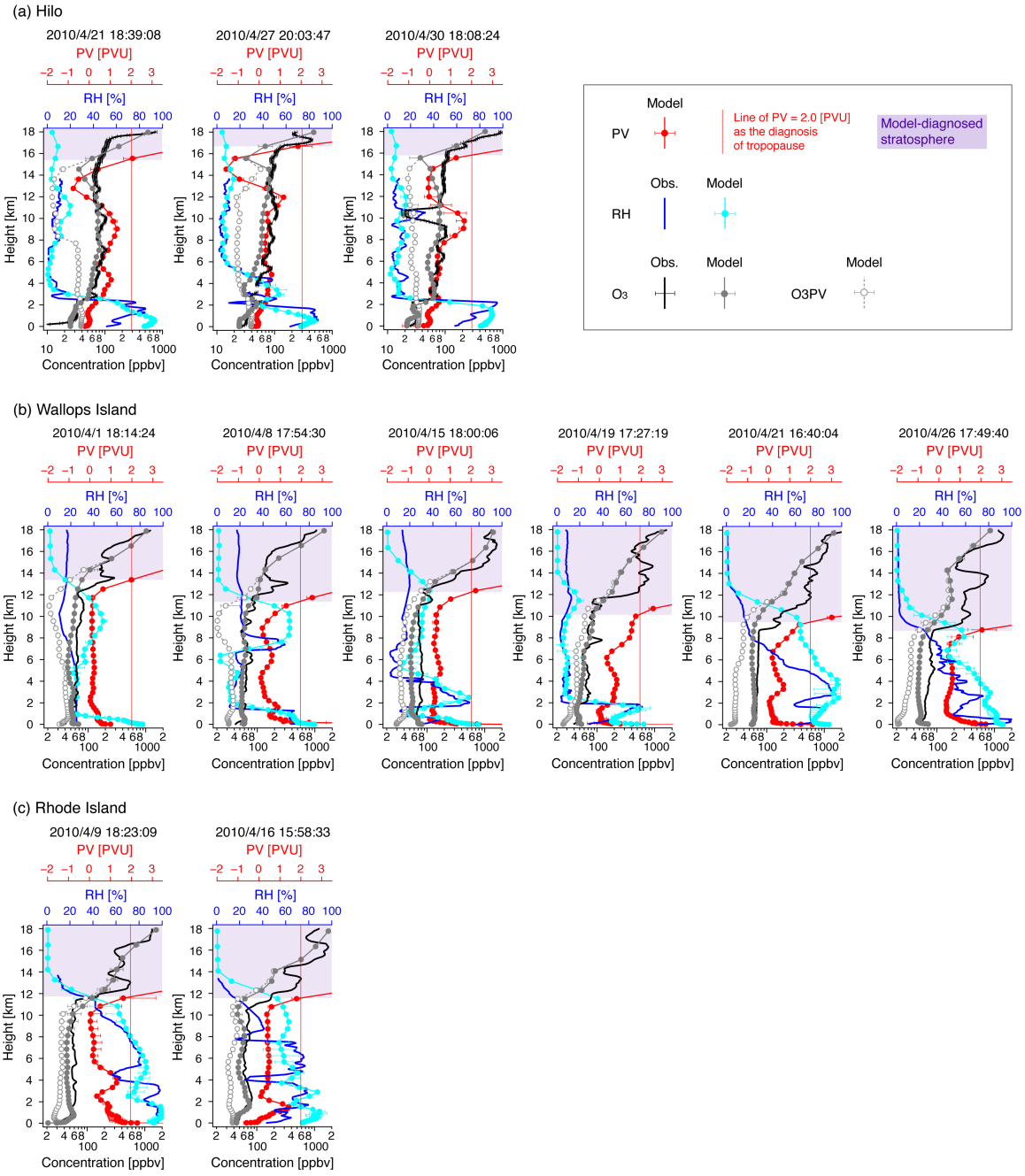

Figure S6. Vertical profiles of observed and modeled O_3 and RH at U.S. ozonesonde sites of (a) Hilo (HI), (b) Wallops Island (VA), and (c) Rhode Island (RI). Also see Figure S5 for ozonesonde measurement times. For modeled O_3 and RH, the hourly result corresponding to the ozonesonde measurement time is shown by circles, and the maximum and minimum model results within ±2 hours of the measurement time are shown by whiskers. For observed O_3 at Hilo and Boulder, the range of uncertainties of the O_3 observations is shown by whiskers. Modeled O3PV and PV are also shown. Modeled PV profiles are plotted in red, and vertical lines corresponding to a PV value of 2 PVU are inserted as an index of the tropopause, and the layer range diagnosed as stratospheric air mass is colored in purple. See also Figure 5.

