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Effective radiative forcing in the aerosol–climate model CAM5.3-MARC-ARG

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Introduction

This document contains supplementary tables and supplementary figures for the manuscript titled *"Effective radiative forcing in the aerosol–climate model CAM5.3-MARC-ARG"*. The supplementary figures are grouped thematically: cloud condensation nuclei concentration (Figs. S1 and S2), cloud water path and fraction (Figs. S3–S7), total precipitation rate (Fig. S8), wind speed (Fig. S9), snow cover and rate (Figs. S10 and S11), and black carbon deposition (Figs. S12 and S13).

Supplementary Tables

Table S1: Global mass budgets and lifetimes of sulfate aerosol for the year-1850 MARC simulation. Corresponding results for the year-2000 MARC simulation are shown in Table 1 in the main manuscript.

	Sulfate aerosol	in NUC	in AIT	in ACC	in MOS	in MBS
Sources, Tg(SO4)/yr	+211.03 ± 0.29	+0.01 ± 0.00	+0.07 ± 0.00	+204.50 ± 0.29	+6.26 ± 0.02	+0.56 ± 0.01
Binary nucleation	+0.00 ± 0.00	+0.00 ± 0.00				
Condensation	+4.57 ± 0.02	+0.01 ± 0.00	+0.07 ± 0.00	+3.21 ± 0.01	+0.97 ± 0.01	+0.32 ± 0.01
Aging (source)	+5.24 ± 0.01				+5.09 ± 0.01	+0.15 ± 0.00
Growth (source)			+0.01 ± 0.00	+0.07 ± 0.00		
Coagulation (source)			+0.00 ± 0.00	+0.00 ± 0.00	+0.20 ± 0.00	+0.08 ± 0.00
Hydrometeor evaporation	+201.22 ± 0.29			+201.22 ± 0.29		
Sinks, Tg(SO4)/yr	-211.13 ± 0.29	-0.01 ± 0.00	-0.07 ± 0.00	-204.57 ± 0.29	-6.29 ± 0.02	-0.56 ± 0.01
Growth (sink)		-0.01 ± 0.00	-0.07 ± 0.00			
Coagulation (sink)		-0.00 ± 0.00	-0.00 ± 0.00	-0.28 ± 0.00		
Nucleation scavenging by stratiform clouds	-149.54 ± 0.27	-0.00 ± 0.00	-0.00 ± 0.00	-146.04 ± 0.27	-3.26 ± 0.01	-0.24 ± 0.00
Nucleation scavenging by convective clouds	-10.57 ± 0.02	-0.00 ± 0.00	-0.00 ± 0.00	-10.32 ± 0.02	-0.24 ± 0.00	-0.01 ± 0.00
Impaction scavenging	-48.98 ± 0.02	-0.00 ± 0.00	-0.00 ± 0.00	-46.04 ± 0.02	-2.67 ± 0.01	-0.28 ± 0.00
Dry deposition	-2.04 ± 0.00	-0.00 ± 0.00	-0.00 ± 0.00	-1.89 ± 0.00	-0.12 ± 0.00	-0.02 ± 0.00
Burden, Tg(SO4)	0.52 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.40 ± 0.00	0.11 ± 0.00	0.01 ± 0.00
Lifetime, days	0.90 ± 0.00	0.18 ± 0.00	0.09 ± 0.00	0.72 ± 0.00	6.28 ± 0.05	5.78 ± 0.15

Table S2: Global mass budgets and lifetimes of organic carbon aerosol for the year-1850 MARC simulation. Corresponding results for the year-2000 MARC simulation are shown in Table 2 in the main manuscript.

	Organic carbon aerosol	in pure OC	in MOS
Sources, Tg/yr	+87.94 ± 0.00	+87.94 ± 0.00	+6.15 ± 0.01
Emission	+87.94 ± 0.00	+87.94 ± 0.00	
Aging (source)			+5.34 ± 0.01
Coagulation (source)			+0.81 ± 0.00
Sinks, Tg/yr	-87.90 ± 0.01	-87.87 ± 0.01	-6.17 ± 0.01
Aging (sink)		-5.34 ± 0.01	
Coagulation (sink)		-0.81 ± 0.00	
Nucleation scavenging by stratiform clouds	-3.32 ± 0.01	-0.00 ± 0.00	-3.32 ± 0.01
Nucleation scavenging by convective clouds	-0.22 ± 0.00	+0.00 ± 0.00	-0.22 ± 0.00
Impaction scavenging	-80.68 ± 0.01	-78.16 ± 0.01	-2.52 ± 0.01
Dry deposition	-3.67 ± 0.00	-3.56 ± 0.00	-0.11 ± 0.00
Burden, Tg	1.29 ± 0.00	1.19 ± 0.00	0.11 ± 0.00
Lifetime, days	5.37 ± 0.01	4.92 ± 0.01	6.37 ± 0.04

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Table S3: Global mass budgets and lifetimes of black carbon aerosol for the year-1850 MARC simulation. Corresponding results for the year-2000 MARC simulation are shown in Table 3 in the main manuscript.

	Black carbon aerosol	in pure BC	in MBS
Sources, Tg/yr	+3.08 ± 0.00	+3.08 ± 0.00	+0.16 ± 0.00
Emission	+3.08 ± 0.00	+3.08 ± 0.00	
Aging (source)			+0.16 ± 0.00
Sinks, Tg/yr	-3.09 ± 0.00	-3.09 ± 0.00	-0.16 ± 0.00
Aging (sink)		-0.16 ± 0.00	
Nucleation scavenging by stratiform clouds	-0.08 ± 0.00	-0.00 ± 0.00	-0.08 ± 0.00
Nucleation scavenging by convective clouds	-0.00 ± 0.00	-0.00 ± 0.00	-0.00 ± 0.00
Impaction scavenging	-2.81 ± 0.00	-2.74 ± 0.00	-0.07 ± 0.00
Dry deposition	-0.19 ± 0.00	-0.18 ± 0.00	-0.00 ± 0.00
Burden, Tg	0.05 ± 0.00	0.05 ± 0.00	0.00 ± 0.00
Lifetime, days	5.86 ± 0.01	5.63 ± 0.01	4.42 ± 0.04

Table S4: Global mass budgets and lifetimes of total sea salt aerosol and total dust aerosol for the year-1850 MARC simulation. Corresponding results for the year-2000 MARC simulation are shown in Table 4 in the main manuscript.

	Sea salt aerosol	Dust aerosol
Sources, Tg/yr	+5510.06 ± 14.81	+3789.26 ± 21.87
Emission	+5510.06 ± 14.81	+3789.26 ± 21.87
Sinks, Tg/yr	-5559.09 ± 14.96	-3812.70 ± 21.36
Impaction scavenging	-2327.11 ± 5.73	-1898.77 ± 8.88
Dry deposition	-3231.97 ± 9.45	-1913.94 ± 14.32
Burden, Tg	9.66 ± 0.02	41.83 ± 0.24
Lifetime, days	0.63 ± 0.00	4.00 ± 0.03

Table S5: Results from the six timing simulations. Each of these simulations consists of "20-day model runs with restarts and history turned off" (CESM Software Engineering Group, 2015)**, repeated five times in order to assess variability. The repetition of each simulation allows the standard error to be calculated via calculation of the corrected sample standard deviation. For consistency, all runs have been submitted on the same day. For each run, 720 processors, spread across 20 nodes on Cheyenne (doi:10.5065/D6RX99HX), have been used. As with the year-2000 and year-1850 simulations (Section 2.3 of the main manuscript), a model resolution of 1.9° × 2.5° has been used, SSTs and greenhouse gas concentrations have been prescribed using year-2000 climatological values, and aerosol and aerosol precursor emissions have followed year-2000 emissions. In contrast to the simulations described in the main manuscript, COSP has not been used in these timing simulations. The simulation costs shown represent the total cost of all model components, including non-atmospheric components such as the land scheme.**

