Observational Indicators of Impact of Aerosols on Cloud & Precipitation from Ground, Satellite, Aircraft Measurements

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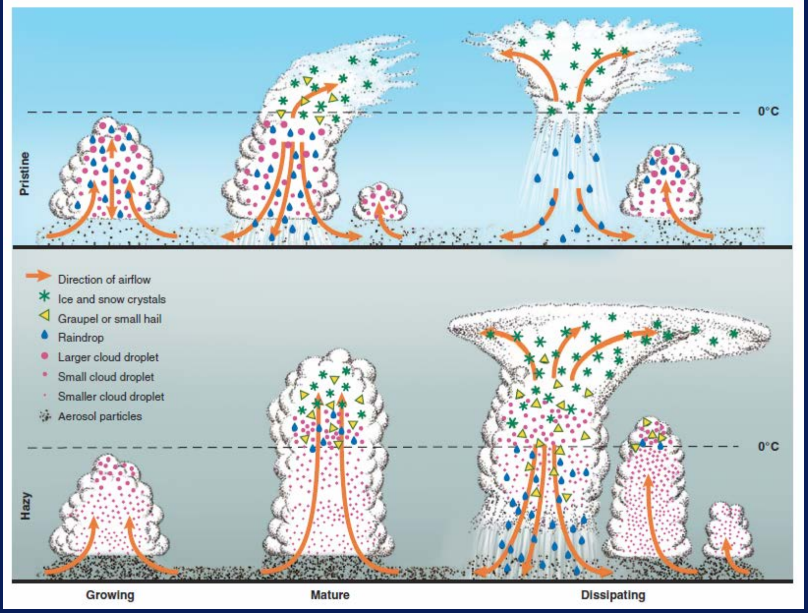


Rosenfeld et al. (Science, 2008)

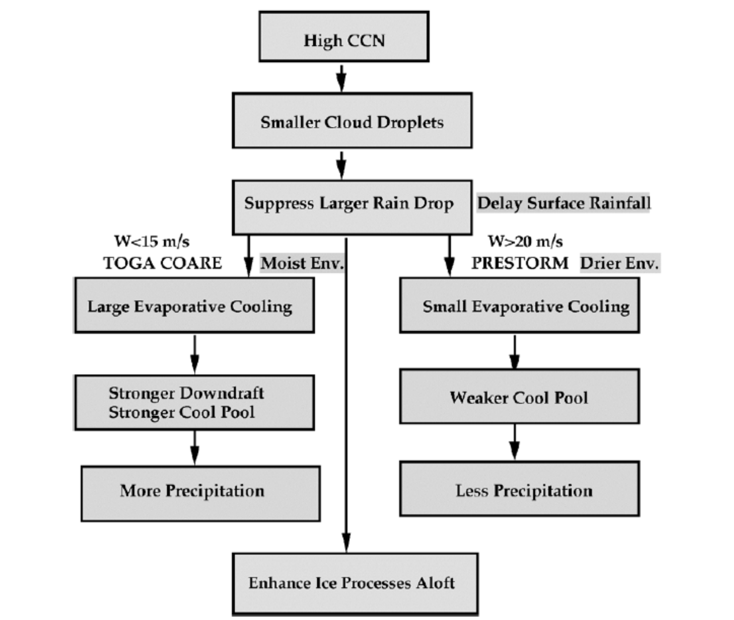
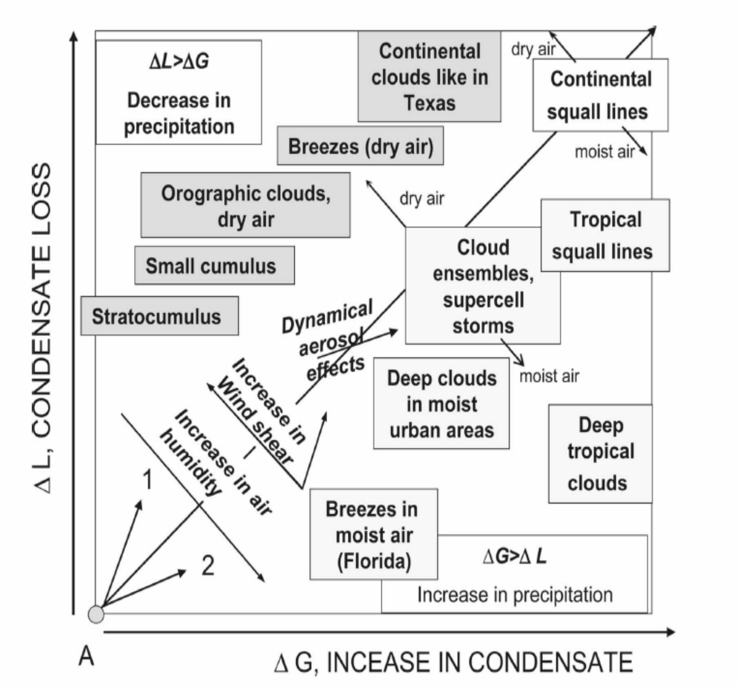


Figure 8. Schematic diagram showing the physical processes that lead to either enhancement (TOGA COARE case) or suppression (PRESTORM case) of precipitation in a dirty environment.

