SRM and tropical monsoon rainfall

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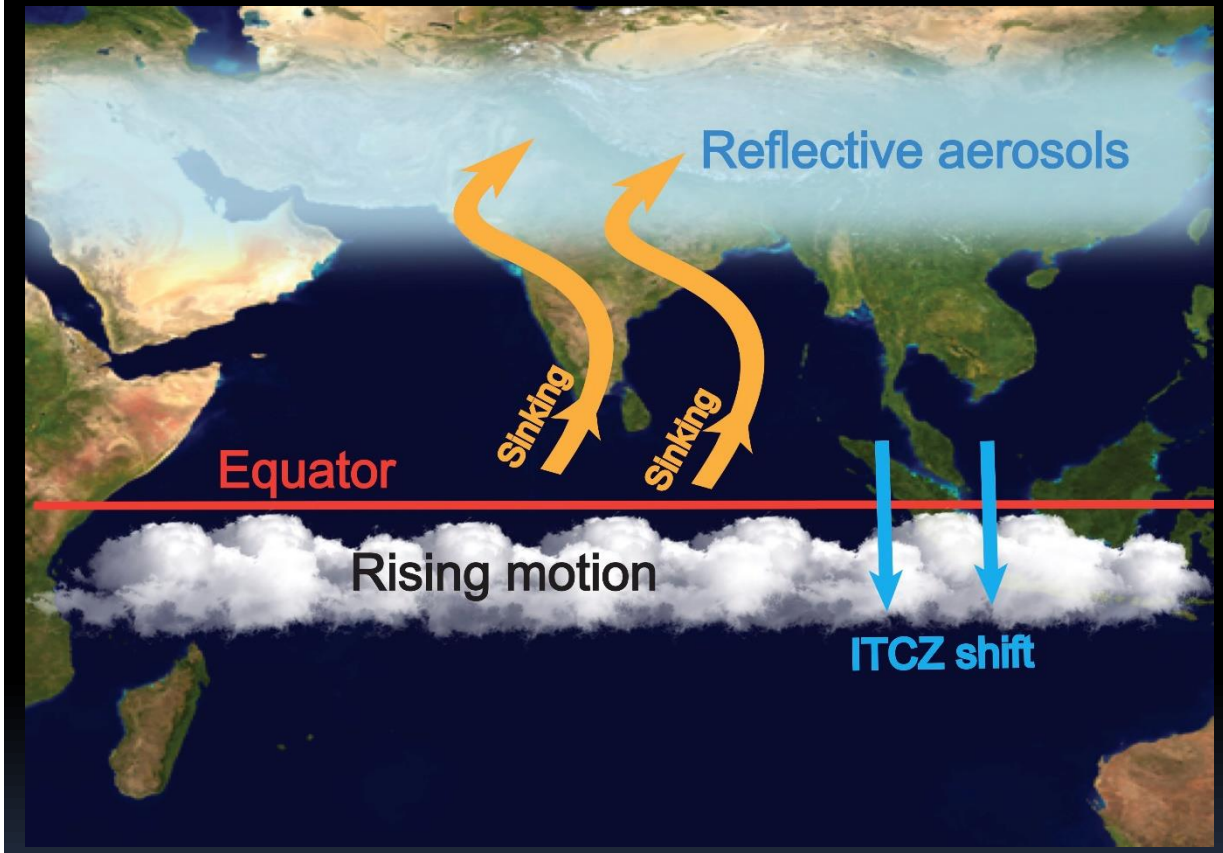
Three mechanisms relevant to SAI impacts on tropical monsoons

- Interhemispheric differences in AOD: can disrupt the latitudinal position of ITCZ and monsoons. Like in the seasonal cycle, ITCZ would move into the warmer hemisphere. Risk can be avoided by injecting aerosols at multiple latitudes.
- Global mean AOD: an increase would cause a decrease in monsoon rainfall. Hydrological sensitivity to sulfate aerosols is larger than for CO2. Moderate SG deployment can help to avoid this problem
- Height of aerosols: Precipitation shows little sensitivity to the height of the sulfate aerosol layer in the stratosphere. This is because of the compensation between fast and slow responses in precipitation when the height of the aerosol layer is altered

Mechanism 1: Change in interhemispheric difference in Aerosol optical depth (AOD)

How do aerosols affect tropical monsoons?

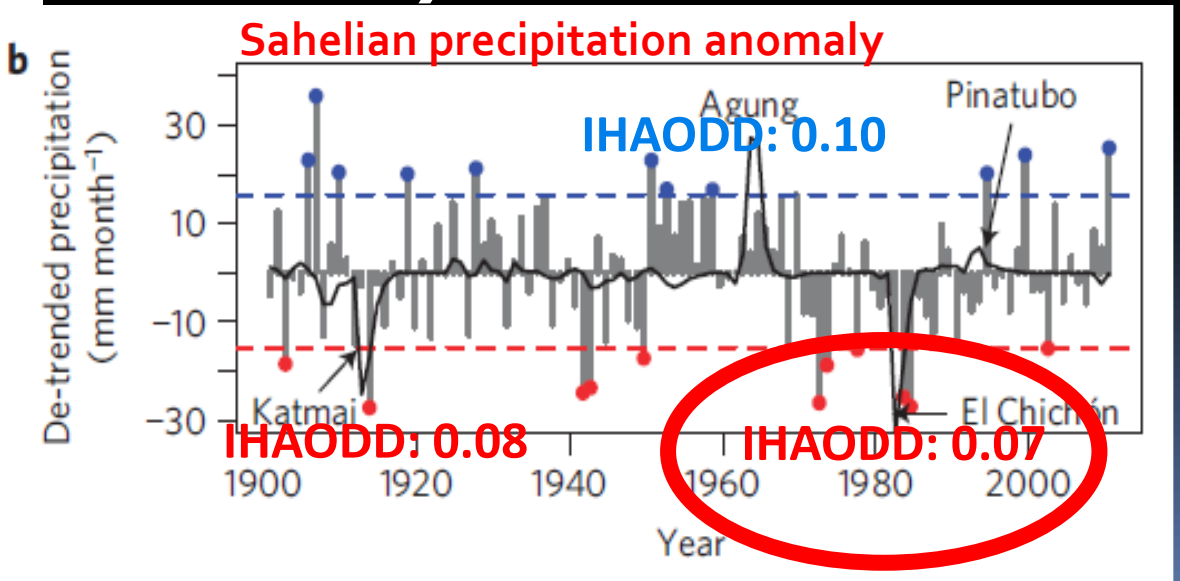


Too much of reflective aerosols (sulfates) in one hemisphere could push the tropical rain belts to the other hemisphere

Too much of absorbing aerosols (black carbon) in one hemisphere could pull the tropical rain belts into that hemisphere – energetics principle (ITCZ moves into the warmer hemisphere)

Aerosols and tropical monsoons

- Eruption of the El Chichon (in Mexico) in the 1980s caused an additional interhemispheric AOD difference of about 0.07 and led to a major rainfall deficit in the African Sahel (Haywood et al 2013)



Aerosols and tropical monsoons

Sulfate injections into the stratosphere leading to additional sulfate AOD difference between the hemispheres of ~ 0.2 leads to persistent droughts (rainfall deficits >10%) over India (Krishnamohan and Bala, 2022 Climate Dynamics)

Sensitivity of tropical monsoon precipitation to the latitude of stratospheric aerosol injections

