

Supplementary material

Table S1: Additional model details and simulation details. Adapted from Kremser et al. (2016).

Model	Stratospheric compounds	Het. Chem.	OH	Injection height	Location of injection	Sulfur source species	QBO	Reference
CESM(WACCM)	sulfate, PSC	Y	Interactive	22-26 km	0° N and 118° E	Pre-industrial OCS (337 pptv), DMS, pre-industrial anthropogenic SO ₂ , SO ₂ from passively degassing volcanoes.	Nudged	Mills et al. (2016)
MAECHAM5-HAM	sulfate	N	Prescribed	Single model level at ~24 km	0° N and 118° E	DMS, OCS (~500 pptv)	NA	Niemeier et al. (2009); Stier et al. (2005)
SOCOL	sulfate, PSC	Y	Interactive	22-26 km	8° S and 118° E	Pre-industrial anthropogenic SO ₂ , DMS, CS ₂ , OCS (500 pptv). SO ₂ from passively degassing volcanoes.	Nudged	Sheng et al. (2015)
UM-UKCA	sulfate, organics, meteoric dust, PSC	Y	Interactive	22-26 km	0° N and 118° E	Pre-industrial anthropogenic SO ₂ , DMS, OCS (~500 pptv), SO ₂ from passively degassing volcanoes.	Internally generated	Dhomse et al. (2014)

Table S2: Ice cores used for volcanic sulfate deposition fluxes after Tambora and their metadata.

5 Antarctica core details taken from Table S1, Sigl et al. (2014).

Antarctic ice cores				Greenland ice cores			
Ice core	LAT	LON	Ref.	Ice core	LAT	LON	Ref.
WDC06A	-79.47	-112.09	<i>Sigl et al. (2013)</i>	B20	79	-36.5	<i>Bigler et al. (2002), Gao et al. (2006)</i>
WDC05Q	-79.47	-112.08	<i>Sigl et al. (2013)</i>	GISP2	72.6	-38.5	<i>Gao et al. (2006), Zielinski et al. (1994)</i>
SP04	-89.95	17.67	<i>Budner & Cole-Dai, (2003)</i>	20D	65	-45	<i>Gao et al. (2006), Mayewski et al. (1990)</i>
SP01	-89.95	17.67	<i>Ferris et al. (2011)</i>	NGRIP	75.1	-42.3	<i>Plummer et al. (2012)</i>
DML05	-75.00	0.02	<i>Traufetter et al. (2004)</i>	NEEM-2011-S1	77.45	-51.06	<i>Sigl et al. (2013)</i>
DML07	-75.58	3.43	<i>Traufetter et al. (2004)</i>	Humboldt	78.53	-56.83	<i>Sigl et al. (2013)</i>
B40	-75.00	0.06	<i>Sigl et al. (2014)</i>	Site T	72.58	-38.45	<i>Mosley-Thompson et al. (2003)</i>
NUS08-4	-82.82	19.90	<i>Sigl et al. (2014)</i>	GITS	77.14	-61.095	<i>Mosley-Thompson et al. (2003)</i>
NUS08-5	-82.63	17.87	<i>Sigl et al. (2014)</i>	D2	71.75	-46.33	<i>Mosley-Thompson et al. (2003)</i>
NUS07-2	-76.07	22.47	<i>Sigl et al. (2014)</i>	D3	69.8	-44.00	<i>Mosley-Thompson et al. (2003)</i>
NUS07-5	-78.65	35.63	<i>Sigl et al. (2014)</i>	Raven	65.9	-46.3	<i>Mosley-Thompson et al. (2003)</i>
NUS07-7	-82.07	54.88	<i>Sigl et al. (2014)</i>	Dye 3	65.18	-43.83	<i>Larsen et al. (2008)</i>
EDC96	-75.10	123.35	<i>Castellano et al. (2005)</i>	GRIP	72.58	-37.64	<i>Larsen et al. (2008)</i>
DFS10	-77.40	39.62	<i>Sigl et al. (2014)</i>	SU07	72.5	-38.5	<i>Cole-Dai et al. (2009)</i>
DF01	-77.37	39.70	<i>Motizuki et al. (2014)</i>				
W10k	-66.75	112.83	<i>Sigl et al. (2014)</i>				
DIV2010	-77.95	-95.96	<i>Sigl et al. (2014)</i>				
NUS08-7	-74.88	1.60	<i>Sigl et al. (2014)</i>				
NUS07-1	-73.72	7.98	<i>Sigl et al. (2014)</i>				
TalosDome	-72.48	159.06	<i>Stenni et al. (2002)</i>				
Taylor Dome	-77.81	158.72	<i>Mayewski et al. (1996)</i>				
DomeA	-80.37	77.22	<i>Jiang et al. (2012)</i>				
DSS	-66.77	112.80	<i>Plummer et al. (2012)</i>				
Siple	-75.91	-83.91	<i>Cole-Dai et al. (1997)</i>				
Dyer	-70.66	-64.87	<i>Cole-Dai et al. (1997)</i>				
PlatRemote	-84.00	43.00	<i>Cole-Dai et al. (2000)</i>				

Table S3: Ice cores used for pre-industrial background sulfate deposition fluxes (1850-1860 mean) taken from Lamarque et al. (2013).

