



Supplement of

Air quality and radiative impacts of downward-propagating sudden stratospheric warmings (SSWs)

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Williams et al. (2023): Supplementary Information

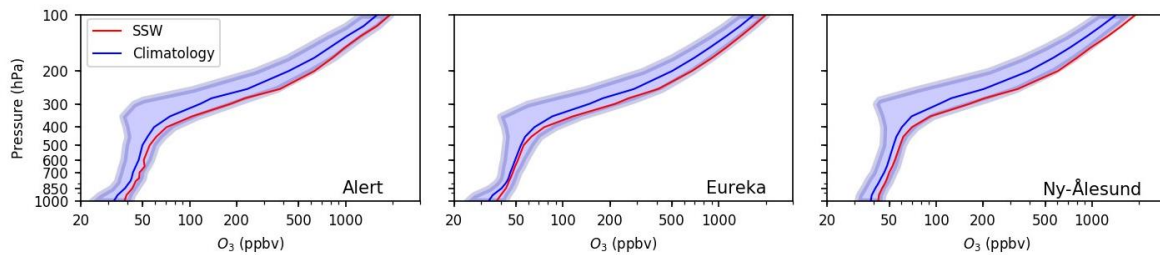


Figure S1 – Mean PJO-type SSW profiles composited from all profiles within 0 to +70 days of an SSW central warming date with remaining December to April (excluding all SSW profiles) soundings used in compositing a mean climatology profile (when such events occur more frequently). Blue shaded region represents 1σ around the climatological mean.

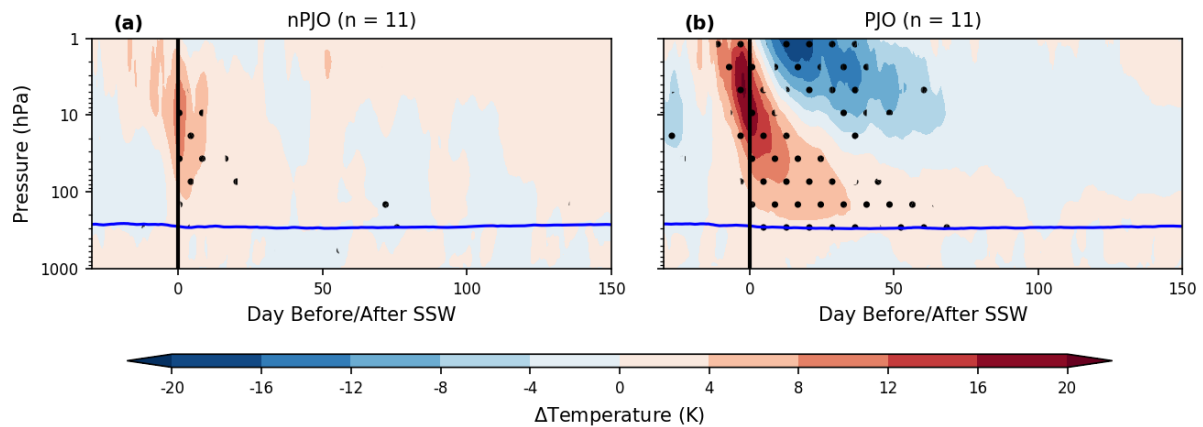


Figure S2 – Vertical-time composites of polar-cap ($60\text{--}90^\circ\text{ N}$) deseasonalised temperature (K) anomalies for (a) nPJO-type SSWs ($n = 11$) and (b) PJO-type SSWs ($n = 11$) (1980-2013) using specified-dynamics simulations from the EMAC CCM. Statistical significance at the 95 % level ($p < 0.05$) is indicated by stippling. The World Meteorological Organisation (WMO) defined thermal tropopause is displayed for reference in each panel (blue solid line).

