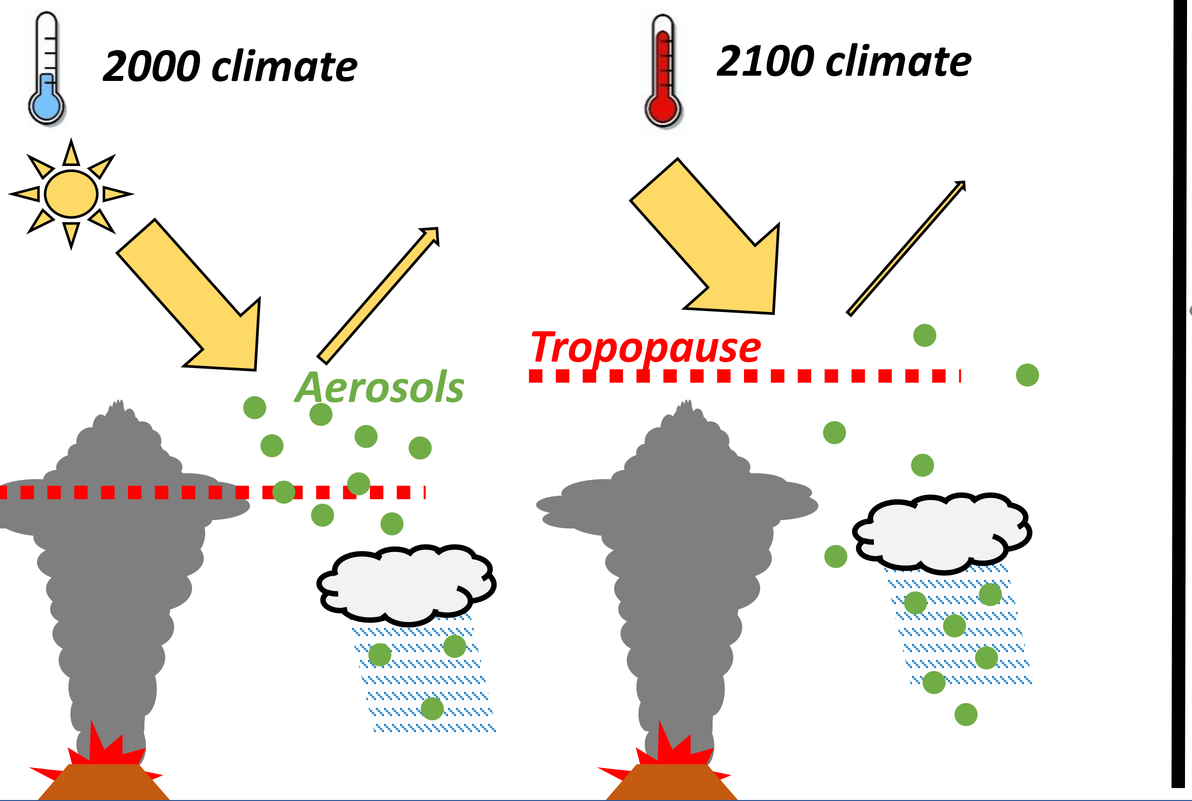
In brief: How will climate change affect the radiative forcing of tropical eruptions?

