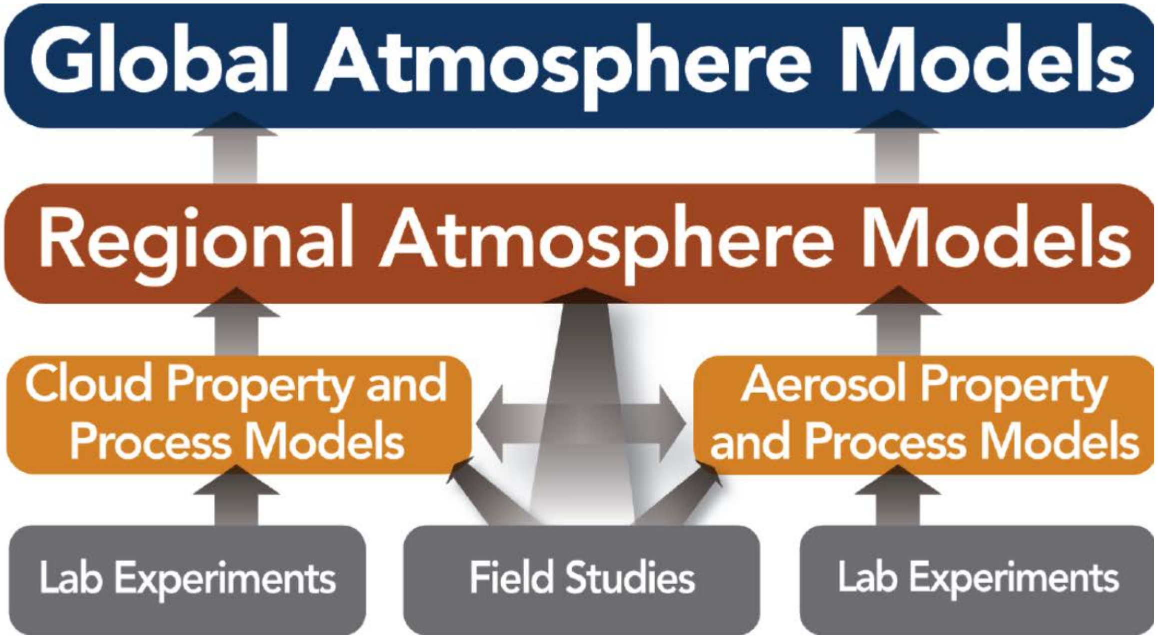
Answering Shallow Warm Clouds Science Questions

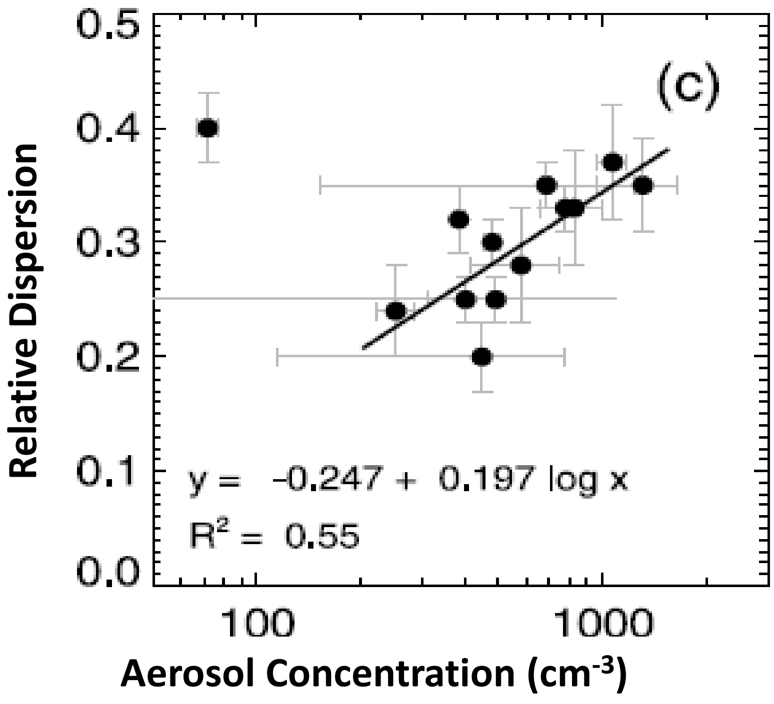
- Why do climate models produce a large aerosol indirect effect?
- What processes control diversity in the sensitivity of warm low clouds to aerosol perturbations?



What processes control diversity in the sensitivity of warm low clouds to aerosol perturbations?

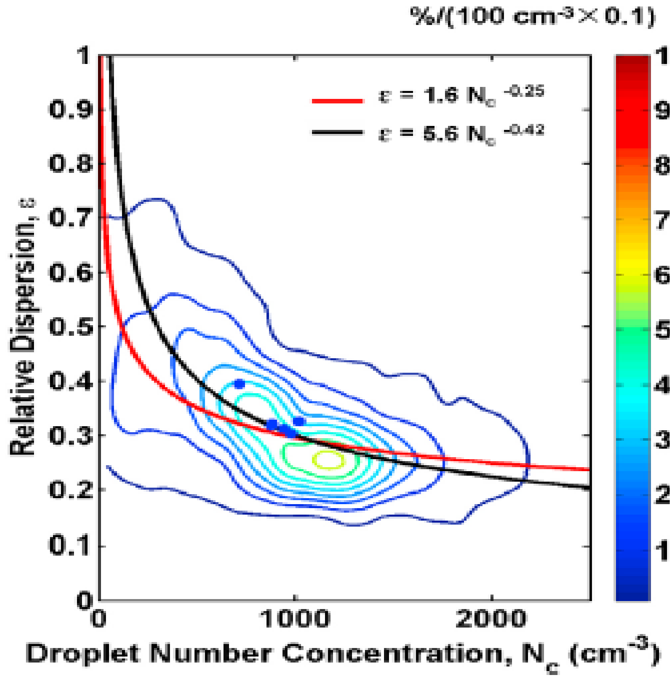
Separation of Dynamical Effects from Aerosol Effect

Aerosol-Limited Regime



Stratiform clouds during MASE (Lu et al., JGR 2007)

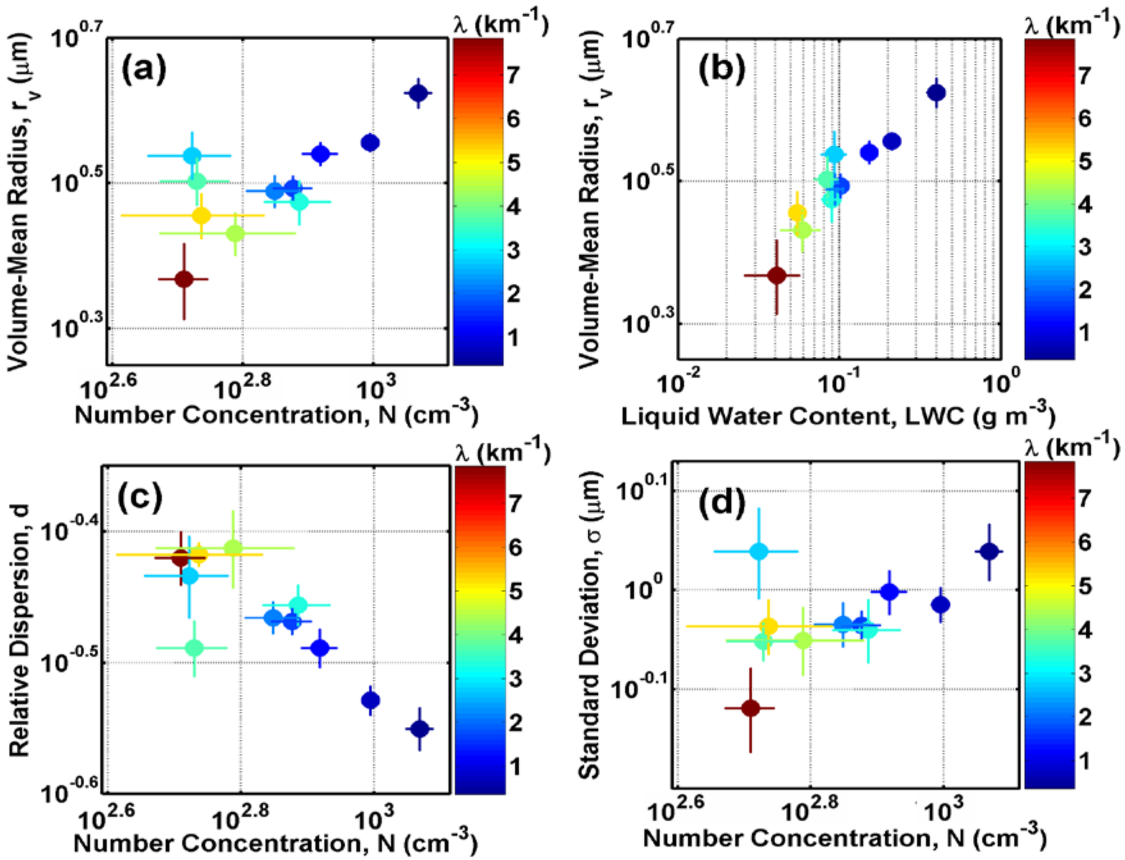
Dynamics-Limited Regime



Cumulus clouds during RACORO (Lu et al., GRL, 2012)

