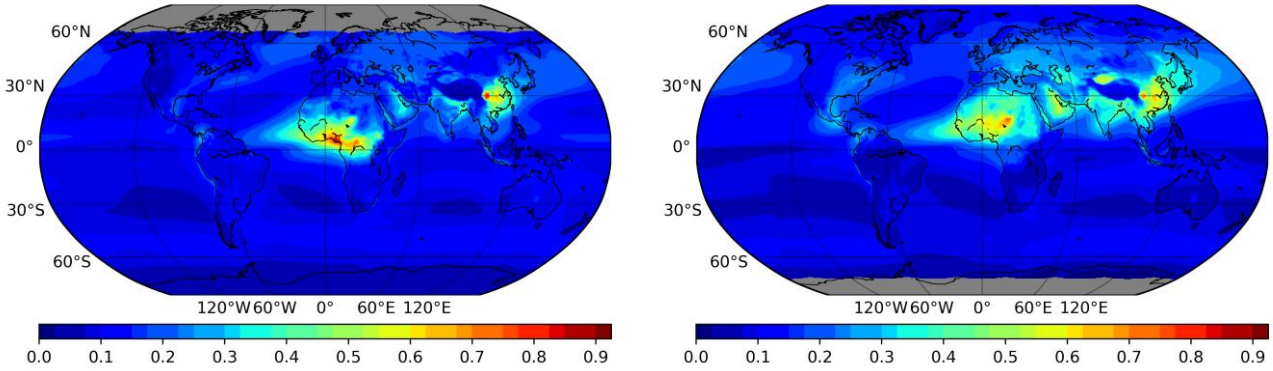
atmosphere

MDPI

Article

Global Clear–Sky Aerosol Speciated Direct Radiative Effects over 40 Years (1980–2019)

Supplement

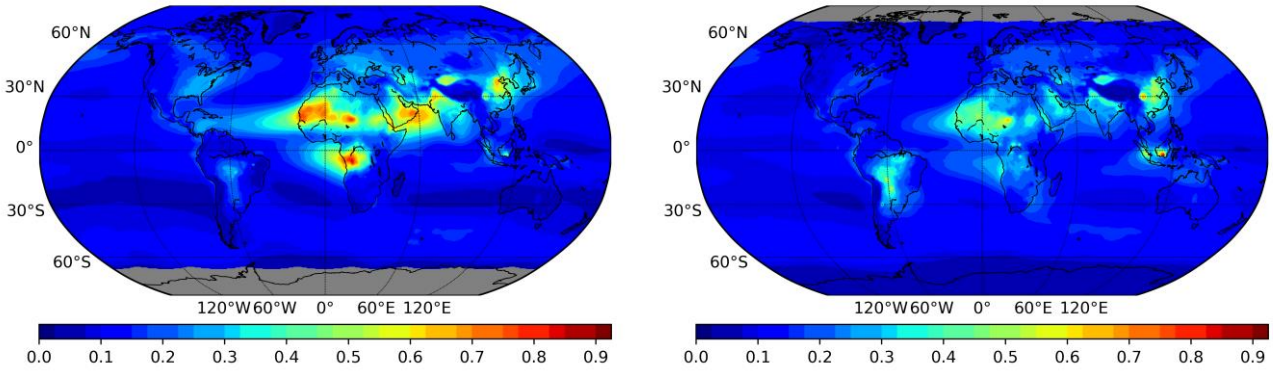


min=0.027 max=0.851 mean=0.128

(a)

min=0.021 max=0.764 mean=0.141

(b)



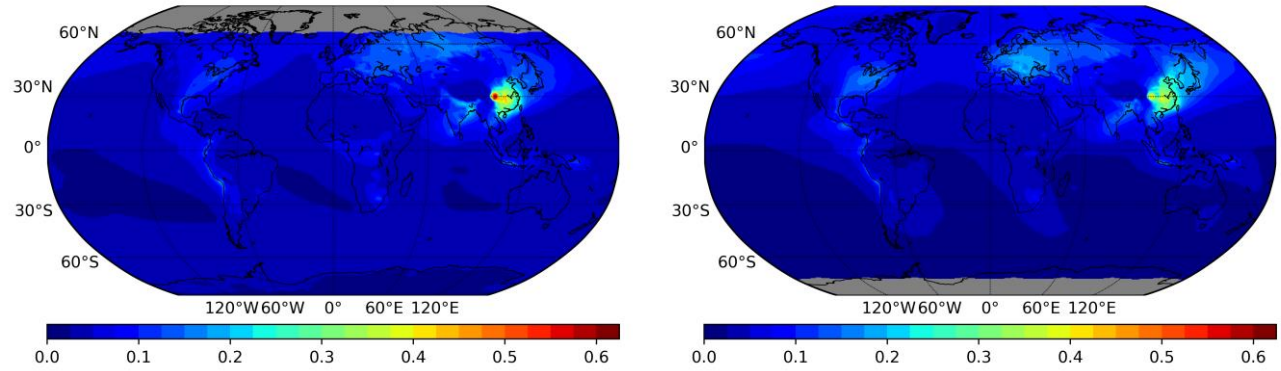
min=0.022 max=0.859 mean=0.153

(c)

min=0.029 max=0.920 mean=0.138

(d)

Figure S1i. Mean seasonal (1980–2019) global distribution of MERRA-2 Optical Depth at the wavelength of 550 nm for the total aerosol load. (**a**) winter, (**b**) spring, (**c**) summer, (**d**) autumn.

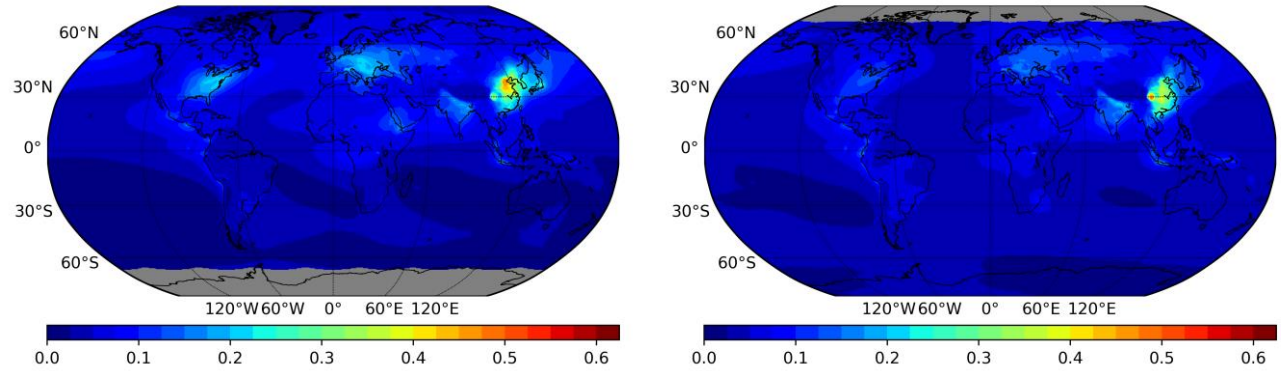


min=0.020 max=0.613 mean=0.048

(a)

min=0.015 max=0.429 mean=0.048

(b)



min=0.016 max=0.474 mean=0.052

(c)

min=0.018 max=0.495 mean=0.049

(d)

Figure S1ii. Mean seasonal (1980–2019) global distribution of MERRA-2 Optical Depth at the wavelength of 550 nm for sulfate particles. (**a**) winter, (**b**) spring, (**c**) summer, (**d**) autumn.

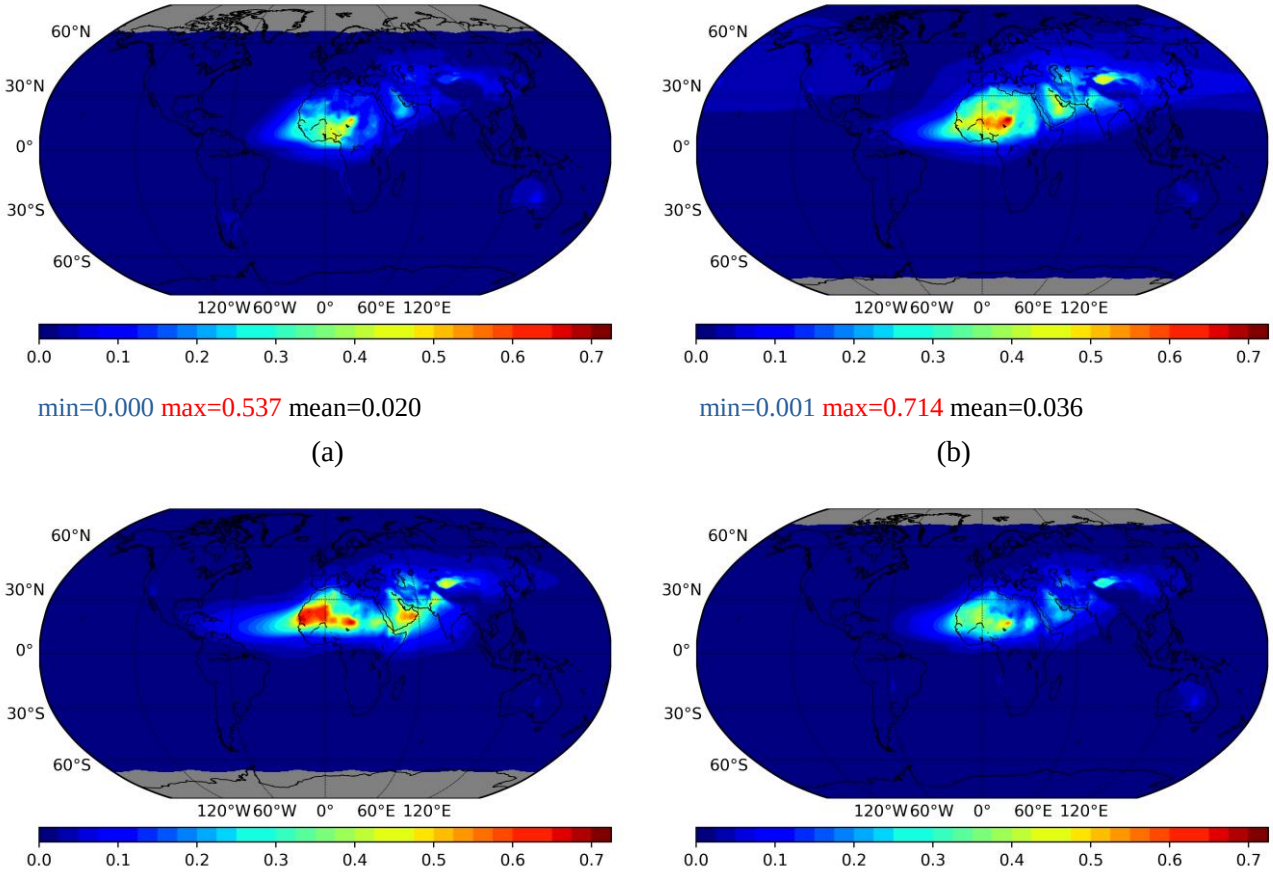


Figure S1iii. Mean seasonal (1980–2019) global distribution of MERRA–2 Optical Depth at the wavelength of 550 nm for dust particles. (**a**) winter, (**b**) spring, (**c**) summer, (**d**) autumn.

