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Icelandic volcanic emissions and climate

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Methods

Global simulations were performed with the Community Atmosphere Model (CAM) version 5[1]. The model was run in specified dynamics mode (with dynamics from a previous model simulation, not a particular meteorological year) to constrain the winds and temperatures, but allowing aerosols, water vapor and clouds to be predicted. Model resolution is 1.9° latitude by 2.5° longitude and the simulations repeat the same annual cycle for 10 years. CAM5 includes a detailed treatment of aerosols. Cloud drop number concentrations are determined by the aerosol distribution, and cloud microphysical processes respond to the cloud drop number. Thus Aerosol Cloud Interactions (ACI) in CAM5 include both aerosol-induced cloud albedo effects and changes in cloud fraction and cloud lifetime. ACI are defined by the change in the shortwave cloud radiative effect between simulations with and without the emissions, adjusted for aerosols[2]. ACI in CAM5 have been evaluated[3] and found to be slightly more sensitive to aerosol perturbations than observations[3] or expert judgment[4]. The configuration is effective at determining radiative forcing differences between two simulations for cloud and aerosol effects[5,6], locally down to 0.5 Wm^{-2}. Emissions of 40kT/d of SO_2 with 2.5% assumed to be SO_4 as ammonium bisulfate following standard methods[1] were released from 1.5-3km altitude above ground level.

Sensitivity

Sensitivity tests are used to estimate the effects of varying altitude, strength of emissions, background meteorology on the radiative forcing (Table 1) and to develop the uncertainty estimates in the manuscript. Table 1 shows for two seasons the total Top of Atmosphere (TOA) flux change, the Aerosol Optical Depth (AOD) change, the ACI, and the fraction of the total TOA flux change, diagnosed as the change in direct forcing from aerosols. Direct effects and ACI do not add exactly to the TOA flux change. The baseline simulation is the 40kT/d emission simulation. Radiative effects are higher in the summer due to greater incoming solar flux and larger sulfate burdens. Sulfate burdens increase through enhanced gas-phase oxidation during summer. The 'SO_2' only simulation indicates a 15% effect of the partitioning of initial emissions between 97.5% SO_2 (baseline case) and 100% SO_2.

For reference, the 'Anthro' values are estimates of the regional impact of all human aerosol emissions (everywhere on the globe) between 2000 and 1750. Values in the main text are reported for a baseline case with 40kT/day of emissions emitted into 1.5-3km altitude. Changing the altitude to be higher (Hi: 3-4.5km) increases the total SO_4 burden, but slightly reduces the forcing. This is because of a slightly broader spread beyond the region averaged. Lower emission altitudes (Lo: 0.5-2km) also causes slightly lower forcing and lower burdens due to more dry deposition at the surface. Using different years of simulated meteorology (Met2, Met3, Met4 with

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40kT/d of SO_2) does not change the overall patterns in Figure 1, but does result in different forcing and SO_4 burden changes. The 30% uncertainty in the Met experiments suggests that meteorological conditions play a significant role in determining the climatic effects of the eruption. The radiative forcing numbers reported in the text result from an average of the 'Base' calculation and the three other 'meteorology' years. Reducing (35 kT/d, 20kT/d), or increasing (60kT/d) emissions changes the forcing, but halving the emissions does not halve the forcing, and increasing emissions by 50% does not increase the forcing proportionally. The sensitivity simulations are used to estimate the standard deviations in the text.

Table 1: Average change over the N. Atlantic (45-70°N, 50W°-15°E) in: Top of Atmosphere flux (ΔTOA in Wm^{-2}), Aerosol Optical Thickness (ΔAOD, unitless), Aerosol Cloud Interactions (ACI in Wm^{-2})[2], the percent of ΔTOA which is due to direct effects of aerosols (% Direct) and the change in SO_4 burden (ΔSO4 in percent) for September-November (SON) and June-August (JJA). All changes are relative to a control simulation without the eruption. 'Anthro' values represent the effect of all human aerosol emissions on the N. Atlantic region (including pre-industrial emissions from domestic fuel sources).

Simulation	SON ΔTOA (Wm^{-2})	ΔAOD	ACI (Wm^{-2})	% Direct	ΔSO4 (%)	JJA ΔTOA (Wm^{-2})	ΔAOD	ACI (Wm^{-2})	% Direct	ΔSO4 (%)
Anthro	-1.45	0.013	-1.43	1.70	506.2	-5.75	0.020	-5.81	2.0	537.2
40kT/d	-0.27	0.006	-0.24	14.2	62.8	-8.64	0.032	-8.25	4.8	146.5
SO_2 only	-0.23	0.004	-0.21	13.1	46.7	-7.35	0.025	-7.00	5.0	120.7
20kT/d	-0.17	0.004	-0.16	13.5	38.7	-6.66	0.017	-6.45	3.2	76.9
60kT/d	-0.33	0.008	-0.30	15.3	83.6	-9.91	0.046	-9.33	6.2	215.0
35kT/d	-0.24	0.005	-0.22	13.9	57.3	-8.27	0.028	-7.93	4.4	129.3
Lo:0.5-2km	-0.28	0.006	-0.27	9.9	52.3	-7.65	0.028	-7.35	3.9	109.9
Hi:3-4.5km	-0.26	0.006	-0.23	18.1	75.0	-7.98	0.031	-7.49	6.8	186.0
Met2	-0.23	0.006	-0.21	17.5	68.0	-6.33	0.019	-6.04	4.8	109.8
Met3	-0.16	0.006	-0.13	25.8	62.6	-7.41	0.030	-6.96	6.7	174.3
Met4	-0.20	0.006	-0.17	21.8	72.7	-7.25	0.033	-6.68	8.6	183.9

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