Aerosol and Deep Cloud Interaction (ADCI)

FOCUS GROUP SCIENCE PLAN

Committed Members
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Non-committed but Highly Valuable Members
Robert Houze, Alexander Khain, Wei-Kuo Tao, Ann Fridlind

Objectives

- Identification of any ADCI-related or induced phenomena by making extensive use of ARM data, as well as other data;
- Investigation of the causality by means of both observation and modeling;
- Quantification of the ADCI impact on cloud, radiation budget and precipitation;
- Investigation of multi-scale interactions and feedbacks associated with the ADCI;
- Narrowing the spread of CRM model simulations of the ADCI by means of CRM inter-comparison for some well-defined cases.
- Improve representation of ADCI in GCM convection parameterizations by incorporating CLUBB scheme.

Various Effects Dictating ADCI

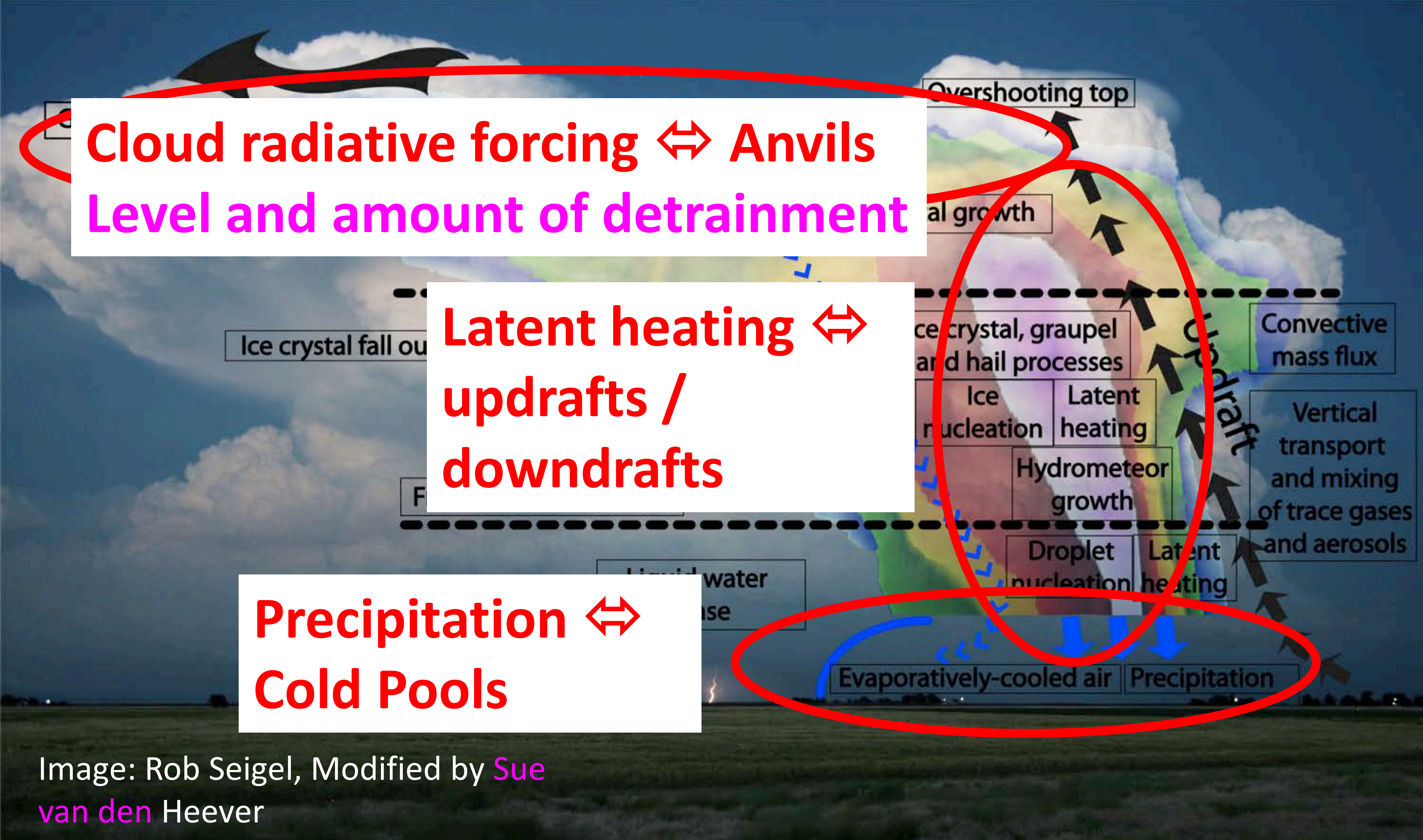
1. Aerosol direct radiative effect – suppressing

2. Aerosol semi-direct effect – conditional enhancing

3. Aerosol first indirect effect – enhancing

4. Net effect: pending on aerosol properties & metoeorological settings

Aerosol Effects on Deep Convection



Cloud radiative forcing ⇔ Anvils

Level and amount of detrainment

Latent heating ⇔ updrafts / downdrafts

Precipitation ⇔ Cold Pools

Image: Rob Seigel, Modified by Sue van den Heever

Key Issues & Uncertainties

- Anvil radiative forcing

  Responses vary from negative to positive responses per observational, CRM and conceptual studies

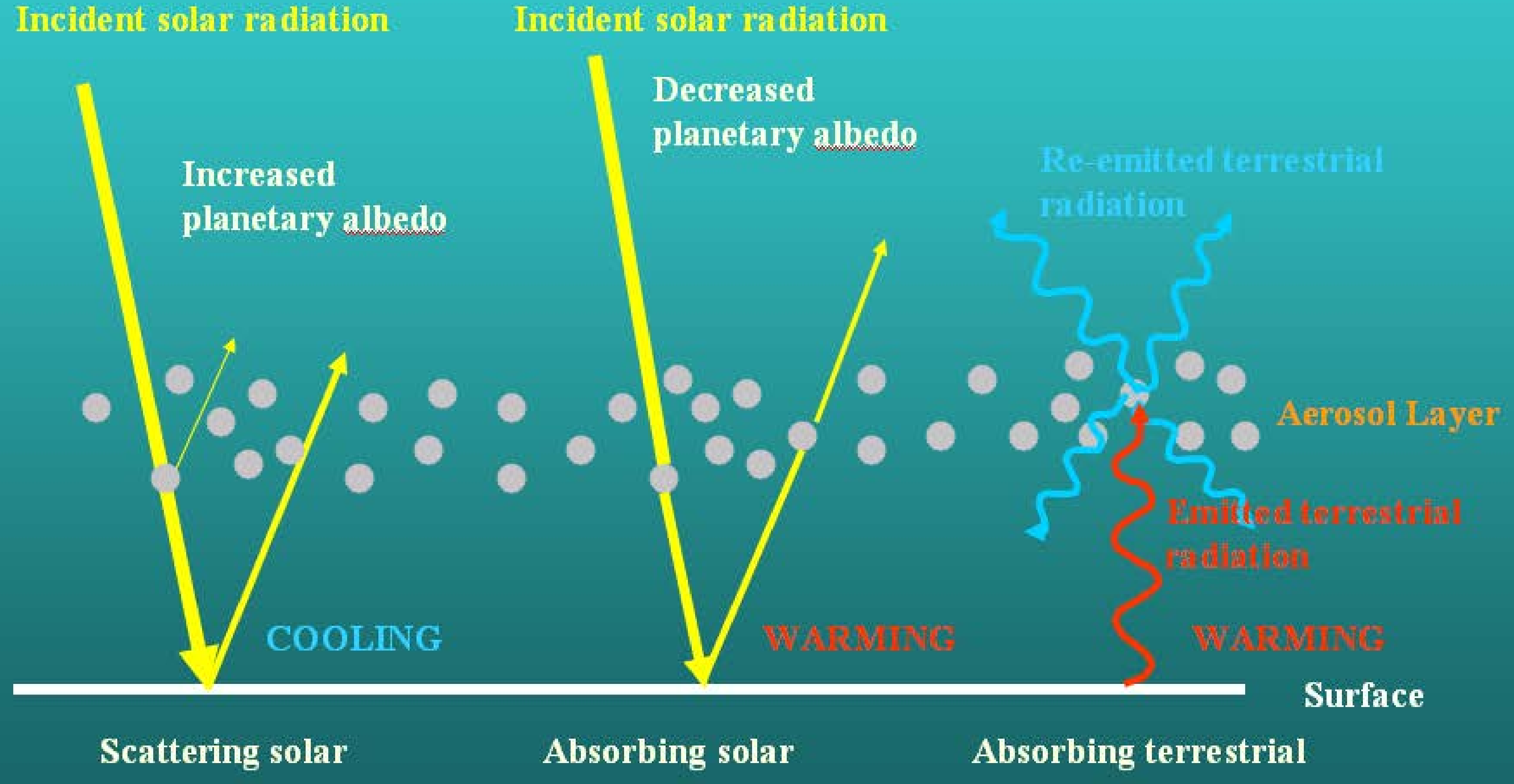
  Anvil fractional coverage affected by aerosol