Aerosol module	Clean-sky radiation diagnostics	Notes	CESM simulation cost ± standard error (processor hours / model year)	Relative simulation cost (% above MAM3 with clean-sky diagnostics switched OFF)
MAM3	OFF	Standard CAM5.3	325.5 ± 0.8	0.0%
MAM7	OFF	Standard CAM5.3 + MAM7	435.6 ± 1.5	+33.8%
MARC	OFF	Clean-sky diagnostics switched off via modification of source code	344.3 ± 0.7	+5.8%
MAM3	ON	Diagnostic clean-sky radiation call specified in simulation namelist	362.3 ± 0.8	+11.3%
MAM7	ON	Diagnostic clean-sky radiation call specified in simulation namelist	472.2 ± 1.0	+45.1%
MARC	ON	Standard CAM5.3-MARC-ARG	361.1 ± 0.7	+10.9%

Supplementary Figures

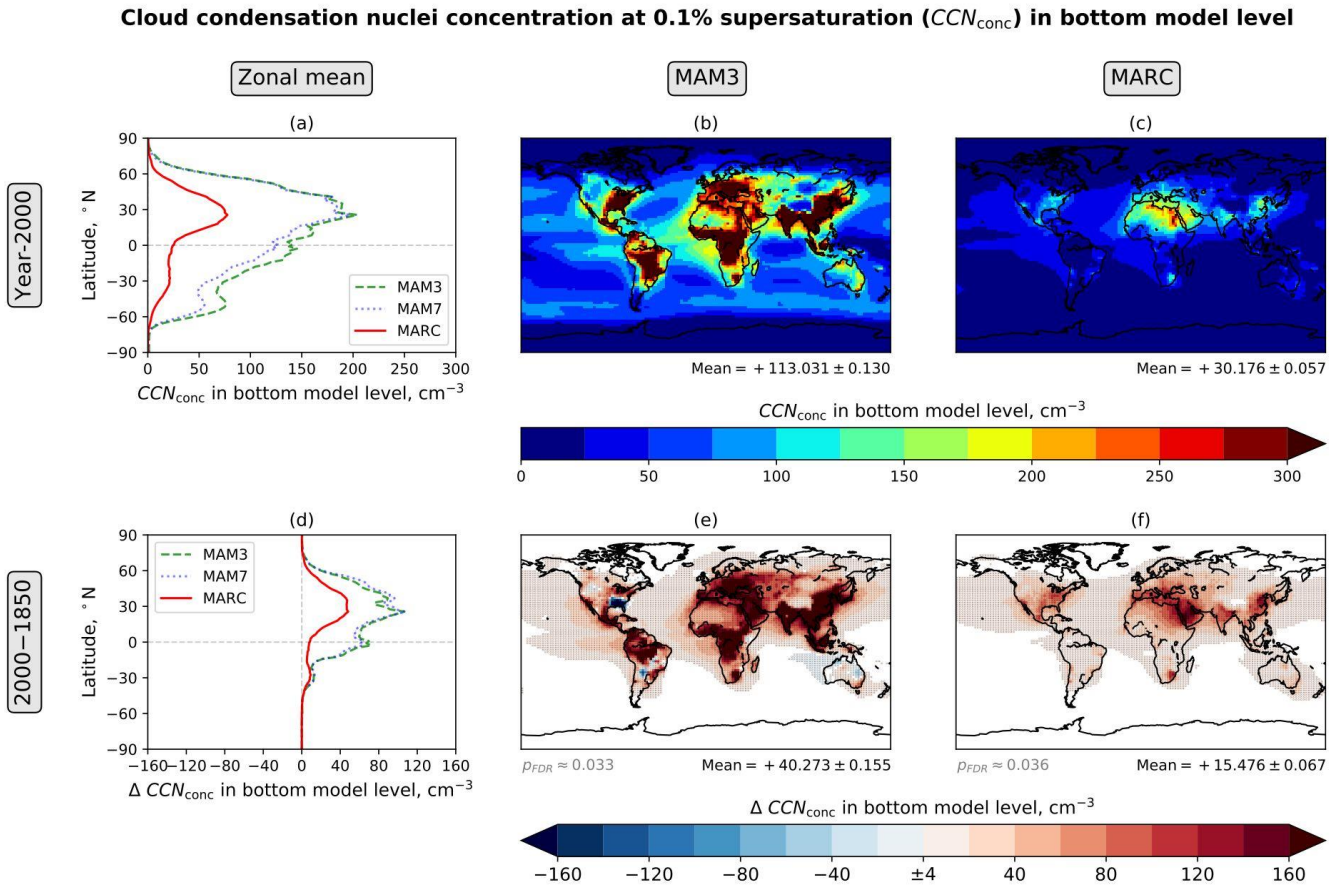

Figure S1: Annual mean cloud condensation nuclei concentration at 0.1% supersaturation (CCN_{conc}) in the bottom model level. The figure components are explained in the caption of Fig. 2.

