Supplementary Information for:

Updated and validated solar irradiance reference spectra for estimating environmental photodegradation rates

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Table S1. Values used for input parameters of SMARTS for comparison to NREL data

Date	Atmosphere	Ozone (DU)	AOD (500 nm)
January 19, 2014	midlatitude winter	306	0.030445[a]
February 26, 2014	midlatitude winter	306	0.030415
March 23, 2014	midlatitude summer	352	0.087332
April 11, 2014	midlatitude summer	335	0.051282
May 28, 2014	midlatitude summer	295	0.044586
June 19, 2014	midlatitude summer	336	0.044069
August 12, 2014	midlatitude summer	294	0.138128
September 24, 2014	midlatitude winter	267	0.07019
October 14, 2014	midlatitude winter	274	0.021974
December 19, 2014	midlatitude winter	292	0.039633

[a]data unavailable from 1/19/2014, so measurement from 1/18/2014 used

Table S2. Values used for input parameters of SMARTS for comparison to NOAA data

Date	Atmosphere	Ozone (DU)	AOD (500 nm)
January 10, 2016	midlatitude winter	350	0.050616
February 25, 2016	midlatitude winter	348	0.049503
March 20, 2016	midlatitude summer	329	0.04065
April 21, 2016	midlatitude summer	335	0.065887
May 4, 2016	midlatitude summer	329	0.056307
June 17, 2016	midlatitude summer	300	0.137968
June 18, 2016	midlatitude summer	273	0.166628
July 27, 2016	midlatitude summer	286	0.137435
August 20, 2016	midlatitude summer	294	0.084295
September 25, 2016	midlatitude winter	274	0.034618
October 20, 2016	midlatitude winter	279	0.029616
November 18, 2016	midlatitude winter	258	0.039043
December 10, 2016	midlatitude winter	285	0.006866

Table S3. Values used for input parameters of SMARTS for comparison to NSF data

Site	Date	Atmosphere	Ozone (DU)	AOD (500 nm)
Ushuaia, Argentina	December 28, 2007	subarctic summer	293	0.025
Barrow, AK, USA	June 25, 2016	arctic summer	342	0.03[a]

[a]data unavailable for 6/25/2016, used representative value for a clear sky day

Table S4. Ozone concentrations used (Dobson units) for the calculation of reference spectra. These values were obtained by looking at the measurements for the last 8 years (averaged over all longitudes, Figures S3-S10)

Latitude/Time	March	June	September	December
0°	255	255	270	245
10°N	255	270	270	245
10°S	255	255	270	255
20°N	270	285	270	250
20°S	255	255	280	270
30°N	300	300	275	270
30°S	265	280	300	280
40°N	345	320	280	310
40°S	270	310	335	290
50°N	390	345	305	350
50°S	280	315	355	310
60°N	400	355	305	370
60°S	290	300	320	320
70°N	420	335	300	NA
70°S	290	NA	220	295

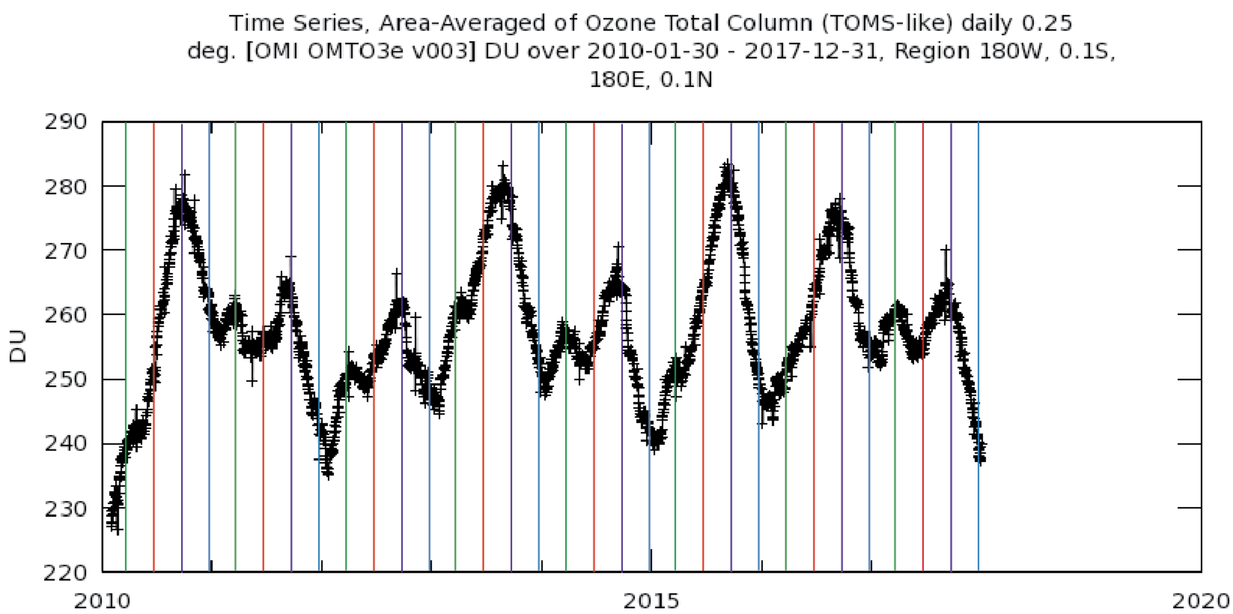


Figure S1. Ozone concentrations for 2010-2017 at 0°, averaged over all longitudes. The vertical lines represent the approximate time for the reference spectra (March 20=green, June 21=red, September 22=purple, December 22=blue). Data was downloaded from giovanni.gsfc.nasa.gov.