- Latent heating & vertical velocity:
  - Cloud base height & mixed-phase microphysical processes
  - Vertical velocity
  - Feedbacks between latent heating and vertical motion
- Detrainment
  - Level and amount
- Precipitation

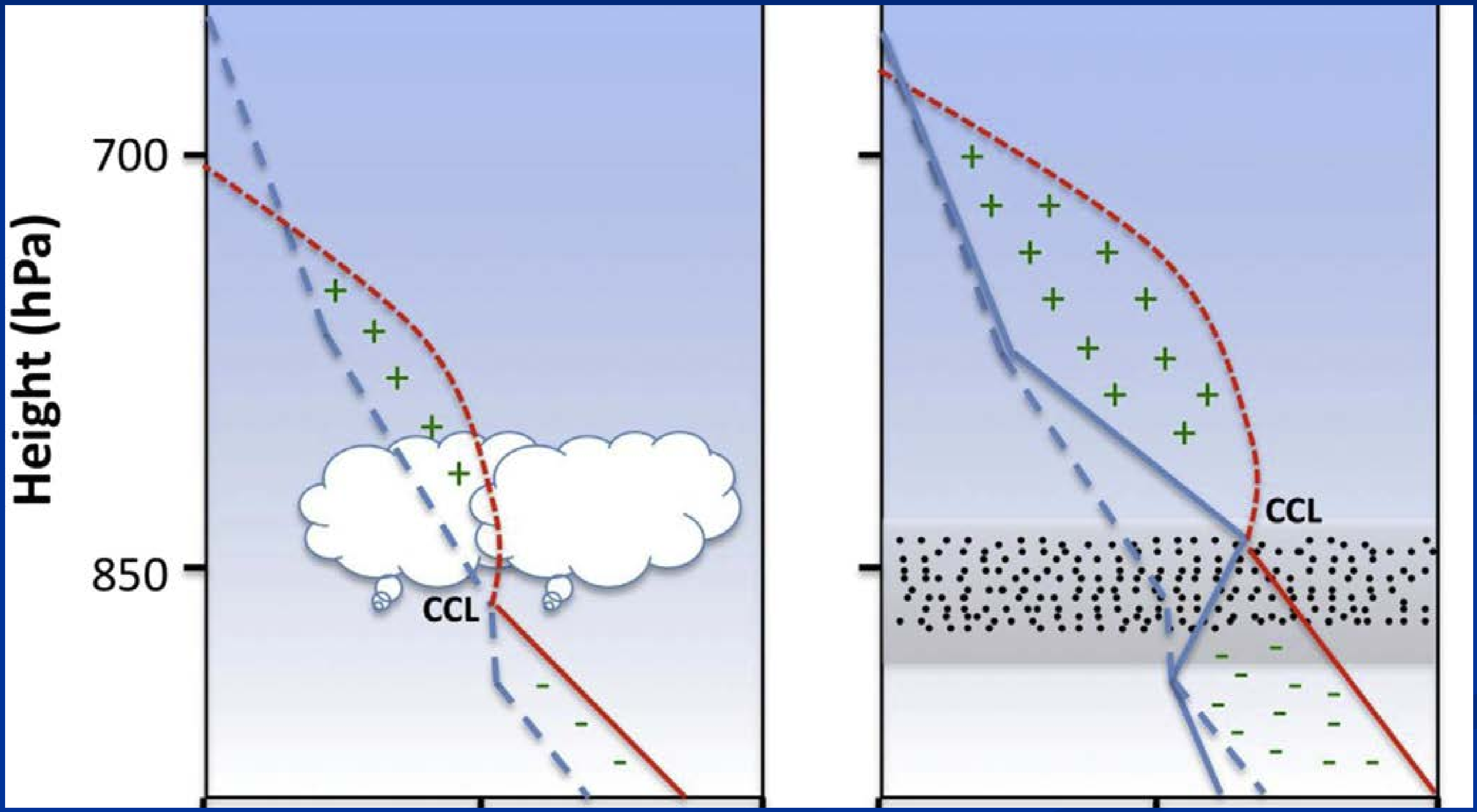
  "Among these modeling studies, the most striking difference is that cumulative precipitation can either increase or decrease in response to higher concentrations of CCN." (Tao et al 2012, Rev. of Geophy.). For CAPI, both rain amount and PDF matter !

Direct effect

(clear skies for simplicity)

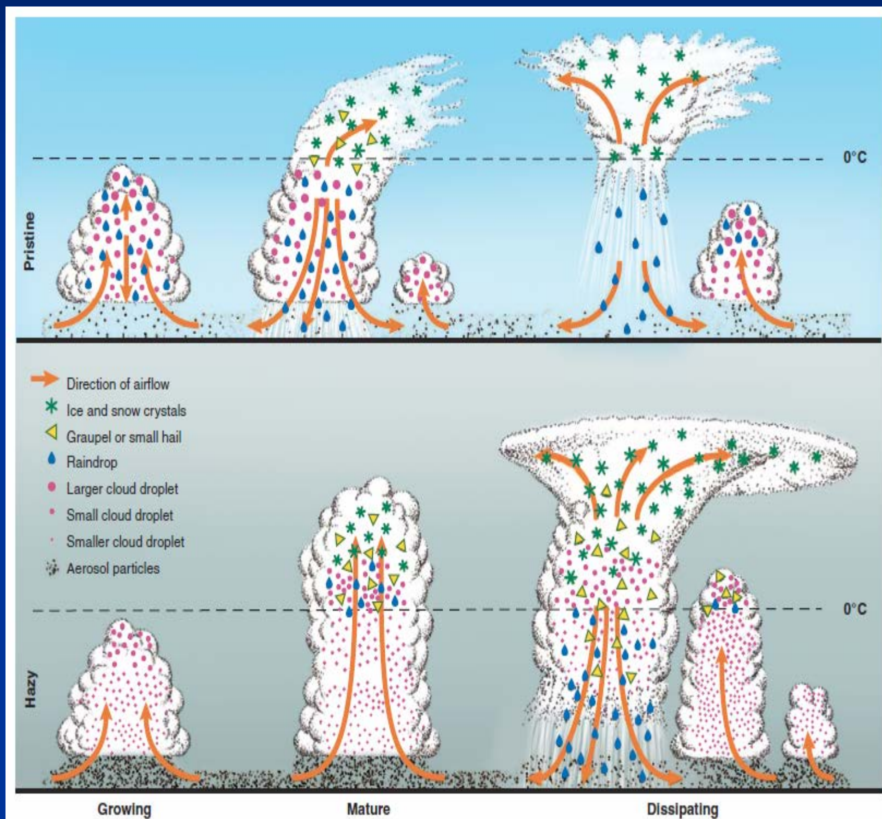


Aerosol and Cloud Interaction due to Semi-Direct Effect

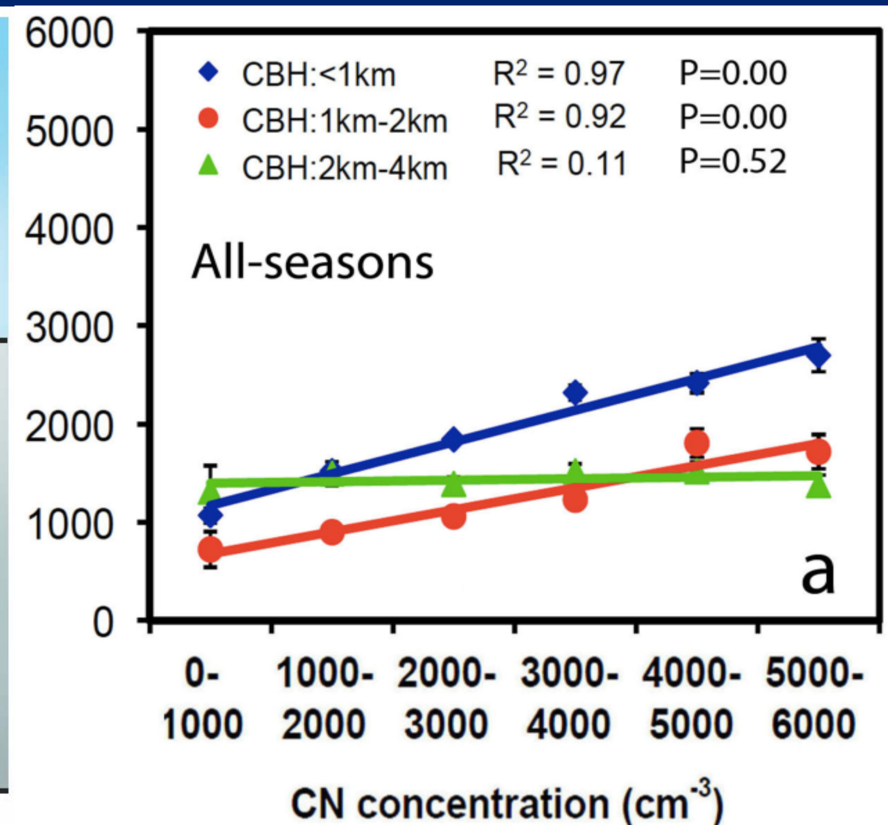


Wang et al. (2013, AE)