Separation of Dynamical Effects from Aerosol Effect: Entrainment

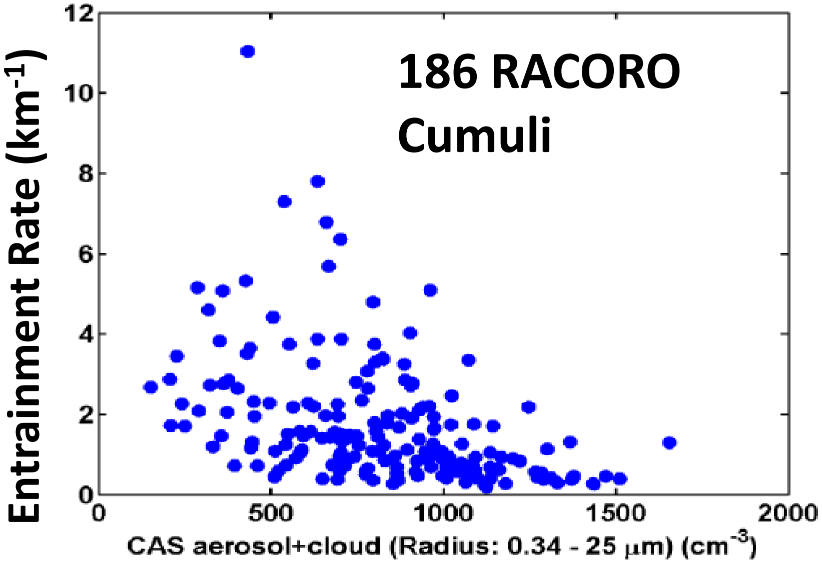
- **Decreases of LWC, N, rv, and σ with entrainment rate.**
- **Increase of relative dispersion with entrainment rate.**

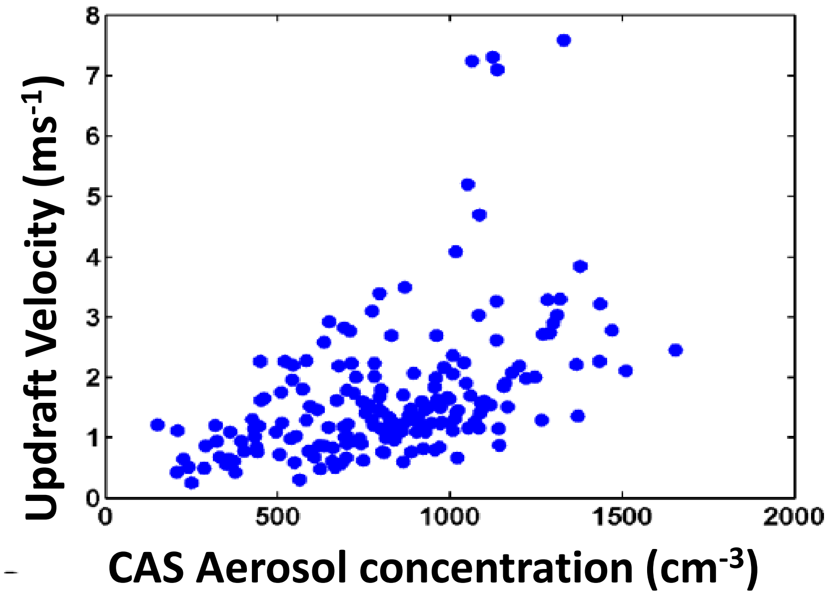


Dependence of microphysical relationships on entrainment rate (λ) as observed from 186 RACORO cumuli (Lu et al, GRL, 2013)

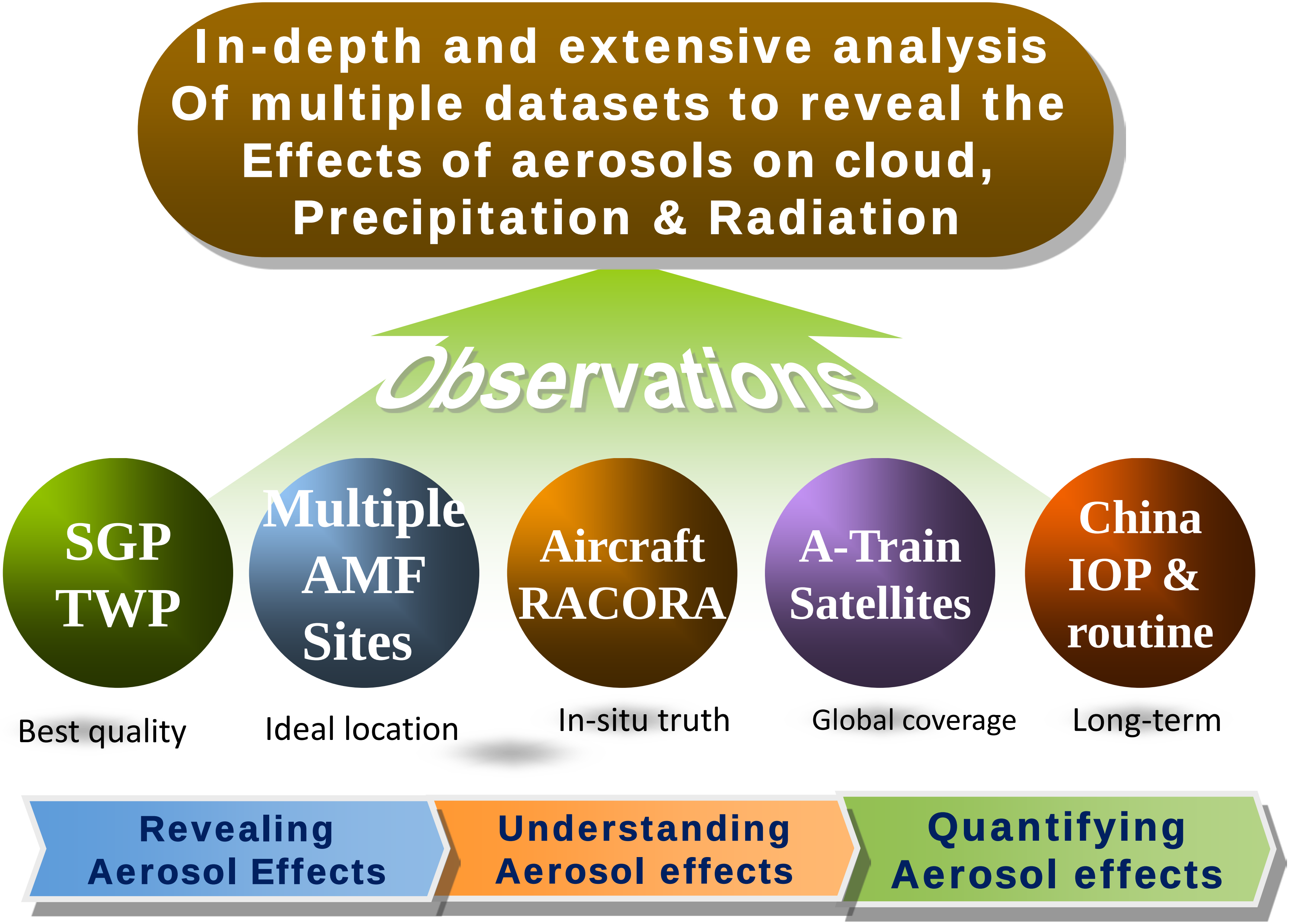
Correlations between Aerosol, Updraft and Entrainment

- Positive correlation between updraft and aerosol concentration.
- Negative correlation between entrainment rate and aerosol concentration.
- Negative correlations between updraft and entrainment rate.
- Cause-effects or common constraints, both makes the separation challenging.