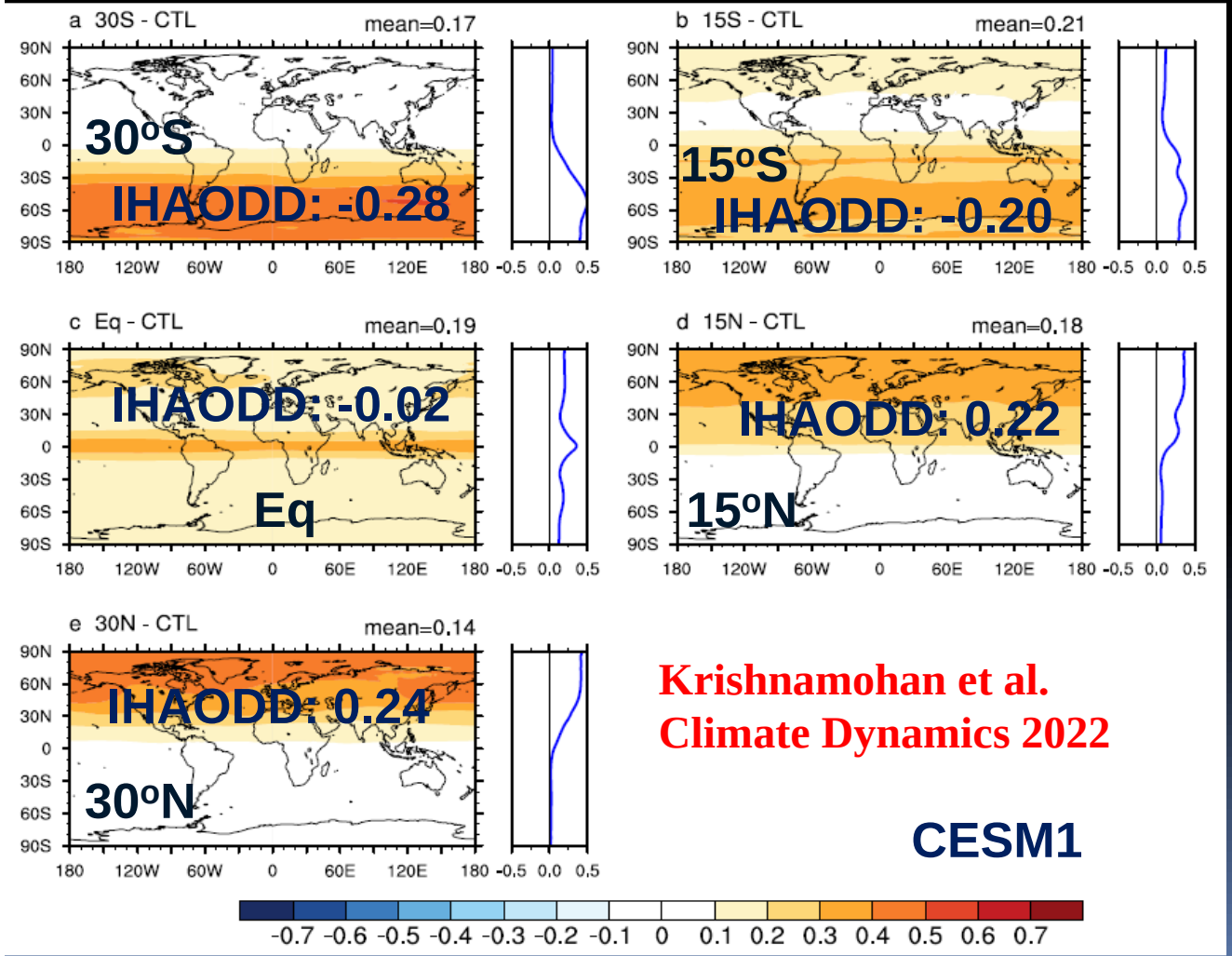
K. S. Krishnamohan[1,2] · Govindasamy Bala[1]

Climate Dynamics 2022

Received: 15 May 2021 / Accepted: 23 December 2021

Aerosols and tropical monsoons

Sulfate injections into the stratosphere at five different latitudes to offset global warming in the RCP8.5 scenario leads to interhemispheric difference in AOD



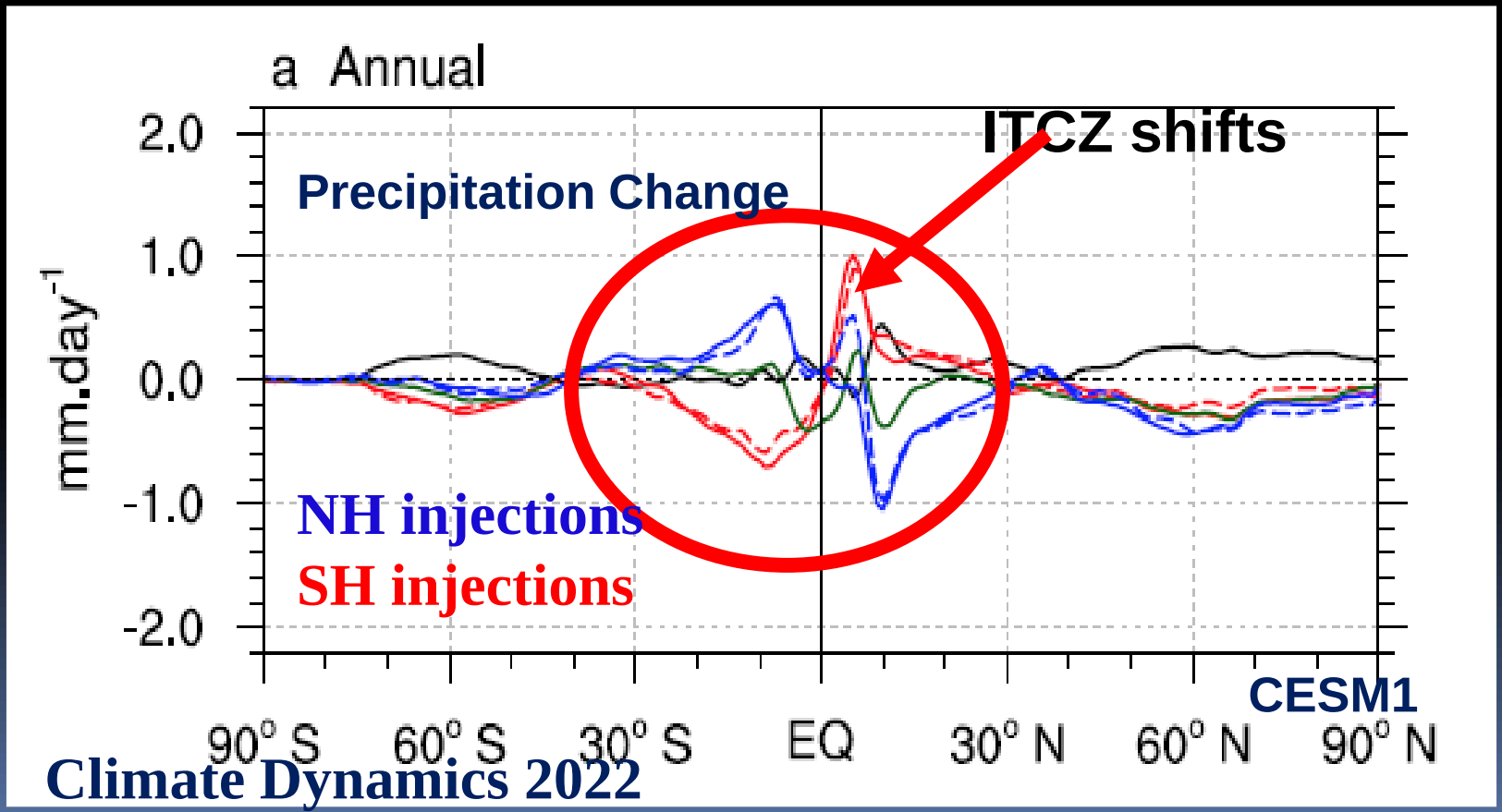
Krishnamohan et al.
Climate Dynamics 2022