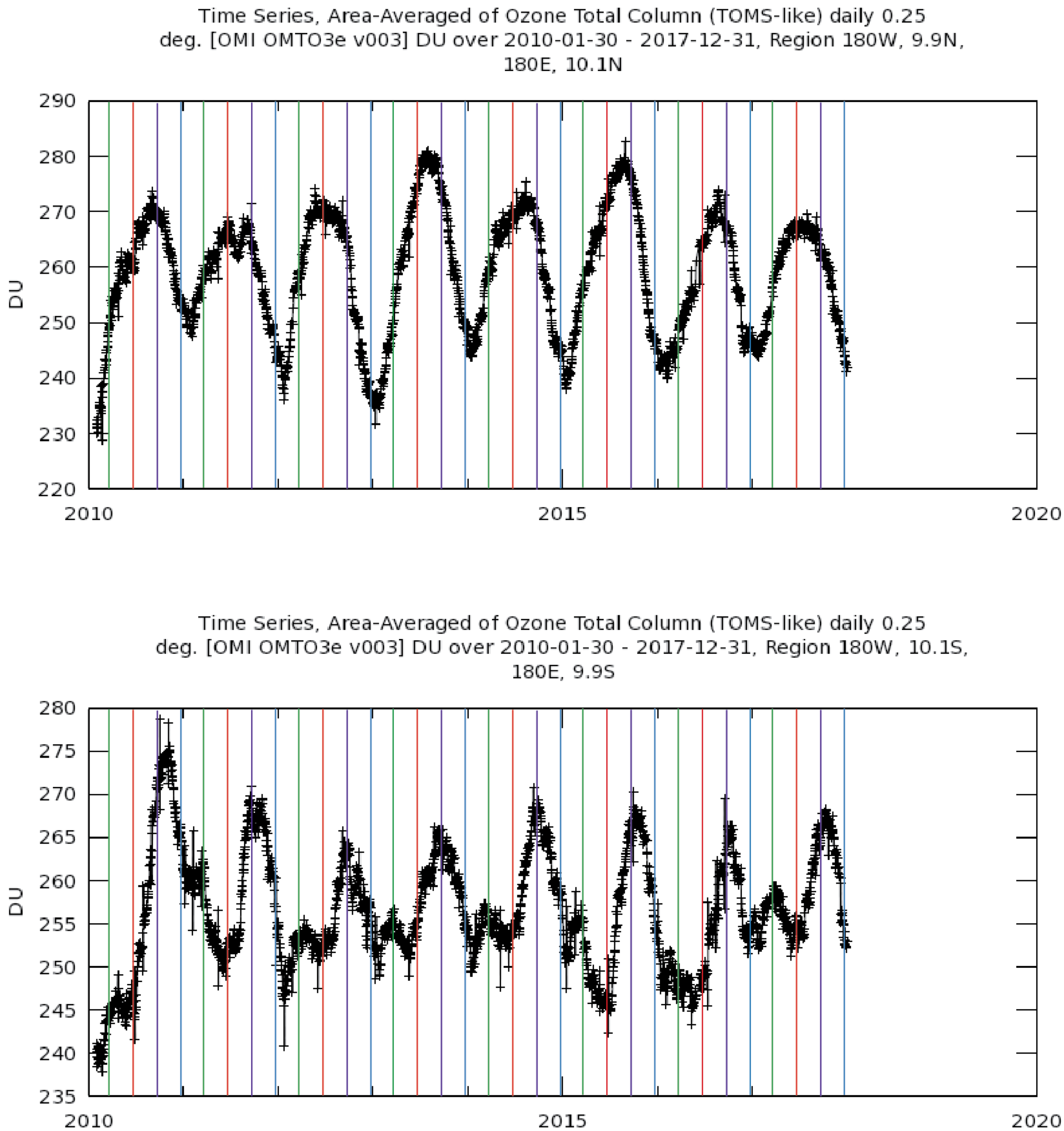
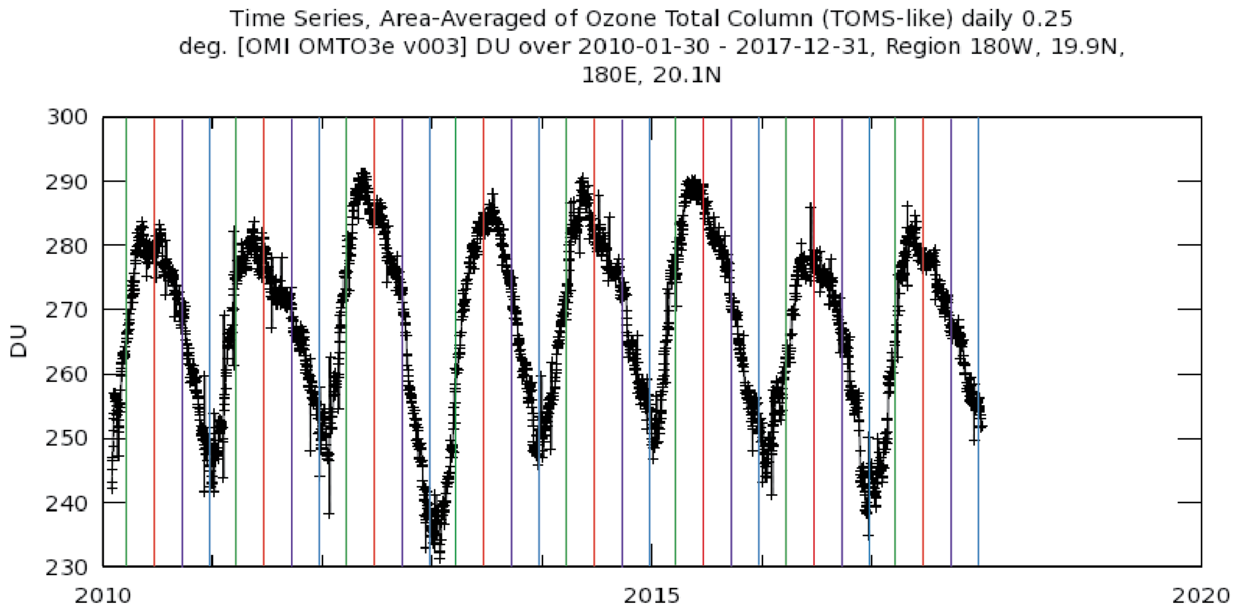


Figure S2. Ozone concentrations for 2010-2017 at 10°N (top) and 10°S (bottom), averaged over all longitudes. The vertical lines represent the approximate time for the reference spectra (March 20=green, June 21=red, September 22=purple, December 22=blue). Data was downloaded from giovanni.gsfc.nasa.gov.



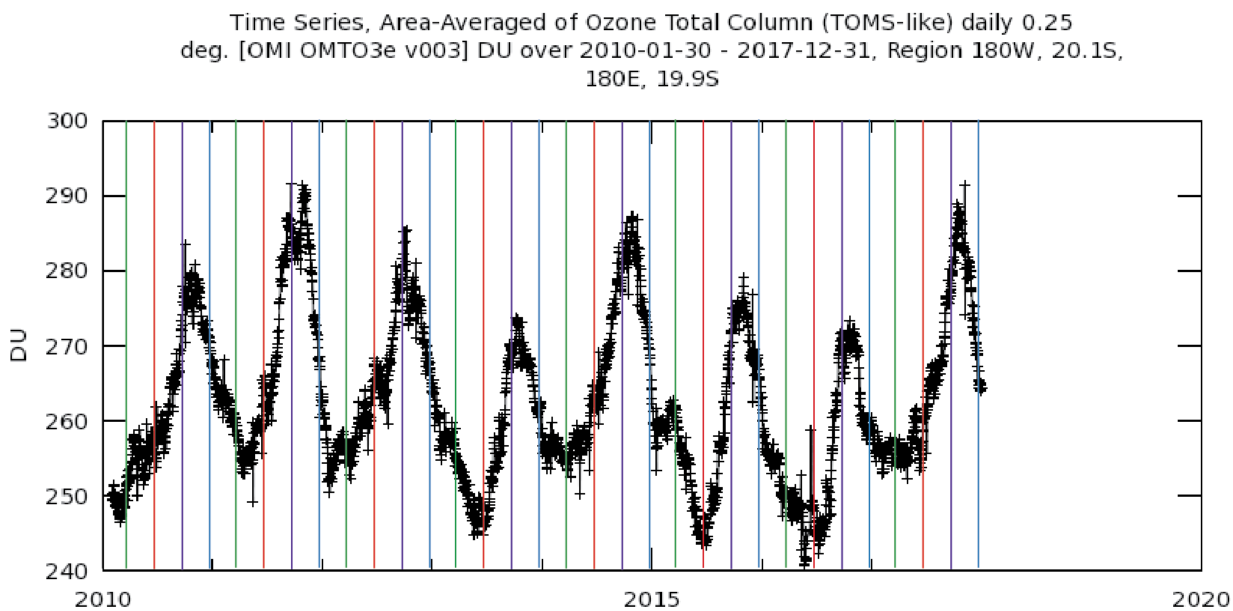
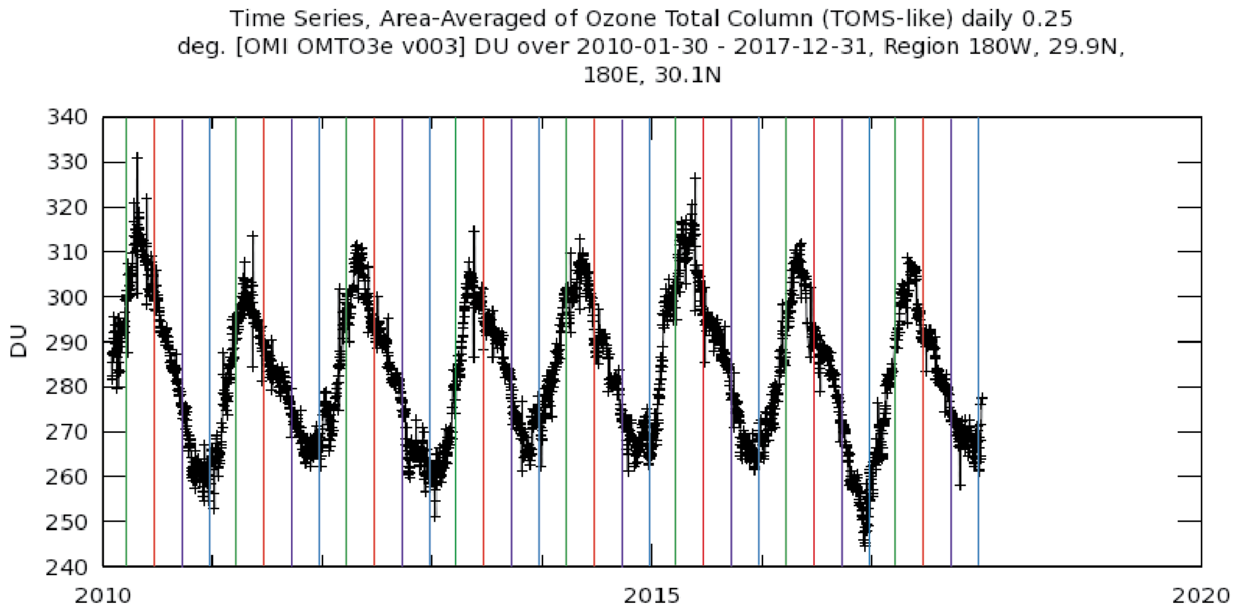