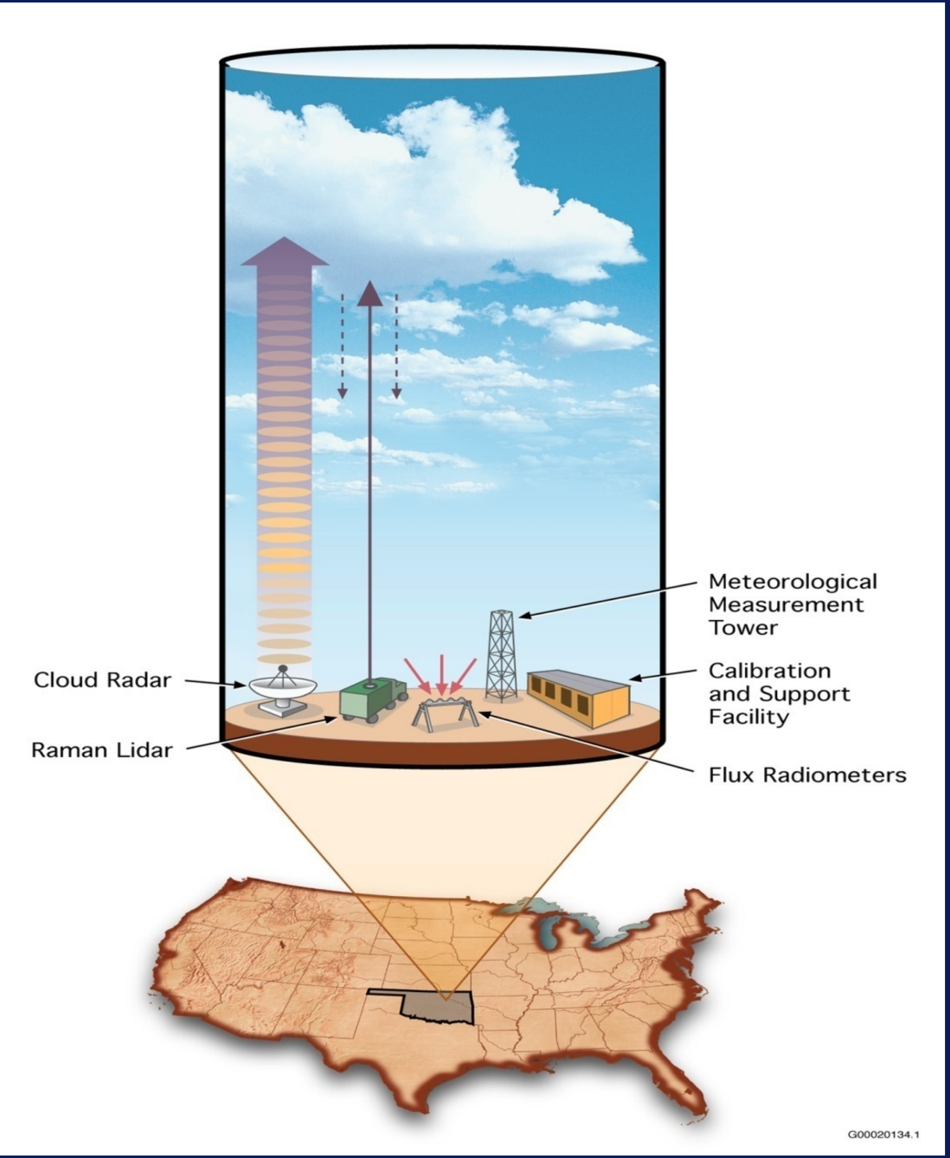


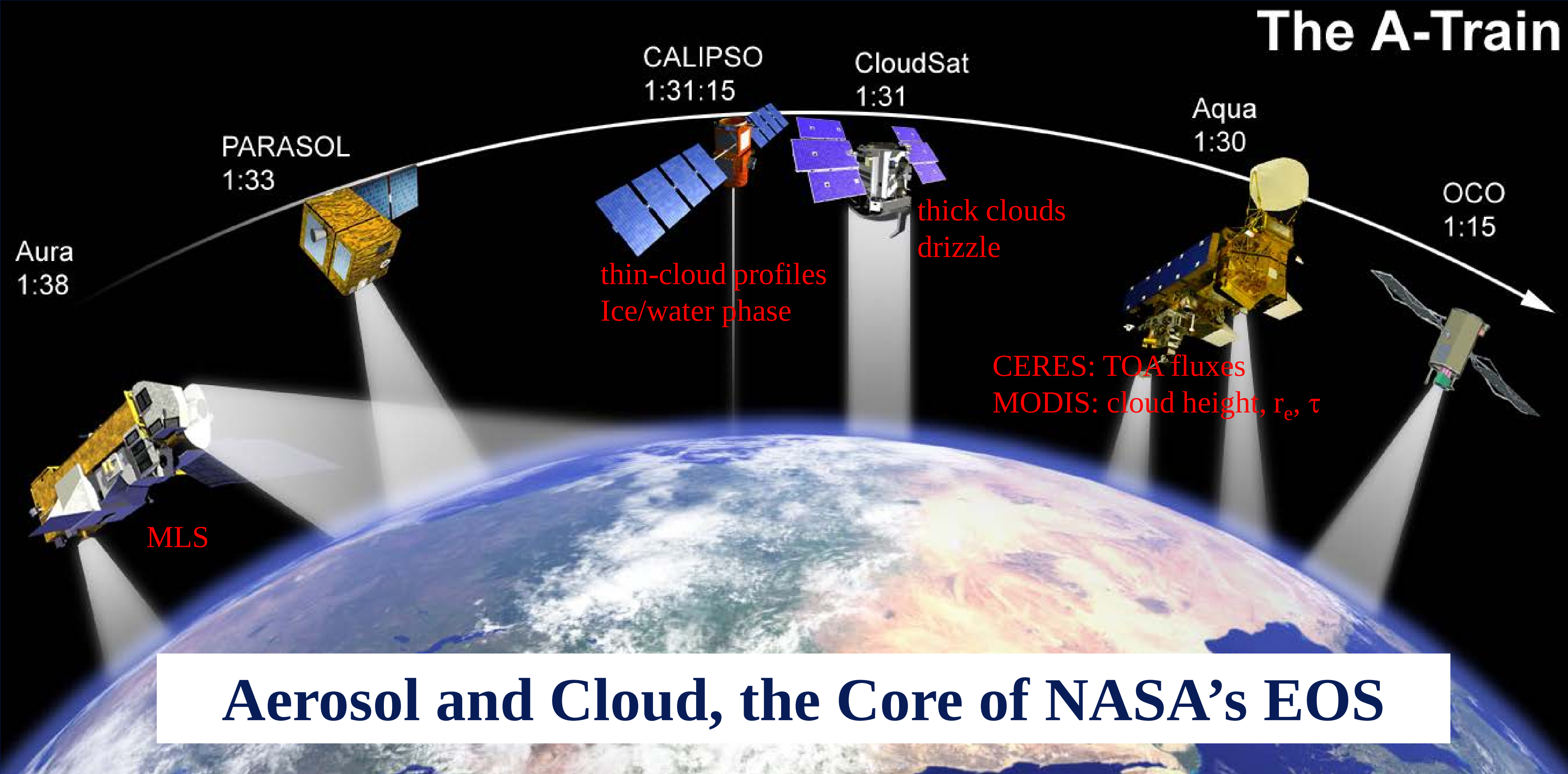
Tao et al. (2007), Lee et al. (2010)

Khain et al. (2008)

10-Year ARM Datasets Used

- Rain gauge (CO2Flx:
  Rain gauge (SMOS:
- Surface Meteorological Observation System)
- Microwave Radiometer:
  - Liquid water path
  - Column water vapor
- ARSCL: Active Remote Sensing of Clouds
  - Cloud bases and tops
- TSI condensation particle counter
  - use the measurements made priori to rain to avoid rain contamination due to washout effect





Aerosol and Cloud, the Core of NASA's EOS

Cloud ice/water mass	CloudSat MLS AMSR
Cloud microphysics	MODIS CloudSat PARASOL
Precipitation	CloudSat

Aerosol-Cloud Interation	CALIPSO MODIS PARASOL OMI
Cloud optics	CALIPSO, MODIS, and PARASOL

RACORO – Air-borne Data

Jan. to Jun. in 2009 at ARM SGP site

Routine
Aerial Vehicle Program (AVP)
Clouds with Low Optical Water Depths (CLOWD)
Optical
Radiative
Observations

- **Improve our understanding of how boundary layer clouds interact with aerosols & radiative fluxes**

- **Long-term, routine flights in the boundary layer, liquid-water clouds at SGP**
  - **Microphysical properties**
  - **Optical properties and radiative fluxes, and**
  - **Associated aerosol properties & atmos. State**

Andy Vogelmann, Greg McFarquhar, Dave Turner, Jennifer Comstock, Graham Feingold, Chuck Long and John Ogren

nature geoscience

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ARTICLES

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Long-term impacts of aerosols on the vertical development of clouds and precipitation

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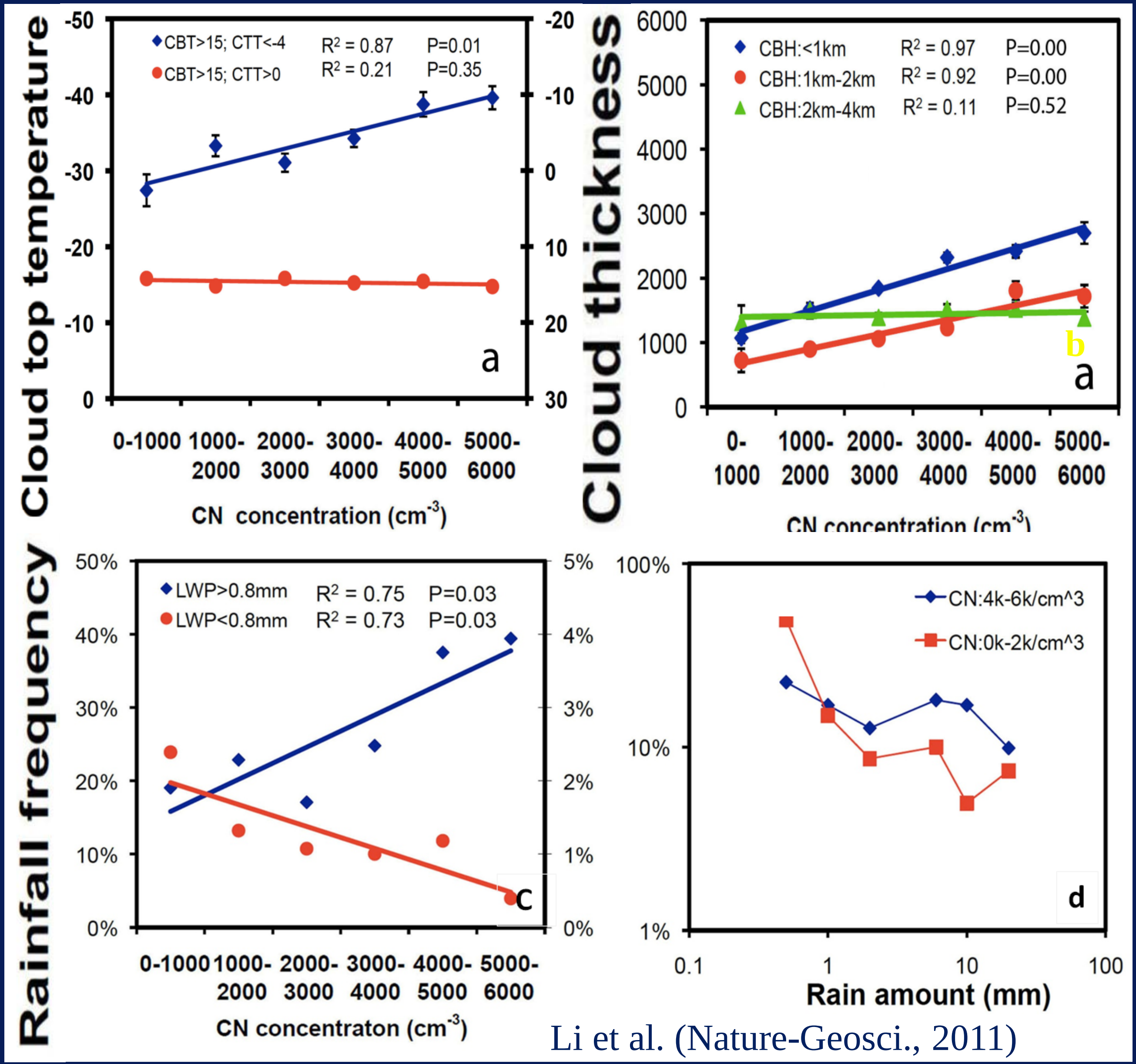
Aerosols alter cloud density and the radiative balance of the atmosphere. This leads to changes in cloud microphysics and atmospheric stability, which can either suppress or foster the development of clouds and precipitation. The net effect is largely unknown, but depends on meteorological conditions and aerosol properties. Here, we examine the long-term impact of aerosols on the vertical development of clouds and rainfall frequencies, using a 10-year dataset of aerosol, cloud and meteorological variables collected in the Southern Great Plains in the United States. We show that cloud-top height and thickness increase with aerosol concentration measured near the ground in mixed-phase clouds—which contain both liquid water and ice—that have a warm, low base. We attribute the effect, which is most significant in summer, to an aerosol-induced invigoration of upward winds. In contrast, we find no change in cloud-top height and precipitation with aerosol concentration in clouds with no ice or cool bases. We further show that precipitation frequency and rain rate are altered by aerosols. Rain increases with aerosol concentration in deep clouds that have a high liquid-water content, but declines in clouds that have a low liquid-water content. Simulations using a cloud-resolving model confirm these observations. Our findings provide unprecedented insights of the long-term net impacts of aerosols on clouds and precipitation.

