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Supplement of

Evidence for an earlier greenhouse cooling effect in the stratosphere before 1980 over the Northern Hemisphere

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Supplement Table S1: Trend calculations in northern hemisphere summer (JJA) based on the monthly normalised time series of temperature (^{o}C/decade) at various levels calculated from RICH dataset and filtered from natural variations at the latitudinal belts a) 5–30^{o} N, b) 30–60^{o} N and c) 60–90^{o} N. The trends calculations refer to the periods 1958–1979, 1980–2001 and 1980–2005.

Period 1958–1979

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
Level (hPa)	Trend	t-test	Trend	t-test	Trend	t-test
850	0.00 ± 0.11	0.00	-0.06 ± 0.05	-1.15	-0.16 ± 0.03	-5.12
500	-0.18 ± 0.09	-1.96	-0.25 ± 0.04	-6.33	-0.06 ± 0.04	-1.24
300	-0.22 ± 0.13	-1.74	-0.31 ± 0.04	-6.90	-0.17 ± 0.05	-3.54
100	-0.22 ± 0.29	-0.77	-0.34 ± 0.05	-6.90	-0.13 ± 0.06	-2.39
50	0.06 ± 0.33	0.19	-0.54 ± 0.08	-6.47	-0.39 ± 0.12	-3.34
30	0.00 ± 0.31	0.01	-0.66 ± 0.10	-6.86	-0.46 ± 0.11	-4.34

Period 1980–2001

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
Level (hPa)	Trend	t-test	Trend	t-test	Trend	t-test
850	0.30 ± 0.10	2.95	0.37 ± 0.06	6.37	0.13 ±0.03	4.77
500	0.08 ± 0.08	1.00	0.31 ± 0.05	6.43	-0.01 ± 0.04	-0.34
300	0.00 ± 0.14	-0.01	0.24 ± 0.05	4.75	0.09 ± 0.05	2.00
100	-0.62 ± 0.32	-1.92	-0.53 ± 0.06	-8.96	0.01 ± 0.05	0.18
50	-0.79 ± 0.34	-2.37	-0.89 ± 0.09	-9.88	-0.53 ± 0.11	-4.73
30	-0.81 ± 0.30	-2.67	-0.93 ± 0.09	-10.22	-0.82 ± 0.09	-8.85

Period 1980–2005

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
Level (hPa)	Trend	t-test	Trend	t-test	Trend	t-test
850	0.44 ± 0.08	5.52	0.39 ± 0.05	8.58	0.11 ± 0.02	5.83
500	0.21 ± 0.07	3.17	0.29 ± 0.04	8.20	0.03 ± 0.03	1.08
300	0.06 ± 0.11	0.51	0.24 ± 0.04	6.66	0.13 ± 0.03	3.89
100	-0.42 ± 0.25	-1.66	-0.34 ± 0.05	-6.91	0.00 ± 0.04	-0.07
50	-0.62 ± 0.26	-2.37	-0.67 ± 0.08	-8.91	-0.37 ± 0.09	-4.06
30	-0.66 ± 0.24	-2.81	-0.73 ± 0.07	-10.02	-0.62 ± 0.08	-7.80

Supplement Table S2: Trend calculations in northern hemisphere summer (JJA) based on the monthly normalised time series of the layer mean temperature (^{o}C/decade) calculated from FU-Berlin and filtered from natural variations at the latitudinal belts a) 5–30^{o} N, b) 30–60^{o} N and c) 60–90^{o} N. The layers are: L4: 100–50 hPa and L5: 50–30 hPa. The trend calculations refer to the periods 1958–1979 and 1980–2001.