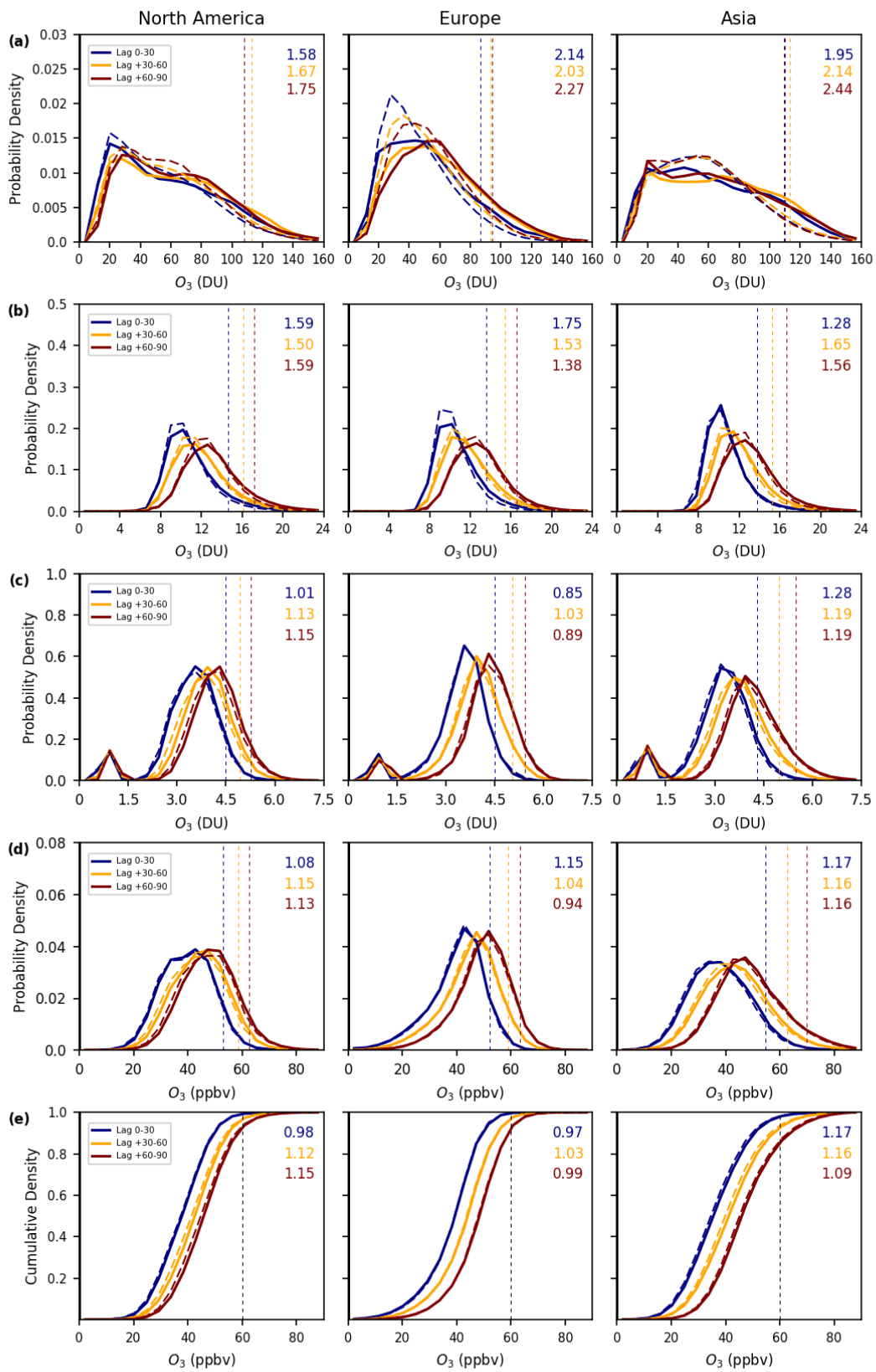


Figure S3 – Time-area averaged distributions for North America (30° N–70° N, 150° W–60° W), Europe (30° N–70° N, 30° W–30° E) and Asia (30° N–70° N, 30° E–180° E) for (a) the LMS (100–300 hPa), (b) upper troposphere (300–500 hPa), (c) the planetary boundary layer (900–1000 hPa) subcolumn ozone, as well as (d) modelled surface ozone mixing ratios (ppbv) for lags 0–30 days (blue lines), 30–60 days (orange lines) and 60–90 days (red lines) following the SSW central warming date. Solid lines represent SSW composite distributions and dashed lines represent the composite generated from the EMAC climatology (1980–2013) excluding SSW events. The cumulative ozone distributions with respect to climatology for the model surface level are additionally shown (e) to highlight the overall shift towards anomalously high ozone values even near the surface. Risk ratio (RR) values of the probability of an exceedance in the 95-percentile level of each climatological distribution (dashed vertical lines) are indicated, with the exception of (e) where the values represent a RR increase in the likelihood of an exceedance in the 60 ppbv threshold (a typical surface air quality standard).