Figure S3. Ozone concentrations for 2010-2017 at 20°N (top) and 20°S (bottom), averaged over all longitudes. The vertical lines represent the approximate time for the reference spectra (March 20=green, June 21=red, September 22=purple, December 22=blue). Data was downloaded from giovanni.gsfc.nasa.gov.



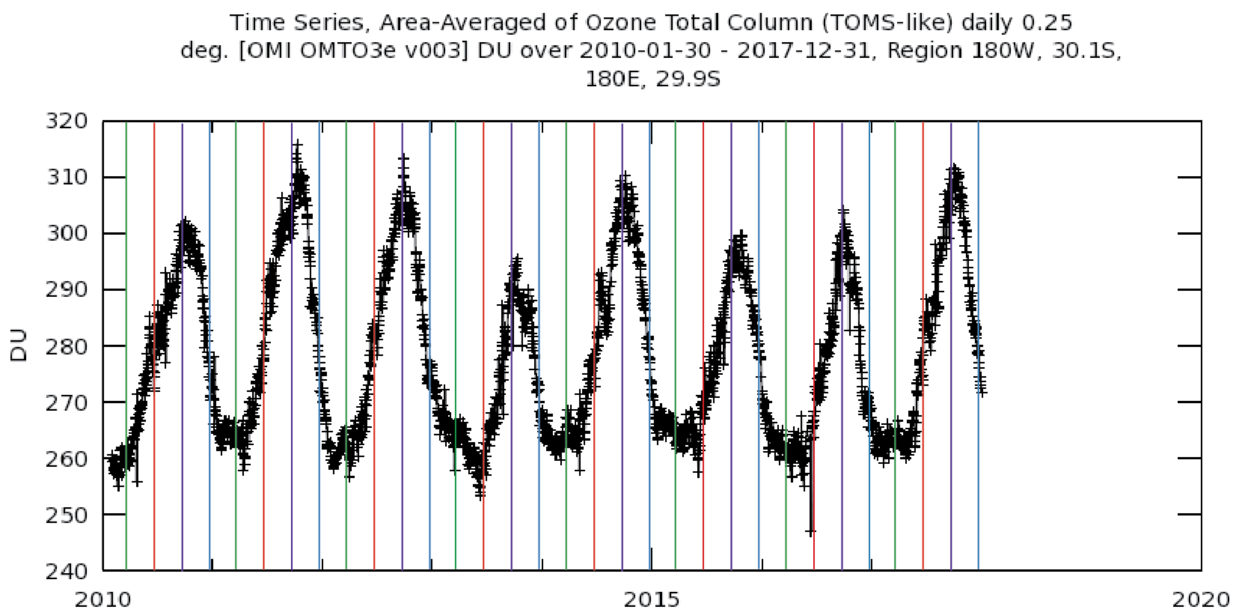


Figure S4. Ozone concentrations for 2010-2017 at 30°N (top) and 30°S (bottom), averaged over all longitudes. The vertical lines represent the approximate time for the reference spectra (March 20=green, June 21=red, September 22=purple, December 22=blue). Data was downloaded from giovanni.gsfc.nasa.gov.