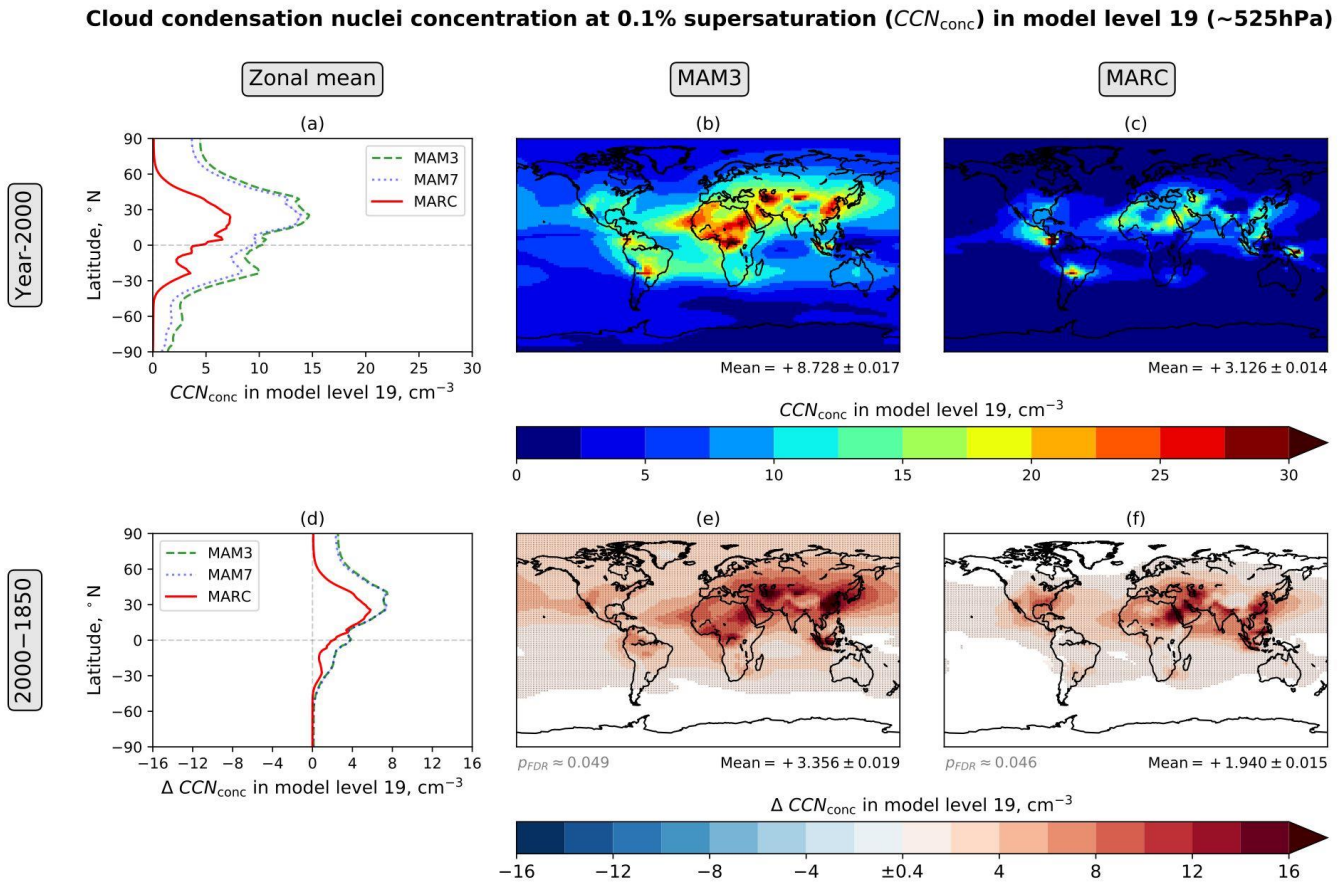

Figure S2: Annual mean cloud condensation nuclei concentration at 0.1% supersaturation (CCN_{conc}) in model level 19 (in the mid-troposphere). The figure components are explained in the caption of Fig. 2.

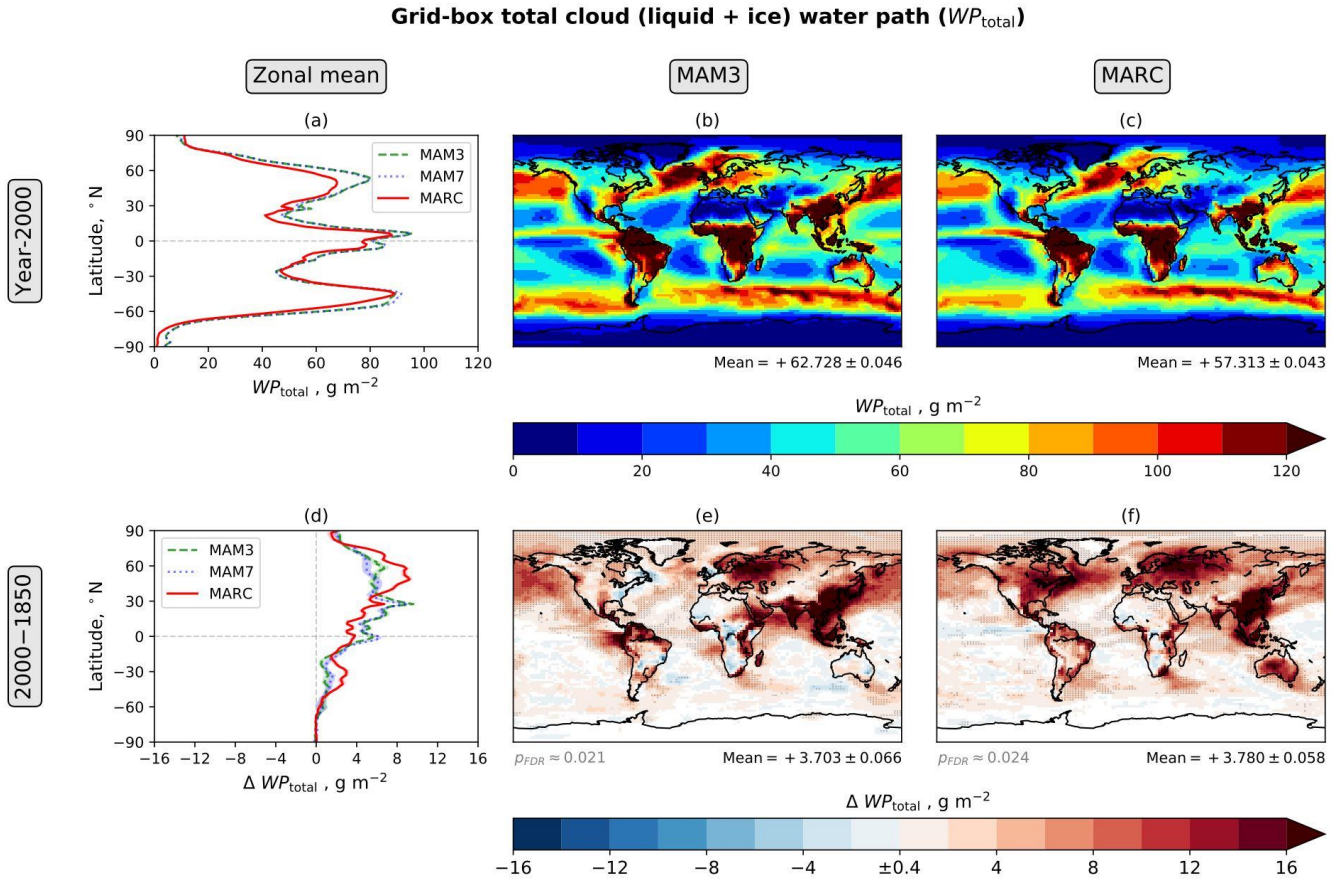

Figure S3: Annual mean grid-box total cloud water path ($WP_{\text{total}} = WP_{\text{liquid}} + WP_{\text{ice}}$). The figure components are explained in the caption of Fig. 2.

