Association of aerosols in the Asian summer monsoon anticyclone with Indian summer monsoon rainfall

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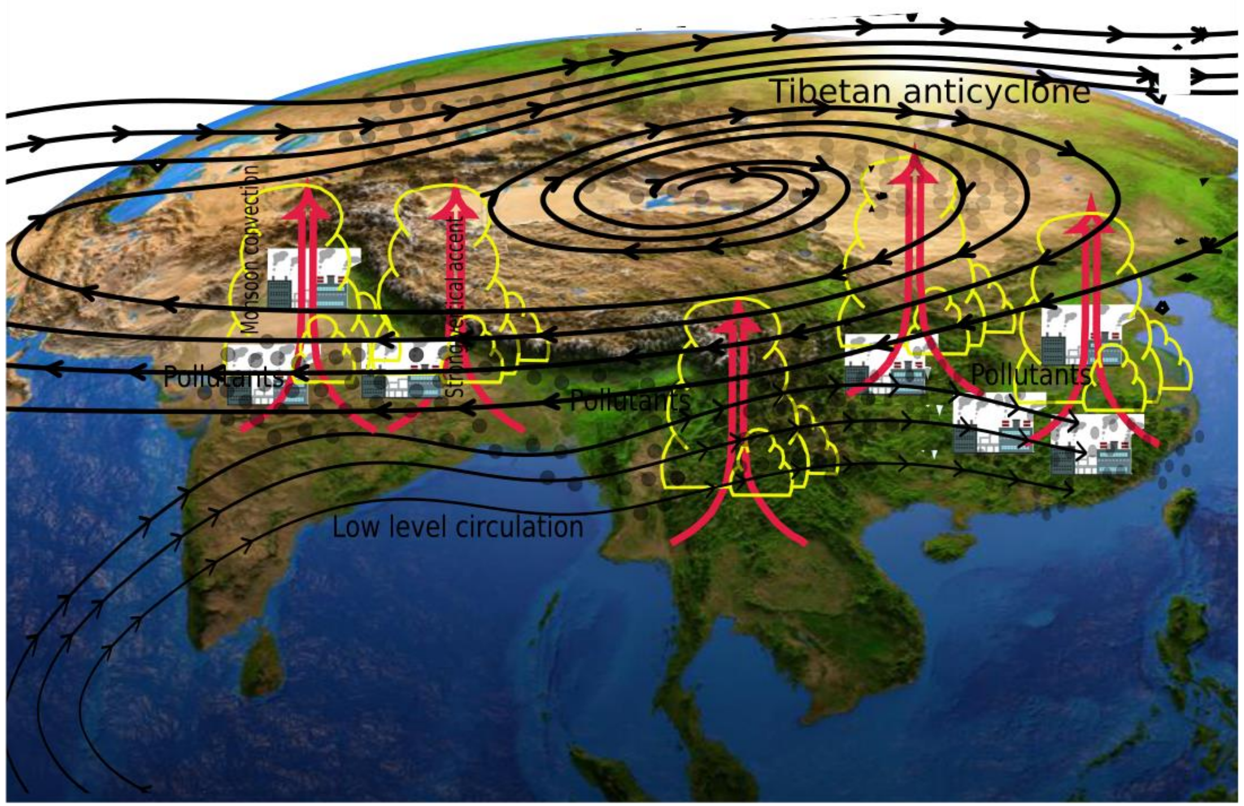
Outline of the talk

- Anthropogenic aerosols
- Volcanic aerosols
- Transport of aerosols from the ASMA to the rest of the word

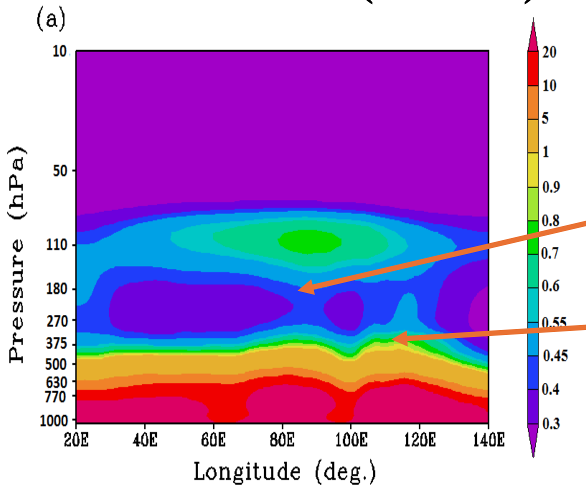
Asian Summer Monsoon Anticyclone (ASMA)

Pollution transport into the monsoon anticyclone



The ECHAM-HAMMOZ chemistry-climate model simulations

BC distribution (60-120E)

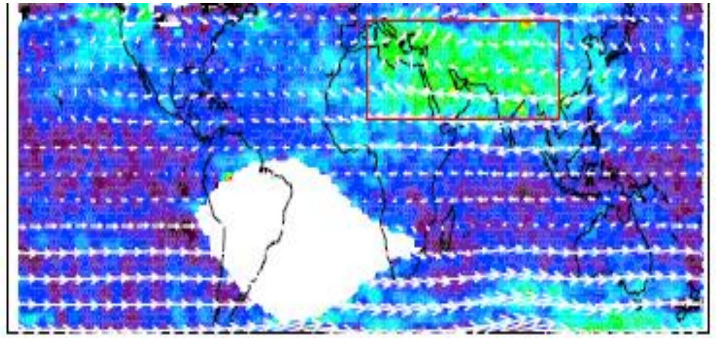


- Transport into the ASMA occurs via two branches:
- (1) over South Asia
- (2) over East Asia

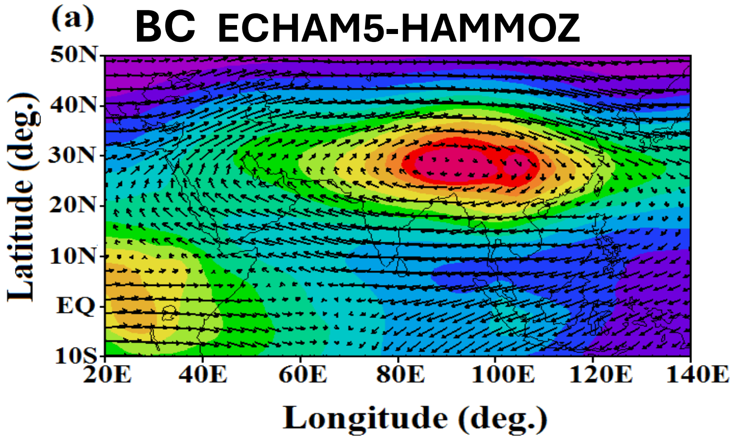
- **Asian summer monsoon convection is important in transporting boundary layer pollutants from Asia to the ASMA.**

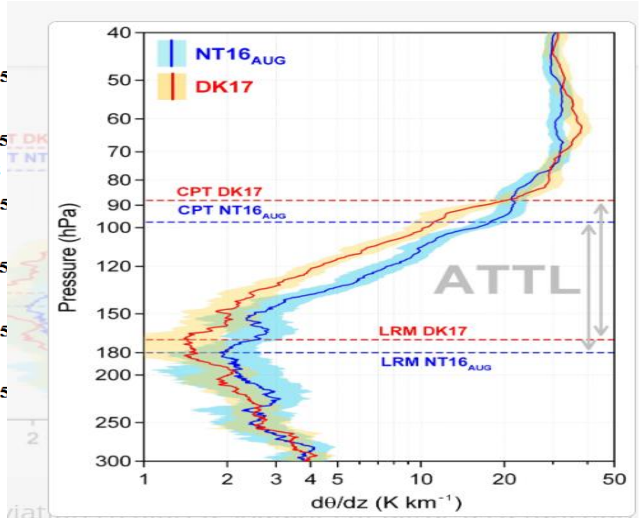
Aerosols into the monsoon anticyclone

CALIPSO 15 - 17 km (Jul-Aug 2006)