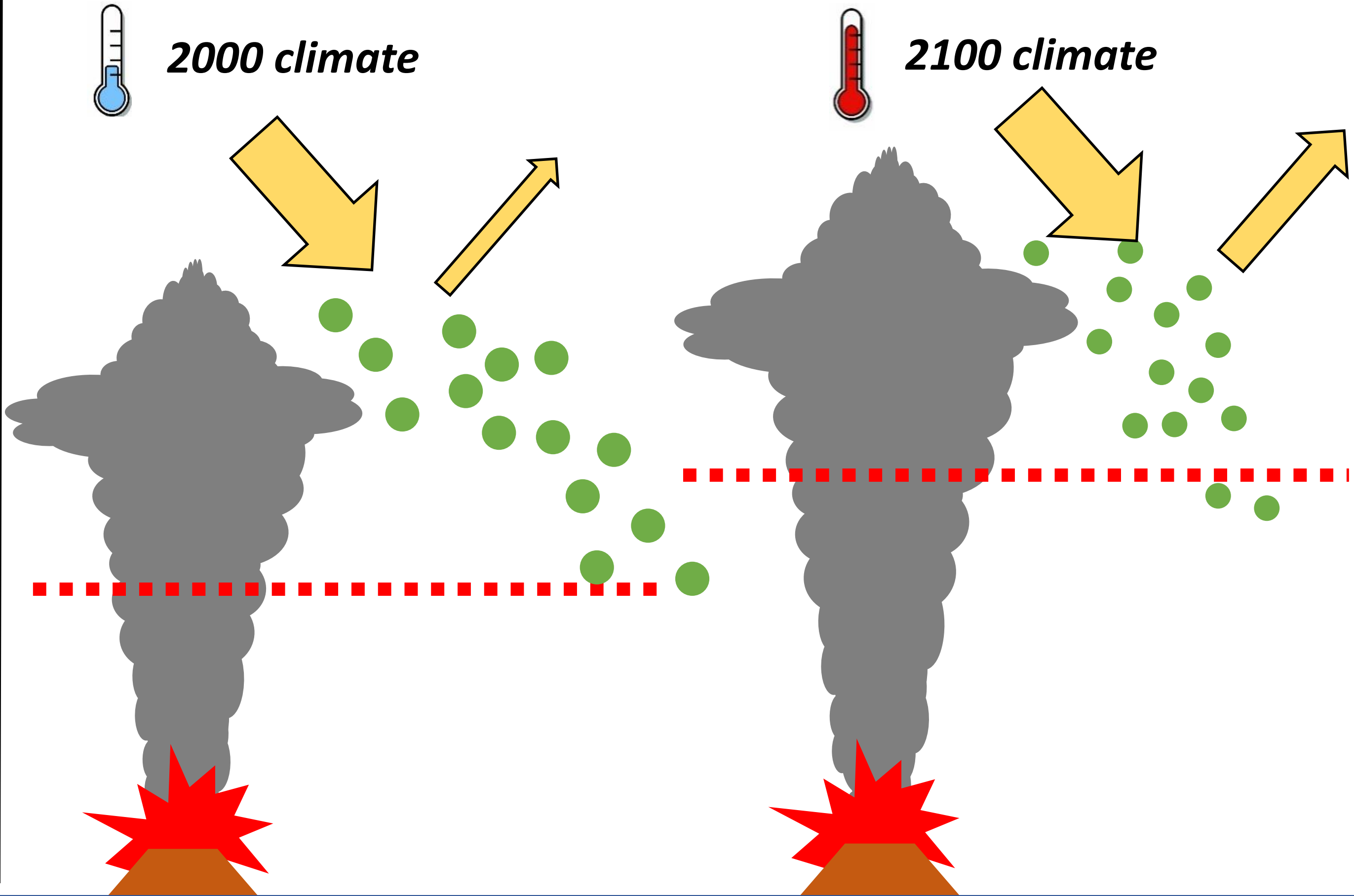
Moderate explosive eruptions (VEI≈4) *injecting 1 Tg SO_2 in the upper troposphere-lower stratosphere:*

- 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 1st in the model column corresponding to