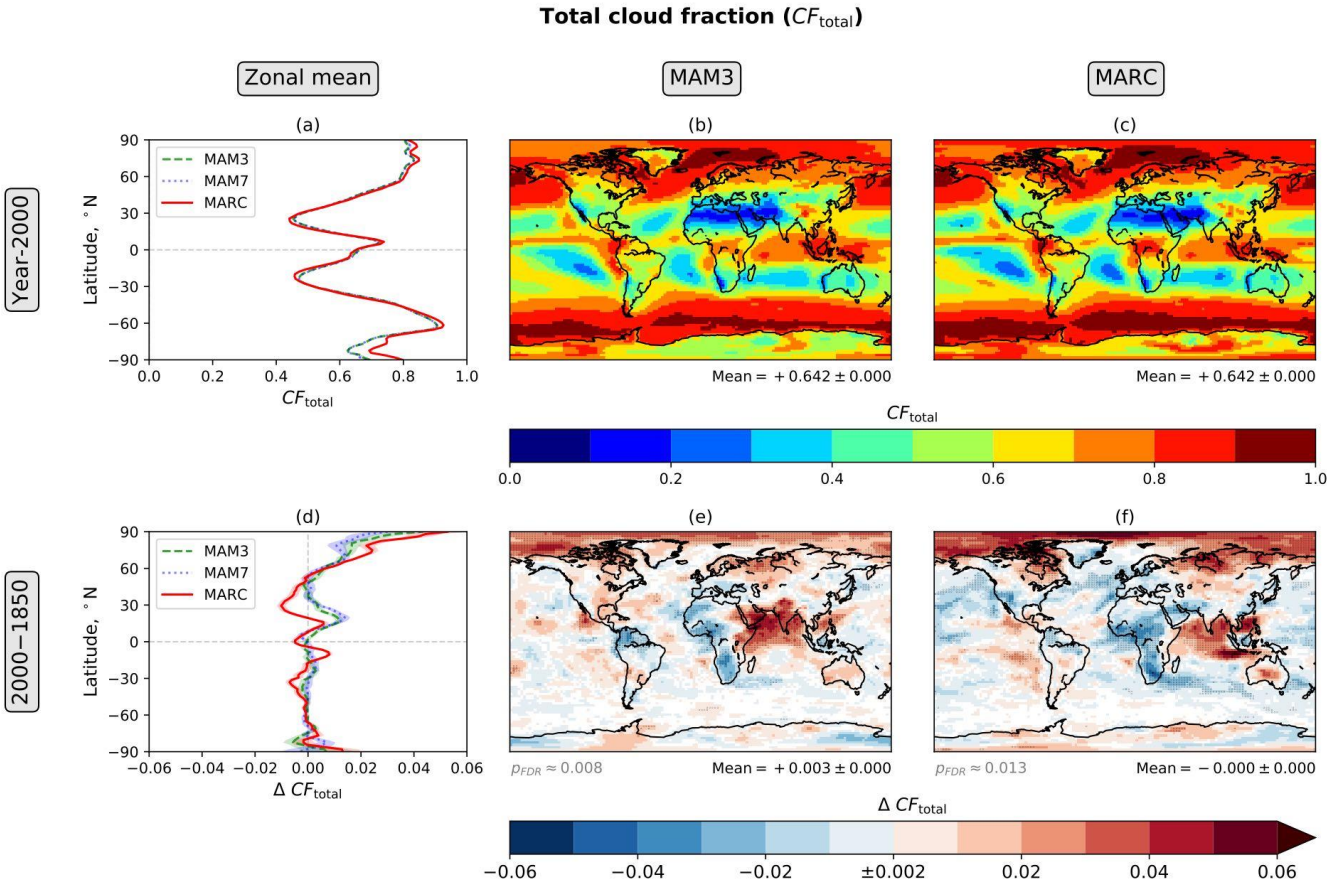

Figure S4: Annual mean total cloud fraction (CF_{total}). The figure components are explained in the caption of Fig. 2.

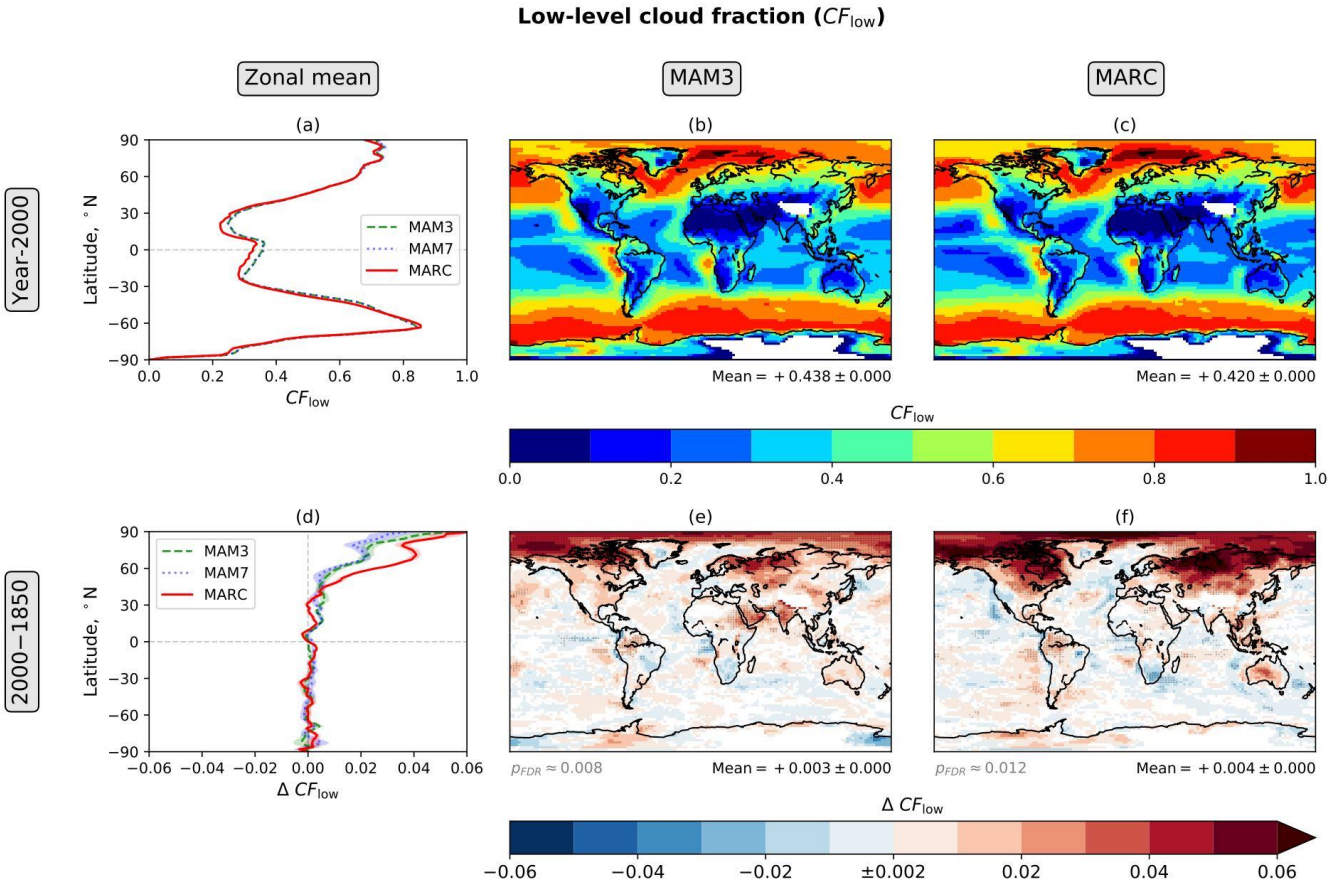

Figure S5: Annual mean low-level cloud fraction (CF_{low}). The figure components are explained in the caption of Fig. 2.