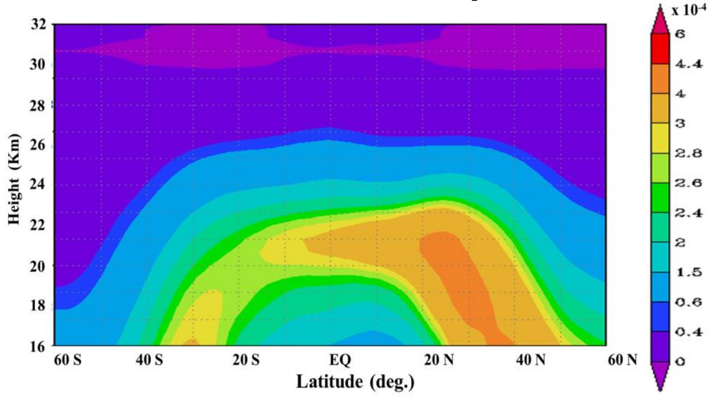


adopted from Vernier et al., 2015

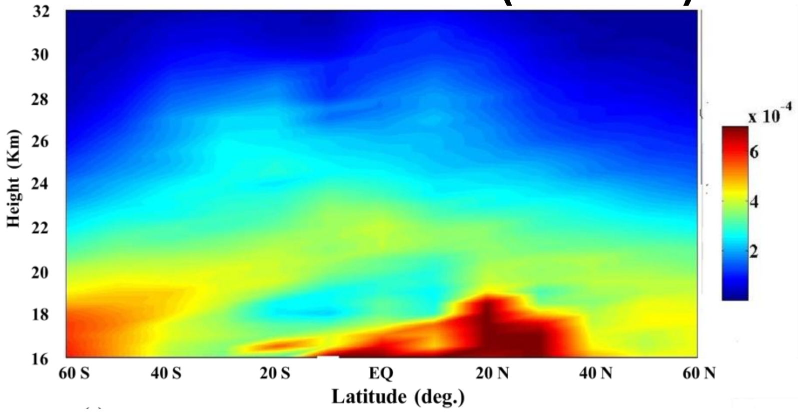




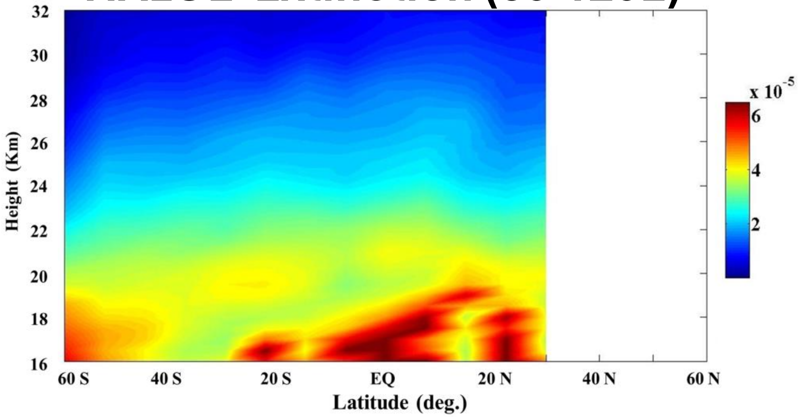
ECHAM Extinction (60-120E)



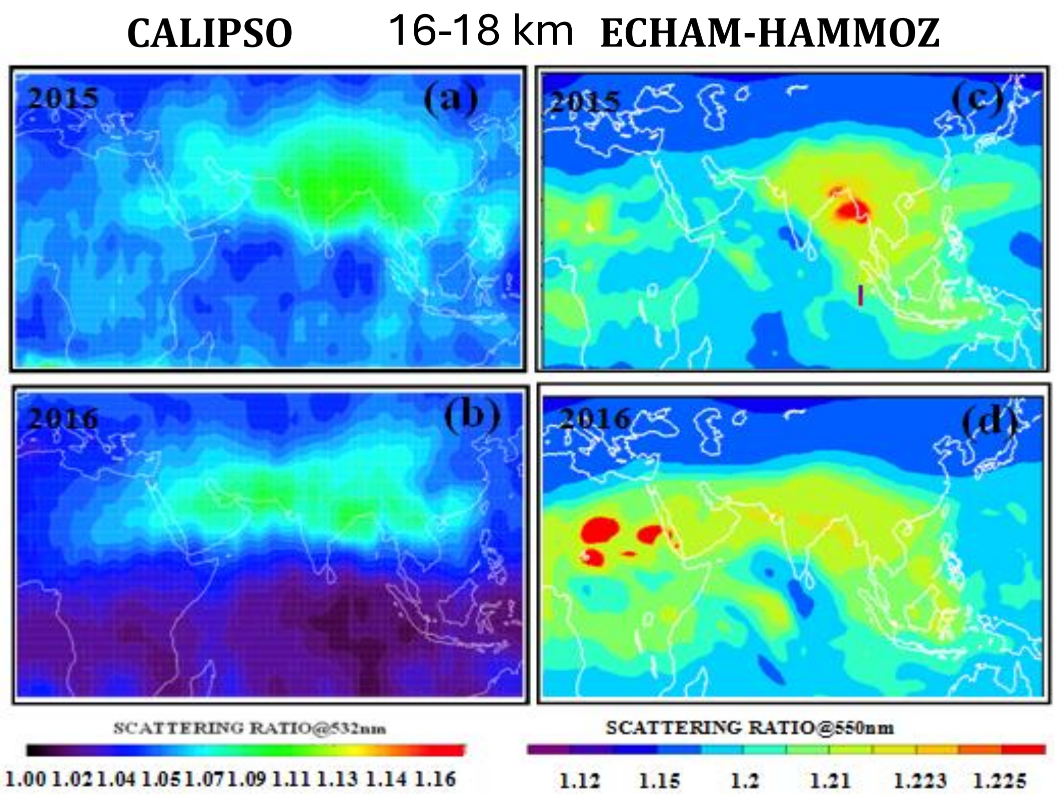
SAGEII Extinction (60-120E)



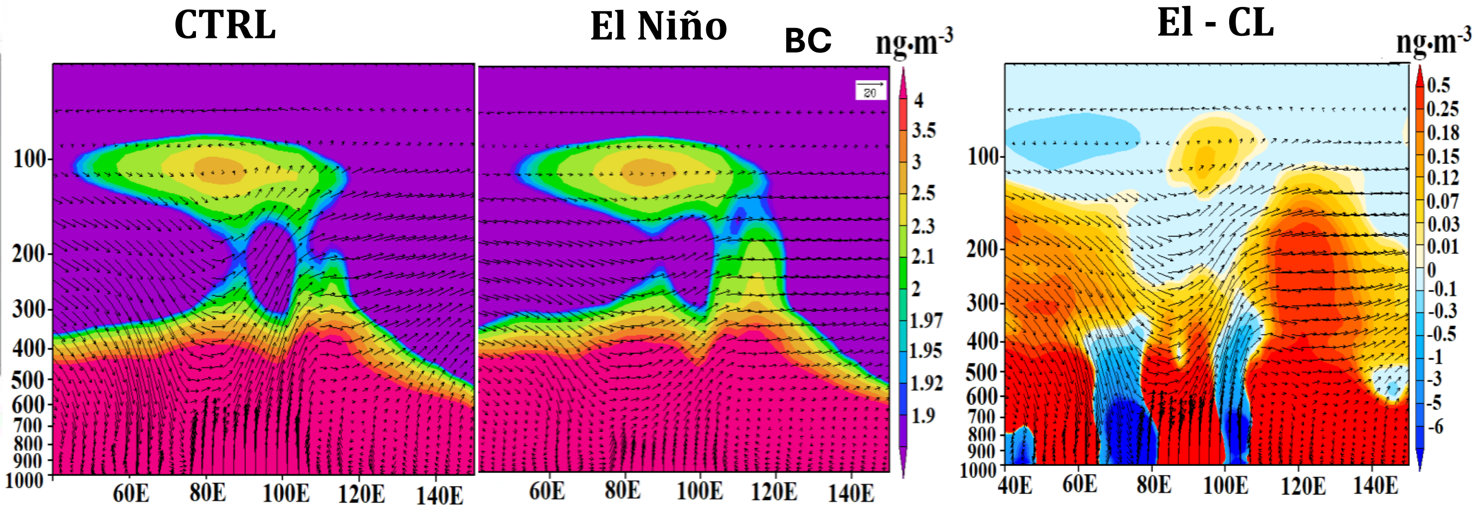
HALOE Extinction (60-120E)