Region	Statistic		Lag (days from onset)		
			0-30	30-60	60-90
North America	Median	Clim SSW P-Value	55.79 ± 2.10 (51.62, 59.74) 60.92 ± 2.71 (55.51, 66.15) < 0.001	60.35 ± 1.39 (57.42, 62.83) 68.66 ± 1.63 (65.65, 71.89) < 0.001	60.34 ± 0.81 (58.61, 61.73) 68.17 ± 2.24 (63.78, 72.59) < 0.001
	90 th Percentile	Clim SSW P-Value	104.55 ± 3.14 (97.66, 109.85) 112.23 ± 2.39 (107.16, 116.64) < 0.001	106.33 ± 1.84 (102.46, 109.59) 117.77 ± 2.30 (113.14, 122.24) < 0.001	102.99 ± 2.50 (98.07, 107.71) 114.54 ± 4.18 (106.21, 122.62) < 0.001
	95 th Percentile	Clim SSW P-Value	118.32 ± 2.86 (111.84, 122.96) 124.67 ± 2.54 (119.34, 129.50) < 0.001	119.14 ± 1.90 (114.94, 122.36) 128.97 ± 2.46 (124.41, 134.06) < 0.001	115.81 ± 3.26 (109.08, 121.74) 127.75 ± 5.23 (117.17, 137.49) < 0.001
Europe	Median	Clim SSW P-Value	44.76 ± 1.76 (41.12, 47.96) 53.38 ± 2.24 (49.22, 58.03) < 0.001	50.68 ± 1.51 (47.67, 53.59) 59.88 ± 1.65 (56.87, 63.26) < 0.001	55.19 ± 1.08 (52.95, 57.19) 62.50 ± 1.65 (59.59, 65.98) < 0.001
	90 th Percentile	Clim SSW P-Value	83.40 ± 2.24 (78.48, 87.20) 96.88 ± 4.20 (89.37, 105.80) < 0.001	89.91 ± 1.90 (85.84, 93.25) 102.12 ± 1.87 (98.42, 105.61) < 0.001	91.68 ± 1.43 (88.82, 94.34) 105.53 ± 3.29 (98.47, 111.34) < 0.001
	95 th Percentile	Clim SSW P-Value	94.13 ± 2.34 (89.11, 98.29) 110.01 ± 5.81 (99.75, 121.87) < 0.001	101.22 ± 1.91 (97.21, 104.68) 113.24 ± 1.98 (109.30, 117.07) < 0.001	102.39 ± 1.58 (99.01, 105.20) 117.14 ± 3.15 (110.55, 122.99) < 0.001
Asia	Median	Clim SSW P-Value	59.71 ± 2.15 (55.13, 63.56) 67.47 ± 2.45 (62.97, 72.61) < 0.001	62.75 ± 0.91 (60.95, 64.51) 74.75 ± 1.36 (72.01, 77.30) < 0.001	61.42 ± 1.20 (59.07, 63.78) 71.29 ± 2.40 (66.46, 75.68) < 0.001
	90 th Percentile	Clim SSW P-Value	102.66 ± 3.11 (96.06, 108.19) 116.47 ± 3.91 (109.01, 124.27) < 0.001	105.87 ± 1.28 (103.27, 108.22) 121.72 ± 2.38 (117.37, 126.68) < 0.001	103.17 ± 2.16 (98.79, 107.28) 121.25 ± 3.30 (113.82, 126.64) < 0.001
	95 th Percentile	Clim SSW P-Value	115.02 ± 3.40 (107.69, 120.90) 127.56 ± 4.22 (118.70, 135.10) < 0.001	117.94 ± 1.35 (115.13, 120.44) 132.20 ± 2.63 (127.40, 137.46) < 0.001	115.06 ± 2.50 (109.70, 119.47) 132.36 ± 2.96 (125.56, 137.08) < 0.001

Table S1 – 100–300 hPa subcolumn median, 90th percentile and 95th percentile ozone of stratospheric origin (O₃S) values (DU) for each regionally derived climatological (Clim) and PJO-type SSW composited (n = 11) distributions over the 1980-2013 period of the EMAC model simulations. One standard deviation (1σ) around each value is indicated, with the numbers in parentheses representing the 95 % confidence intervals around each value (as determined through bootstrap sampling with replacement over 10000 iterations). The associated p-value from a two-sample t-test is additionally shown and highlighted in red where statistical significance is inferred (p < 0.05), as are cases where the 95 % confidence intervals do not overlap.

Region	Statistic		Lag (days from onset)		
			0-30	30-60	60-90
North America	Median	Clim SSW P-Value	6.55 ± 0.21 (6.11, 6.93) 6.74 ± 0.19 (6.36, 7.11) 0.038	6.90 ± 0.11 (6.66, 7.08) 7.10 ± 0.14 (6.83, 7.38) 0.001	6.93 ± 0.06 (6.81, 7.05) 7.35 ± 0.11 (7.13, 7.56) < 0.001
	90 th Percentile	Clim SSW P-Value	11.47 ± 0.34 (10.75, 12.09) 12.60 ± 0.41 (11.79, 13.41) < 0.001	12.40 ± 0.25 (11.88, 12.89) 13.58 ± 0.48 (12.68, 14.54) < 0.001	12.98 ± 0.14 (12.70, 13.25) 14.08 ± 0.24 (13.58, 14.52) < 0.001
	95 th Percentile	Clim SSW P-Value	13.22 ± 0.42 (12.35, 13.99) 14.75 ± 0.51 (13.74, 15.72) < 0.001	14.35 ± 0.29 (13.72, 14.88) 15.91 ± 0.62 (14.73, 17.09) < 0.001	14.97 ± 0.18 (14.60, 15.29) 16.43 ± 0.27 (15.87, 16.92) < 0.001
Europe	Median	Clim SSW P-Value	5.86 ± 0.16 (5.54, 6.19) 6.48 ± 0.22 (6.06, 6.91) < 0.001	6.39 ± 0.17 (6.04, 6.70) 6.83 ± 0.18 (6.50, 7.20) < 0.001	6.75 ± 0.09 (6.55, 6.91) 7.17 ± 0.13 (6.93, 7.42) < 0.001
	90 th Percentile	Clim SSW P-Value	10.15 ± 0.39 (9.40, 10.91) 11.41 ± 0.47 (10.55, 12.36) < 0.001	11.41 ± 0.37 (10.68, 12.12) 12.37 ± 0.35 (11.72, 13.06) < 0.001	12.08 ± 0.21 (11.67, 12.47) 12.68 ± 0.15 (12.38, 12.96) < 0.001
	95 th Percentile	Clim SSW P-Value	11.91 ± 0.49 (10.92, 12.85) 13.30 ± 0.59 (12.18, 14.47) < 0.001	13.36 ± 0.43 (12.49, 14.12) 14.45 ± 0.44 (13.61, 15.31) < 0.001	13.96 ± 0.20 (13.56, 14.36) 14.64 ± 0.18 (14.28, 15.01) < 0.001
Asia	Median	Clim SSW P-Value	6.27 ± 0.19 (5.89, 6.62) 6.52 ± 0.17 (6.21, 6.87) 0.004	6.67 ± 0.12 (6.42, 6.88) 7.27 ± 0.16 (6.96, 7.61) < 0.001	6.92 ± 0.04 (6.85, 6.99) 7.36 ± 0.13 (7.13, 7.63) < 0.001
	90 th Percentile	Clim SSW P-Value	10.27 ± 0.30 (9.66, 10.81) 10.88 ± 0.39 (10.13, 11.62) < 0.001	11.07 ± 0.23 (10.57, 11.49) 12.73 ± 0.45 (11.83, 13.59) < 0.001	11.78 ± 0.18 (11.41, 12.12) 13.20 ± 0.40 (12.38, 13.94) < 0.001
	95 th Percentile	Clim SSW P-Value	11.90 ± 0.36 (11.17, 12.56) 12.64 ± 0.47 (11.71, 13.53) < 0.001	12.81 ± 0.28 (12.21, 13.31) 14.81 ± 0.50 (13.80, 15.75) < 0.001	13.62 ± 0.20 (13.20, 13.99) 15.25 ± 0.43 (14.36, 16.04) < 0.001

