Pacific Northwest
NATIONAL LABORATORY

Fan, J., and Z. Li (2022), Aerosol interactions with deep convection, book chapter in “Aerosols and Climate” edited by Ken Carslaw. Elsevier.

Observational needs for aerosol impacts on deep convective clouds

Jiwen Fan

Laboratory Fellow

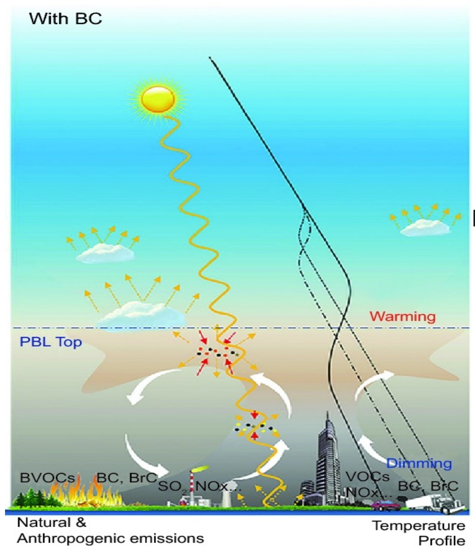
jiwen.fan@pnnl.gov

U.S. DEPARTMENT OF ENERGY BATTELLE

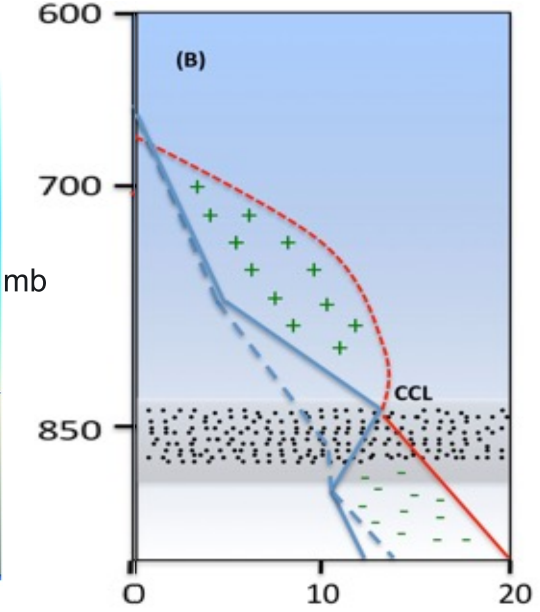
Challenging problems and key data needed (1)

- **Concerning aerosol-radiation interactions (ARI), how do aerosols at different vertical levels and temporally-evolving aerosol properties affect PBL evolution, temperature inversion, turbulence and stability, and convective clouds?**

  - **Vertical profile of aerosol properties and temporal evolving aerosol properties** are difficult to achieve from measurements (TBS).
  - **High temporal-resolution measurements** of turbulence, PBL, cloud, and precipitation are needed but difficult to obtain (multiple platforms).
  - Need to capture **spatial heterogeneity** of aerosols, turbulence, PBL, cloud, and precipitation



Residing in PBL heats lower levels, stabilizes atmosphere and suppresses deep convection (Fan et al., 2008; Li et al., 2017)



Concentrating on the top of PBL makes atmosphere less stable (Wang et al., 2014)

Challenging problems and key data needed (2)

▶ Concerning ACI, the challenging problems include

- **What are the aerosols feeding into convective updrafts?**
  - Aerosol properties (CCN/INP) **profile;** those **right below cloud bases right before convective initiation** are especially important.

- **What measurements are needed to single out aerosol impact from that of co-varied meteorology?**
  - Need **long-term measurements** at **multiple locations** over the world :

  - In the region **with similar weather day-to-day** like wet seasons of Amazon, **long-term observations** can be extremely beneficial to extract the signal of aerosol effects (Fan et al. 2018).