Elevated aerosol layer over South Asia: Indian droughts during El Niño



- ❖ **During El Niño, the ATAL is thicker and centered over the Indian region.**
- ❖ **The ATAL is widespread and thinner during a normal year.**



- ➢ **Aerosols in the ATAL are transported from (1) South Asia and (2) East Asia.**
- ➢ **During El Niño, aerosols in the ATAL are mostly from East Asia.**

Fadnavis et al., Sci. Reports, 2019

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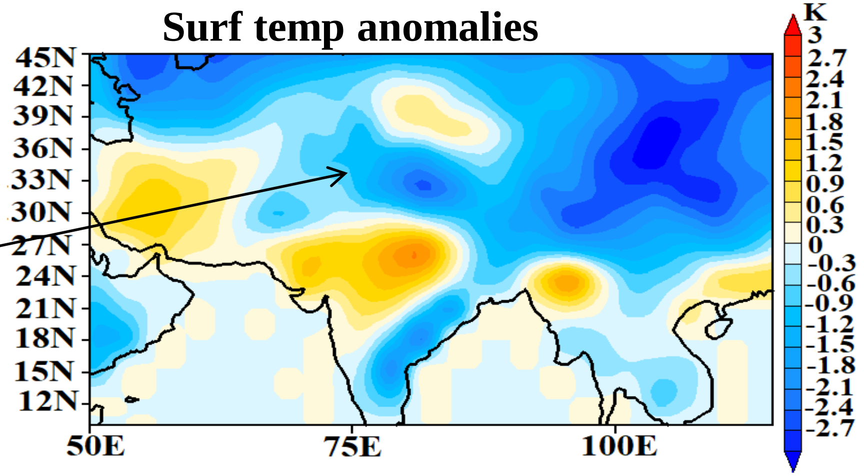
Impact of aerosol layer during El Niño

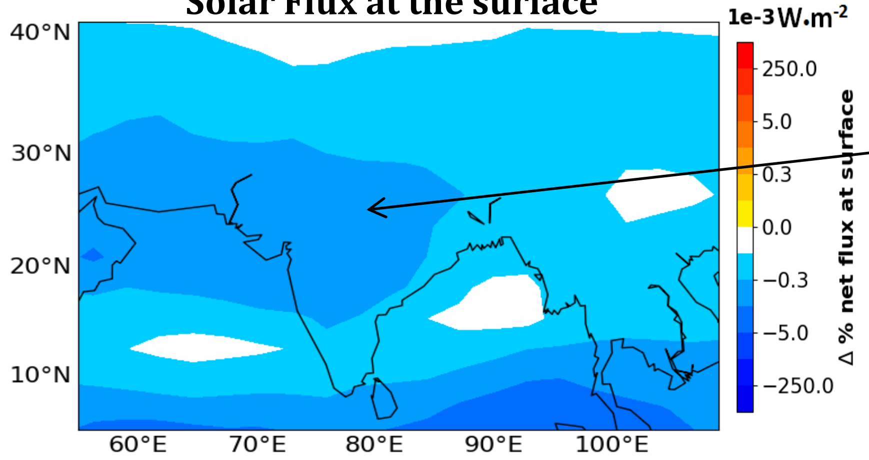
Aero-on EL-CL

Surf temp anomalies



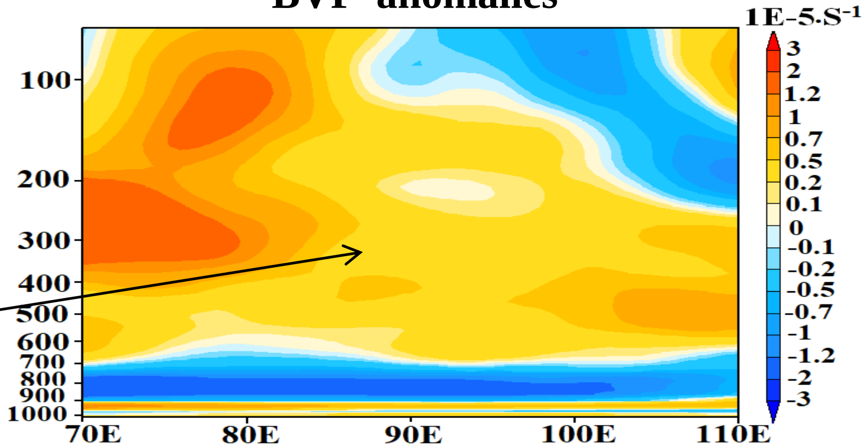
Surface cooling over the IGP

Solar Flux at the surface



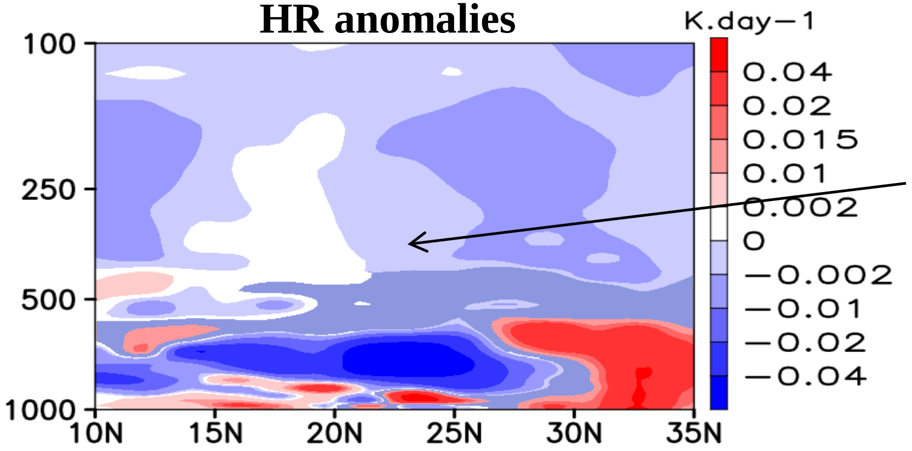
Reduction in solar radiations at the surface.