the Mt Pinatubo location (15.1^{o}N, 120.4^{o}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:

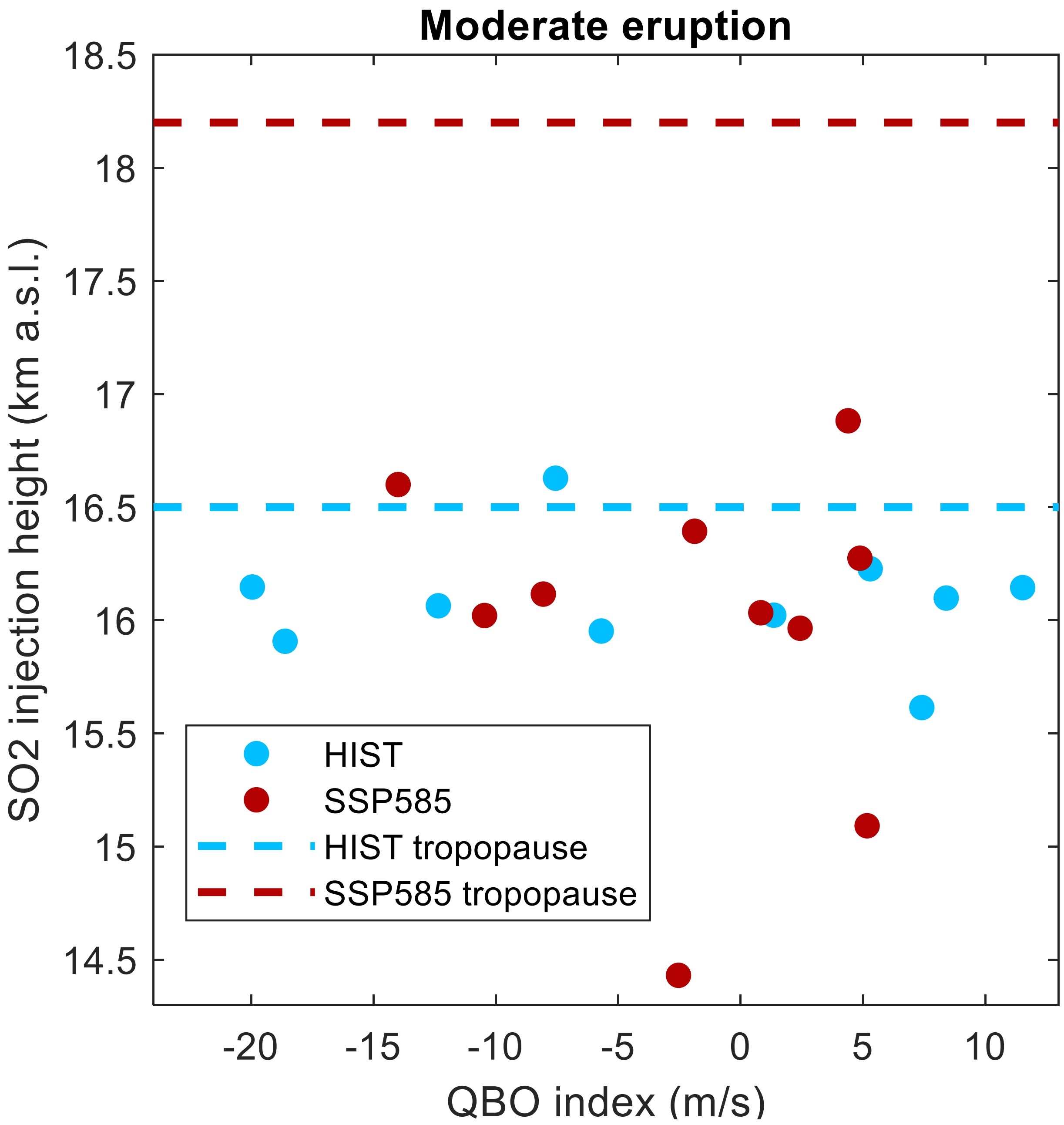
i) Moderate eruption: 1 Tg SO_2, MER = 10^6 kg/s
ii) Strong eruption: 10 Tg SO_2, MER = 10^7 kg/s