Antarctic ice cores			Arctic ice cores		
Ice core	LAT	LON	Ice core	LAT	LON
W10	-66.3	112.83	ACT11d	66.47	-46.3
DIV	-76.77	-101.73	D4	71.4	-43.9
WD	-79.47	-112.68	Zoe	72.6	-38.3
NUS Site8_7	-74.88	1.6	NEEMS3	77.43	-51.05
NUS Site8_5	-82.63	17.87	Tunu	78.00	-33.98
NUS Site7_7	-82.07	54.88	McCall	69.3	-143.8
NUS Site7_5	-78.65	35.63	Akademmi Nauk	80.52	94.82
NUS Site7_2	-76.07	22.47	Flade Isblink	81.58	-15.7
NUS Site7_1	-73.72	7.98			

Pre-industrial background sulfate burdens [kg SO₄ m⁻²]

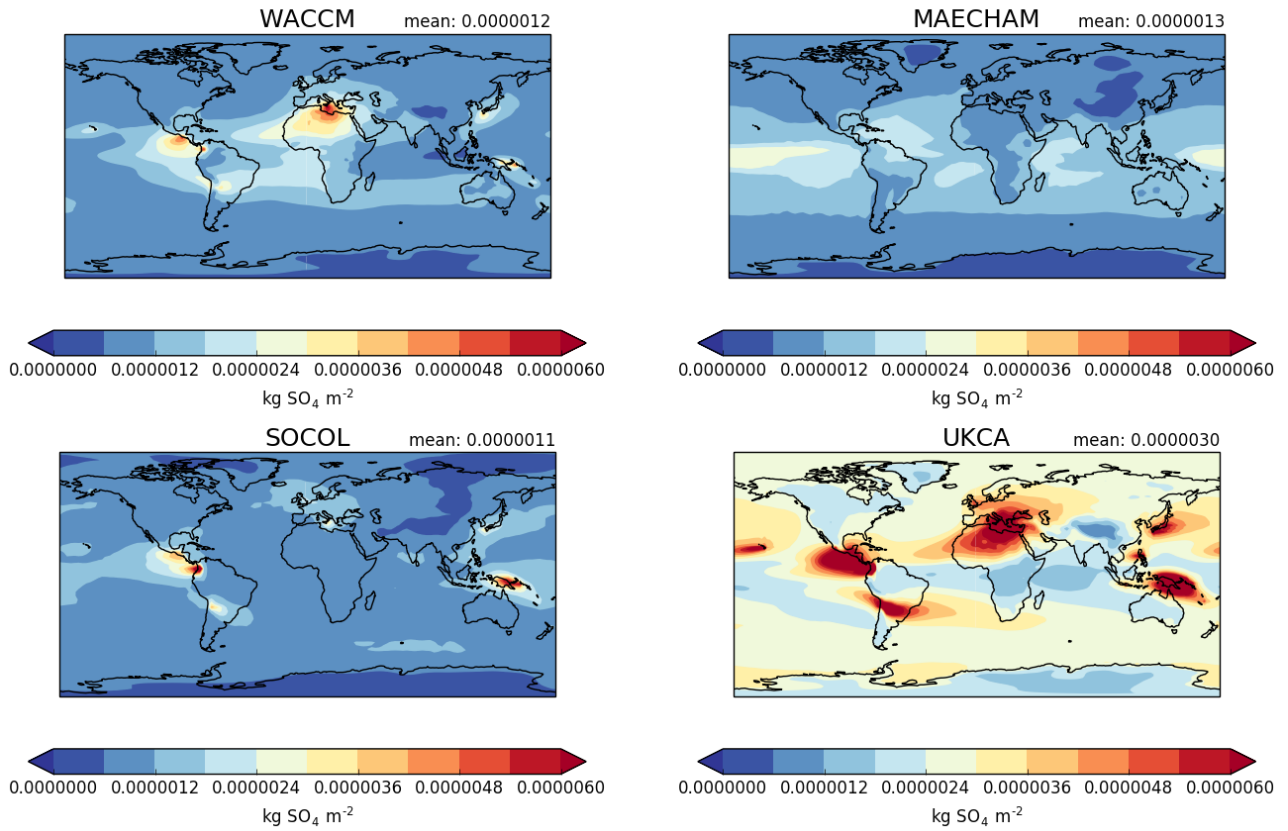