BVF anomalies



Stability in the troposphere over the Indian region

HR anomalies

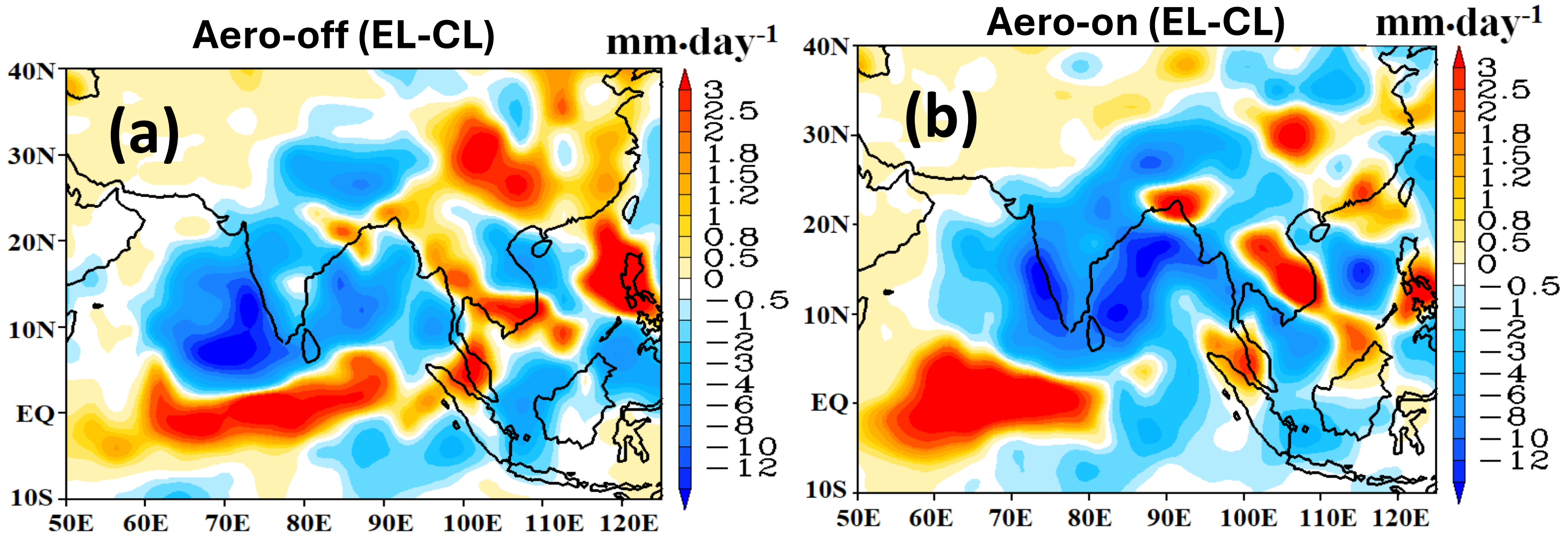


Tropospheric cooling

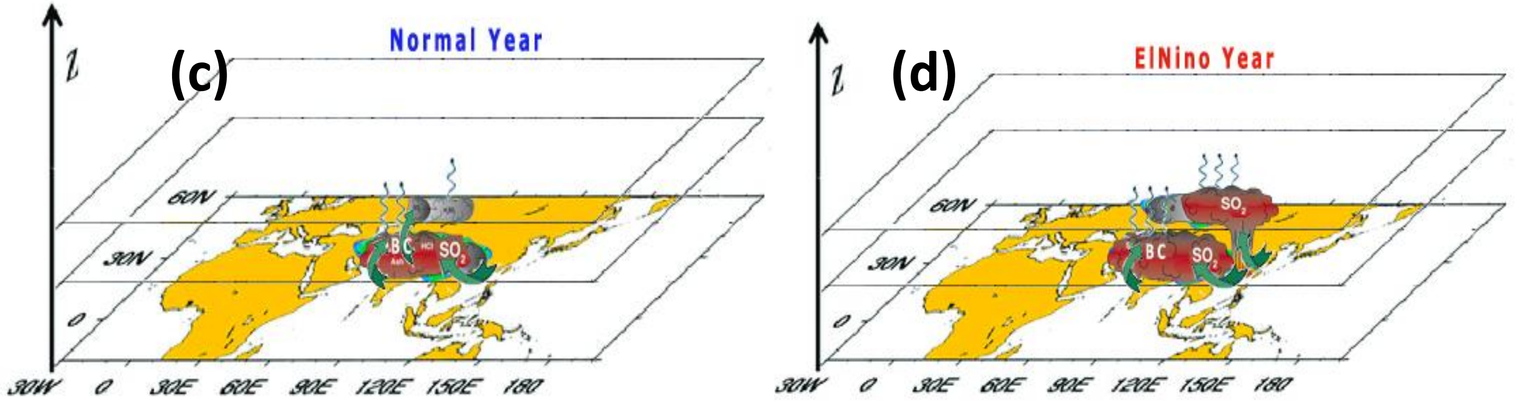
The Aerosol Layer over South Asia caused surface cooling, reduction in solar radiations, increased stability of the troposphere, and cooling of the troposphere.

Fadnavis et al., Sci. Reports, 2019

Impact on precipitation during El Niño



The changes in aerosols exacerbated the severity of droughts during El Niño (rainfall reduction by 17%).

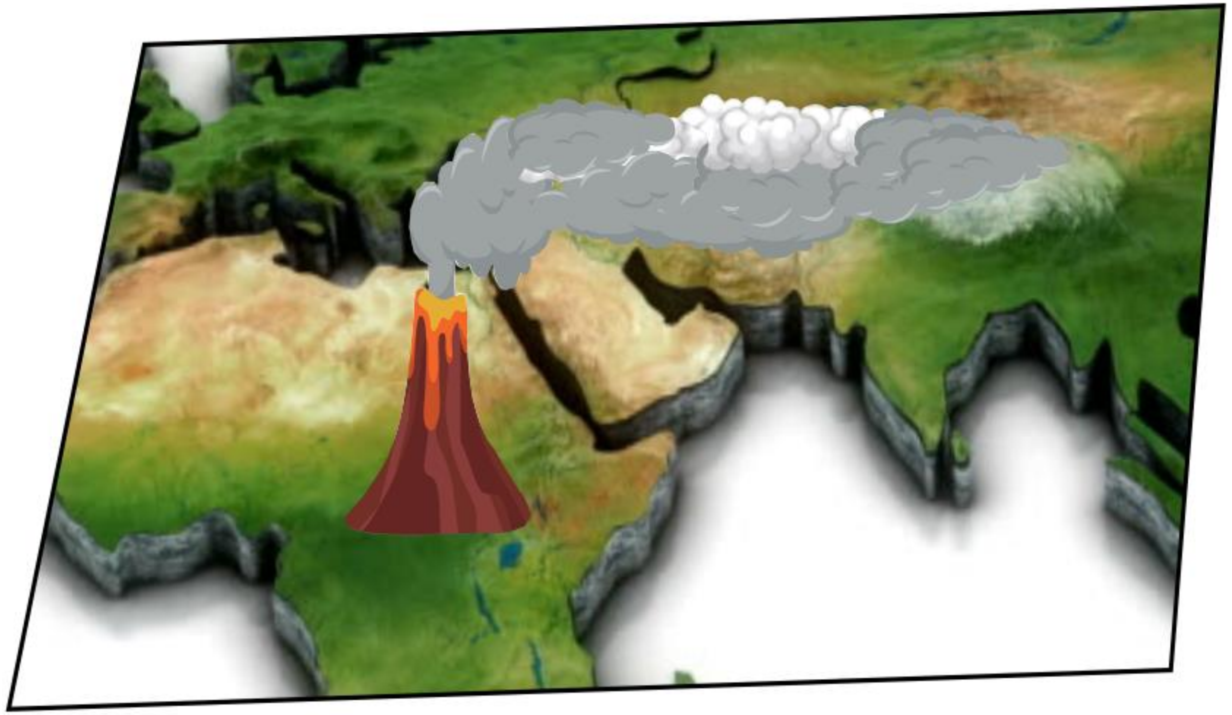


- ❖ The added blanket of aerosol layer leads to a weakening of the monsoon Hadley circulation.
- ❖ The anomalous large-scale subsidence results in amplifying the severity of monsoon droughts.