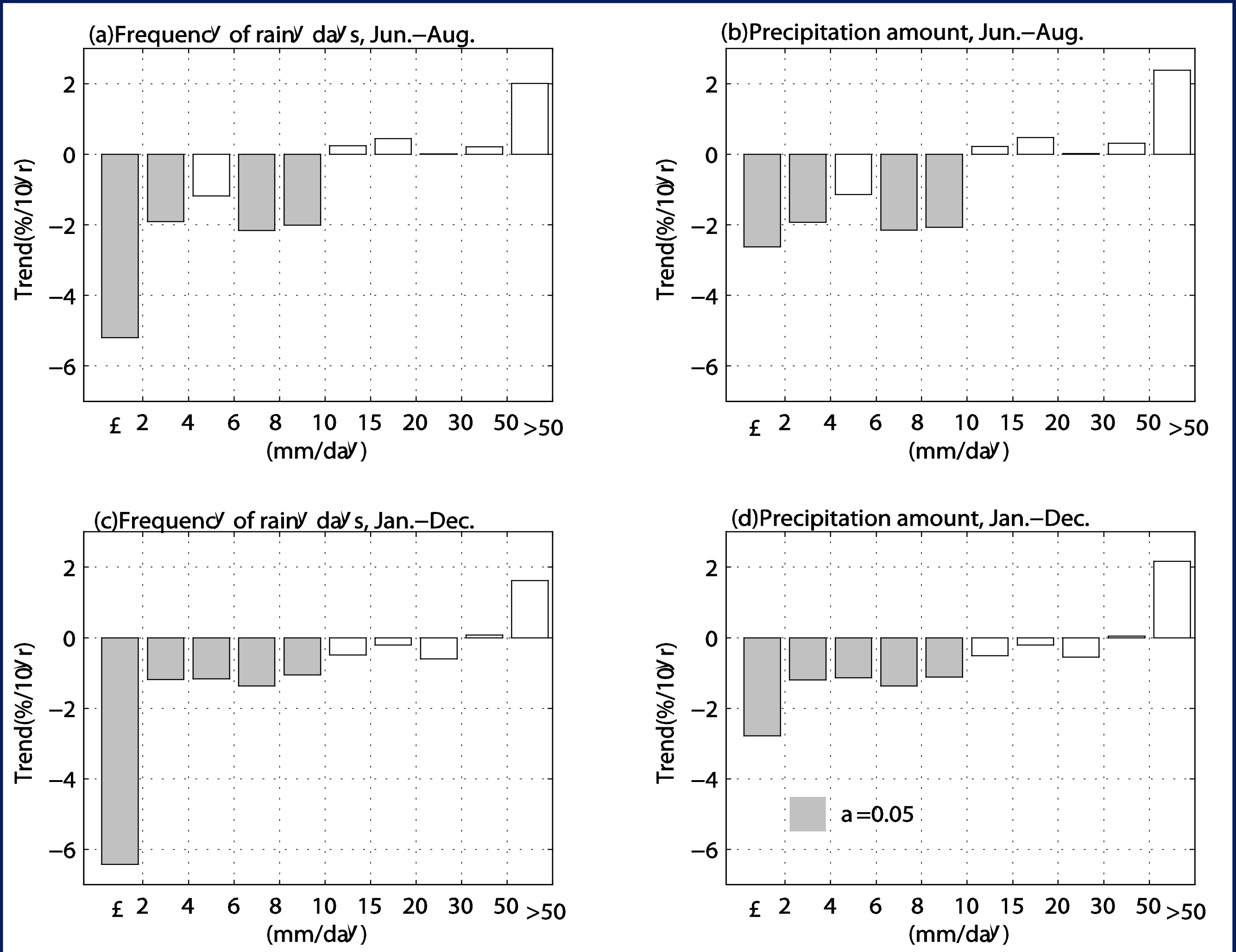
Long-term impact of aerosols on cloud top temperature Cloud thickness and rainfall frequency u



CBT: cloud base temp.
CBH: cloud base height
LWP: liquid water path
CN: condensation nuclei

Li et al. (Nature-Geosci., 2011)

Linear trends of frequency of rainy days (left) and precipitation amount (right) for different rain intensity over East China for 1956-2005



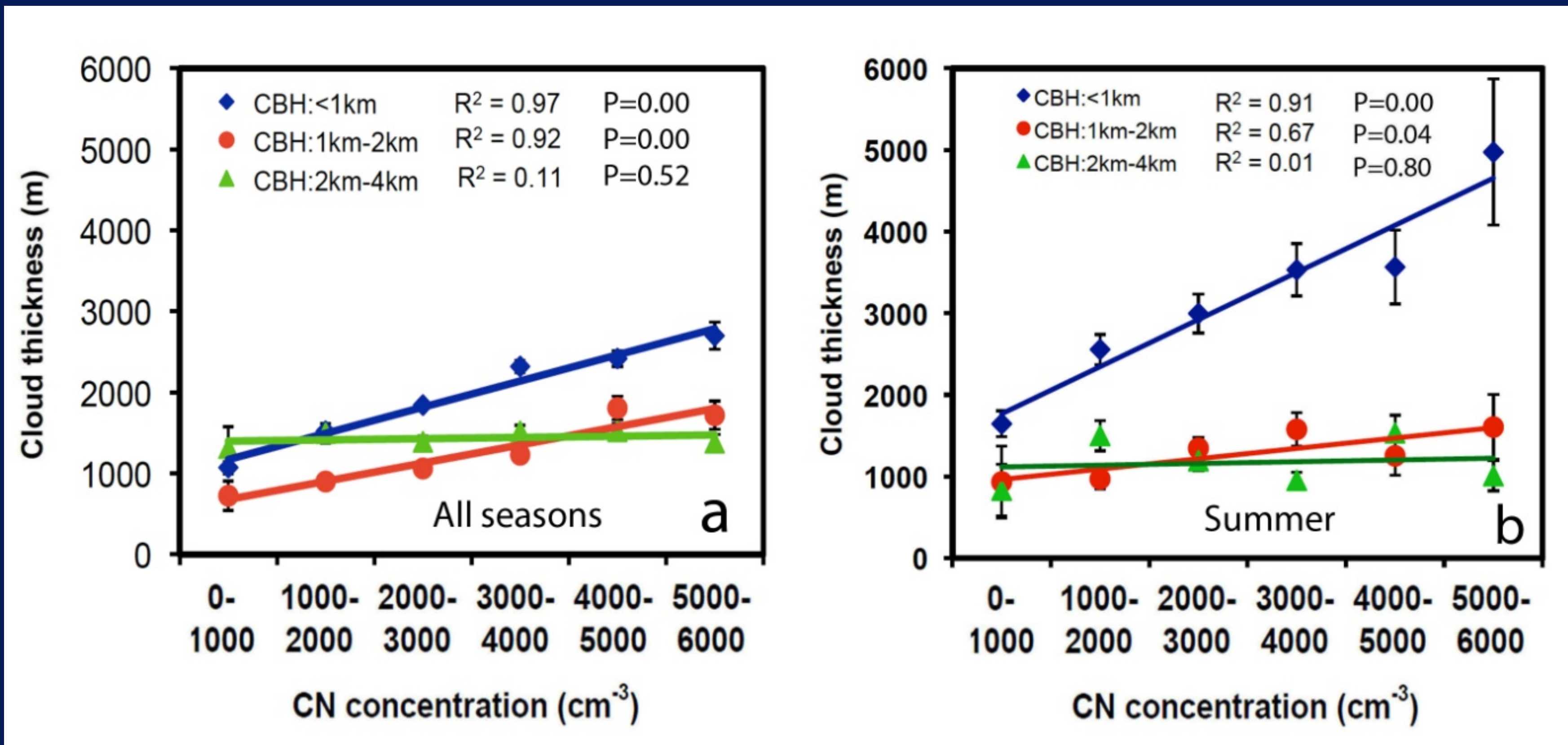
Drizzle/light rains decreased,
Heavy rain / flood increased Steadily