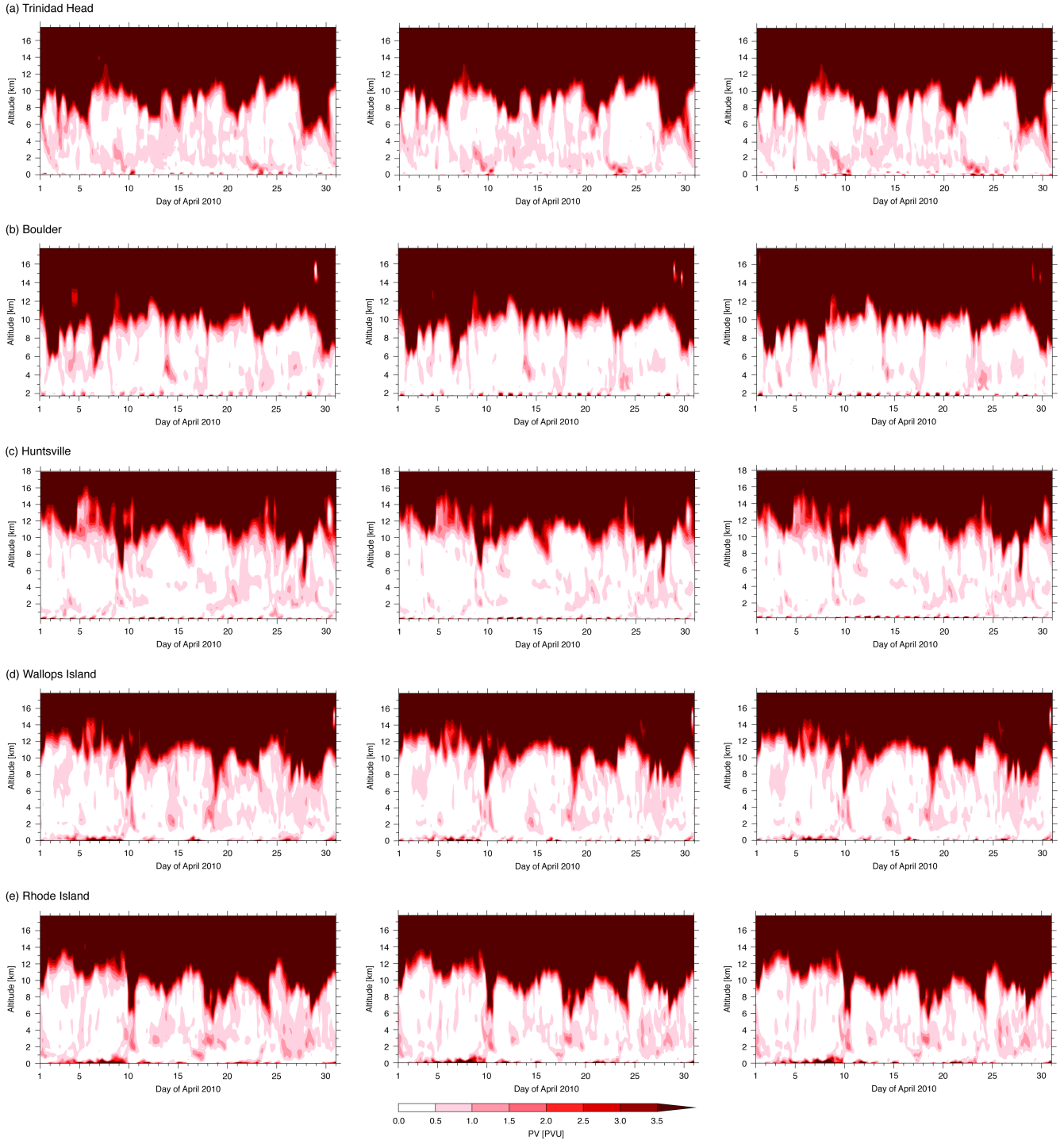

Figure S7. Curtain plots of modeled PV by (left) WRF over northern hemisphere with a 108 km horizontal grid resolution, (center) WRF over CONUS domain with a 36 km horizontal grid resolution, and (right) WRF over CONUS domain with a 12 km horizontal grid resolution at U.S. ozonesonde sites of (a) Trinidad Head (CA), (b) Boulder (CO), (c) Huntsville (AL), (d) Wallops Island (VA), and (e) Rhode Island (RI) during April 2010.