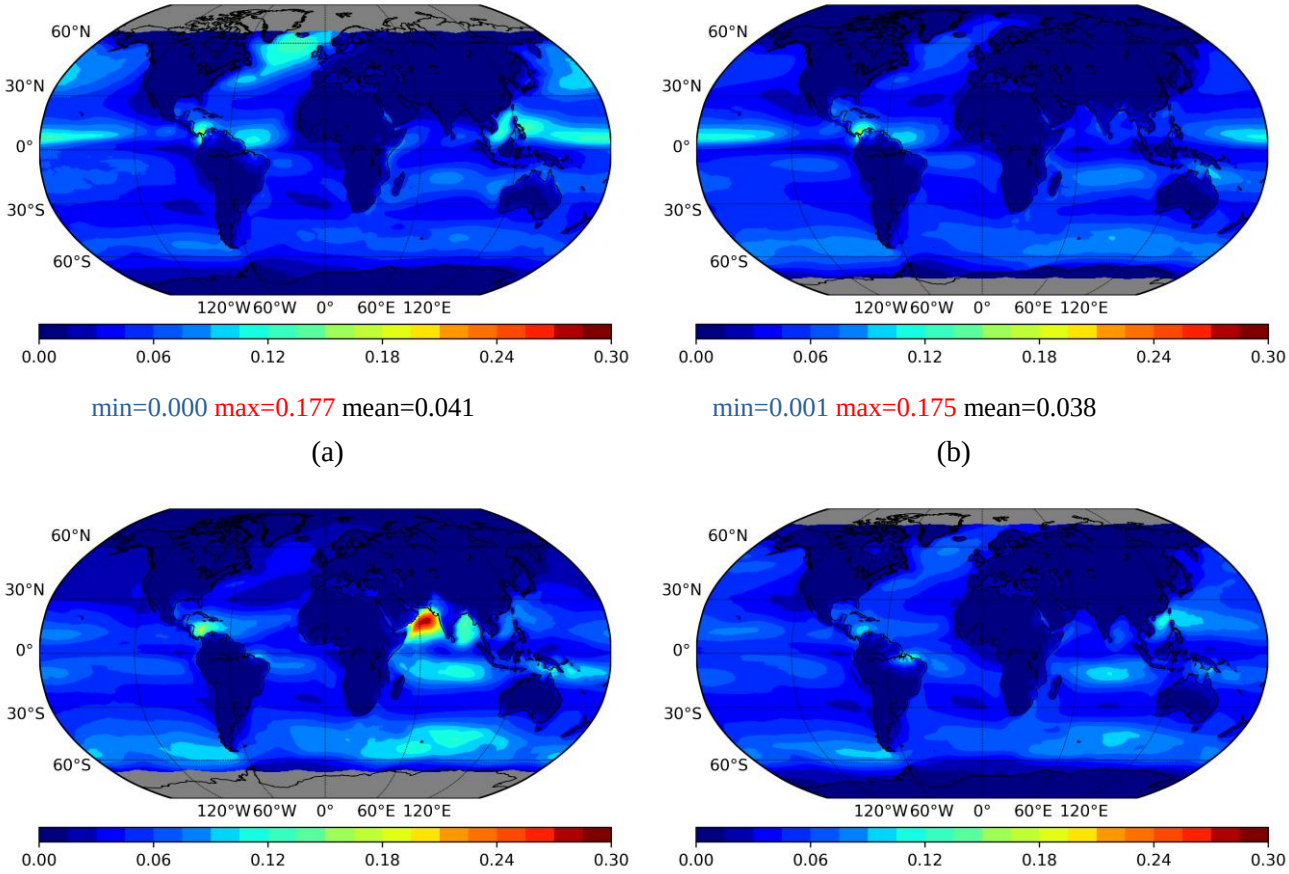


Figure S1iv. Mean seasonal (1980–2019) global distribution of MERRA–2 Optical Depth at the wavelength of 550 nm for dust particles. (**a**) winter, (**b**) spring, (**c**) summer, (**d**) autumn.

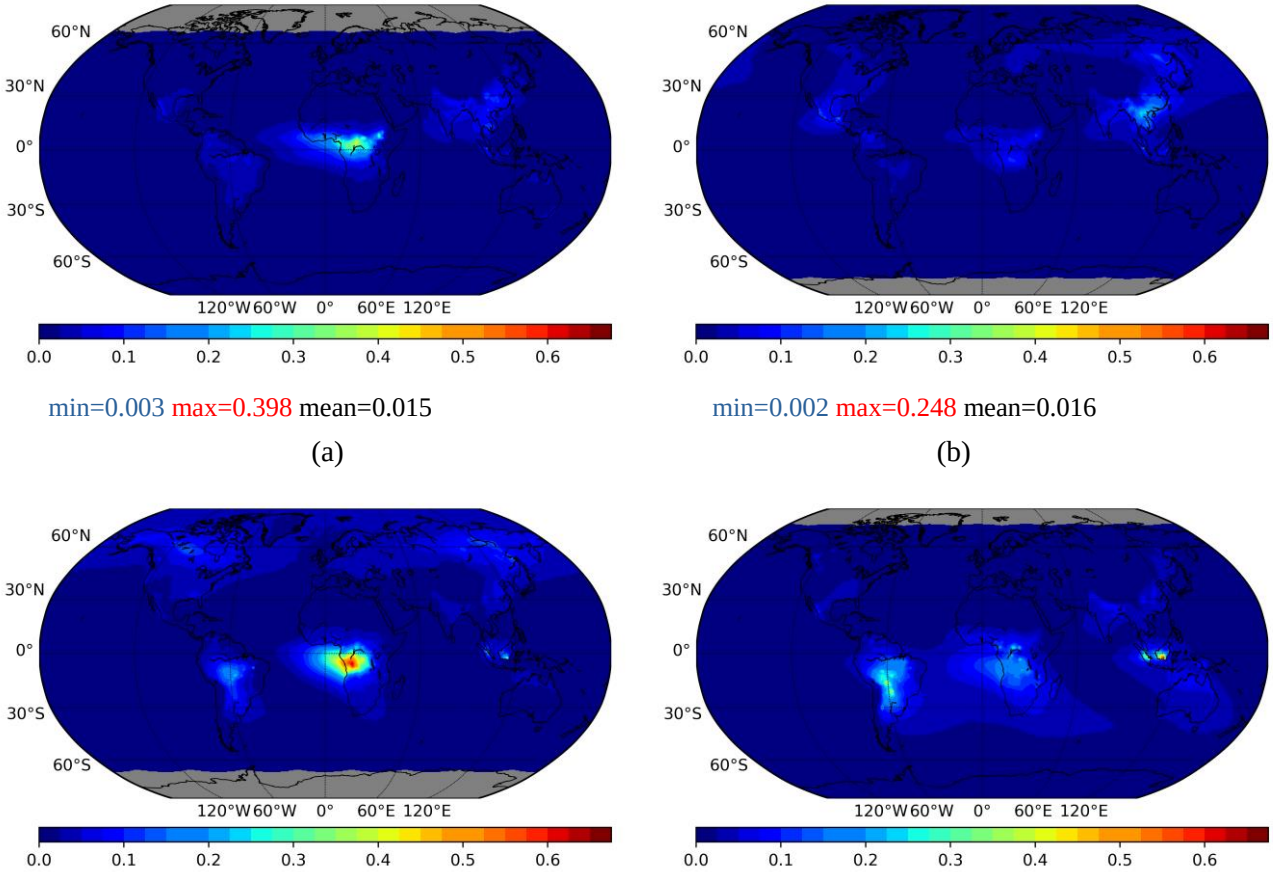
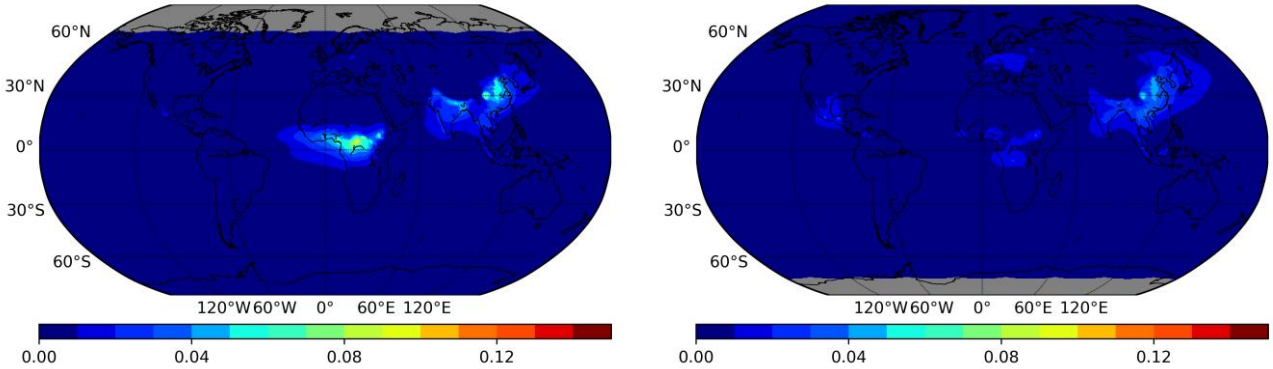


Figure S1v. Mean seasonal (1980–2019) global distribution of MERRA−2 Optical Depth at the wavelength of 550 nm for organic carbon particles. (**a**) winter, (**b**) spring, (**c**) summer, (**d**) autumn.