Period 1958–1979

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
layer	Trend	t-test	Trend	t-test	Trend	t-test
L4	0.13 ± 0.40	0.33	-0.28 ± 0.10	-2.89	-0.90 ± 0.13	-7.05
L5	-0.14 ± 0.35	-0.40	-0.85 ± 0.09	-9.17	-0.86 ± 0.14	-6.23

Period 1980–2001

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
layer	Trend	t-test	Trend	t-test	Trend	t-test
L4	-0.64 ± 0.37	-1.74	-0.76 ± 0.07	-10.44	-0.52 ± 0.11	-4.91
L5	-0.96 ± 0.38	-2.56	-1.11 ± 0.09	-12.17	-0.95 ± 0.14	-6.98

Supplement Table S3: Trend calculations based on the monthly normalised time series of the layer mean temperature (^{o}C/decade) and tropopause pressure TP (hPa/decade) calculated from NCEP reanalysis and filtered from natural variations at the latitudinal belts a) 5–30^{o} N, b) 30–60^{o} N and c) 60–90^{o} N. The layers are: L1: 1000–925 hPa, L2: 925–500 hPa, L3: 500–300 hPa, L4: 100–50 hPa, and L5: 50–30 hPa. The trends calculations refer to the periods 1958–1979, 1980–2001, 1980–2005 and 1980–2011.

Period 1958–1979

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
Layer	Trend	t-test	Trend	t-test	Trend	t-test
L1	0.07 ± 0.05	1.28	-0.03 ± 0.02	-1.28	0.13 ± 0.01	10.03
L2	0.02 ± 0.04	0.44	-0.10 ± 0.02	-5.72	-0.02 ± 0.02	-0.87
L3	-0.38 ± 0.04	-10.23	-0.25 ± 0.02	-13.83	-0.14 ± 0.03	-5.73
L4	-0.56 ± 0.15	-3.61	-0.69 ± 0.03	-24.49	-0.31 ± 0.06	-5.44
L5	-0.63 ± 0.17	-3.62	-0.74 ± 0.04	-16.84	-0.56 ± 0.05	-11.47
TP	**2.35 ± 0.62**	**3.78**	**1.99 ± 0.14**	**14.19**	**-0.29 ± 0.12**	**-2.45**

Period 1980–2001

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
Layer	Trend	t-test	Trend	t-test	Trend	t-test
L1	0.47 ± 0.06	8.27	0.23 ± 0.02	10.79	0.03 ± 0.01	2.30
L2	0.08 ± 0.04	1.91	0.19 ± 0.02	9.49	0.05 ± 0.02	2.52
L3	0.10 ± 0.04	2.69	0.07 ± 0.02	2.98	-0.06 ± 0.02	-2.63
L4	-0.70 ± 0.17	-4.09	-0.80 ± 0.03	-24.47	-0.78 ± 0.05	-14.49
L5	-0.76 ± 0.18	-4.25	-0.84 ± 0.04	-20.42	-0.68 ± 0.04	-15.61
TP	**-3.09 ± 0.84**	**-3.70**	**-1.05 ± 0.17**	**-6.08**	**-0.42 ± 0.12**	**-3.54**

Period 1980–2005

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
Layer	Trend	t-test	Trend	t-test	Trend	t-test
L1	0.78 ± 0.05	17.41	0.29 ± 0.02	17.17	0.09 ± 0.01	9.12
L2	0.23 ± 0.03	6.94	0.25 ± 0.02	16.37	0.13 ± 0.01	9.33
L3	0.26 ± 0.03	8.77	0.11 ± 0.02	6.84	0.04 ± 0.02	2.37
L4	-0.38 ± 0.13	-2.88	-0.61 ± 0.03	-21.14	-0.76 ± 0.04	-18.40
L5	-0.50 ± 0.14	-3.67	-0.66 ± 0.03	-19.56	-0.55 ± 0.04	-13.88
TP	**-2.25 ± 0.64**	**-3.50**	**-0.49 ± 0.13**	**-3.70**	**-0.52 ± 0.09**	**-5.84**