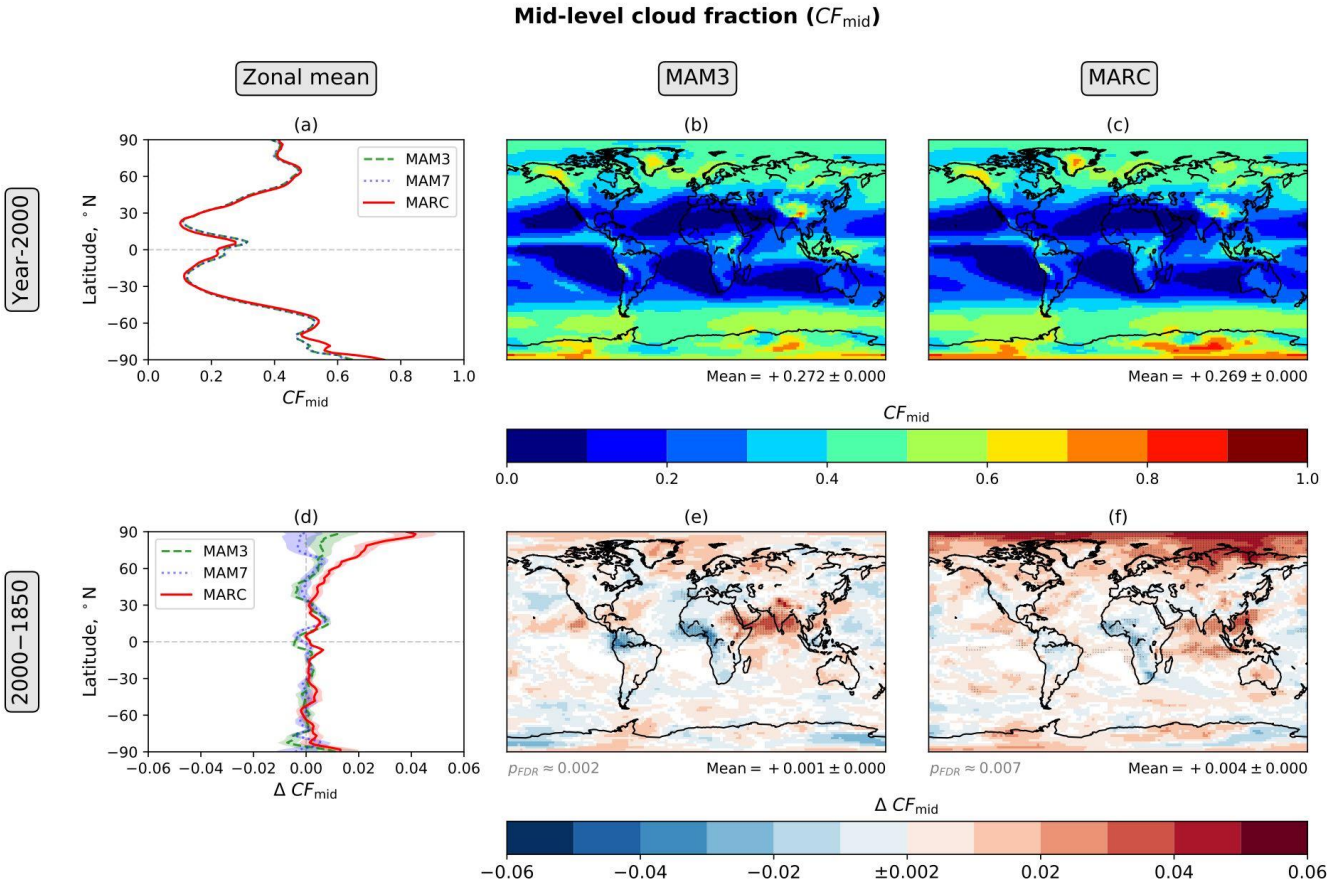

Figure S6: Annual mean mid-level cloud fraction (CF_{mid}). The figure components are explained in the caption of Fig. 2.

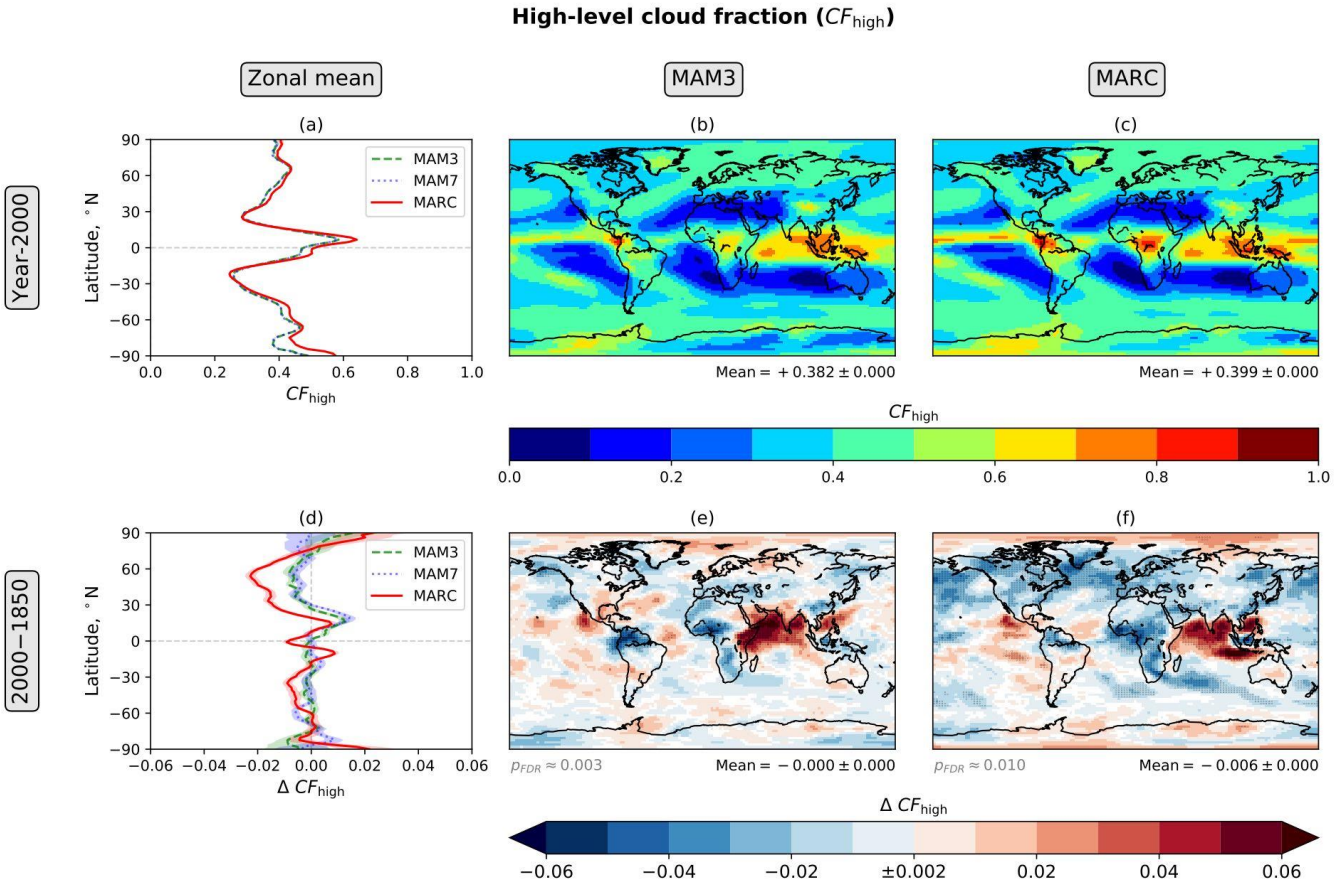

Figure S7: Annual mean high-level cloud fraction (CF_{high}). The figure components are explained in the caption of Fig. 2.