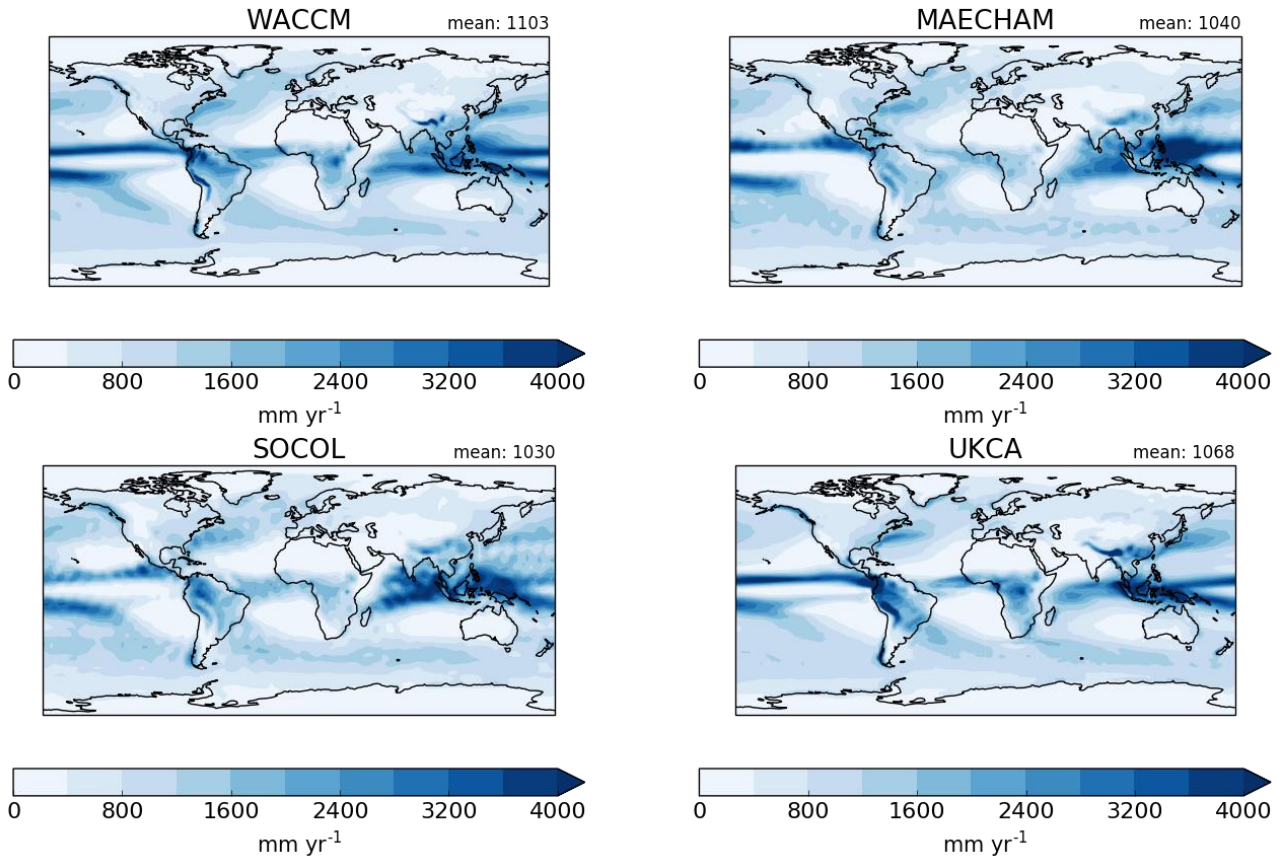


Figure S1: Pre-industrial background (no Tambora) global atmospheric sulfate burdens in each model control simulation (year average). WACCM and MAECHAM are averages of 60 months; UKCA is an average of 48 months and SOCOL is an average of 12 months.

Pre-industrial background precipitation



15 **Figure S2:** Pre-industrial background global precipitation in each model control simulation (year average). WACCM and MAECHAM are averages of 60 months; UKCA is an average of 48 months and SOCOL is an average of 12 months.