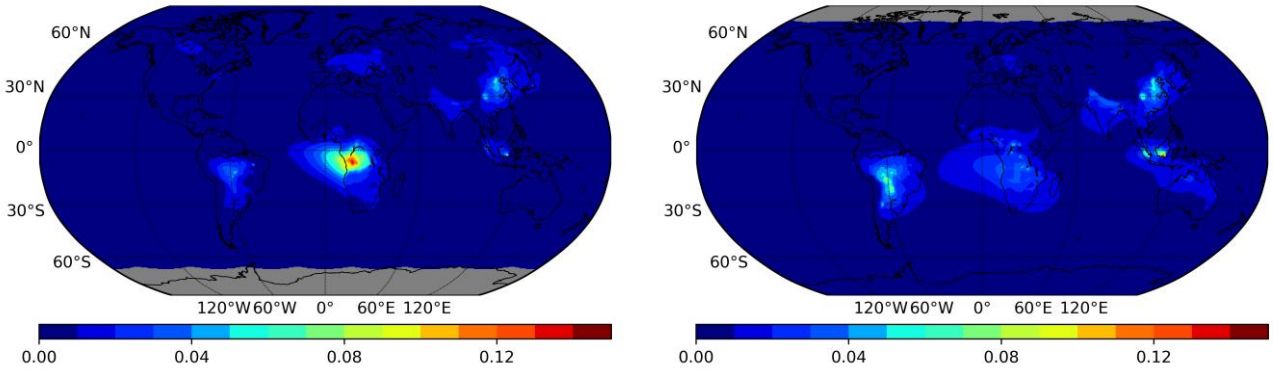


min=0.001 max=0.094 mean=0.005

(a)

min=0.001 max=0.055 mean=0.004

(b)



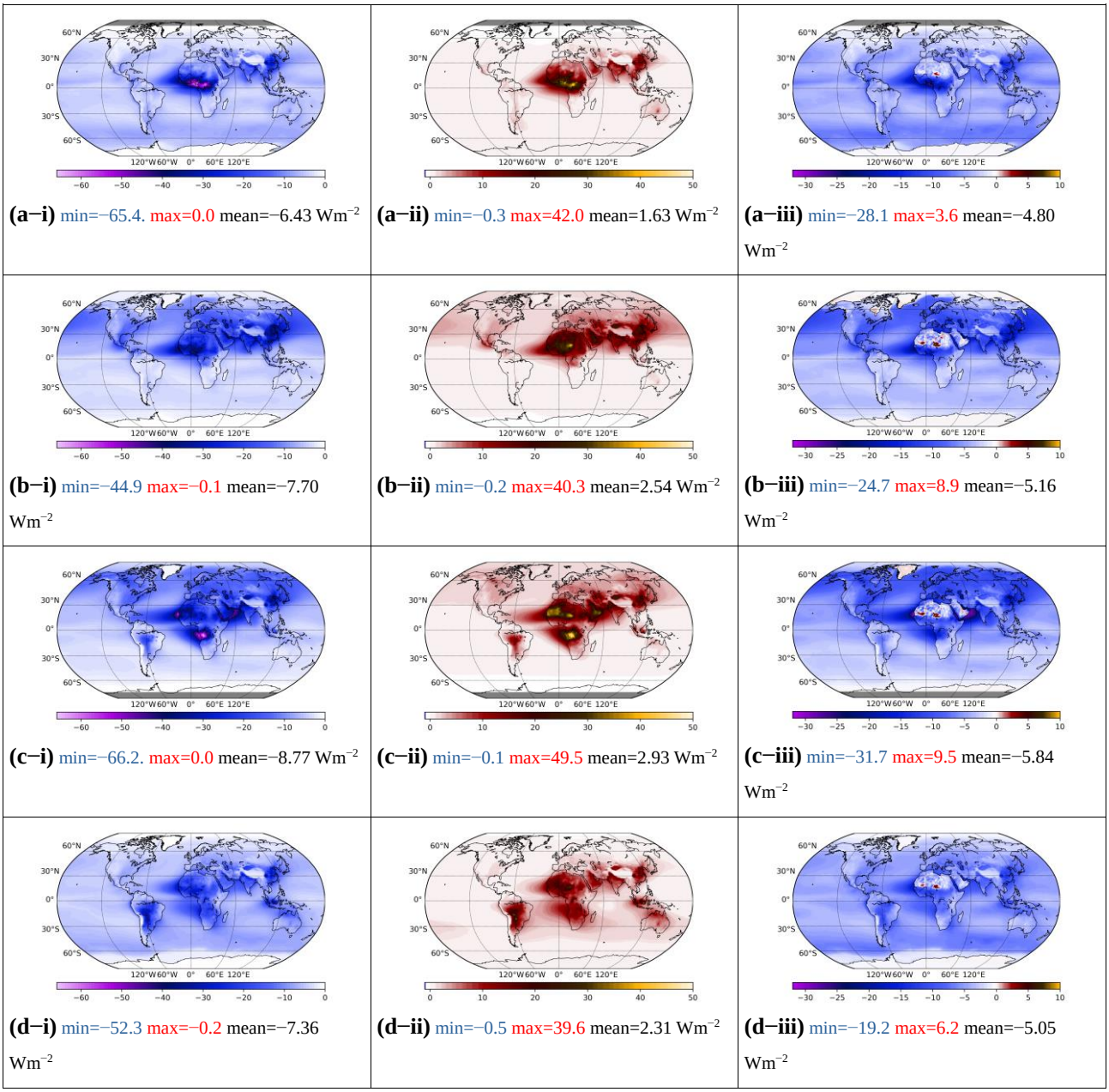
min=0.001 max=0.137 mean=0.005

(c)

min=0.001 max=0.133 mean=0.006

(d)

Figure S1vi. Mean seasonal (1980–2019) global distribution of MERRA–2 Optical Depth at the wavelength of 550 nm for black carbon particles. (**a**) winter, (**b**) spring, (**c**) summer, (**d**) autumn.



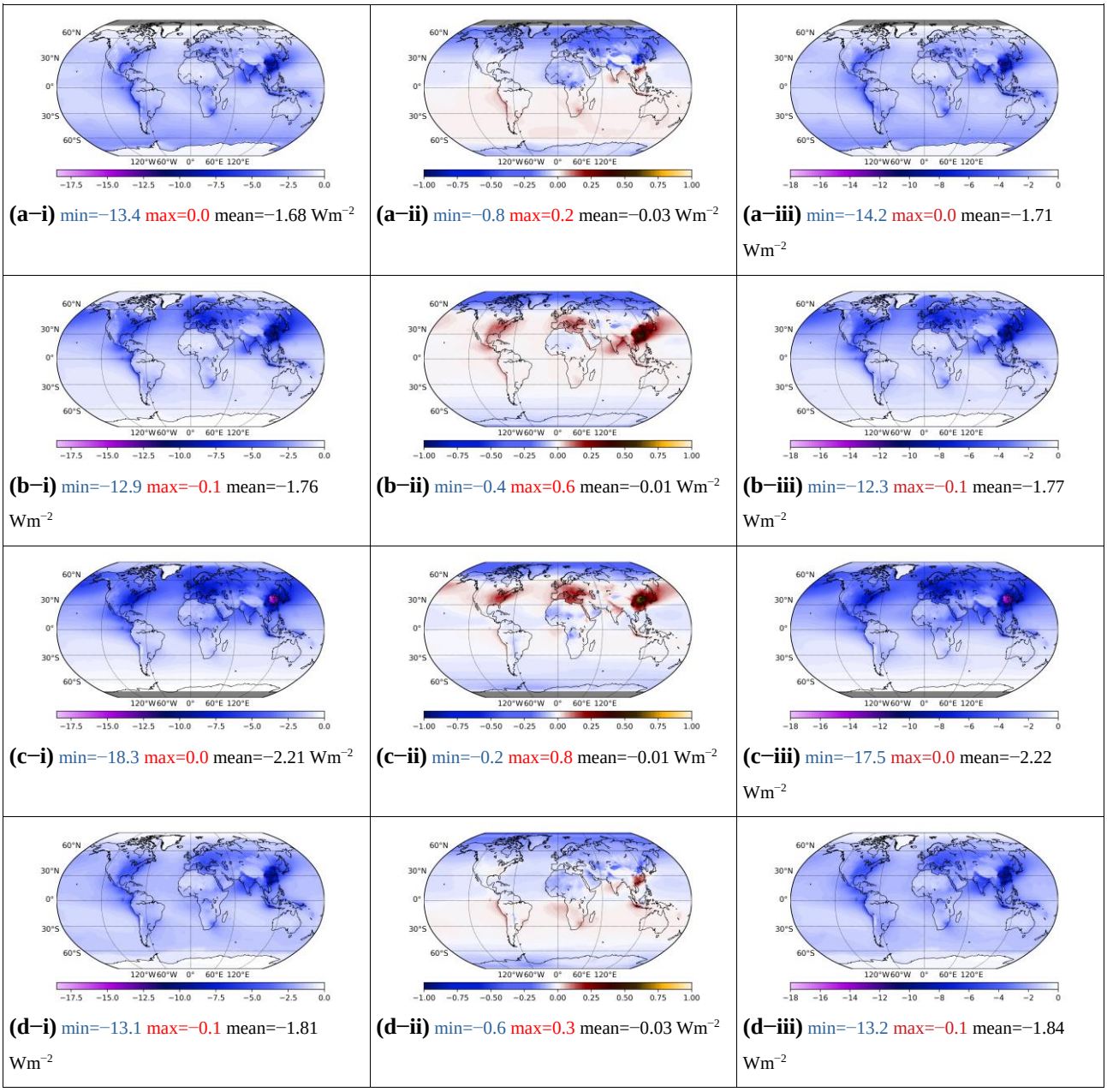
(a–i) min=−65.4. max=0.0 mean=−6.43 Wm^{-2} **(a–ii)** min=−0.3 max=42.0 mean=1.63 Wm^{-2} **(a–iii)** min=−28.1 max=3.6 mean=−4.80 Wm^{-2}

(b–i) min=−44.9 max=−0.1 mean=−7.70 Wm^{-2} **(b–ii)** min=−0.2 max=40.3 mean=2.54 Wm^{-2} **(b–iii)** min=−24.7 max=8.9 mean=−5.16 Wm^{-2}

(c–i) min=−66.2. max=0.0 mean=−8.77 Wm^{-2} **(c–ii)** min=−0.1 max=49.5 mean=2.93 Wm^{-2} **(c–iii)** min=−31.7 max=9.5 mean=−5.84 Wm^{-2}

(d–i) min=−52.3 max=−0.2 mean=−7.36 Wm^{-2} **(d–ii)** min=−0.5 max=39.6 mean=2.31 Wm^{-2} **(d–iii)** min=−19.2 max=6.2 mean=−5.05 Wm^{-2}

Figure S2. Mean (1980–2019) global distribution of total aerosol Direct Radiative Effects (**i**) at the Earth's surface, (**ii**) within the Atmosphere and (**iii**) at the Top Of the Atmosphere, during (**a**) winter, (**b**) spring, (**c**) summer and (**d**) autumn.