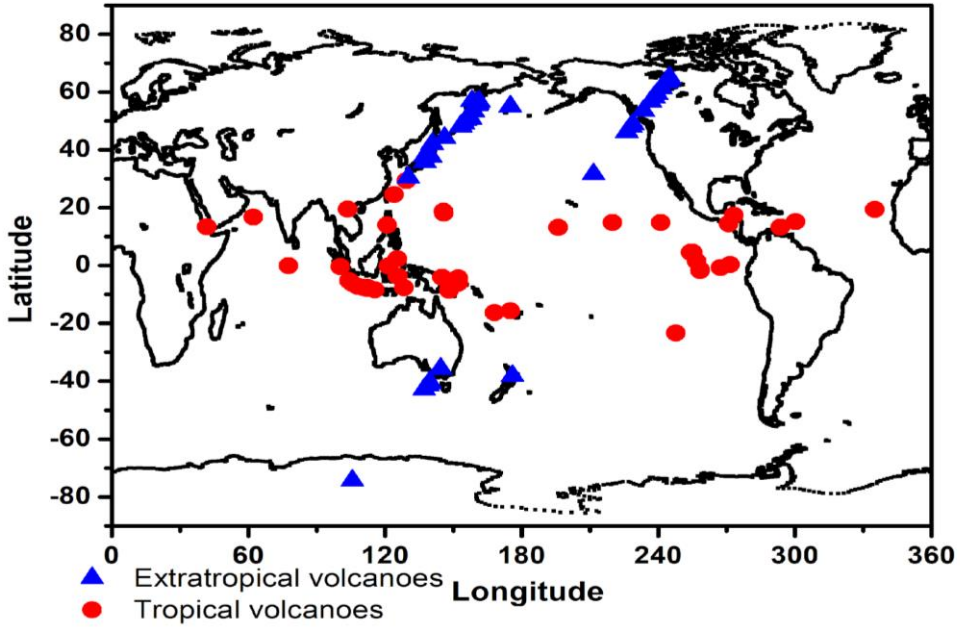
Fadnavis et al., 2019

Tropical volcanoes : implications on Indian droughts

Tropical volcanic eruption



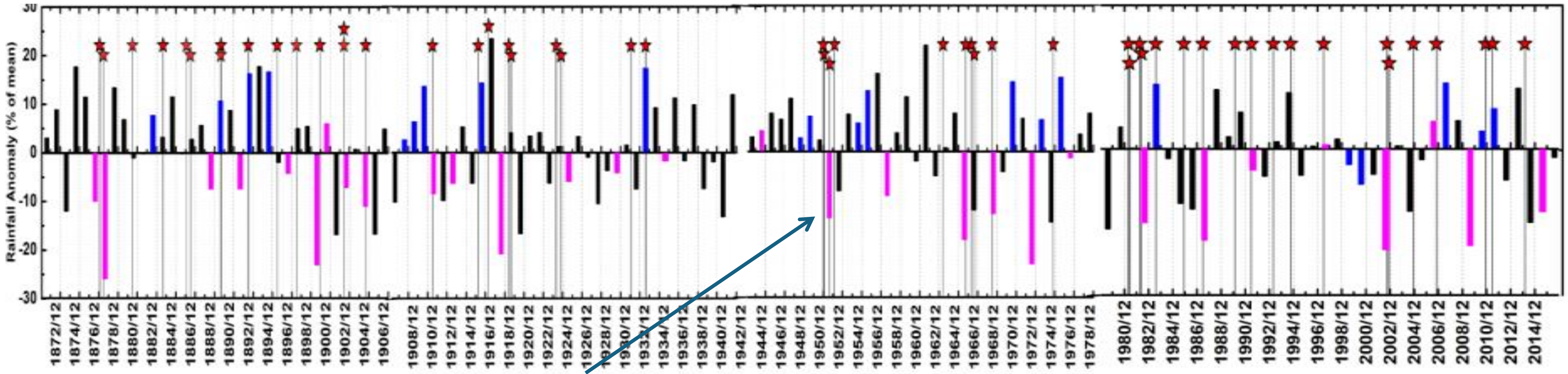
Location of tropical/ extra-tropical Volcanoes



During 1871 – 2016 (145 Years)

Fadnavis et al., Sci Rep. 2021

Tropical volcanoes and Indian summer monsoon



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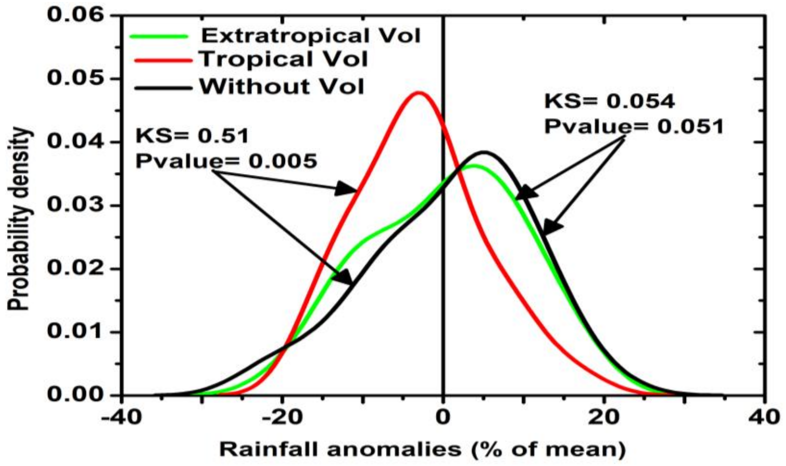
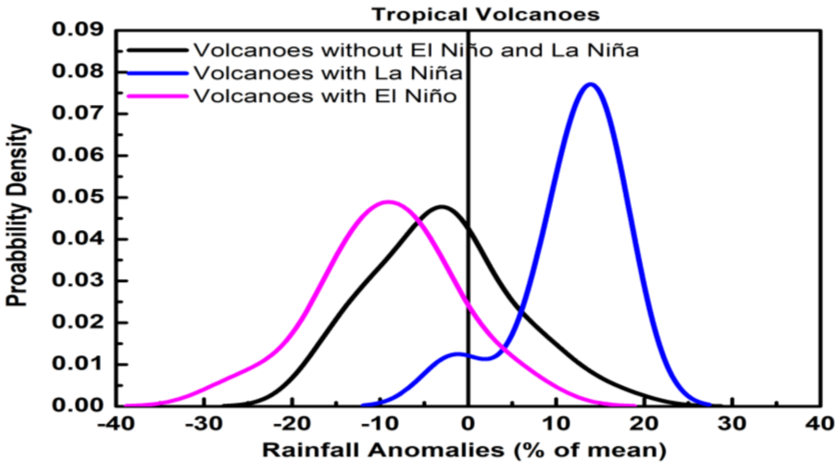
India meteorology rain gauge data

Time series of June–September mean precipitation anomaly (%) during 1871 –2016 along with tropical (30ºS-30N) volcanic eruptions indicated with stars.





Probability distribution of rainfall anomalies within two years of volcanic eruption during El Niño, La Niña, and normal years.