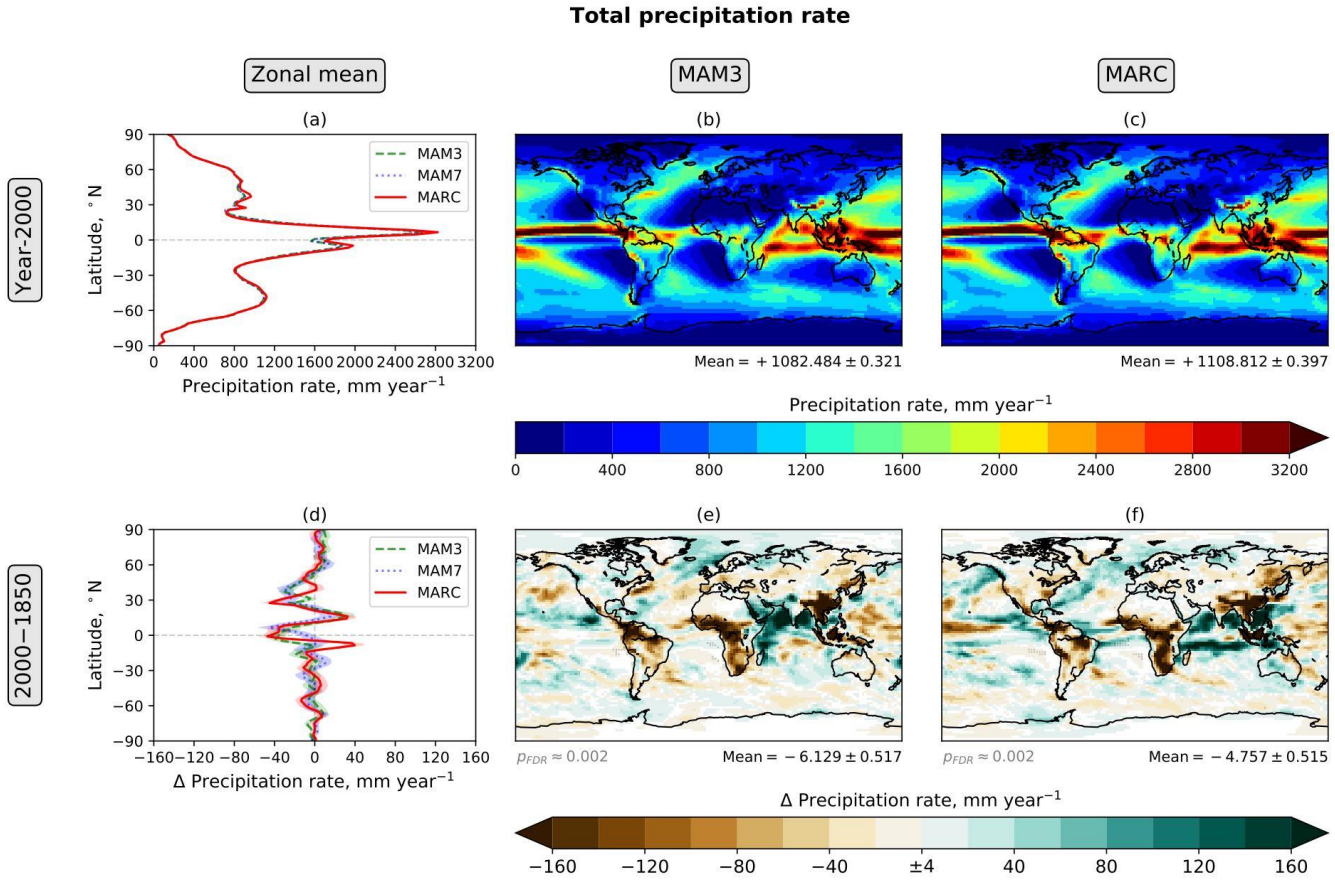

Figure S8: Annual mean total precipitation rate. The figure components are explained in the caption of Fig. 2.

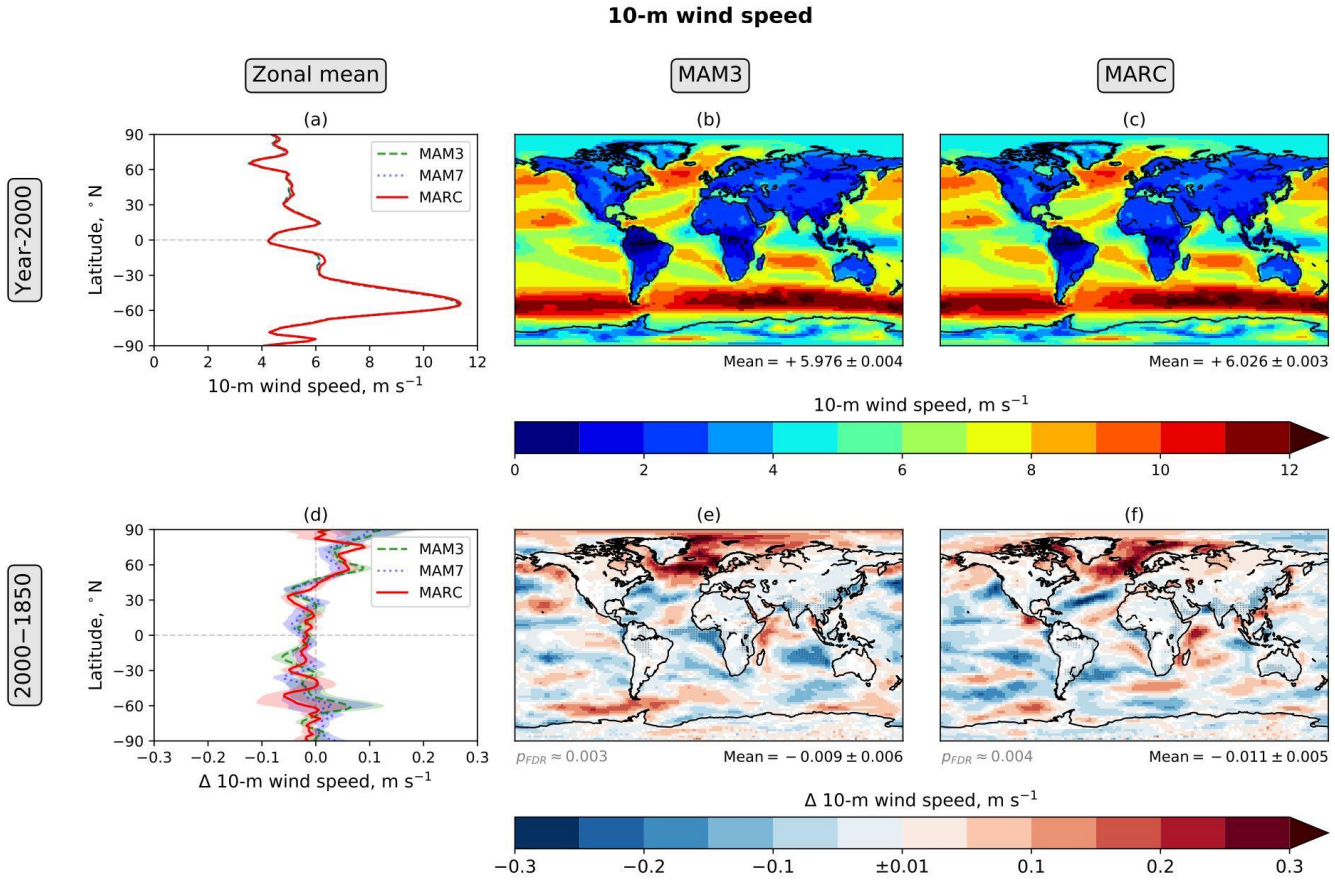

Figure S9: Annual mean 10-m wind speed. The figure components are explained in the caption of Fig. 2.