CESM1

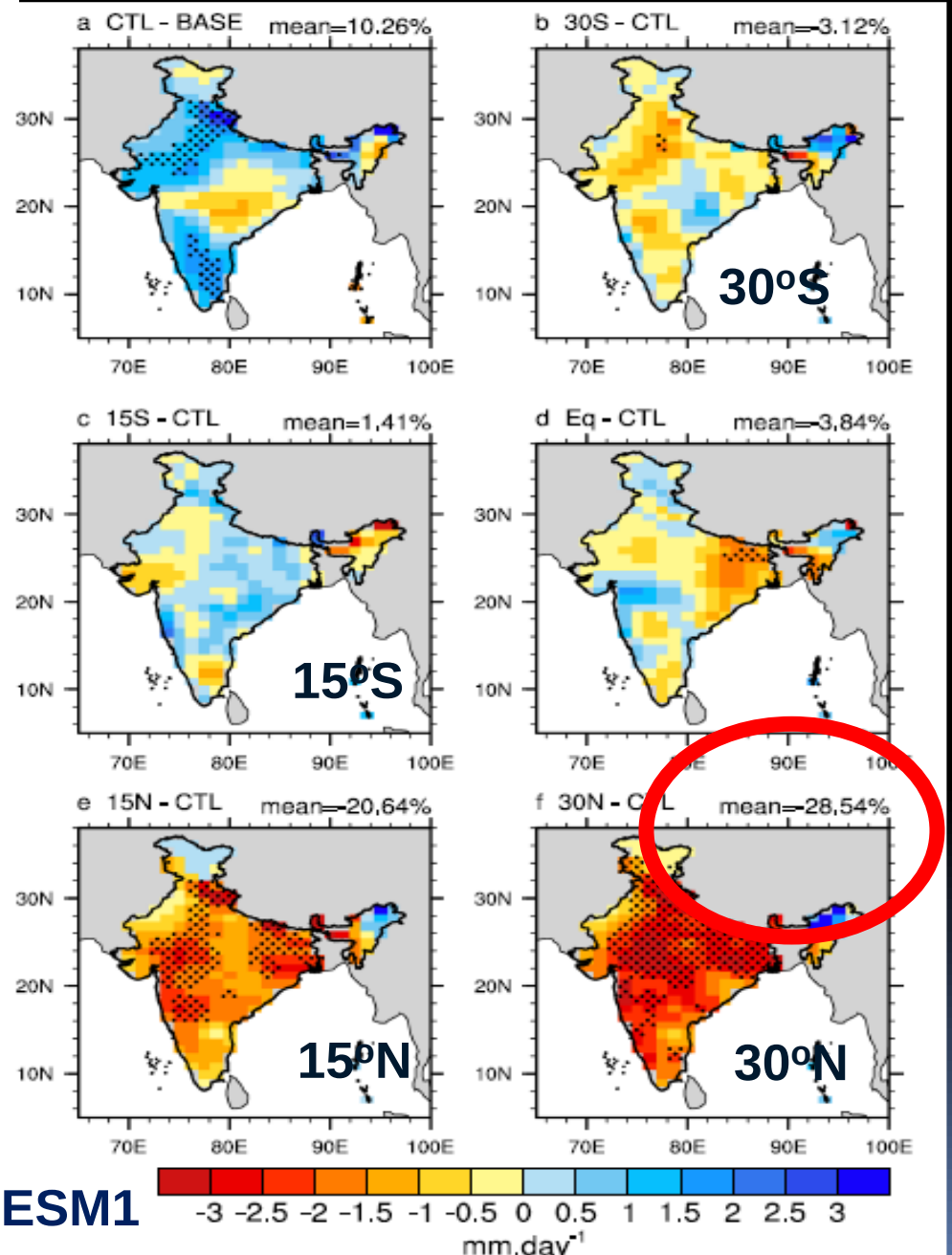
Stratospheric aerosol geoengineering simulations

Aerosols and ITCZ shifts

When reflecting aerosols are injected into the NH, there is a reduction in rainfall in the NH monsoon regions and vice versa.