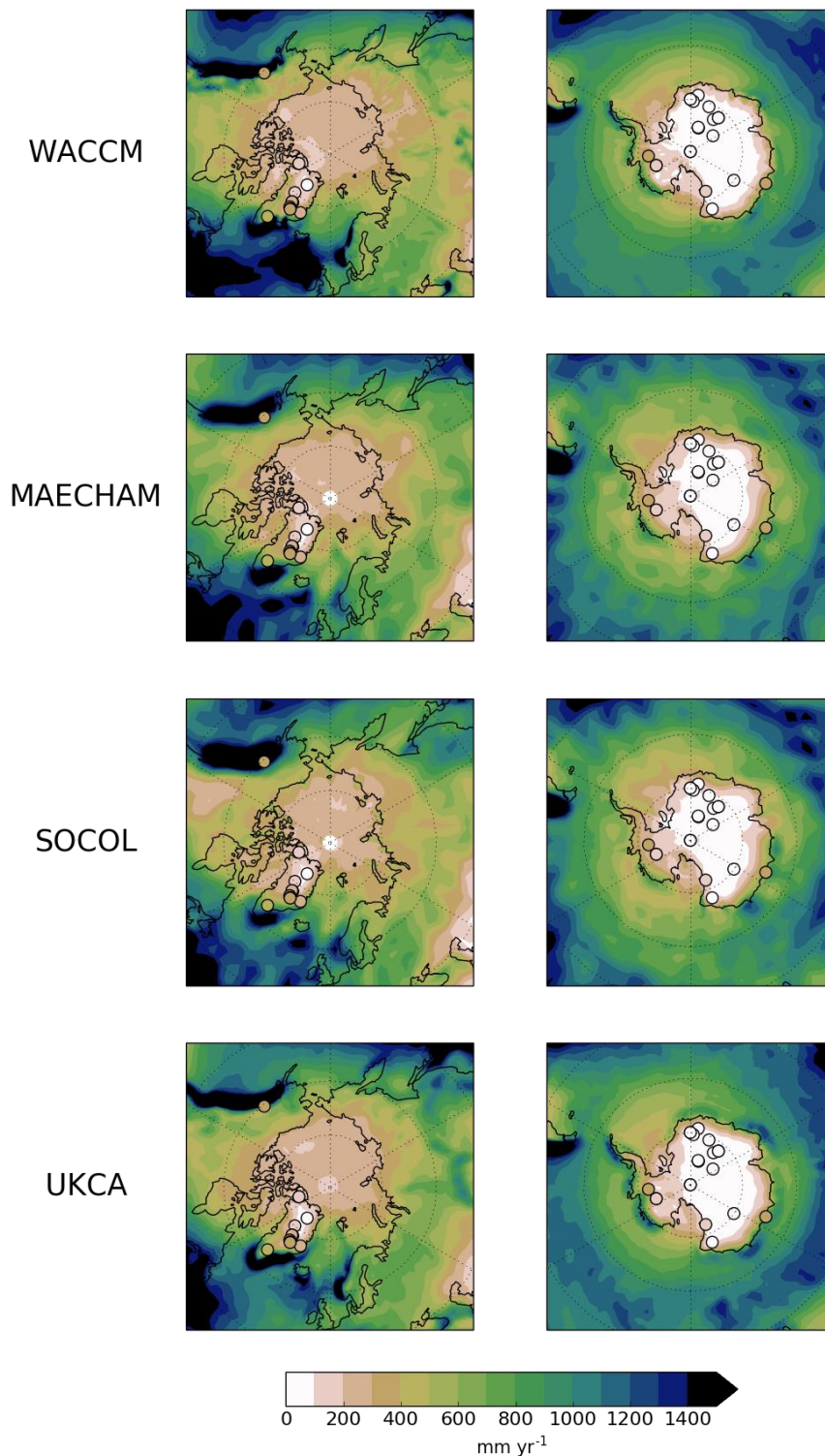
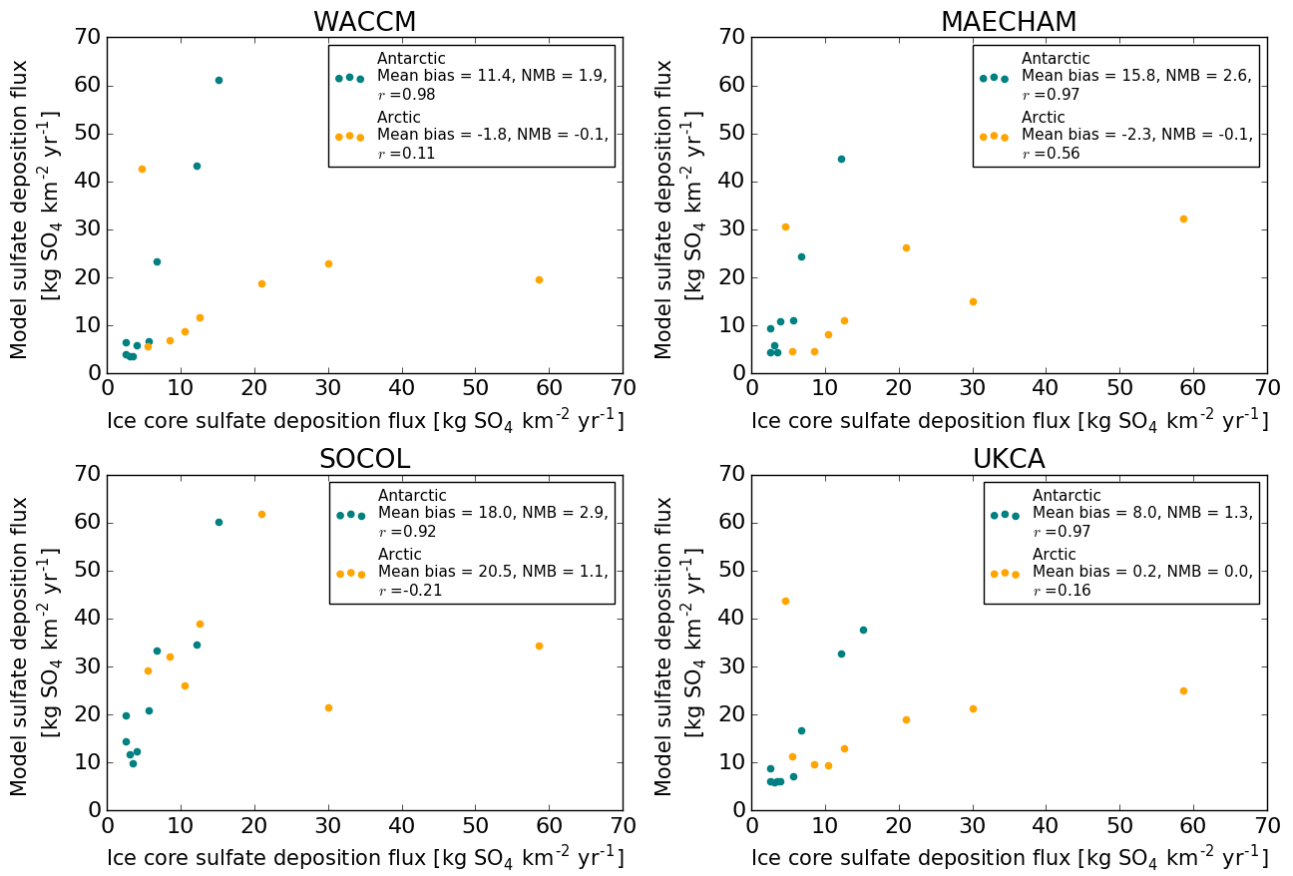