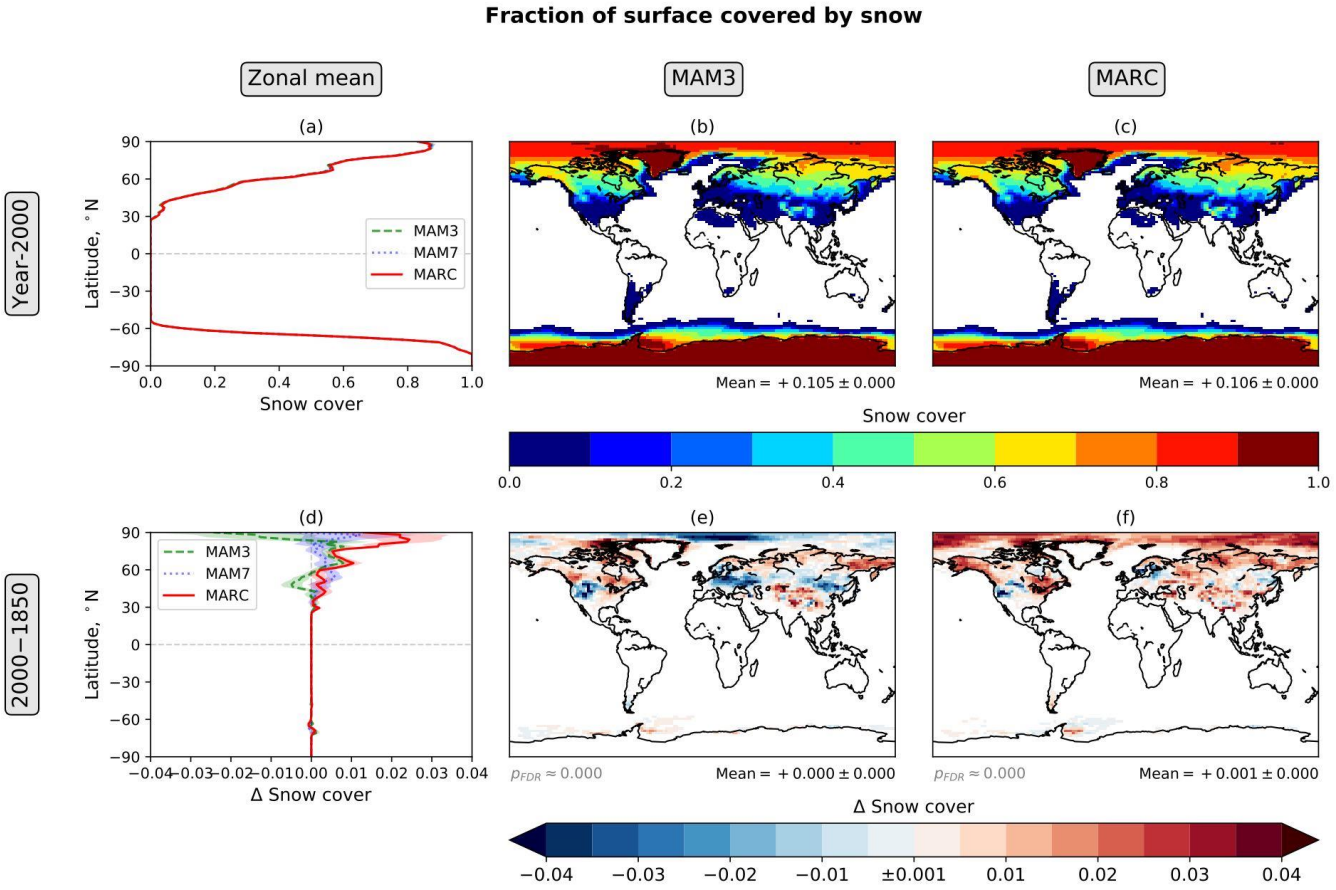

Figure S10: Annual mean fraction of the earth's surface covered by snow. The figure components are explained in the caption of Fig. 2.

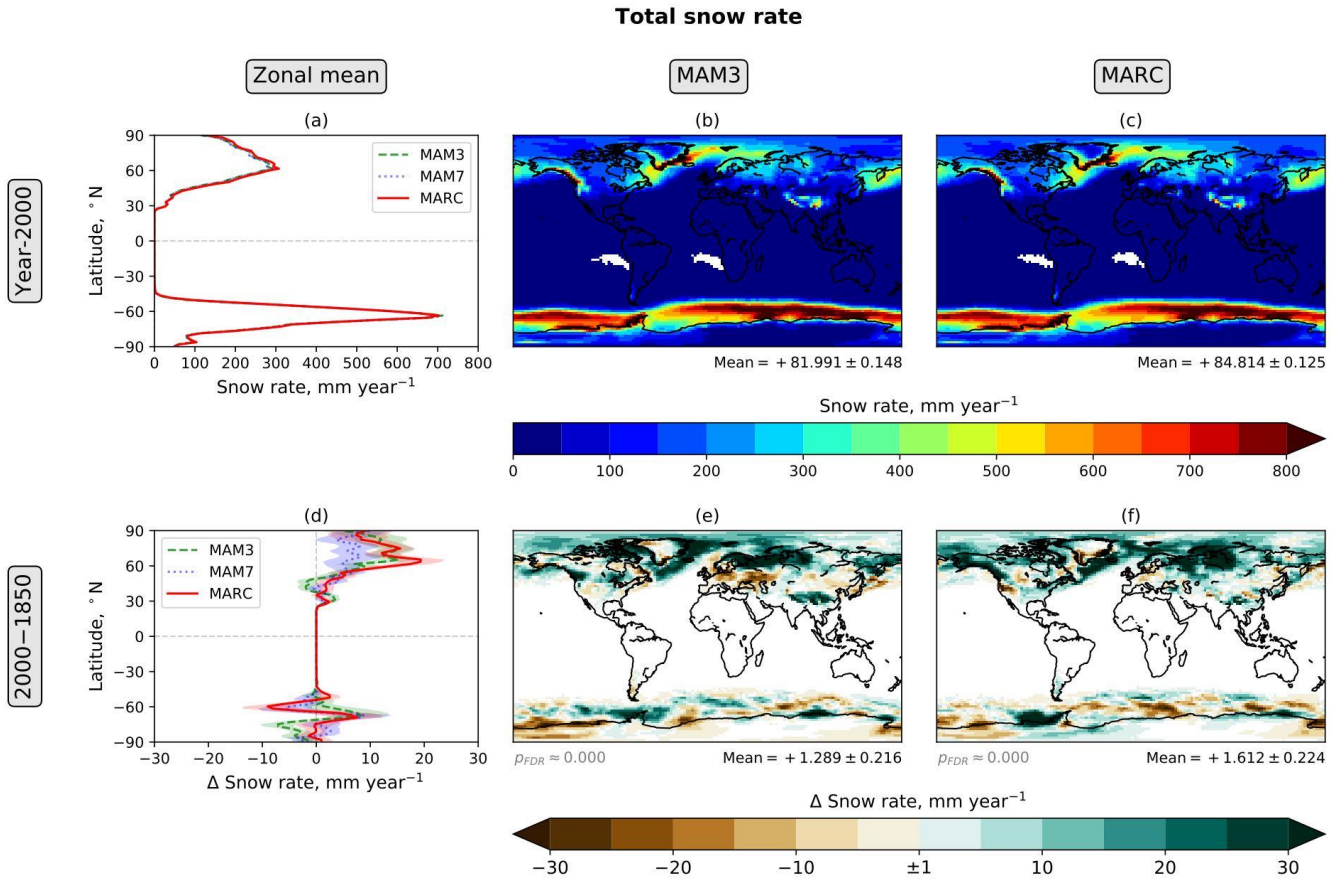

Figure S11: Annual mean total snow rate. The figure components are explained in the caption of Fig. 2.

