



*Supplement of*

## **Validation of tropospheric NO<sub>2</sub> column measurements of GOME-2A and OMI using MAX-DOAS and direct sun network observations**

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**Table S1:** Statistics of the comparisons for the satellite versus MAX-DOAS or Direct-sun TROPO comparisons per station. Closest pixel within 50km, with pixel sizes <100km for GOME-2 and <40km for OMI are presented. The two lines of the linear regression statistics are the daily and monthly mean results respectively. For the biases, the mean and median monthly values are given. Intercept I and bias (SAT-GB) are in  $\times 10^{15}$  molec/cm $^2$ .

Station by station comparisons	Satellite and time period	All pixels						Only pixels over station		
		R	S	I	#	Bias (SAT-GB) [ $\times 10^{15}$ molec/cm $^2$ ]	Bias (%)	#	Bias (SAT-GB) [ $\times 10^{15}$ molec/cm $^2$ ]	Bias (%)
<b>Direct sun TROPO</b>										
Beijing	OMI (20080703 - 20090405)	0.79 0.89	0.52 0.61	4.27 0.021	59 9	-13 ; -11	-39% ; -35%	44	-11 ; -7.4	-33% ; -32%
	GOME2-A (20080622 - 20090416)	0.79 0.9	0.52 0.54	1.63 1.32	115 10	-13 ; -13	-42% ; -43%	113	-13 ; -13	-41% ; -42%
Boulder	OMI (20131219 - 20150828)	0.24 0.19	0.12 0.16	1.72 1.70	210 20	-4.4 ; -3.4	-58% ; -54%	94	-2.9 ; -2.2	-39% ; -36%
	GOME2-A (20131225 - 20150826)	0.49 0.49	0.40 0.36	0.47 0.55	119 20	-2.6 ; -2.7	-52% ; -47%	93	-2.7 ; -2.8	-56% ; -54%
Busan	OMI (20120318 - 20150523)	0.41 0.47	0.30 0.33	5.88 5.38	75 25	-5 ; -4.6	-227 ; -33%	45	-5.9 ; -5.7	-30% ; -35%
	GOME2-A (20120314 - 20150524)	0.49 0.6	0.28 0.45	5.84 3.11	178 24	-5.2 ; -5.7	-32% ; -32%	166	-5.1 ; -4.7	-31% ; -30%
FMI	OMI (20120210 - 20130410)	0.27 0.2	0.10 0.067	1.94 2.01	47 11	-1.7 ; -1.5	11% ; -31%	25	0.04 ; 0.9	120% ; 90%
	GOME2-A (20110910 - 20130621)	0.47 0.76	0.37 0.911	0.89 -0.98	88 13	-1.3 ; -1.5	-39% ; -26%	83	-1.3 ; -1.4	-41% ; -26%
Four Corners NM	OMI (20120605 - 20150824)	0.51 0.72	0.41 0.54	2.62 1.89	155 28			129		<b>51% ; -6.9%</b>
	GOME2-A (20120606 - 20150827)	0.3 0.42	0.14 0.37	3.68 2.05	235 29	-0.72 ; -0.62 -2.8 ; -2	-5% ; -17% -35% ; -39%	222	-0.07 ; -0.42 -2.9 ; -2	-35% ; -45%
GSFC	OMI (20090523 - 20150830)	0.63 0.75	0.63 0.61	1.89 1.95	293 68			182	0.35 ; 0.55	14% ; 6.2%
	GOME2-A (20090601 - 20150827)	0.48 0.58	0.44 0.54	3.37 3.02	537 66	-0.79 ; -0.55 -0.35 ; -0.61	-3.3% ; -8.5% -0.2% ; -8.8%	497	-0.28 ; -0.57 -0.28 ; -0.57	1.2% ; -8.6%
Harvard	OMI	0.53	0.41	1.35	52			30		

	(20141110 - 20150827)	0.58	0.3	2.12	7	-2 ; -1.5	-30% ; -29%		-1.3 ; -1.4	-17% ; -12%
IZO	GOME2-A	0.2	0.27	2.72	32			27		
	(20141110 - 20150819)	0.46	0.77	0.38	8	-1 ; -1.2	-17% ; -24%	89	-0.93 ; -1.2	-16% ; -24%
	OMI	0.13	0.11	1.21	158					
	(20130109 - 20150713)	0.18	0.12	1.22	27	2.2 ; 2.1	220% ; 190%	181	2.1 ; 1.9	-180% ; -210%
	GOME2-A	0.049	0.056	0.64	221					
Langley	(20130108 - 20150712)	-0.24	-0.26	0.50	29	1.4 ; 1.3	190% ; -190%		1.5 ; 1.3	240% ; -200%
	OMI	0.28	0.30	2.83	73			52		
	(20100127 - 20140617)	0.45	0.33	2.41	17	-0.6 ; -1.1	-3.1% ; -16%	151	-0.49 ; -5.2	-3.7% ; -16%
Mauna Loa	GOME2-A	0.47	0.59	0.50	159					
	(20100204 - 20140614)	0.51	0.77	0.25	19	-0.89; -0.77	-17% ; -15%			
	OMI	-0.047	-0.023	0.75	29			5		
	(20141107 - 20150508)	0.14	0.066	0.70	6	0.5 ; 0.37	210% ; -120%		-1.2 ; -1.2	-60% ; -60%
	GOME2-A	-0.35	-0.35	0.75	33			30		
NASA HQ	(20141106 - 20150518)	-0.25	-0.47	0.87	6	-0.7; -0.53	-62% ; -61%			
	OMI	0.5	0.37	2.5	116			74		
	(20120830 - 20150830)	0.34	0.20	3.45	19	-1.8 ; -0.66	-18% ; -14%		-1 ; -0.6	-16% ; -14%
	GOME2-A	0.5	0.4	2.89	105			82		
	(20120830 - 20150827)	0.1	0.05	5.98	20	-2 ; -1.3	-15% ; -18%		-1.8 ; -0.6	-11% ; -11%
SERC	OMI	0.56	0.71	0.8	71			57		
	(20100924 - 20130105)	0.71	0.85	0.41	22	-0.31 ; -0.79	-4.1% ; -14%		-0.63 ; -0.83	-11% ; -11%
	GOME2-A	0.52	0.82	1.32	140			131		
Seoul	(20100925 - 20130110)	0.7	0.94	0.69	22	-0.28 ; -0.006	3.6% ; 0.4%		0.4 ; 0.26	6.6% ; 4.6%
	OMI	0.22	0.15	15.7	92			42		
	(20120309 - 20150828)	0.01	0.005	20.42	27	-13 ; -8.9	-27% ; -29%		-2.8 ; -0.86	-5.2% ; -3.8%
Thessaloniki	GOME2-A	0.35	0.08	17.7	132			122		
	(20120310 - 20150828)	0.49	0.13	14.6	29	-15 ; -7.4	-31% ; -30%		-13 ; -7.1	-28% ; -29%
	OMI	0.69	0.33	1.14	19			14		
	(20110415 - 20140507)	0.86	0.28	1.19	11	-5.5 ; -2.4	370% ; -51%		-4.9 ; -2.2	-430% ; -47%
	GOME2-A	0.39	0.17	1.01	114			108		
UHMT	(20110204 - 20140519)	0.52	0.24	0.98	22	-5.7 ; -4.1	-66% ; -71%		-5.6 ; -3.9	-65% ; -71%
	OMI	0.73	0.60	3.12	40			24		
	(20120316 - 20150419)	0.68	0.59	3.37	14	0.57 ; 0.68	19% ; 15%		2.5 ; 2.4	49% ; 43%
Xianghe	GOME2-A	0.52	0.45	2.8	102			98		
	(20120322 - 20150430)	0.53	0.57	2.5	16	-0.24/-0.085	5.8% ; -1.2%		-0.21 ; -0.22	4.2% ; -3.9%
	OMI	0.87	0.81	0.94	639			462		
	(20100321 - 20180108)	0.88	0.84	0.16	92	-2.6/-2.5	-15% ; -17%		-3.4 ; -3.1	-19% ; -18%
	GOME2-A	0.89	0.79	2.04	878			844		
	(20100309 - 20180116)	0.88	0.76	2.25	94	-3.4 ; -3.4	-13% ; -14%		-3.2 ; -3.2	-13% ; -14%

<u><b>MAX-DOAS</b></u>										
Athens	OMI (20121001 - 20180815)	0.41 0.46	0.21 0.25	2 1.6	324 65	-3.3; -2.6	-44% ; -49%	225	-3.4 ; -2	-33% ; -38%
Beijing-CMA	GOME2-A (20120928 - 20180818)	0.46 0.52	0.30 0.35	2.4 2.4	487 65	-1.6; -1.1	-20% ; -26%	442	-1.4 ; -1.1	-16% ; -18%
	OMI (20080809 - 20110925)	0.78 0.84	0.57 0.70	3.13 -2.54	429 38	429 -1.5; -1.4	-37% ; -35%	107	-14; -14	-34% ; -33%
Beijing	GOME2-A (20080809 - 20110925)	0.76 0.81	0.50 0.56	1.01 -1.36	429	-19; -18	-48% ; -48%	406	-19; -17	-47% ; -49%
	OMI (20080712 - 20090405)	0.66 0.7	0.36 0.34	8.10 7.46	64 10	-15; -12	-38% ; -39%	44	-9.2 ; -6.1	-25% ; -24%
Bremen	GOME2-A (20080622 - 20090416)	0.77 0.98	0.45 0.47	3.04 2.20	116 11	-16; -19	-45% ; -46%	106	-15 ; -16	-44% ; -45%
	OMI (20050513 - 20180821)	0.43 0.59	0.26 0.26	2.8 2.7	265 69	-2.9 ; -2.7	-29% ; -36%	40	-1.7 ; -0.4	2% ; -8%
Bujumbura	GOME2-A (20071224 - 20180818)	0.28 0.1	0.21 0.05	2.84 4	496 81	-3.2 ; -2.6	-38% ; -38%	339	-3.2 ; -2.7	-36% ; -40%
	OMI (20131215 - 20170719)	0.033 -0.07	0.03 -0.07	1.29 1.53	142 43	-0.59 ; -0.58	-21% ; -31%	49	-0.71 ; -0.91	-30% ; -46%
Cabauw	GOME2-A (20131224 - 20170722)	-0.07 0.11	-0.003 0.034	0.89 0.53	156 42	-3.8 ; -3.3	-83% ; -84%	119	-4 ; -3.4	-81% ; -84%
	OMI (20110304 – 20180814)	0.52 0.69	0.45 0.49	5.4 5.2	70 22	0.6 ; 1.2	<b>29% ; 20%</b>	41	1.5 ; 0.8	<b>49% ; 18 %</b>
Cape Hedo	GOME2-A (20110306 - 20180804)	0.33 0.28	0.38 0.25	6 6.6	130 18	1.2 ; 1.9	<b>45% ; 28%</b>	112	1.2 ; 1.5	<b>32% ; 19%</b>
	OMI (20070331 - 20151229)	0.24 0.27	0.33 0.43	0.62 0.56	477 101	0.08 ; -0.04	<b>18% ; 5%</b>	277	0.091 ; 0.032	<b>28% ; 5.2%</b>
Chiba	GOME2-A (20070412 - 20151213)	0.18 0.17	0.28 0.22	-0.02 0.16	697 100	1.2 ; 1.9	-77% ; -75%	633	-0.65 ; -0.64	-74% ; -70%
	OMI (20120608 - 20170708)	0.56 0.51	0.50 0.58	4.5 4.25	358 62	-0.65 ; -1.3	0.8% ; -10%	249	-0.75 ; -1.1	3.1% ; -7.3%
De Bilt	GOME2-A (20120607 - 20170721)	0.51 0.33	0.42 0.28	5.9 7.75	391 61	-0.67 ; -0.64 -2.3 ; -2	-9.6% ; -17%	354	-1.6 ; -1.9	-6.6% ; -13%
	OMI (20071115 - 20180807)	0.5 0.37	0.37 0.35	4.8 5	219 61	-0.44 ; -1.2	3.8e9% ; -14%	112	0.21 ; 0.81	<b>14% ; 13%</b>
	GOME2-A (20071114 - 20180805)	0.56 0.51	0.47 0.46	2.8 2.6	322 66	-2.6 ; -2.6	2.6e9% ; -26%	280	-2.3 ; -2.2	3e9% ; -22%