Qian et al. (JGR, 2009)

Dependence on Cloud Base Height (CBH) & Convection on Cloud Thickness

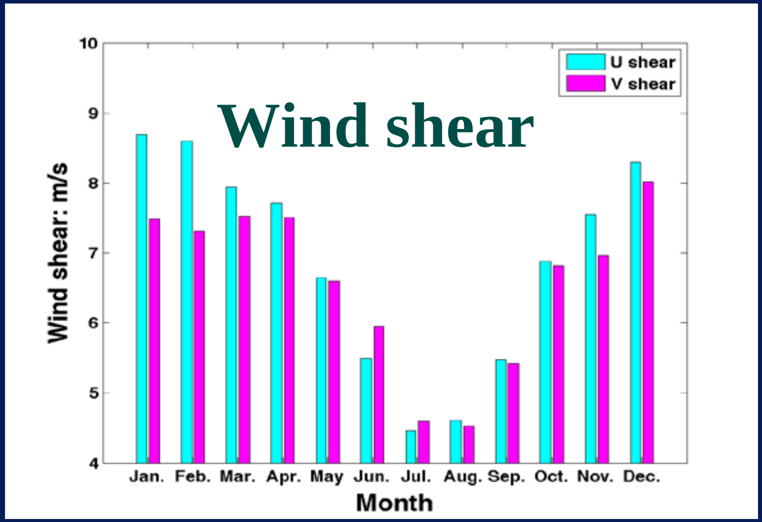
All Seasons

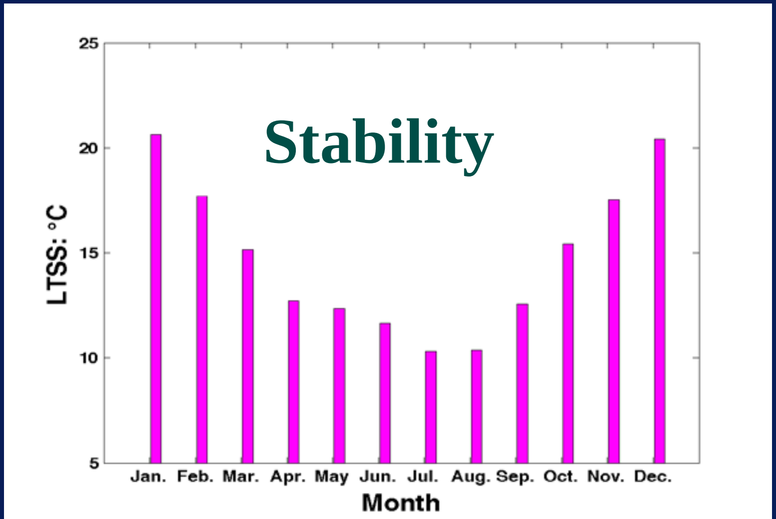
Summers

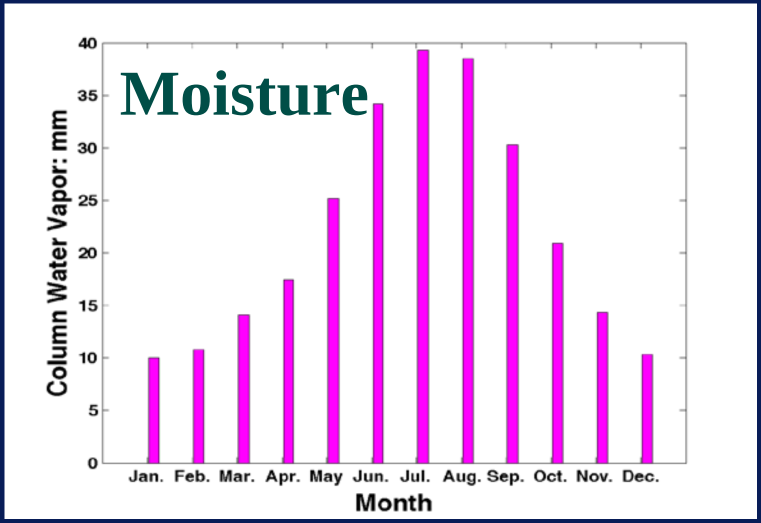


For low clouds (<1km), cloud thickness increases by a factor of 2!
For high clouds (>2km), cloud thickness is not affected at all!.

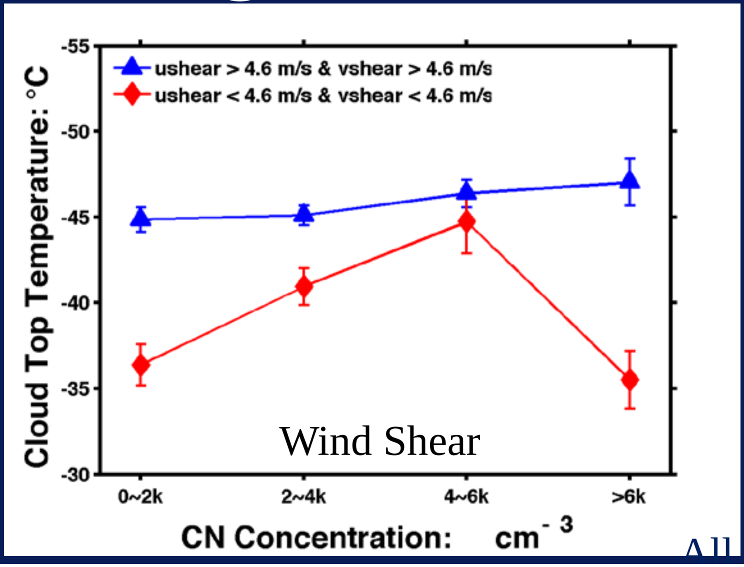
Dependence of aerosol invigoration effect on meteorological variables :