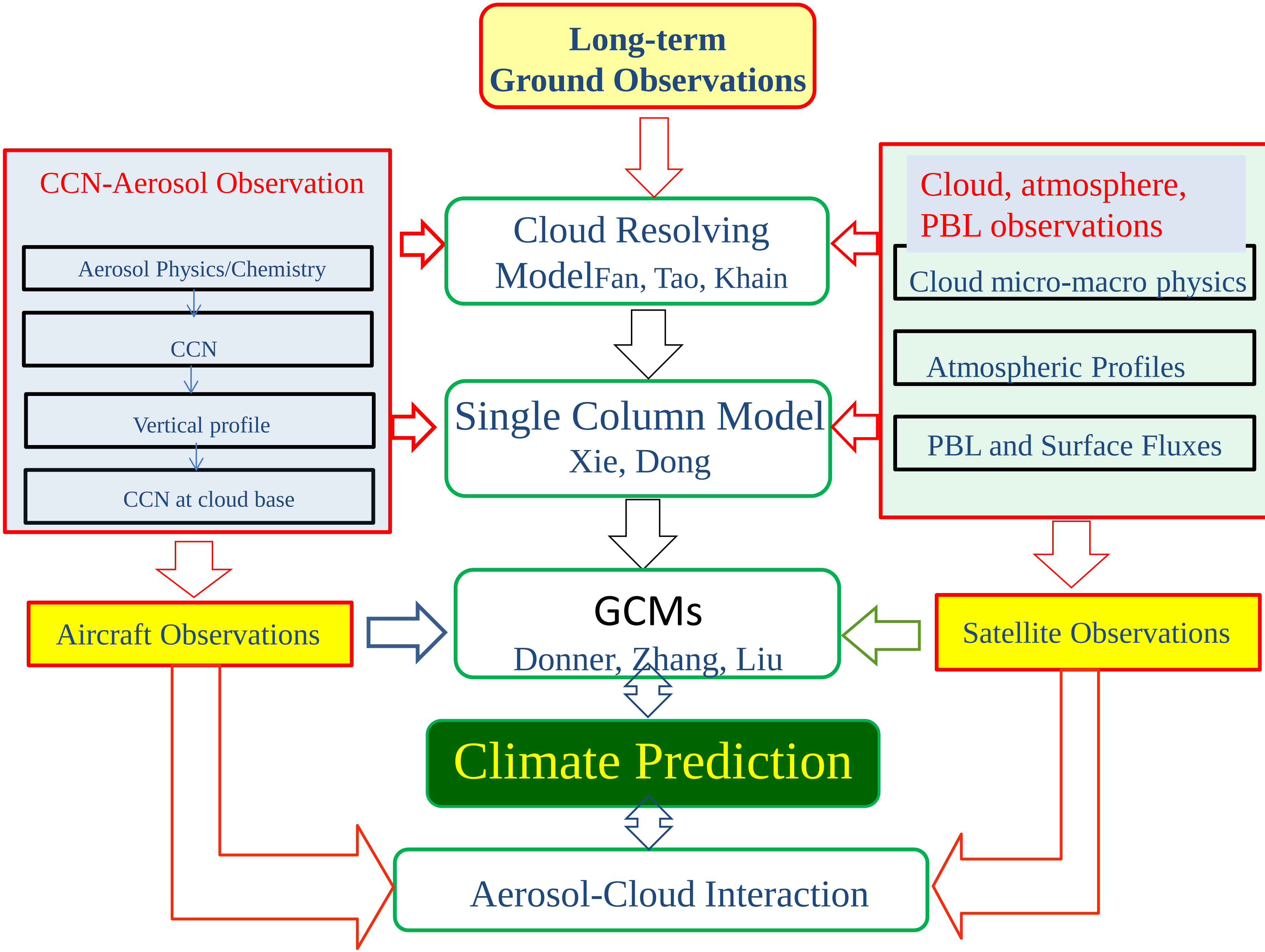




Zhanqing Li, University of Maryland

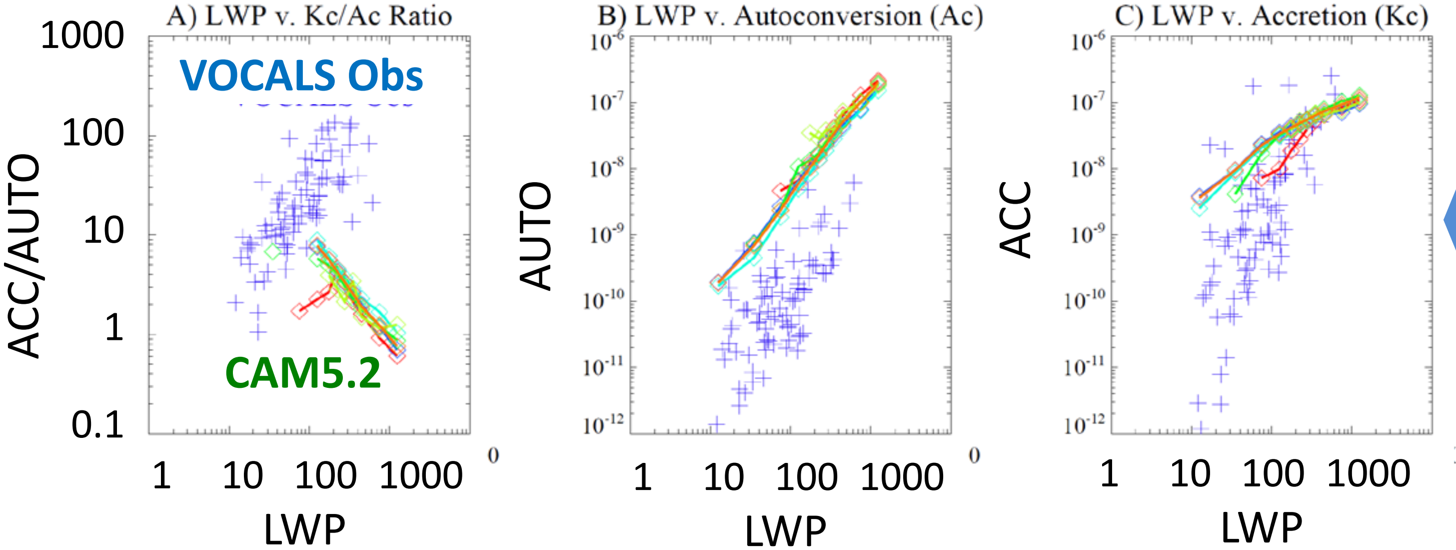


Zhanqing Li

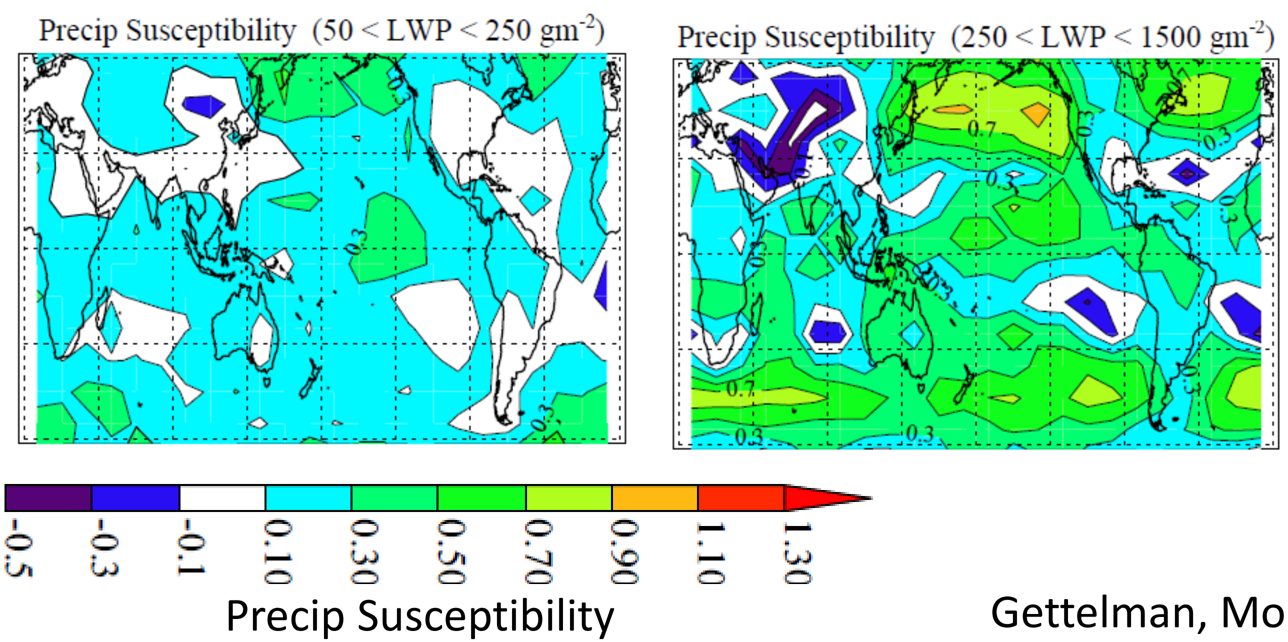

Long-term
Ground Observations
CCN-Aerosol Observation
Aerosol Physics/Chemistry
CCN
Vertical profile
CCN at cloud base
Cloud Resolving
ModelFan, Tao, Khain
Single Column Model
Xie, Dong
Cloud, atmosphere,
PBL observations
Cloud micro-macro physics
Atmospheric Profiles
PBL and Surface Fluxes
Aircraft Observations
GCMs
Donner, Zhang, Liu
Satellite Observations
Climate Prediction
Aerosol-Cloud Interaction

Why do climate models produce a large aerosol indirect effect?