Fukue	OMI (20090301 - 20151208)	0.55 0.43	0.48 0.49	1.03 1.02	260 72	-0.11/-0.18	11% ; -6.8%	137	0.1 ; 0.19	30% ; 18%
Gwangju	GOME2-A (20090307 - 20151213)	0.7 0.85	0.63 0.59	0.39 0.50	394 80	-0.73 ; -0.49	-21% ; -24%	364	-0.6 ; -0.49	-19% ; -23%
Hohenpeissenberg	OMI (20080220 - 20151231)	0.57 0.68	0.27 0.29	2.8 2.44	343 73	-4.7 ; -3.9	-40% ; -44%	193	-3.6 ; -3.1	-28% ; -34%
Kasuga	GOME2-A (20080220 - 20151226)	0.33 0.27	0.12 0.11	3.9 3.93	417 75	-6.8 ; -5.8	-51% ; -55%	393	-6.7 ; -5.8	-51% ; -54%
Mainz	OMI (20120605 - 20121221)	0.31 0.8	0.23 0.66	2.09 0.75	32 7	0.52 ; -0.017	0.34% ; -1.3%	12	0.67 ; 0.33	64% ; 17%
Nairobi	GOME2-A (20120615 - 20121225)	0.035 0.32	0.64 0.48	1.57 0.44	50 7	-0.86 ; -0.42	-28% ; -8.1%	45	-0.99 ; -0.45	-32% ; -28%
OHP	OMI (20130701 - 20180408)	0.41 0.48	0.30 0.27	2.03 3	196 144	-4 ; -4.2	-43% ; -52%	84	-3.7 ; -3.3	-42% ; -44%
Reunion	GOME2-A (20130617 - 20180816)	0.44 0.32	0.22 0.19	3.1 3.48	126 39	-5.8 ; -5.3	-53% ; -57%	108	-5.9 ; -5.3	-52% ; -55%
Thessaloniki	OMI (20050603 - 20141126)	-0.07 -0.23	-0.01 -0.03	0.84 1	153 51	-5.4; -4.3	-46% ; -52%	46	-4 ; -3	-25% ; -30%
Tsukuba	GOME2-A (20071128 - 20141128)	0.056 -0.31	0.012 -0.05	0.59 0.95	275 47	-6.4; -6.7 -5.1; -4.6	-80% ; -86%	207	-5.9; -5.7	-42% ; -49%
	OMI (20050211 - 20161212)	0.33 0.53	0.31 0.37	1.38 1.16	983 129	-0.6 ; -0.49	-78% ; -85%	3	-7.2 ; -2.3	-85% ; -88%
	GOME2-A (20070309 - 20161218)	0.48 0.59	0.69 0.56	-0.34 -0.01	1049 106	-1.2 ; -1.1	-44% ; -42%	974	-5.2; -3.1	-70% ; -78%
	OMI (20160501 - 20171126)	0.034 -0.073	0.32 -0.067	0.92 0.94	61 14	0.09 ; 0.07	36% ; 14%	11	-1.1 ; 1	-40% ; -41%
	GOME2-A (20160429 - 20180102)	0.096 0.2	0.06 0.77	0.21 0.16	145 21	-1.4 ; -1.4	-81% ; -79%	65	0.1; -0.012	21% ; 5%
	OMI (20110415 - 20180815)	0.41 0.7	0.17 0.27	1.7 1	284 63	-5.5; -4.8	-58% ; -61%	207	-4.8; -3.2	-92% ; -76%
	GOME2-A (20110204 - 20180819)	0.27 0.45	0.07 0.13	1.6 1.3	565 73	-8.1; -7.2	-72% ; -75%	506	-4.8 ; -3.2	-39% ; -53%
	OMI (20100602 - 20140408)	0.68 0.65	0.78 0.60	1.63 2.82	175 41	-0.079 ; 0.13	3.9% ; 3%	120	-7.9 ; -6.5	-70% ; -75%
	GOME2-A	0.53	0.45	2.86	359			337	-0.17 ; -0.37	3.8% ; -6%

	(20070126 - 20140410)	0.54	0.44	2.99	47	-2.2 ; -2.4	-22% ; -27%		-2.3 ; -2.3	-23% ; -26%
Uccle	OMI	0.76	0.51	2.56	148			91		
	(20110430 - 20160228)	0.77	0.40	3.57	45	-3.8 ; -2.3	-20% ; -28%		-3.3 ; -2.2	-13% ; -16%
	GOME2-A	0.49	0.33	3.37	285			255		
	(20110429 - 20160228)	0.56	0.53	0.96	53	-4.4 ; -3.6	-37% ; -33%		-4.5 ; -3.9	-36% ; -34%
Xianghe	OMI	0.86	0.75	4.13	395			279		
	(20100316 - 20170707)	0.9	0.78	3.69	83	-0.26 ; 0.13	5.5% ; 0.68%		-1.3 ; -0.65	3.6% ; -4.4%
	GOME2-A	0.85	0.68	5.7	677			644		
	(20100309 - 20170707)	0.88	0.71	4.15	84	-2.9 ; -2.3	-7.9% ; -8.7%		-3 ; -2.1	-7.2% ; -7.9%
Yokosuka	OMI	0.72	0.45	3.76	520			368		
	(20071021 - 20151226)	0.83	0.45	3.76	99	-7.5 ; -5.6	-29% ; -34%		-6.6 ; -5.2	-24% ; -33%
	GOME2-A	0.61	0.31	5.65	852			784		
	(20071020 - 20151229)	0.73	0.35	4.99	99	-11 ; -11	-43% ; -45%		-11 ; -10	-41% ; -44%
Zvenigorod	OMI	0.57	0.12	2.12	194			137		
	(20081009 - 20121225)	0.74	0.14	2.18	50	-8.7 ; -4.5	-40% ; -59%		-7.7 ; -2.4	-41% ; -55%
	GOME2-A	0.47	0.22	2.95	345			334		
	(20081016 - 20121027)	0.56	0.23	2.56	46	-5.5 ; -4.3	-39% ; -45%		-5.7 ; -4.3	-44% ; -46%

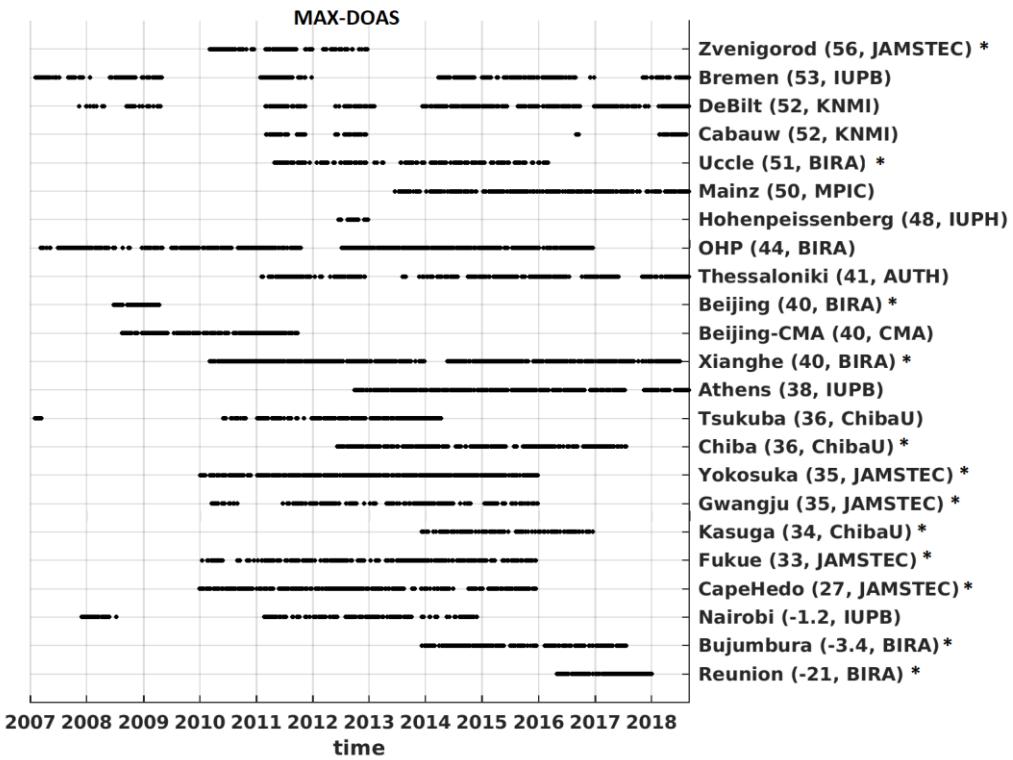


Figure S1. Visualization of the time coverage of the 23 ground-based MAX-DOAS dataset used in this study. The sites that also retrieved low tropospheric profiles are marked with an \*.

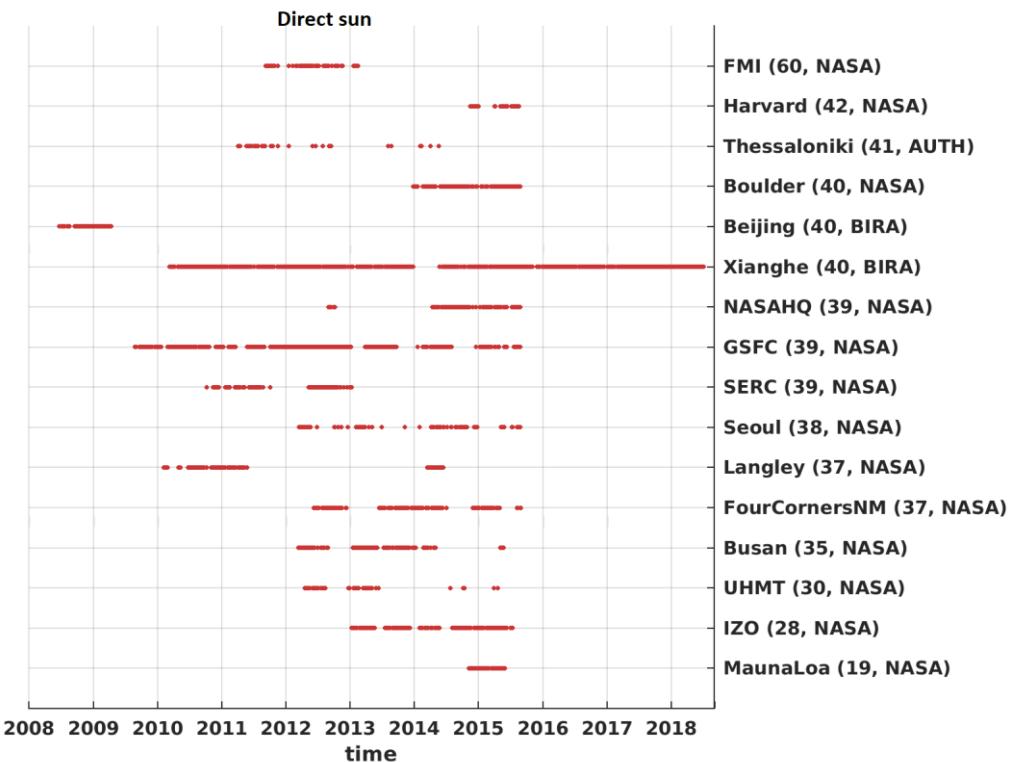


Figure S2. Visualization of the time coverage of the 16 ground-based direct sun dataset used in this study.