Period 1980–2011

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
Layer	Trend	t-test	Trend	t-test	Trend	t-test
L1	0.84 ± 0.04	23.96	0.28 ± 0.01	21.09	0.12 ± 0.01	13.76
L2	0.29 ± 0.03	11.03	0.26 ± 0.01	20.60	0.17 ± 0.01	14.32
L3	0.25 ± 0.02	10.58	0.15 ± 0.01	10.96	0.10 ± 0.01	7.00
L4	-0.29 ± 0.11	-2.72	-0.46 ± 0.03	-17.68	-0.64 ± 0.03	-19.56
L5	-0.43 ± 0.11	-3.93	-0.50 ± 0.03	-16.84	-0.42 ± 0.03	-13.16
TP	**-1.23 ± 0.53**	**-2.32**	**-0.72 ± 0.12**	**-5.77**	**-0.76 ± 0.08**	**-10.00**

Supplement Table S4: Trend calculations based on the monthly normalised time series of temperature (^{o}C/decade) at various levels calculated from RICH dataset and filtered from natural variations at the latitudinal belts a) 5–30^{o} N, b) 30–60^{o} N and c) 60–90^{o} N. The trend calculations refer to the periods 1958–1979, 1980–2001 and 1980–2005.

Period 1958–1979

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
Level (hPa)	Trend	t-test	Trend	t-test	trend	t-test
850	-0.06 ± 0.05	-1.03	-0.10 ± 0.03	-3.51	-0.13 ± 0.02	-8.05
500	-0.19 ± 0.05	-4.16	-0.26 ± 0.02	-12.98	-0.04 ± 0.02	-1.80
300	-0.11 ± 0.06	-1.69	-0.34 ± 0.02	-15.24	-0.14 ± 0.02	-5.83
100	-0.07 ± 0.14	-0.52	-0.42 ± 0.02	-17.06	-0.26 ± 0.03	-9.39
50	-0.09 ± 0.17	-0.52	-0.69 ± 0.04	-16.63	-0.44 ± 0.06	-7.66
30	-0.02 ± 0.16	-0.15	-0.67 ± 0.05	-14.10	-0.32 ± 0.05	-6.10

Period 1980–2001

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
Level (hPa)	Trend	t-test	Trend	t-test	trend	t-test
850	0.28 ± 0.05	5.67	0.36 ± 0.03	12.61	0.15 ± 0.01	11.17
500	0.10 ± 0.04	2.49	0.29 ± 0.02	12.20	0.04 ± 0.02	2.03
300	0.09 ± 0.07	1.22	0.21 ± 0.02	8.38	0.15 ± 0.02	6.51
100	-0.40 ± 0.16	-2.52	-0.43 ± 0.03	-14.65	0.00 ± 0.02	0.03
50	-0.75 ± 0.17	-4.49	-0.86 ± 0.04	-19.37	-0.61 ± 0.06	-10.86
30	-0.89 ± 0.15	-5.91	-0.97 ± 0.04	-21.61	-0.83 ± 0.05	-18.23

Period 1980–2005

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
Level (hPa)	Trend	t-test	Trend	t-test	trend	t-test
850	0.47 ± 0.04	11.98	0.37 ± 0.02	16.61	0.14 ± 0.01	14.75
500	0.27 ± 0.03	8.08	0.28 ± 0.02	15.99	0.09 ± 0.01	6.71
300	0.18 ± 0.05	3.36	0.21 ± 0.02	11.81	0.18 ± 0.02	11.13
100	-0.17 ± 0.13	-1.33	-0.27 ± 0.02	-11.13	0.02 ± 0.02	1.08
50	-0.56 ± 0.13	-4.32	-0.66 ± 0.04	-17.81	-0.48 ± 0.05	-10.54
30	-0.80 ± 0.12	-6.78	-0.78 ± 0.04	-21.50	-0.62 ± 0.04	-15.75

Supplement Table S5: Trend calculations based on the monthly normalised time series of the layer mean temperature (^{o}C/decade) calculated from FU-Berlin and filtered from natural variations at the latitudinal belts a) 5–30^{o} N, b) 30–60^{o} N and c) 60–90^{o} N. The layers are: L4: 100–50 hPa and L5: 50–30 hPa. The trend calculations refer to the periods 1958–1979 and 1980–2001.