Simulation of NABRO volcano: ECHAM6-HAMMOZ and MPI-ESM

- **We performed Nabro volcano and control simulations starting from 1 to 10 January 2011 to obtain a 10-member ensemble mean. These simulations ended on 31 December 2013. In all 10 members of simulations, 1.5 Tg of SO_2 was injected at 42 °E, 13 °N on 12 June 2011.**

- **Simulations indicate that the Nabro volcanic plume formed a thick aerosol layer in the UTLS over the Indian region lasting up to October 2012.**

- **The volcanic aerosol partially enters the monsoon anticyclone, causing a thickening of the ATAL during monsoon 2011 (July-August-September).**

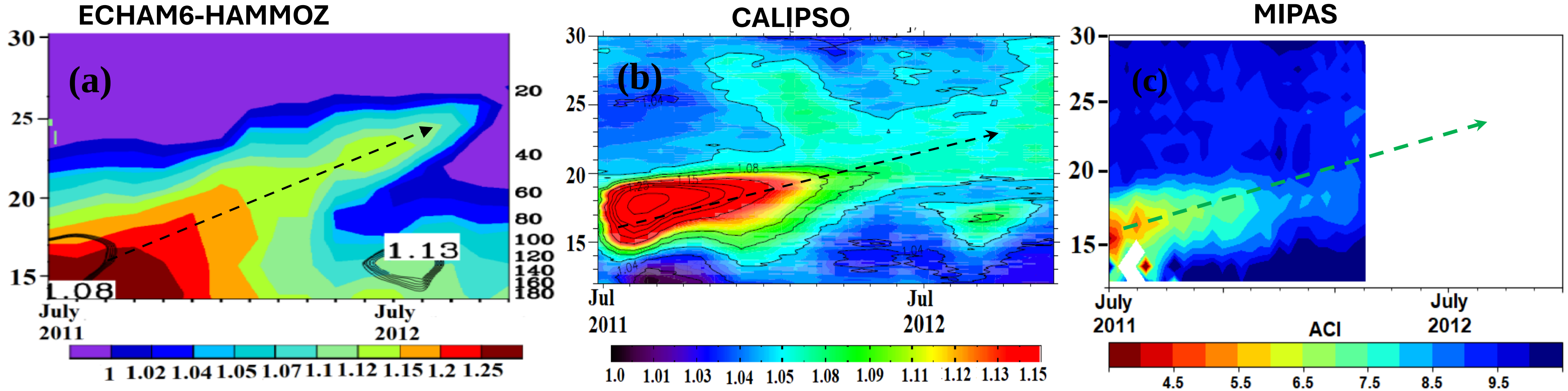
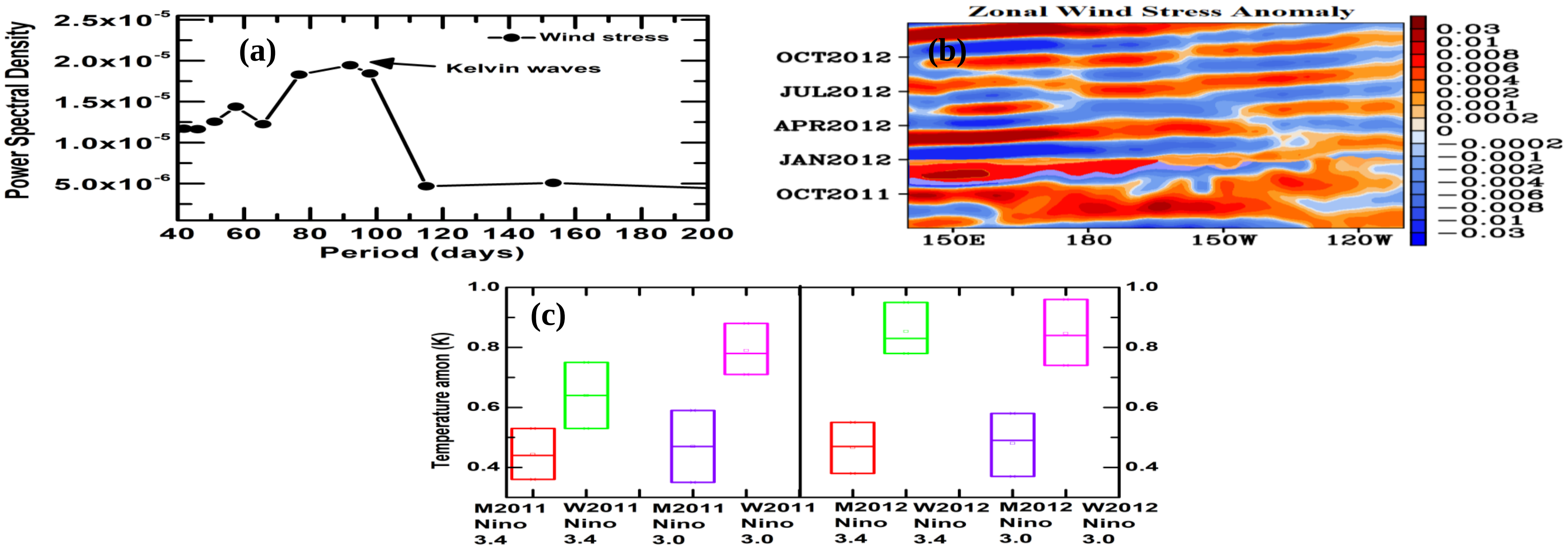


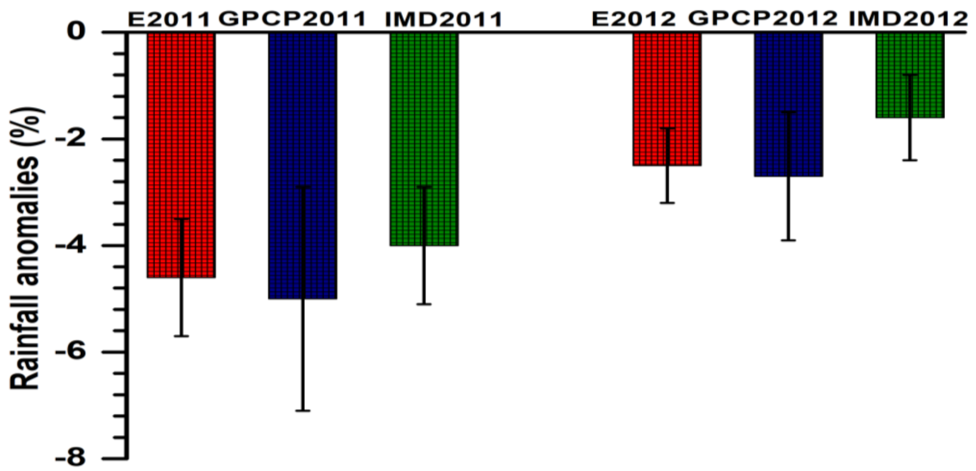
Fig.: Scattering ratio (532nm) vertical distribution during July 2011 – November 2012 averaged over India (70 – 95 °E; 10 – 30 °N), (a) ECHAM6-HAMMOZ (b) CALIPSO, and Aerosol cloud index (ACI) estimates from MIPAS (c).