Impact of aerosol invigoration effect

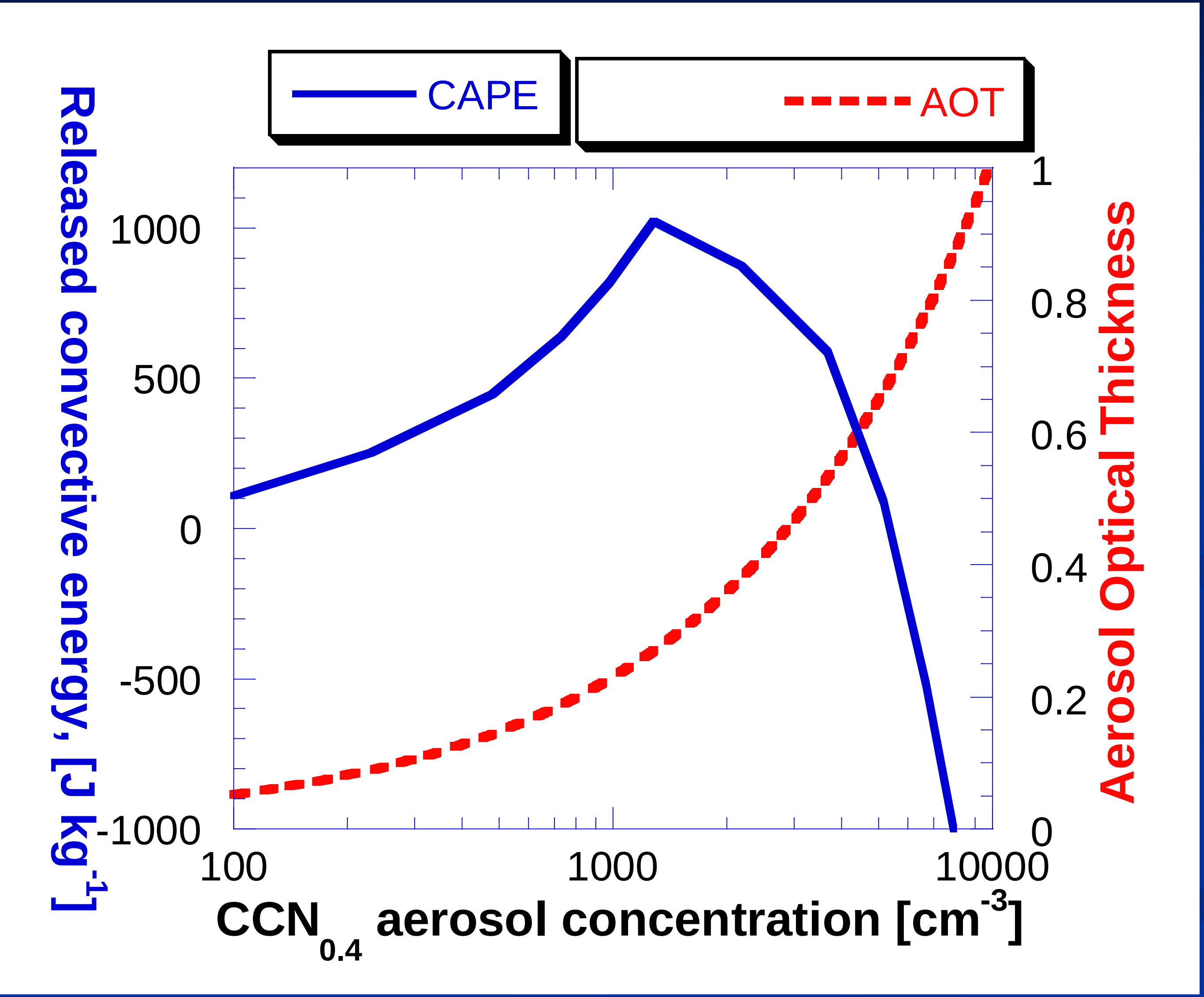


Rosenfeld et al (2008, Science)



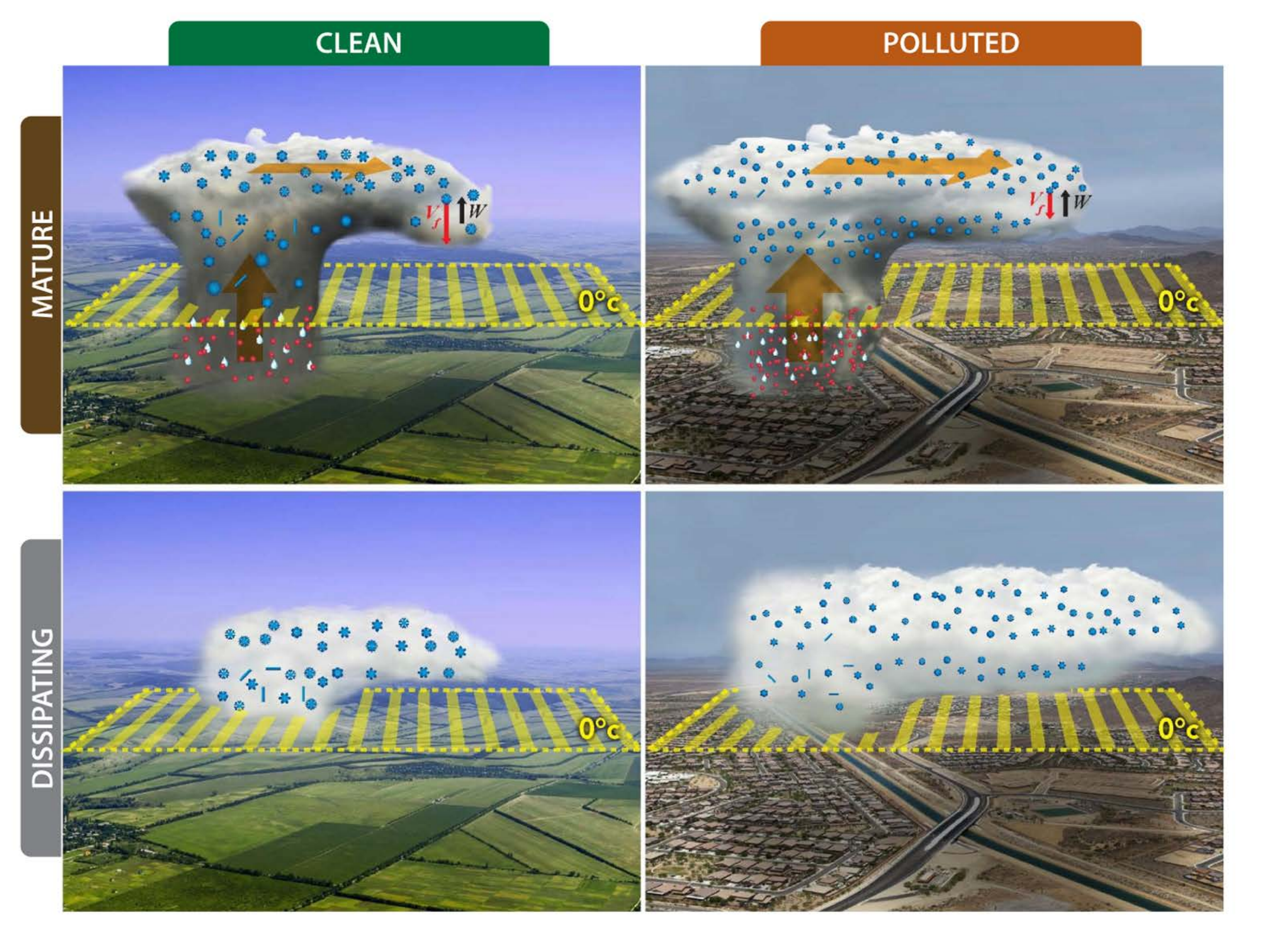
Li et al (2011, Nature-Geosci)

Released CAPE as a function of CCN concentrations



Koran et al. (2008, Science)

Joint Impact of Aerosol Microphysical and Thermodynamic Effects on ADCI



Fan et al. (2013, PNAS)

Outstanding Questions

- How to disentangle aerosol effects from meteorological variability and identify the key meteorological controls on convective cloud characteristics?
- How much are the impacts of aerosol on DCC-induced cloud radiative forcing due to changes in cloud microphysical and macro-physical parameters?
- How do various multi-scale factors work together to dictate the overall effect?
- What are the specific regimes where aerosols might have the greatest influence on convective clouds?
- How do we represent the various mechanisms associated with different factors in convection parameterizations used in meso- and large-scale models?
- Can we identify specific processes contributing to the large spread of CRM deep convection simulations?

Observations Needed & Challenges

- **CCN near cloud base and IN inside clouds**
- **Vertical velocity through the depth of deep convective systems**
- Profiles of radiative & latent heating rates
- Anvil heights and extent
- Large spatial domain measurements to monitor evolution of cloud system
- Continuous coverage of diurnal variation
- Diverse environmental conditions

Observation Tasks

- Analyze ARM and other data attempting to sort out various physical mechanisms of the ADCI by accounting for all processes.
- Conduct dedicated field experiments using aircraft to get the essential variables affecting the ADCI, especially their veridical profiles, developing and validating novel approaches of getting CCN, vertical wind and heating rates.
- Evaluate the global impact of ADCI on aerosol radiative forcing and precipitation by combining satellite and ground data.

