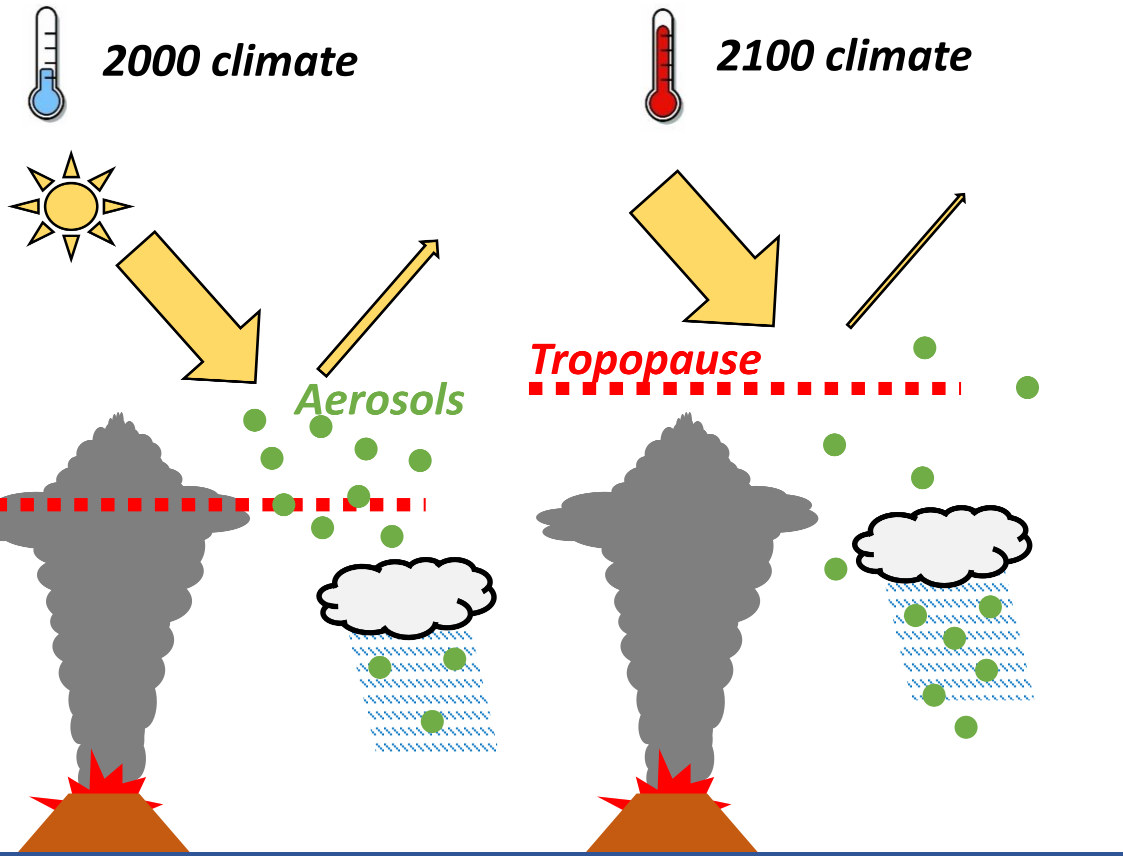
In brief: How will climate change affect the radiative forcing of tropical eruptions?