Too much precipitation from autoconversion in CAM5



ACC and AUTO correctly increase with LWP but ratio ACC/AUTO decreases with LWP in contrast to observations



Precipitation susceptibility in CAM5 increases with LWP because of increasing dominance of autoconversion

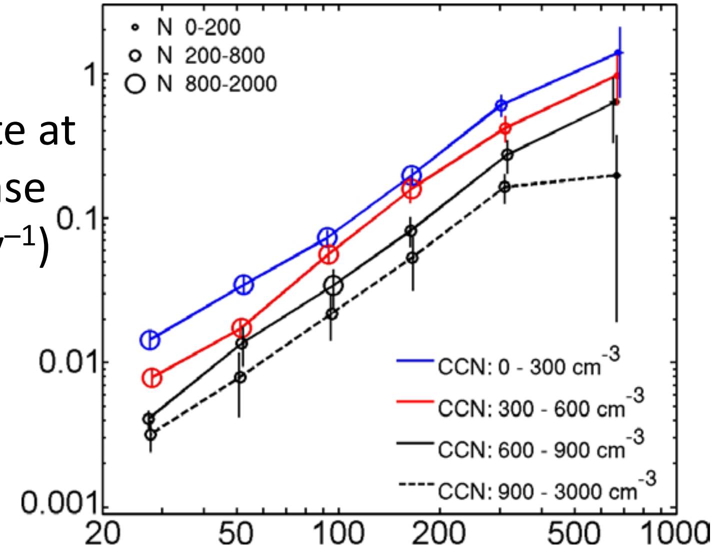
Gettelman, Morrison, Terai, Wood (2013)

Drizzle-related metrics for CAPI using AMF Azores and COPS data

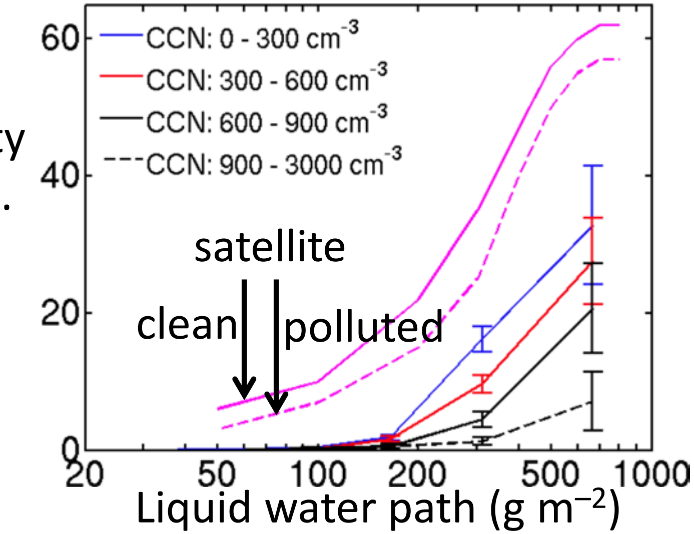
J. Mann, C. Chiu, R. Hogan, E. O'Connor, A. Jefferson

University of Reading

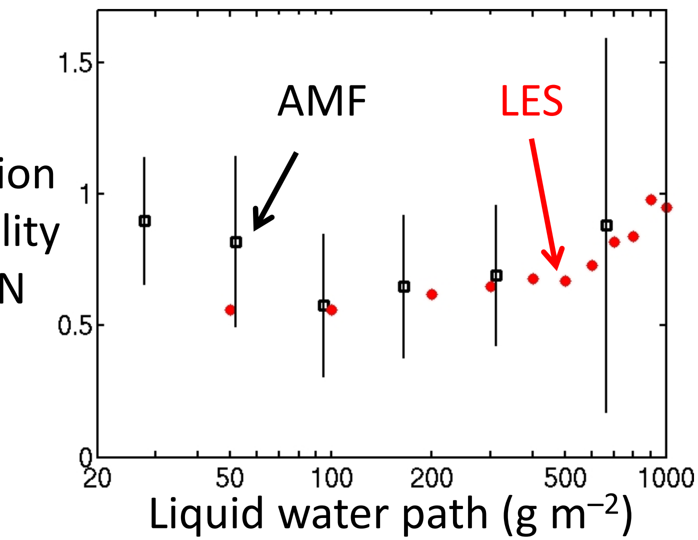
Drizzle rate at cloud base (mm day^{-1})



Probability of Precip. (POP)