(a–i) min=−13.4 max=0.0 mean=−1.68 Wm^{-2}

(a–ii) min=−0.8 max=0.2 mean=−0.03 Wm^{-2}

(a–iii) min=−14.2 max=0.0 mean=−1.71 Wm^{-2}

(b–i) min=−12.9 max=−0.1 mean=−1.76 Wm^{-2}

(b–ii) min=−0.4 max=0.6 mean=−0.01 Wm^{-2}

(b–iii) min=−12.3 max=−0.1 mean=−1.77 Wm^{-2}

(c–i) min=−18.3 max=0.0 mean=−2.21 Wm^{-2}

(c–ii) min=−0.2 max=0.8 mean=−0.01 Wm^{-2}

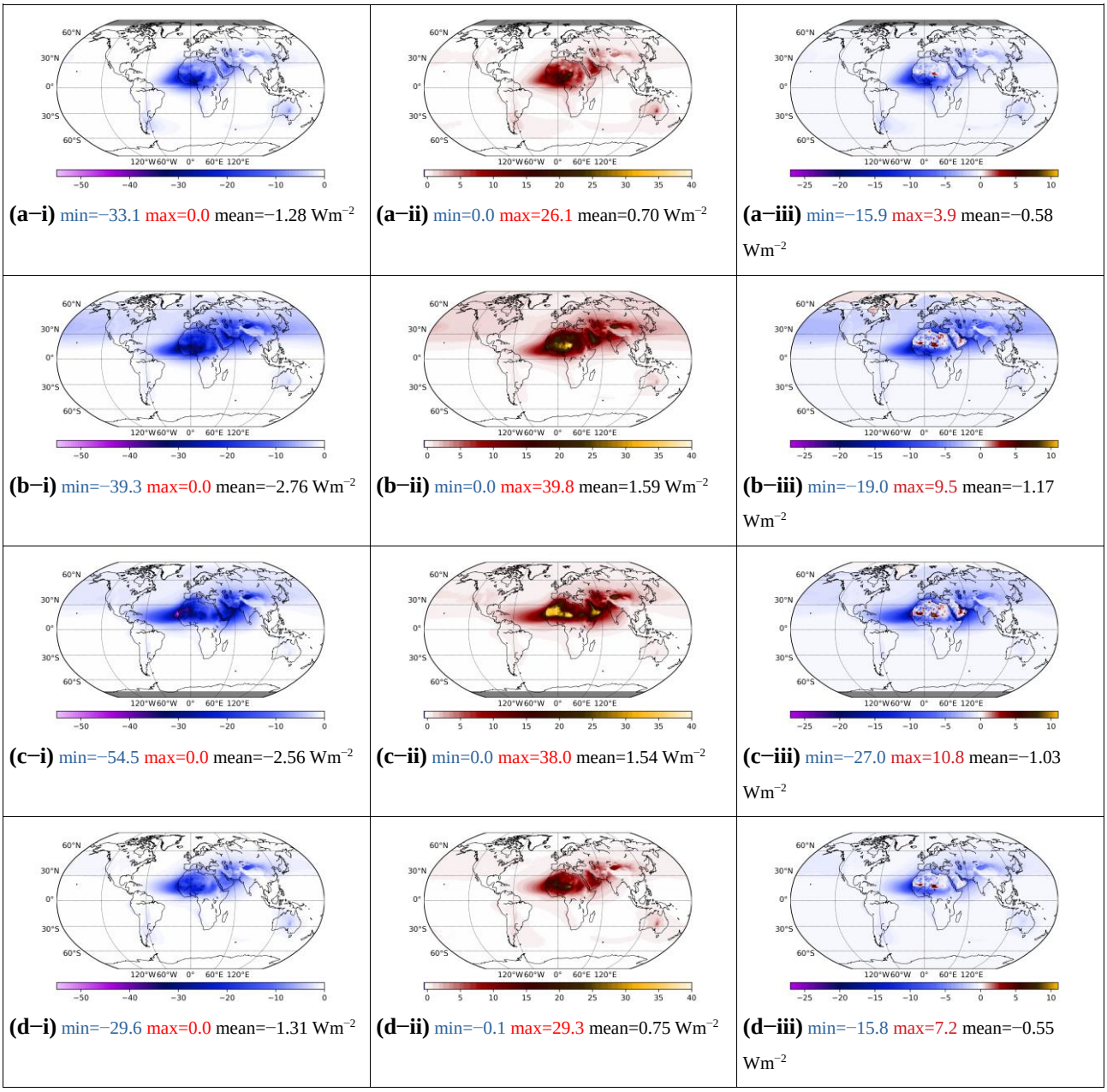
(c–iii) min=−17.5 max=0.0 mean=−2.22 Wm^{-2}

(d–i) min=−13.1 max=−0.1 mean=−1.81 Wm^{-2}

(d–ii) min=−0.6 max=0.3 mean=−0.03 Wm^{-2}

(d–iii) min=−13.2 max=−0.1 mean=−1.84 Wm^{-2}

Figure S3. Mean (1980–2019) global distribution of sulfate aerosol Direct Radiative Effects (**i**) at the Earth's surface, (**ii**) within the Atmosphere and (**iii**) at the Top Of the Atmosphere, during (**a**) winter, (**b**) spring, (**c**) summer and (**d**) autumn.



(a–i) min=−33.1 max=0.0 mean=−1.28 Wm^{-2} **(a–ii)** min=0.0 max=26.1 mean=0.70 Wm^{-2} **(a–iii)** min=−15.9 max=3.9 mean=−0.58 Wm^{-2}

(b–i) min=−39.3 max=0.0 mean=−2.76 Wm^{-2} **(b–ii)** min=0.0 max=39.8 mean=1.59 Wm^{-2} **(b–iii)** min=−19.0 max=9.5 mean=−1.17 Wm^{-2}

(c–i) min=−54.5 max=0.0 mean=−2.56 Wm^{-2} **(c–ii)** min=0.0 max=38.0 mean=1.54 Wm^{-2} **(c–iii)** min=−27.0 max=10.8 mean=−1.03 Wm^{-2}

(d–i) min=−29.6 max=0.0 mean=−1.31 Wm^{-2} **(d–ii)** min=−0.1 max=29.3 mean=0.75 Wm^{-2} **(d–iii)** min=−15.8 max=7.2 mean=−0.55 Wm^{-2}

Figure S4. Mean (1980–2019) global distribution of dust aerosol Direct Radiative Effects (**i**) at the Earth's surface, (**ii**) within the Atmosphere and (**iii**) at the Top Of the Atmosphere, during (**a**) winter, (**b**) spring, (**c**) summer and (**d**) autumn.