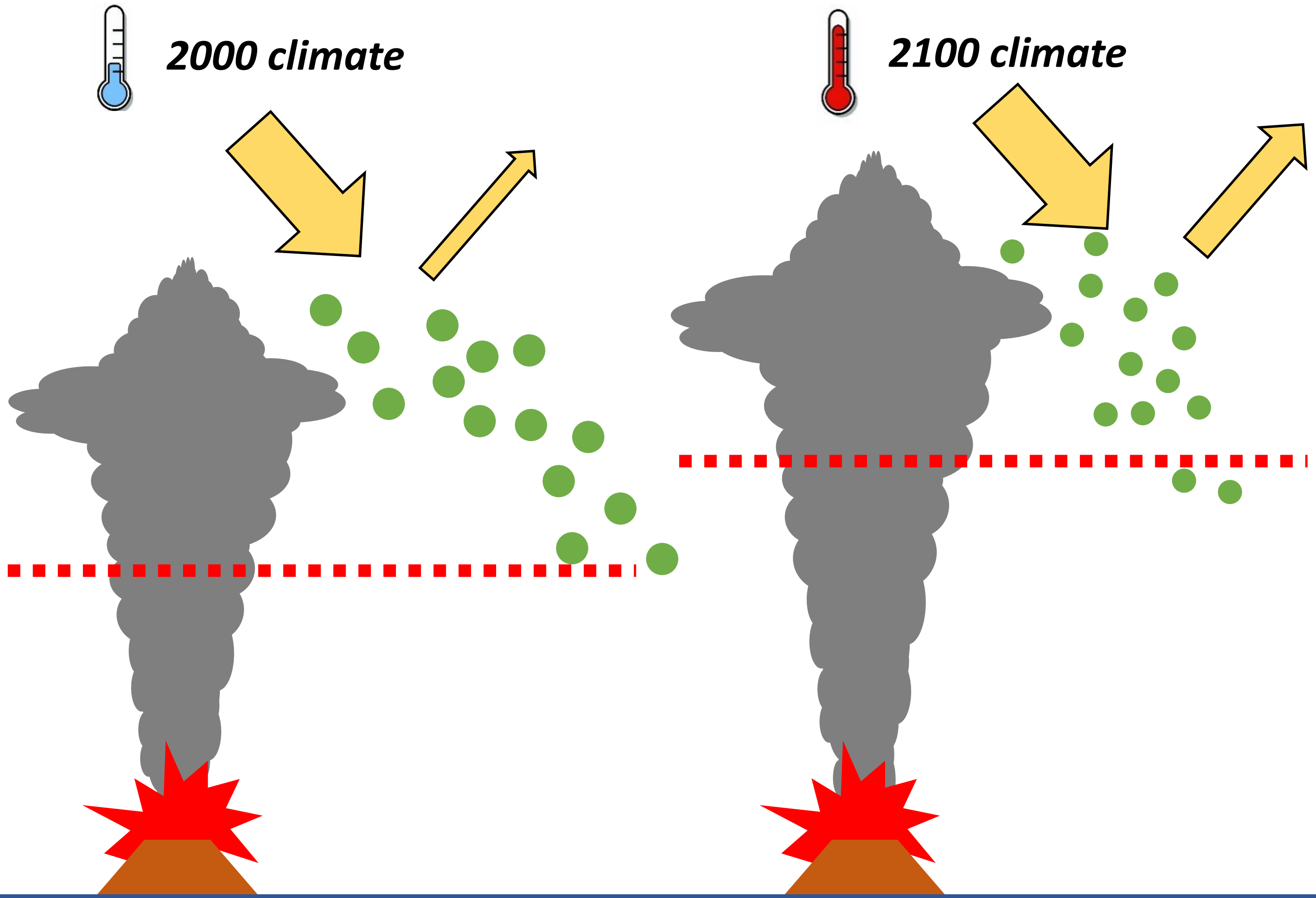
Moderate eruptions injecting ca. 1 Tg SO_2 in upper troposphere-lower stratosphere:

- Tropopause height increases but SO_2 injection height does not
- 2-4 fold decrease in stratospheric aerosol burden & SAOD



Large eruptions injecting ca. 10 Tg SO_2 in stratosphere:

- Acceleration of Brewer-Dobson circulation → decreased aerosol lifetime but smaller aerosols
- Net effect = forcing increase 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. refs), 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. refs)

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 1st in the model column corresponding to the Mt Pinatubo location (15.1°N, 120.4°E).

- SO_2 injection height is calculated using a plume model which main inputs are the mass eruption rate (MER) and atmospheric profiles (temperature, wind, pressure, humidity) (*Aubry et al., GRL 2019*)

- We run experiments for:

Two eruption case scenarios:

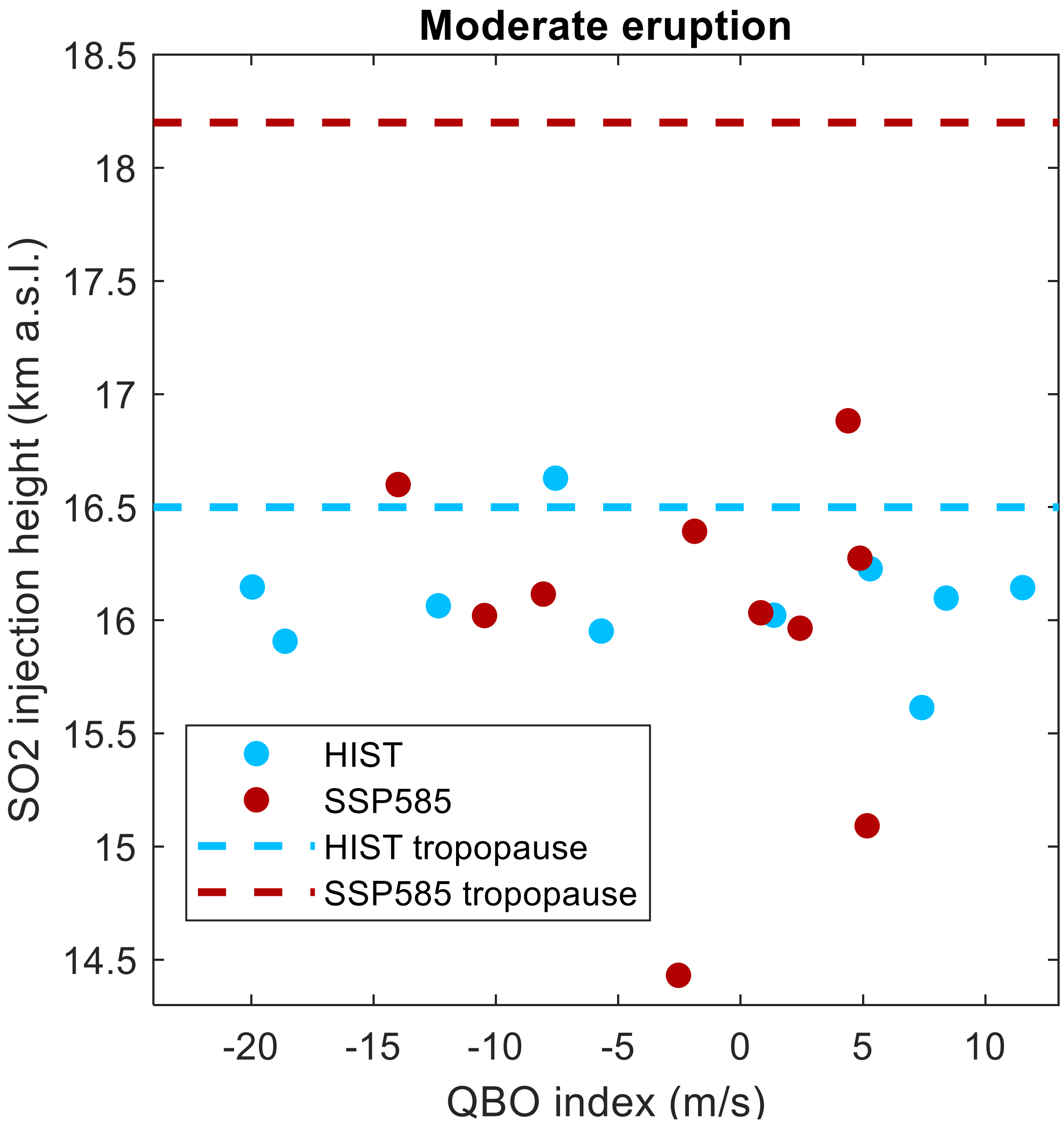
i) Moderate eruption: 1 Tg SO_2, MER = 10^6 kg/s
ii) Strong eruption: 10 Tg SO_2, MER = 10^7 kg/s

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-biennal oscillation phase and SO_2 injection height