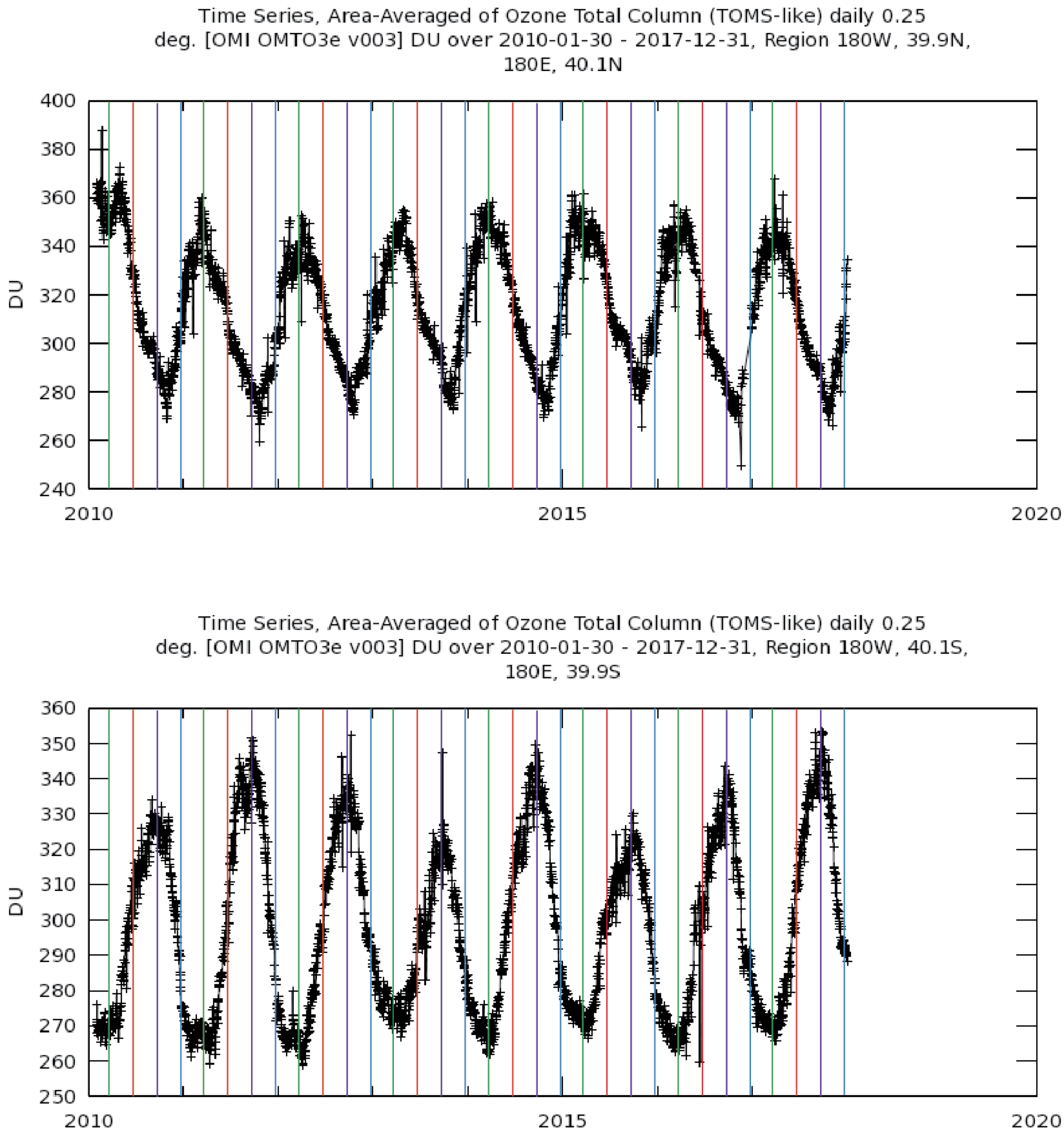
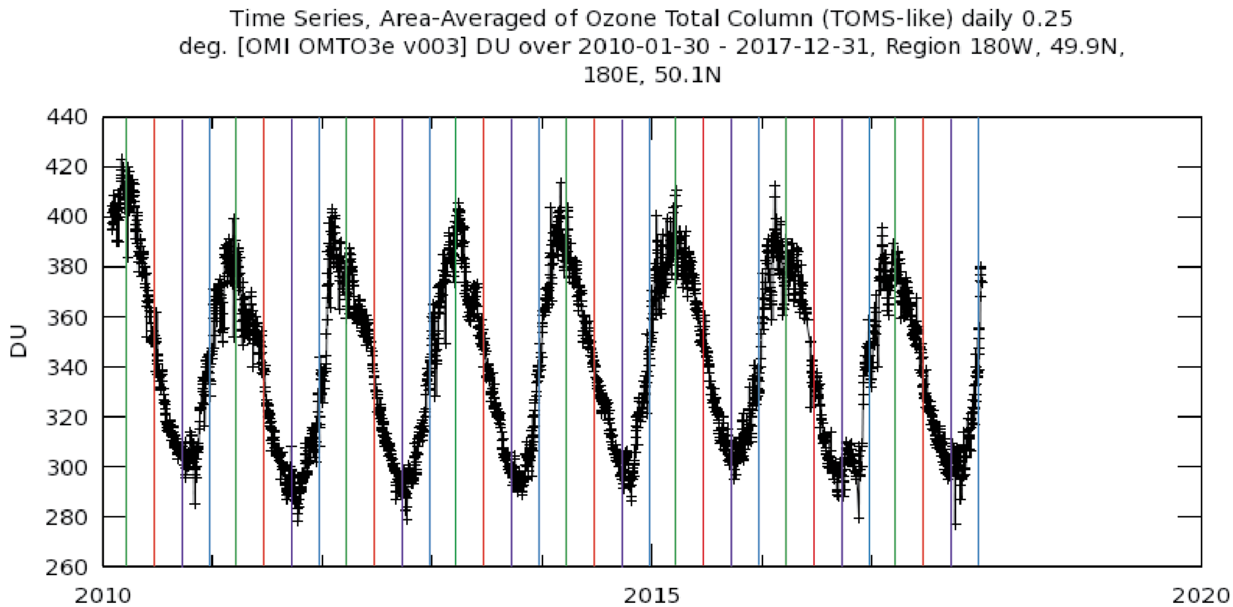


Figure S5. Ozone concentrations for 2010-2017 at 40°N (top) and 40°S (bottom), averaged over all longitudes. The vertical lines represent the approximate time for the reference spectra (March 20=green, June 21=red, September 22=purple, December 22=blue). Data was downloaded from giovanni.gsfc.nasa.gov.



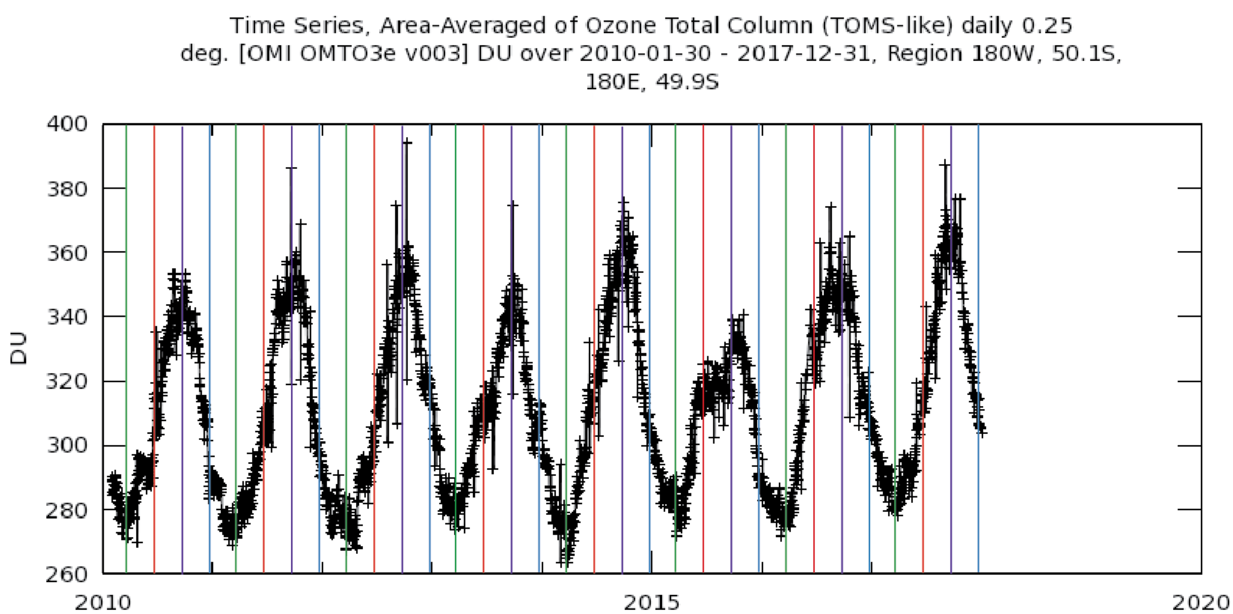
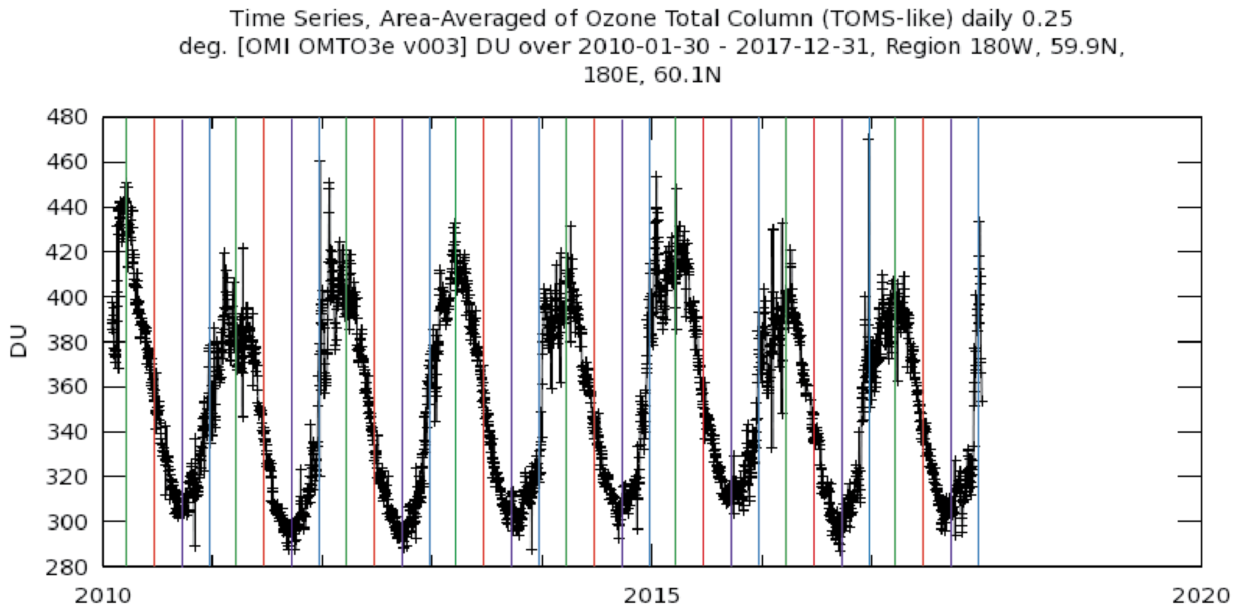