Association of volcanic eruptions with ENSO



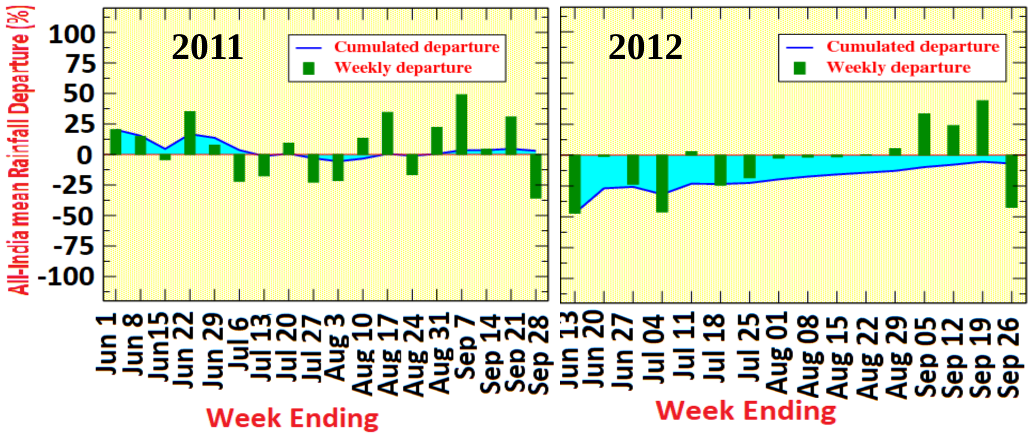
- **The surface cooling over the Indian region induced by the aerosol layer from Nabro caused an atmospheric westerly wind anomaly in the central Pacific in July 2011 after the eruption.**
- **This wind anomaly resulted in downwelling equatorial oceanic Kelvin waves through air-sea interactions and eventually drove a surface warming in the central Pacific from July 2011 to February 2013.**
- **The simulations also show that warming due to Kelvin wave dissipation is stronger in the following year (monsoon and winter seasons in 2012) than the year of volcanic eruption (monsoon and winter seasons in 2012).**

Reduction in Indian summer monsoon precipitation



Distribution of anomalies (Vol-CTL) of rainfall (%) (averaged for Indian region and for monsoon 2011 and monsoon 2012 from MPI-ESM, Global Precipitation Climatology Project (GPCP), India Meteorology Department (IMD).

India meteorology rain gauge data



Weekly departure of rainfall for the monsoon in 2011, and 2012 show a reduction in Indian summer monsoon rainfall.

➢Nabro volcano has induced a reduction in precipitation over the Indian region by -4.6% (-4.85 mm day-1) in the 2011 monsoon and -2.5% (-3.12 mm day-1) in the 2012 monsoon.

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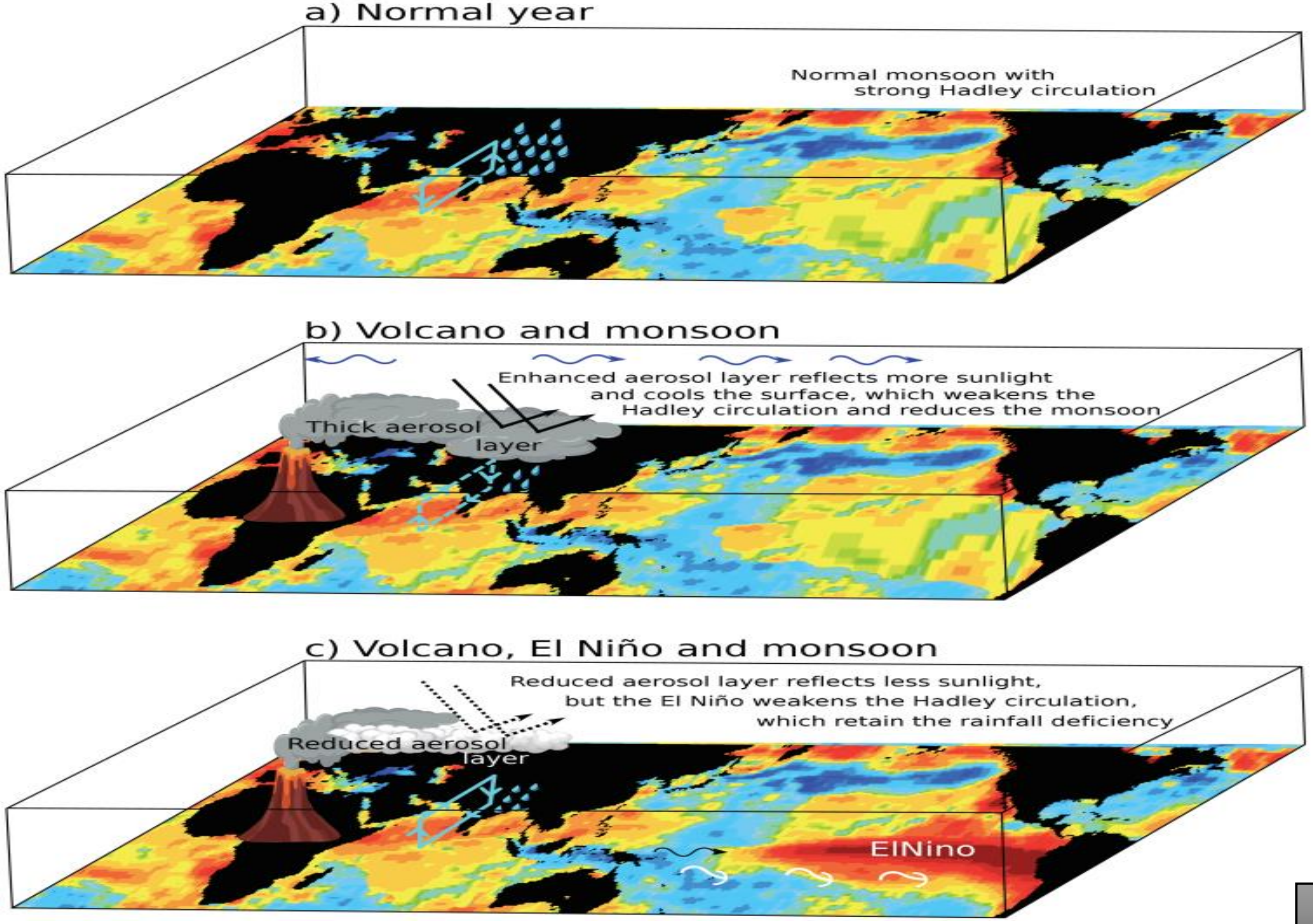
A schematic of the impact of volcanic eruptions on monsoon precipitation



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Long-range transport of South and East Asian anthropogenic aerosols into the ASMA

Experiments: (1) CTL: (2001-2016)
Anthropogenic aerosols are switched off over (2) South Asia (SAS0) (2001-2016), (3) East Asia (EAS0) (2001-2016)

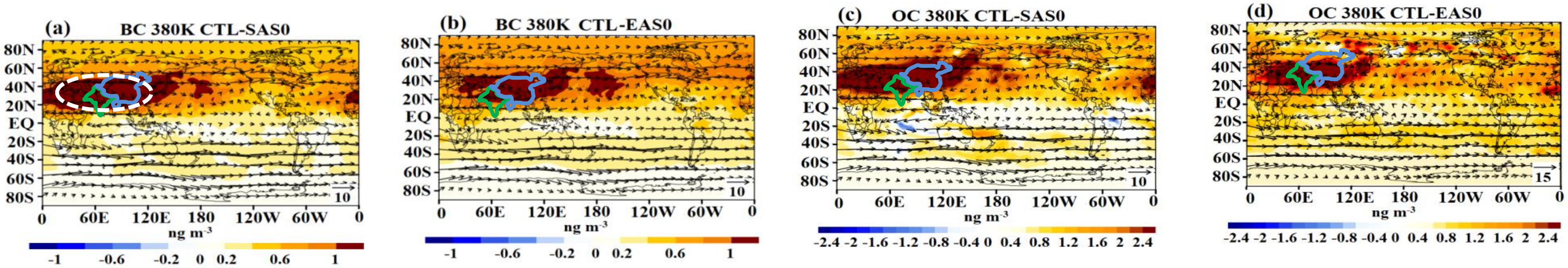

Fig: The spatial distribution of anomalies of BC (ng m-3) at 380 K potential temperature level for (a) South Asian (CTL - SAS0), (b) and East Asian (CTL - EAS0), (c-d) same as (a-b) but for OC, (e-f) same as (a-b) but for sulfate aerosols.

- The vertical extent of heat–driven convection at the southern slopes of the Himalayas seems to extend to higher altitudes than in East Asia which plays an important role in lifting South Asian aerosols deep into the UTLS

- Figure 1a-d shows that the amounts of aerosols in the monsoon anticyclone are larger for South Asia than for East Asia.