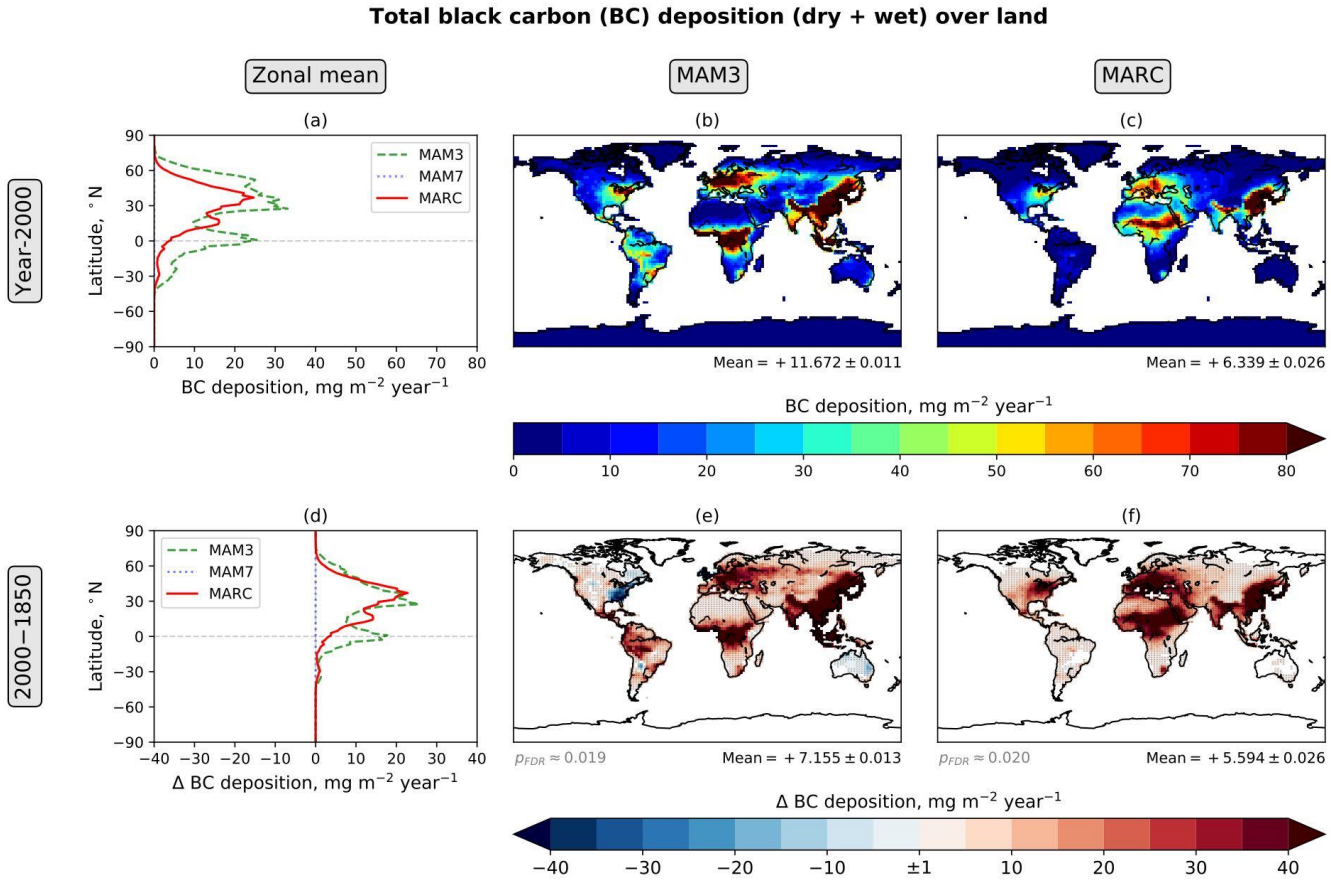

Figure S12: Annual mean total black carbon deposition over land. The figure components are explained in the caption of Fig. 2. The values for MAM7 are zero: in our simulations using CESM 1.2.2, MAM7 apparently fails to pass deposited black carbon to the land scheme.

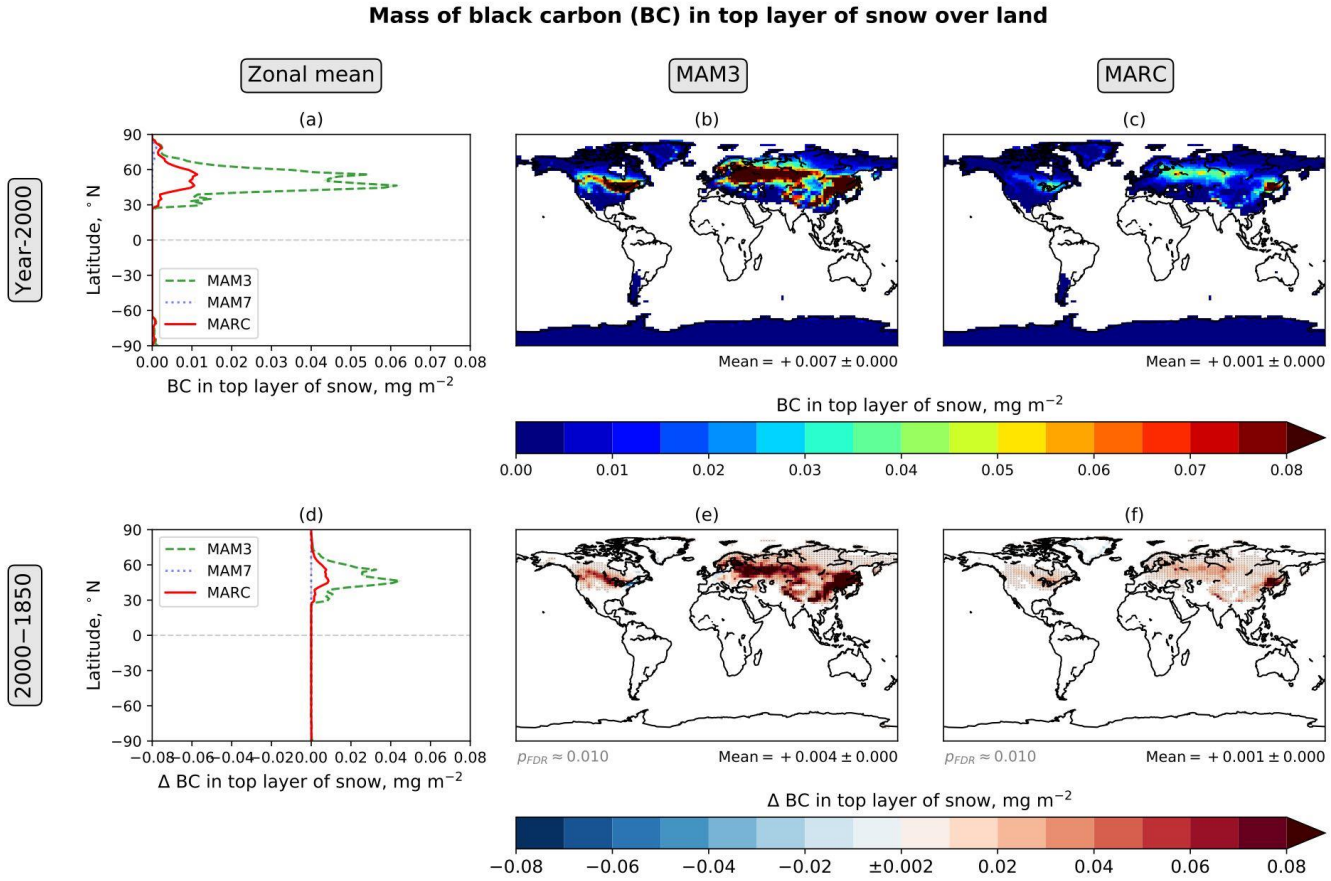

Figure S13: Annual mean mass of black carbon in the the top layer over snow over land. The figure components are explained in the caption of Fig. 2.

References

CESM Software Engineering Group: CESM User's Guide (CESM1.2 Release Series User's Guide), [online] Available from: http://www.cesm.ucar.edu/models/cesm1.2/cesm/doc/usersguide/ug.pdf [accessed 2017-10-31], 2015.