Figure S6. Ozone concentrations for 2010-2017 at 50°N (top) and 50°S (bottom), averaged over all longitudes. The vertical lines represent the approximate time for the reference spectra (March 20=green, June 21=red, September 22=purple, December 22=blue). Data was downloaded from giovanni.gsfc.nasa.gov.



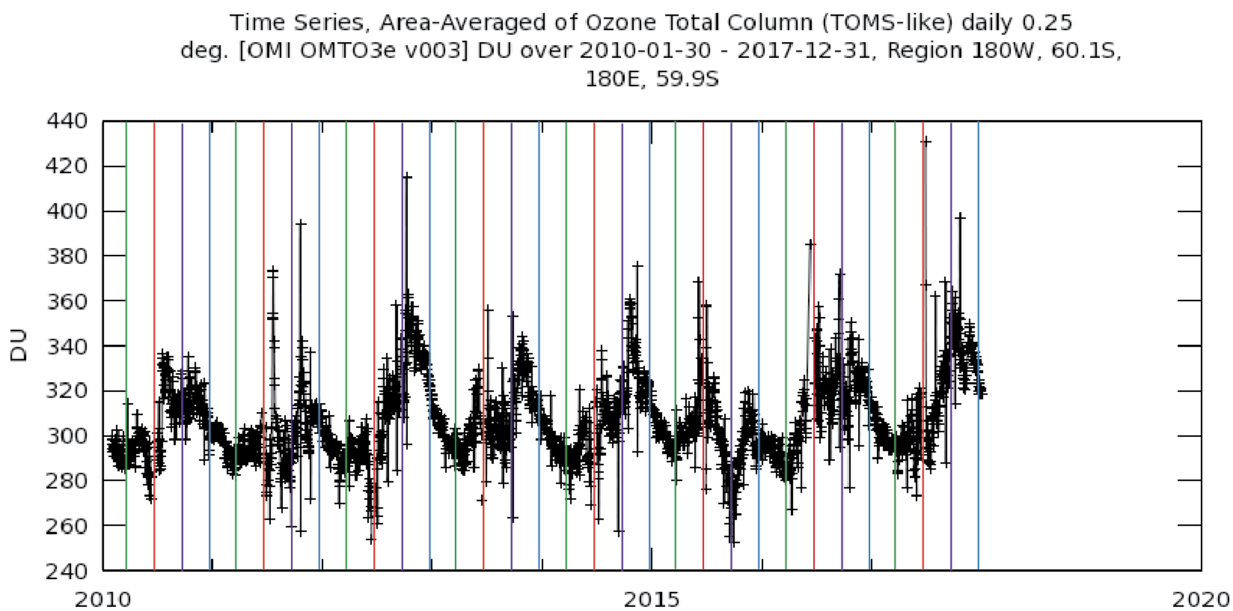
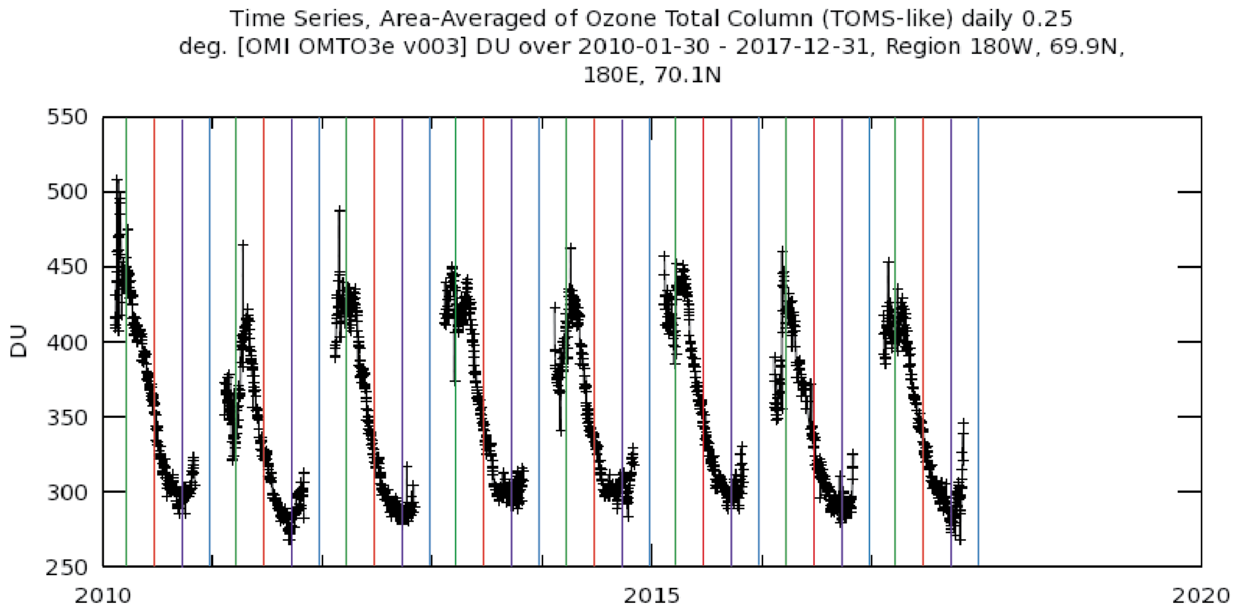


Figure S7. Ozone concentrations for 2010-2017 at 60°N (top) and 60°S (bottom), averaged over all longitudes. The vertical lines represent the approximate time for the reference spectra (March 20=green, June 21=red, September 22=purple, December 22=blue). Data was downloaded from giovanni.gsfc.nasa.gov.