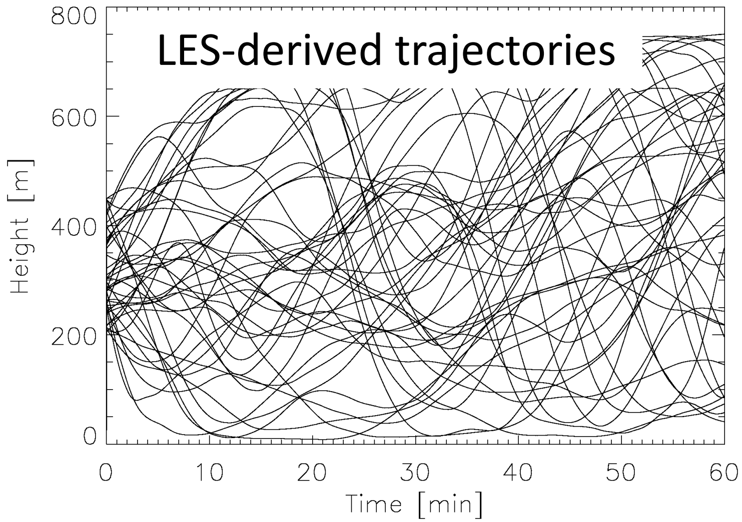
Precipitation susceptibility w.r.t. CCN



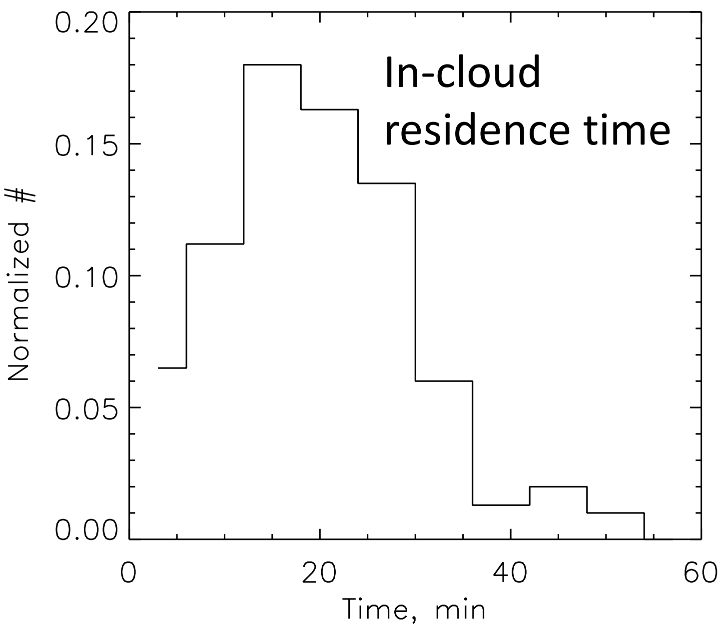
Key finding

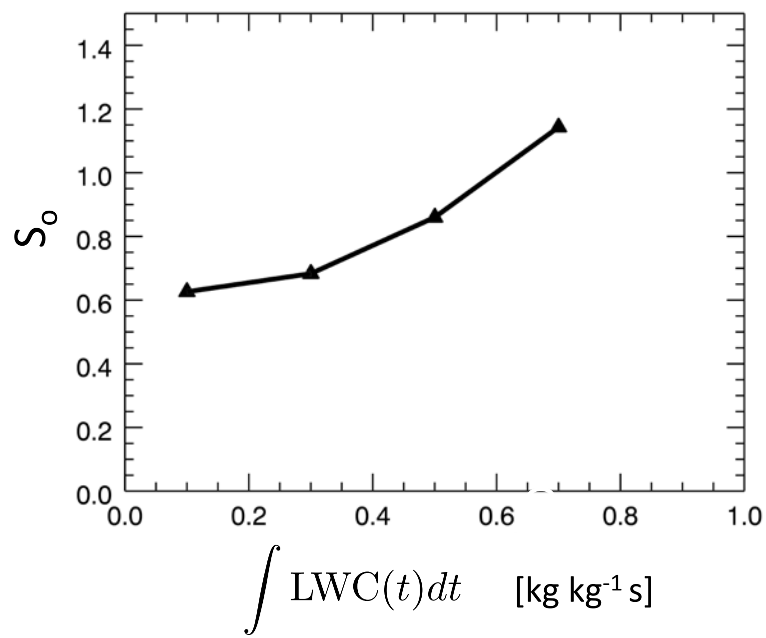
- Precip. susceptibility from AMF agrees with LES and has a local min. at LWP of 100 g m^{-2}, but uncertainty is large.
- POP from AMF is much smaller than that from satellite obs., suggesting a larger POP discrepancy between obs. and climate models.

S_o increases with LWP because *time-integrated LWC* is a limiting factor



- Run parcel model along ensemble of LES trajectories (stratocumulus)
- Warm microphysical processes
  - bin microphysics
- Range of aerosol conditions
- Calculate $S_o = -d\ln R/d\ln N$

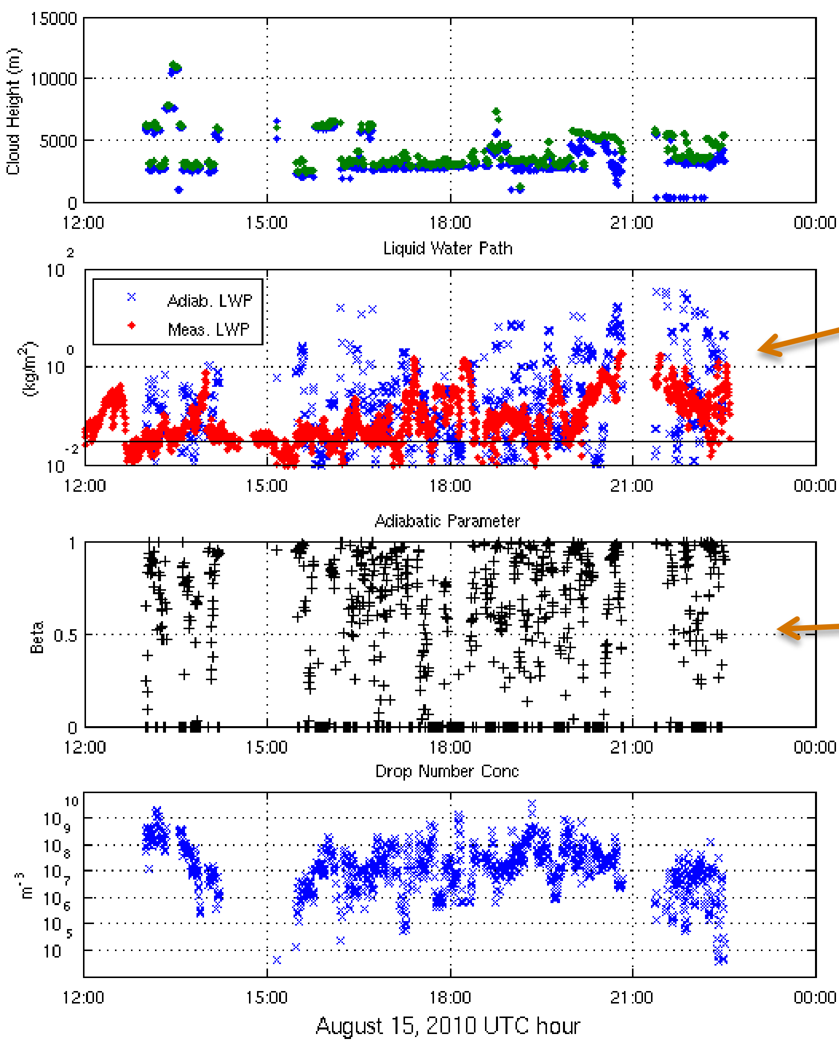




Feingold and McComiskey Poster 154 Tuesday

New Evaluation VAP, NDROP:
Droplet Number & Sub-adiabaticity

New Product Implements McComiskey et al. (2009) *JGR* method, calculating droplet number concentration from cloud optical depth and liquid water path. Also estimates adiabatic liquid water path/adiabatic parameter (β).



Calculated and measured liquid water path:

$$LWP_{adiab} = \frac{1}{2} C_w H^2$$

Sub-adiabaticity parameter from meas/calc LWP:

$$\beta = 1 - \frac{LWP_{mwr}}{LWP_{adiab}}$$

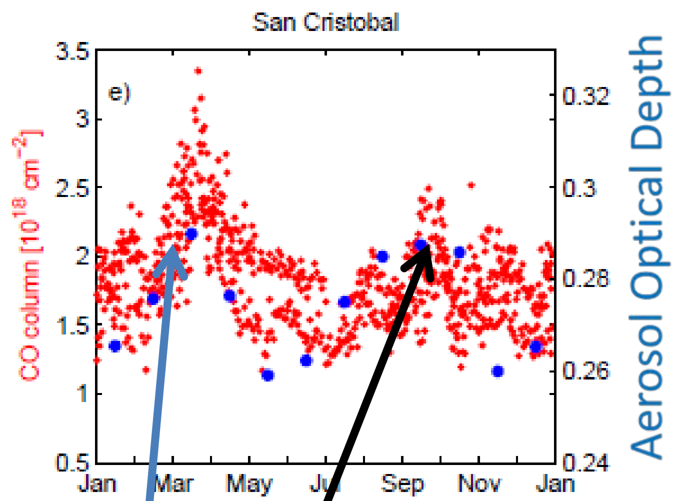
where,
C_w = adiabatic condensation rate
H = cloud height

New field studies

CORMORANT (Cumulus Ocean Radiation Measurements over a Natural Tropical Site)

Science Goal

- Investigate relationship between clouds, aerosols, air-sea fluxes and upper ocean properties around the Galapagos Islands, a key region in controlling eastern equatorial Pacific ocean dynamics.
  - Investigate response of clouds to variations in aerosols in cleaner environment than Caribbean in context of variations in ocean-atmosphere fluxes
  - Region of strong upwelling: source of organic emission contributing to aerosols?
  - Proposed AMF/AVP deployment at San Cristobal together with N-S transects from BAE Orion, 220 foot long research vessel of Oceanographic Institute of Navy of Ecaudor



Bremer et al. 2003

Fires in northern Amazonia February-March?

Transport of biomass burning products from Brazil?

Complete Science Questions

1) What is relationship between clouds, aerosols, air-sea fluxes & upper ocean properties around the Galapagos, a relatively pristine ocean region in eastern equatorial Pacific with large shallow cumulus populations?

2) What factors & processes control mean structure of ITCZ-cold tongue complex and its variability on time scales from intraseasonal to interannual? How can coupled models be improved to represent mean state & variability of eastern equatorial Pacific? What role do cloud processes play in determining amplitude of interannual variability? How do air-sea interactions affect timing/amplitude of tropical instability waves?

3) What are effects of biological & organic sources of aerosols associated with ocean upwelling near Galapagos on cloud condensation nuclei & evolution of clouds? How frequently are aerosols associated with biomass burning detected in Galapagos, and what is their impact on cloud properties in this relatively pristine environment?

4) How does vertical structure of boundary layer change with strong variations in SST and air-sea fluxes in a N-S direction about Galapagos, and what is impact on cloud properties?

5) What factors & processes influence formation, development, dissipation and diurnal cycle of cumuli near Galapagos, and how does this contrast from factors & processes in more polluted warm pool Caribbean environment?

6) Can models using a hierarchy of scales adequately resolve physical processes controlling formation & evolution of cumuli in the environs of the Galapagos, including large-scale cloud radiative impacts?