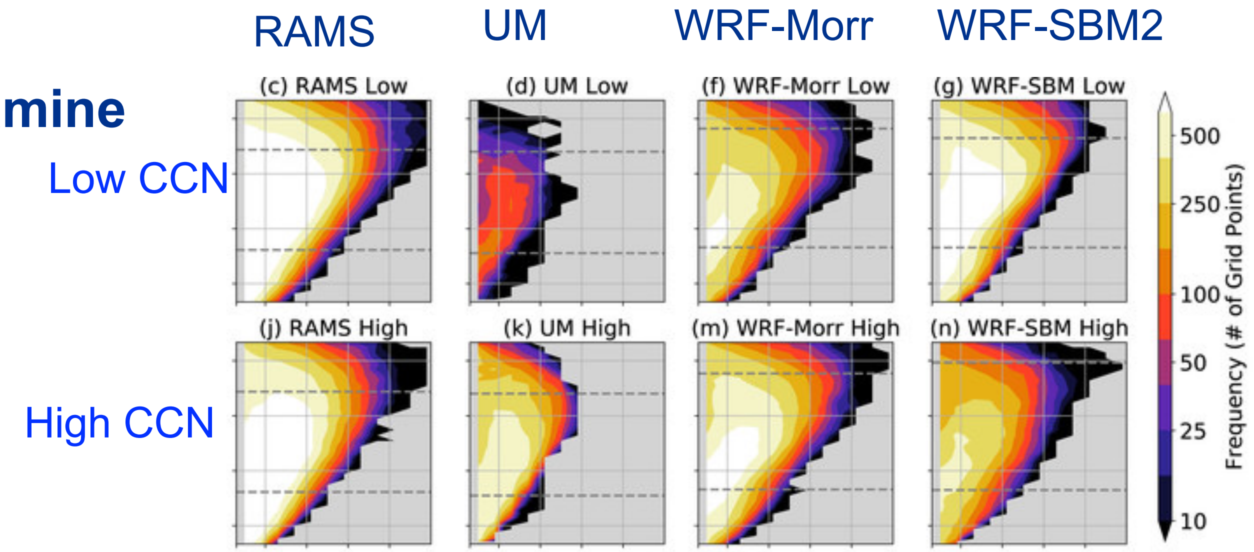
  - In regions **with quite variable meteorology** like SGP, much longer time period would be needed (Varble 2018).

GoAmazon set up a good example for disentangling aerosol effects but longer-time would be more convincing.

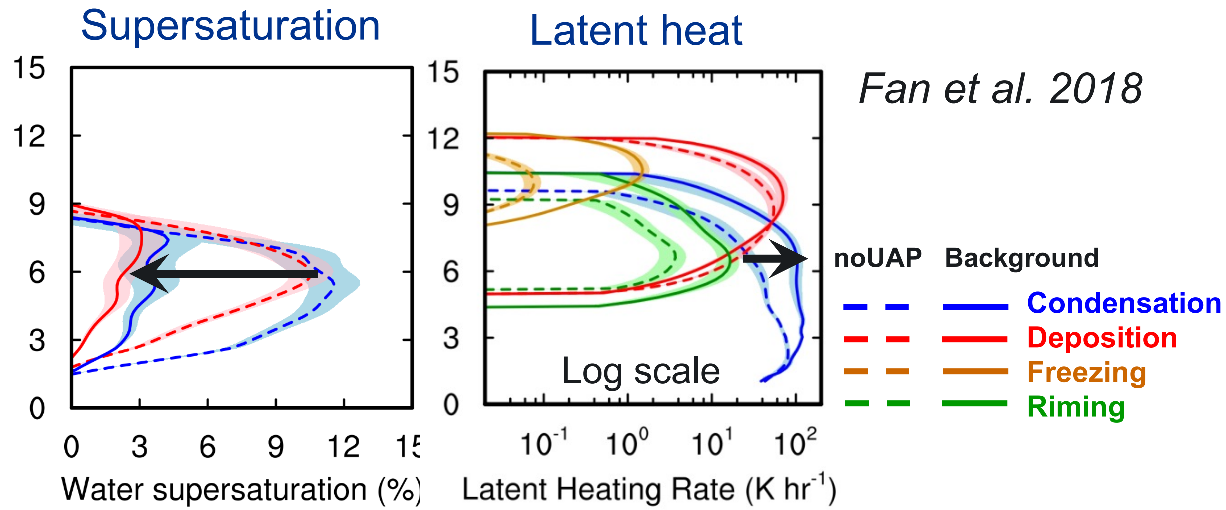
TRACER in Houston has more variable meteorology thus need measurements of much longer time to provide statistically robust results.

Challenging problems and key data needed (3)

- **What measurements are needed to examine aerosol indirect effect on dynamics?**
  - Need measurements of **concurrent updraft speeds, thermodynamics, and cloud microphysics** in convective cores (TRACER aims to providing such dataset).
  - Need high **temporal and spatial meteorological** data in the storm **inflow and outflow** regions (aerosol indirect effect on cold pool) – need mobile tracks to follow the movements of the storm
  - New data such as **latent heating and supersaturation** would be extremely helpful (difficult to have) .