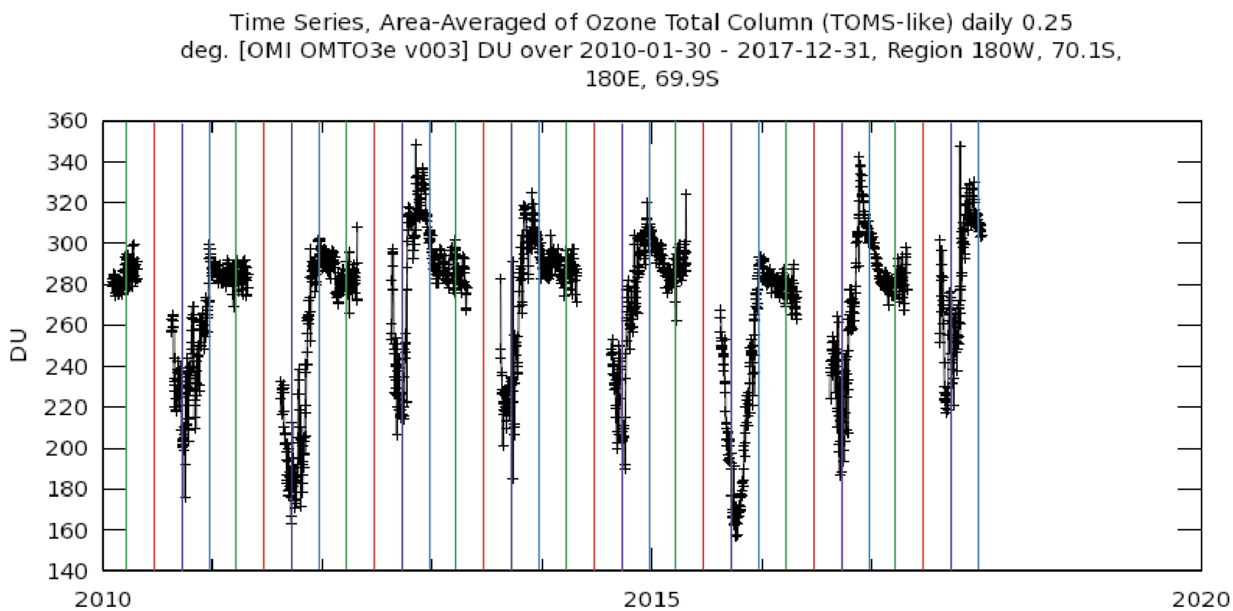


Figure S8. Ozone concentrations for 2010-2017 at 70°N (top) and 70°S (bottom), averaged over all longitudes. The vertical lines represent the approximate time for the reference spectra (March 20=green, June 21=red, September 22=purple, December 22=blue). Data was downloaded from giovanni.gsfc.nasa.gov.

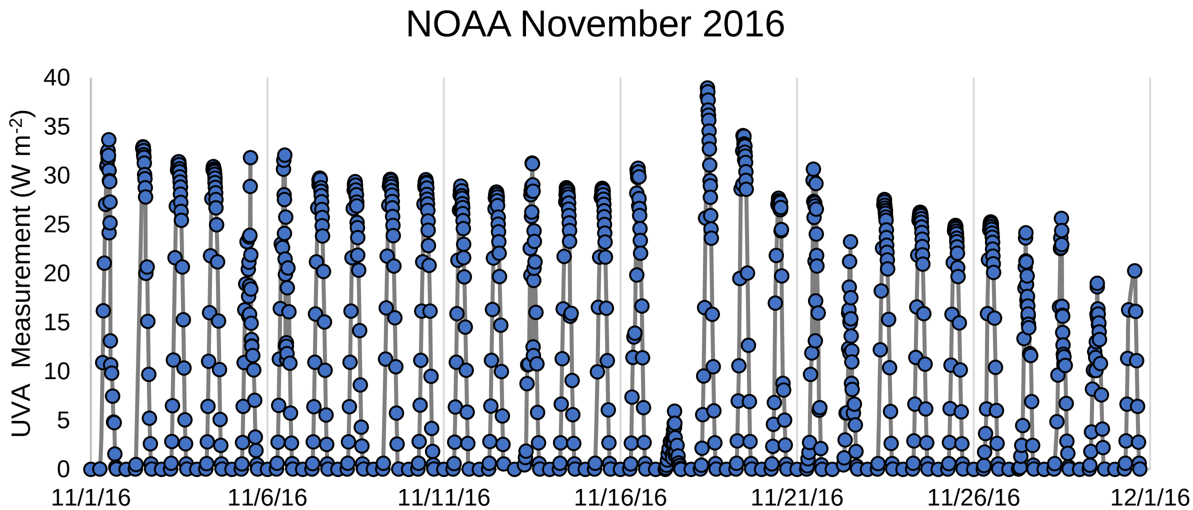


Figure S9. Total UVA irradiance measurements (315-400 nm) from the NOAA spectroradiometer (Boulder, CO) for November 2016

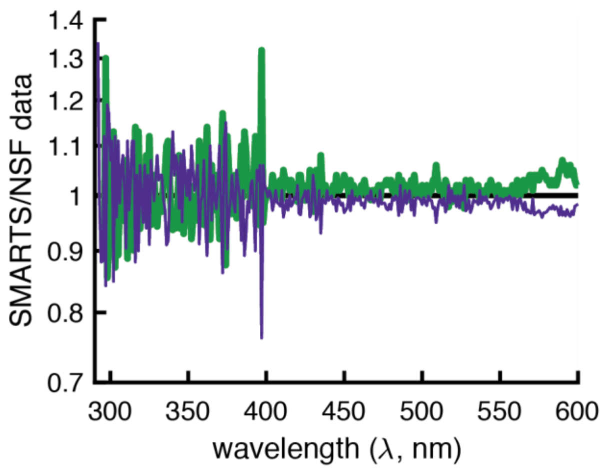


Figure S10. Comparison of clear sky summertime solar irradiance data measured by the NSF facilities in Barrow (Utqiaġvik), AK, USA (green, 71.3°N, June 2016) and Ushuaia, Argentina (purple, 54.8°S, December 2007) after adjusting the ozone concentrations from 293 to 278 DU for Ushuaia and from 342 to 332 DU for Barrow.

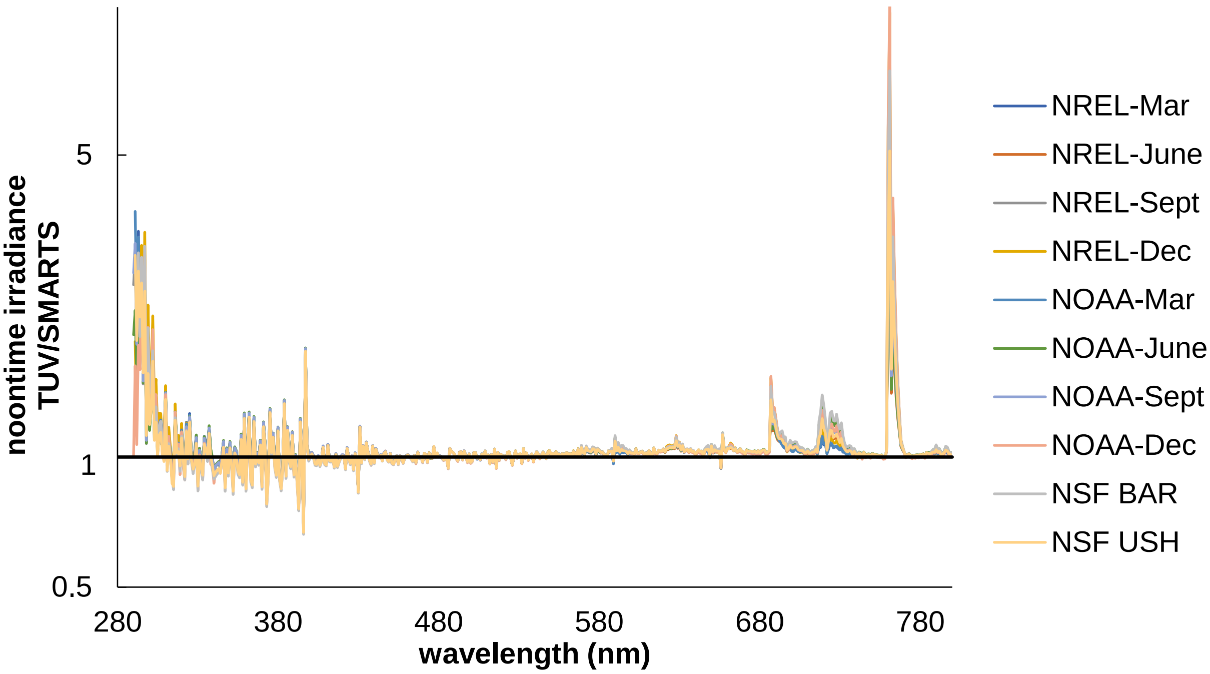


Figure S11. Comparison of the noontime spectral irradiances modeled by the TUV Radiation Model and SMARTS. Values above one indicate that TUV modeled higher irradiance. The conditions used to calculate spectra are indicated in the legend (i.e., NREL-Mar means the atmospheric conditions at the NREL site in March were used).