Table S2 – Same as Table S1 but for the 300–500 hPa subcolumn (upper troposphere).

Region	Statistic		Lag (days from onset)		
			0-30	30-60	60-90
North America	Median	Clim SSW P-Value	1.65 ± 0.04 (1.57, 1.72) 1.75 ± 0.03 (1.69, 1.82) < 0.001	1.69 ± 0.03 (1.63, 1.74) 1.86 ± 0.03 (1.80, 1.92) < 0.001	1.54 ± 0.08 (1.37, 1.67) 1.75 ± 0.08 (1.58, 1.88) < 0.001
	90 th Percentile	Clim SSW P-Value	2.06 ± 0.03 (1.98, 2.11) 2.15 ± 0.04 (2.08, 2.23) < 0.001	2.10 ± 0.02 (2.05, 2.14) 2.30 ± 0.05 (2.21, 2.39) < 0.001	2.02 ± 0.04 (1.91, 2.09) 2.24 ± 0.04 (2.16, 2.31) < 0.001
	95 th Percentile	Clim SSW P-Value	2.17 ± 0.03 (2.10, 2.22) 2.26 ± 0.04 (2.18, 2.35) < 0.001	2.21 ± 0.03 (2.16, 2.26) 2.42 ± 0.05 (2.32, 2.51) < 0.001	2.14 ± 0.04 (2.04, 2.21) 2.36 ± 0.04 (2.29, 2.42) < 0.001
Europe	Median	Clim SSW P-Value	1.71 ± 0.04 (1.62, 1.77) 1.77 ± 0.03 (1.71, 1.83) < 0.001	1.72 ± 0.03 (1.65, 1.77) 1.85 ± 0.04 (1.72, 1.91) < 0.001	1.56 ± 0.08 (1.39, 1.70) 1.69 ± 0.09 (1.50, 1.85) 0.002
	90 th Percentile	Clim SSW P-Value	2.09 ± 0.04 (2.01, 2.15) 2.19 ± 0.06 (2.08, 2.30) < 0.001	2.10 ± 0.03 (2.04, 2.15) 2.25 ± 0.03 (2.18, 2.30) < 0.001	2.04 ± 0.05 (1.93, 2.13) 2.25 ± 0.07 (2.11, 2.37) < 0.001
	95 th Percentile	Clim SSW P-Value	2.19 ± 0.03 (2.12, 2.25) 2.30 ± 0.06 (2.19, 2.40) < 0.001	2.21 ± 0.03 (2.15, 2.26) 2.36 ± 0.03 (2.30, 2.42) < 0.001	2.16 ± 0.05 (2.06, 2.24) 2.38 ± 0.06 (2.25, 2.48) < 0.001
Asia	Median	Clim SSW P-Value	1.61 ± 0.04 (1.52, 1.68) 1.69 ± 0.04 (1.61, 1.77) < 0.001	1.65 ± 0.03 (1.59, 1.71) 1.82 ± 0.03 (1.77, 1.87) < 0.001	1.52 ± 0.07 (1.38, 1.64) 1.74 ± 0.07 (1.58, 1.84) < 0.001
	90 th Percentile	Clim SSW P-Value	2.00 ± 0.04 (1.92, 2.06) 2.09 ± 0.05 (1.99, 2.18) < 0.001	2.04 ± 0.03 (1.97, 2.10) 2.21 ± 0.04 (2.14, 2.29) < 0.001	1.96 ± 0.04 (1.86, 2.03) 2.18 ± 0.04 (2.10, 2.25) < 0.001
	95 th Percentile	Clim SSW P-Value	2.10 ± 0.04 (2.02, 2.16) 2.20 ± 0.05 (2.10, 2.29) < 0.001	2.15 ± 0.04 (2.07, 2.21) 2.32 ± 0.04 (2.24, 2.40) < 0.001	2.07 ± 0.04 (1.98, 2.14) 2.29 ± 0.04 (2.22, 2.36) < 0.001

Table S3 – Same as Tables S1 and S2 but for the 900–1000 hPa subcolumn (PBL approximation).