A thunderstorm case in Houston (Marinescu et al., 2021)

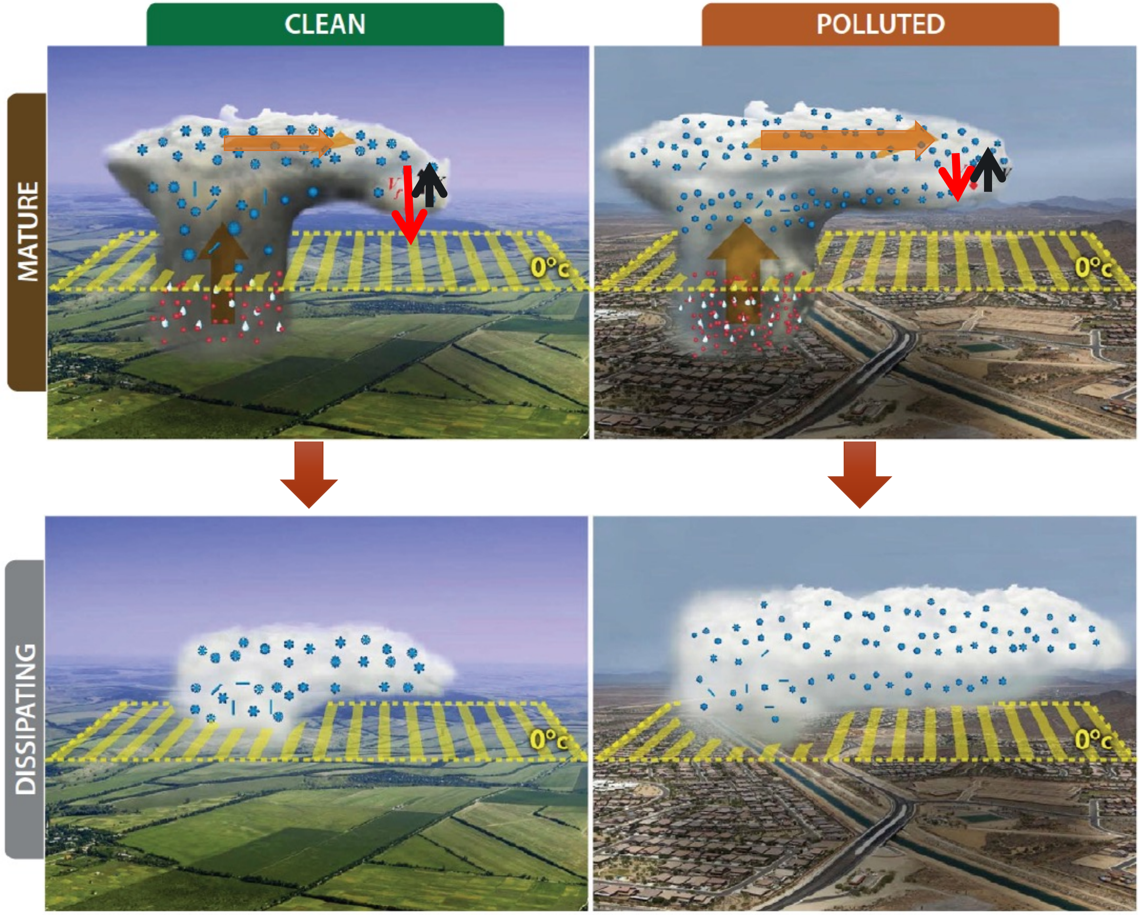


Fan et al. 2018

Challenging problems and key data needed (4)

- **Concerning the mixed-phase regime**
  - Develop more reliable **methods** to **distinguish liquid and ice** particle properties
  - New observations in **ice nuclei particles (INP) and ice nucleation and freezing processes**.