Table S5. Comparison of noontime irradiances modeled by the TUV calculator and SMARTS in the UVB, UVA, and PAR regions (in W m^{-2}). Values greater than 100% indicate that the TUV calculator resulted in higher irradiances.

		TUV/SMARTS		
Site:		NREL		
Month:	March	June	Sept	Dec
UVB	104.6%	103.5%	103.6%	106.1%
UVA	101.9%	101.7%	101.5%	101.2%
PAR	101.6%	101.7%	101.9%	102.0%
Site:		NOAA		
Month:	March	June	Sept	Dec
UVB	104.5%	104.5%	103.4%	101.1%
UVA	101.6%	102.0%	101.4%	98.7%
PAR	101.7%	101.9%	101.9%	101.8%
Site:	NSF BAR	NSF USH		
Month:	June	Dec		
UVB	99.8%	100.5%		
UVA	97.8%	99.2%		
PAR	102.1%	101.8%		

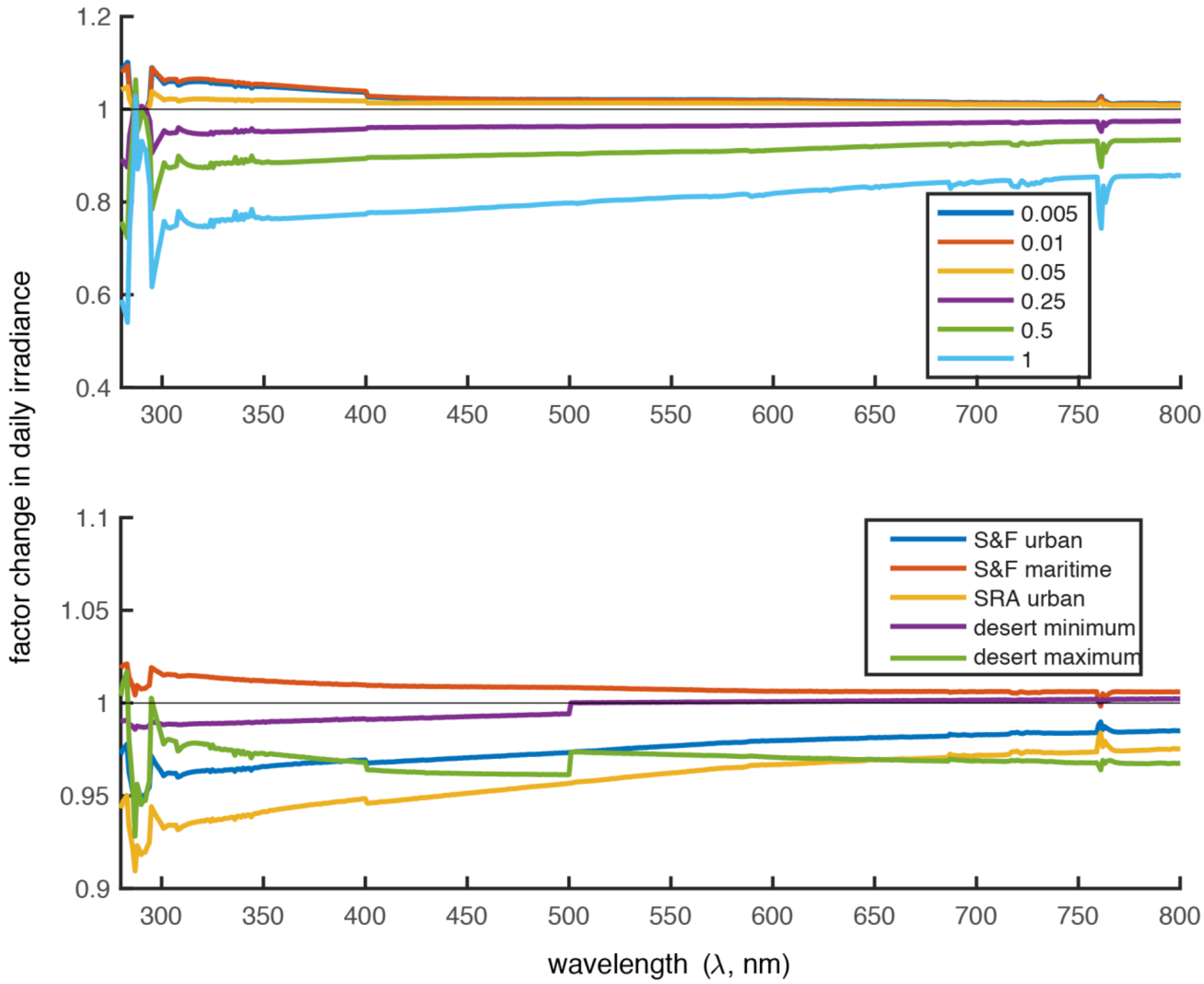


Figure S12. Sensitivity analysis for aerosol inputs in SMARTS. The top panel shows the influence of changing the aerosol optical depth from 0.005 to 1.0 from the baseline used in the reference spectra (0.1 aerosol optical depth, Shettle and Fenn rural aerosol model). The bottom panel shows the influence of changing the aerosol model from the baseline used in the reference spectra (0.1 aerosol optical depth, Shettle and Fenn rural aerosol model).