Two climate scenarios:

i) Historical 1990-2000
ii) SSP5 8.5 (upper greenhouse gas emission trajectory) 2090-2100

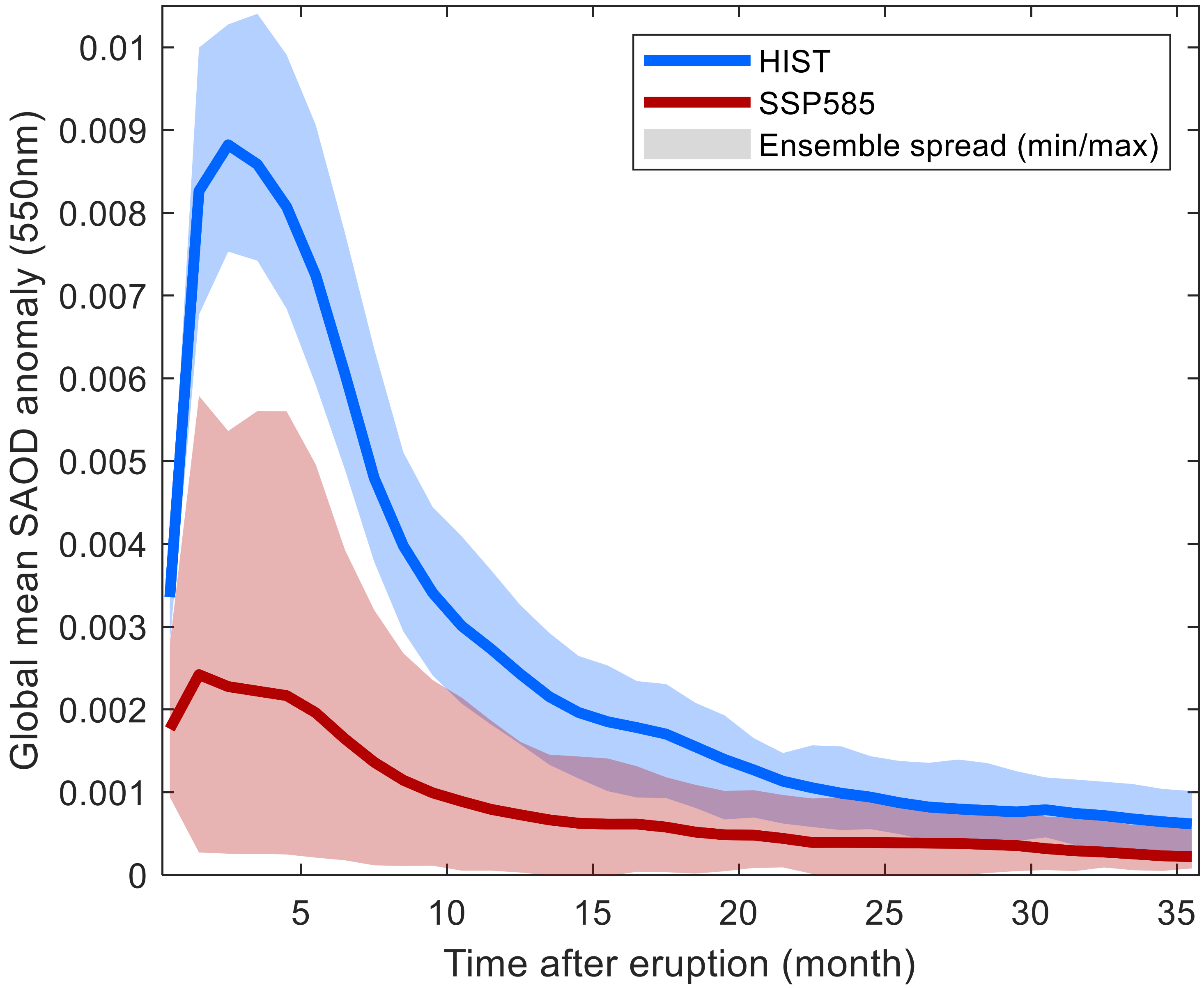
- For each combination of eruption & climate scenario, we run 10 experiments with initial conditions chosen to sample a variety of quasi-biennal oscillation phase and SO_2 injection height

