Cloud Response to Short-term Sulfate Aerosol Forcing over the Tropics

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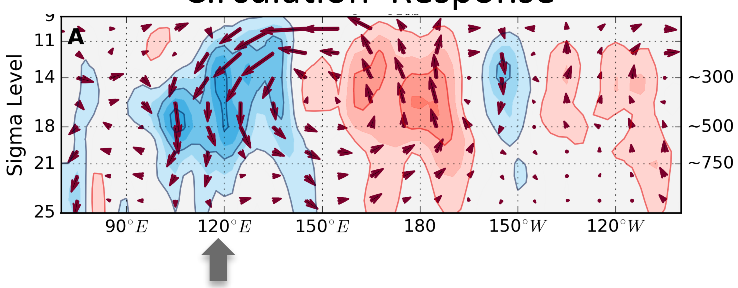
Goal/Importance

To examine **high cloud response** over tropical Indian ocean & maritime continent to increase in sulfate aerosols using a **fully coupled climate model**.

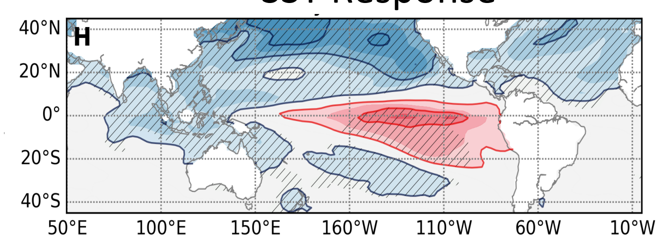
- strength of tropical convection
- how well are the tropical clouds represented in climate models
- can affect regional climate and circulation patterns in future climate (Voigt and Shaw, 2015)
- highly sensitive to aerosols' abundance (Tao et. al., 2012;Fan et. al., 2016;Altaratz et. al., 2014)
- atmospheric circulation response to sulfates can trigger tropical Pacific ocean dynamical response. (manuscript in preparation)

Circulation Response



Maritime Continent

SST Response



Background: Aerosols and Tropical High Clouds

- **Increased aerosol loading leads to taller clouds with larger anvils**
- warm rain suppression => condensates ascend higher => latent heat release at higher level => **convection invigoration** (Andreae et. al., 2004; Koren et. al., 2005)
- **stronger winds** causes larger spread and dilution of convective outflows (Koren et. al. 2010)
- **cloud microphysical processes** alone can explain increase in high cloud amount or macrophysical features (Fan et. al., 2013)
- **mixed phase clouds with warm base are more susceptible** to aerosol induced invigoration (Li et. al., 2011)

Removal of high frequency meteorological influences is fundamental to these studies.

How does **SST response** to short-term sulfate aerosol forcing affects,

- high cloud amount and
- precipitation

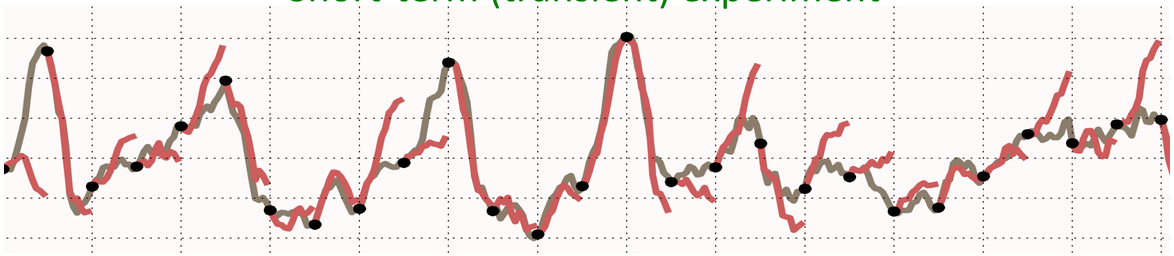
in the **presence of aerosol-cloud interactions (ACI)** over the tropics?