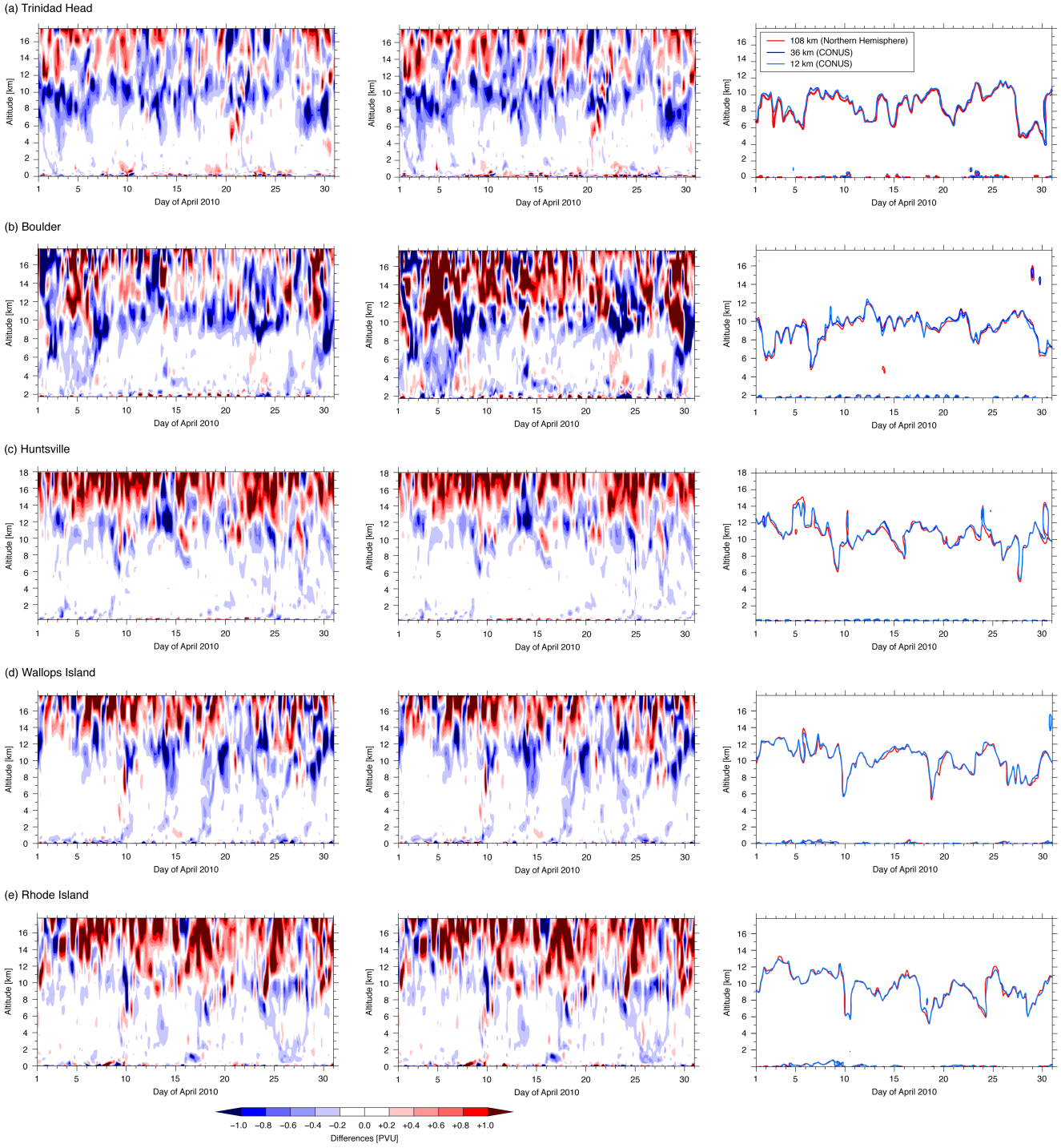

Figure S8. Curtain plots of (right) the difference of modeled PV calculated from 36 km−108 km, (center) from 12 km−108 km, and (right) modeled PV lines of 2 PVU by 108 km (red), 36 km (blue), and 12 km (sky blue) at U.S. ozonesonde sites of (a) Trinidad Head (CA), (b) Boulder (CO), (c) Huntsville (AL), (d) Wallops Island (VA), and (e) Rhode Island (RI) during April 2010.