Modeling Challenges

What can explain large differences among different modeling studies?

- - different cases (sensitivity to environment, e.g., shear, RH, CAPE)
- - differences in models and model parameterizations (e.g., bulk vs. bin microphysics)
- - different spatial and temporal scales
- Stage in the lifecycle
- How can we best use ARM observations (and other datasets) to constrain models?

What collaborative activities can help address these issues?

- - e.g., systematic modeling studies to address differences for observationally based cases a la GCSS/GASS???

Modeling Tasks

- CRM inter-comparison on the simulation of ADCI and pertinent parameterizations for some ideal cases and ensembles to study the mechanisms of ADCI and identify any common problems.
- Test and improve SCMs in dealing with ADCI with reference to any metrics measuring the ADCI from observations and CRM ensemble simulation,
- Implement CLUBB into CAM5 and GFDL model and to evaluate its effect on the simulation of ADCI.
- Simulate and evaluate the impact of ADCI on global climate, especially on aerosol radiative forcing and rainfall simulation.

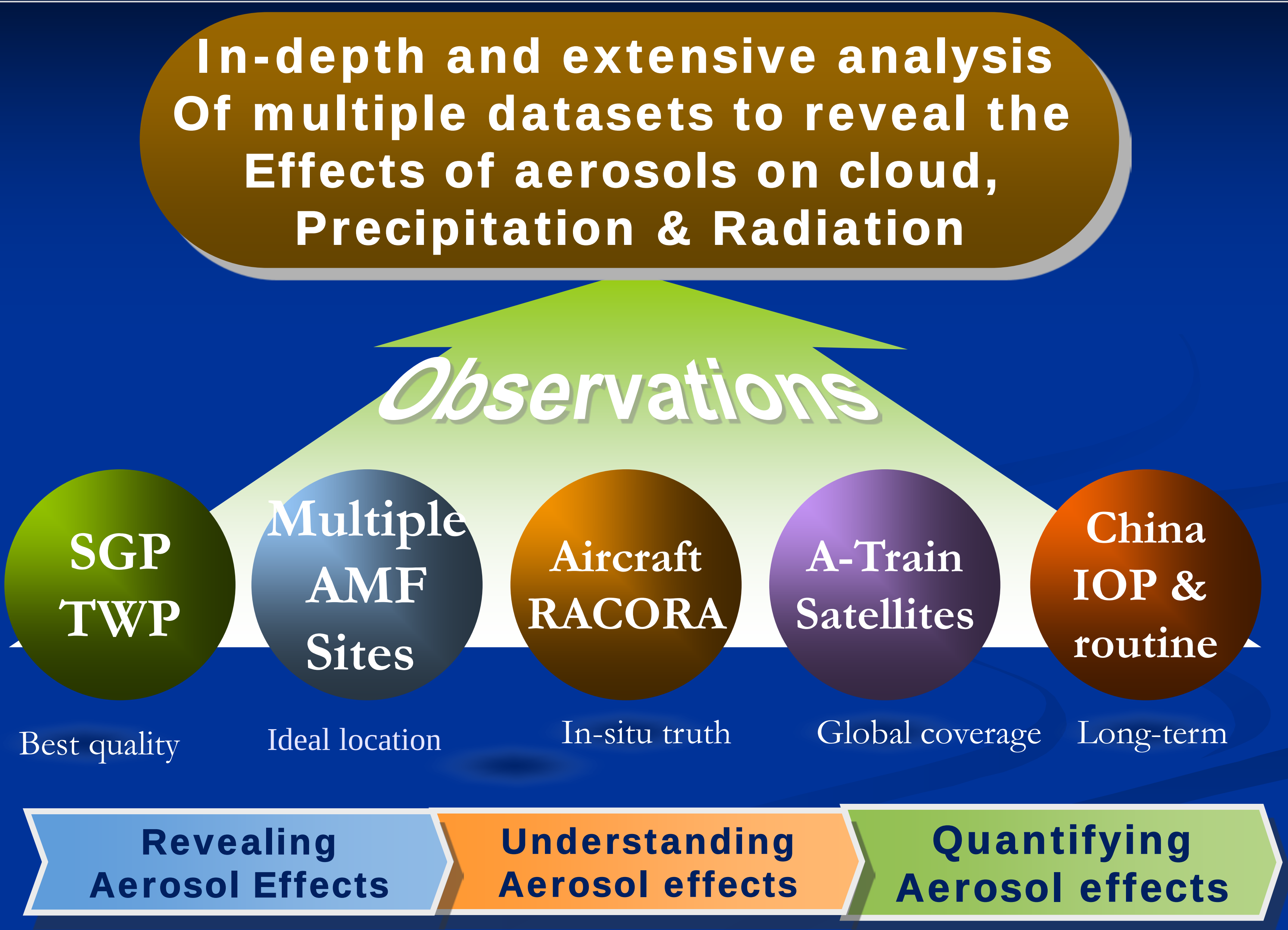
Observation-based investigations

Observation and analysis studies aim to

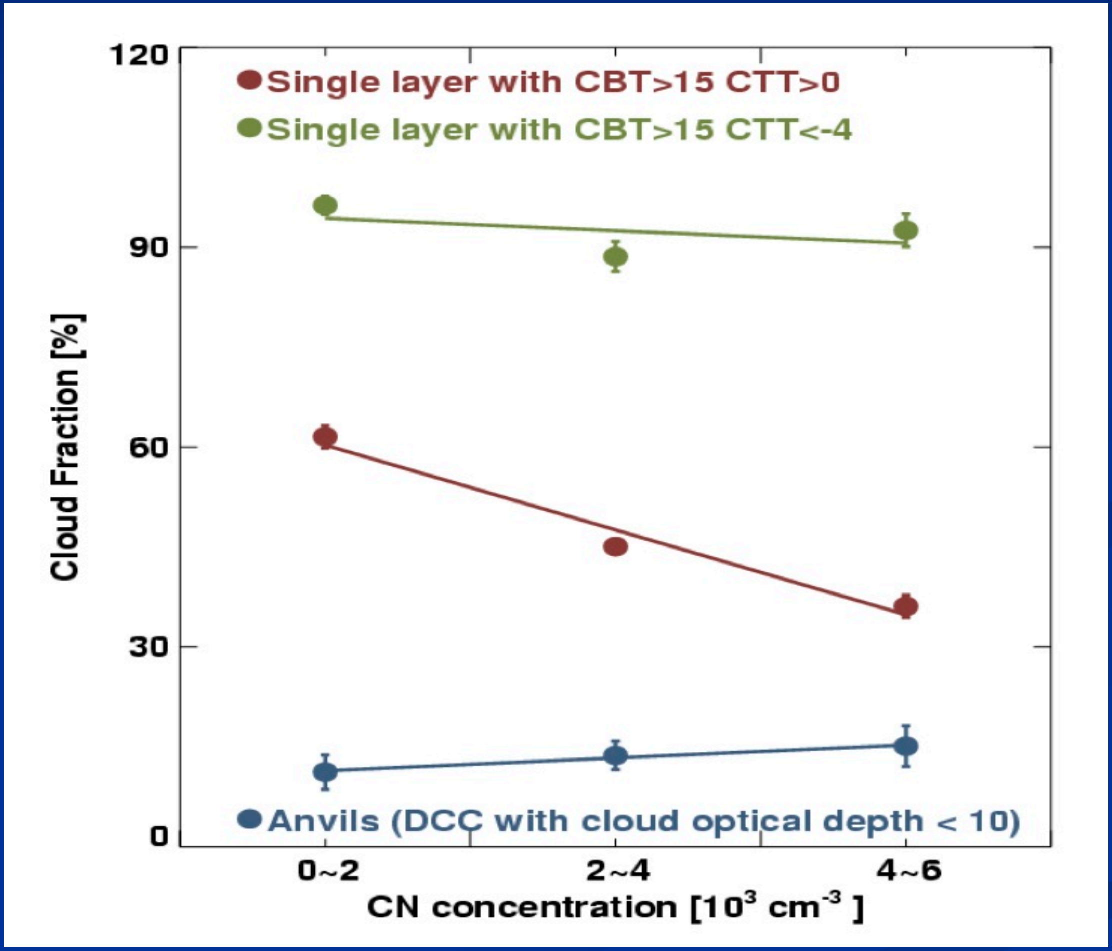
- reveal any ADCI phenomena,
- understand underlying processes and mechanisms, and
- quantify the effects on weather and climate.