Moderate eruption: Closer look at initial conditions

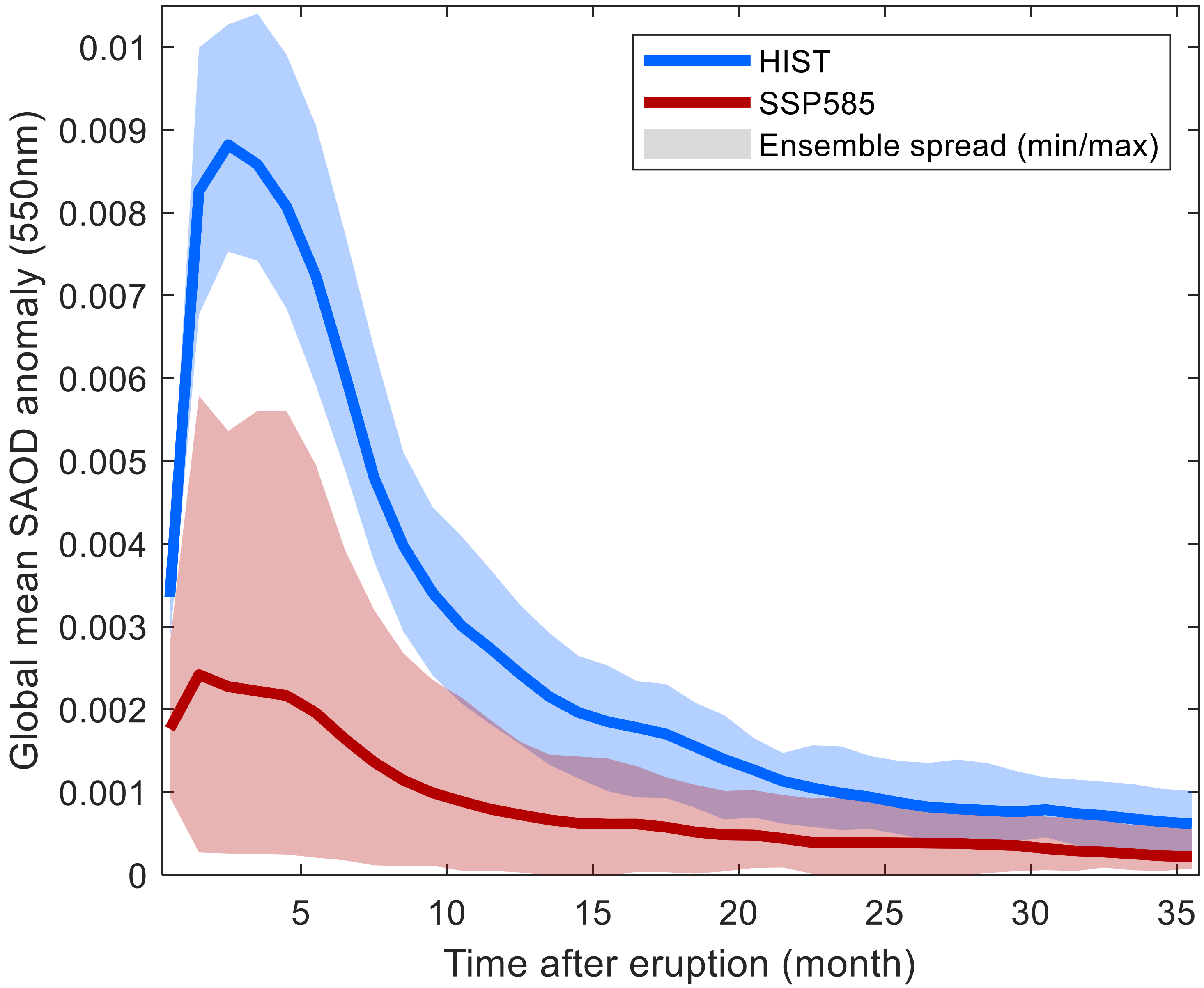


- Mass eruption rate chosen to have upper tropospheric-lower stratospheric SO_2 injection for historical climate, consistent with many recent moderate eruptions (e.g. Merapi 2010, Nabro 2011, Kelut 2014)

- **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. JGR 2016, GRL 2019)

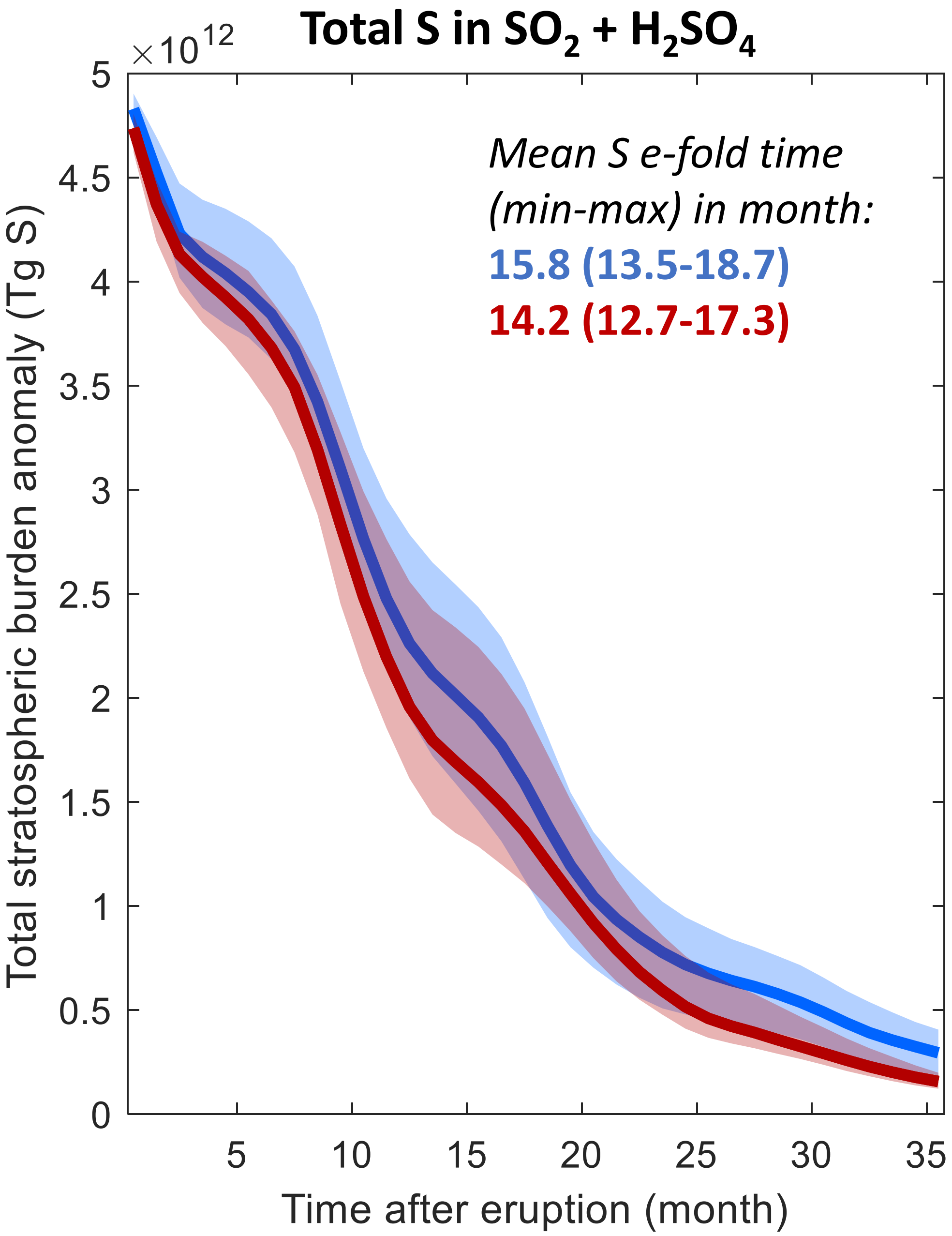
- **However, in the SSP5 8.5 climate, the average tropopause height is 1.75 km higher**