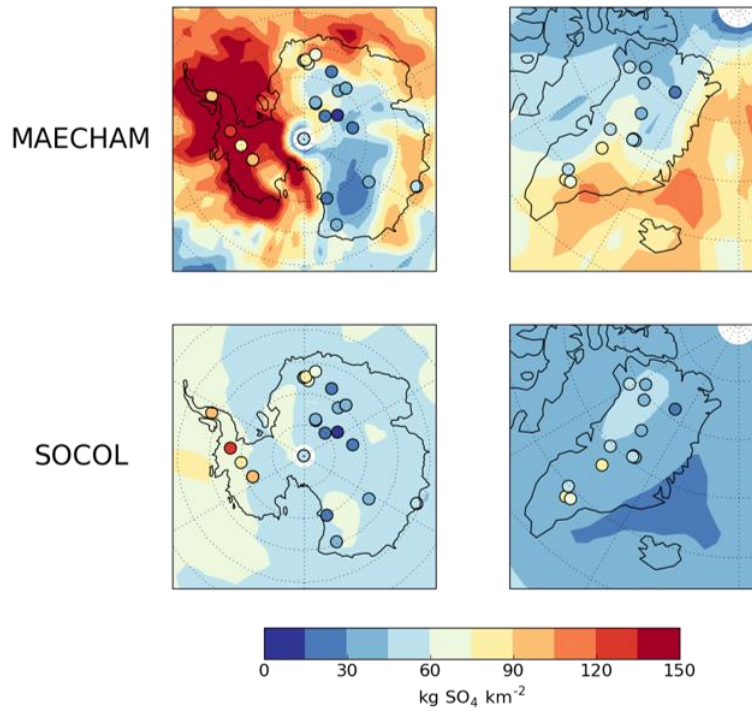