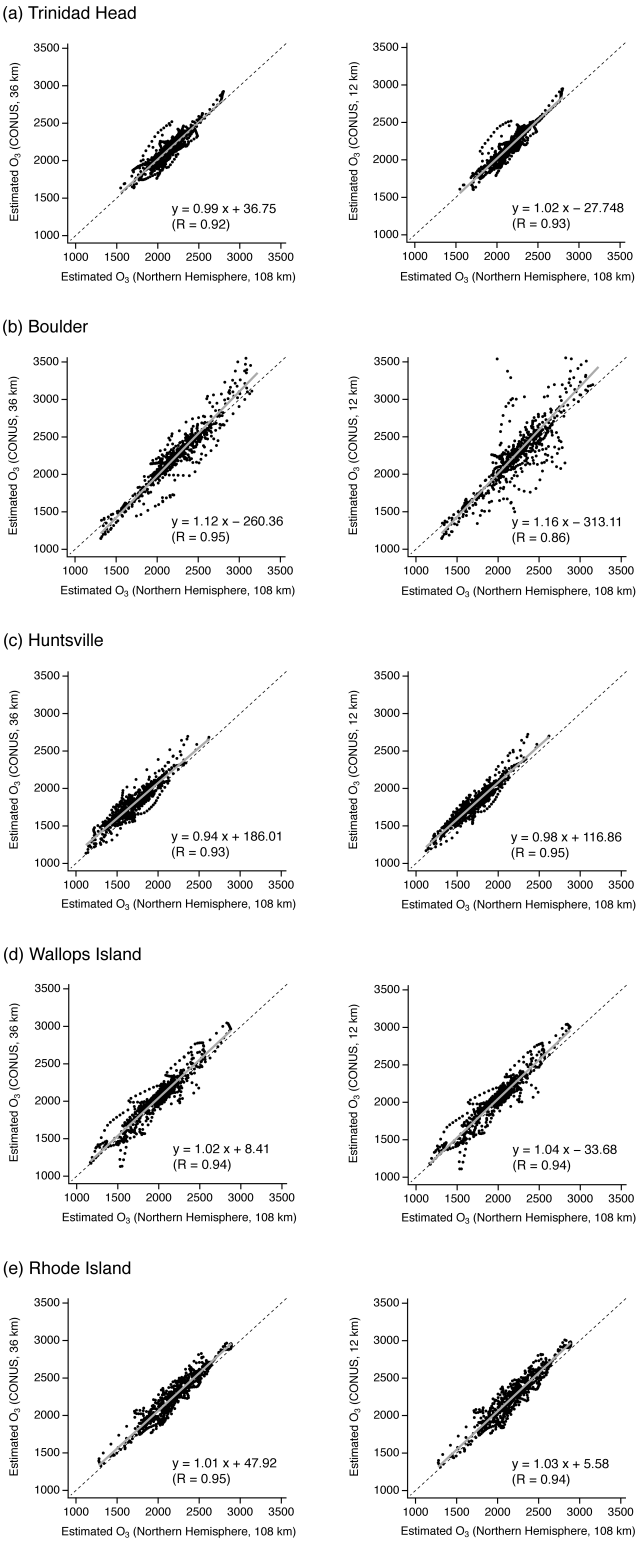

Figure S9. Correspondence of estimated O_3 concentration based on O_3/PV relation at the uppermost layer as (left) 108 km vs. 36 km and (right) 108 km vs. 12 km at U.S. ozonesonde sites of (a) Trinidad Head (CA), (b) Boulder (CO), (c) Huntsville (AL), (d) Wallops Island (VA), and (e) Rhode Island (RI). Plots are hourly data during April 2010 (total number is 720).