Region	Statistic		Lag (days from onset)		
			0-30	30-60	60-90
North America	Median	Clim SSW P-Value	17.94 ± 0.43 (17.05, 18.71) 18.86 ± 0.39 (18.14, 19.64) < 0.001	18.28 ± 0.32 (17.61, 18.86) 20.16 ± 0.40 (19.40, 20.95) < 0.001	16.71 ± 0.88 (14.78, 18.18) 19.08 ± 0.88 (17.10, 20.49) < 0.001
	90 th Percentile	Clim SSW P-Value	23.88 ± 0.42 (22.97, 24.59) 24.85 ± 0.51 (23.86, 25.82) < 0.001	24.29 ± 0.33 (23.58, 24.85) 26.50 ± 0.45 (25.64, 27.40) < 0.001	23.13 ± 0.64 (21.69, 24.17) 25.88 ± 0.50 (24.76, 26.68) < 0.001
	95 th Percentile	Clim SSW P-Value	25.45 ± 0.41 (24.53, 26.14) 26.47 ± 0.59 (25.31, 27.58) < 0.001	25.94 ± 0.31 (25.28, 26.47) 28.22 ± 0.53 (27.20, 29.30) < 0.001	24.94 ± 0.57 (23.65, 25.88) 27.58 ± 0.41 (26.67, 28.25) < 0.001
Europe	Median	Clim SSW P-Value	19.35 ± 0.47 (18.38, 20.19) 20.14 ± 0.38 (19.46, 20.96) < 0.001	19.43 ± 0.38 (18.63, 20.13) 20.91 ± 0.49 (19.80, 21.71) < 0.001	17.40 ± 1.02 (15.28, 19.20) 18.83 ± 1.23 (16.30, 20.99) 0.008
	90 th Percentile	Clim SSW P-Value	25.02 ± 0.46 (24.00, 25.81) 26.20 ± 0.73 (24.92, 27.70) < 0.001	25.22 ± 0.39 (24.40, 25.90) 26.95 ± 0.33 (26.26, 27.56) < 0.001	24.34 ± 0.66 (22.92, 25.48) 26.99 ± 0.86 (25.21, 28.51) < 0.001
	95 th Percentile	Clim SSW P-Value	26.43 ± 0.44 (25.44, 27.18) 27.84 ± 0.77 (26.33, 29.21) < 0.001	26.70 ± 0.38 (25.87, 27.34) 28.47 ± 0.36 (27.73, 29.15) < 0.001	25.99 ± 0.65 (24.62, 27.09) 28.72 ± 0.76 (27.10, 29.98) < 0.001
Asia	Median	Clim SSW P-Value	17.06 ± 0.52 (15.95, 18.00) 17.66 ± 0.51 (16.68, 18.67) 0.013	17.89 ± 0.37 (17.15, 18.58) 19.61 ± 0.36 (18.94, 20.36) < 0.001	16.87 ± 0.65 (15.44, 17.99) 19.11 ± 0.70 (17.55, 20.29) < 0.001
	90 th Percentile	Clim SSW P-Value	23.29 ± 0.47 (22.27, 24.10) 24.33 ± 0.57 (23.23, 25.44) < 0.001	24.05 ± 0.37 (23.29, 24.72) 25.99 ± 0.44 (25.13, 26.85) < 0.001	23.54 ± 0.44 (22.58, 24.28) 25.69 ± 0.39 (24.91, 26.41) < 0.001
	95 th Percentile	Clim SSW P-Value	25.03 ± 0.46 (24.01, 25.81) 26.14 ± 0.65 (24.83, 27.35) < 0.001	25.96 ± 0.38 (25.15, 26.65) 27.80 ± 0.51 (26.79, 28.76) < 0.001	25.77 ± 0.32 (25.08, 26.33) 27.66 ± 0.45 (26.77, 28.50) < 0.001

Table S4 – Same as Tables S1–S3 but for the model surface level.