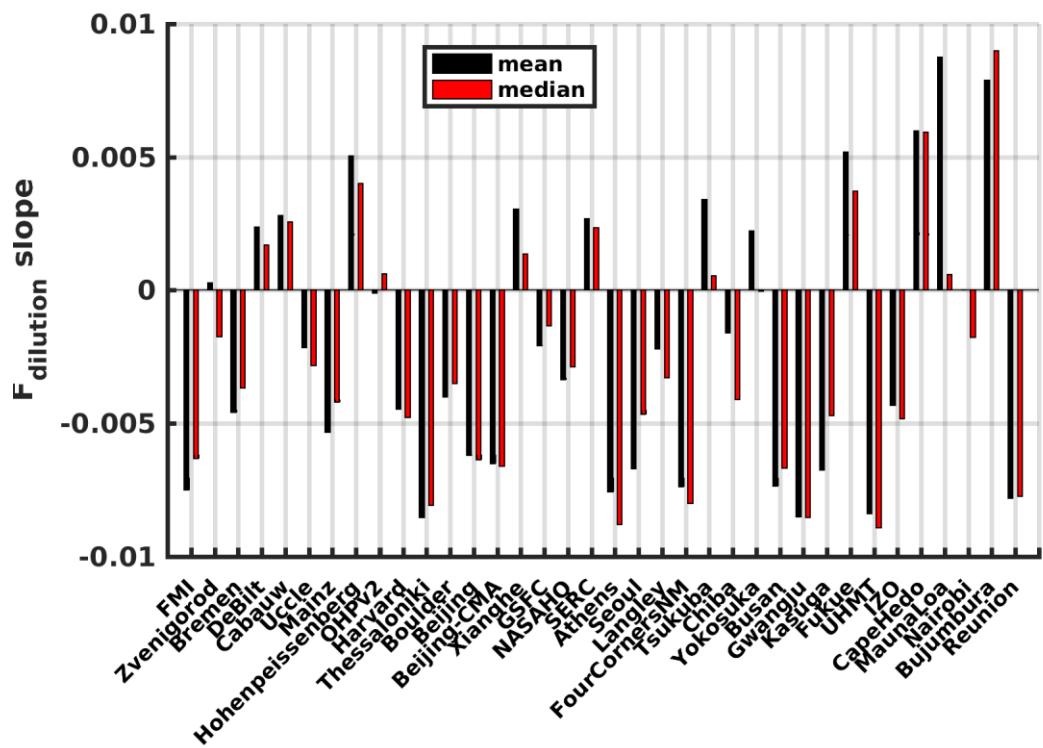


Figure S3. Dilution factor slope at each station (both on mean and median values), see text in Sect. 6.1 for details.

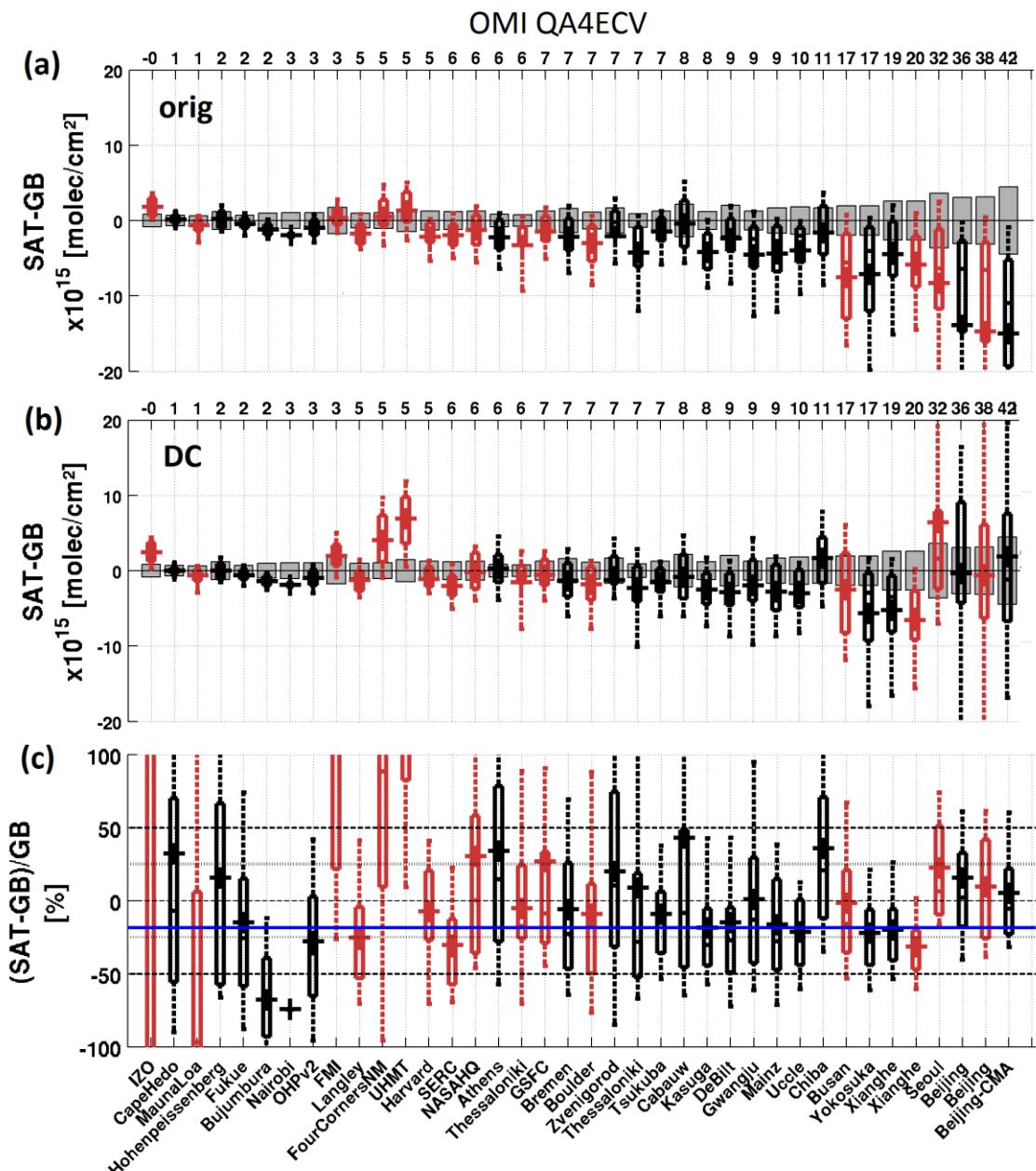


Figure S4. Box and whisker plot of the daily OMI QA4ECV v1.1 biases for each station (a) for the original data, (b) and (c) when correcting for the dilution effect, in absolute and relative values. MAX-DOAS stations are presented in black, direct sun stations in dark red. The stations are ordered by increasing values of the ground-based VCDtropo, and corresponding values are given in the upper horizontal axis. The box and whisker plots are defined as in Fig 10. In panels (a) and (b), grey bars are the  $\pm$  comparison error, calculated adding in quadrature the satellite and ground-based VCDtropo errors.

### GOME2-A QA4ECV

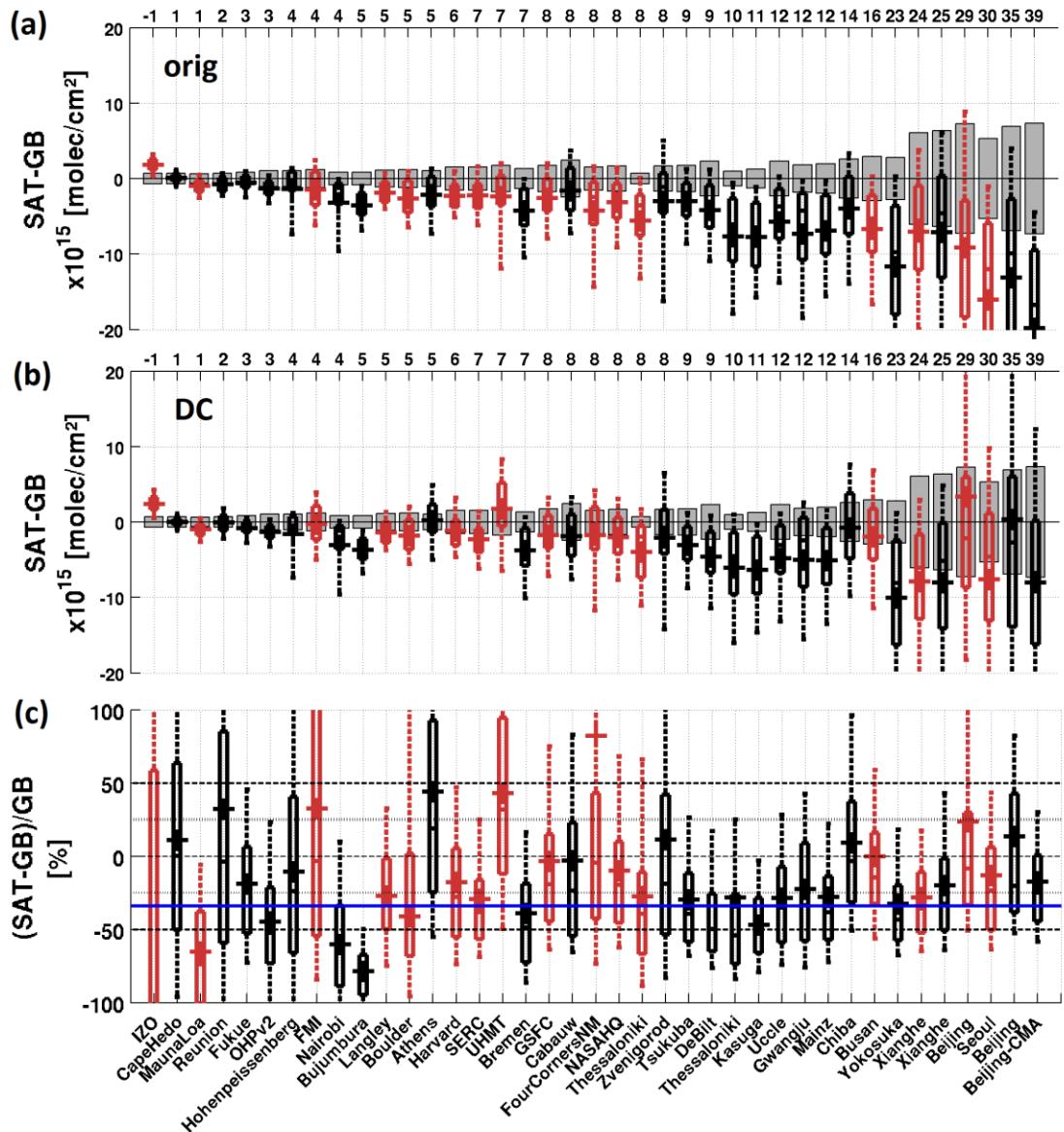


Figure S5. Box and whisker plot of the daily GOME-2A QA4ECV v1.1 biases for each station (a) for the original data, (b) and (c) when correcting for the dilution effect, in absolute and relative values. MAX-DOAS stations are presented in black, direct sun stations in dark red. The stations are ordered by increasing values of the ground-based VCDtropo, and corresponding values are given in the upper horizontal axis. The box and whisker plots are defined as in Fig 10. In panels (a) and (b), grey bars are the  $\pm$  comparison error, calculated adding in quadrature the satellite and ground-based VCDtropo errors.