Model/Experiment Details

- CESM 1.1.2 – fully coupled
- Resolution – 2deg. atm/1deg. ocn
- Preindustrial control simulation
- Perturbation – present day sulfate aerosols
- CAM5 physics
- Aerosols –interactive(MAM3) and parameterized Aerosol-Cloud Interaction(ACI)

1850S 2000S

Short-term (transient) experiment

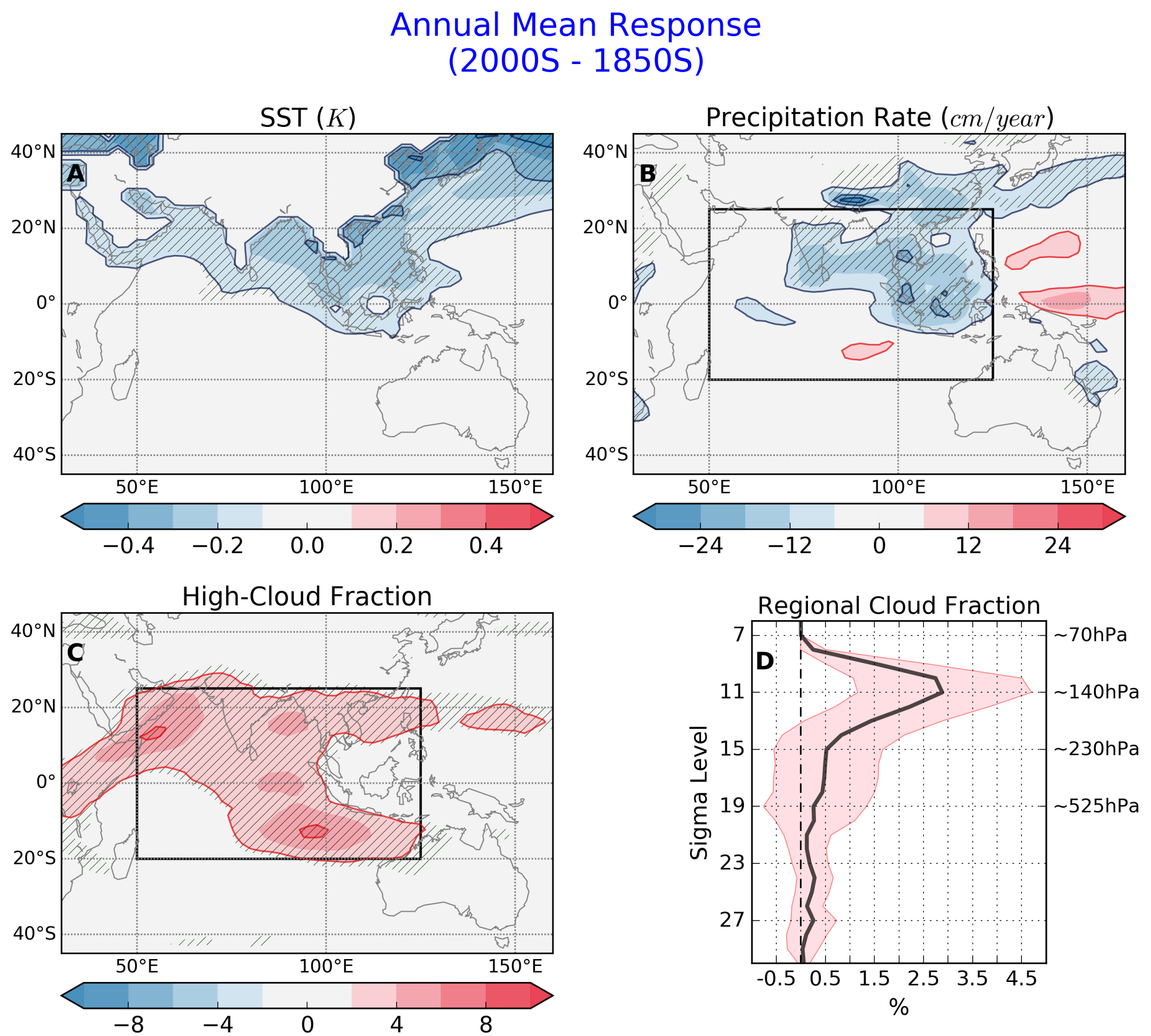


- Ensemble – 110 members; each 4 year long*

*(results presented are from first year only)