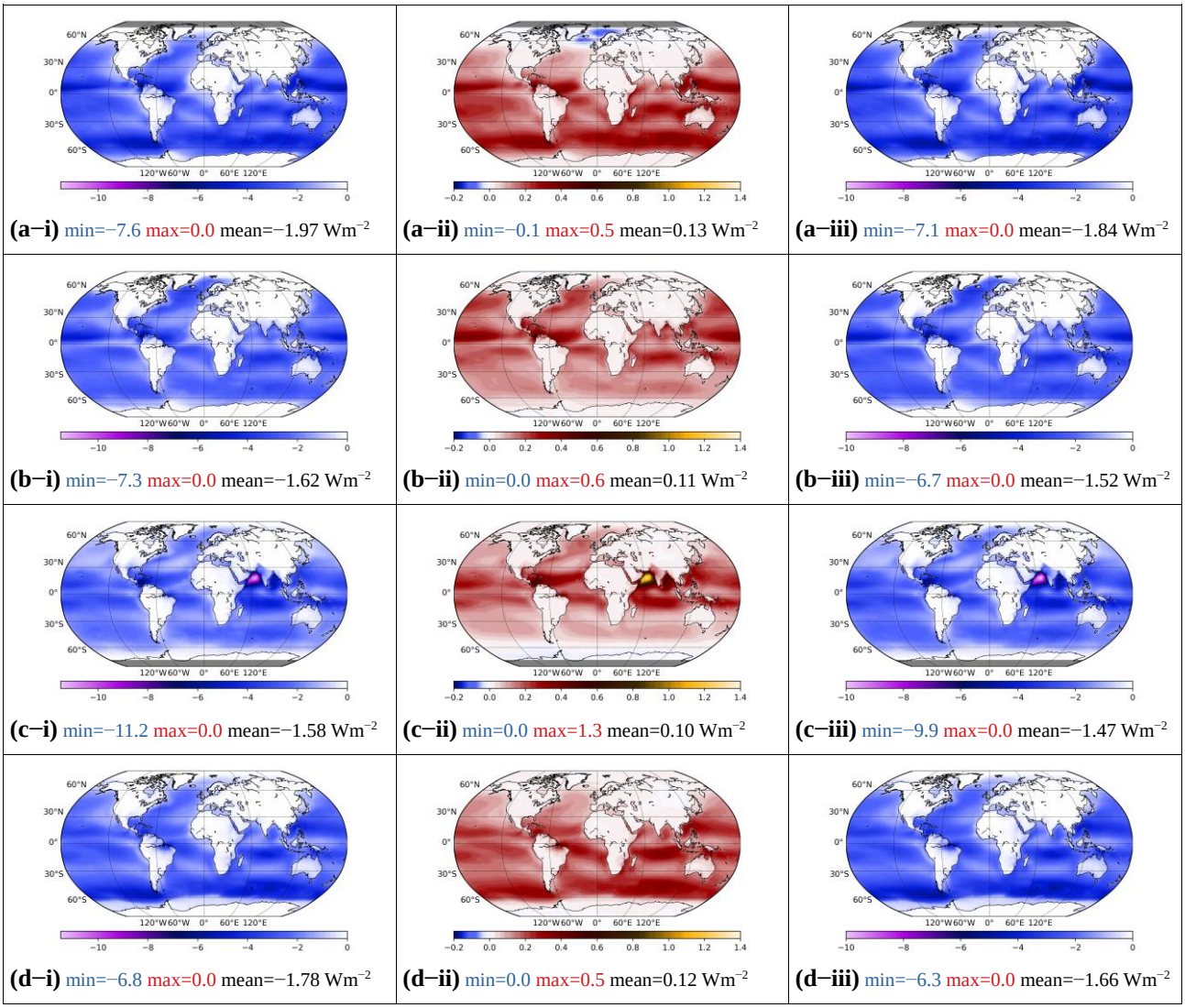
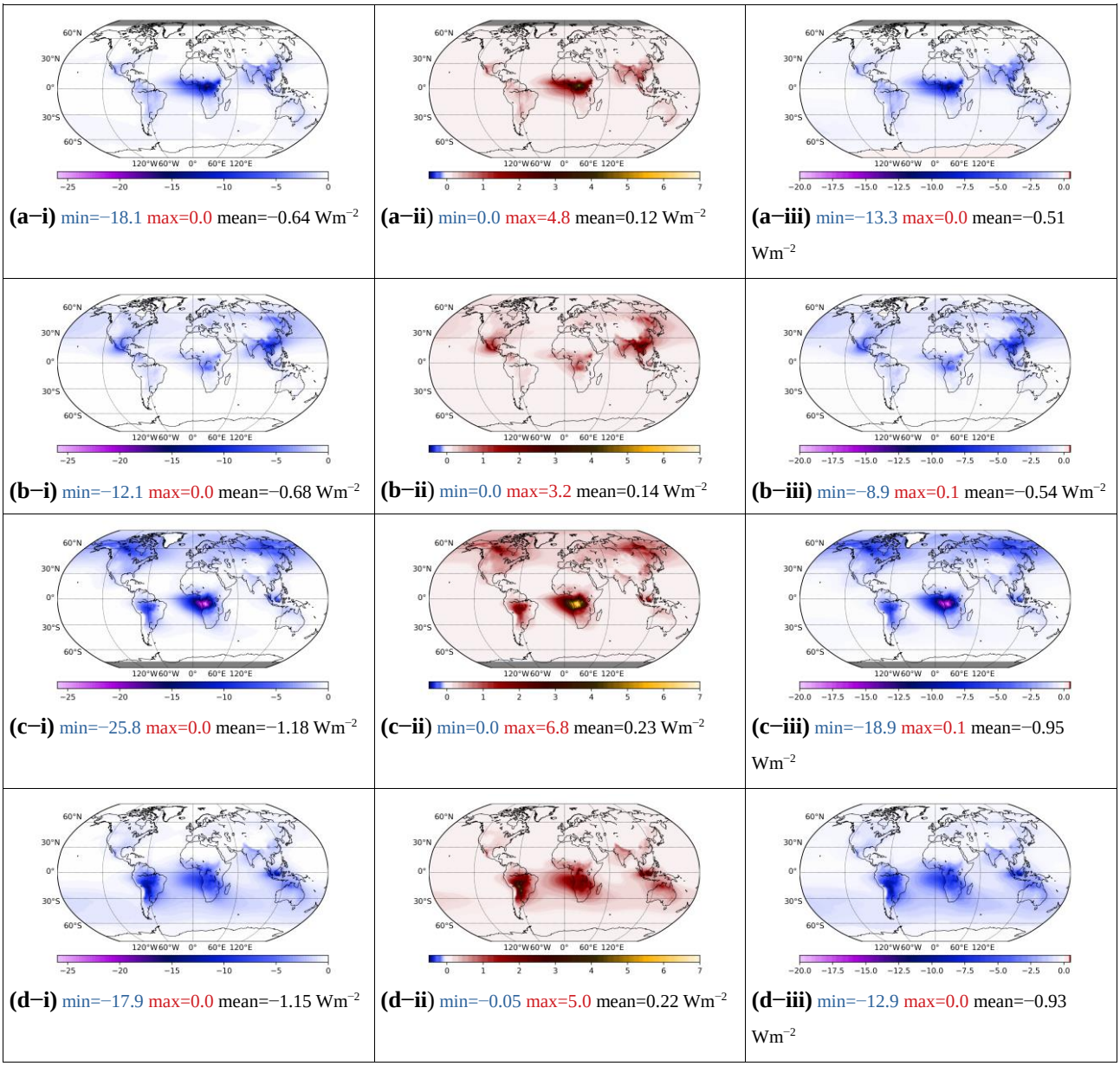


Figure S5. Mean (1980–2019) global distribution of sea salt aerosol Direct Radiative Effects (**i**) at the Earth's surface, (**ii**) within the Atmosphere and (**iii**) at the Top Of the Atmosphere, during (**a**) winter, (**b**) spring, (**c**) summer and (**d**) autumn.



(a−i) min=−18.1 max=0.0 mean=−0.64 Wm^{-2} **(a−ii)** min=0.0 max=4.8 mean=0.12 Wm^{-2} **(a−iii)** min=−13.3 max=0.0 mean=−0.51 Wm^{-2}

(b−i) min=−12.1 max=0.0 mean=−0.68 Wm^{-2} **(b−ii)** min=0.0 max=3.2 mean=0.14 Wm^{-2} **(b−iii)** min=−8.9 max=0.1 mean=−0.54 Wm^{-2}

(c−i) min=−25.8 max=0.0 mean=−1.18 Wm^{-2} **(c−ii)** min=0.0 max=6.8 mean=0.23 Wm^{-2} **(c−iii)** min=−18.9 max=0.1 mean=−0.95 Wm^{-2}

(d−i) min=−17.9 max=0.0 mean=−1.15 Wm^{-2} **(d−ii)** min=−0.05 max=5.0 mean=0.22 Wm^{-2} **(d−iii)** min=−12.9 max=0.0 mean=−0.93 Wm^{-2}

Figure S6. Mean (1980–2019) global distribution of organic carbon aerosol Direct Radiative Effects (**i**) at the Earth's surface, (**ii**) within the Atmosphere and (**iii**) at the Top Of the Atmosphere, during (**a**) winter, (**b**) spring, (**c**) summer and (**d**) autumn.

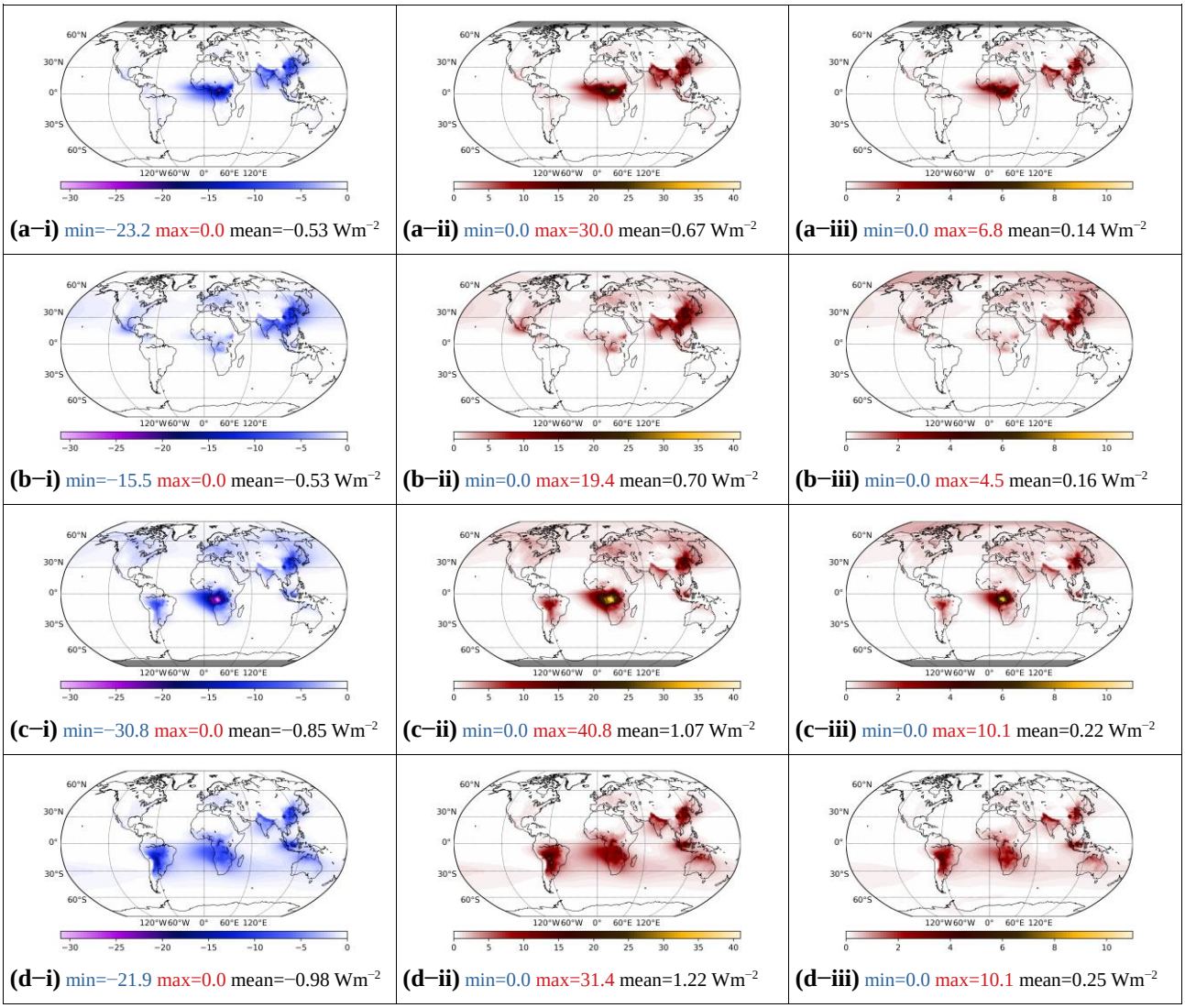
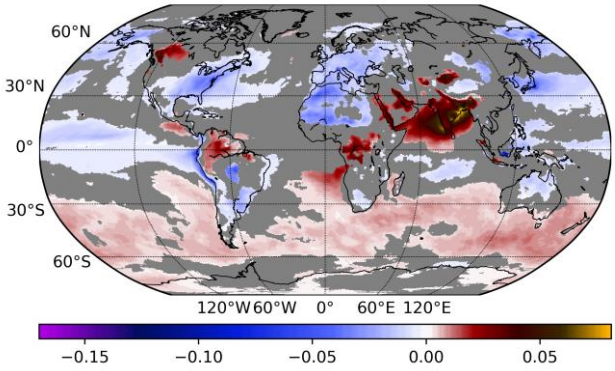
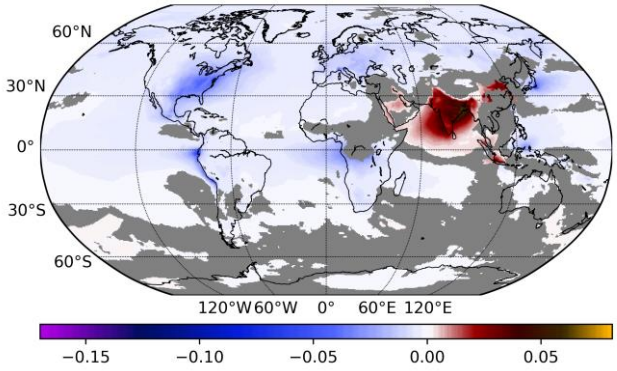