Athens, OMI QA4ECV grid  $0.025^\circ \times 0.025^\circ$

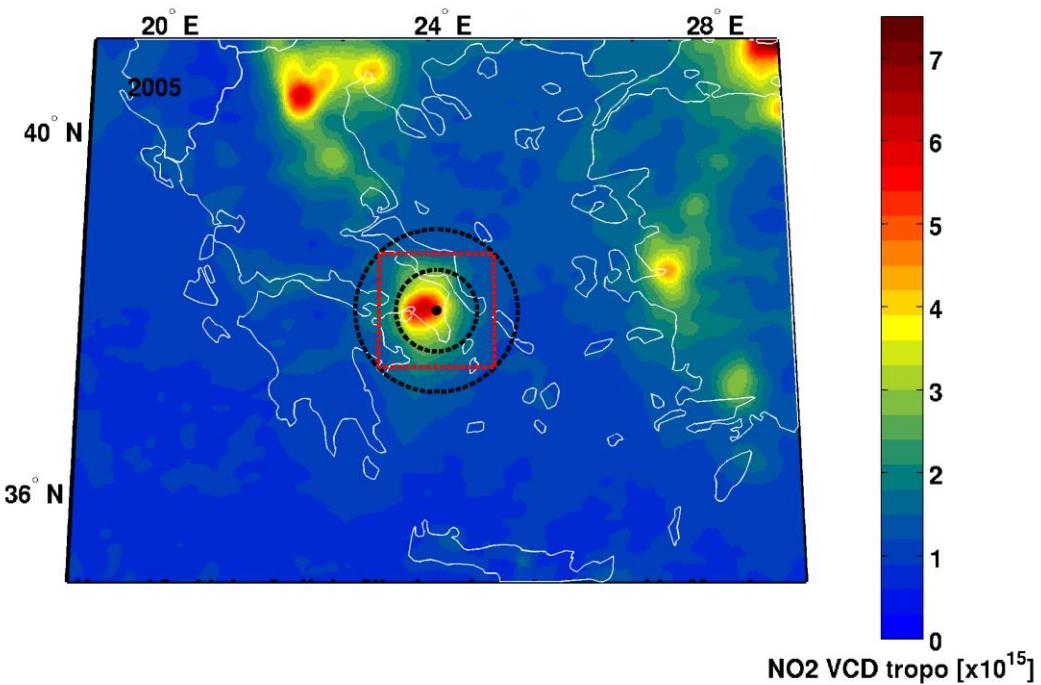


Figure S6. NO<sub>2</sub> maps used for the Dilution Correction for MAX-DOAS Athens station.

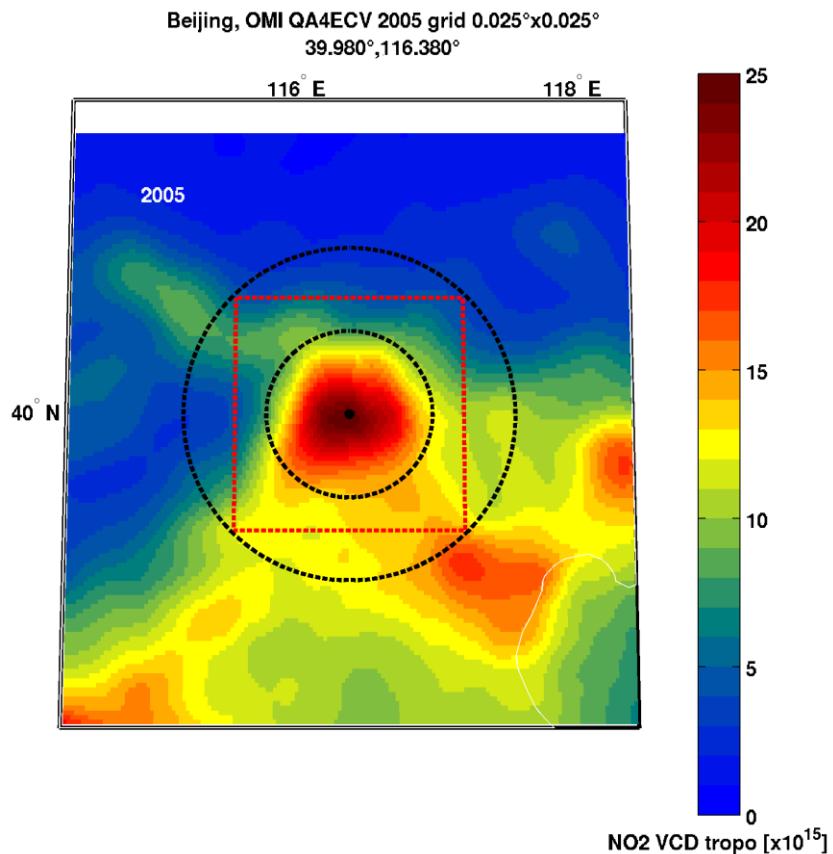


Figure S7. As figure S6, but for MAX-DOAS and direct sun Beijing station.

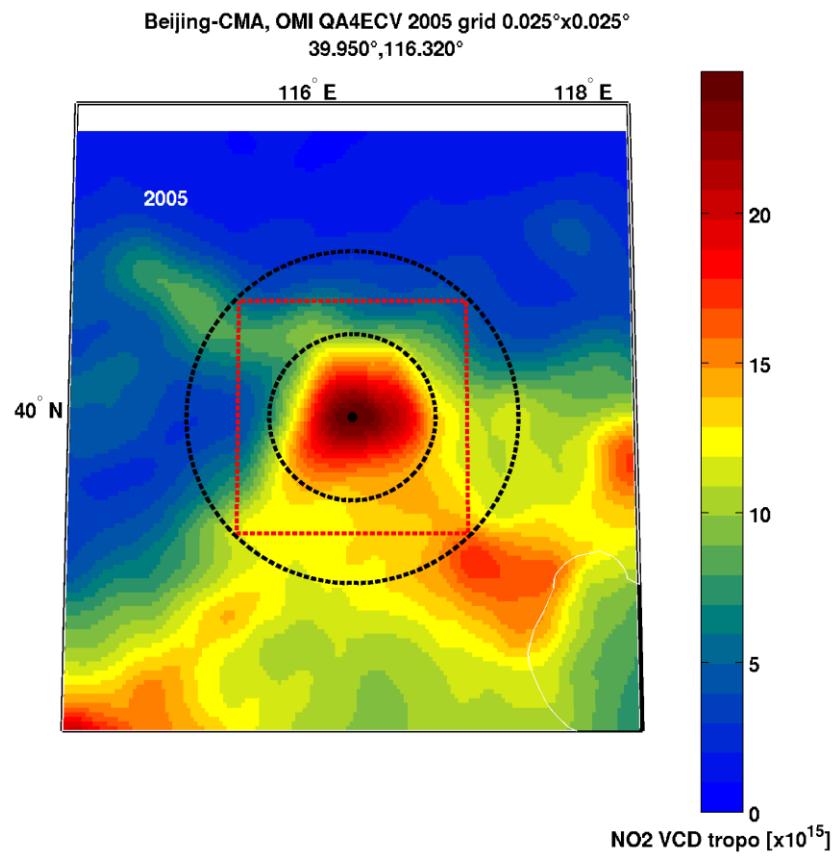


Figure S8. As figure S6, but for MAX-DOAS Beijing-CMA station.

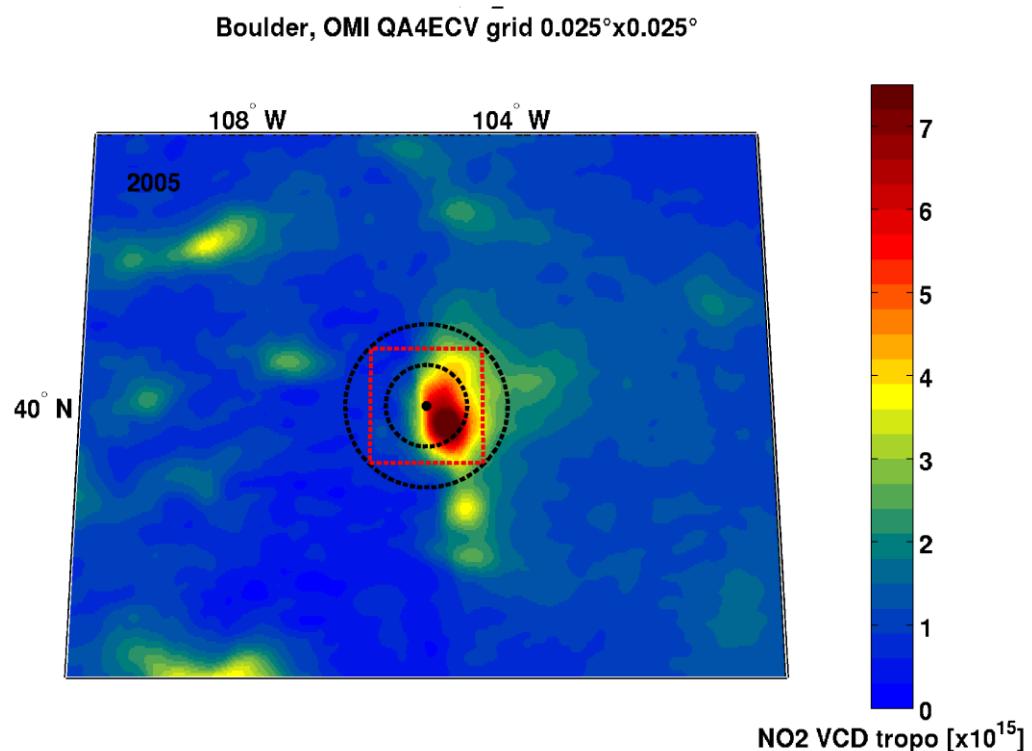


Figure S9. As figure S6, but for direct sun Boulder station.

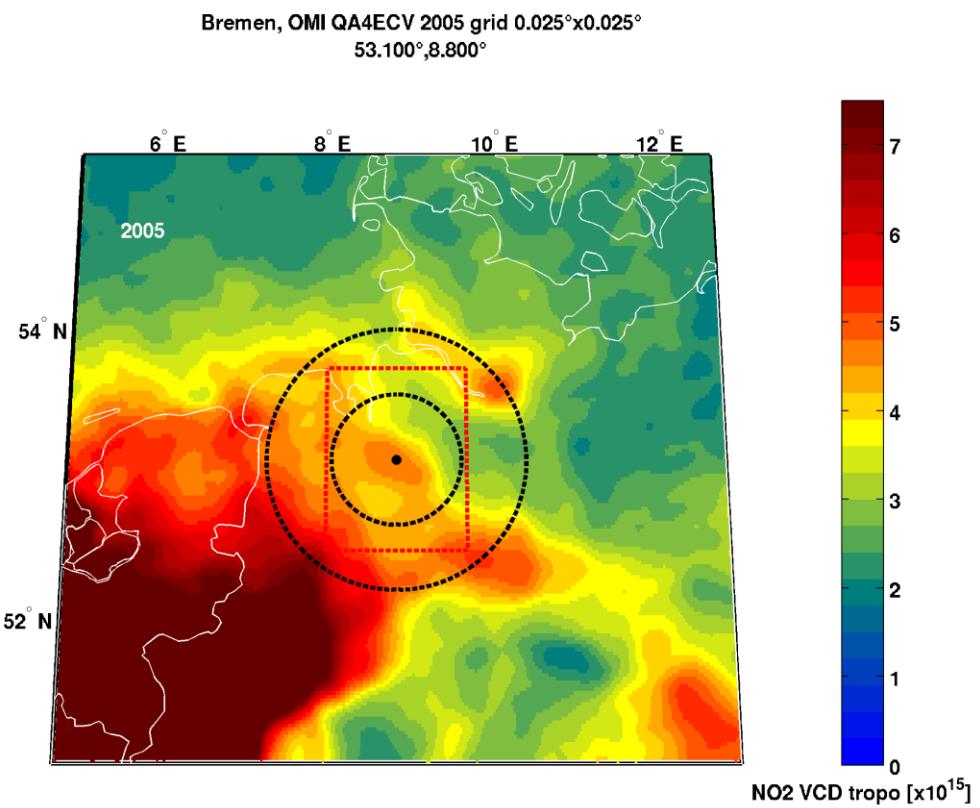


Figure S10. As figure S6, but for MAX-DOAS Bremen station.