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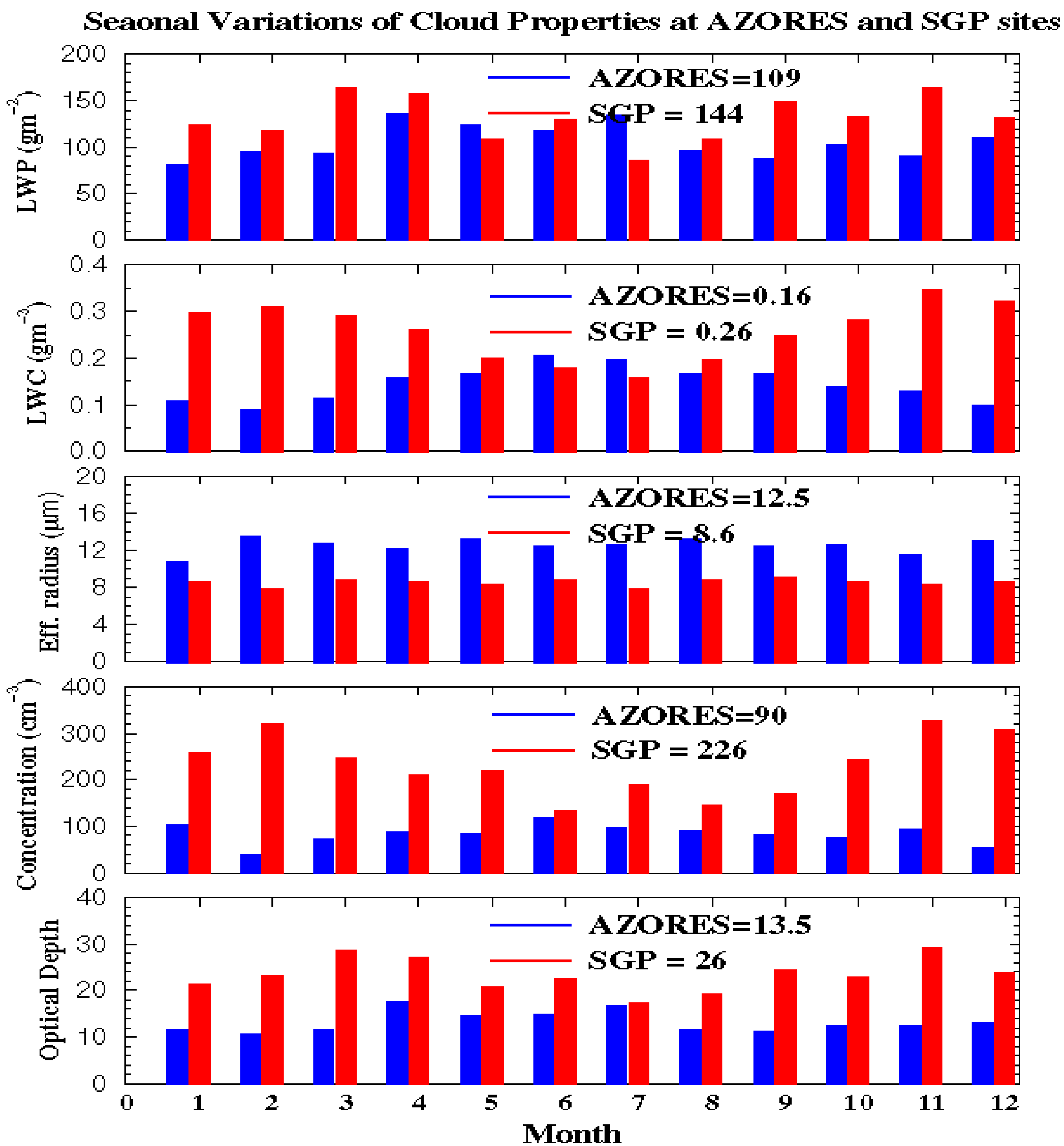
Seasonal Variations of LWP/re/N/tau



<u>a-b) LWP and LWC</u>:
SGP > AZORES
Decrease from Winter to Summer at SGP, increase at AZORES.

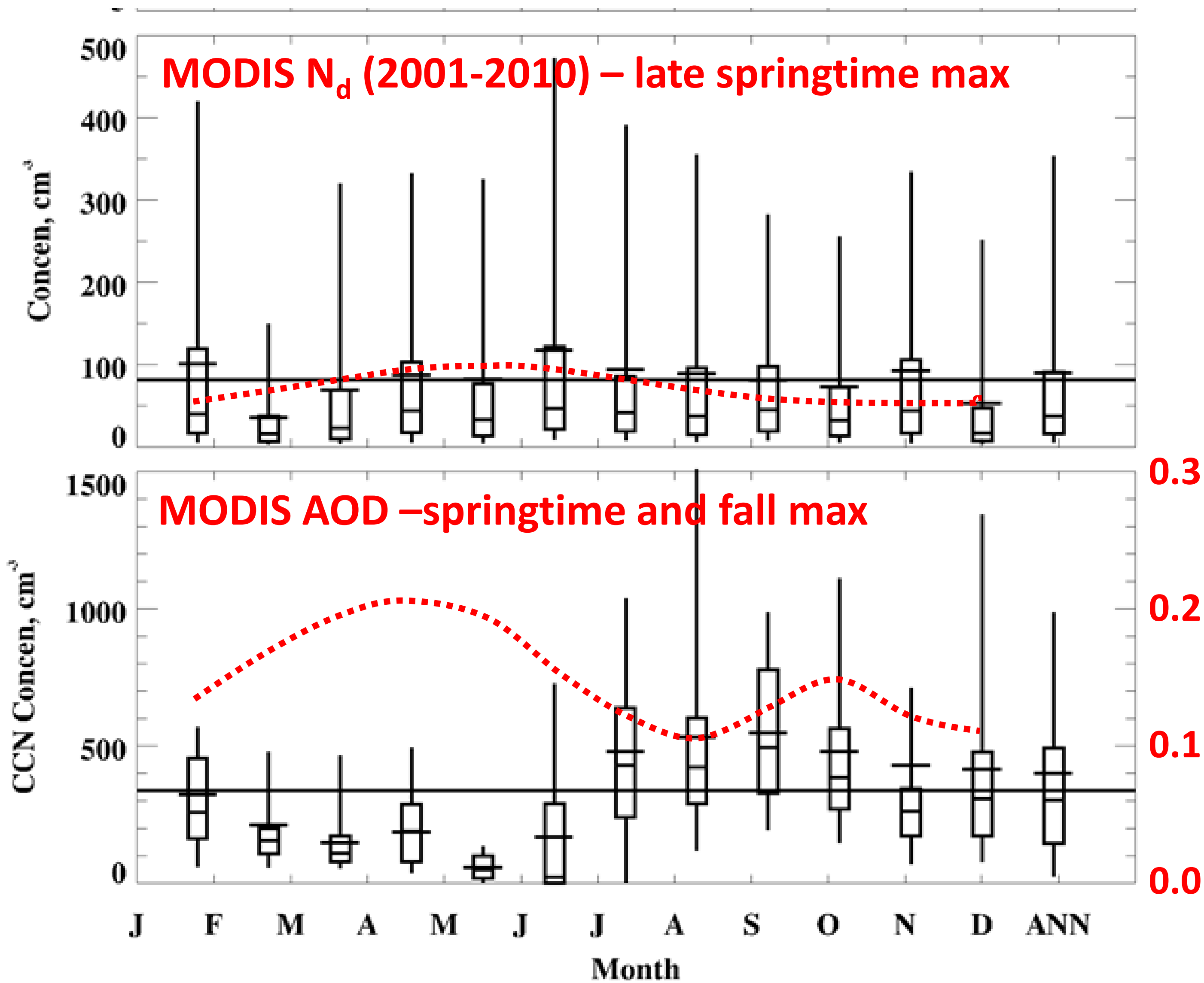
<u>c) Effective radius</u>:
SGP < AZORES
No seasonal variation

<u>d) Number concentration</u>
SGP > AZORES
Following their LWC patterns

<u>e) Optical depth</u>
SGP > AZORES
Following their LWP patterns
(tau=1.5LWP/re)