Figure S3: Pre-industrial background polar precipitation in each model control simulation (year average) (shading) and ice core accumulation ($\text{mm liquid water equivalent yr}^{-1}$) in ice cores (filled circles). (Sigl et al., 2014). Antarctic ice core accumulation rates are an average of annual ice core accumulation from 1850-1860 taken from Sigl et al. (2014). Greenland ice core accumulation rates are taken from Gao et al. (2006) (their Table 1). WACCM and MAECHAM model data are averages of 60 months of control simulation; UKCA is an average of 48 months and SOCOL is an average of 12 months.



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Figure S4: Pre-industrial background ice core sulfate deposition fluxes vs. modelled pre-industrial sulfate fluxes [kg SO₄ km⁻²] in Antarctica (orange) and in the Arctic (teal) for each model. Included in the legend is the mean bias, Normalized Mean Bias (NMB) and correlation coefficient (r).



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Figure S5: Cumulative deposited sulfate [$\text{kg SO}_4 \text{ km}^{-2}$] for MAECHAM and SOCOL (ensemble mean). Results have been reduced by a factor of 3 (for MAECHAM the slope of the regression line between simulated deposited sulfate and ice core records in Antarctica was 3.7 and 1.7 in Greenland. SOCOL is reduced by the same factor for comparison). MAECHAM is able to simulate the spatial pattern of ice sheet deposited sulfate when compared to ice cores but the magnitude is ~ 3 times too large.

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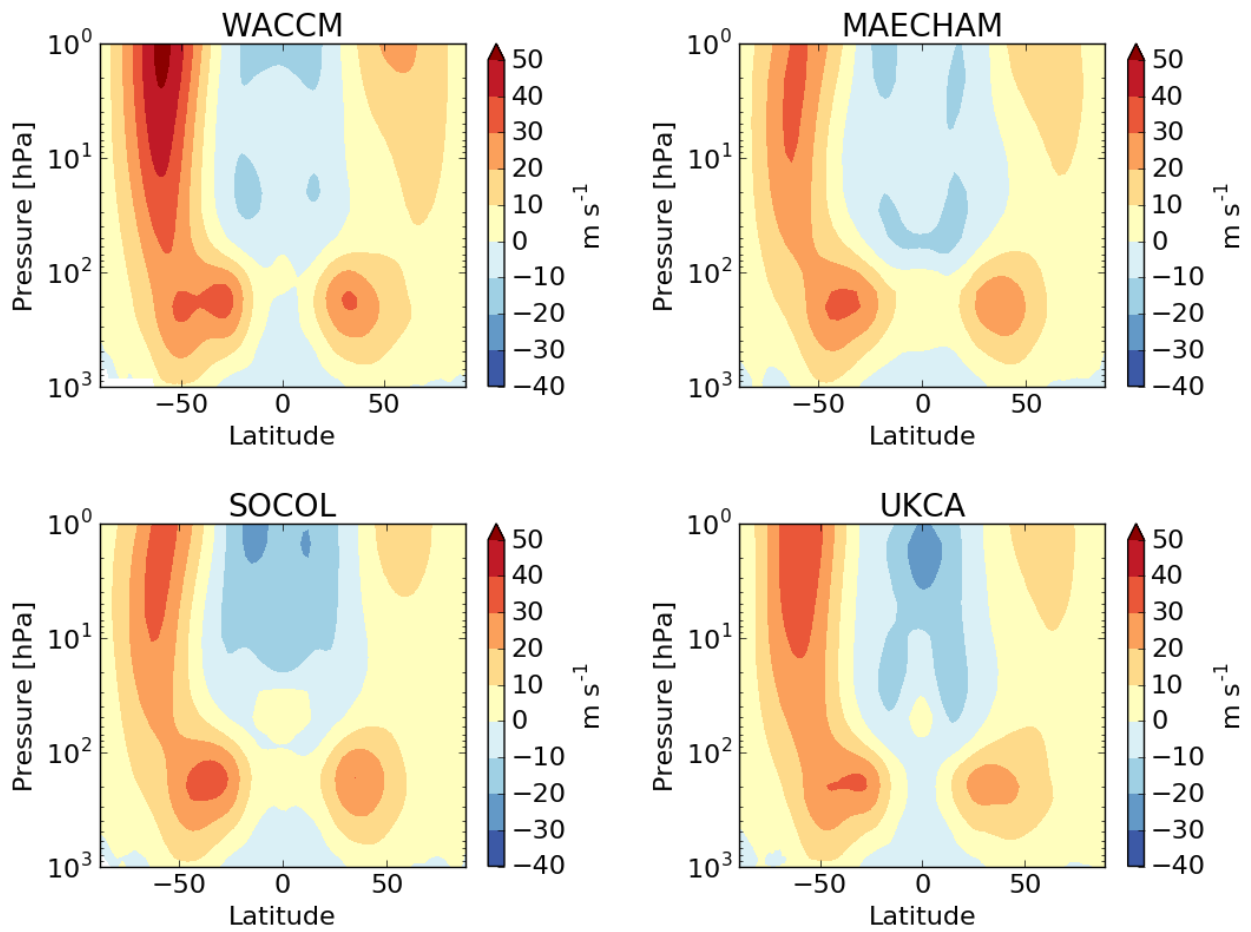


Figure S6: Zonal mean climatological (year average) zonal wind in each model control run [m s^{-1}]. Zonal wind is output on 36 pressure levels in UKCA, 33 pressure levels in MAECHAM and 32 pressure levels in SOCOL. Zonal wind in WACCM is output on an atmosphere hybrid sigma pressure coordinate and has been interpolated to the pressure levels used in UKCA.