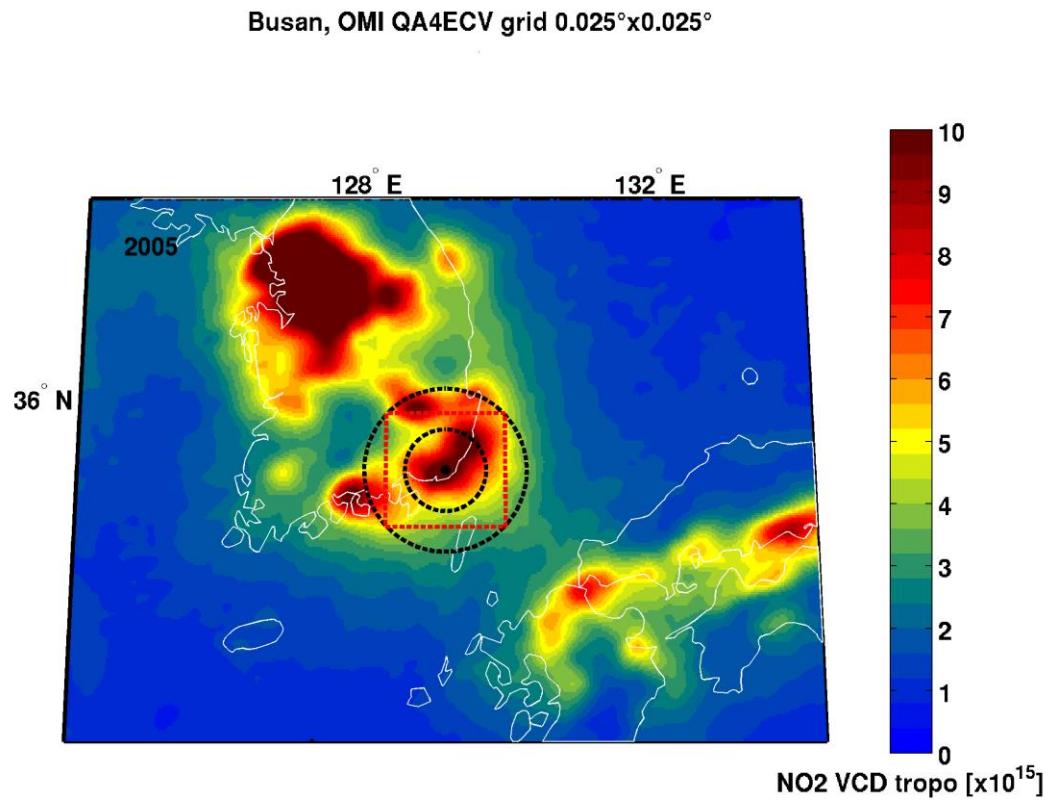


Figure S11. As figure S6, but for direct sun Busan station.

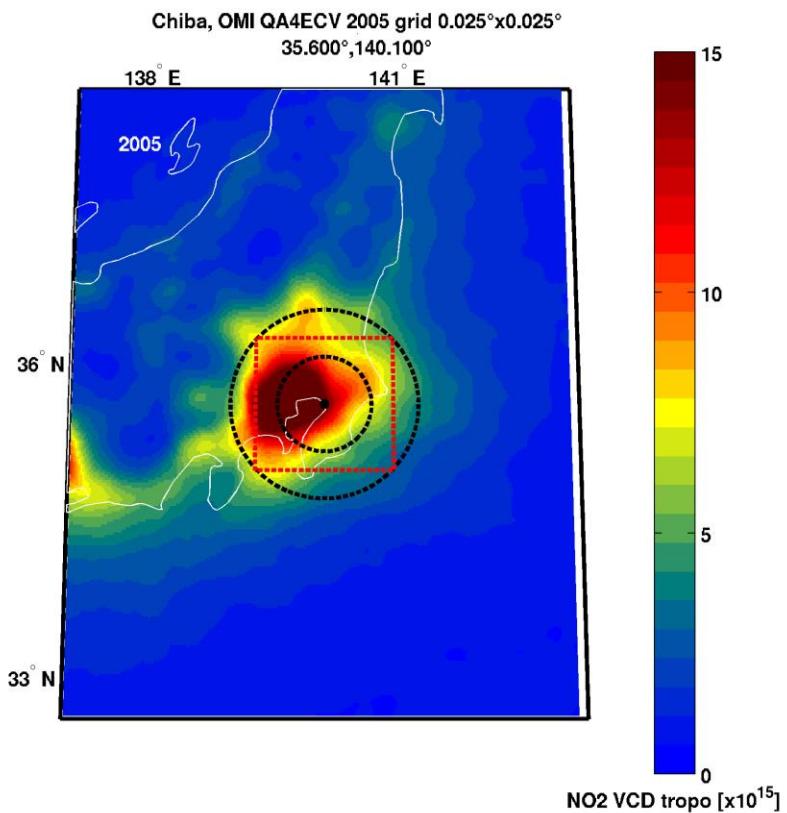


Figure S12. As figure S6, but for MAX-DOAS Chiba station.

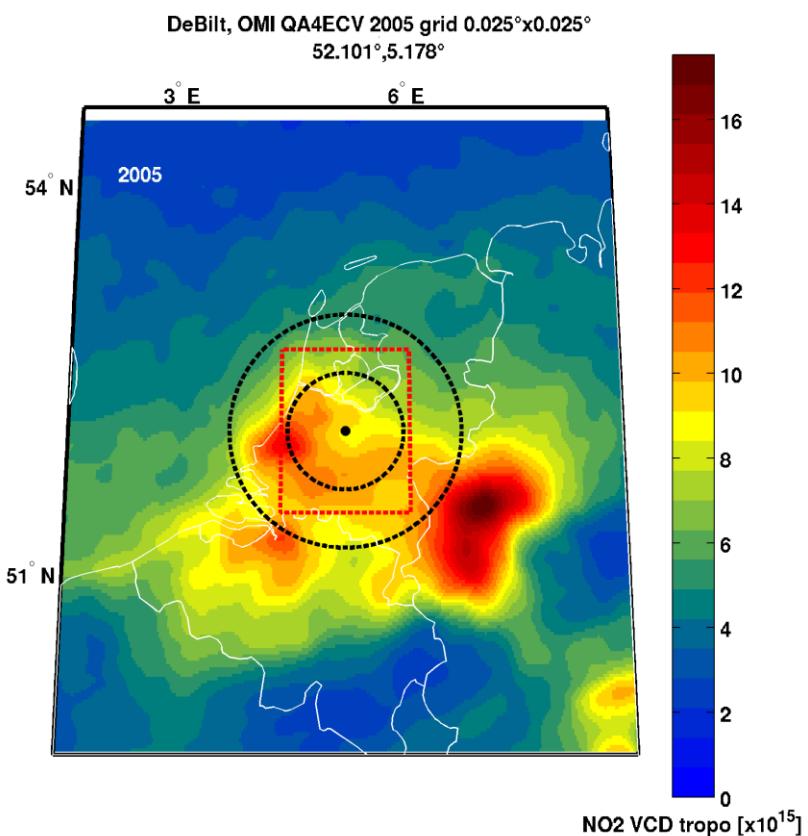


Figure S13. As figure S6, but for MAX-DOAS De Bilt station.

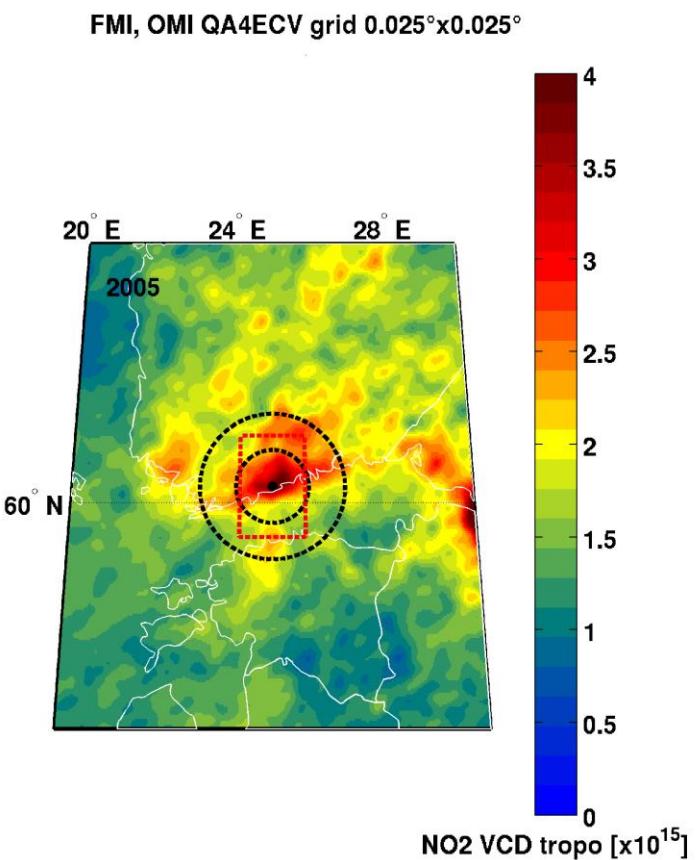


Figure S14. As figure S6, but for direct sun FMI-Helsinki station.

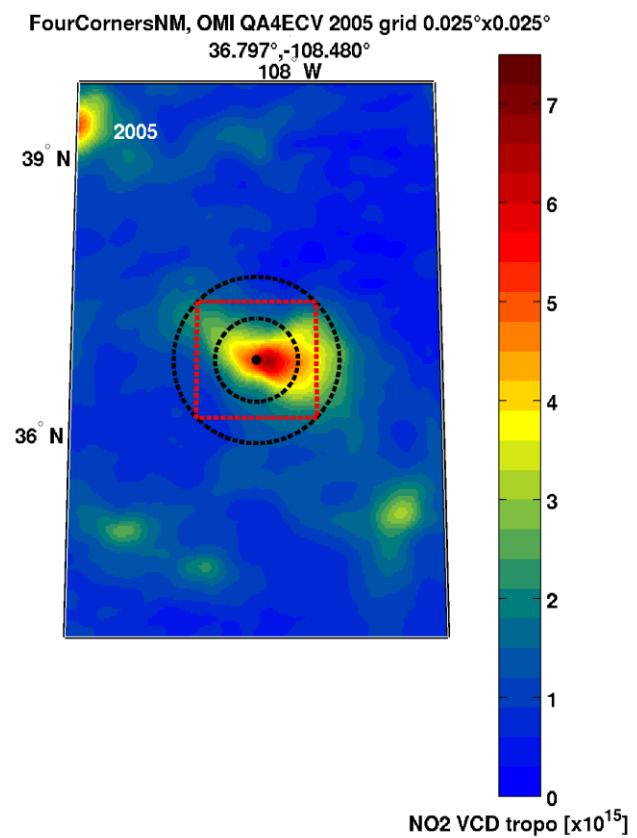


Figure S15. As figure S6, but for direct sun FourCorners (New Mexico) station.