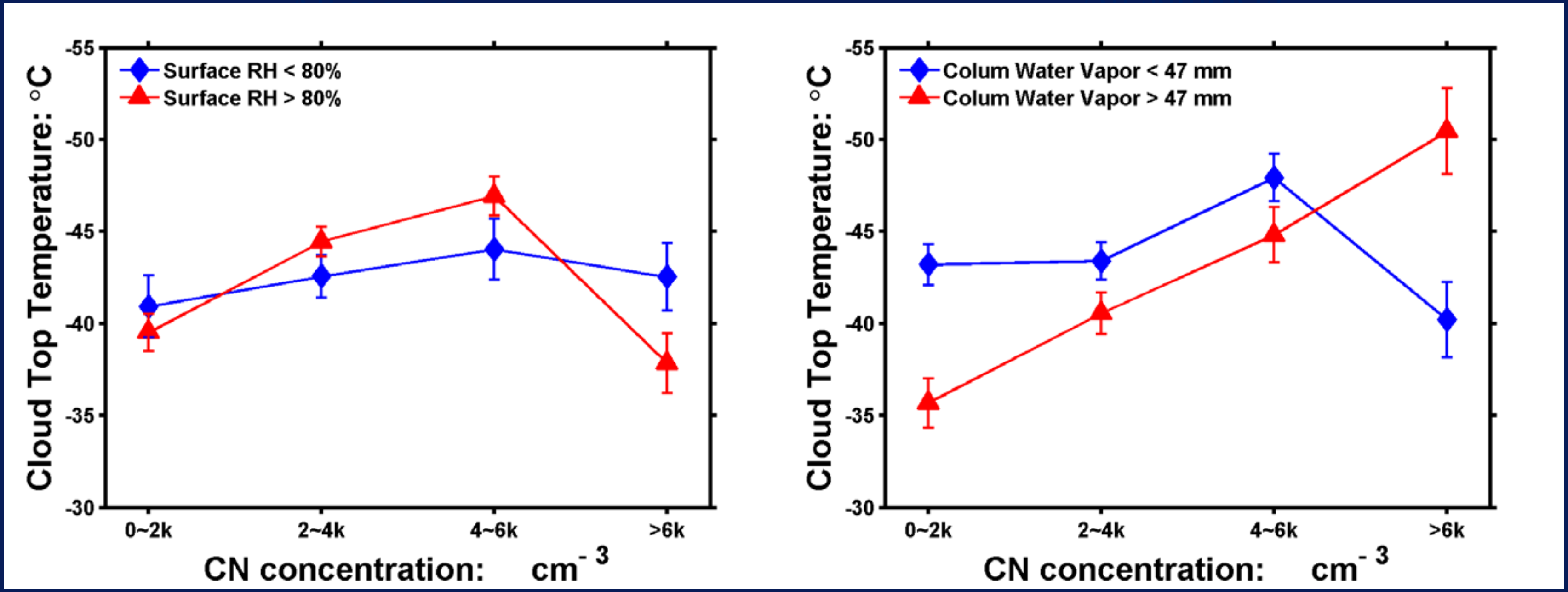




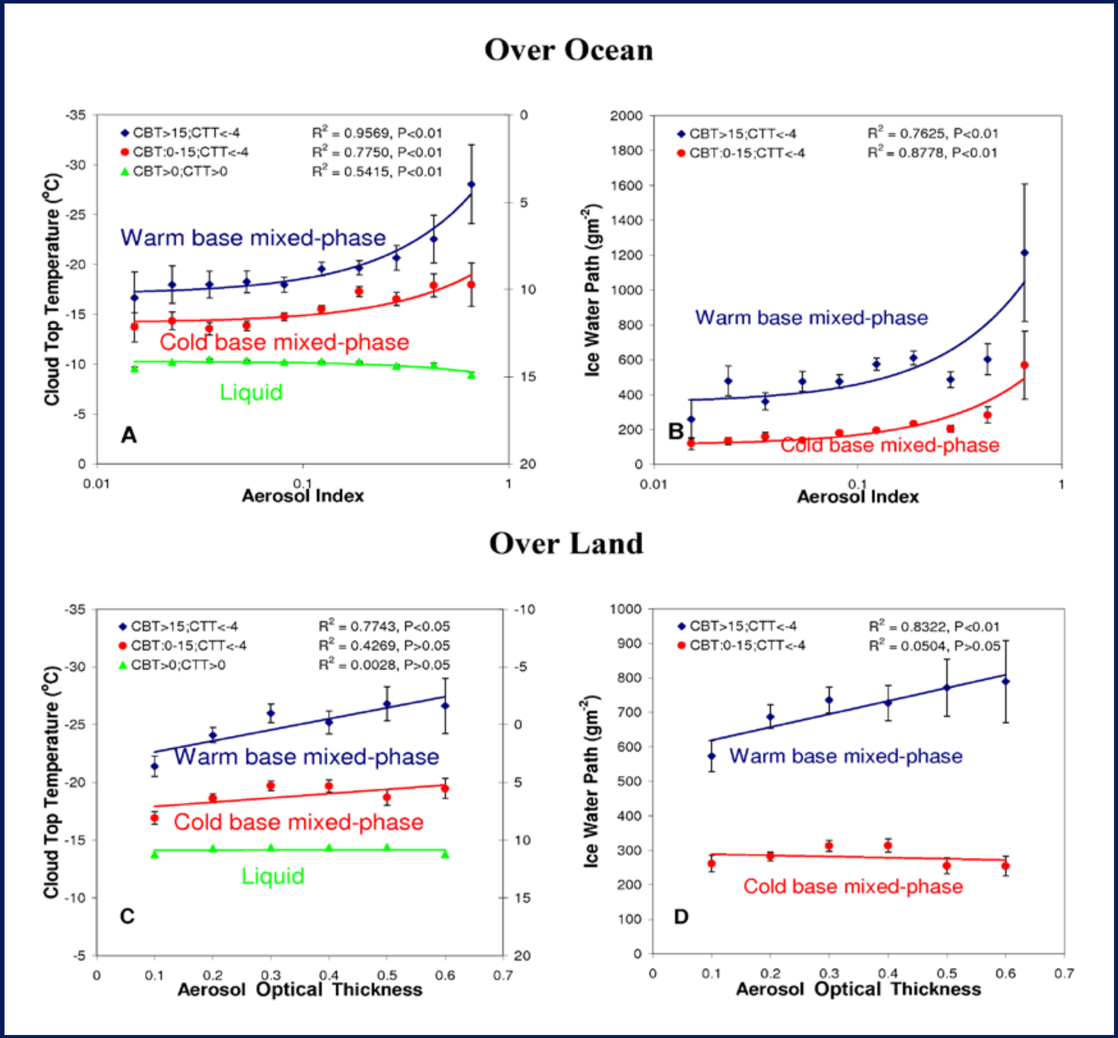


Dependence of aerosol invigoration effect on meteorological variables :





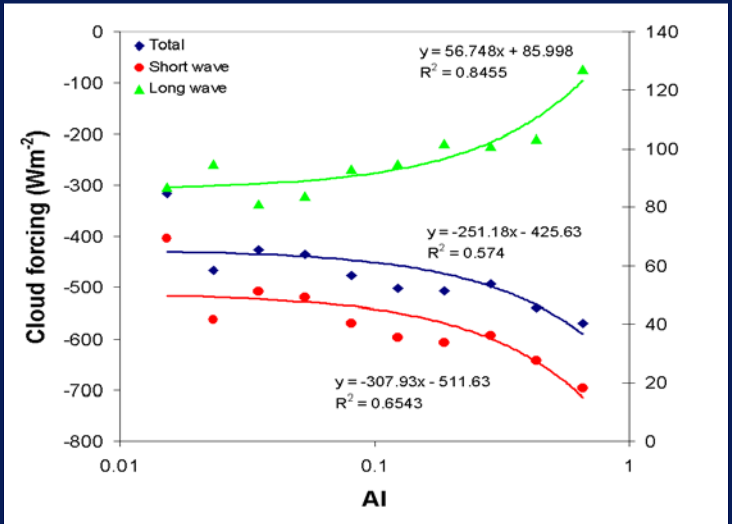
Changes of cloud top with CN From Global Satellite Measurements



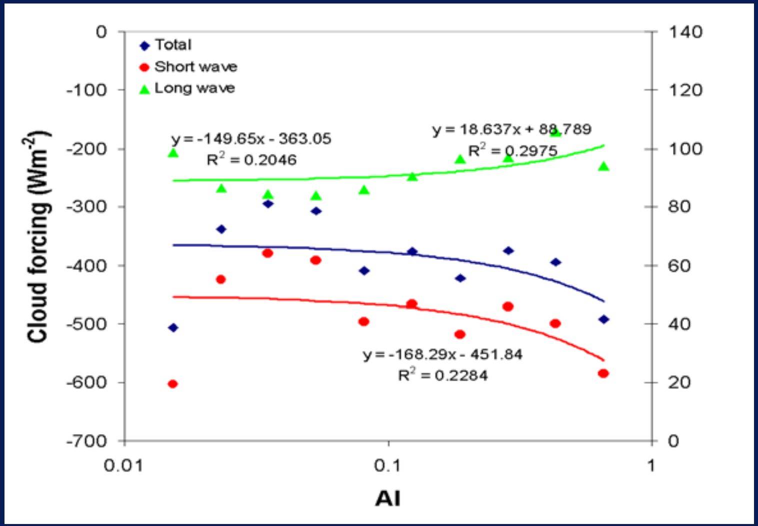
The phenomena is global or ubiquitous

Impact on aerosol radiative forcing due to The macro- and micro-physcial changes by Aerosols A missing term in the climate forcing estimation