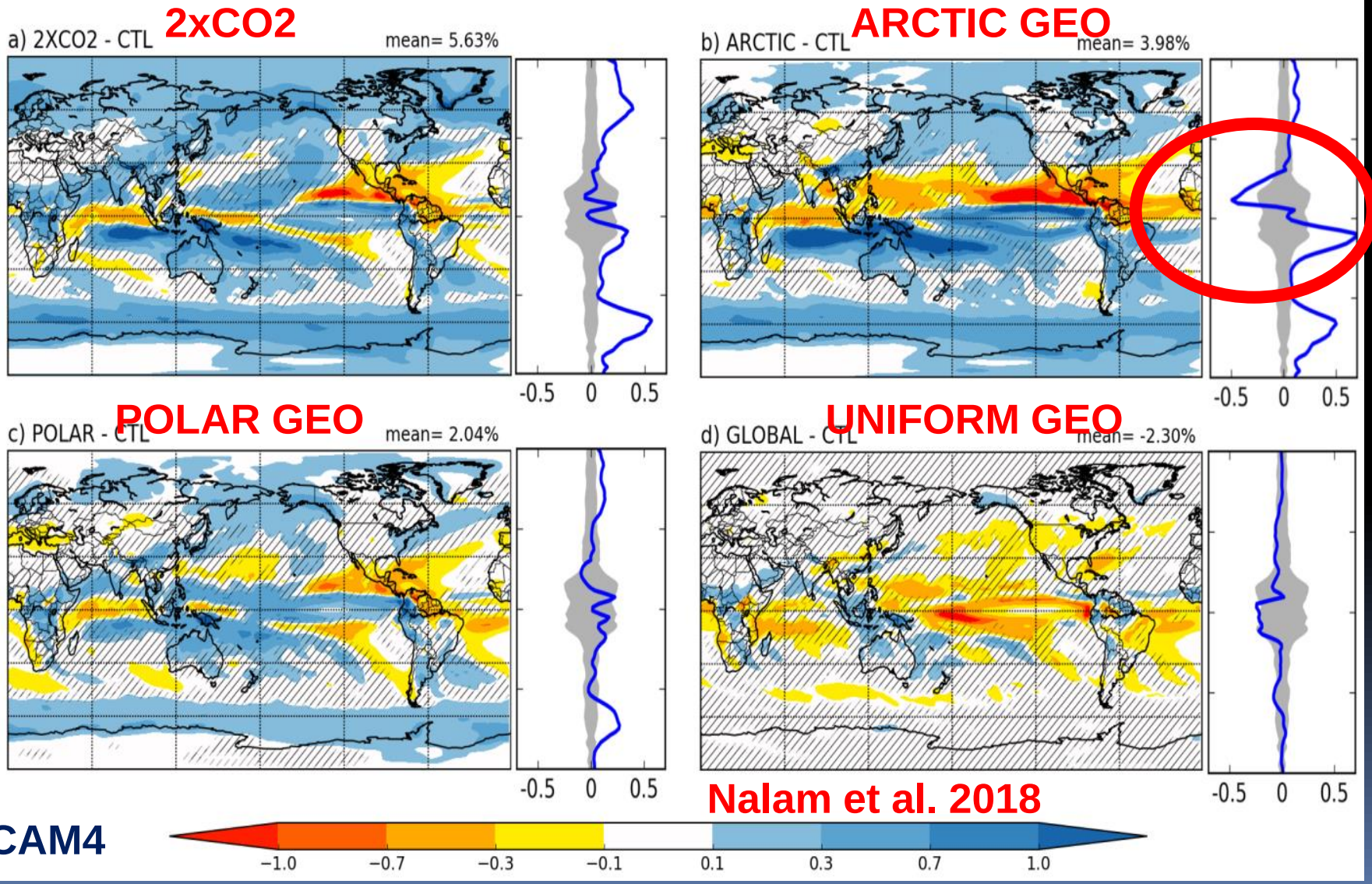
Aerosols and tropical monsoons



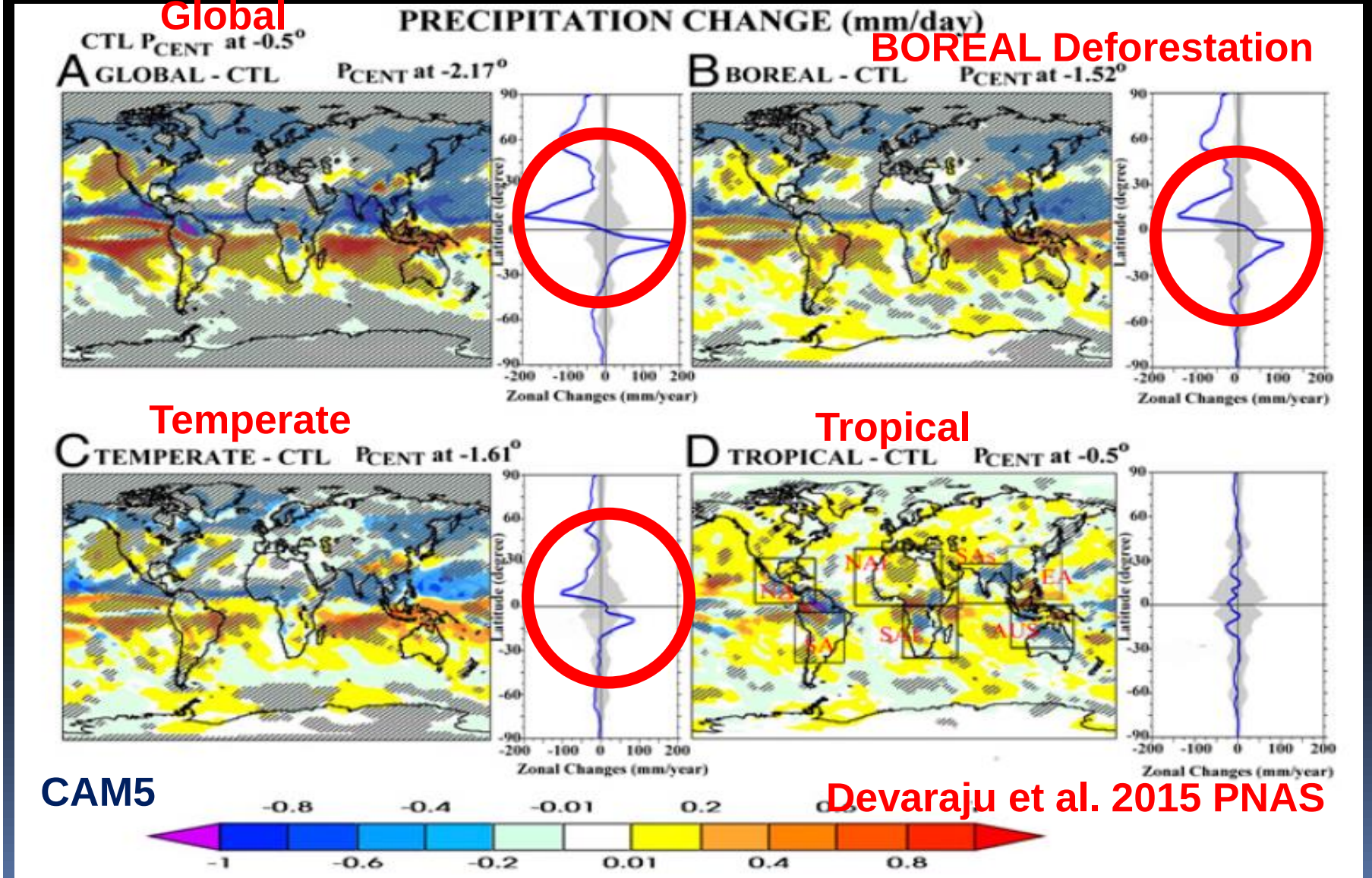
Over India, the mean precipitation decline could be close to 30% if aerosols are injected at 30°N

Krishnamohan et al. Climate Dynamics 2022

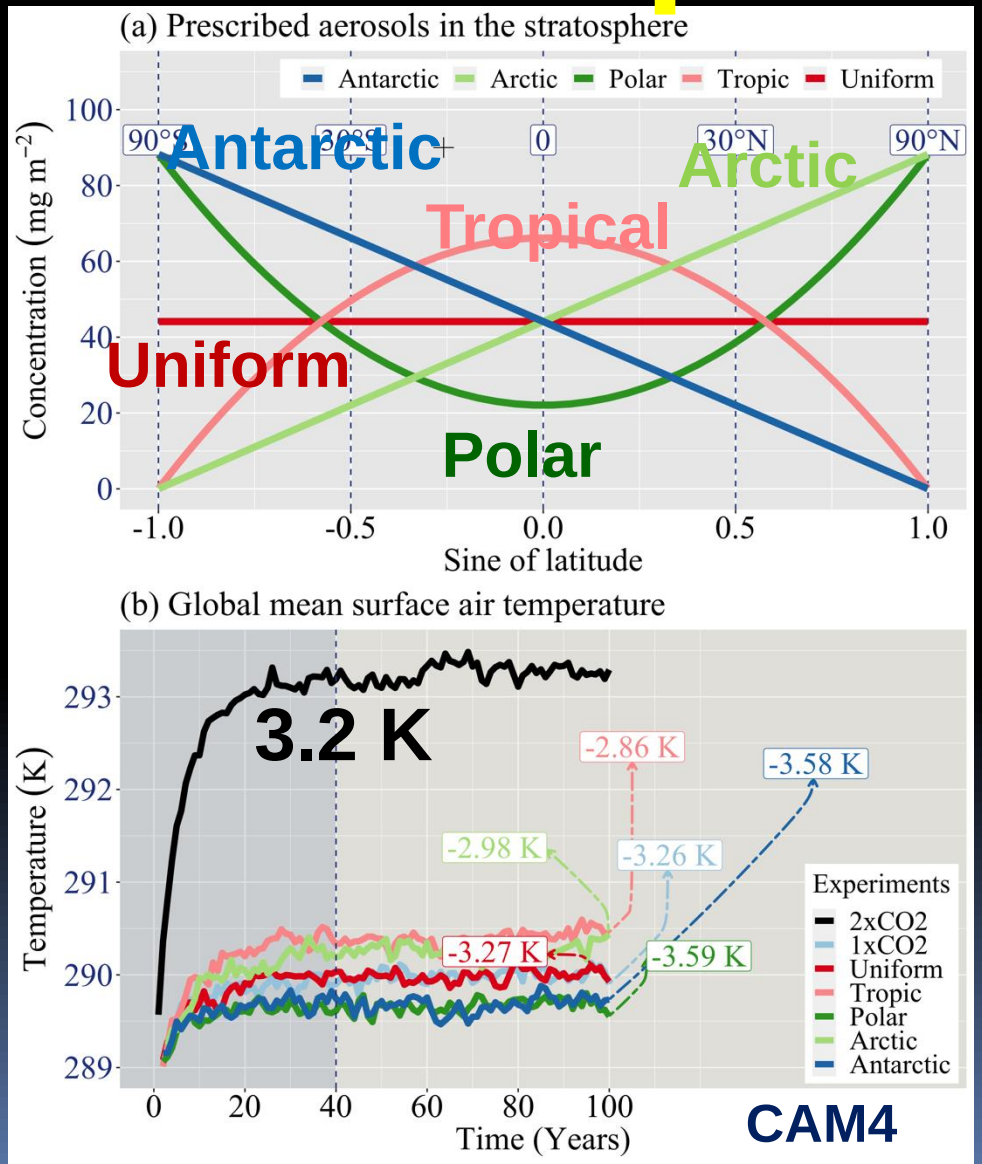
The ITCZ shift is also clear in Arctic geoengineering simulation



The ITCZ shift is independent of the forcing mechanism (deforestation)