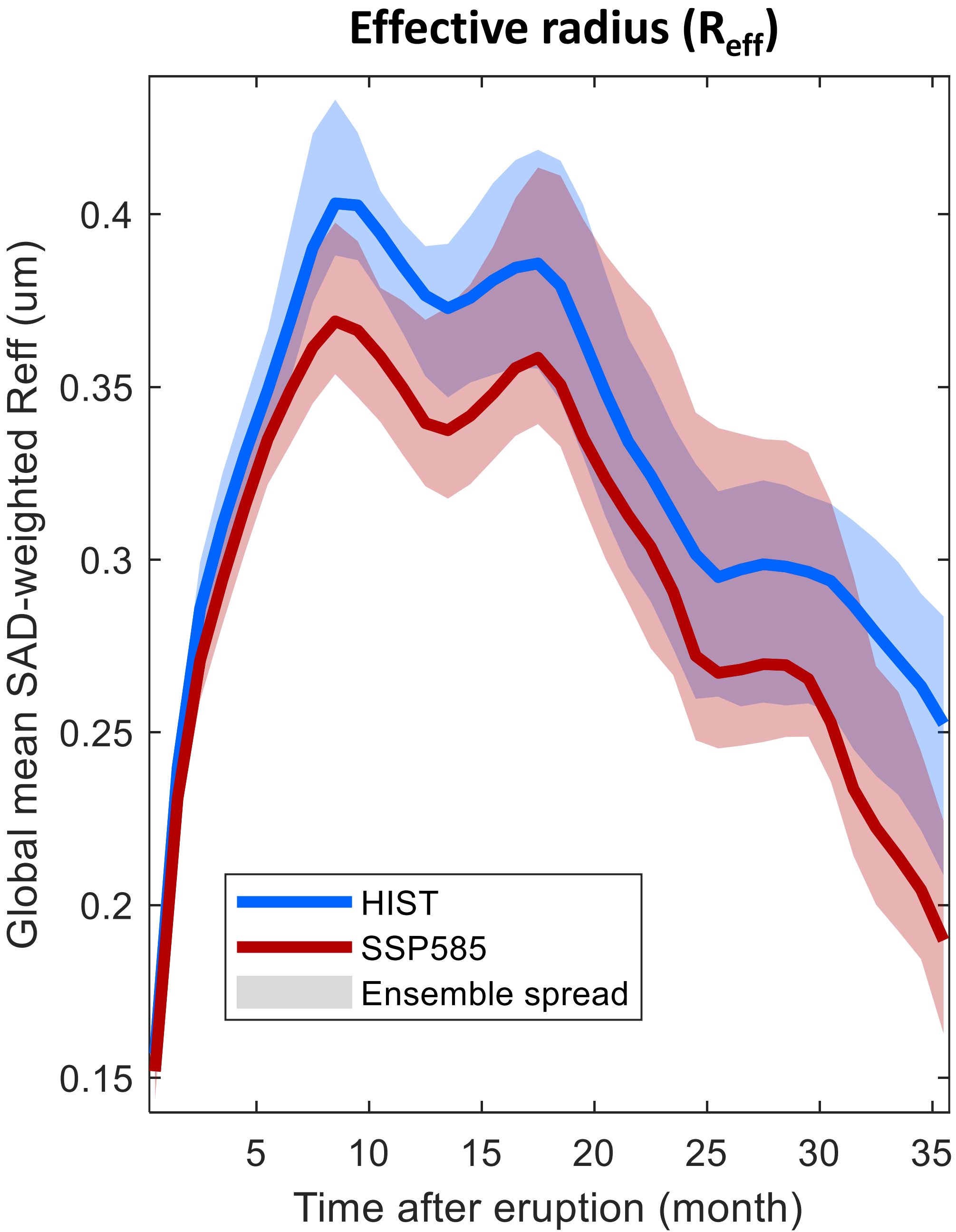
Moderate eruption: Stratospheric Aerosol Optical Depth (SAOD)