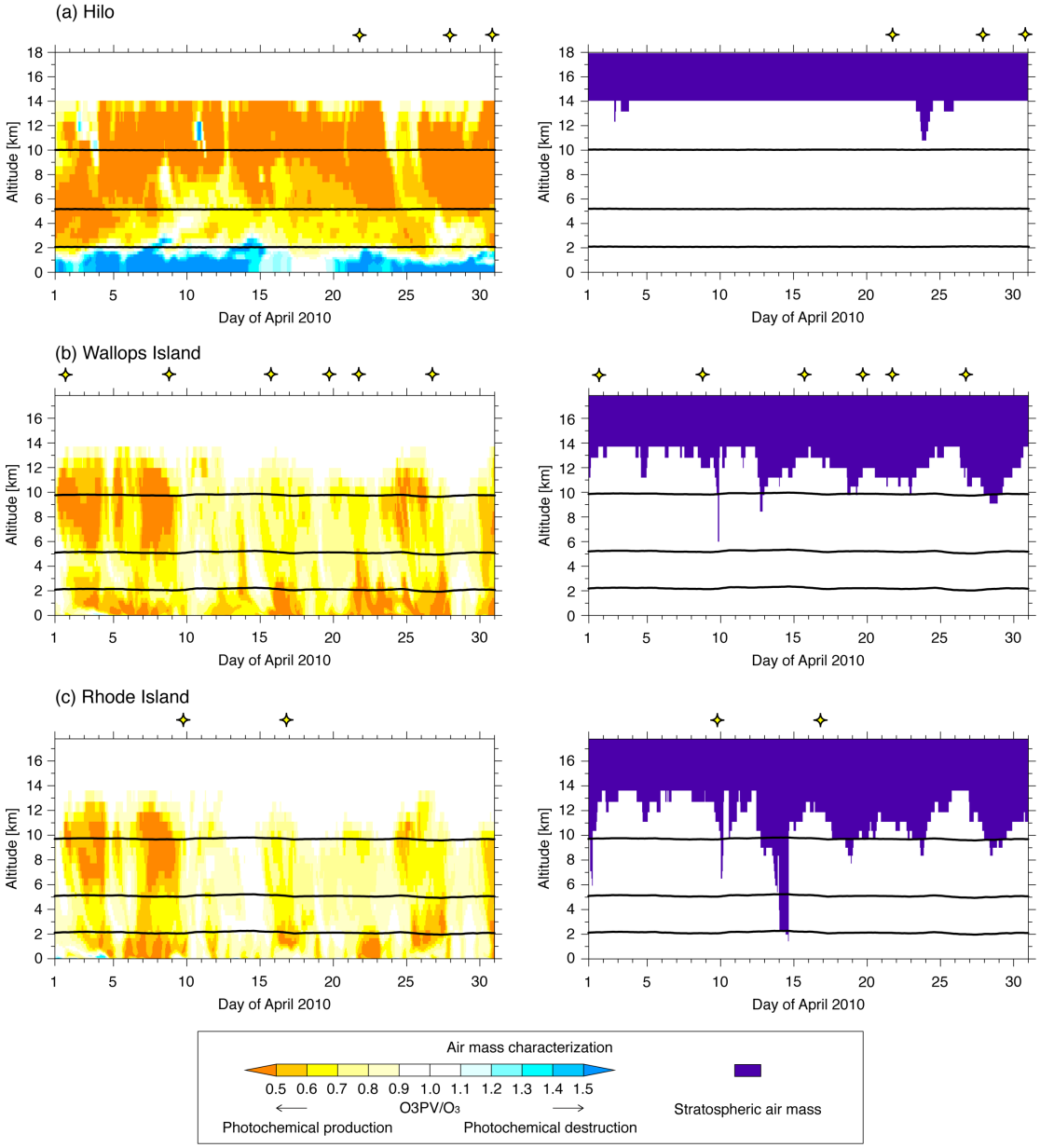

Figure S10. Curtin plot of model-diagnosed air mass characterization for (left) O3PV/O_3 and (right) stratospheric air mass at U.S. ozonesonde sites of (a) Hilo (HI), (b) Wallops Island (VA), and (c) Rhode Island (RI) during April 2010. See also Figure 9.