Investigators: Z. Li, D. Rosenfeld, X. Dong

Exploitation of All-kinds of Observations



Changes of Cloud Fraction with Aerosol Number Concentration from 10 Years of GOES Data by P. Minnis



Fan et al. (2013, PNAS)

Long-term Meteor Data Revealing the Suppressing Effect of Absorbing Aerosol on Thunderstorms (Li's team)

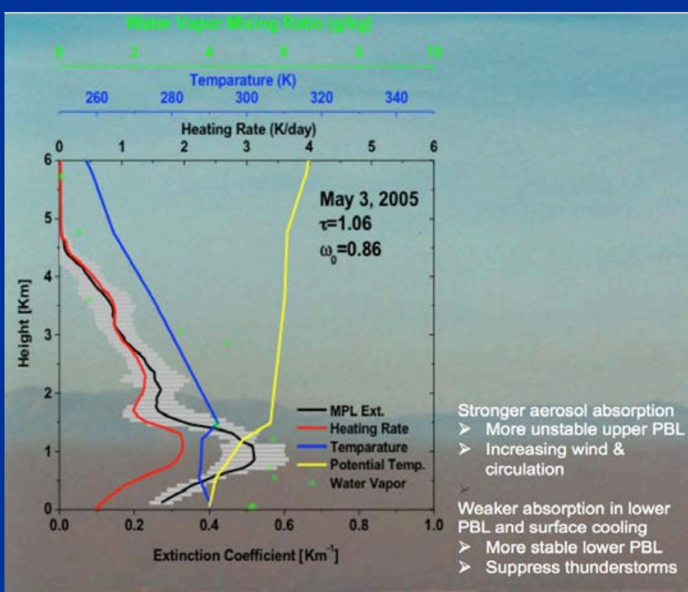
Science Question

What's the impact of the buildup of absorbing aerosol on local climate ?

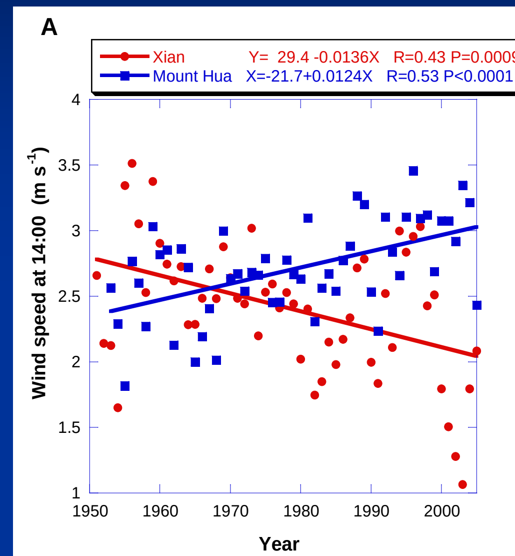
Can the effect be detected to explain long-term climate changes in China?

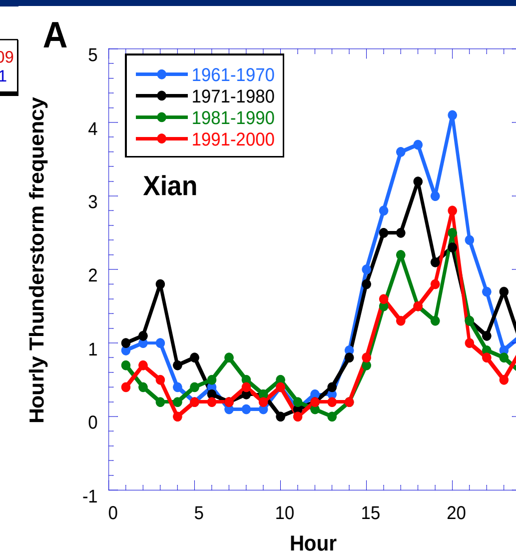
Background

- Absorbing is being increasingly recognized for its multi-effects on climate
- Evaluating and separating the effects are possible over terrain-plain regions
- The high loading and rapid increasing trend of BC aerosol in China is an ideal testbed for the study.



50-year trends of wind speed and thunderstorms





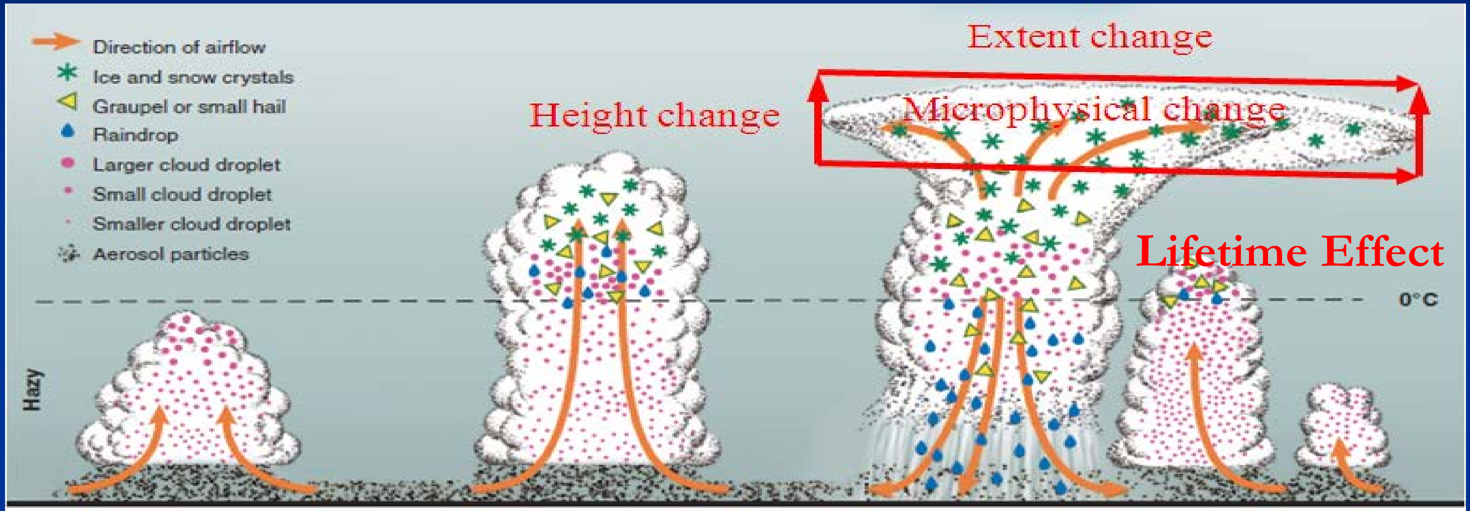
Key Findings

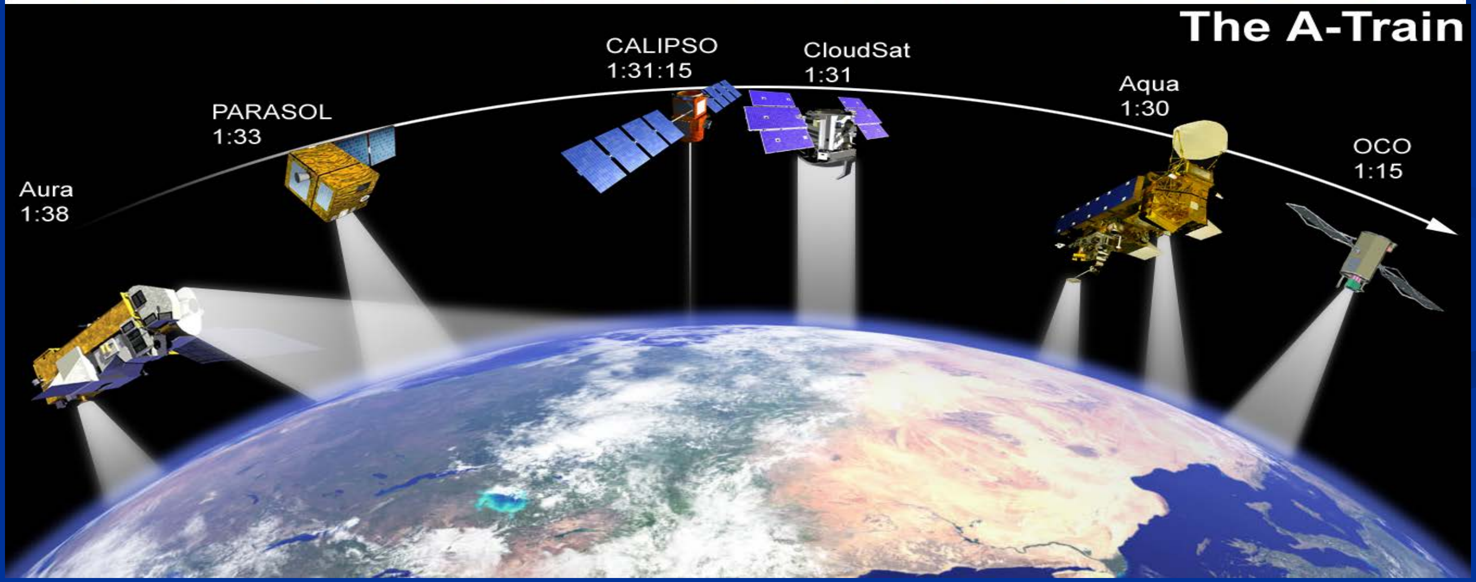
- Wind speed has decreased steadily at Xi'an in the plain over the past 50 years when visibility has reduced by 50%, but an opposite trend mountain at a nearby mountain top station.
- The number of thunderstorms at Xi'an has declined from 1960s through 2000s.

Publication

Yang, et al., 2013, Heavy air pollution suppresses summer thunderstorms in central China, *J. Atmos. & Solar-Terrestrial Phy*. 28-40, doi:10.1016/j.jastp.2012.12.023.