Recent work: Prescribed Aerosol experiments

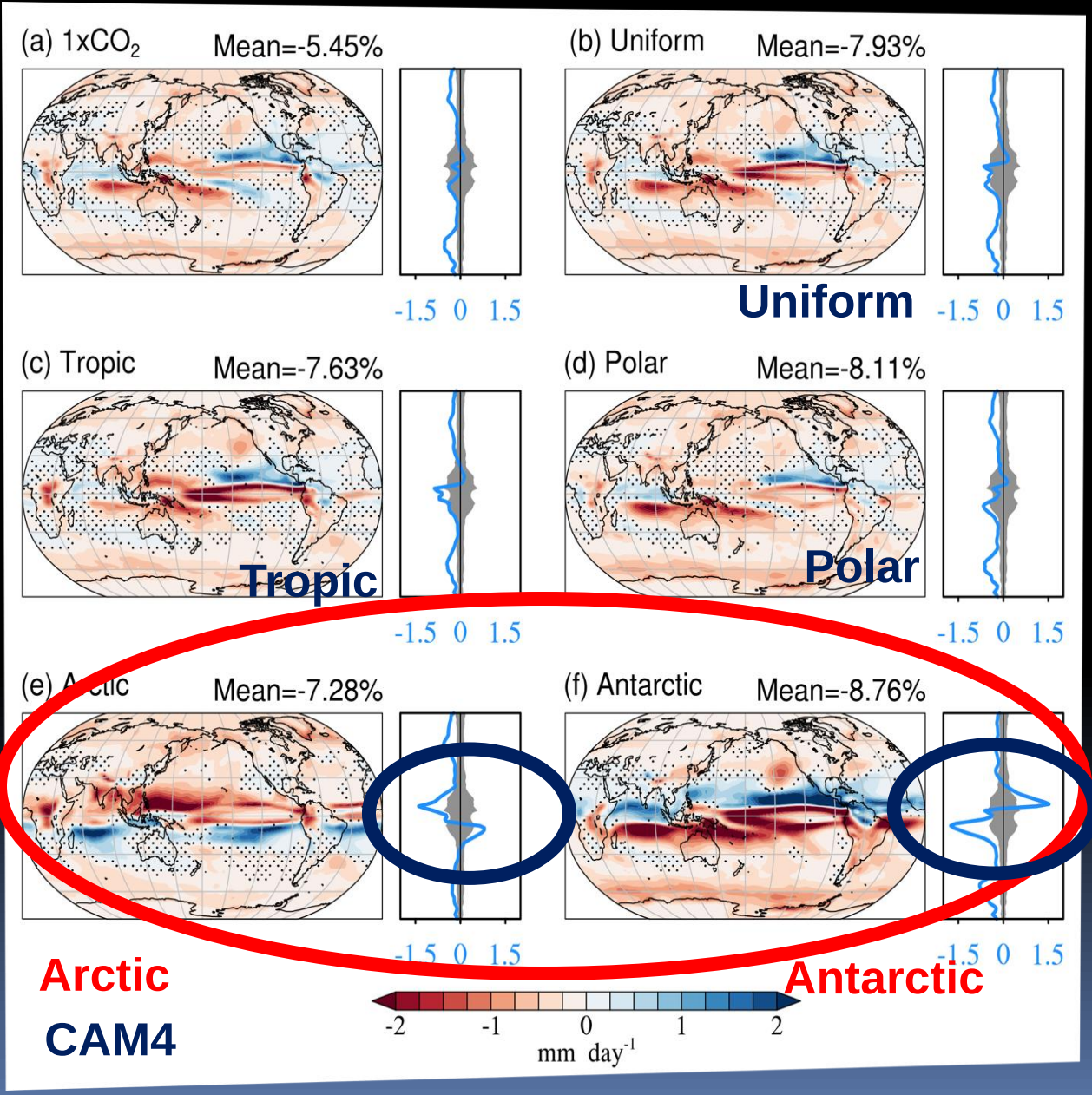


5 idealized distributions with a fixed total amount of 22.5 Mt of volcanic aerosols at 22 km

Global warming is fully or partly offset or overcompensated with aerosols in the stratosphere

Roose et al. Climate Dyn (2023)

Precipitation results

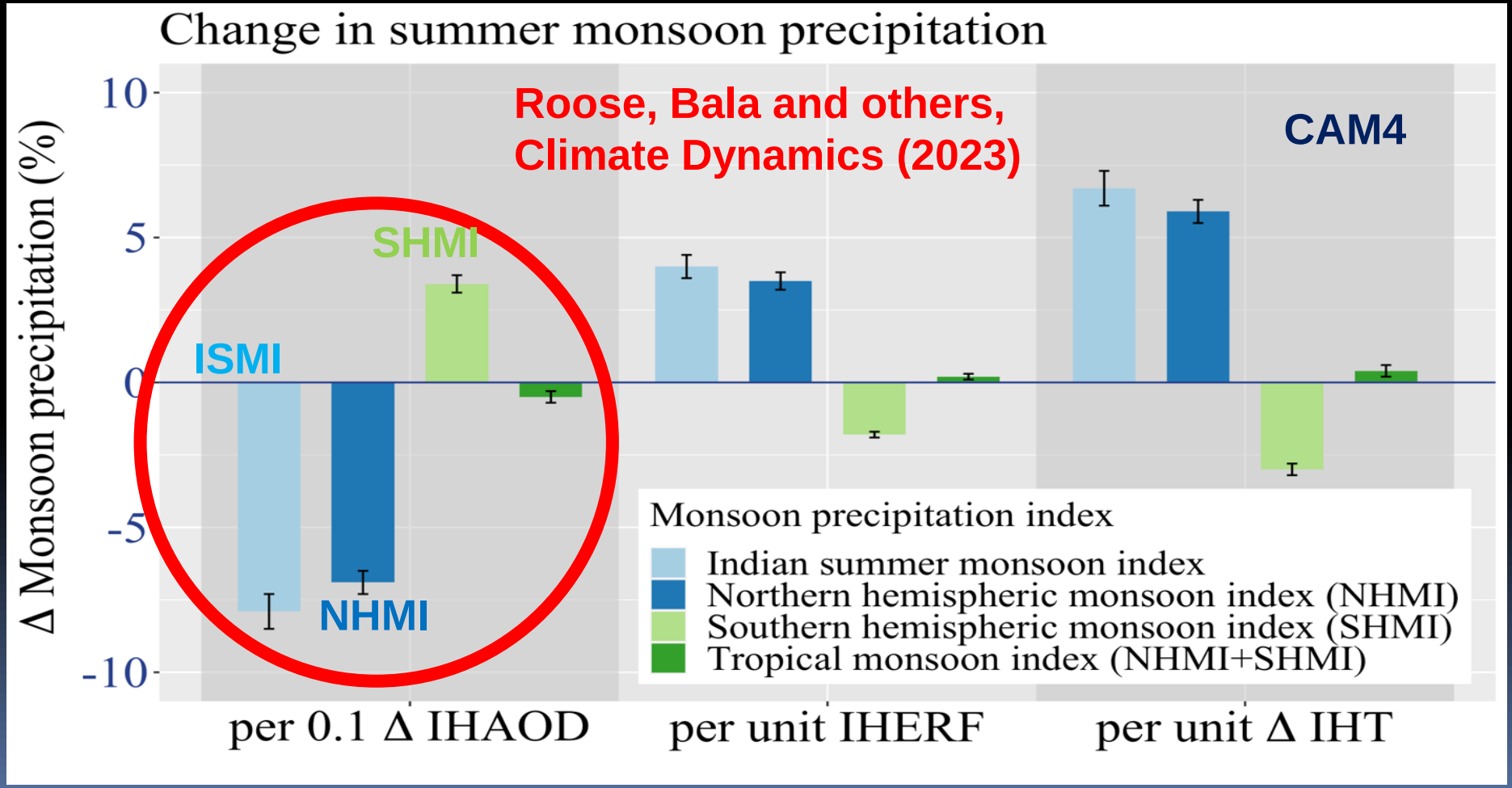


Tropical monsoon precipitation shows little sensitivity to the symmetric cases but large sensitivity to the asymmetric (Arctic and Antarctic) cases

Roose, Bala and others, Climate Dynamics (2023)