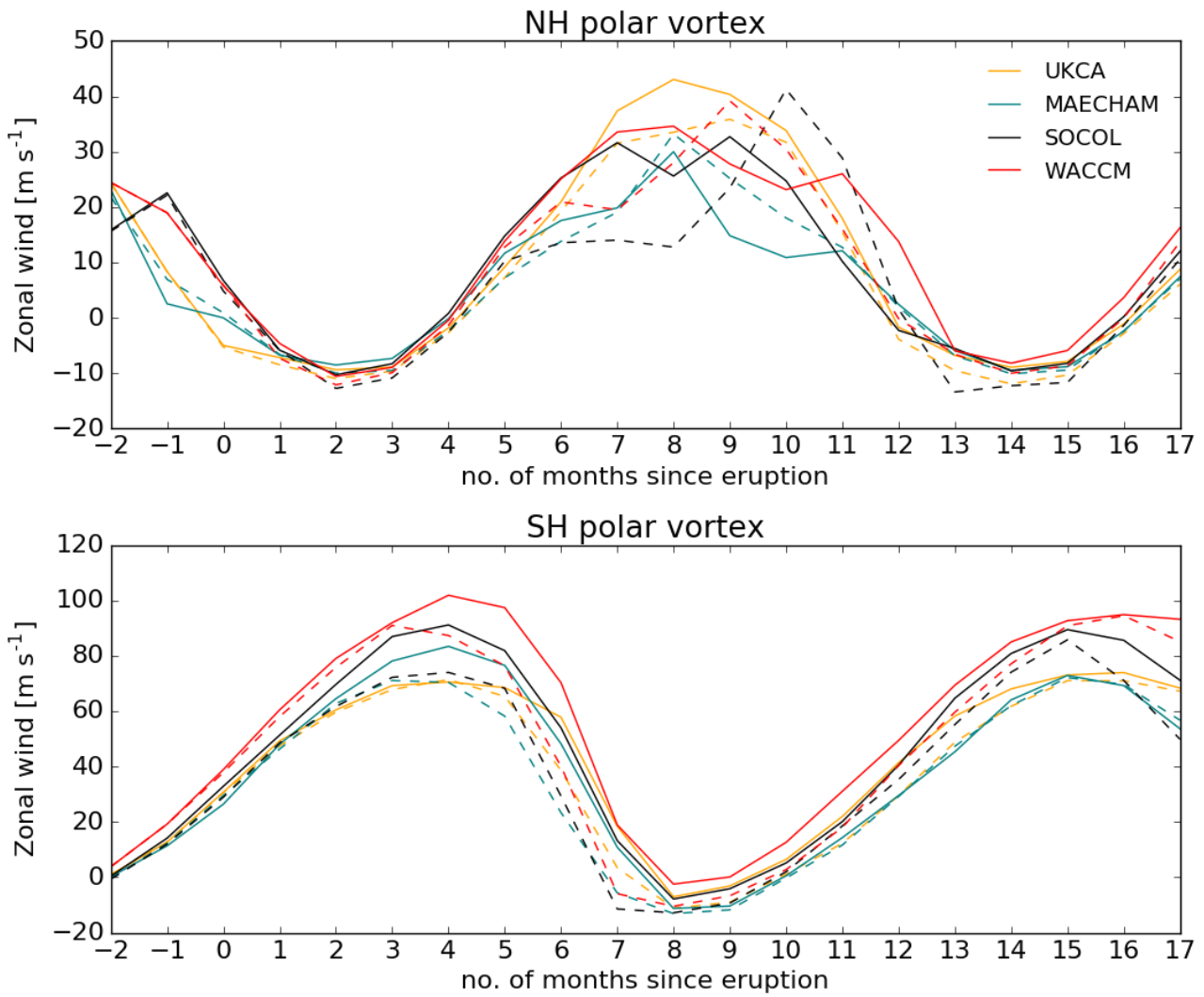
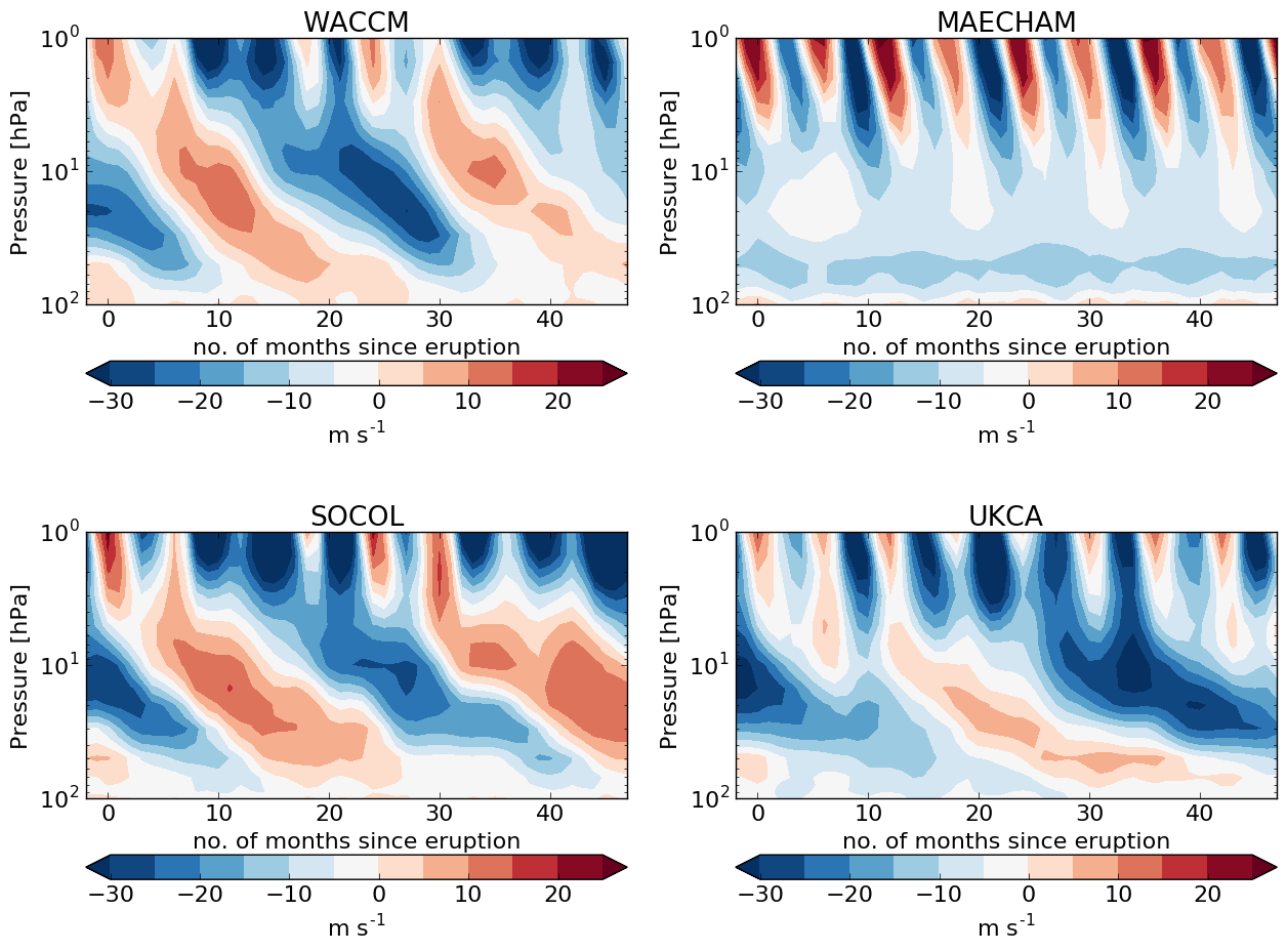