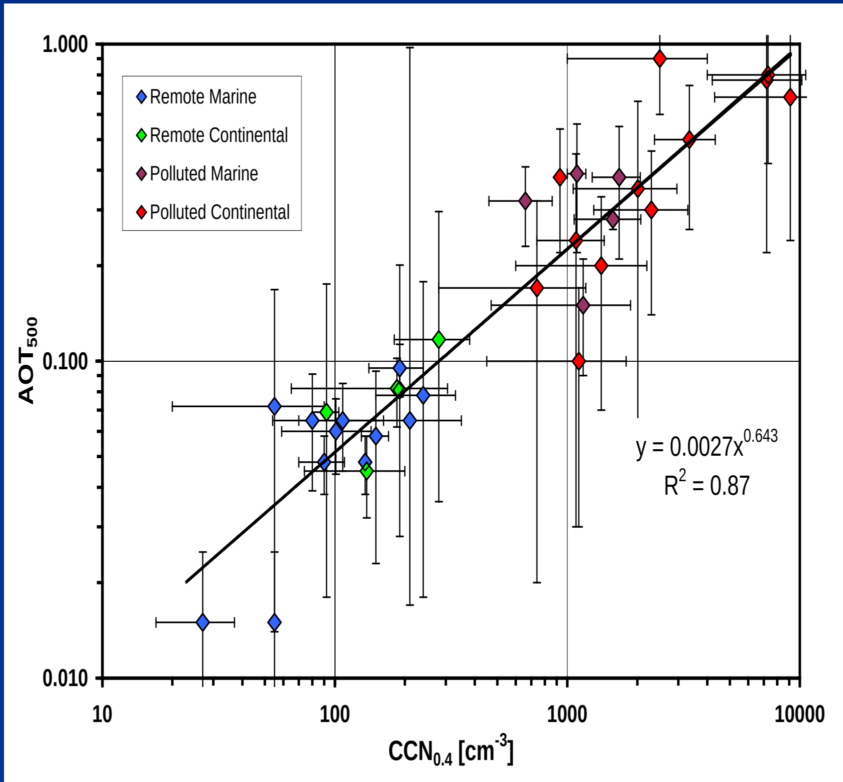
Use of Long-term ARM Ground and Global Satellite to Determine the Impact of ADCI on cloud radiative forcing (Aerosol-Mediated CRF) (Li's team)





Use of Multiple AMF Data for Improving Estimates of Cloud Condensation Nuclei Concentration (Li's team)

To gain a deep insight into the relationship between CCN concentration and aerosol quantities for improving the estimation of the CCN concentration from aerosol optical quantities measurements



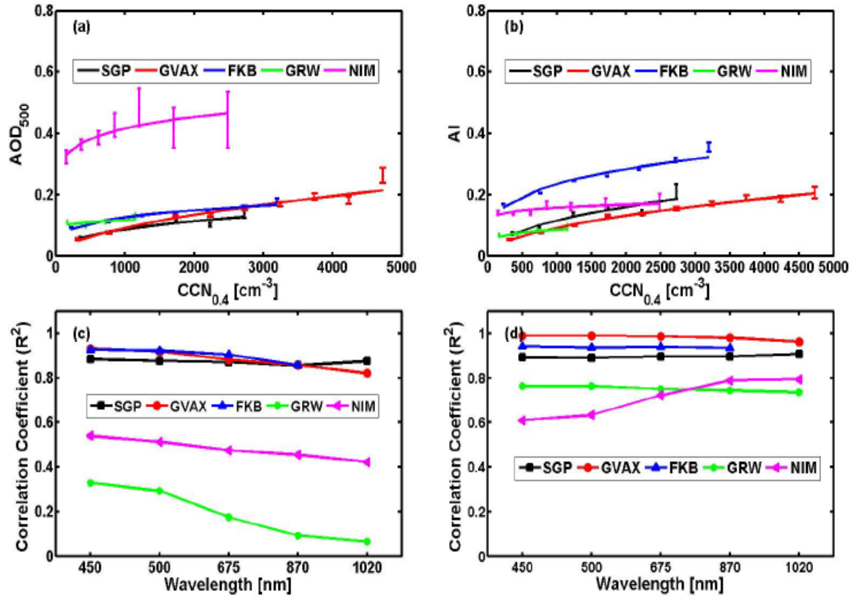


Fig. 1. (a) Relationship between AOD at 500 nm and $CCN_{0.4}$, **(b)** relationship between AI and $CCN_{0.4}$ **(c)** their correlation coefficients, and **(d)** same as **(c)**, but for AI in lieu of AOD.

Publication

Liu, J., and Z. Li, 2014: Estimation of cloud condensation nuclei concentration from aerosol optical properties: influential factors and uncertainties, Atmos. Chem. Phys., 14, doi:10.5194/acp-14-471-2014.

Aircraft-based Observations Needed

- ***Closure between aerosols and cloud base drop size distribution*** (DSD)
- ***Vertical evolution of DSD***, mixing mode and secondary nucleation before rain initiation
- ***Rain initiation*** height and cloud drop size
- ***Ice initiation*** temperature, height and types
- ***Cloud glaciation***
- ***Formation mode of anvil ice***
- ***Exhaust of aerosols and vapor from the anvil.***

Satellite Observation

- ***Convective cloud base drop concentrations***
- ***Cloud base updrafts*** contrast between surface skin and air temperatures.
- ***Heights for initiation of warm rain, mixed phase precipitation and glaciation temperatures***
- ***Cloud top rising rate of large convective elements***
- ***The extent of mixed phase precipitation forming processes***

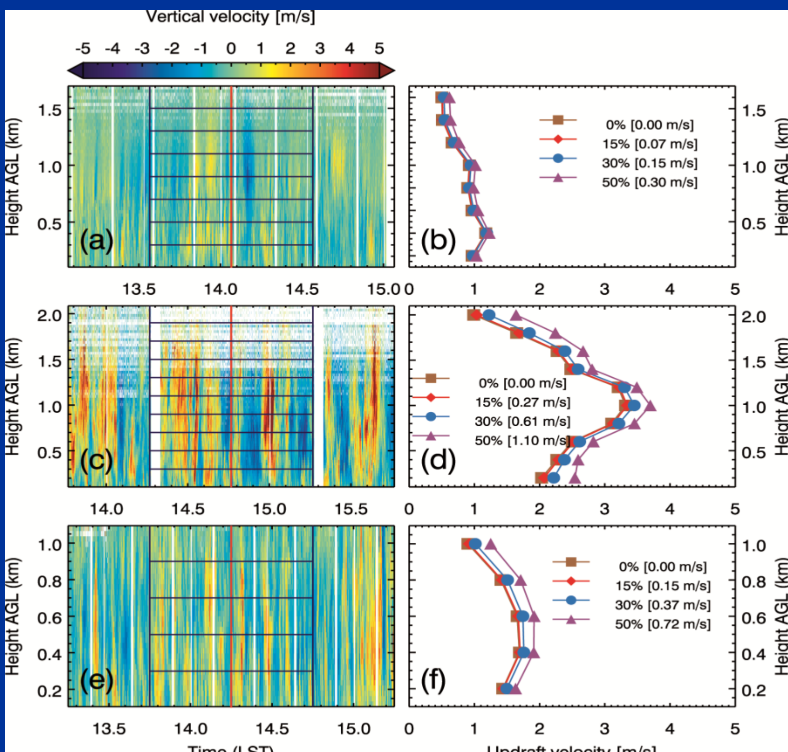
Satellite inference of thermals and cloud base updraft speeds based on retrieved surface and cloud base temperatures

Youtong Zheng[1,2], Daniel Rosenfeld[2] and Zhanqing Li[1]
[1]University of Maryland; [2]The Hebrew University of Jerusalem

1. Calculating updraft speed (W) with Doppler lidar

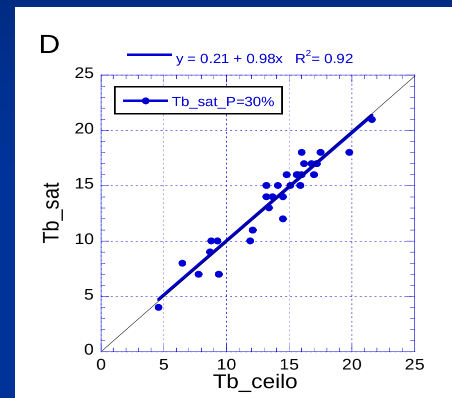
$$W = \sum \frac{N_i W_i^2}{N_i W_i} \Big| W_i > 0$$

N_i stands for the frequency of occurrence of W_i.



2. Satellite-retrieved cloud base temperature

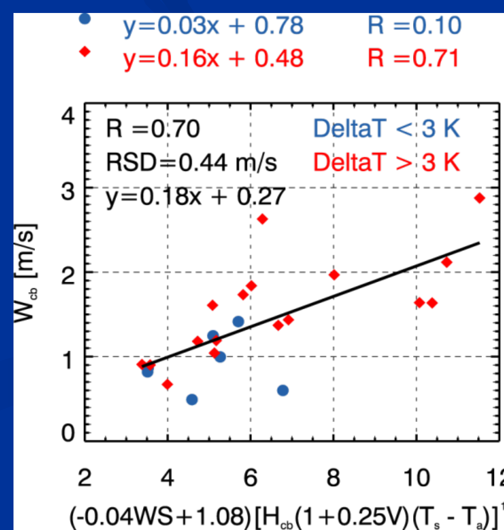
Tb by satellite



Tb by ceilometer

Tb: Cloud base temperature

3. Cloud base updraft estimation (W_{cb})



DeltaT: Temperature difference between cloud base and cloud top.