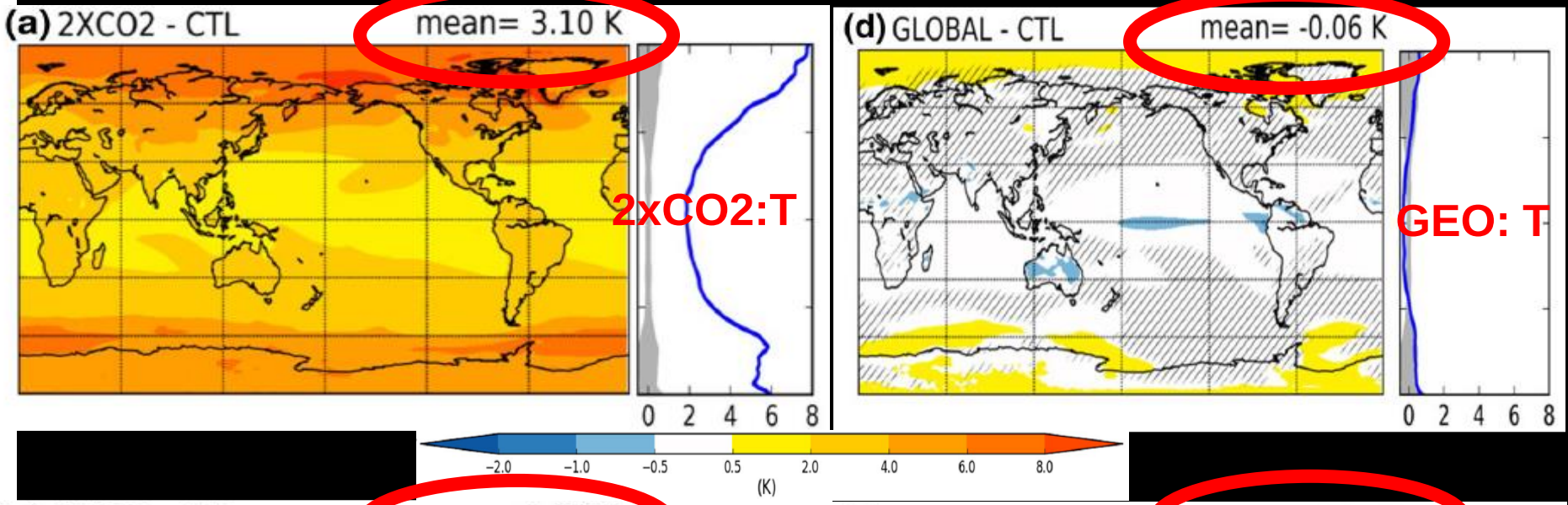
Summary of the results

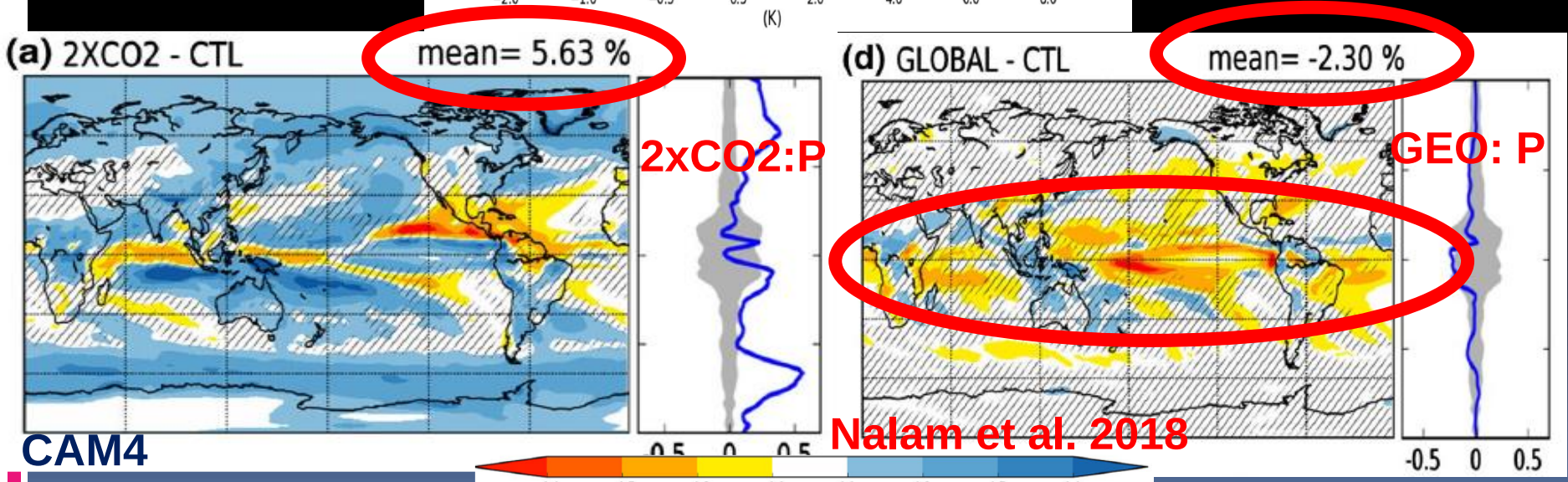
Tropical monsoon rainfall changes per unit interhemispheric differences in AOD, radiative forcing and temperature



Mechanism 2: Change in Global mean AOD would also affect monsoon rainfall

Overcompensation of precipitation when global warming is fully offset by uniform distribution of aerosols around the planet





CAM4

Nalam et al. 2018

Mechanism 1+2: Change in Interhemispheric difference in AOD and change in global mean AOD

New work combines the first two mechanisms

We express the global and regional tropical monsoon precipitation changes in terms of global mean AOD (AOD_N+AOD_S) and interhemispheric difference in AOD (AOD_N-AOD_S)

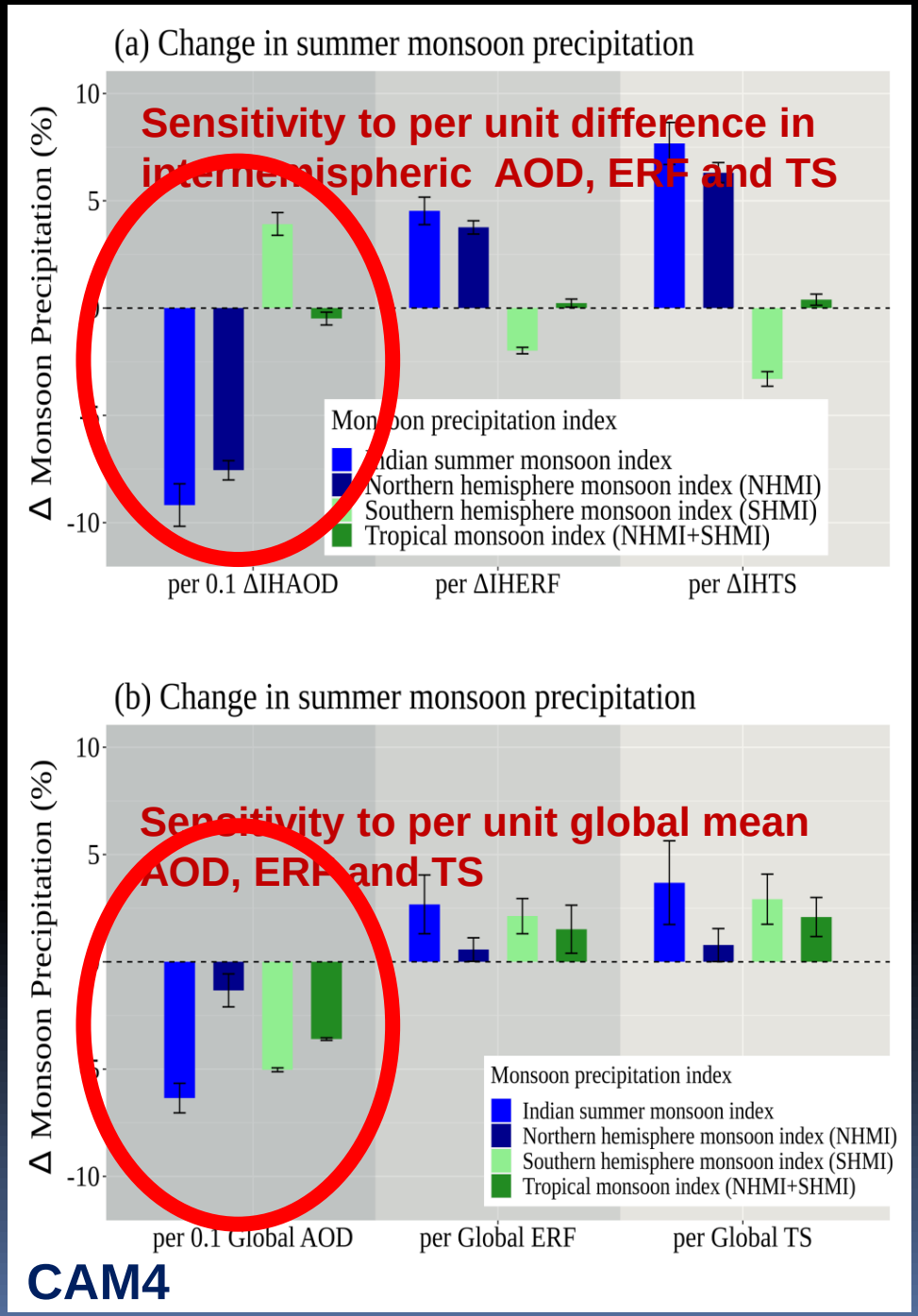
$$\Delta P\ (\%) = a(AOD_N+AOD_S) + b(AOD_N-AOD_S) + r$$

How good is this relationship for reflective aerosols placed at a specific height in the stratosphere?