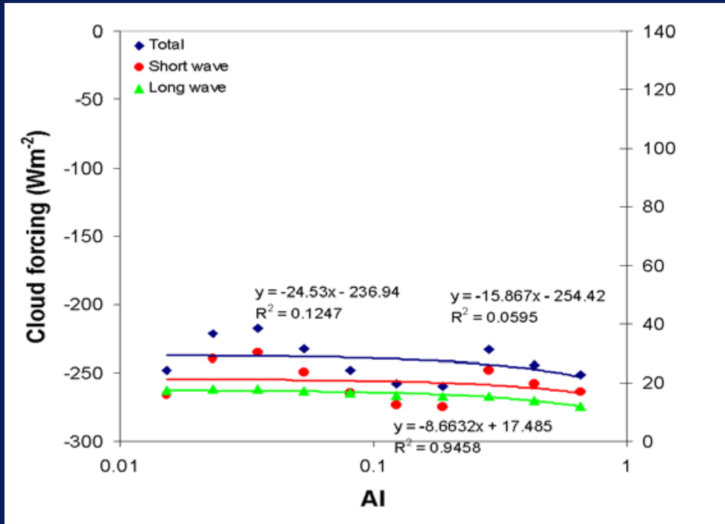
Warm base mixed-phase



Cold base mixed-phase

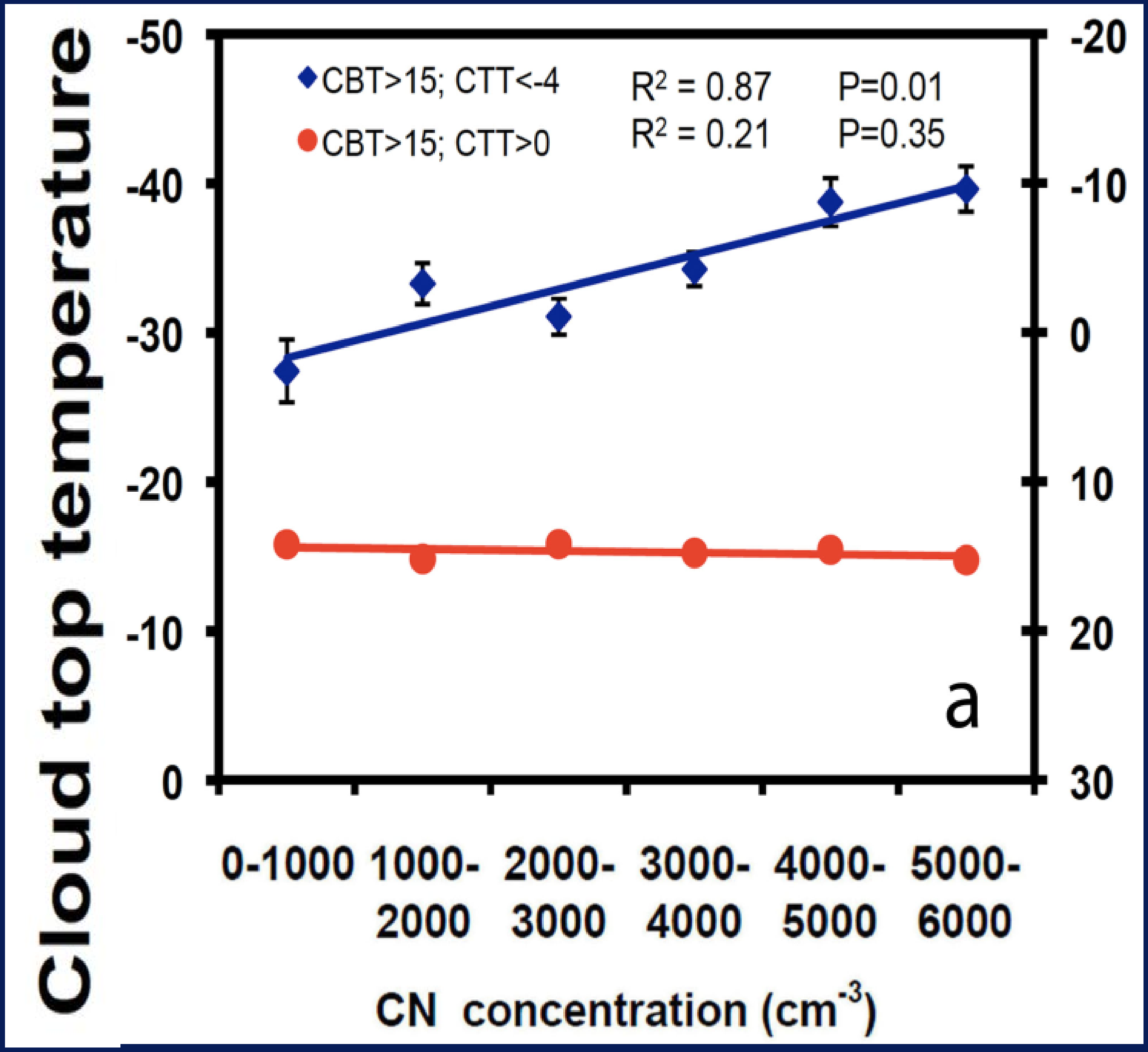


Only the microphysical effect is accounted for in the current estimates



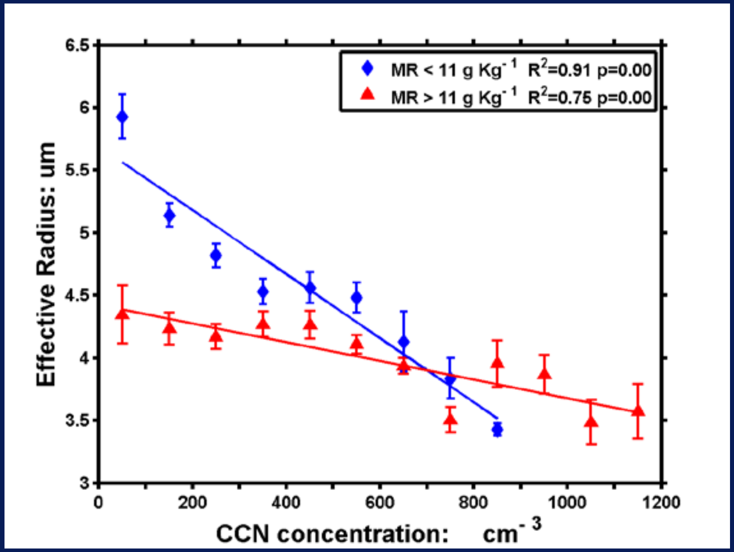
Liquid clouds – Microphysical effect

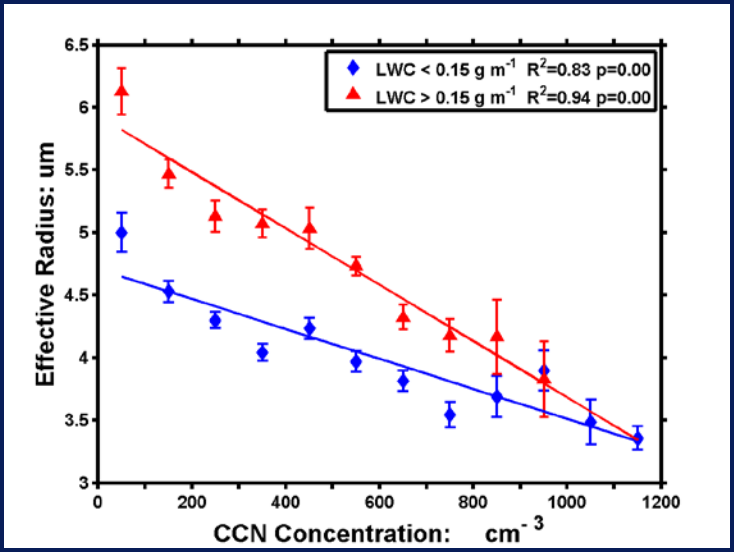
For warm clouds, aerosols have no radiative effect due to Changes in macrophysics but in microphysics