- **Concerning stratiform and anvil**
  - Cloud **area** and **depth**
  - Ice and snow **size** and **fall speed**



Fan et al., 2013

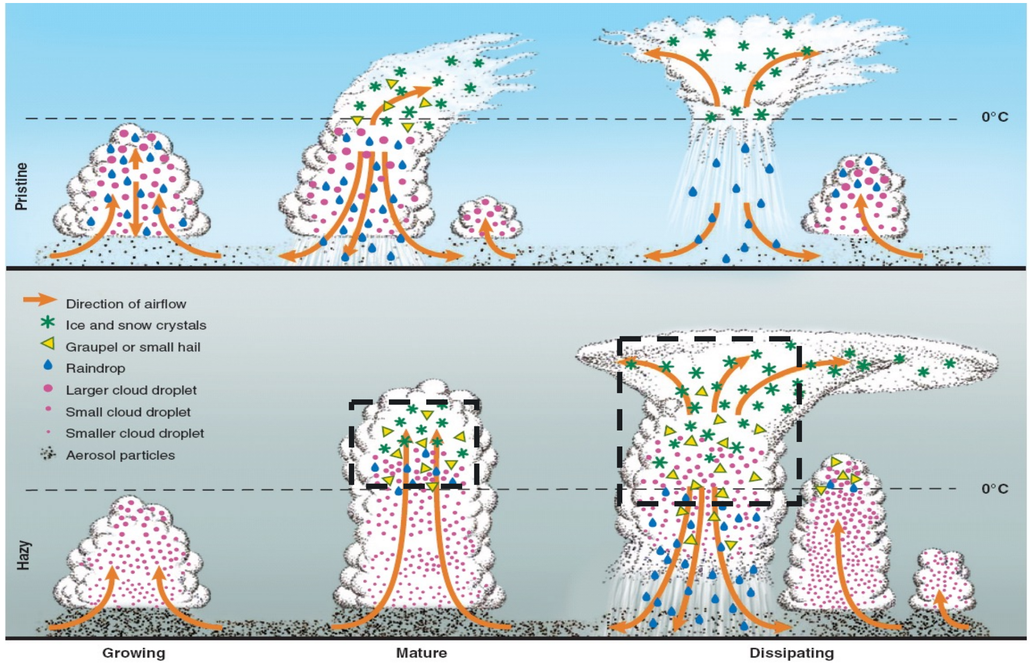
Back-up slides

Major mechanisms: aerosol-cloud interactions (ACI) impacts on deep convective clouds

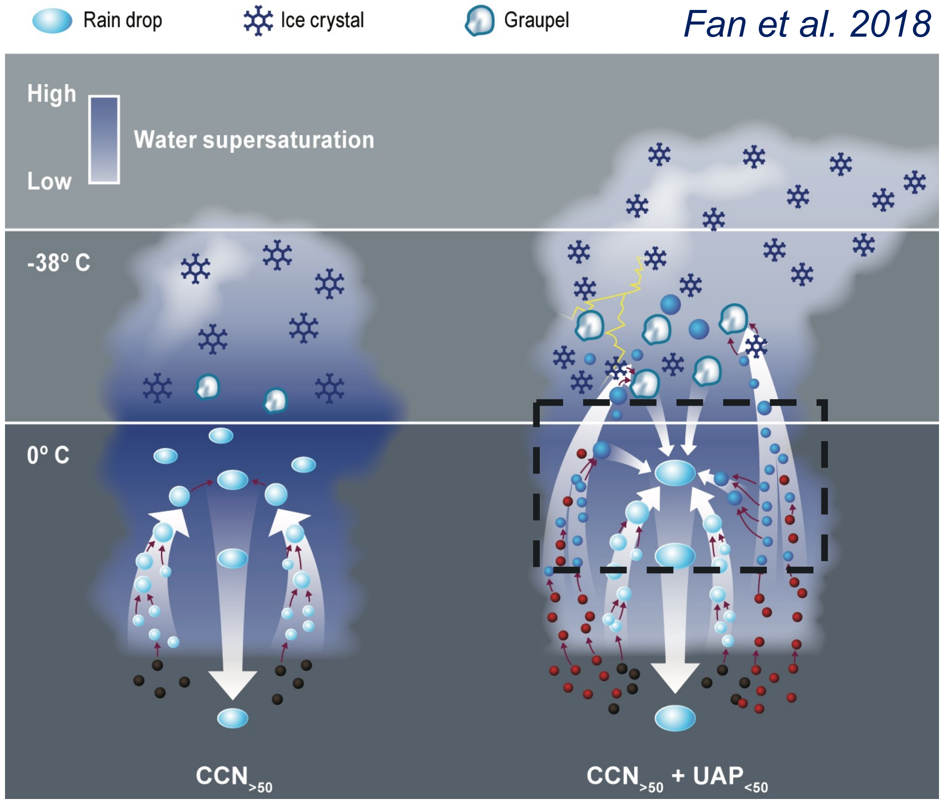
1. "Cold-phase invigoration": Induced by enhanced drop freezing (e.g., *Andreae et al. 2004, Khain et al. 2005, van den Heever et al. 2006; Rosenfeld et al. 2008, Fan et al. 2012)*