- 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

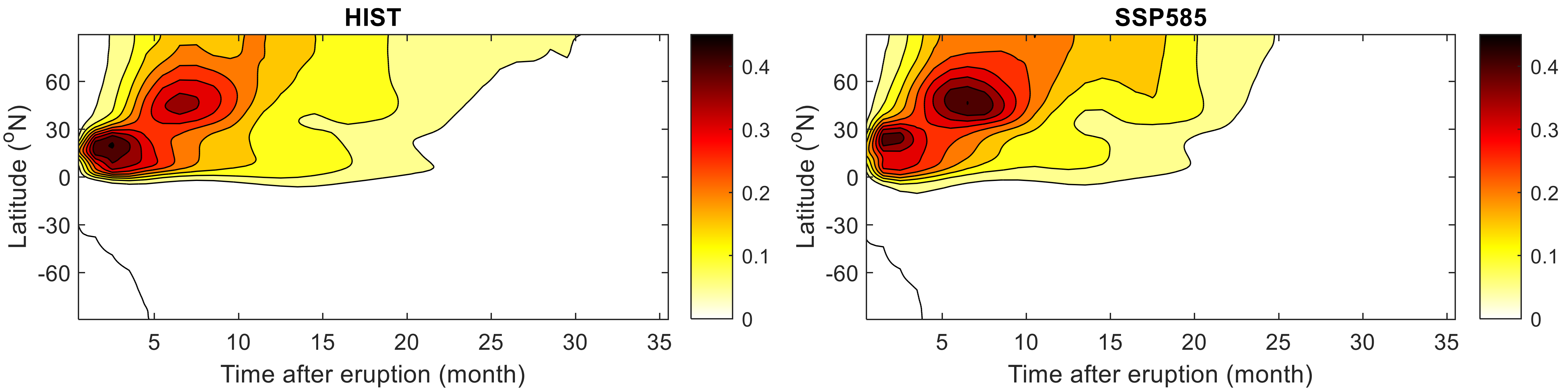


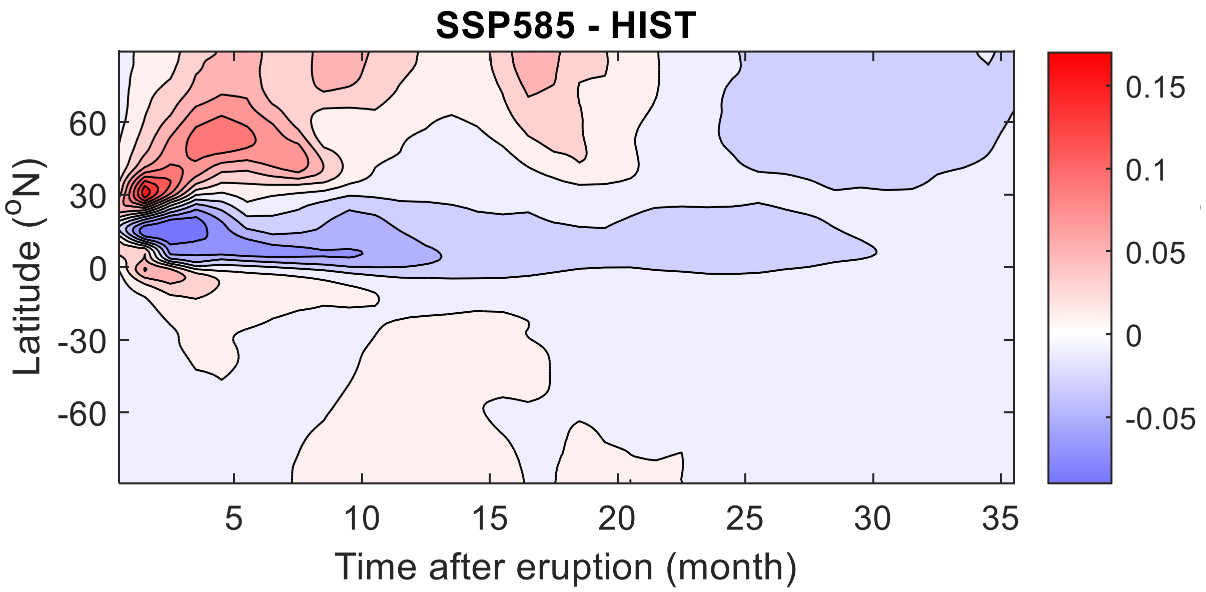


For the strong eruption, we find:

- 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%

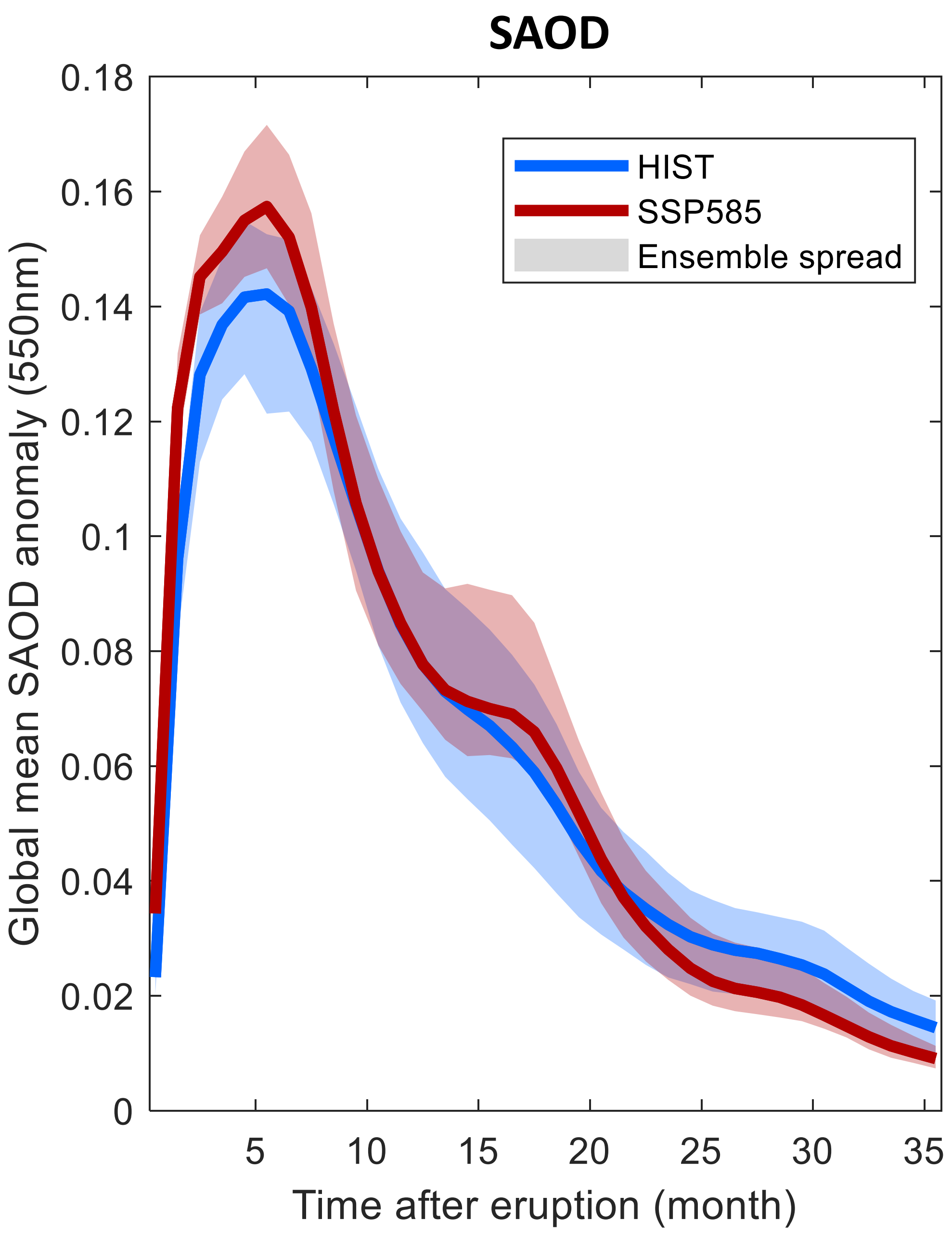
Strong eruption: Latitudinal transport of the aerosols