Period 1958–1979

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
layer	Trend	t-test	Trend	t-test	Trend	t-test
L4	0.26 ± 0.20	1.31	-0.24 ± 0.05	-4.89	-0.94 ± 0.06	-14.59
L5	0.01 ± 0.18	0.04	-0.84 ± 0.05	-18.26	-0.86 ± 0.07	-12.47

Period 1980–2001

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
layer	Trend	t-test	Trend	t-test	Trend	t-test
L4	-0.54 ± 0.18	-3.01	-0.63 ± 0.04	-17.37	-0.53 ± 0.05	-9.90
L5	-0.72 ± 0.19	-3.88	-0.90 ± 0.05	-19.88	-0.94 ± 0.07	-13.96

Supplement Table S6: Trend calculations based on the monthly normalised time series of the layer mean temperature (^{o}C/decade) and tropopause pressure TP (hPa/decade) calculated from WACCM and filtered from natural variations at the latitudinal belts a) 5–30^{o} N, b) 30–60^{o} N and c) 60–90^{o} N. The layers are: L1: 1000–925 hPa, L2: 925–500 hPa, L3: 500–300 hPa, L4: 100–50 hPa and L5: 50–30 hPa. The trends calculations refer to the periods 1958–1979, 1980–2001 and 1980–2005.

Period 1958–1979

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
Layer	Trend	t-test	Trend	t-test	Trend	t-test
L1	0.80 ± 0.23	3.53	-0.13 ± 0.16	-0.80	0.11 ± 0.05	2.34
L2	0.36 ± 0.04	8.32	0.05 ± 0.02	2.35	0.17 ± 0.01	15.77
L3	0.12 ± 0.03	4.14	0.05 ± 0.02	2.24	0.22 ± 0.02	14.30
L4	-0.52 ± 0.16	-3.26	-0.25 ± 0.05	-5.12	-0.31 ± 0.05	-6.74
L5	-0.50 ± 0.17	-2.90	-0.30 ± 0.07	-4.46	-0.53 ± 0.05	-11.03
TP	**0.87 ± 0.56**	**1.56**	**-1.47 ± 0.22**	**-6.55**	**-0.49 ± 0.26**	**-1.88**

Period 1980–2001

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
Layer	Trend	t-test	Trend	t-test	Trend	t-test
L1	0.16 ± 0.21	0.78	0.32 ± 0.18	1.82	0.36 ± 0.05	7.12
L2	0.37 ± 0.05	7.34	0.27 ± 0.02	12.36	0.22 ± 0.02	10.55
L3	0.30 ± 0.04	8.48	0.26 ± 0.02	10.36	0.30 ± 0.03	9.03
L4	-0.19 ± 0.14	-1.36	-0.10 ± 0.07	-1.51	-0.22 ± 0.07	-2.99
L5	-0.14 ± 0.16	-0.90	-0.39 ± 0.08	-4.73	-0.39 ± 0.08	-4.88
TP	**-1.98 ± 0.50**	**-3.93**	**-0.45 ± 0.21**	**-2.12**	**-0.31 ± 0.26**	**-1.17**

Period 1980–2005

	90–60^{o} N		60–30^{o} N		30–05^{o} N	
Layer	Trend	t-test	Trend	t-test	Trend	t-test
L1	0.30 ± 0.16	1.85	0.10 ± 0.14	0.68	0.36 ± 0.04	9.15
L2	0.39 ± 0.04	10.24	0.27 ± 0.02	14.71	0.24 ± 0.02	15.27
L3	0.30 ± 0.03	10.90	0.27 ± 0.02	13.61	0.33 ± 0.02	13.47
L4	-0.33 ± 0.11	-2.98	-0.06 ± 0.05	-1.11	-0.20 ± 0.05	-3.90
L5	-0.32 ± 0.12	-2.55	-0.32 ± 0.06	-5.20	-0.32 ± 0.06	-5.66
TP	**-3.60 ± 0.43**	**-8.47**	**-0.38 ± 0.17**	**-2.23**	**-0.56 ± 0.20**	**-2.81**