Region	Statistic		Lag (days from onset)		
			0-30	30-60	60-90
North America	Median	Clim SSW P-Value	56.28 ± 2.12 (52.06, 60.30) 61.48 ± 2.71 (56.18, 66.71) < 0.001	60.93 ± 1.39 (58.05, 63.45) 69.28 ± 1.64 (66.22, 72.48) < 0.001	61.12 ± 0.76 (59.46, 62.46) 68.97 ± 2.19 (64.73, 73.22) < 0.001
	90 th Percentile	Clim SSW P-Value	104.58 ± 3.17 (97.52, 109.84) 112.26 ± 2.34 (107.37, 116.57) < 0.001	106.34 ± 1.84 (102.47, 109.67) 117.81 ± 2.31 (113.14, 122.23) < 0.001	103.05 ± 2.47 (98.15, 107.74) 114.61 ± 4.21 (107.43, 122.57) < 0.001
	95 th Percentile	Clim SSW P-Value	118.33 ± 2.88 (111.68, 122.94) 124.69 ± 2.50 (119.55, 129.37) < 0.001	119.12 ± 1.90 (114.98, 122.39) 128.99 ± 2.47 (124.37, 134.09) < 0.001	115.81 ± 3.21 (109.15, 121.69) 127.80 ± 5.29 (117.19, 137.58) < 0.001
Europe	Median	Clim SSW P-Value	45.68 ± 1.74 (42.06, 48.83) 54.01 ± 2.23 (49.92, 58.64) < 0.001	51.66 ± 1.52 (48.64, 54.58) 60.84 ± 1.66 (57.78, 64.25) < 0.001	56.37 ± 1.08 (54.09, 58.35) 63.57 ± 1.62 (60.77, 67.17) < 0.001
	90 th Percentile	Clim SSW P-Value	83.56 ± 2.17 (78.86, 87.33) 96.86 ± 4.13 (89.52, 105.57) < 0.001	89.99 ± 1.90 (85.92, 93.29) 102.17 ± 1.88 (98.49, 105.74) < 0.001	91.78 ± 1.41 (88.95, 94.42) 105.60 ± 3.29 (98.62, 111.25) < 0.001
	95 th Percentile	Clim SSW P-Value	94.23 ± 2.29 (89.39, 98.36) 109.89 ± 5.76 (99.82, 121.79) < 0.001	101.25 ± 1.92 (97.25, 104.71) 113.25 ± 1.98 (109.38, 117.20) < 0.001	102.43 ± 1.58 (99.09, 105.23) 117.15 ± 3.16 (110.53, 122.84) < 0.001
Asia	Median	Clim SSW P-Value	60.15 ± 2.13 (55.70, 63.98) 67.92 ± 2.43 (63.36, 72.99) 0.003	63.35 ± 0.89 (61.62, 65.10) 75.23 ± 1.33 (72.53, 77.74) < 0.001	62.26 ± 1.11 (60.06, 64.44) 72.06 ± 2.30 (67.42, 76.32) < 0.001
	90 th Percentile	Clim SSW P-Value	102.70 ± 3.09 (96.14, 108.26) 116.57 ± 3.89 (109.20, 124.24) < 0.001	105.92 ± 1.28 (103.32, 108.28) 121.75 ± 2.35 (117.55, 126.68) < 0.001	103.22 ± 2.16 (98.88, 107.28) 121.28 ± 3.29 (113.84, 126.84) < 0.001
	95 th Percentile	Clim SSW P-Value	115.02 ± 3.38 (107.66, 120.92) 127.65 ± 4.19 (118.98, 135.09) < 0.001	117.95 ± 1.36 (115.17, 120.45) 132.22 ± 2.59 (127.49, 137.45) < 0.001	115.08 ± 2.51 (109.78, 119.42) 132.35 ± 2.98 (125.44, 137.21) < 0.001

Table S5 – 100–300 hPa subcolumn median, 90th percentile and 95th percentile ozone values (DU) for each regionally derived climatological (clim) and PJO-type SSW composited (n = 11) distributions over the 1980-2013 period of the EMAC model simulations. One standard deviation (1 σ) around each value is indicated, with the numbers in parentheses representing the 95 % confidence intervals around each value (as determined through bootstrap sampling with replacement over 10000 iterations). The associated p-value from a two-sample t-test is additionally shown and highlighted in red where statistical significance is inferred ($p < 0.05$), as are cases where the 95 % confidence intervals do not overlap.