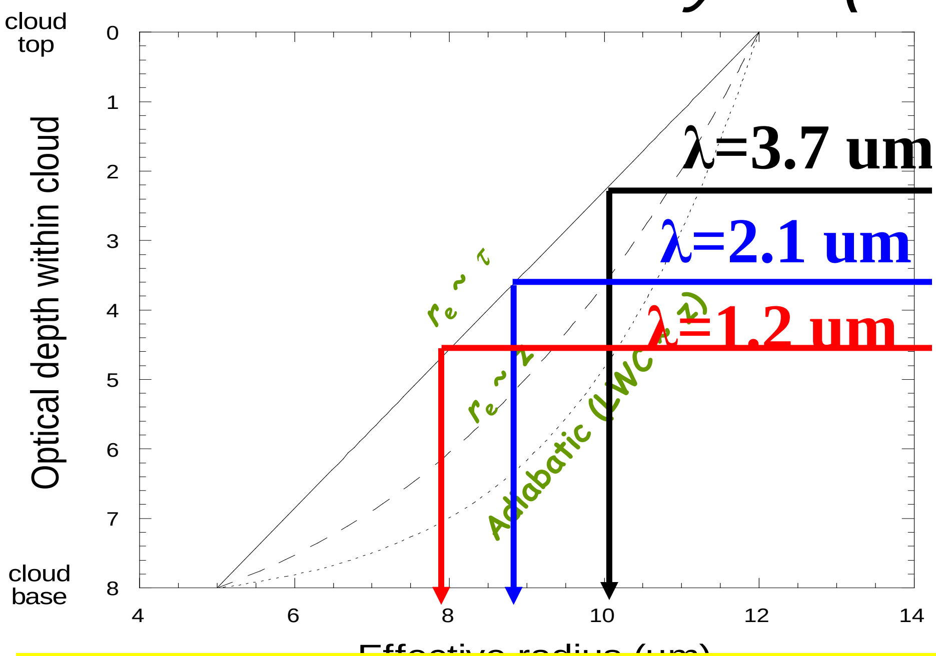
Seasonal variation of N_d and CCN, Azores

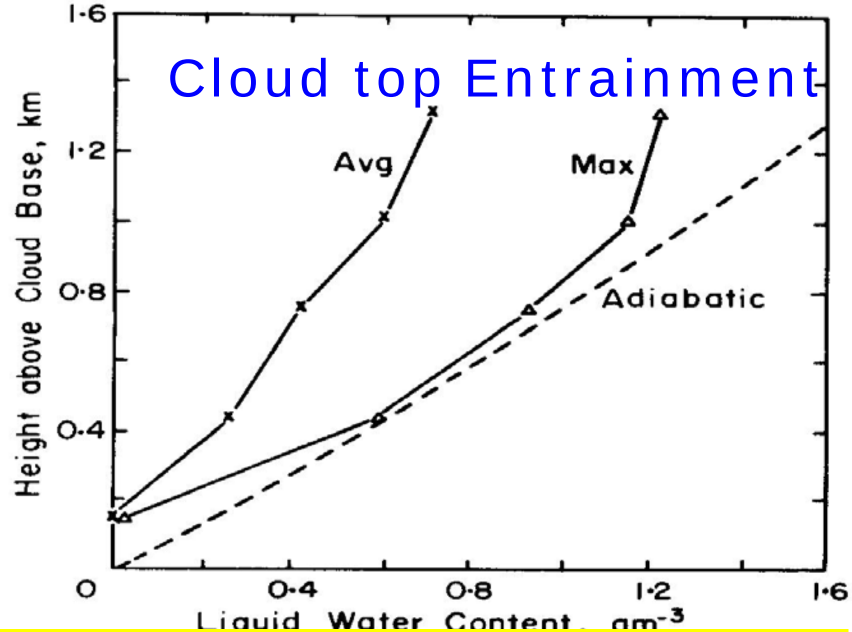
Azores seasonal cycle of retrieved cloud droplet concentration and CCN concentration



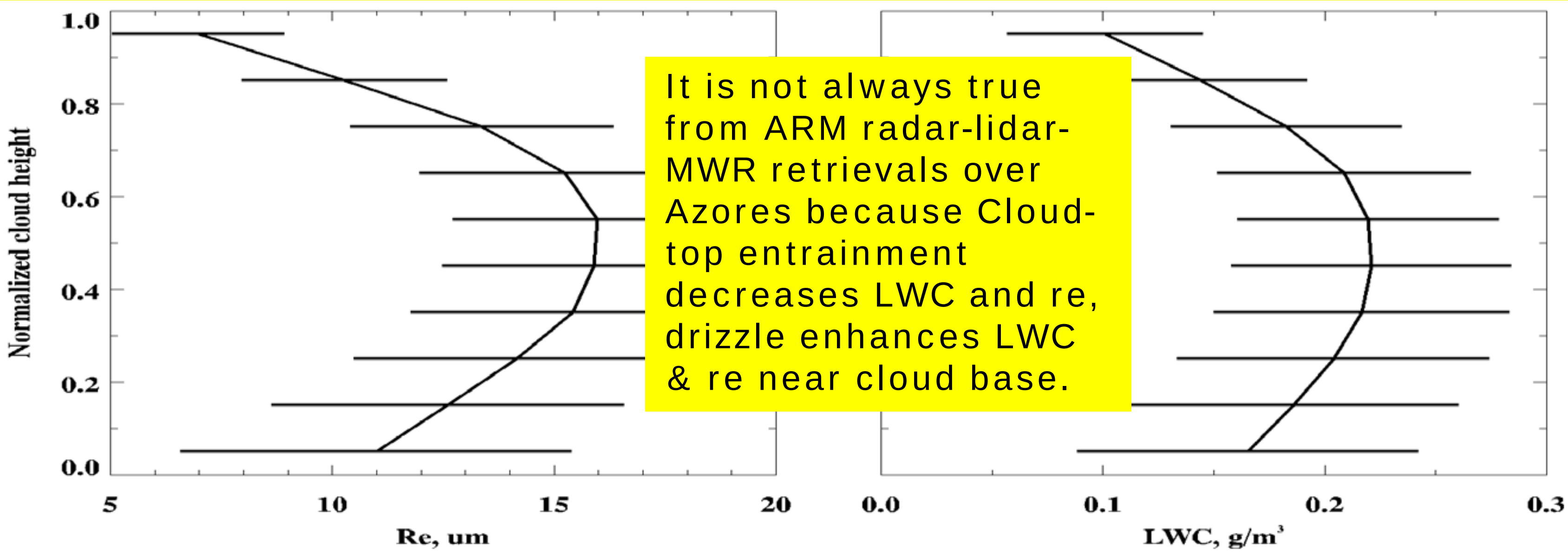
AMF: Xiquan Dong, MODIS Rob Wood

Theoretically re(3.7)>re(2.1)>re(1.2)





Both LWC & re should increase from base to top if adiabatic (condensational growth).



It is not always true from ARM radar-lidar-MWR retrievals over Azores because Cloud-top entrainment decreases LWC and re, drizzle enhances LWC & re near cloud base.

Marine Boundary Layer Clouds, Aerosols and Interactions (MBL-CAI)

PI: Xiquan Dong, University of North Dakota

Co-Is: Robert Wood, Mike Poellot, Zhanqing Li, and Pat Minnis

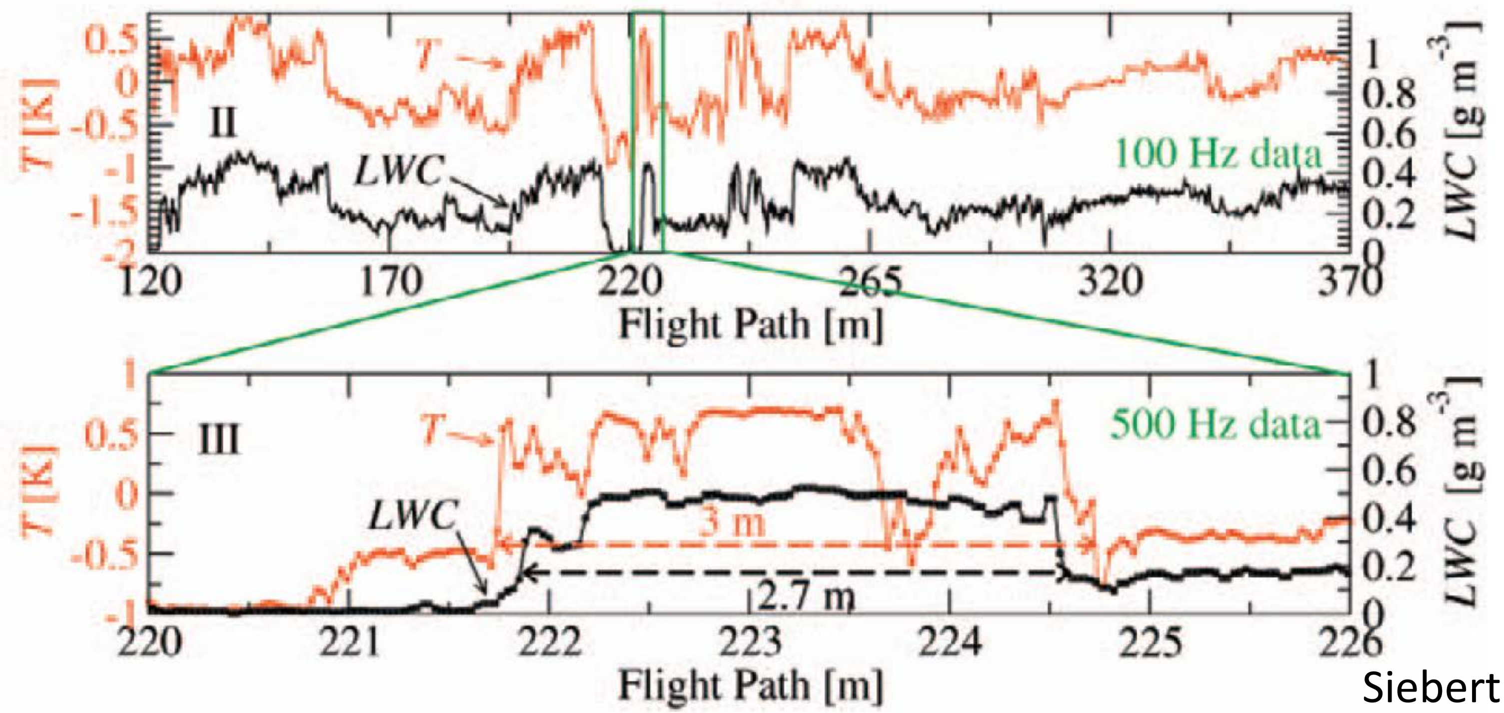
A month-long IOP during the period June-August 2015 over the ARM Azores site (~60 flight hours)