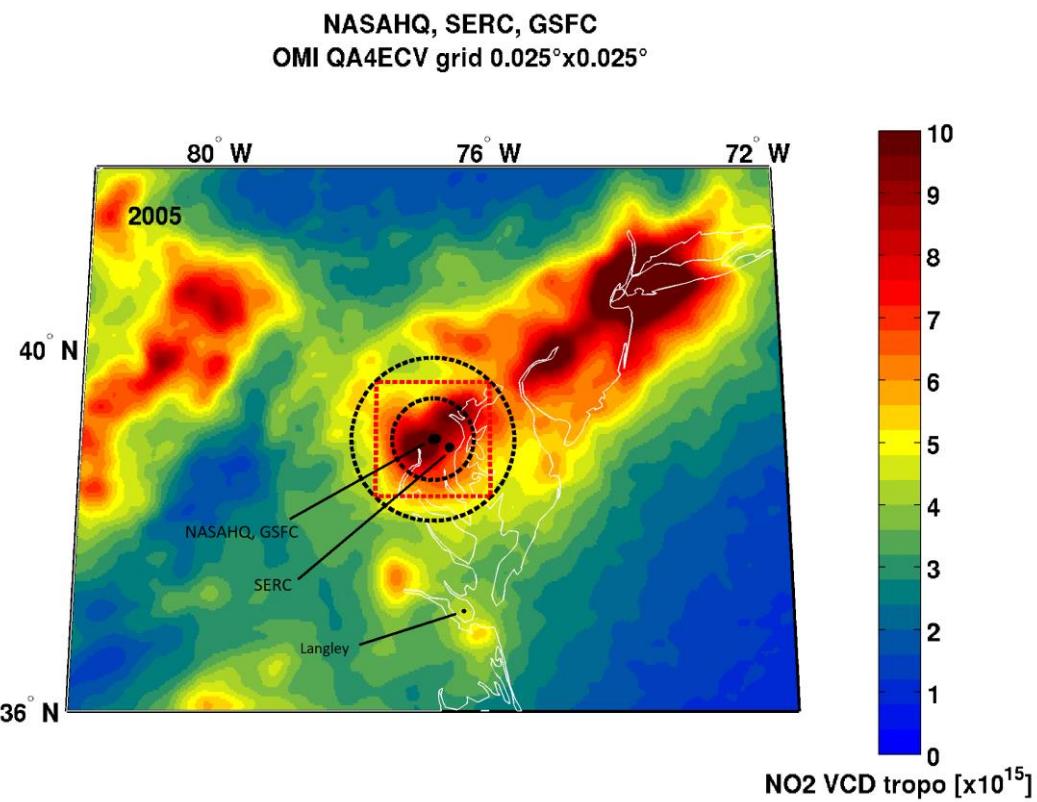


Figure S16. As figure S6, but for direct sun GSFC station.

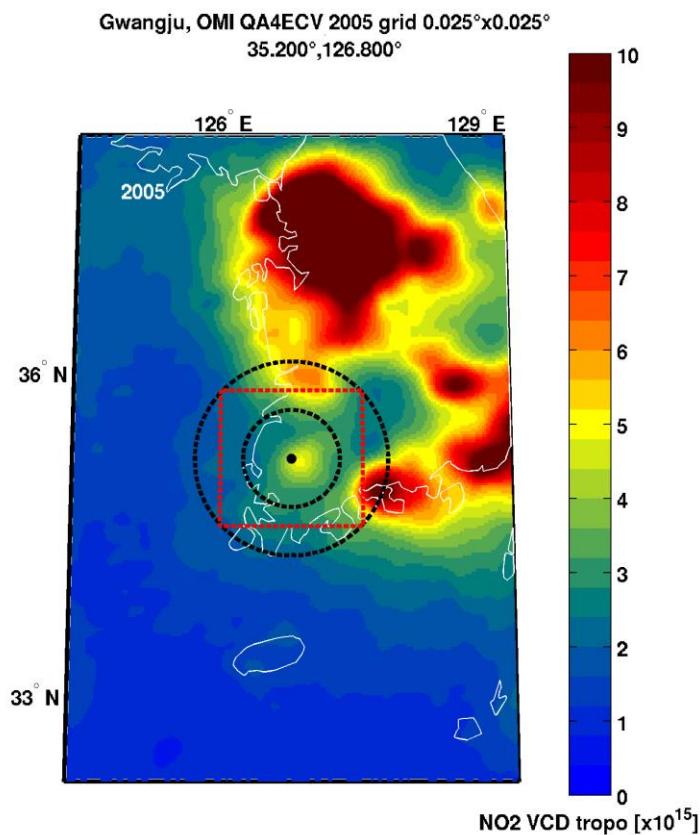


Figure S17. As figure S6, but for MAX-DOAS Gwangju station.

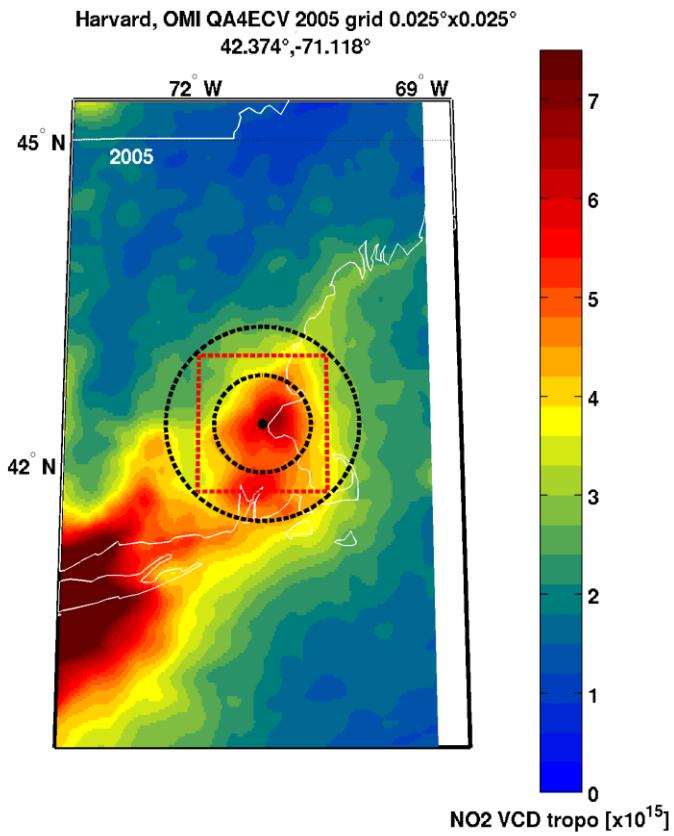


Figure S18. As figure S6, but for direct sun Harvard station.

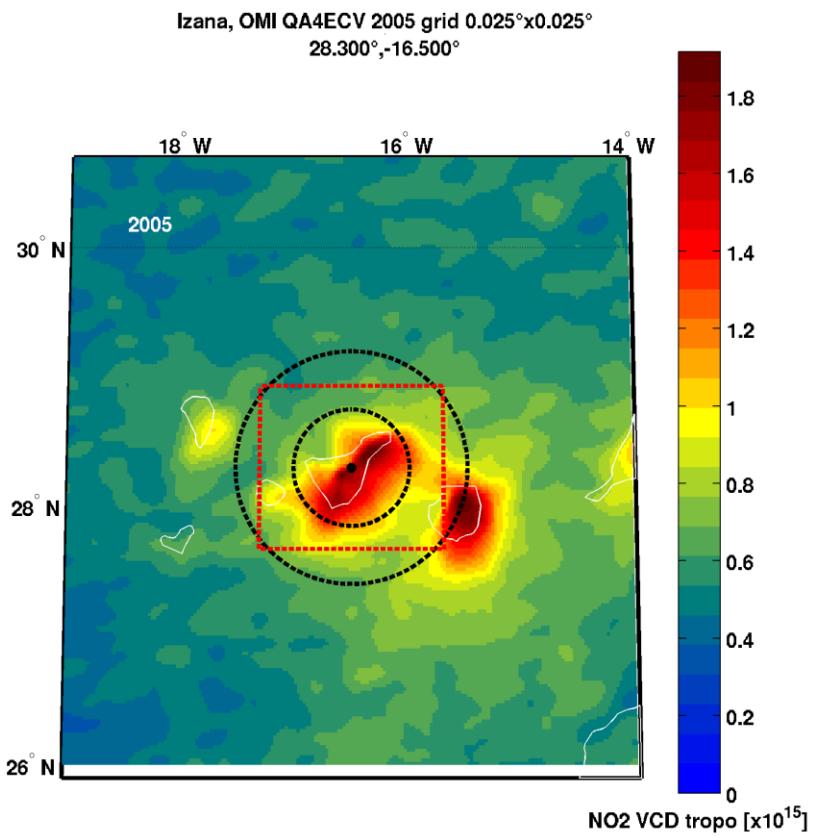


Figure S19. As figure S6, but for direct sun Izana (IZO) station.

Japan, OMI QA4ECV grid  $0.025^\circ \times 0.025^\circ$

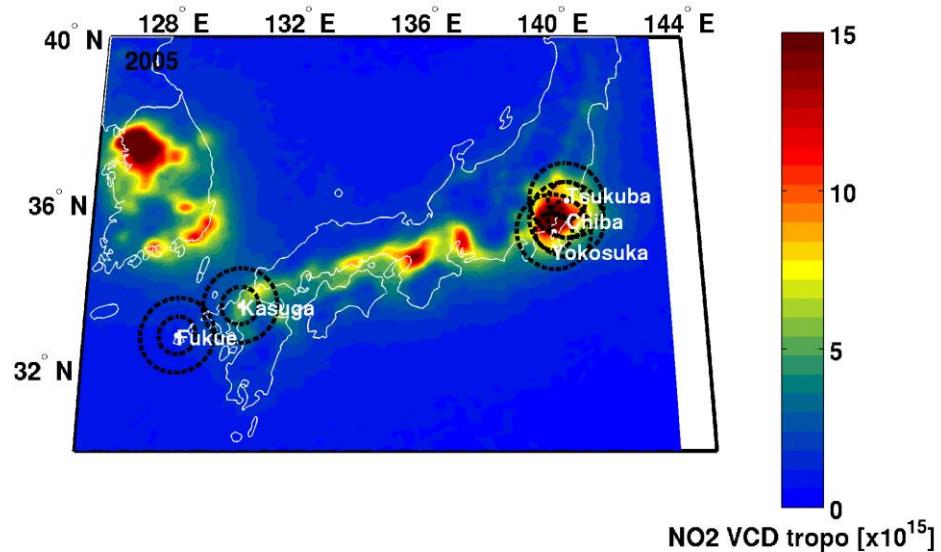


Figure S20. As figure S6, but for MAX-DOAS Kasuga station.

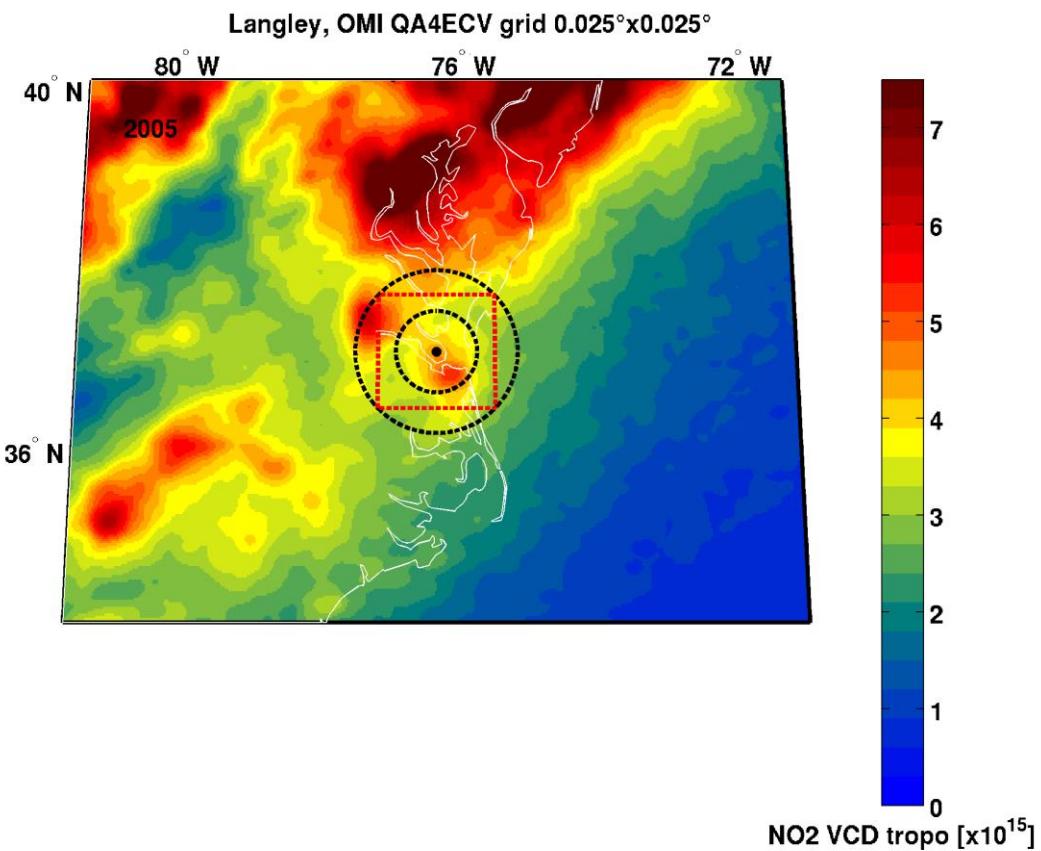


Figure S21. As figure S6, but for direct sun Langley station.