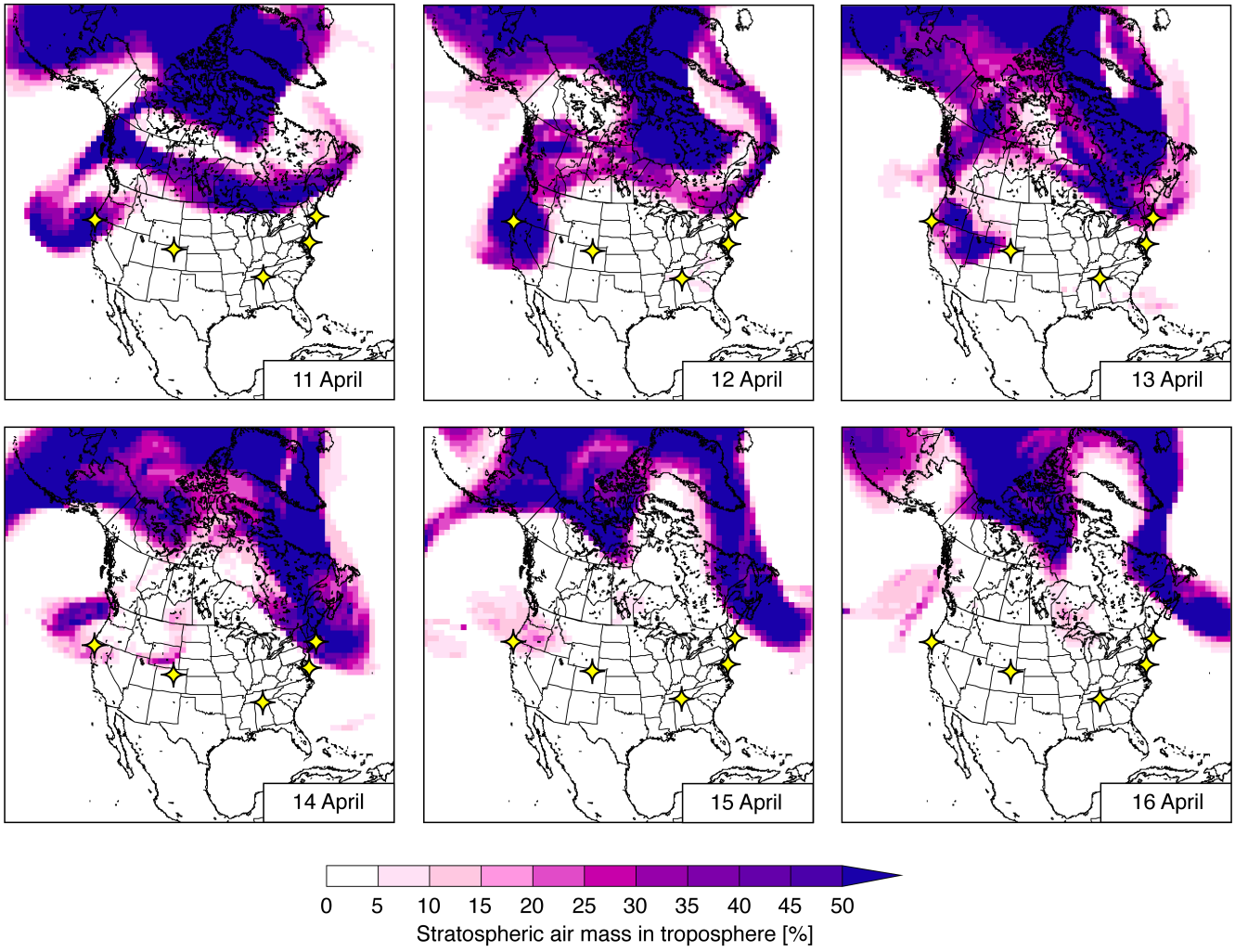

Figure S11. Spatial distributions of day-to-day variations of stratospheric air mass contributions to total tropospheric O_3 column over the U.S. during middle April 2010. Yellow stars indicate the ozonesonde observational sites. See also Figure 11.

Table S1. Statistical analysis of modeled O_3 mixing ratios to ozonesonde as latitude dependence.