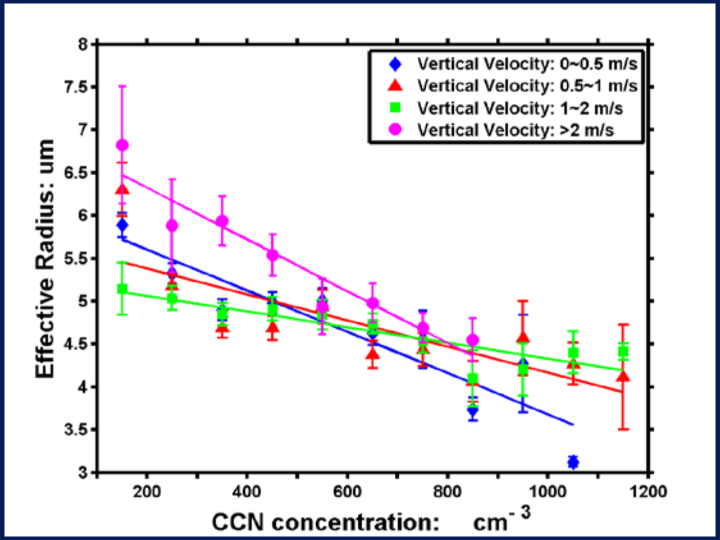


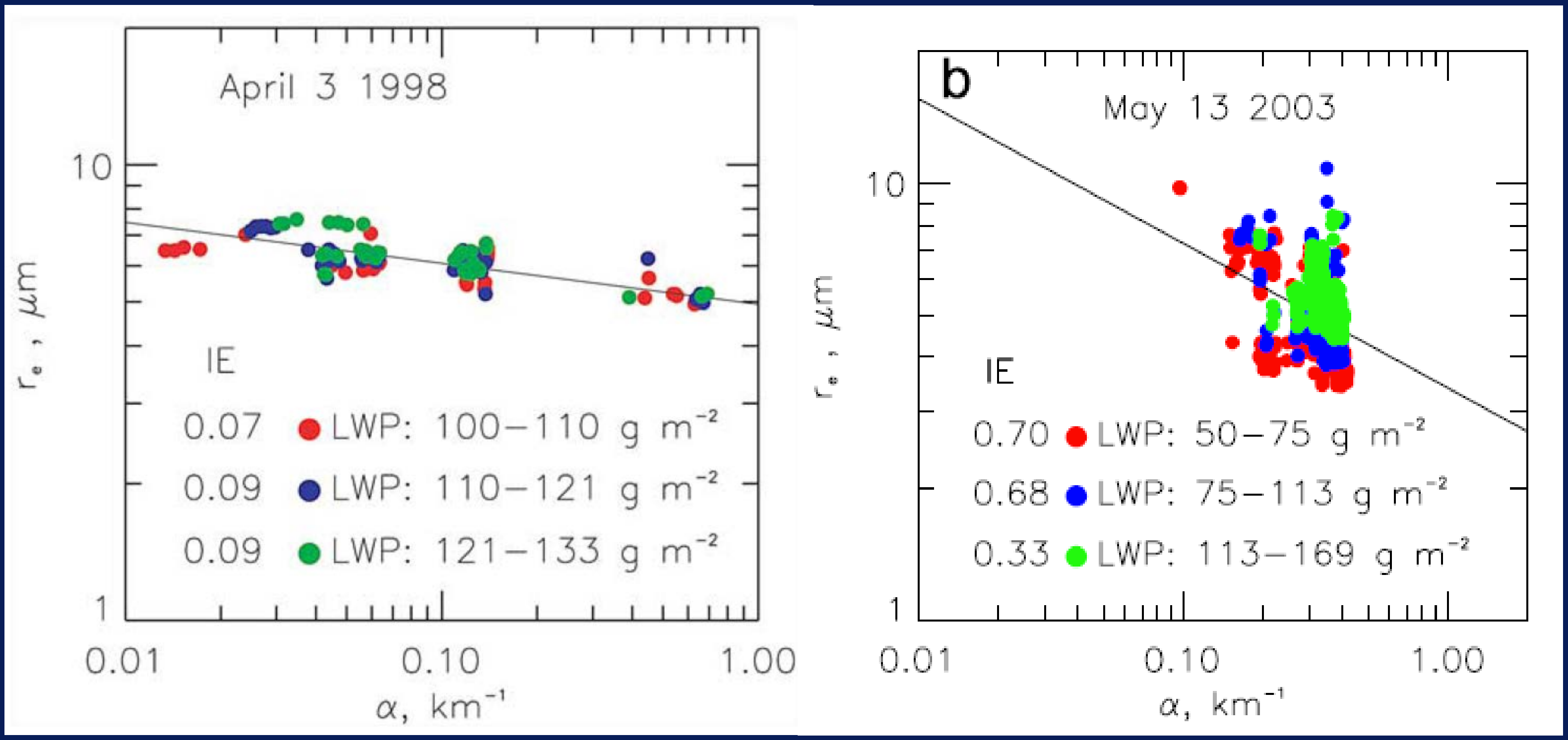
Li et al. (Nature-Geosci., 2011)

Told us the Twomey effect depends on meteorological variables







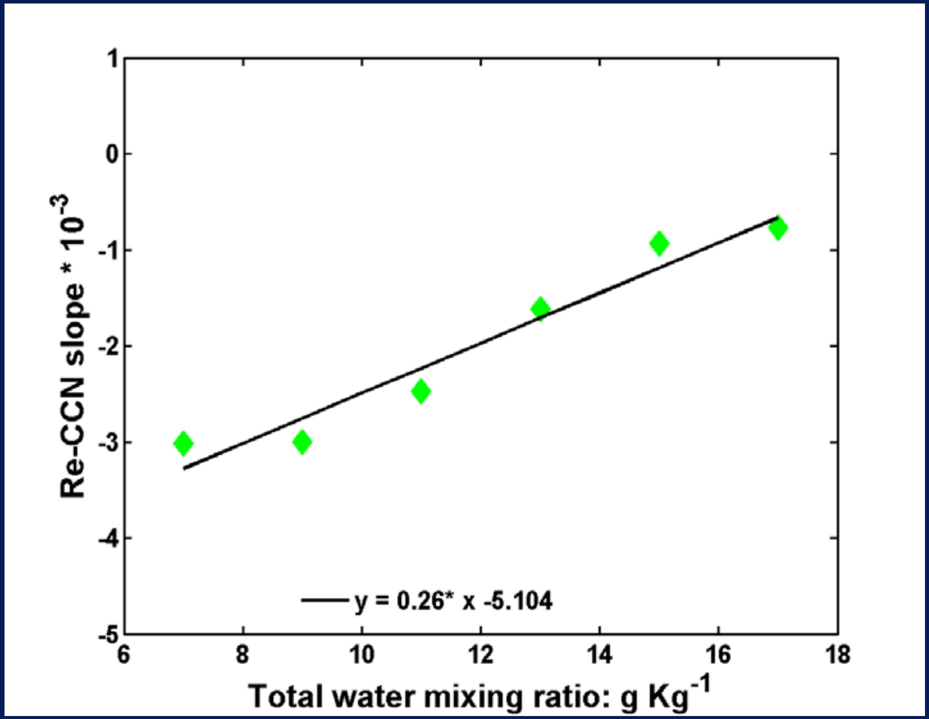


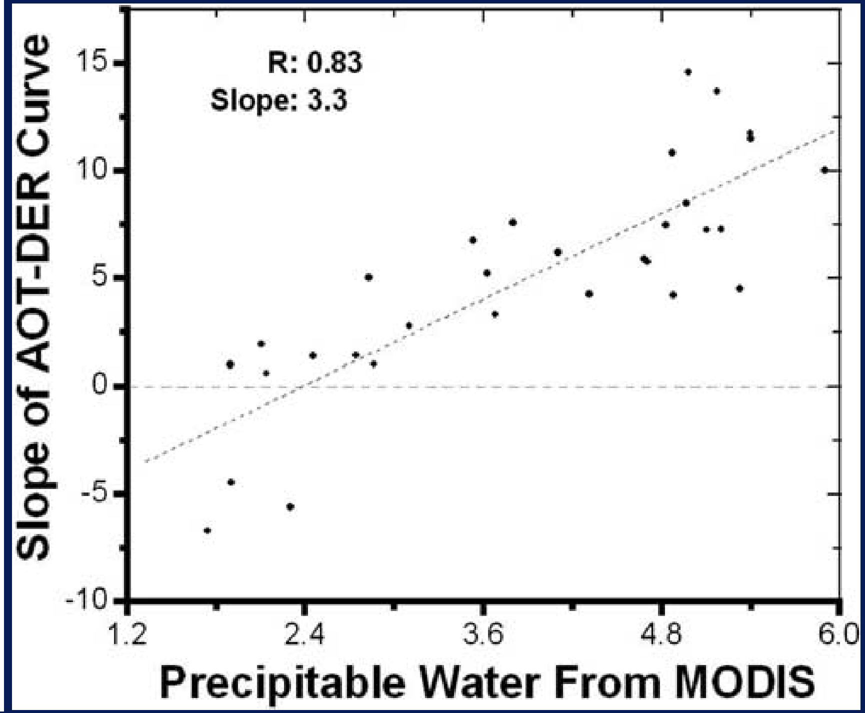
Felgold et al. (2003, 2006)