Region	Statistic		Lag (days from onset)		
			0-30	30-60	60-90
North America	Median	Clim	10.33 ± 0.28 (9.81, 10.90)	11.46 ± 0.35 (10.78, 12.14)	12.60 ± 0.32 (11.91, 13.16)
		SSW	10.65 ± 0.31 (10.08, 11.30)	11.72 ± 0.39 (10.98, 12.50)	12.92 ± 0.29 (12.41, 13.45)
	P-Value	0.020	0.115	0.023	
North America	90 th Percentile	Clim	13.62 ± 0.41 (12.79, 14.41)	15.07 ± 0.38 (14.27, 15.74)	16.26 ± 0.27 (15.68, 16.71)
		SSW	14.63 ± 0.50 (13.66, 15.63)	15.99 ± 0.55 (14.91, 17.05)	17.09 ± 0.27 (16.57, 17.62)
	P-Value	< 0.001	< 0.001	< 0.001	
North America	95 th Percentile	Clim	15.01 ± 0.47 (14.04, 15.87)	16.52 ± 0.38 (15.71, 17.19)	17.53 ± 0.26 (17.07, 18.08)
		SSW	16.33 ± 0.58 (15.17, 17.45)	17.81 ± 0.64 (16.49, 19.00)	18.71 ± 0.30 (18.16, 19.31)
	P-Value	< 0.001	< 0.001	< 0.001	
Europe	Median	Clim	10.05 ± 0.25 (9.61, 10.59)	11.29 ± 0.41 (10.49, 12.08)	12.61 ± 0.37 (11.82, 13.26)
		SSW	10.43 ± 0.32 (9.84, 11.08)	11.55 ± 0.41 (10.79, 12.38)	12.81 ± 0.36 (12.09, 13.48)
	P-Value	0.006	0.153	0.214	
Europe	90 th Percentile	Clim	12.87 ± 0.45 (11.97, 13.74)	14.62 ± 0.45 (13.66, 15.45)	15.88 ± 0.28 (15.25, 16.35)
		SSW	13.85 ± 0.51 (12.85, 14.80)	15.34 ± 0.49 (14.33, 16.26)	16.31 ± 0.31 (15.67, 16.88)
	P-Value	< 0.001	0.002	0.003	
Europe	95 th Percentile	Clim	14.10 ± 0.53 (13.01, 15.05)	15.91 ± 0.48 (14.92, 16.79)	17.02 ± 0.26 (16.45, 17.46)
		SSW	15.29 ± 0.59 (14.08, 16.38)	16.81 ± 0.52 (15.76, 17.77)	17.61 ± 0.29 (17.01, 18.15)
	P-Value	< 0.001	< 0.001	< 0.001	
Asia	Median	Clim	10.16 ± 0.26 (9.67, 10.69)	11.27 ± 0.37 (10.54, 12.00)	12.52 ± 0.36 (11.79, 13.20)
		SSW	10.34 ± 0.26 (9.86, 10.90)	11.69 ± 0.41 (10.93, 12.51)	12.87 ± 0.41 (12.00, 13.62)
	P-Value	0.120	0.020	0.046	
Asia	90 th Percentile	Clim	12.90 ± 0.35 (12.17, 13.54)	14.32 ± 0.39 (13.49, 15.01)	15.76 ± 0.37 (14.99, 16.43)
		SSW	13.30 ± 0.47 (12.37, 14.19)	15.34 ± 0.53 (14.28, 16.32)	16.55 ± 0.45 (15.62, 17.37)
	P-Value	0.036	< 0.001	< 0.001	
Asia	95 th Percentile	Clim	14.08 ± 0.39 (13.25, 14.79)	15.53 ± 0.39 (14.69, 16.21)	16.98 ± 0.35 (16.23, 17.60)
		SSW	14.63 ± 0.53 (13.55, 15.58)	16.89 ± 0.59 (15.72, 17.99)	18.00 ± 0.49 (17.01, 18.89)
	P-Value	0.012	< 0.001	< 0.001	

Table S6 – Same as Table S5 but for the 300–500 hPa subcolumn (upper troposphere).

Region	Statistic		Lag (days from onset)		
			0-30	30-60	60-90
North America	Median	Clim	3.34 ± 0.08 (3.20, 3.50)	3.68 ± 0.11 (3.47, 3.89)	3.96 ± 0.08 (3.78, 4.11)
		SSW	3.41 ± 0.08 (3.28, 3.58)	3.79 ± 0.10 (3.59, 3.98)	4.07 ± 0.08 (3.90, 4.22)
	P-Value	0.053	0.024	0.004	
North America	90 th Percentile	Clim	4.25 ± 0.10 (4.05, 4.44)	4.65 ± 0.11 (4.42, 4.85)	4.92 ± 0.08 (4.75, 5.05)
		SSW	4.26 ± 0.09 (4.08, 4.42)	4.69 ± 0.11 (4.47, 4.89)	4.99 ± 0.07 (4.83, 5.12)
	P-Value	0.808	0.425	0.041	
North America	95 th Percentile	Clim	4.51 ± 0.12 (4.28, 4.74)	4.98 ± 0.12 (4.72, 5.18)	5.23 ± 0.08 (5.07, 5.37)
		SSW	4.51 ± 0.09 (4.32, 4.67)	4.96 ± 0.11 (4.73, 5.17)	5.29 ± 0.08 (5.12, 5.42)
	P-Value	1.000	0.688	0.094	
Europe	Median	Clim	3.53 ± 0.08 (3.38, 3.70)	3.88 ± 0.12 (3.65, 4.10)	4.23 ± 0.10 (4.01, 4.41)
		SSW	3.51 ± 0.08 (3.37, 3.68)	3.92 ± 0.11 (3.70, 4.13)	4.27 ± 0.09 (4.08, 4.43)
	P-Value	0.564	0.444	0.336	
Europe	90 th Percentile	Clim	4.30 ± 0.14 (4.04, 4.57)	4.80 ± 0.13 (4.51, 5.02)	5.16 ± 0.10 (4.94, 5.33)
		SSW	4.25 ± 0.13 (4.00, 4.50)	4.78 ± 0.16 (4.45, 5.07)	5.12 ± 0.10 (4.90, 5.29)
	P-Value	0.412	0.751	0.359	
Europe	95 th Percentile	Clim	4.54 ± 0.16 (4.23, 4.85)	5.07 ± 0.13 (4.77, 5.27)	5.43 ± 0.10 (5.22, 5.60)
		SSW	4.48 ± 0.15 (4.18, 4.74)	5.05 ± 0.17 (4.68, 5.33)	5.37 ± 0.10 (5.14, 5.54)
	P-Value	0.375	0.760	0.170	
Asia	Median	Clim	3.16 ± 0.09 (3.01, 3.35)	3.53 ± 0.13 (3.27, 3.77)	3.90 ± 0.11 (3.66, 4.10)
		SSW	3.22 ± 0.09 (3.06, 3.39)	3.59 ± 0.11 (3.38, 3.81)	3.98 ± 0.09 (3.79, 4.15)
	P-Value	0.134	0.257	0.077	
Asia	90 th Percentile	Clim	4.05 ± 0.11 (3.85, 4.27)	4.60 ± 0.18 (4.24, 4.94)	5.13 ± 0.14 (4.82, 5.37)
		SSW	4.12 ± 0.10 (3.92, 4.31)	4.65 ± 0.17 (4.32, 4.96)	5.12 ± 0.14 (4.83, 5.38)
	P-Value	0.090	0.511	0.869	
Asia	95 th Percentile	Clim	4.32 ± 0.13 (4.07, 4.55)	4.97 ± 0.20 (4.56, 5.31)	5.52 ± 0.14 (5.21, 5.76)
		SSW	4.40 ± 0.12 (4.16, 4.63)	5.01 ± 0.18 (4.62, 5.32)	5.53 ± 0.15 (5.20, 5.79)
	P-Value	0.149	0.627	0.863	