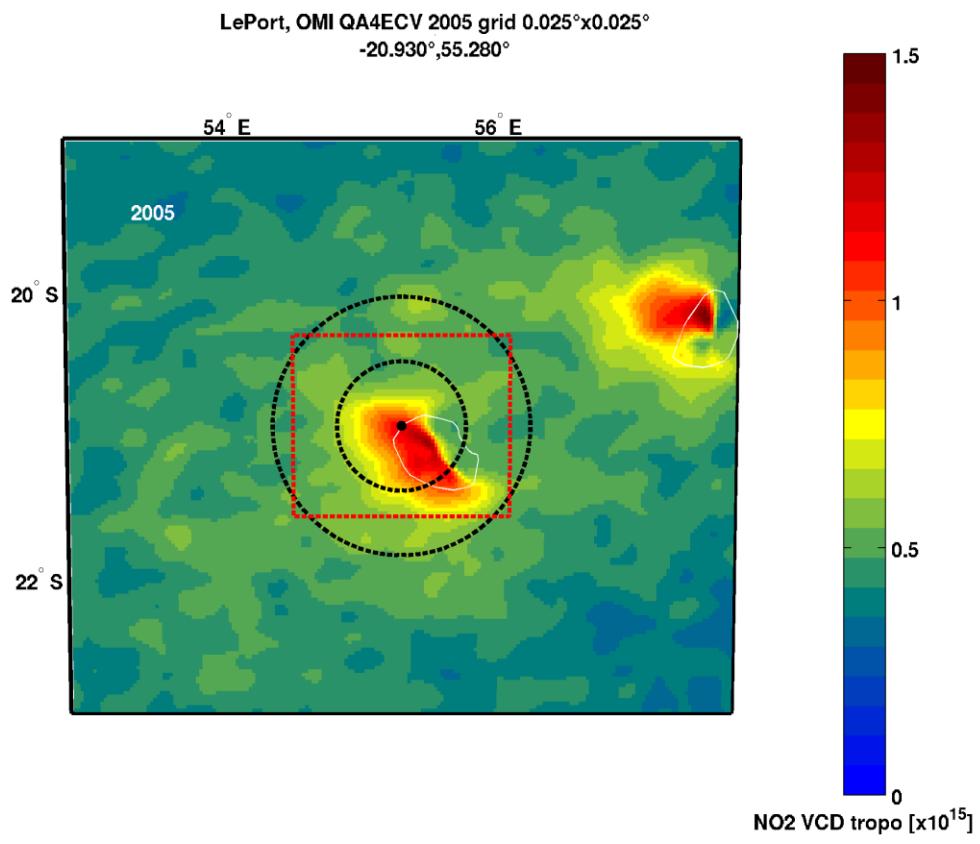


Figure S22. As figure S6, but for MAX-DOAS Reunion Island LePort station.

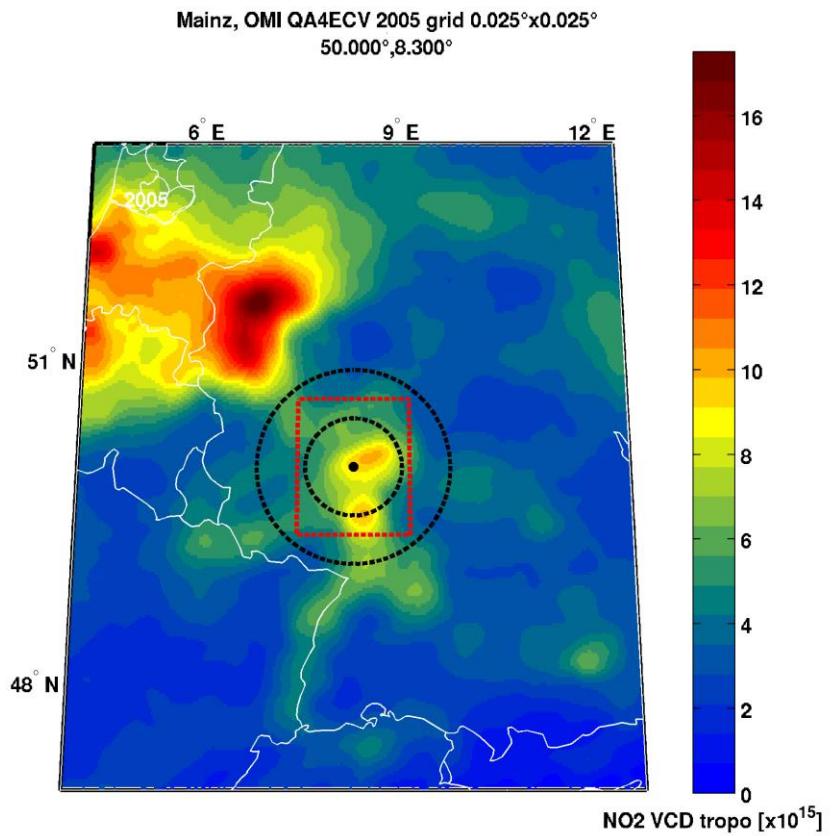


Figure S23. As figure S6, but for MAX-DOAS Mainz station.

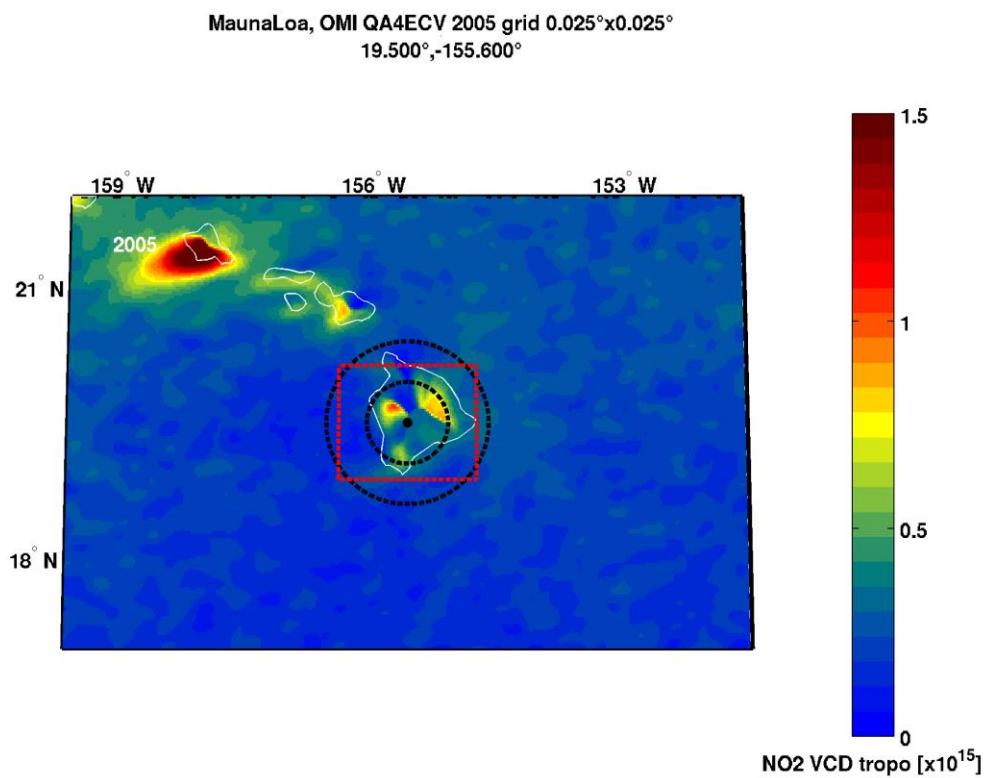


Figure S24. As figure S6, but for direct sun MaunaLoa (Hawaii) station.

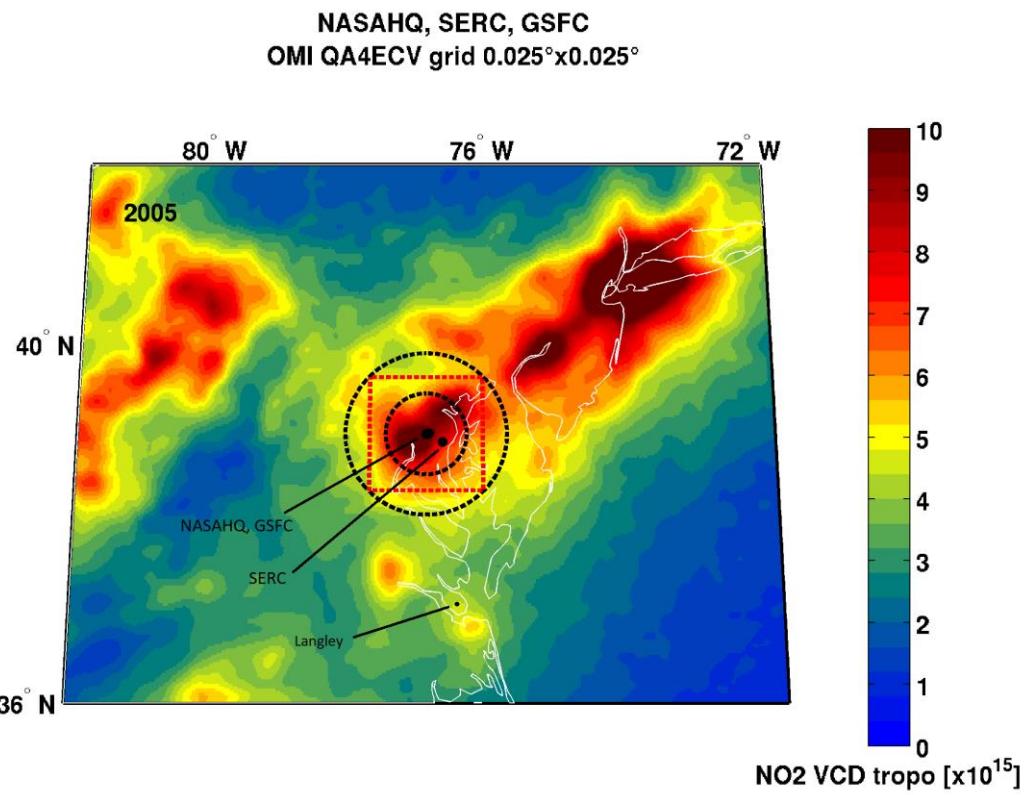


Figure S25. As figure S6, but for direct sun NASA HQ (Head Quarter) station, and indication of SERC, GSFC and Langley stations.