Figure S7: NH and SH polar vortices (defined as zonal mean zonal wind [m s^{-1}] at grid cells closest to 10 hPa and 60 degrees N/S) in the perturbed simulations (solid lines) and control simulations (dashed lines) for each model (ensemble mean – colours). Results are plotted for the first 18 months after the eruption.

Table S4: Mean polar (60° - 90°) cumulative deposited sulfate [$\text{kg SO}_4 \text{ km}^{-2}$] and revised BTDF factors [$* 10^9 \text{ km}^{-2}$] calculated from mean polar deposited sulfate and hemispheric peak atmospheric sulfate burden as opposed to ice sheet deposited sulfate (ensemble mean).

Model	Arctic deposition [$\text{kg SO}_4 \text{ km}^{-2}$]	NH_BTDF [10^9 km^{-2}]	Antarctic deposition [$\text{kg SO}_4 \text{ km}^{-2}$]	SH_BTDF [10^9 km^{-2}]
WACCM	131	0.26	108	0.53
MAECHAM	175	0.21	287	0.17
SOCOL	124	0.25	174	0.32
UKCA	77	0.38	53	1.07



55 **Figure S8:** Tropical mean ($15^{\circ}\text{S} - 15^{\circ}\text{N}$) zonal wind for the volcanic simulations in each model
 (ensemble mean). Tropical winds in UKCA, SOCOL and WACCM oscillate, exhibiting
 characteristics of the QBO, with downward propagating easterly and westerly winds, but length of
 phase differs. QBO easterly phase is longer in UKCA; ~ 2.5 years compared to ~ 1.5 years in WACCM
 and SOCOL. MAECHAM does not include representation of the QBO and winds remain easterly in
 60 the lower stratosphere throughout the simulations.

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