Figure S7. Mean (1980–2019) global distribution of black carbon aerosol Direct Radiative Effects (**i**) at the Earth's surface, (**ii**) within the Atmosphere and (**iii**) at the Top Of the Atmosphere, during (**a**) winter, (**b**) spring, (**c**) summer and (**d**) autumn.



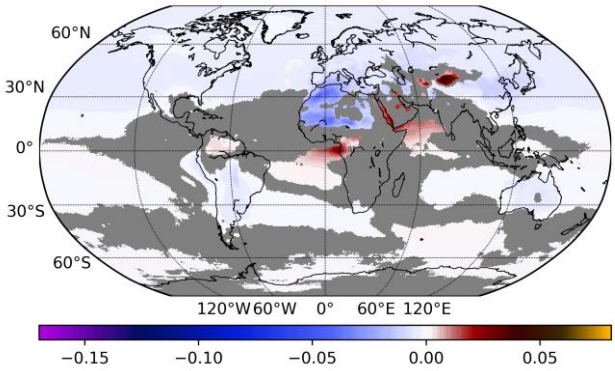
min=−0.170 max=0.081 decade^{-1}

(i)



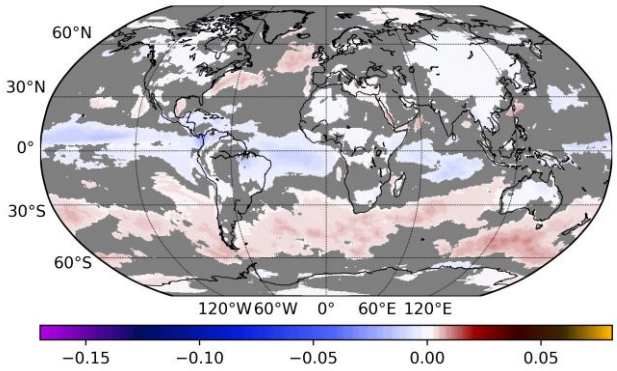
min=−0.068 max=0.062 decade^{-1}

(ii)



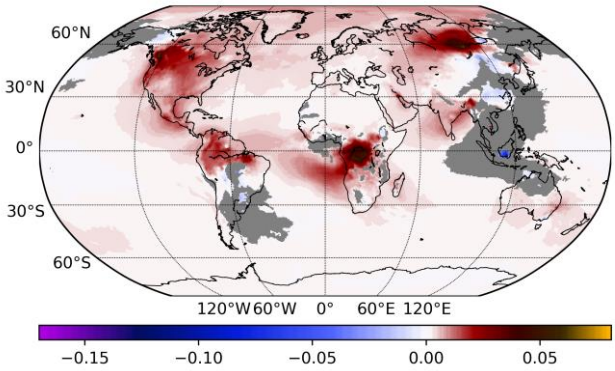
min=−0.045 max=0.054 decade^{-1}

(iii)



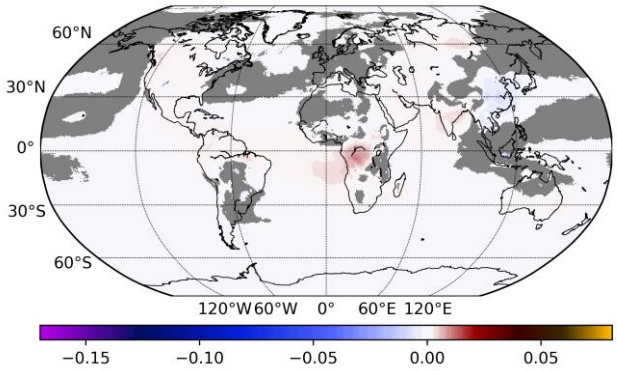
min=−0.026 max=0.010 decade^{-1}

(iv)



min=−0.143 max=0.064 decade^{-1}

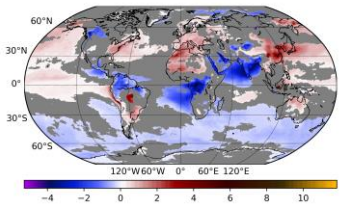
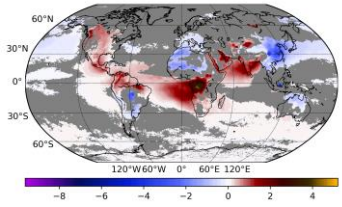
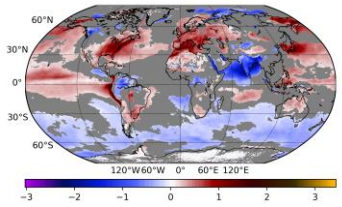
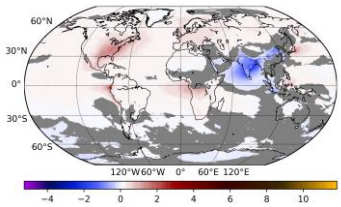
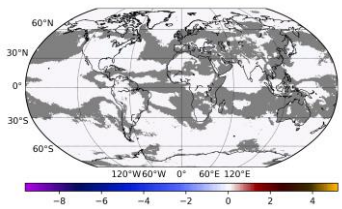
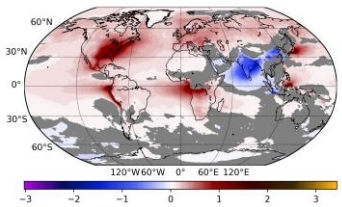
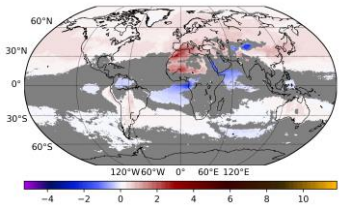
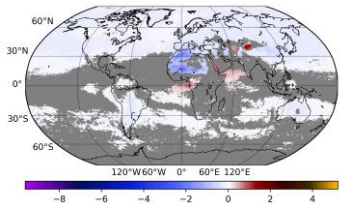
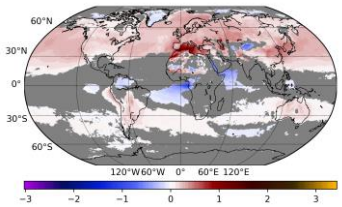
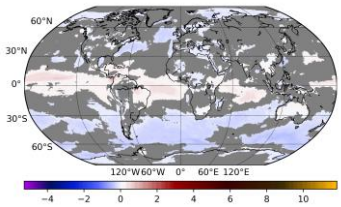
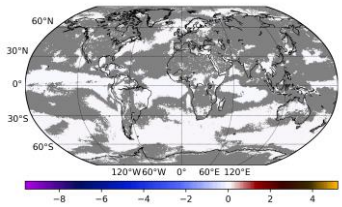
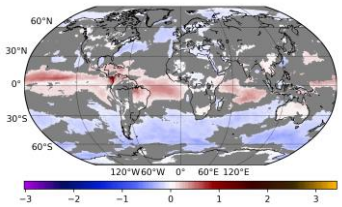
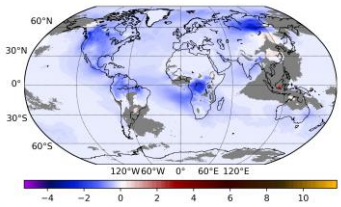
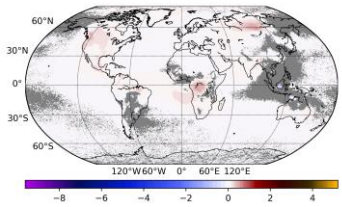
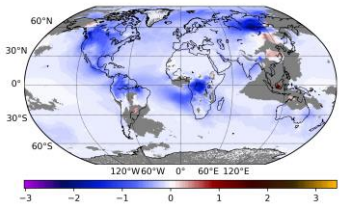
(v)