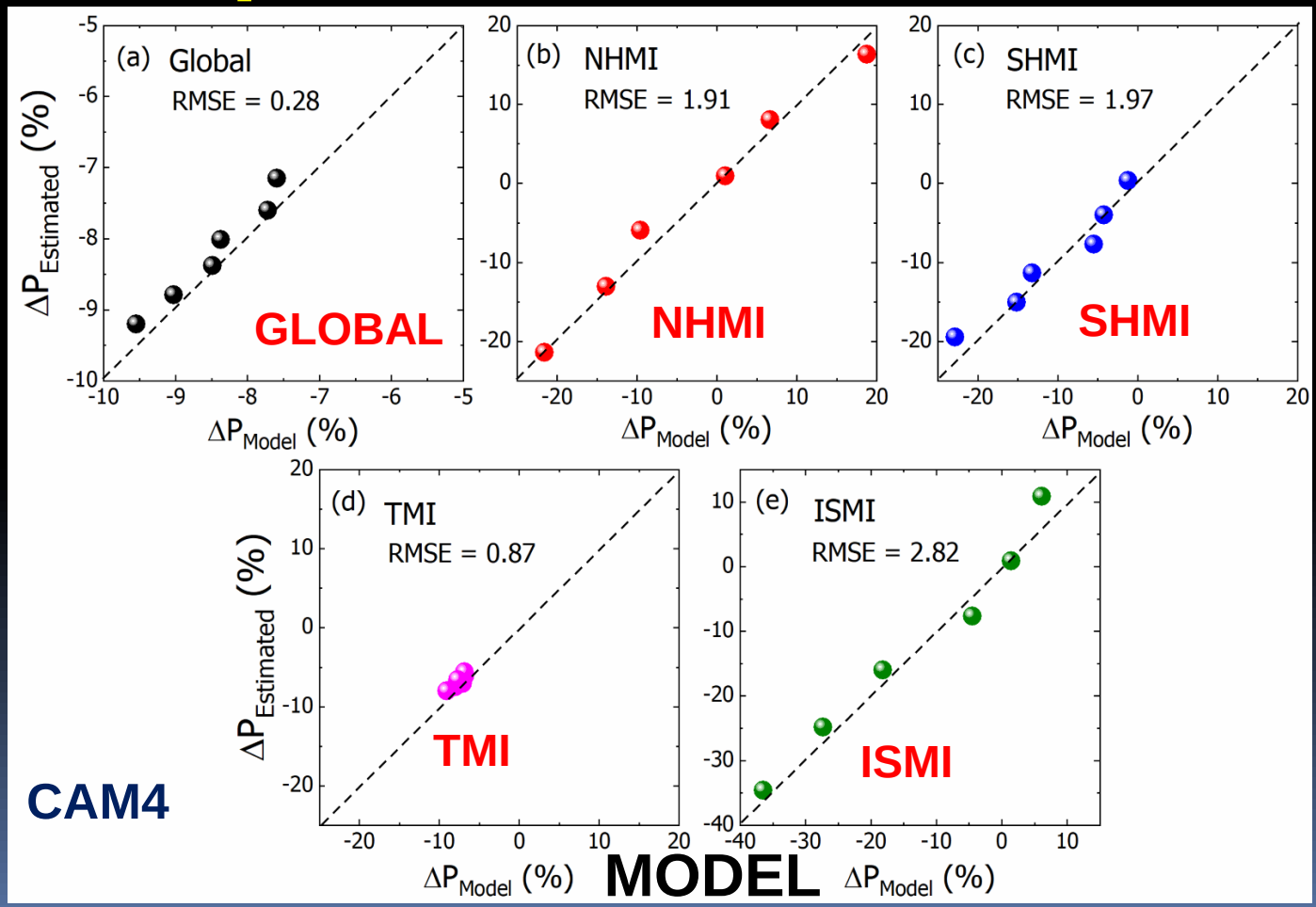
Sensitivity of tropical monsoon precipitation indices to the

(a) interhemispheric AOD, effective radiative forcing (Wm^{-2}), and temperature (K) differences

(b) global AOD mean, global mean ERF (Wm^{-2}) and global mean TS (K)



To a good accuracy (within 2%), monsoon precipitation changes are determined by just 2 parameters: Global mean AOD and Interhemispheric difference in AOD



Mechanism 3: Sensitivity of the hydrological cycle to the altitude of the aerosols

Mechanism 3: Heating in the aerosol layer could increase the vertical stability and reduce rainfall in the tropics when aerosols are placed near the tropopause

OPEN ACCESS
IOP Publishing
Environmental Research Letters
Environ. Res. Lett. 9 (2014) 014001 (7pp)
doi:10.1088/1748-9326/9/1/014001

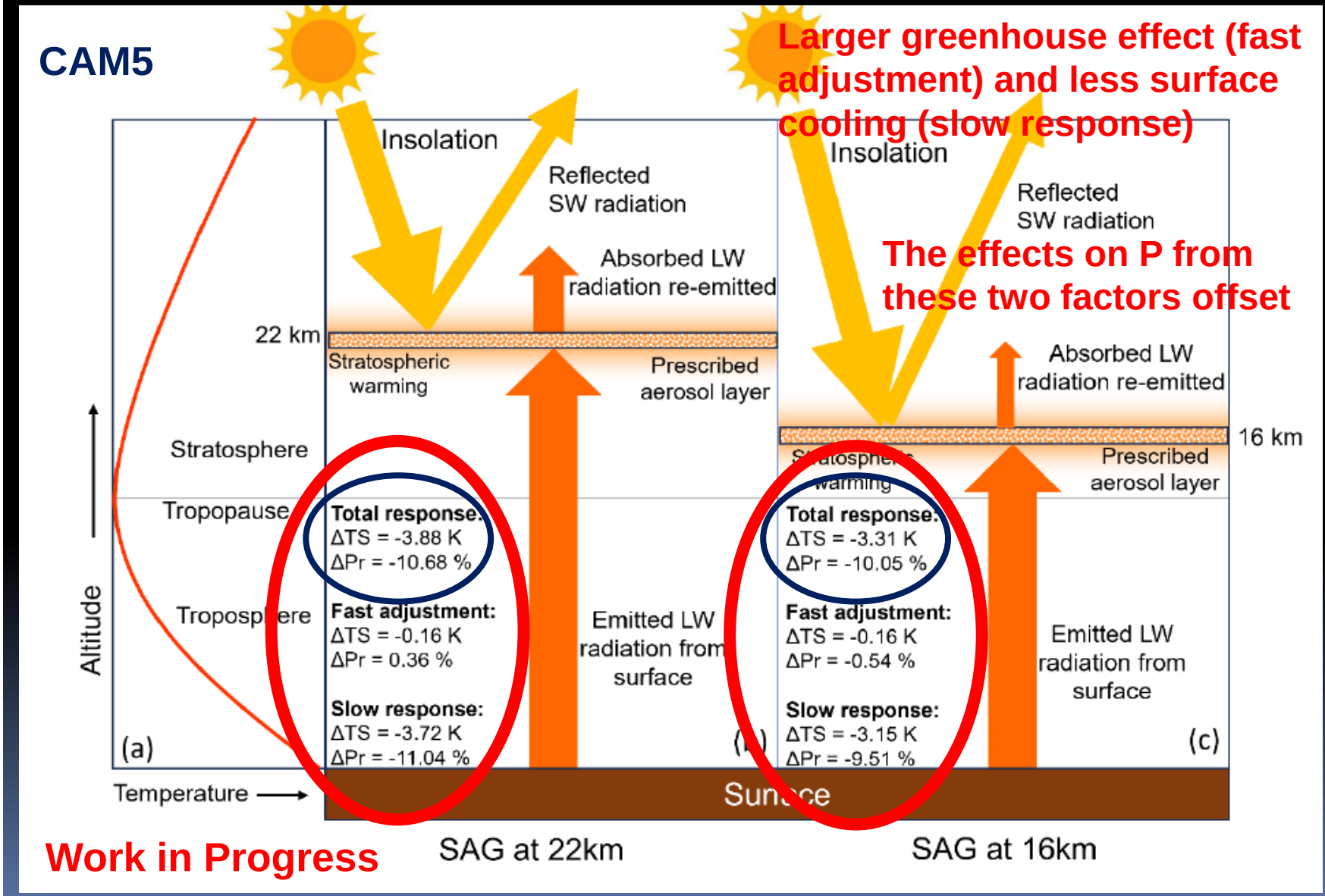
Weakened tropical circulation and reduced precipitation in response to geoengineering

Ferraro et al. 2014

Angus J Ferraro, Eleanor J Highwood and Andrew J Charlton-Perez

Heating would depend on the aerosol type, size and the height of the aerosol layer