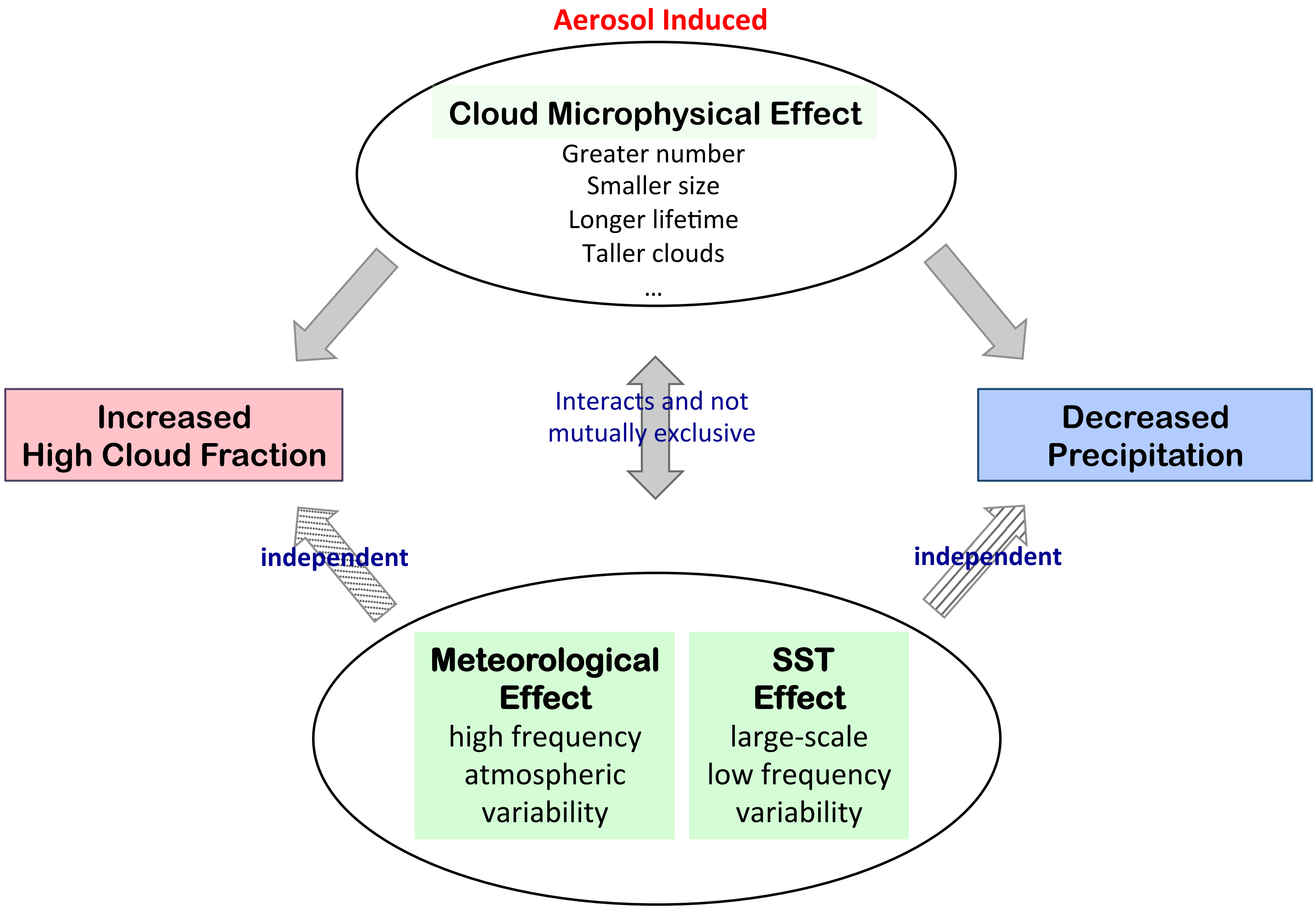
Short-term approach is important to reduce tropical Pacific's intrinsic noise