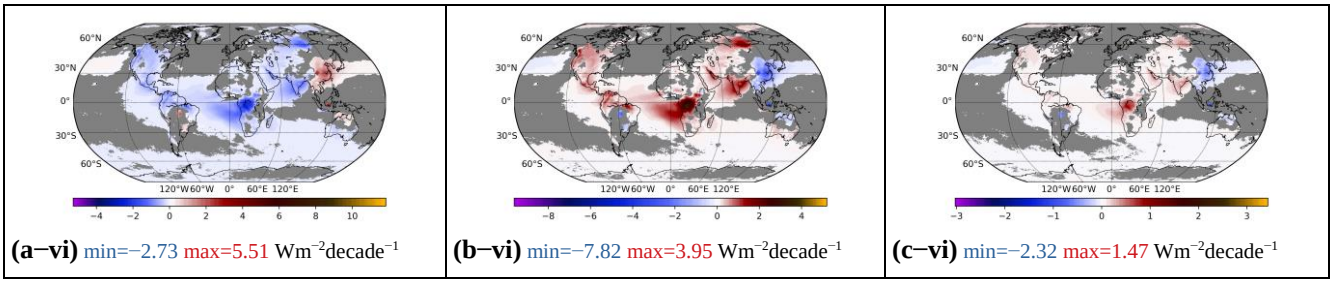


min=−0.027 max=0.012 decade^{-1}

(vi)

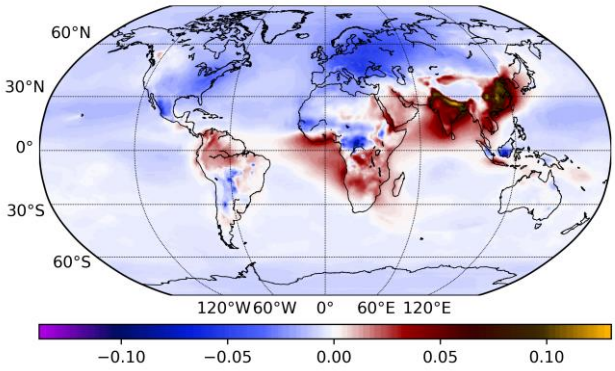
Figure S8. Slopes of deseasonalized MERRA−2 Optical Depth anomalies at the wavelength of 550 nm, over the period 2001–2019, for: (**i**) total aerosol load, (**ii**) sulfate, (**iii**) dust, (**iv**) sea salt, (**v**) organic carbon and (**vi**) black carbon particles. Only 0.5°×0.625° cells where trends are statistically significant at a 95% confidence level are shown. (units are decade^{-1})

Total − Surfnet  **(a−i)** min=−5.27. max=11.84 $Wm^{-2}decade^{-1}$	**Total − Atm**  **(b−i)** min=−9.61 max=5.20 $Wm^{-2}decade^{-1}$	**Total − TOA**  **(c−i)** min=−2.33 max=2.42 $Wm^{-2}decade^{-1}$
Sulfate − Surfnet  **(a−ii)** min=−1.78 max=2.30 $Wm^{-2}decade^{-1}$	**Sulfate – Atm**  **(b−ii)** min=−0.09 max=0.07 $Wm^{-2}decade^{-1}$	 **Sulfate – TOA** **(c−ii)** min=−1.72 max=2.28 $Wm^{-2}decade^{-1}$
Dust − Surfnet  **(a−iii)** min=−2.57 max=3.12 $Wm^{-2}decade^{-1}$	**Dust– Atm**  **(b−iii)** min=−2.15 max=1.78 $Wm^{-2}decade^{-1}$	**Dust– TOA**  **(c−iii)** min=−1.00 max=1.31 $Wm^{-2}decade^{-1}$
Sea Salt− Surfnet  **(a−iv)** min=−0.46 max=1.04 $Wm^{-2}decade^{-1}$	**Sea Salt – Atm**  **(b−iv)** min=−0.06 max=0.05 $Wm^{-2}decade^{-1}$	**Sea Salt – TOA**  **(c−iv)** min=−0.43 max=0.98 $Wm^{-2}decade^{-1}$
Organic Carbon − Surfnet  **(a−v)** min=−3.78 max=4.77 $Wm^{-2}decade^{-1}$	**Organic Carbon – Atm**  **(b−v)** min=−1.33 max=0.75 $Wm^{-2}decade^{-1}$	**Organic Carbon – TOA**  **(c−v)** min=−3.03 max=3.43 $Wm^{-2}decade^{-1}$
Black Carbon − Surfnet	**Black Carbon – Atm**	**Black Carbon – TOA**



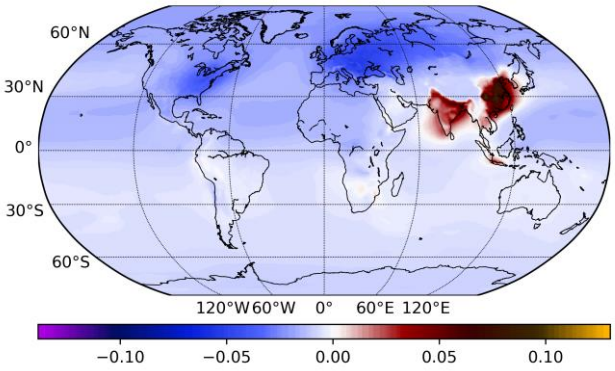
(a−vi) min=−2.73 max=5.51 $Wm^{-2}decade^{-1}$ **(b−vi)** min=−7.82 max=3.95 $Wm^{-2}decade^{-1}$ **(c−vi)** min=−2.32 max=1.47 $Wm^{-2}decade^{-1}$

Figure S9. Slopes of deseasonalized Direct Radiative Effects anomalies over the period 2001−2019: (**a**) at the Earth's surface, (**b**) within the Atmosphere and (c) at the Top Of the Atmosphere. (**i**) total aerosol load, (**ii**) sulfate, (**iii**) dust, (**iv**) sea salt, (**v**) organic carbon and (**vi**) black carbon particles. Only 0.5°×0.625° cells where trends are statistically significant at a 95% confidence level are shown. (units are $Wm^{-2}decade^{-1}$).



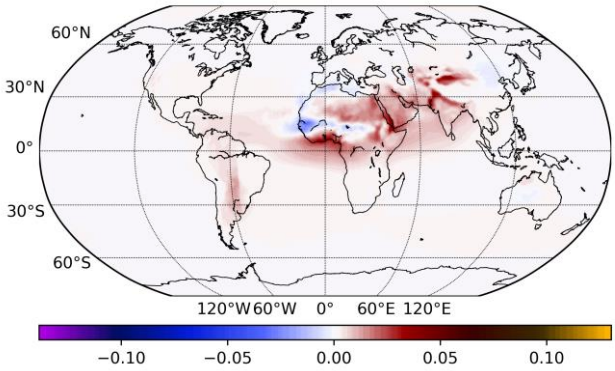
min=−0.139 max=0.130 decade^{-1}

(i)



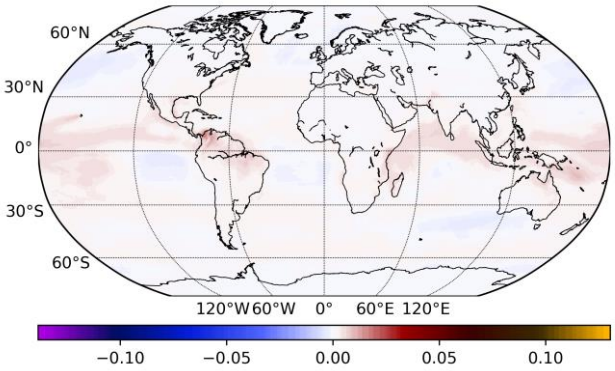
min=−0.059 max=0.104 decade^{-1}

(ii)



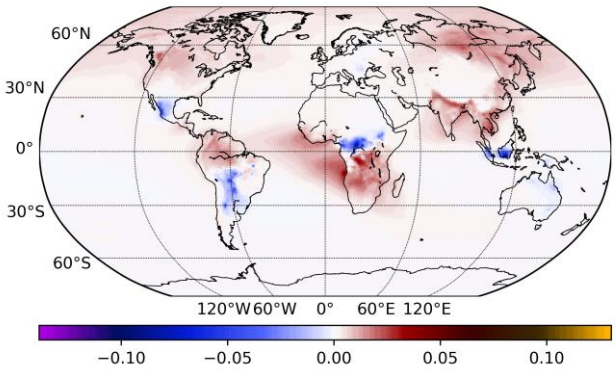
min=−0.031 max=0.048 decade^{-1}

(iii)



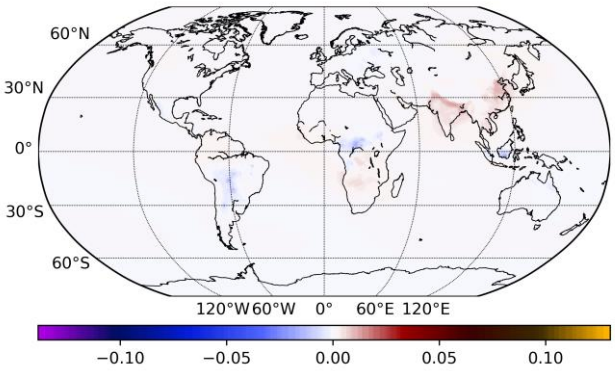
min=−0.004 max=0.024 decade^{-1}

(iv)