2. "Warm-phase invigoration": induced by enhanced condensation (*Wang 2005, Fan et al. 2007, Sheffield et al., 2015*). **The effect is manifested by ultrafine aerosol particles** (*Khain et al. 2012, Fan et al. 2018*)

Rosenfeld et al. 2008



Fan et al. 2018



Major mechanisms: aerosol-cloud interactions (ACI) impacts on deep convective clouds

3. Through modulating cold pool properties: enhance or weaken cold pool (C), depending on wind shear (∆U) conditions (*Lee et al., 2008; Chen et al., 2020*) **and the altitude of the dry layer** (*Grant and Van Den Heever, 2015*).

Clean (C is strong) Polluted (C is weakened)

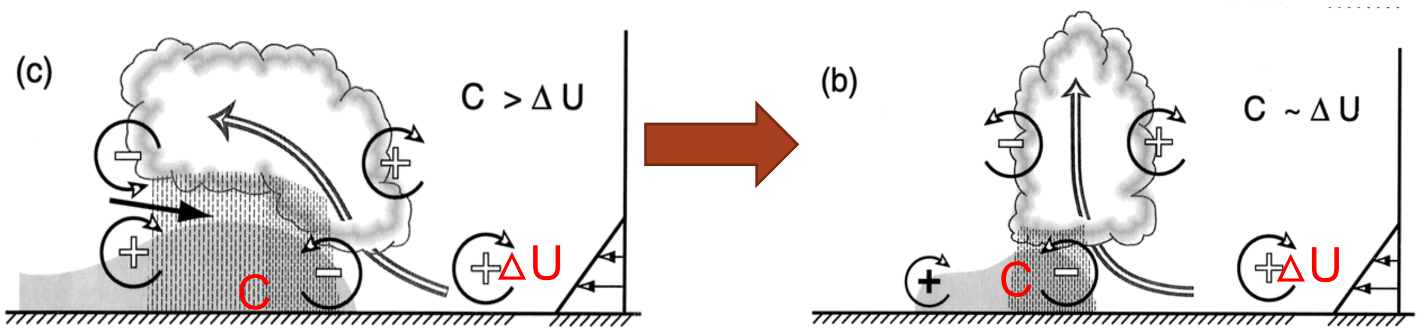
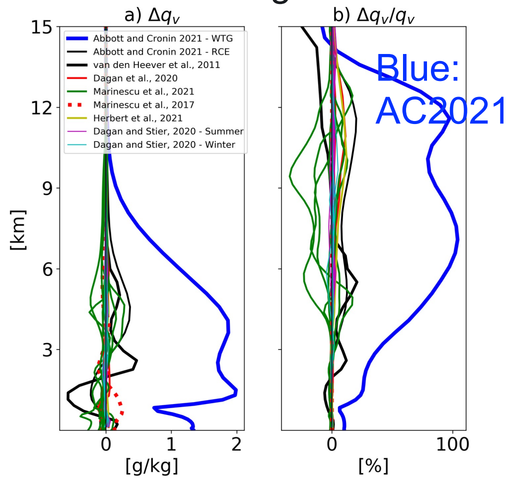


Figure from Weisman and Rotunno (2004)

Weakened C leads to invigorated convection because of a more optimal balance between C and ∆U (Lebo and Morrison 2014; Chen et al. 2020)

4. Through the feedback to environment: e.g., feedback of upper-level heating to circulation (*Fan et al. 2012*)**; enhanced droplet evaporation increases environmental humidity over a long-time scale** (*Abbott and Cronin, 2021; AC2021*).