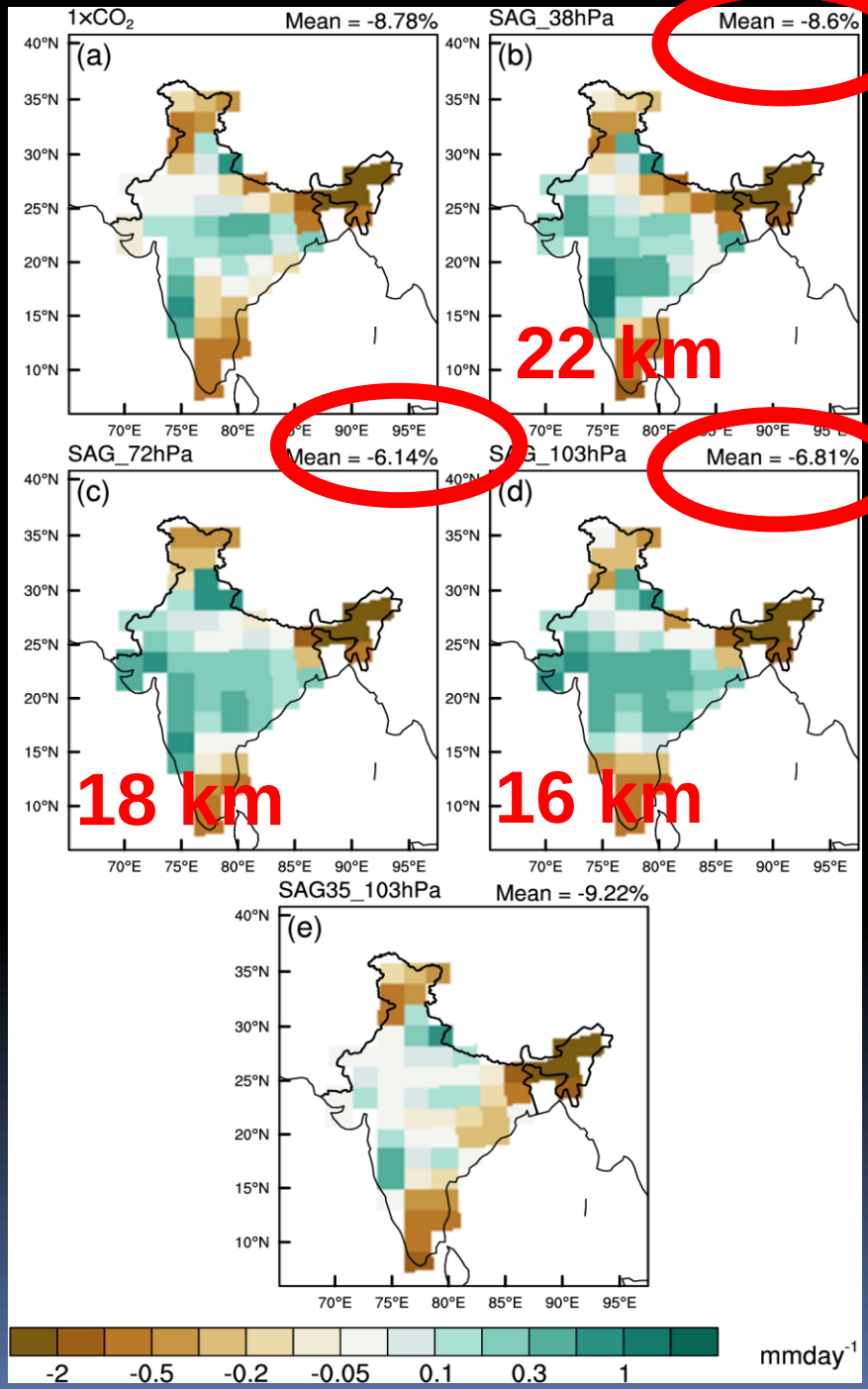
However, little precipitation sensitivity to the altitude of sulfate aerosol layer



Indian monsoon rainfall shows little sensitivity to the altitude of the sulfate aerosol layer in the stratosphere

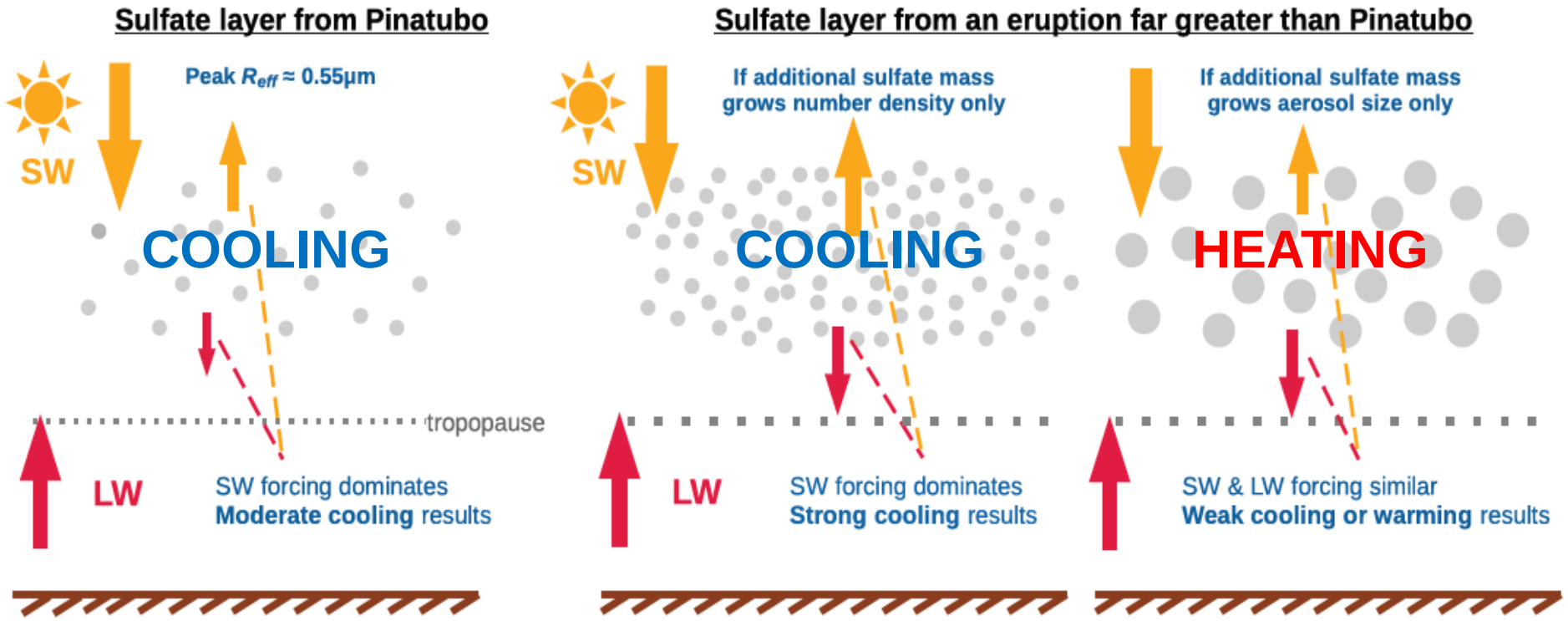
Work in Progress

Panels show only the aerosol effect



A range of outcomes is possible when massive amount of SO_2 is injected into the stratosphere

15 FEBRUARY 2024 MCGRAW ET AL. Journal of Climate 1455



We need to understand a lot more and hence more research is needed

Key Messages

- Interhemispheric differences in AOD caused by SAI can disrupt the latitudinal position of ITCZ and monsoons. Risk can be avoided by injecting aerosols at the equator or at multiple latitudes so the aerosol distribution is globally uniform.
- Global mean AOD: an increase would cause a decrease in monsoon rainfall. Sensitivity to sulfate aerosols is larger than for CO2. Moderate SG deployment can help to avoid this problem
- Altitude of Aerosols: Precipitation shows little sensitivity to the height of the sulfate aerosol layer in the stratosphere. This is because of the compensation between fast and slow responses in precipitation when the height of the aerosol layer is altered

Way Forward

- Investigation using more realistic model simulations (Coupled models, aerosol injections, aerosol microphysics, aerosol transport, aerosol-cloud interactions, etc.)
- Sensitivity of monsoon precipitation to the size of aerosol particles?
- Sensitivity to the type (optical properties) of aerosol particles?
- How monsoon variability is altered?
- Assessment of robustness using multiple models.
- Assessment of uncertainty?

For more details, visit our poster today and tomorrow:

"Stratospheric Aerosol Geoengineering and Tropical Monsoon Precipitation: Climate Modelling Research at IISc" by G. Bala and KH Usha