min=−0.119 max=0.039 decade^{-1}

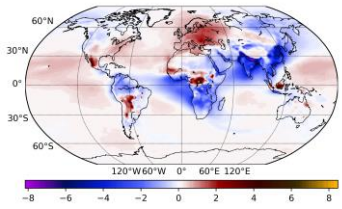
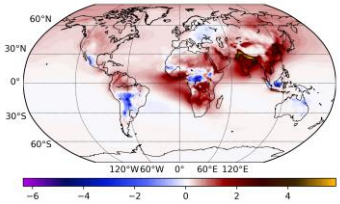
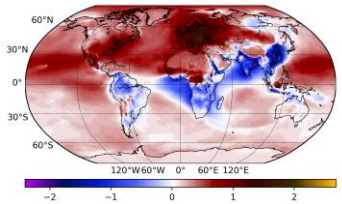
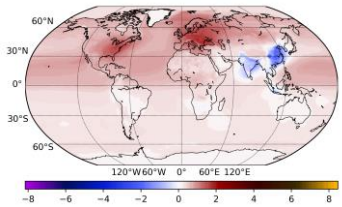
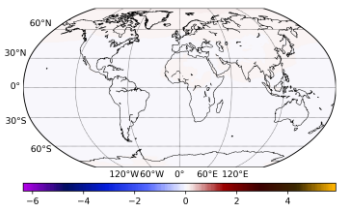
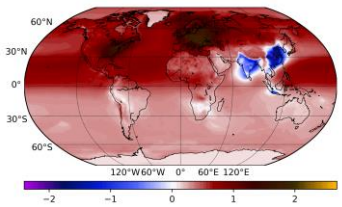
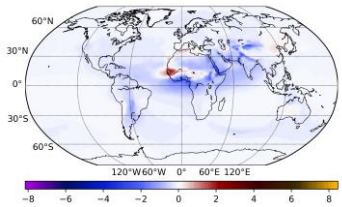
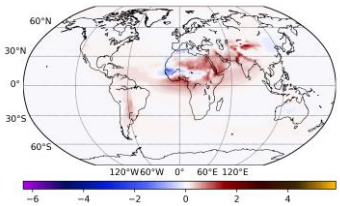
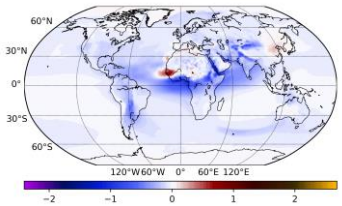
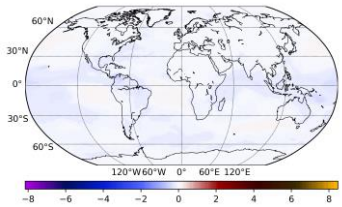
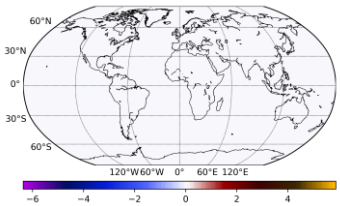
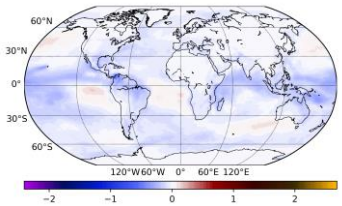
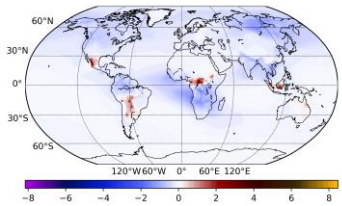
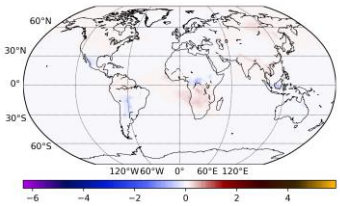
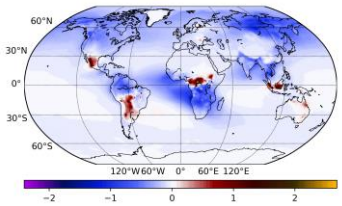
(v)

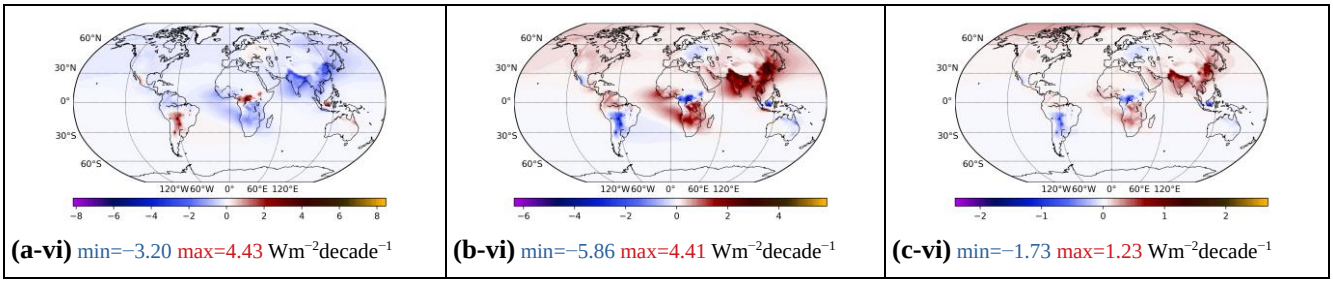


min=−0.022 max=0.014 decade^{-1}

(vi)

Figure S10. Slopes of deseasonalized MERRA−2 Optical Depth anomalies at the wavelength of 550 nm, over the period 1980−2019, for: (**i**) total aerosol load, (**ii**) sulfate, (**iii**) dust, (**iv**) sea salt, (**v**) organic carbon and (**vi**) black carbon particles. Only 0.5°×0.625° cells where trends are statistically significant at a 95% confidence level are shown. (units are decade^{-1})

Total − Surfnet  **(a−i)** min=−8.15. max=8.47 $Wm^{-2}decade^{-1}$	**Total - Atm**  **(b-i)** min=−6.36 max=5.88 $Wm^{-2}decade^{-1}$	**Total − TOA**  **(c-i)** min=−2.41 max=2.68 $Wm^{-2}decade^{-1}$
Sulfate - Surfnet  **(a-ii)** min=−2.22 max=1.94 $Wm^{-2}decade^{-1}$	**Sulfate – Atm**  **(b-ii)** min=−0.01 max=0.18 $Wm^{-2}decade^{-1}$	 **Sulfate – TOA** **(c-ii)** min=−2.15 max=1.97 $Wm^{-2}decade^{-1}$
Dust - Surfnet  **(a-iii)** min=−2.89 max=2.01 $Wm^{-2}decade^{-1}$	**Dust– Atm**  **(b-iii)** min=−1.44 max=1.91 $Wm^{-2}decade^{-1}$	**Dust– TOA**  **(c-iii)** min=−1.39 max=0.87 $Wm^{-2}decade^{-1}$
Sea Salt− Surfnet  **(a-iv)** min=−0.84 max=0.17 $Wm^{-2}decade^{-1}$	**Sea Salt – Atm**  **(b-iv)** min=−0.01 max=0.05 $Wm^{-2}decade^{-1}$	**Sea Salt – TOA**  **(c-iv)** min=−0.79 max=0.16 $Wm^{-2}decade^{-1}$
Organic Carbon − Surfnet  **(a-v)** min=−1.92 max=3.60 $Wm^{-2}decade^{-1}$	**Organic Carbon – Atm**  **(b-v)** min=−0.97 max=0.45 $Wm^{-2}decade^{-1}$	**Organic Carbon – TOA**  **(c-v)** min=−1.50 max=2.63 $Wm^{-2}decade^{-1}$
Black Carbon - Surfnet	**Black Carbon – Atm**	**Black Carbon – TOA**



(a-vi) min=−3.20 max=4.43 $Wm^{-2}decade^{-1}$ **(b-vi)** min=−5.86 max=4.41 $Wm^{-2}decade^{-1}$ **(c-vi)** min=−1.73 max=1.23 $Wm^{-2}decade^{-1}$

Figure S11. Slopes of deseasonalized Direct Radiative Effects anomalies over the period 1980-2019: (**a**) at the Earth's surface, (**b**) within the Atmosphere and (**c**) at the Top Of the Atmosphere. (**i**) total aerosol load, (**ii**) sulfate, (**iii**) dust, (**iv**) sea salt, (**v**) organic carbon and (**vi**) black carbon particles. (units are $Wm^{-2}decade^{-1}$)

Table S1. Decadal total aerosol AOD and DREs (in Wm^{-2}) over: the globe, the North and South Hemispheres, global land and global ocean areas and 5 selected world regions (Saharan and Arabian Deserts, Southern Africa, India, East Asia and Mediterranean).

		1980–1989	1990–1999	2000–2009	2010–2019
Global	DRE surface	−7.139	−7.792	−7.651	−7.671
	DRE atmosphere	1.973	2.010	2.686	2.745
	DRE TOA	−5.166	−5.781	−4.965	−4.926
	AOD	0.137	0.150	0.136	0.136
Northern Hemisphere	DRE surface	−9.494	−9.819	−10.203	−10.084
	DRE atmosphere	2.891	2.952	4.104	4.115
	DRE TOA	−6.603	−6.867	−6.099	−5.969
	AOD	0.179	0.186	0.175	0.172
Southern Hemisphere	DRE surface	−4.800	−5.778	−5.116	−5.275
	DRE atmosphere	1.061	1.075	1.277	1.384
	DRE TOA	−3.739	−4.704	−3.839	−3.890
	AOD	0.095	0.116	0.098	0.100
Global Land	DRE surface	−9.448	−9.908	−10.495	−10.481
	DRE atmosphere	4.142	4.275	5.371	5.428
	DRE TOA	−5.306	−5.633	−5.124	−5.053
	AOD	0.174	0.184	0.175	0.174
Global Ocean	DRE surface	−6.101	−6.840	−6.372	−6.408
	DRE atmosphere	0.998	0.992	1.479	1.539
	DRE TOA	−5.103	−5.848	−4.893	−4.869
	AOD	0.120	0.135	0.119	0.119
Saharan-Arabian Deserts	DRE surface	−17.531	−18.022	−18.876	−18.749
	DRE atmosphere	12.439	12.585	14.295	14.184
	DRE TOA	−5.092	−5.437	−4.581	−4.565
	AOD	0.325	0.341	0.338	0.335
Southern Africa	DRE surface	−8.653	−11.052	−12.641	−13.556
	DRE atmosphere	4.457	5.724	6.973	7.835
	DRE TOA	−4.195	−5.328	−5.668	−5.721
	AOD	0.131	0.164	0.178	0.184
India	DRE surface	−13.025	−14.221	−20.898	−22.827
	DRE atmosphere	5.346	5.768	10.916	11.690
	DRE TOA	−7.679	−8.453	−9.981	−11.138
	AOD	0.206	0.230	0.316	0.357
East Asia	DRE surface	−15.778	−17.695	−23.524	−22.248
	DRE atmosphere	6.235	7.026	11.544	10.111
	DRE TOA	−9.544	−10.669	−11.980	−12.137
	AOD	0.264	0.303	0.388	0.389

Mediterranean	DRE surface	−13.012	−11.916	−11.792	−10.805
	DRE atmosphere	4.411	3.915	5.031	4.655
	DRE TOA	−8.601	−8.002	−6.761	−6.151
	AOD	0.232	0.215	0.189	0.174