Fadnavis et al., NPJ. 2024

Long-range transport of South and East Asian anthropogenic aerosols into the Arctic

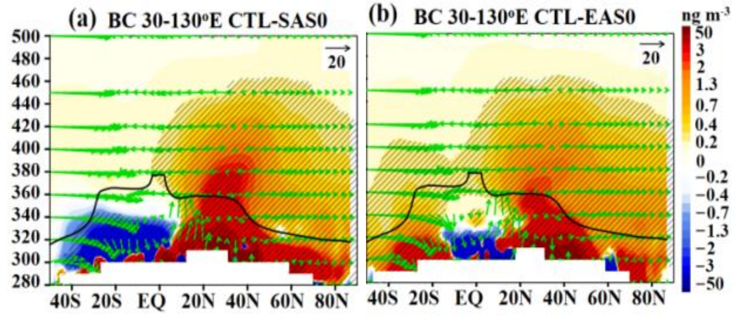

Fig: Latitude Potential Temperature section of anomalies of BC aerosols (ng m-3) for South Asia (CTL-SAS0) and East Asia (CTL-EAS0)

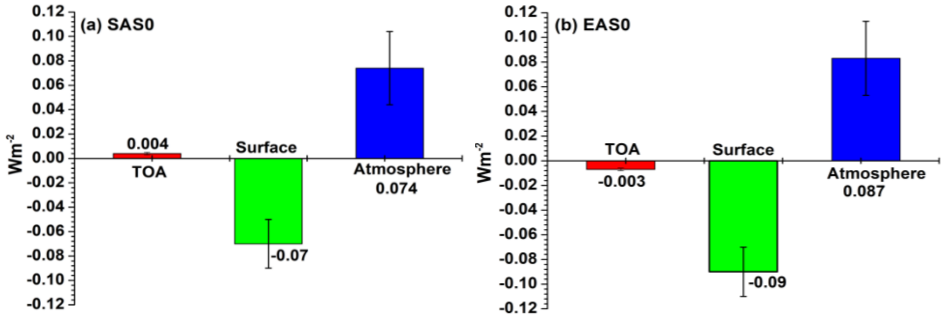

Fig: ECHAM6-HAMMOZ model estimated anomalies of seasonal mean net Radiative Forcing (RFari) (W m^{-2}) at the TOA and Surface and in the atmosphere over the Arctic due to aerosol transport from (a) South Asia (CTL - SAS0) and (b) East Asia (CTL - EAS0).

- Aerosols are transported to the Arctic from the ASAM.
- Over the Arctic, the East Asian anthropogenic aerosols that include large amounts of sulfate cause a seasonal mean net radiative forcing at the top of the atmosphere (TOA) of -0.003±0.001Wm^{-2} and a surface cooling of -0.56 K
- while the black carbon dominated aerosol from South Asia shows a positive TOA forcing of +0.004 ± 0.001Wm^{-2} with an only minor surface cooling of -0.043 K.
- East and South Asian anthropogenic emissions contribute significantly to the aerosol transported to the Arctic, negative net RF at the surface of -0.09 ± 0.02 Wm^{-2} and -0.07 ± 0.02 Wm^{-2}, respectively.

Fadnavis et al., NPJ. 2024

A schematic depicting transport of aerosols from the ASMA to the Arctic

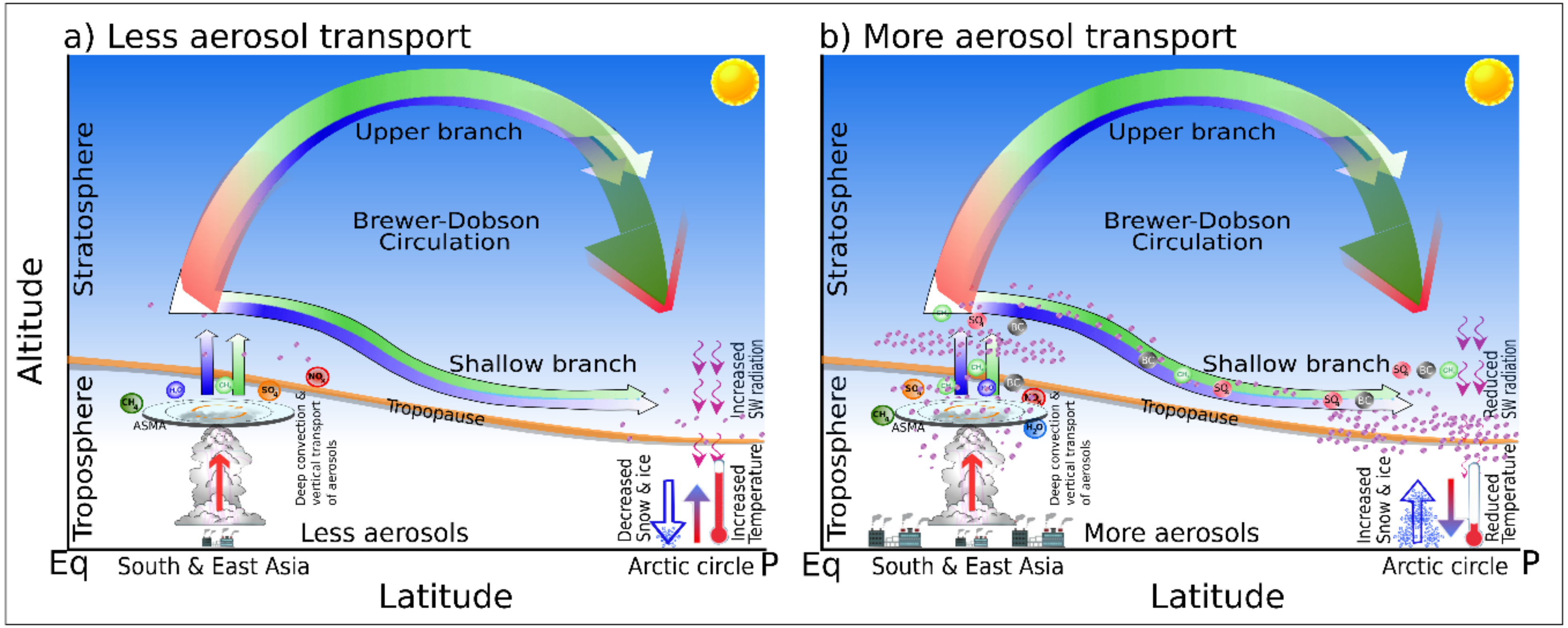

Fig: A schematic depicting monsoon convection transporting aerosols to the Asian summer monsoon anticyclone (ASMA) and to the Arctic by lower branch of brewer dobson circulation for model simulations with (a) anthropogenic aerosols over South/East Asia switched off (SAS0 or EAS0), less aerosol scenario and (b) anthropogenic aerosols over South/East Asia (CTL) relatively more aerosol scenario.

Fadnavis et al., NPJ. 2024

Conclusions

- **Asian pollutants enter the ASMA via two branches: (1) South Asia (2) East Asia.**
- **The aerosol layer in the UTLS over North India during El Nino forms a lid that causes solar insolation and decreases precipitation.**
- **Tropical volcanoes form an aerosol layer over India. It causes tropospheric cooling, leading to down welling Kelvin waves (KW). KW dissipation in the central Pacific results in El-Nino like warming.**
- **The aerosol layer causes precipitation reduction in the year of volcanic eruption due to solar inhibition. The precipitation reduction in the next year of volcanic eruption is because of El Nino like warming and associated subsidence over India.**
- **South Asian aerosols lifted to the UTLS by the monsoon convection are also transport to the Arctic lower stratosphere**


Thank you!