Response to Increase in Sulfate Aerosols



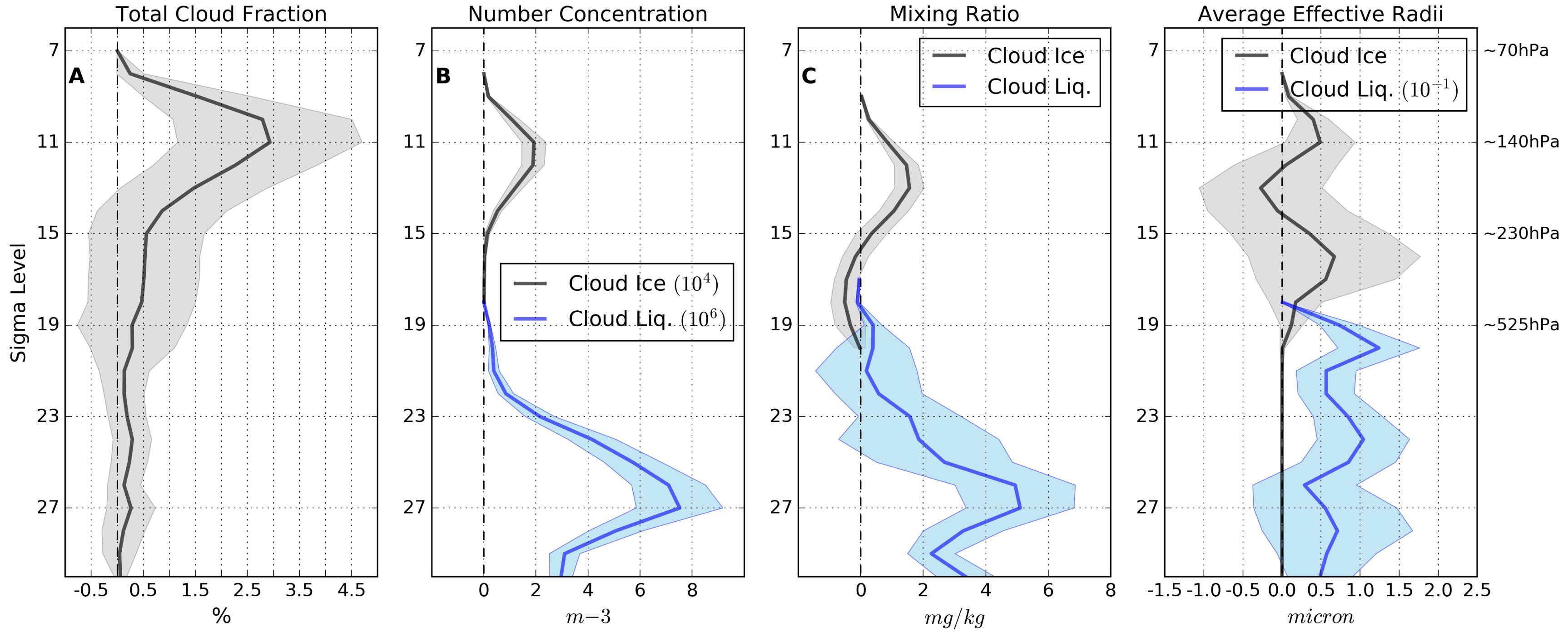
What causes increase in high clouds and decrease in precipitation?

Conceptual Explanation



In-Cloud Response

Annual Mean Response
(2000S - 1850S)



In mean response,

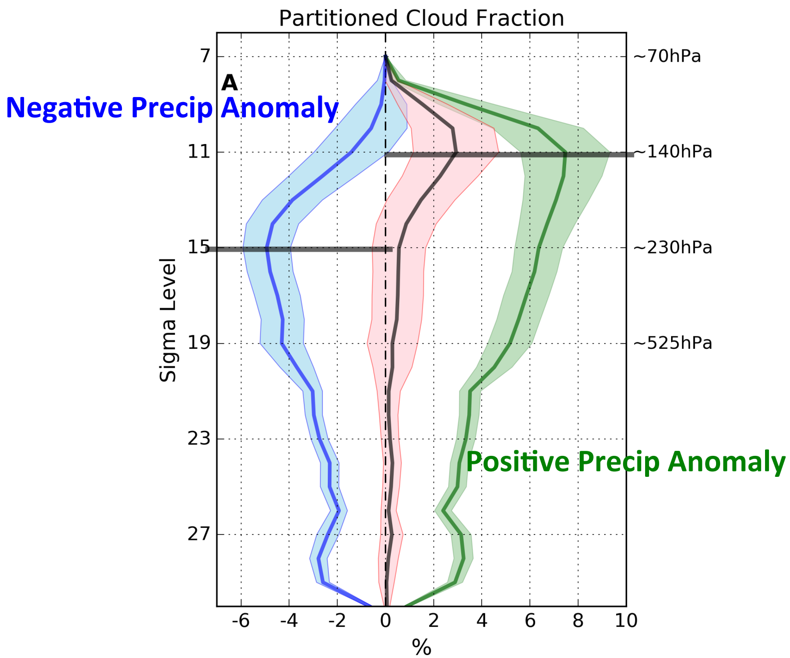
- number of particle increases,
- amount of condensate increases,
- average size increases but
- precipitation decreases