	N	Mean		R	NMB	NME
		Observation	Model			
Ozonesonde						
< 40°N sites						
−boundary layer	517	47.12	49.13	0.55***	4.3%	21.6%
−free troposphere	483	81.07	59.55	0.75***	−26.5%	29.6%
−upper model layer	283	538.86	461.51	0.90***	−14.4%	33.8%
40°−50°N sites						
−boundary layer	907	49.20	48.95	0.37***	−0.5%	16.6%
−free troposphere	831	77.97	58.12	0.76***	−25.5%	29.0%
−upper model layer	488	932.12	845.30	0.92***	−9.3%	26.9%
50°−60°N sites						
−boundary layer	966	46.64	43.37	0.55***	−7.0%	16.9%
−free troposphere	776	78.39	56.28	0.78***	−28.2%	29.3%
−upper model layer	461	1026.12	861.52	0.94***	−16.0%	25.1%
> 60°N sites						
−boundary layer	387	40.30	37.06	0.56***	−8.0%	20.3%
−free troposphere	378	92.86	60.65	0.78***	−34.7%	35.8%
−upper model layer	221	1260.21	1061.29	0.94***	−15.8%	25.3%

Note: Corresponded hourly modeled O_3 mixing ratio is used for the comparison with ozonesonde data. Significance levels by Students' t-test for correlation coefficients between observations and simulations are remarked as $^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$, and lack of a mark indicates no significance. Ozonesonde observational sites located on < 40°N, 40°−50°N, 50°−60°N, > 60°N, respectively, contain 9, 9, 9, and 6 sites.

Table S2. Statistical analysis of modeled relative humidity to ozonesonde as latitude dependence.

	N	Mean		R	NMB	NME
		Observation	Model			
Ozonesonde						
< 40°N sites						
−boundary layer	517	61.70	70.69	0.63***	14.6%	26.0%
−free troposphere	469	36.38	42.22	0.72***	16.1%	42.3%
−upper model layer	148	13.81	16.64	0.56***	20.5%	77.2%
40°−50°N sites						
−boundary layer	907	59.74	70.99	0.51***	18.8%	27.5%
−free troposphere	810	38.73	43.47	0.77***	12.5%	34.1%
−upper model layer	339	9.45	10.77	0.91***	13.9%	44.2%
50°−60°N sites						
−boundary layer	973	60.79	65.28	0.85***	7.4%	14.5%
−free troposphere	776	36.04	41.90	0.85***	16.2%	27.6%
−upper model layer	461	6.64	9.27	0.93***	39.7%	56.8%
> 60°N sites						
−boundary layer	387	69.36	73.82	0.81***	6.4%	15.4%
−free troposphere	378	42.46	49.42	0.80***	16.4%	29.8%
−upper model layer	172	2.65	4.12	0.74***	55.5%	102.5%

Note: Corresponded hourly modeled O_3 mixing ratio is used for the comparison with ozonesonde data. Significance levels by Students' t-test for correlation coefficients between observations and simulations are remarked as $^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$, and lack of a mark indicates no significance. Ozonesonde observational sites located on < 40°N, 40°−50°N, 50°−60°N, > 60°N, respectively, contain 9, 9, 9, and 6 sites.

Table S3. Elevated CASTNET sites in an alphabetical order.

ID	Site name	State	Longitude (°)	Latitude (°)	Elevation (m a.s.l.)
BBE401	Big Band NP	TX	−103.178	29.303	1052
CAN407	Canyonlands NP	UT	−109.821	38.458	1809
CHA467	Chiricahua NM	AZ	−109.389	32.009	1570
CNT169	Centennial	WY	−106.240	41.365	3175
CON186	Converse Station	CA	−116.913	34.194	1718
GRB411	Great Basin NP	NV	−114.216	39.005	2060
GRC474	Grand Canyon NP	AZ	−112.184	36.059	2073
GTH161	Gothic	CO	−106.986	38.956	2915
JOT403	Joshua Tree NP	CA	−116.389	34.070	1244
LAV410	Lassen Volcanic NP	CA	−121.576	40.540	1756
MEV405	Mesa Verde NP	CO	−108.490	37.198	2165
PAL190	Palo Duro	TX	−101.665	34.881	1053
PET427	Petrified Forest	AZ	−109.892	34.823	1723
PND165	Pinedake	WY	−109.788	42.929	2386
PNF126	Cranberry	NC	−82.045	36.105	1216
ROM206	Rocky Mountain NP Collocated	CO	−105.546	40.278	2742
ROM406	Rocky Mountain NP	CO	−105.546	40.278	2743
SHN418	Shenandoah NP	VA	−78.435	38.523	1073
WNC429	Wind Cave NP	SD	−103.484	43.558	1292
YEL408	Yellowstone NP	WY	−110.400	44.565	2430
YOS404	Yosemite NP	CA	−119.706	37.713	1605

Note: Elevated sites defined as sites with an elevation higher than 1000 m a.s.l. (above sea level). The available sites during April 2010 are listed.