Table S7 – Same as Tables S5 and S6 but for the 900–1000 hPa subcolumn (PBL approximation).

Region	Statistic		Lag (days from onset)		
			0-30	30-60	60-90
North America	Median	Clim	38.08 ± 1.00 (36.25, 40.14)	42.05 ± 1.24 (39.57, 44.45)	45.25 ± 0.95 (43.22, 46.94)
		SSW	38.39 ± 0.99 (36.57, 40.37)	43.13 ± 1.17 (40.80, 45.40)	46.45 ± 0.77 (44.87, 47.85)
	P-Value	0.473	0.049	0.004	
North America	90 th Percentile	Clim	50.32 ± 1.25 (47.92, 52.78)	55.12 ± 1.33 (52.27, 57.47)	58.30 ± 0.93 (56.24, 59.87)
		SSW	50.43 ± 1.27 (48.00, 52.84)	55.64 ± 1.35 (52.84, 58.06)	59.01 ± 0.88 (57.09, 60.53)
	P-Value	0.840	0.374	0.081	
North America	95 th Percentile	Clim	53.41 ± 1.45 (50.60, 56.18)	58.64 ± 1.47 (55.69, 61.33)	62.30 ± 0.94 (60.19, 63.88)
		SSW	53.47 ± 1.42 (50.58, 56.07)	59.05 ± 1.38 (56.06, 61.49)	62.84 ± 0.91 (60.87, 64.39)
	P-Value	0.923	0.508	0.186	
Europe	Median	Clim	41.09 ± 1.01 (39.30, 43.19)	45.31 ± 1.43 (42.42, 48.00)	49.21 ± 1.13 (46.87, 51.25)
		SSW	40.90 ± 0.95 (39.22, 42.93)	45.57 ± 1.27 (43.12, 48.08)	49.63 ± 0.94 (47.62, 51.24)
	P-Value	0.654	0.645	0.355	
Europe	90 th Percentile	Clim	50.54 ± 1.39 (47.80, 53.15)	56.00 ± 1.52 (52.76, 58.71)	60.27 ± 1.01 (57.92, 61.94)
		SSW	50.52 ± 1.63 (47.52, 53.74)	55.97 ± 1.58 (52.74, 58.87)	60.01 ± 0.99 (57.84, 61.69)
	P-Value	0.976	0.964	0.549	
Europe	95 th Percentile	Clim	53.14 ± 1.51 (50.03, 55.92)	59.04 ± 1.55 (55.59, 61.71)	63.35 ± 1.08 (61.03, 65.27)
		SSW	53.28 ± 1.86 (49.49, 56.56)	59.04 ± 1.70 (55.40, 61.90)	62.86 ± 1.02 (60.66, 64.71)
	P-Value	0.848	1.000	0.287	
Asia	Median	Clim	34.47 ± 1.25 (33.22, 38.03)	40.80 ± 1.78 (37.28, 44.24)	45.81 ± 1.34 (42.87, 48.16)
		SSW	35.95 ± 1.13 (32.77, 38.18)	41.49 ± 1.65 (38.21, 44.63)	46.43 ± 1.25 (43.75, 48.72)
	P-Value	0.009	0.357	0.275	
Asia	90 th Percentile	Clim	50.18 ± 1.27 (47.83, 52.76)	56.87 ± 2.20 (52.50, 61.10)	63.49 ± 1.72 (59.73, 66.48)
		SSW	50.96 ± 1.25 (48.49, 53.39)	57.66 ± 1.96 (53.64, 61.29)	63.73 ± 1.88 (59.90, 67.24)
	P-Value	0.162	0.385	0.758	
Asia	95 th Percentile	Clim	54.53 ± 1.53 (51.61, 57.49)	62.35 ± 2.38 (57.44, 66.76)	69.37 ± 1.74 (65.48, 72.29)
		SSW	55.38 ± 1.52 (52.46, 58.36)	63.02 ± 2.14 (58.51, 66.91)	69.91 ± 2.03 (65.53, 73.49)
	P-Value	0.206	0.496	0.511	

Table S8 – Same as Tables S5–7 but for the model surface level.