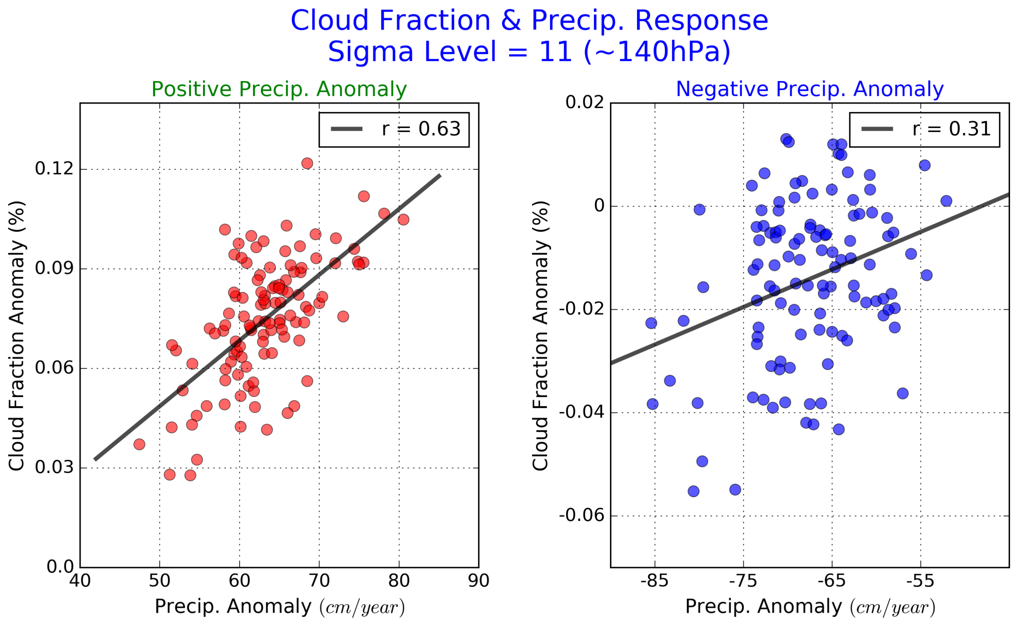
presence of non ACI effect or model discrepancy

Meteorological Influence on Cloud Fraction

- Subsample cloud fraction response based on sign of the precipitation response (110 X 12 months)
- This brings out the effect of higher frequency spatial & temporal variations (meteorological influence*) which otherwise averages out