Modeling



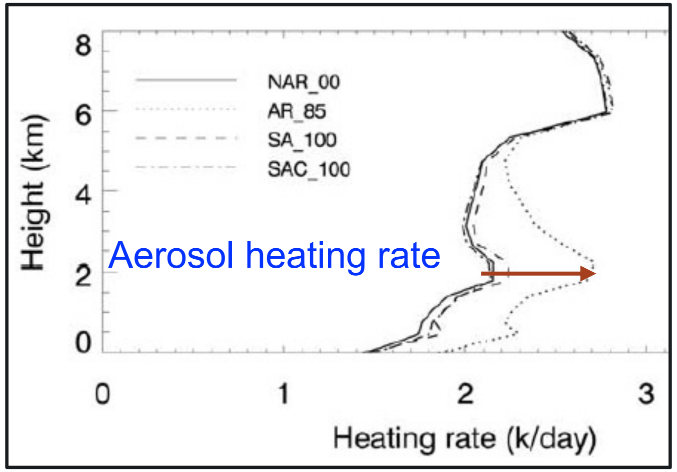
The strong moistening effect in AC2021 is shown to be an artifact caused by the periodic boundary conditions used in long-time model integration

Dagan et al, (2022), Commu. Earth & Envir.

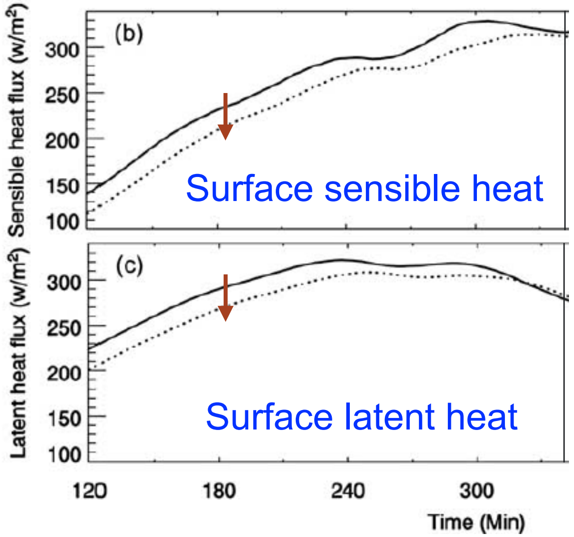
Major mechanisms: aerosol-radiation interaction (ARI) impacts on deep convective clouds

For DCCs, ARI can suppress convection, reducing cloud fraction and precipitation *(Fan et al. 2008)*. **Over the regional scale, similar results were seen for Indian and East Asia monsoon precipitation through aerosol-radiation-land surface feedback** (e.g., *Ramanathan et al. 2005, Menon et al. 2002, Lee et al. 2014*)

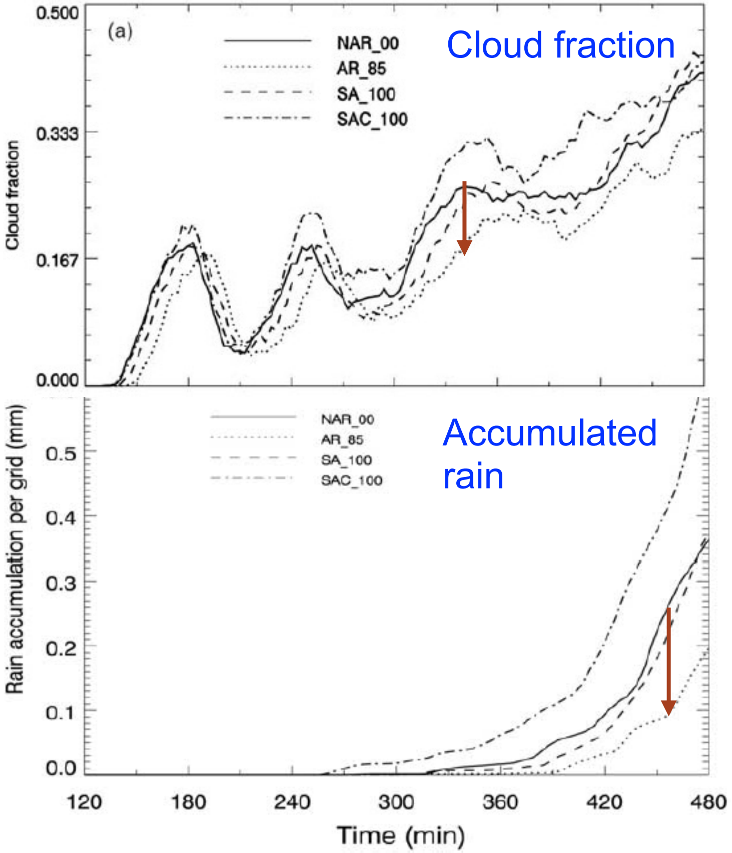
- Heating stabilizes atmosphere



- Reduce surface fluxes



- Decrease cloud fraction and reduce precipitation



Fan et al. 2008