Moderate eruption: Closer look at initial conditions



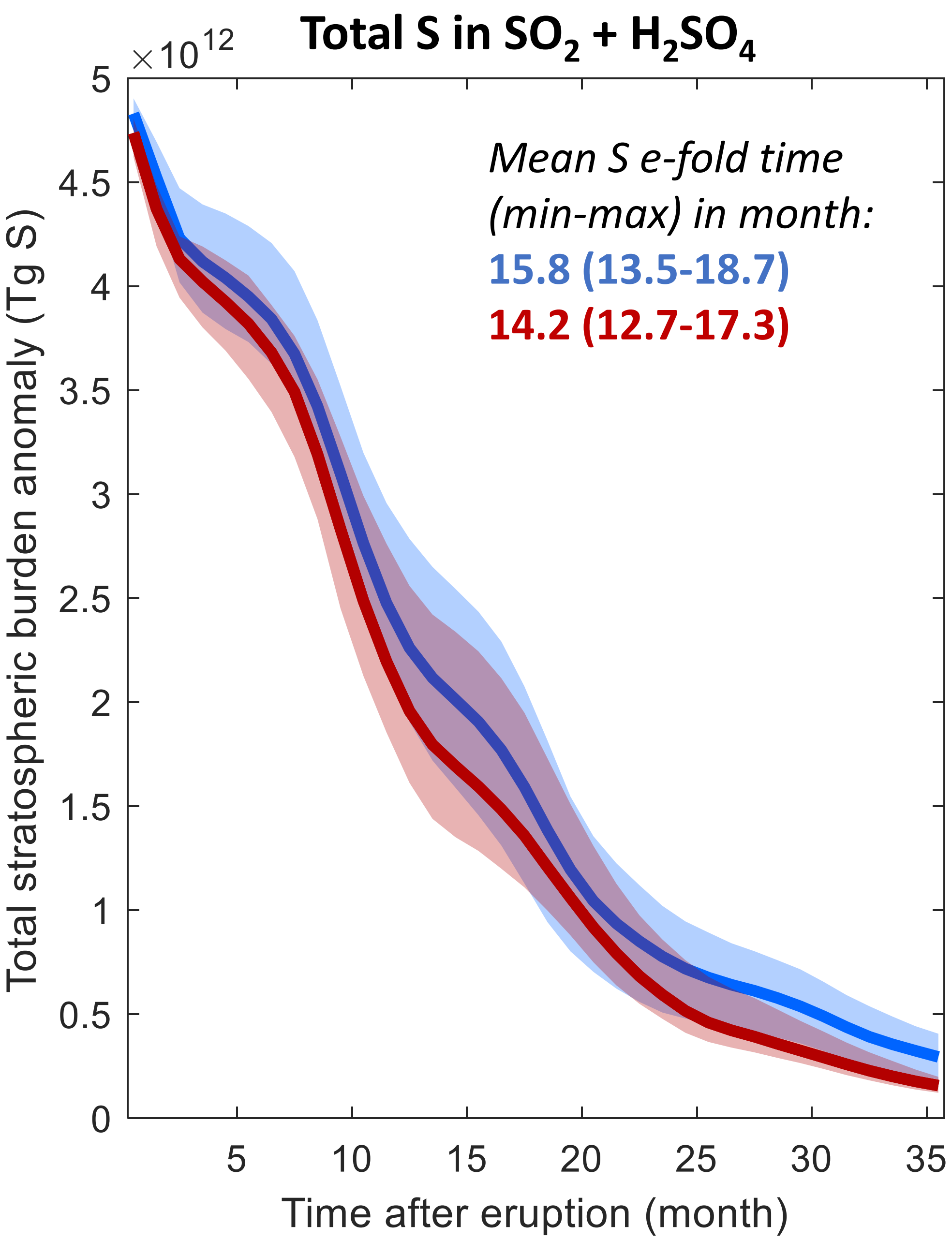
- Mass eruption rate chosen to have upper tropospheric-lower stratospheric SO_2 injection for historical climate, consistent with many recent moderate eruptions (e.g. Merapi 2010, Nabro 2011, Kelut 2014)
- **In the SSP5 8.5 climate, such mass eruption rate results in very similar heights** although depending on exact atmospheric conditions, injection height can be as low as 14.5km due to increased upper-tropospheric stratification (*Aubry et al. 2016, 2019*)
- **However, in the SSP5 8.5 climate, the average tropopause height is 1.75 km higher**