*timescale is limited by monthly averaged fields

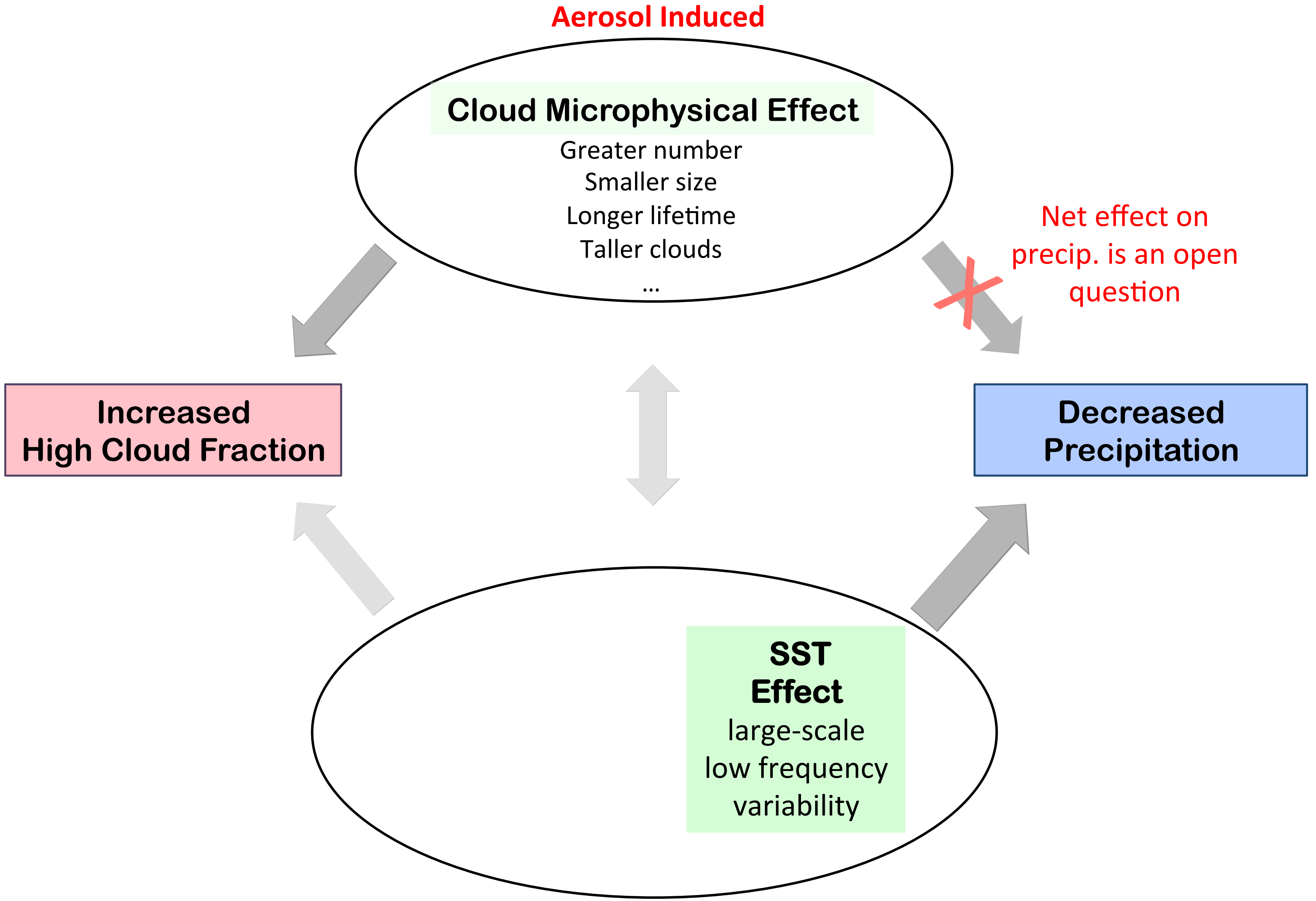




- Positive Precip. Anomaly => Increased CF, higher top
- Negative Precip. Anomaly => Decreased CF, lower top

- linear relation
- slope depends on sign of precip. anomaly

Summary


Aerosol Induced
Cloud Microphysical Effect
Greater number
Smaller size
Longer lifetime
Taller clouds
…
Net effect on precip. is an open question
Increased High Cloud Fraction
Decreased Precipitation
SST Effect
large-scale
low frequency
variability

Conclusions

- In climate model response to sudden increase in sulfate aerosols,
  - increased high cloud fraction is primarily due to changes in cloud microphysical features
  - decreased precipitation is mostly caused by surface cooling

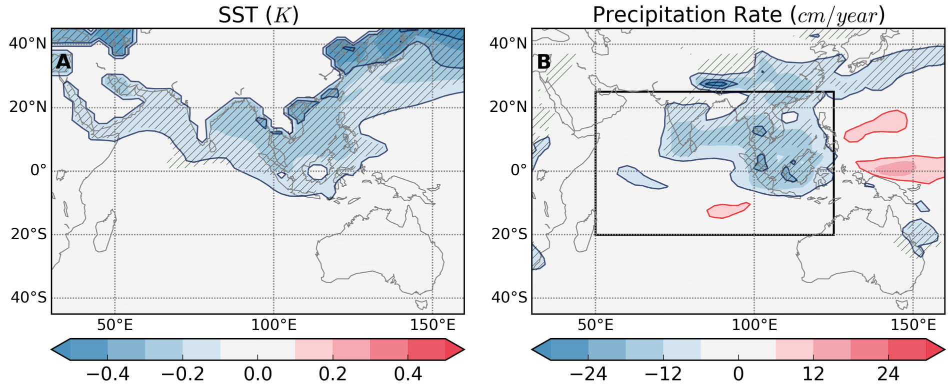
- Further work is needed to
  - completely rule out the effect of ACI on precipitation
  - conversely, how strongly does aerosol induced surface cooling controls precipitation?