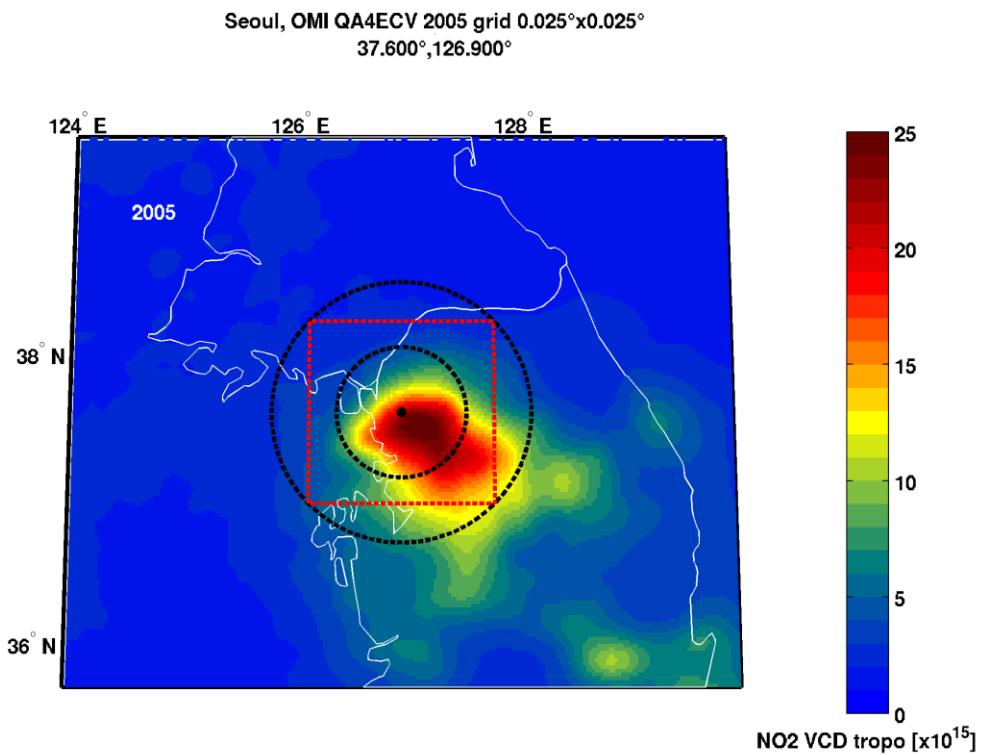


Figure S26. As figure S6, but for direct sun Seoul station.

Thessaloniki, OMI QA4ECV grid  $0.025^\circ \times 0.025^\circ$

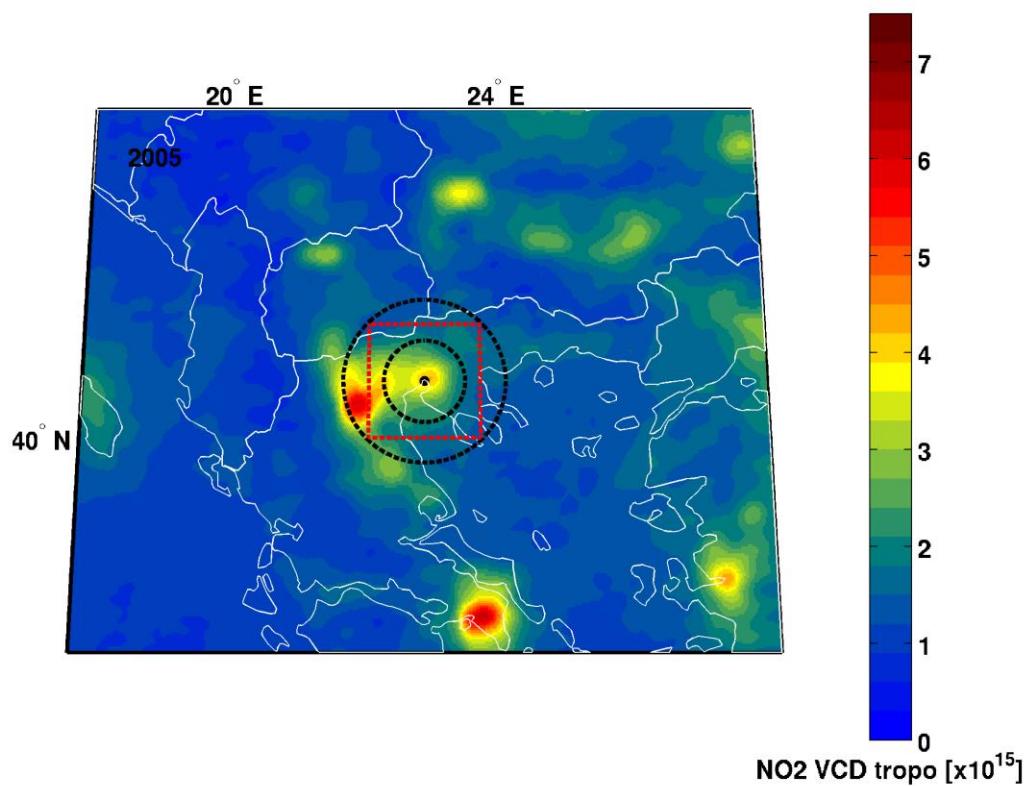


Figure S27. As figure S6, but for MAX-DOAS and direct sun Thessaloniki station.

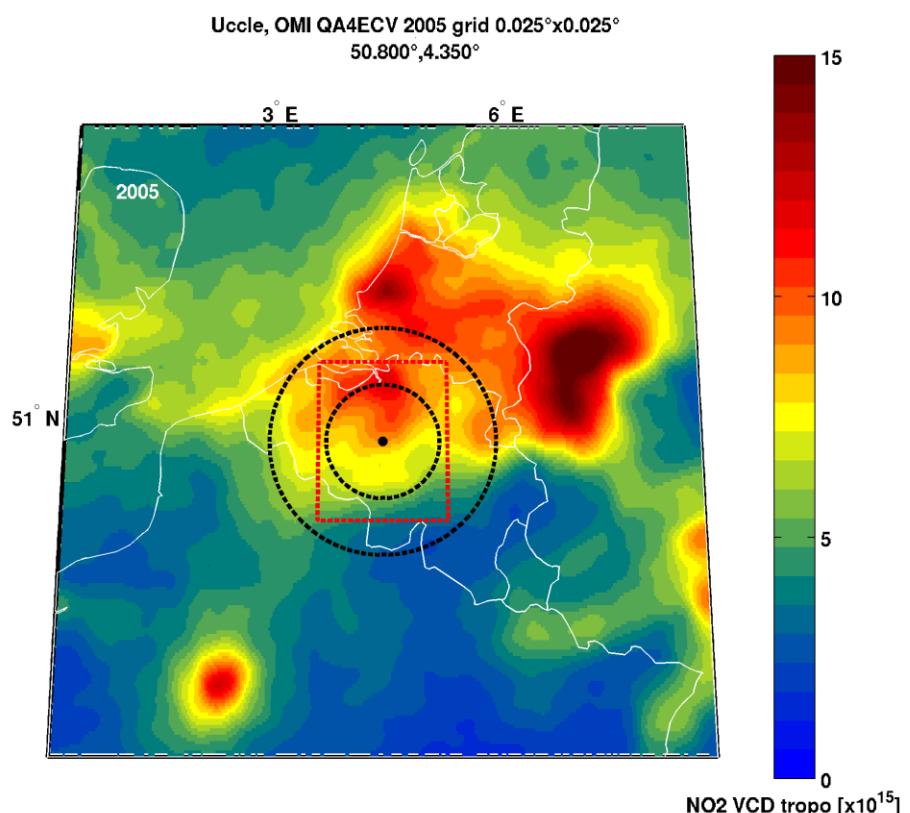


Figure S28. As figure S6, but for MAX-DOAS Uccle station.

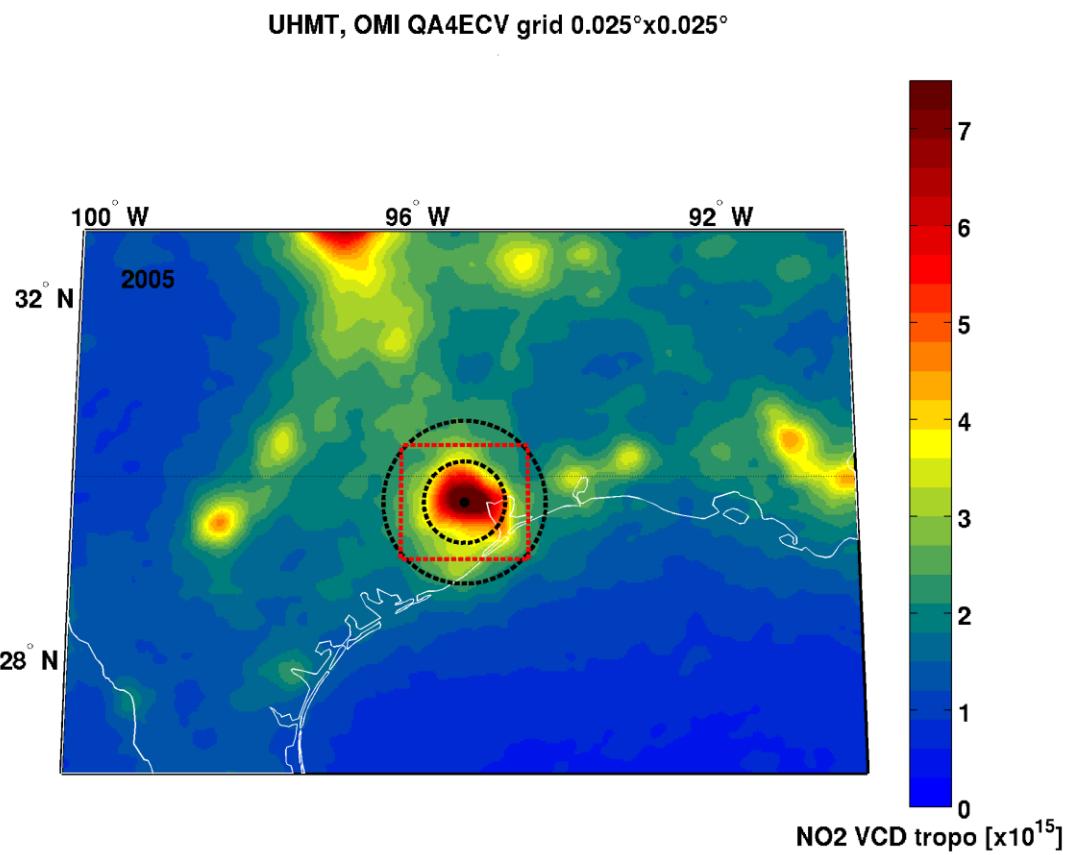


Figure S29. As figure S6, but for direct sun UHMT station.

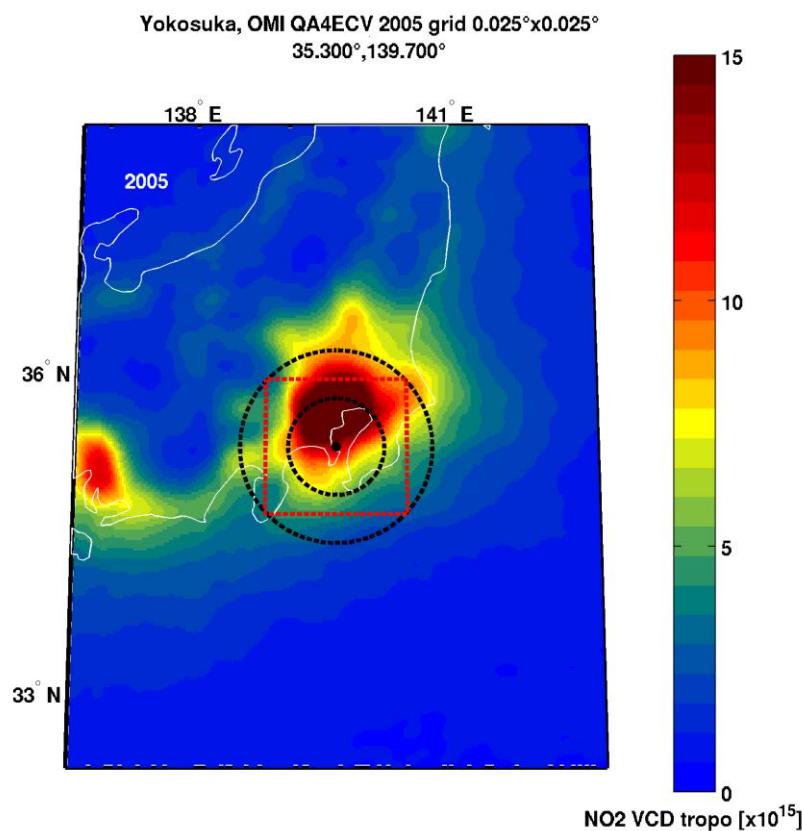


Figure S30. As figure S6, but for MAX-DOAS Yokosuka station.