The Strength of the Twomey Effect Depends Significantly on Moisture

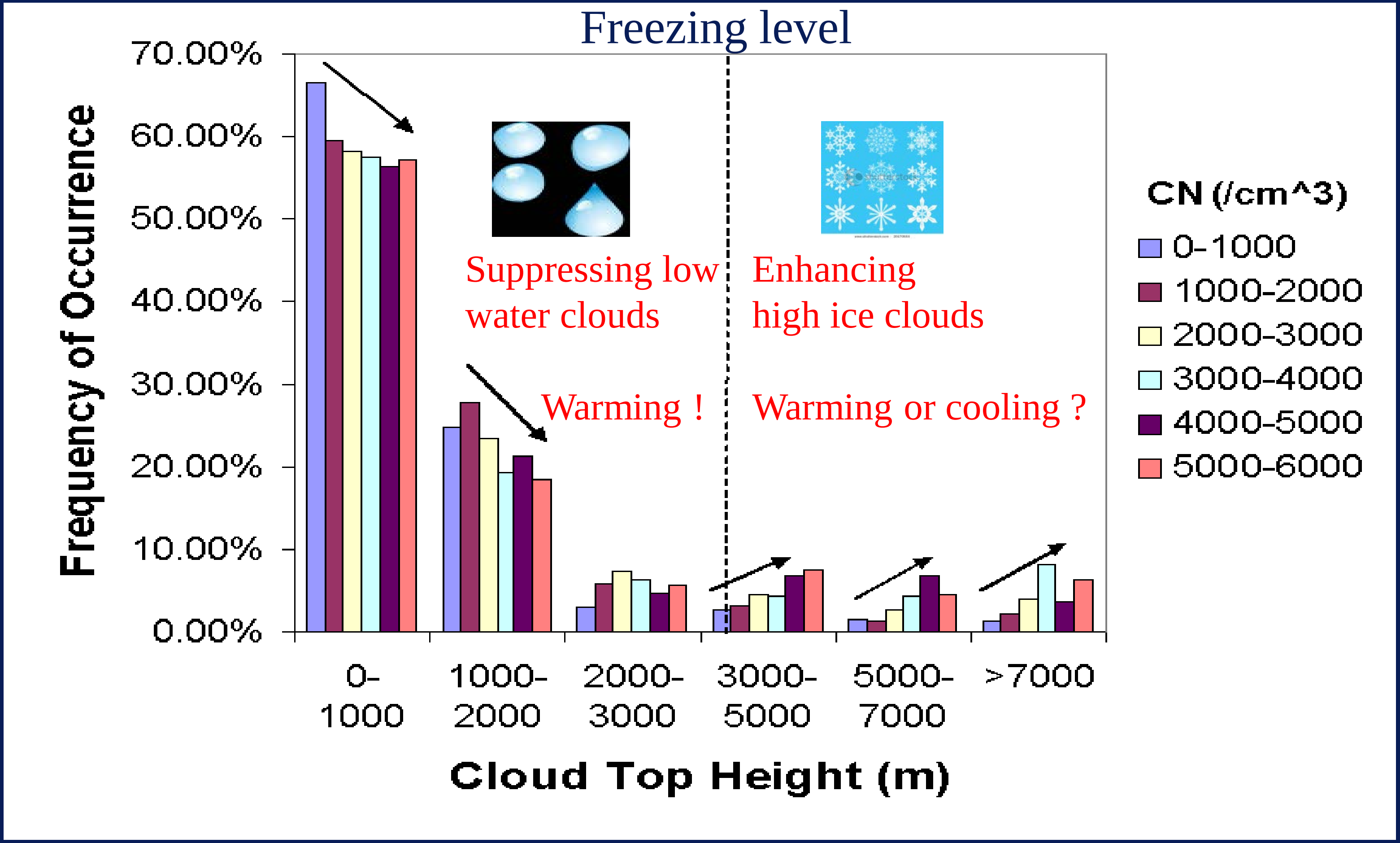
RACORA Aircraft

MODIS Satellite
(Yuan et al. 2008)





Effects on the Frequency of Cloud Occurrence
Another poorly accounted factor in ARF estimate



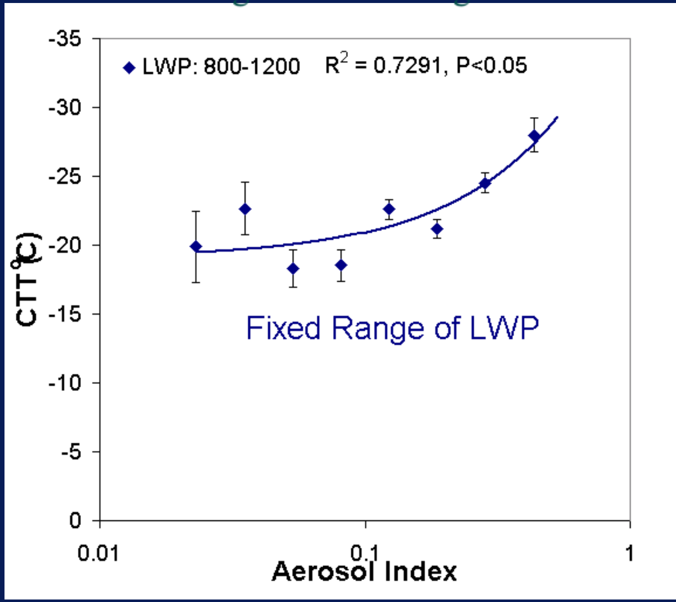
As CN increases, high clouds occurred more frequently but low clouds occurred less frequently

Li et al. (Nature-Geo, 2011)

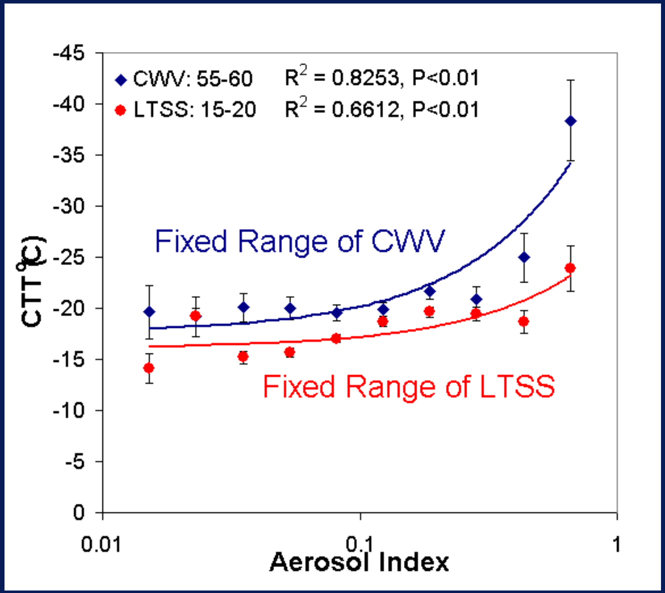
Summary

- Observations from various platforms contains Rich but Hidden information pertaining wide-range effects of aerosols on cloud and precipitation.
- Current estimates of aerosol-induced radiative forcing may have missed a major components associated with the macrophysical (height, coverage/frequency) effect that can be much larger than the microphysical effect.
- It is time to estimate ARF by accounting for meteorological conditions, cloud regimes, day & night, etc.
- The effect on precipitation has a huge large social-economic consequency that has not been conveyed to the public relative to global warming.

LWP in the range of 800-1200 g/cm²



Limited ranges in column water vapor & LTSS



Aerosol index, column water & precipitation rate