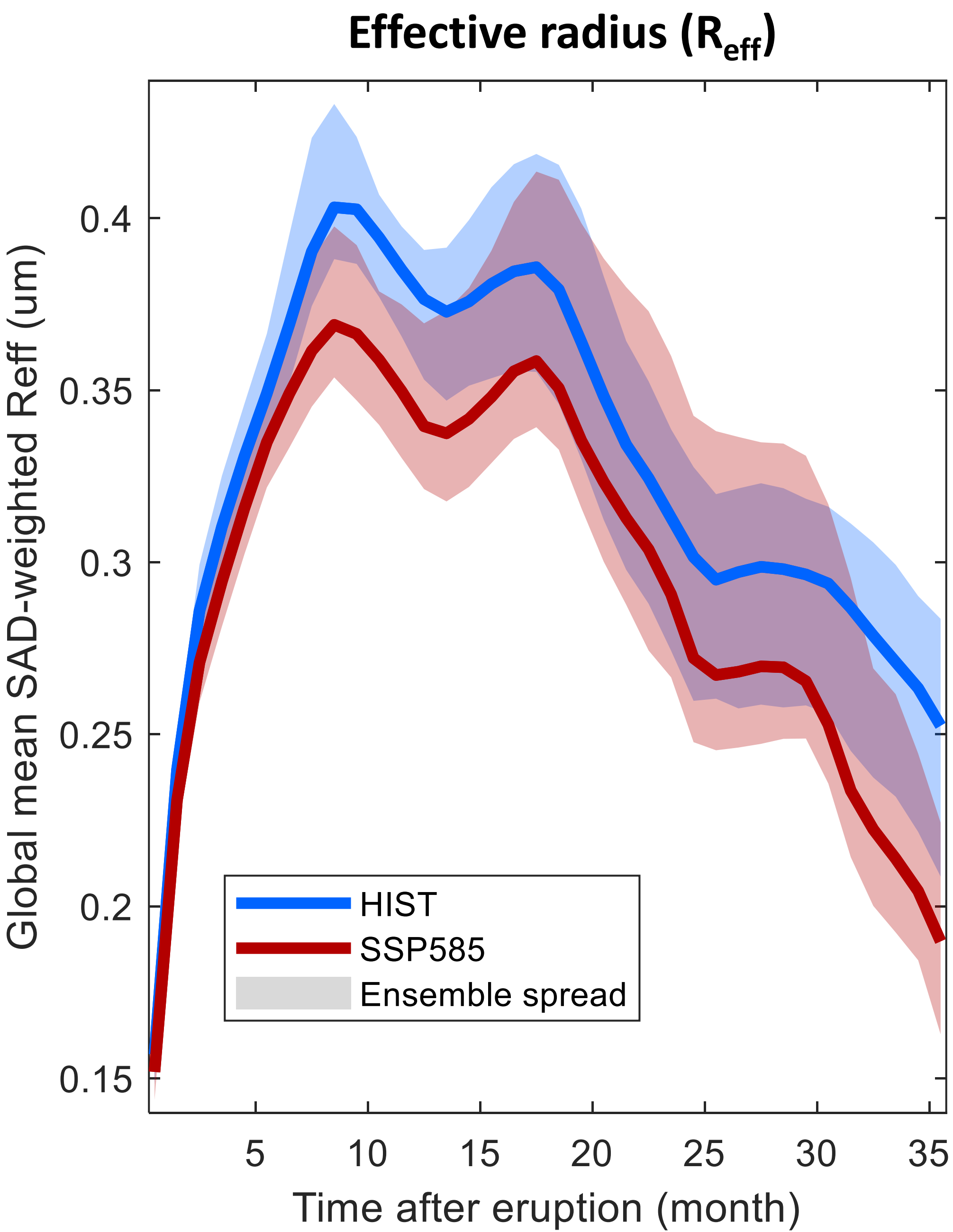
Moderate eruption: Stratospheric Aerosol Optical Depth (SAOD)