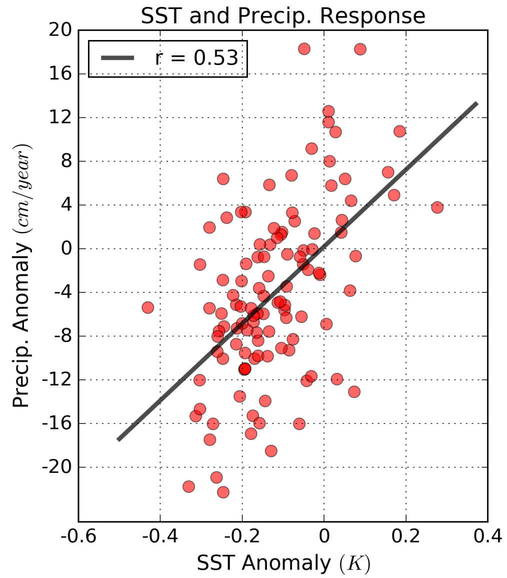
Expansion of ARM network along with aircraft and space-borne instruments looking at clouds and aerosols, simultaneously and more frequently.

Extras

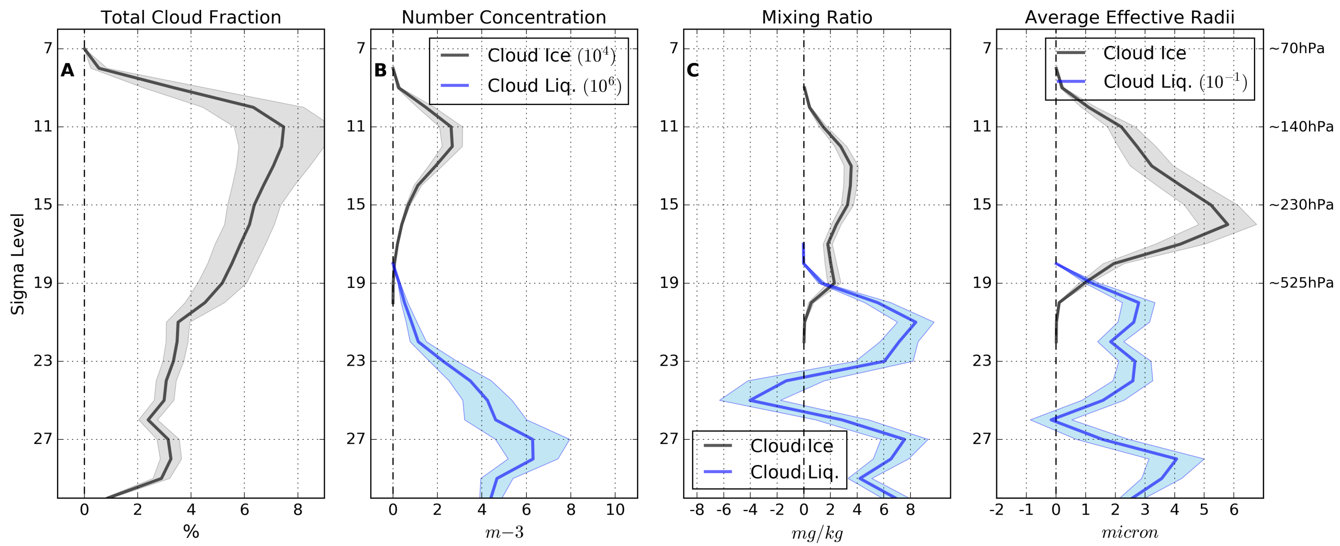
SST and Precipitation

Annual Mean Response
(2000S - 1850S)





Precipitation > 0



Precipitation < 0