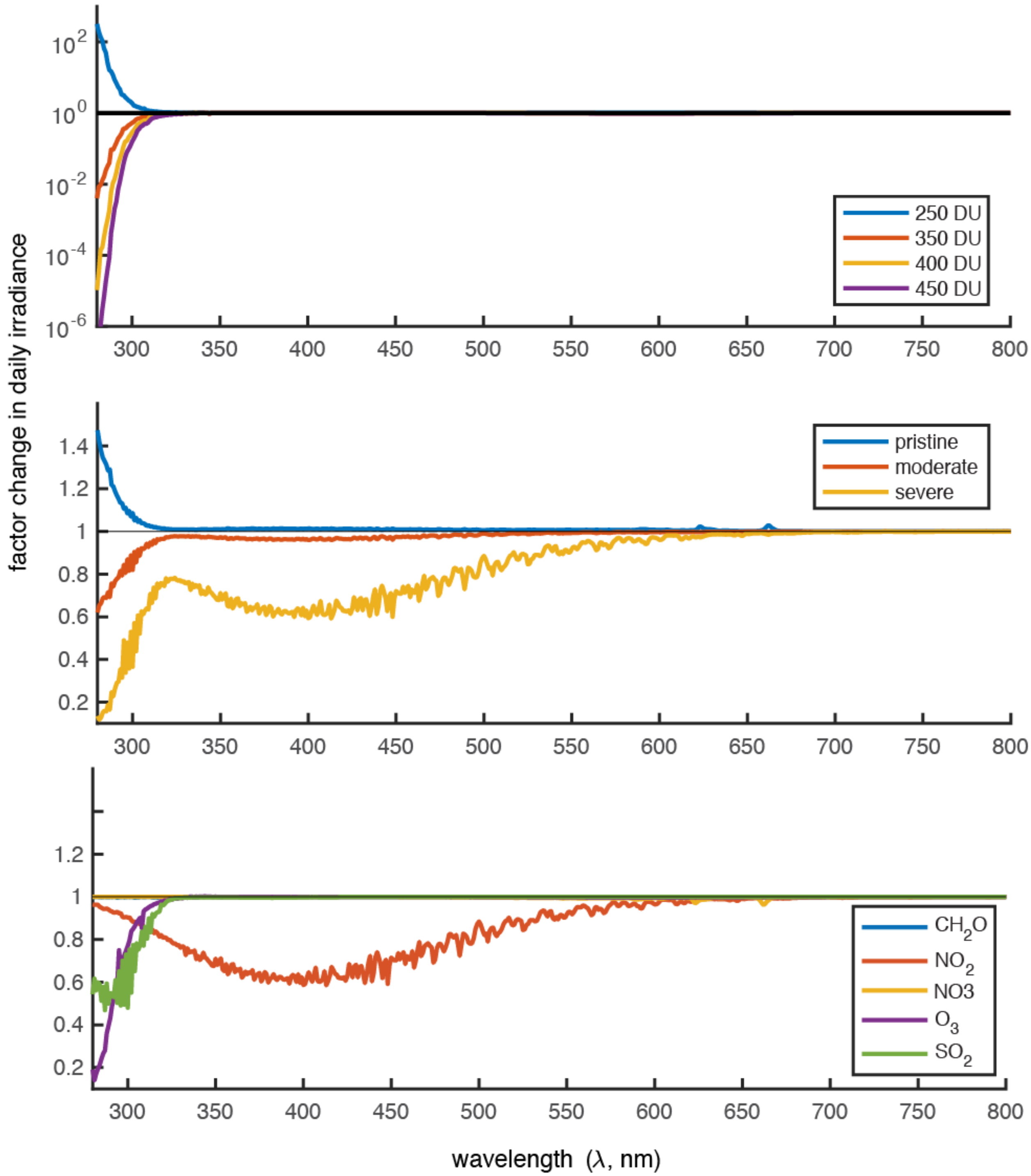


Figure S13. Sensitivity analysis for trace gaseous species concentrations in SMARTS. The top panel shows the influence of changing the ozone concentration from 250 to 450 DU where the value of 1 represents the global average of 300 DU. The middle panel shows the influence of the gaseous absorption pollution level selection where the value of 1 represents the "light pollution" setting which was used in the reference spectra. The bottom panel shows the influence of different gaseous species when changing the concentration from the "pristine" atmosphere to the "severe pollution" atmosphere individually.

Table S6. Gaseous concentrations (ppmv) in SMARTS pre-loaded gaseous absorption selections. These values represent an addition or subtraction of concentrations from the gaseous concentrations stored in the standard atmosphere data.

Gas	Pristine Atmosphere	Light Pollution	Moderate Pollution	Severe Pollution
CH_2O	-0.003	0.001	0.007	0.01
CH_4	0	0.2	0.3	0.4
CO	-0.1	0	0.35	9.9
HNO_2	-9.9E-4	0.0005	0.002	0.01
HNO_3	0	0.001	0.005	0.012
NO	0	0.075	0.2	0.5
NO_2	0	0.005	0.02	0.2
NO_3	-4.9E-4	1E-5	5E-5	2E-4
O_3	-0.007	0.023	0.053	0.175
SO_2	0	0.01	0.05	0.2

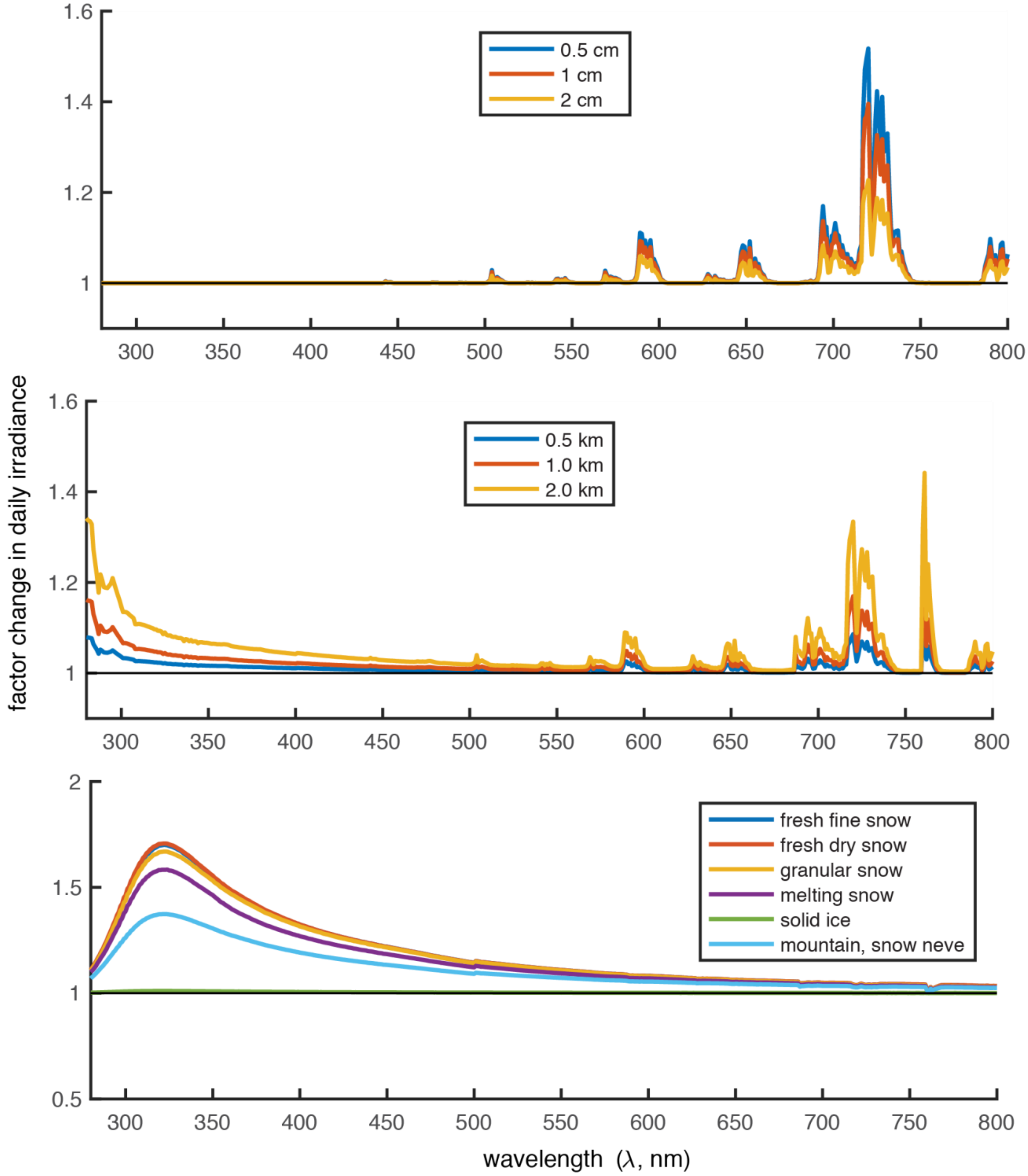


Figure S14. Sensitivity analysis for water vapor, altitude, and albedo in SMARTS. The top panel shows the influence of water vapor concentrations as they are lowered from the value of 4.11 cm of precipitable water (default value for tropical summer atmosphere) to 0.5 cm precipitable water. The middle panel shows the influence of the altitude, which shows influences from the gaseous species (ozone, oxygen, NO_2, SO_2, water vapor) and aerosols. The bottom panel shows the effect of albedo for the snow and ice settings in SMARTS. In the bottom panel, the baseline is the irradiance at 60°N instead of at 0°.