- 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

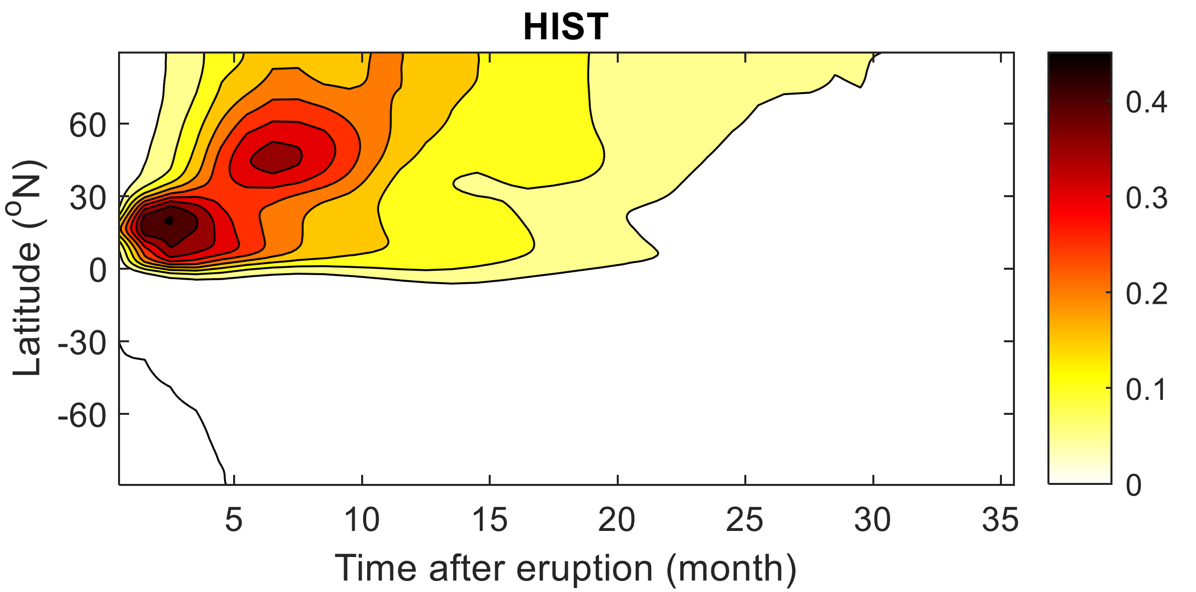


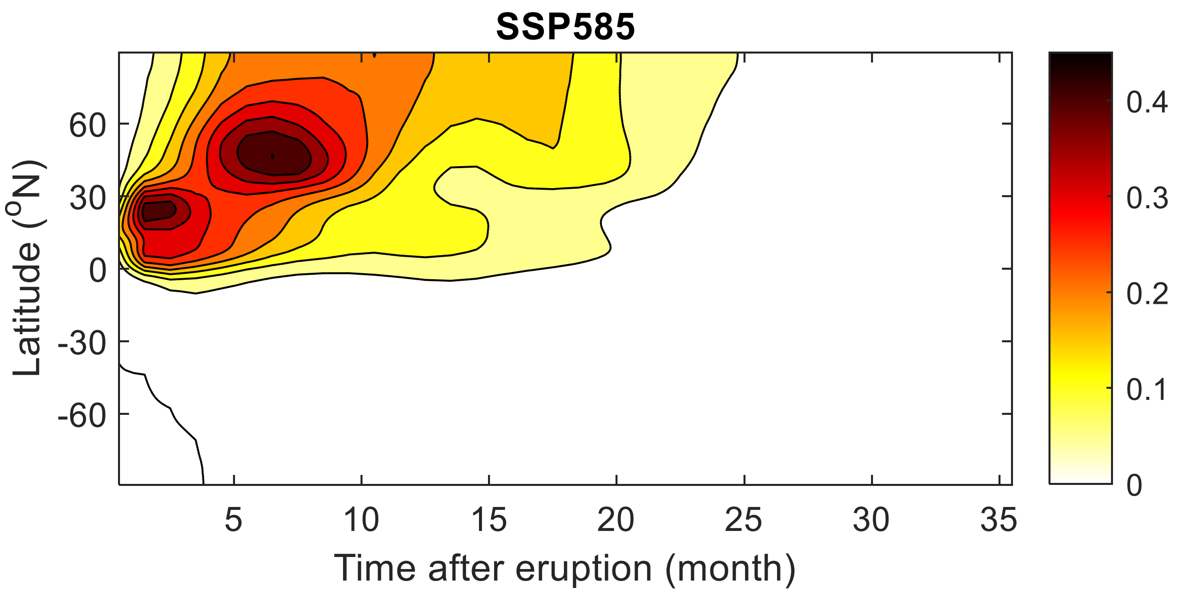


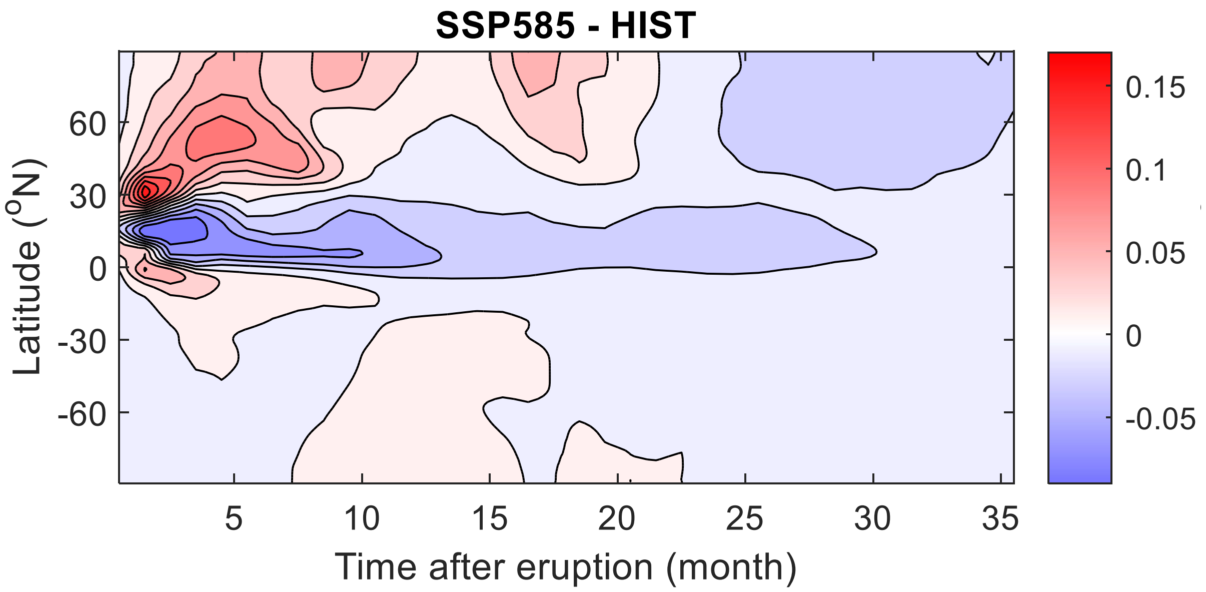
For the strong eruption, we find:

- 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%

Strong eruption: Latitudinal spreading of SAOD



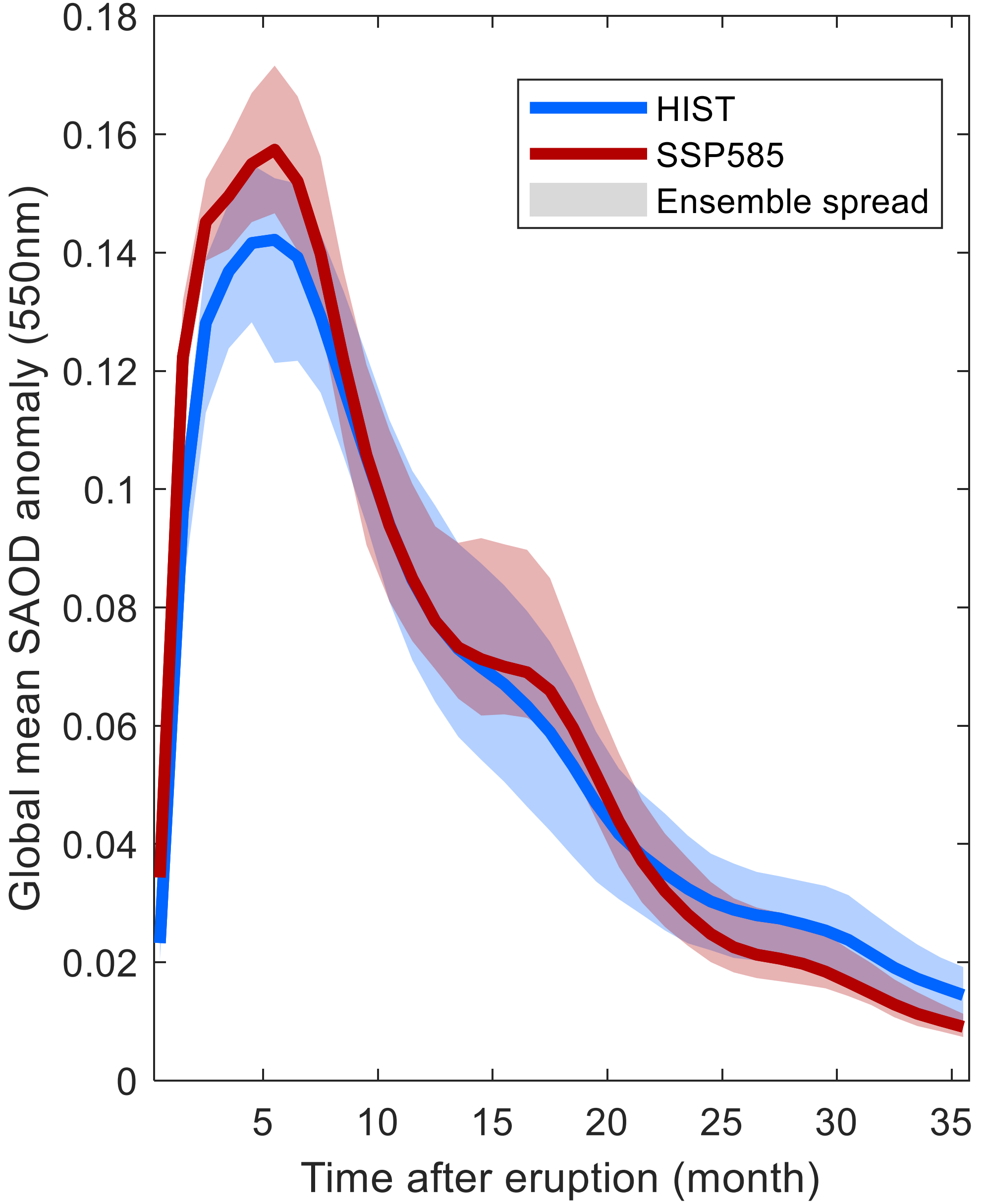




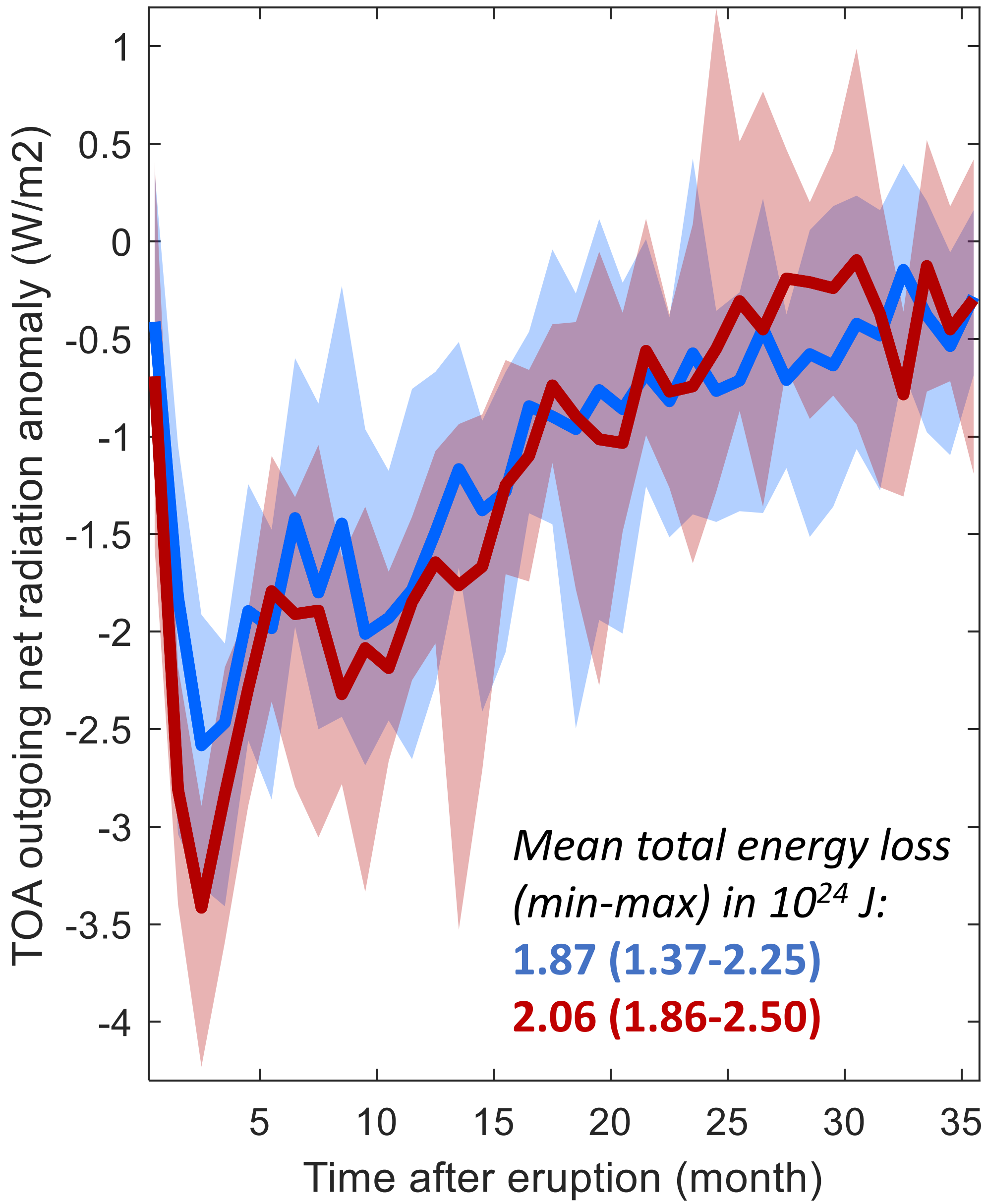
- SAOD perturbation propagates faster to high-latitude in the SSP5 8.5 scenario, as expected given acceleration of Brewer-Dobson circulation
- This faster transport is consistent with reduced aerosol lifetime
- It also explains the R_{eff} decrease with aerosol growing more the longer they are in the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

Strong eruption: SAOD and radiative forcing

SAOD



Top of atmosphere (TOA) net 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 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.