In brief: How will climate change affect the radiative forcing of tropical eruptions?

Moderate explosive eruptions (VEI≈4) injecting 1 Tg SO$_2$ in the upper troposphere-lower stratosphere:
• Tropopause height increases but SO$_2$ injection height does not → decrease in stratospheric aerosol burden
• Stratospheric aerosol optical depth (SAOD) decreases by 300%

Large explosive eruptions (VEI≈5-6) injecting 10 Tg SO$_2$ in the stratosphere:
• Acceleration of Brewer-Dobson circulation → decreased aerosol lifetime but smaller aerosols
• Net effect = SAOD increases by up to 14% & forcing by up to 30%

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Interactive stratospheric aerosol model experiments suggest a strong impact of climate change on the aerosol evolution and radiative forcing from future eruptions

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Motivation

How will climate change affect the climatic impact of future eruptions?

This question is not new but mostly two pools of feedbacks have been investigated:

• Feedbacks governing the frequency-magnitude distribution of volcanic eruptions (e.g. Jellinek and Manga 2004, Swindles et al. 2017), some of which are not relevant for typical 10-300 years time horizon of climate projections (e.g. deglaciation-eruption frequency feedback)

• Feedbacks related to the impact of changes in the background climate on the climate response to a prescribed volcanic forcing (e.g. Zanchettin et al. 2016, Fasullo et al. 2017)

No study has yet investigated how climate change will affect processes directly governing volcanic forcing, such as aerosol microphysics and transport or changes in volcanic column dynamics and SO$_2$ injection height.

→ We investigate this question for tropical eruptions using combined interactive stratospheric aerosol modelling and volcanic plume modelling
Experimental design

• Atmosphere-only simulations in UM-UKCA vn10.2 with interactive stratospheric aerosols (ref)

• Each simulation is 3-year long with a 24-hour injection of SO$_2$ occurring on July 1$^{st}$ in the model column corresponding to the Mt Pinatubo location (15.1°N, 120.4°E).

• SO$_2$ injection height is calculated using a 1D plume model which main inputs are the mass eruption rate (MER) and atmospheric profiles (temperature, wind, pressure, humidity) (Aubry et al., 2019)

• We run experiments for:

  **Two eruption case scenarios:**
  i) Moderate eruption: 1 Tg SO$_2$, MER = $10^6$ kg/s
  ii) Strong eruption: 10 Tg SO$_2$, MER = $10^7$ kg/s

  **Two climate scenarios:**
  i) Historical 1990-2000
  ii) SSP5 8.5 (upper greenhouse gas emission trajectory) 2090-2100

• For each combination of eruption & climate scenario, we run 10 experiments with initial conditions chosen to sample a variety of quasi-biennial oscillation phase and SO$_2$ injection height
Moderate eruption: Closer look at initial conditions

- Mass eruption rate chosen to have upper tropospheric-lower stratospheric SO$_2$ injection for historical climate, consistent with many recent moderate eruptions (e.g. Merapi 2010, Nabro 2011, Kelut 2014)

- In the SSP5 8.5 climate, such mass eruption rate results in very similar heights although depending on exact atmospheric conditions, injection height can be as low as 14.5km due to increased upper-tropospheric stratification (Aubry et al. 2016, 2019)

- However, in the SSP5 8.5 climate, the average tropopause height is 1.75 km higher
Moderate eruption: Stratospheric Aerosol Optical Depth (SAOD)

- As expected from the change in injection/tropopause heights ratio, stratospheric aerosol burden (not shown) strongly decrease in the SSP5 .5 climate scenario.
- As a consequence, SAOD also exhibit a very strong (by a factor 2-4) and significant decrease.
- Note that for the historical climate, the magnitude and timescales of the SAOD perturbation simulated by UM-UKCA are very consistent with those observed following tropical eruptions in the last decade (e.g. Nabro 2011).
Strong eruption: Aerosol burden and effective radius

For the strong eruption, we find:

- A slight decrease in stratospheric aerosol burden
- A significant decrease by 10% of aerosol lifetime
- A significant decrease of effective radius by up to 30%

Mean S e-fold time (min-max) in month:
15.8 (13.5-18.7)
14.2 (12.7-17.3)
Strong eruption: Latitudinal spreading of SAOD

- SAOD perturbation propagates faster to high-latitude in the SSP5 8.5 scenario, as expected given acceleration of Brewer-Dobson circulation.
- This faster transport is consistent with reduced aerosol lifetime.
- It also explains the $R_{eff}$ decrease with aerosol growing more the longer they are in the tropical pipe in UM-UKCA (not shown).
Strong eruption: SAOD and radiative forcing

- Net effect of decreased aerosol lifetime + decreased $R_{eff}$ = overall SAOD increase (by up to 14%)
- In turn, radiative forcing decreases by up to 33%
- We also find a significant increase of total energy loss by 10%

**SAOD**

- Mean total energy loss (min-max) in $10^{24}$ J:
  - 1.87 (1.37-2.25)
  - 2.06 (1.86-2.50)
Summary of our results

How will climate change affect radiative forcing of tropical explosive eruptions?

**Moderate tropical eruption (1Tg SO$_2$)**
- Tropopause rise not compensated by injection height rise → decrease of stratospheric sulfate burden and SAOD by a factor 2-4.
- This suggests that the tropical “stratospheric aerosol background” (Solomon et al. 2011) will decrease in the future

**Strong tropical eruption (10 Tg SO$_2$)**
- Acceleration of Brewer Dobson circulation results in decrease of aerosol lifetime and effective radius
- The net result of these competing effects is an increase of SAOD by up to 14%, a decrease of radiative forcing by up to 30% and an increase of the total energy loss by 10%

→ Reduced forcing for moderate (VEI ≈ 4) tropical eruptions but enhanced forcing for strong (VEI ≈ 5-6) tropical eruptions.