V: surface wind speed

Ts: surface skin temperature

Ta: 2-m air temperature

WS: vertical wind shear

Hcb: cloud base height

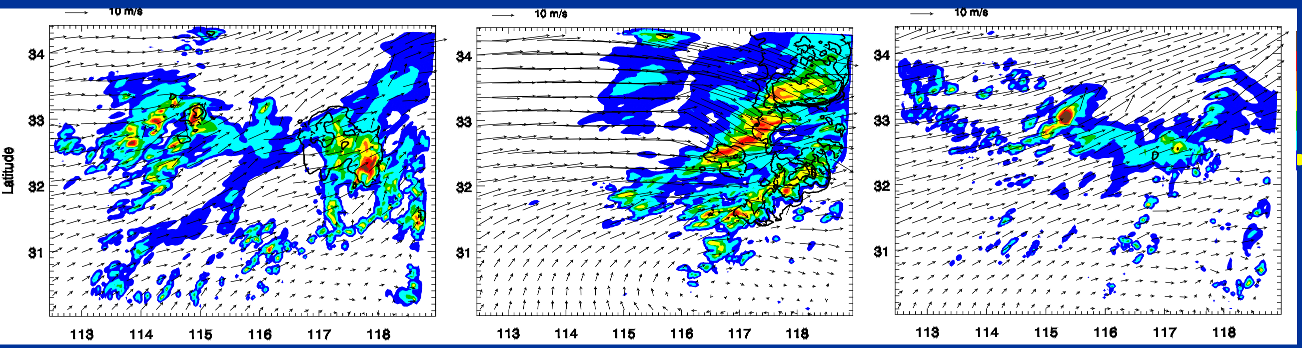
CRM Model Inter-comparison

- Conduct a CRM model intercomparison of ADCI simulations based on MC3E case(s) to identify differences across models and the key processes contributing to the differences,
- Conduct process-level studies of DCCs with the improved models to understand and quantify the mechanisms that cause significant aerosol impacts on dynamical and microphysical properties
- Use CRMs with bin microphysics to improve parameterization of microphysics and cloud-aerosol interactions in DCC parameterizations for GCMs.

Investigators: Fan, Morrison, van den Heever

Roles of Vertical Wind Shear in Cloud System Organization and Aerosol Effects

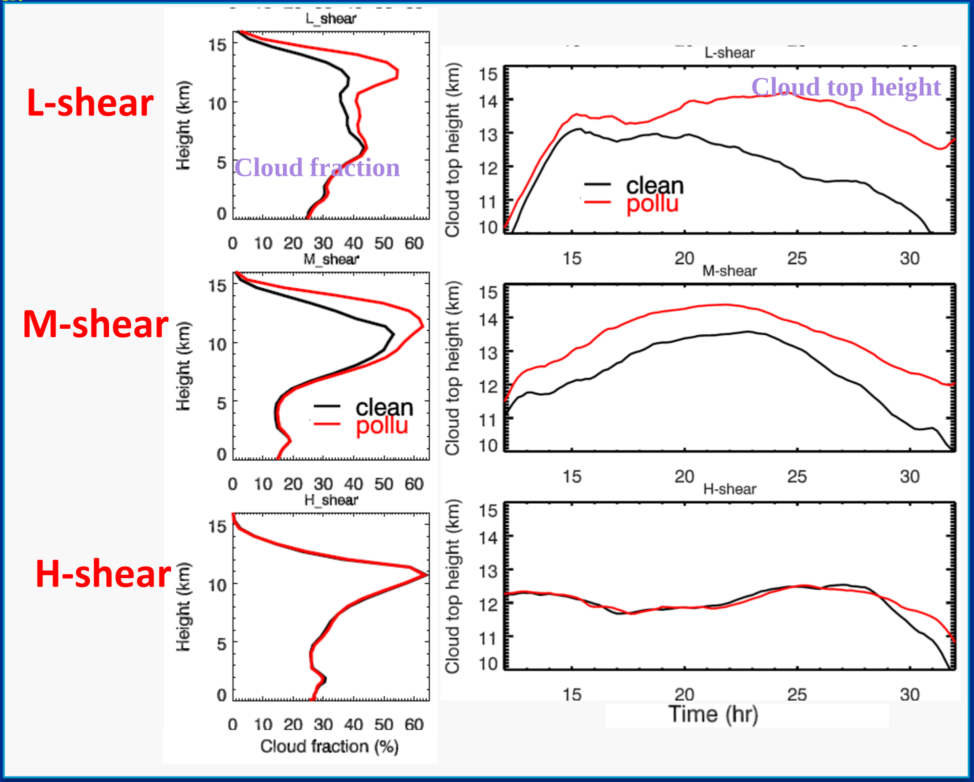
Base run of MCS | Lower-altitude wind shear (L-shear) | Mid-altitude wind shear (M-shear)



Spatial distribution of precipitation; arrows denote wind field.

- Increasing wind shear at the lower-troposphere is favorable for a more organized quasi-line system.
- Strong wind shear in the middle troposphere produces a strong super-cell with much reduced precipitation area.

- No matter in what cloud system, microphysical aerosol effect revealed in Fan et al. PNAS (i.e., increased cloud fraction and top height) is very significant with low or middle-altitude wind shear.
- Strong upper-level wind shear significantly suppress microphysical aerosol effect.



GCM Studies

- ***Capacity building for GCMs in Modeling ADCI***

  Evaluate and improve deep cloud simulations in the single-column model by using field observations and high-resolution CRM results.

- ***GCM simulations of aerosol microphysical, thermodynamic and invigoration effects***
  - single column model simulations will be run using the same cases chosen for the CRM inter-comparison
  - full GCMs will be run with prescribed or interactive aerosols. The simulation will be analyzed in the same way as observations to determine if the models are able to reproduce the observed relationships between aerosol loading and convection

Investigators: G. Zhang, M. Wang & M. Ovchinnikov, L. Donner,

Toward a Unified Cloud Parameterization

(Minghuai Wang and Mikhail Ovchinnikov, PNNL, in collaboration with UWM and NCAR)

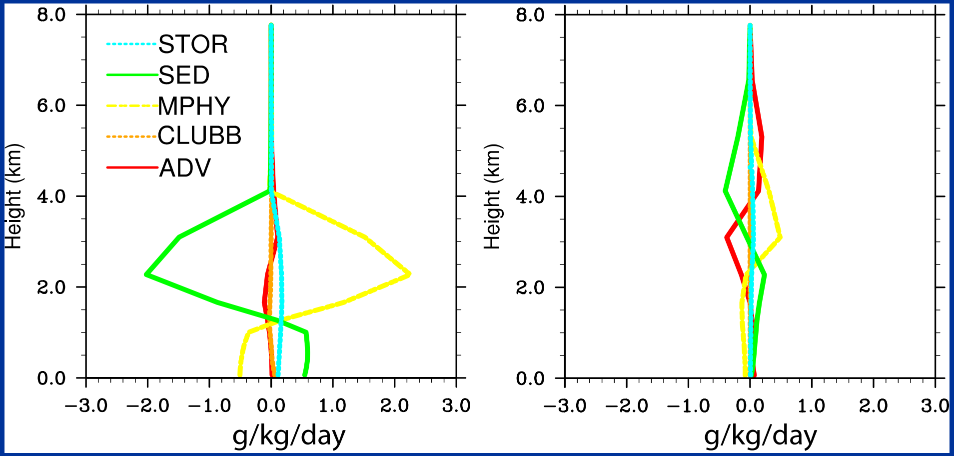
Goals and Approach

- Develop a consistent treatment of aerosol indirect effect in stratiform and convective clouds
- Use CLUBB, an assumed dynamics PDF method for coupling subgrid turbulence and cloud processes and extend to deep convection

Progress:

- Selected and set up CRM and single-column model cases for testing and analysis: **ARM-97**, **TWP-ICE**, and **MC3E**
- Developed tools for budget analysis