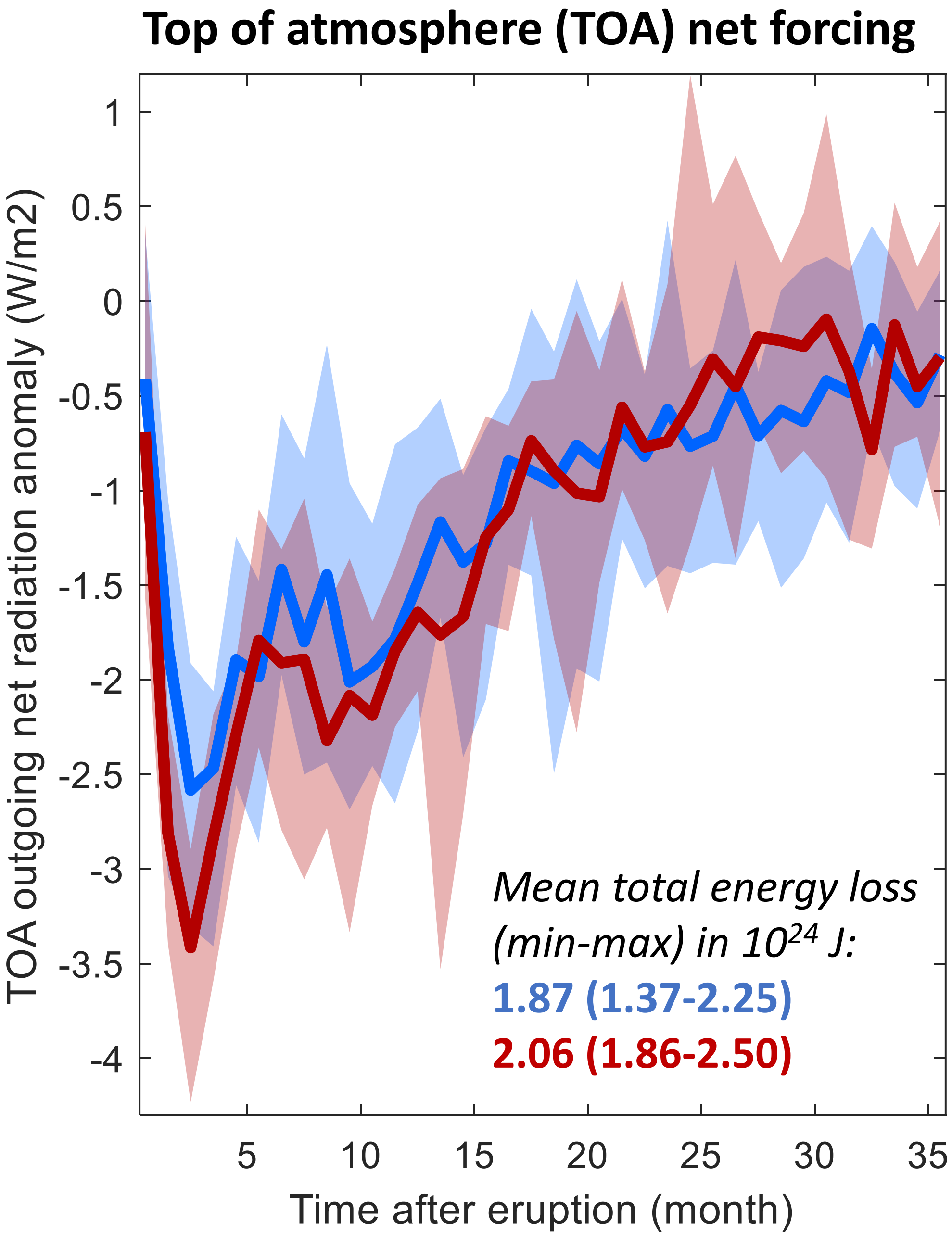




- SAOD perturbation propagates faster to high-latitude in the SSP5 8.5 scenario, as expected given acceleration of Brewer-Dobson circulation
- This faster transport is consistent with reduced aerosol lifetime
- It also explains the R_{eff} decrease with aerosol growing more the longer they are in the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

Strong eruption: SAOD and radiative forcing





- Net effect of decreased aerosol lifetime + decreased Reff = 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%

Summary of our results

How will climate change affect radiative forcing of tropical 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" 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%

→ Our results suggests a more polarized forcing of tropical volcanic eruptions in the future, with reduced forcing for moderate (VEI 3-4) eruptions but enhanced forcing for strong (VEI 5-6) eruptions