Rain Water Budget



CLUBB LES

Next Steps

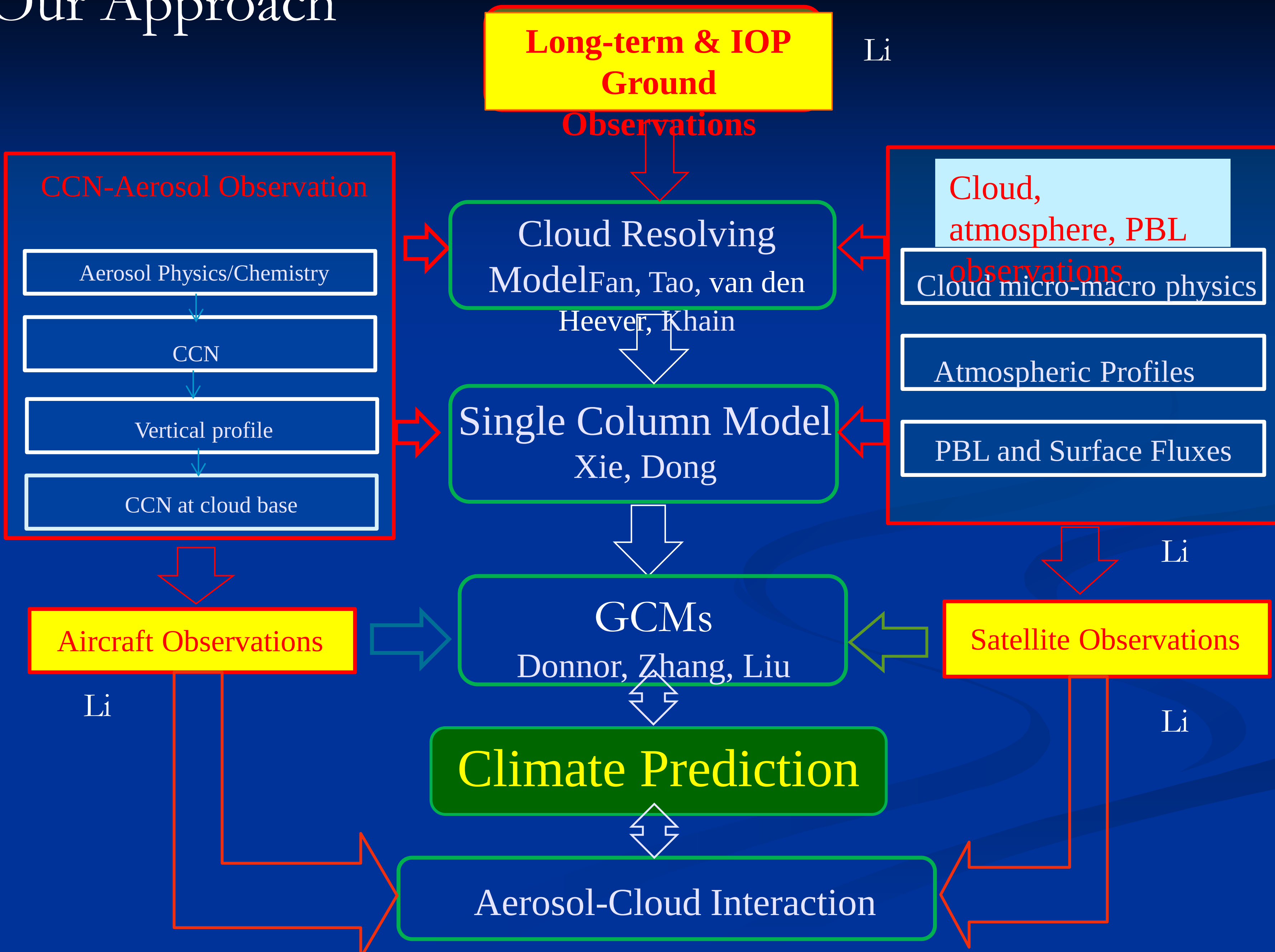
- Compare single-column results with CRM results
- Improve identified shortcomings in transport of cloud and precipitation variables
- Explore aerosol effects on deep convection within the unified scheme

Committed Team Members & Roles

1. Z. Li, Analyses of a variety of observations for revealing and quantifying the ADCI and their radiative effects
2. D. Rosenfeld, Estimation of CCN & vertical velocity at cloud base (also Z. Li).
3. Scott Collis (Ghate, Cmostock, Kirk North), 3-D wind
4. X. Dong, Development of DCS data base and case studies.
5. J. Fan, Leading CRM Inter-comparison, long-term simulations
6. H. Morrison, CRM simulation and paramterizaiton.
7. S. van den Heever, idealized and case study simulations of aerosol effects on deep convection
8. G. Zhang Convective Microphysics Parameterization
9. Leo Donner (GFDL), ADCI Coupling in GFDL AM3
10. M. Wang & Ovchinnikov, Unified CRM-SCM-GCM in Cloud Parameterization

Thank you !
Please join us for
free coffee.

Our Approach



Following Slides for Breakout Discussion

What do we do for the breakout ?

- Progress update and new member presentations
- Explore collaborations
- Identify unmet measurement/retrieval needs
- Discuss potential new field experiments
- Coordination of various activities as a focus group

Talks at Breakout (4:00-6:00)

- 4:00-4:15 Marcus van-lier Walqui: Storm and cell-scale polarimetric radar signatures of deep convective updrafts observed during MC3E
- 4:15-4:30 Wojciech Grabowski: Aerosol indirect effects on deep convection over the Maritime Continent
- 4:30-4:45 Qing Yang: Model evaluation of aerosol wet scavenging in deep convective clouds based on observations collected during the DC3 campaign
- 4:45-5:15 Short highlights and Aerosol-Deep-Convection-Interactions Focus Group discussion
- 5:15-5:30 Jiwen Fan: ASR CRM intercomparison study on aerosol-deep convective cloud interactions
- 5:30-6:00 Discussion of ADCI studies

Recommendation for Observation

1. To continue the pursuit of challenging quantities as identified above

2. To exploit extensive measurements from ground-based (all ARM fixed sites and AMF sites), air-borne (ARM campaigns) and space-borne measurements to attempt to identify and quantify different types of AIEs

3. To provide metrics of the estimates of AIEs from a variety of observation platforms for validation and improvement of a hierarchy of models

Recommendation for Modeling

1. To continue process-oriented modeling exercises to tackle with challenging issues identified

2. To run LES, CRM, SCM and GCM models to try to simulate observed cloud scenes with diverse aerosol inputs and meteorological settings.

3. To analyze modeled quantities in the similar manner as the analyses of observations to examine various relationships as revealed from observations concerning different types of AIEs.

Recommendation for Observers & Modelers

1. Identify deficiencies in both modeling and observations regarding their validity in studying the AIE.

2. Sort out true effects from false appearance.

3. Evaluation of model's performance in simulating the AIEs from local to global scales

Observational studies

Year 1

- Obtain the first aircraft observations of vertical microphysical profiles of convective clouds in Go-Amazon, by the DOE-G1 and the German Halo airplanes. Obtain similar profiles by the G1 in the CALWATER-2 project over California and Eastern Pacific winter storms convective clouds.
- Develop further and validate the satellite capability to measure cloud base drop concentrations and updrafts. Anchor these retrievals to ARM actively remotely sensed retrievals at ARM sites.
- Develop the capability of satellite measurements of convective tops rising rates.
- Obtain the first estimate of ADCI-induced changes in cloud radiative forcing at the SGP by identifying and accounting for its impact on cloud height, cloud fraction (anvil in particular) and cloud microphysics using the same ensembles of 10-years at the SGP.

Observational studies

Year 2

- Improving understanding the joint influences of aerosol's radiative and thermodynamics effects on DCC over aerosol-laden regions of China and India.
- Satellite characterization of full cloud systems of their aerosol, microphysical, dynamical, precipitation and radiative properties.
- Regional analyses of ADCI and its climatic impact on cloud, radiation and precipitation using ARM Mobile Facility measurements.
- Validation of selected retrieved cloud properties when possible over the ASR sites.

CRM Modeling Studies

Year 1

- Set up the inter-comparsion case(s), conduct simulations and submit model data for the first part of CRM intercomparison (fixed flow model).
- Conduct studies for the role of environmental factors in convection invigoration
- Conduct studies to identify the mechanisms that cause significant aerosol impact on dynamical and microphysical properties

CRM Modeling Studies

Year 2

- Analyze the collected data to identify the model differences and evaluate the microphysical processes to find the key processes contributing to the greatest differences. Sensitivity runs may be conducted during the process.

- Set up model configurations for fully coupled dynamical-microphysics part of the CRM inter-comparison and conduct simulations.

- Investigate the role of environmental factors in convection invigoration and factors in convection invigoration

GCM Modeling Studies

Year 1

- Evaluate the single-column version of CAM5 with CLUBB (SCAM5-CLUBB) for MC3E cases against field observations and high-resolution CRM results
- Use the high-resolution CRM results to improve the subgrid transport of microphysical species (e.g., ice and precipitation) in SCAM5-CLUBB
- Evaluate aerosol effects on convection in SCAM5 with the Zhang-McFarlane scheme with two-moment convective microphysics scheme using recent MC3E observations

GCM Modeling Studies

Year 2

- Compare SCAM-CLUBB simulations of deep convection cases for different background aerosol concentrations with high-resolution CRM results.
- GCM intercomparison and comparison with observations of the relationships between aerosol loading and convection activities.
- Investigate ADCI in CAM5 GCM in different convection regimes to determine the influence of meteorological factors (humidity, wind shear, etc.) on convection invigoration.

Approach - Modeling

- Step 1: Idealized simulations
  - using simple, common dynamical framework and multiple microphysical schemes
  - Basic environment determined using SGP data
  - Identify deficiencies in microphysical and aerosol processes using SGP observations => improve them
- Step 2: Case study simulations
  - MC3E cases
  - Comparisons with ARM observations
  - Identify microphysical-dynamical feedbacks
  - Identify processes and feedbacks important to represent in GCM parameterizations