Goals:

1) Validating aerosol and cloud property retrievals
2) Studying the impact of cloud-top entrainment and cloud-base drizzle on the ground-based radar-lidar-MWR retrieved microphysical properties.
3) Determining how CCN concentration changes from the surface to cloud base, studying the relationships between surface CCN measurements with aircraft measurements to further prove/validate the hypothesis that surface CCN can be used to infer cloud base properties.

ACTOS – IFT, Germany

- Helicopter-borne system
- Suite of cloud and turbulence measurements
- Very high time resolution



Siebert et al. (2006)

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Answering Shallow Warm Clouds Science Questions

Steve Ghan presentation slides for reference

Answering Shallow Warm Clouds Science Questions

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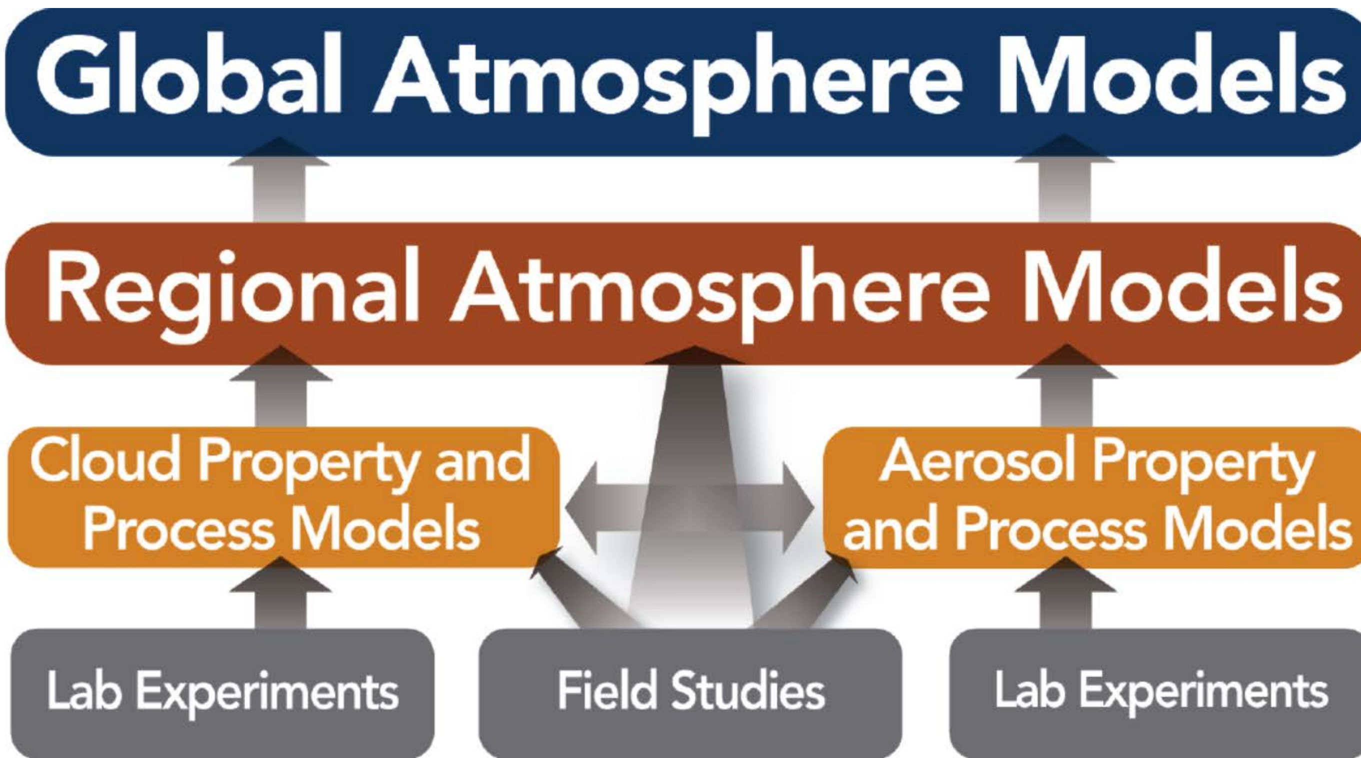
- What processes control diversity in … aerosol



Field Studies

VOCALS stratocumulus

Azores stratocumulus

CHAPS shallow cumulus

ISDAC mixed-phase stratocumulus

MAGIC transitions from closed to open celled shallow convection

RACORO Long-term aircraft sampling of sub-cloud aerosol and then profiles through shallow convective clouds

Aircraft campaign over Azores to validate microphysics, vertical velocity, entrainment retrievals

CORMORANT shallow cumulus Galapagos

SOCRATES southern ocean

Measurements

Combine satellite and surface data to estimate CCN at cloud base (D. Rosenfeld)

Retrieve vertical distribution of CCN from a suite of ground-based sensors (Z. Wang and Z. Li)

Retrieve droplet number from satellite (D. Rosenfeld)

Retrieve droplet effective radius from satellite (D. Rosenfeld, Z. Li)

Retrieve droplet effective radius from surface (C. Chiu, D. Turner, Z. Li, Z. Wang)

Retrieve LWP for thin clouds (D. Turner)

Retrieve LWP under drizzling conditions (D. Turner, M. Cadeddu, R. Hogan)

Retrieve light drizzle (P. Kollias)

Estimate subadiabaticity in LWP from retrieved LWP, cloud base, and cloud top (L. Riihimaki)

Measure entrainment rate above stratocumulus clouds (Y. Liu)

Retrieve updraft velocity at cloud base (V. Ghate, E. Luke, P. Kollias)

Analysis of Droplet Number Effects

Investigate relationships between AOD and CCN to improve the global estimate of CCN from satellite and AERONET for GCM applications

Compare Rosenfeld retrieval of CCN with Ghan and Feingold retrievals at SGP (D. Rosenfeld, G. Feingold and S. Ghan)

Compare Rosenfeld retrieval of droplet number with surface-based number estimated from retrieved CCN spectrum and updraft velocity (D. Rosenfeld, C. Chiu, and S. Ghan)

Explore relationships between aerosols and cloud properties and dynamics (updraft speed, entrainment rates, rainfall frequency and rate) using ground-based, aircraft and satellite retrievals (Z. Li, R. Wood)

Determine ACI metrics across low cloud data sets; systematically examine how they change with cloud dynamics, spatiotemporal scale (A. McComiskey, G. Feingold)

Analysis of Liquid Water Impacts

Estimate precip susceptibility metrics for existing low cloud datasets (G. Feingold, R. Wood)

Calculate S_{pop} from ARM measurements at SGP and Azores (Z. Li, X. Dong, and R. Wood)

Cloud Effects on Aerosol

Measure aerosol scavenging/ precipitation efficiency

Modeling

Analyze CRM results to determine influence of subgrid variations in droplet number and cloud liquid water on autoconversion (G. Feingold)

Compare SCM and CRM simulations driven by boundary conditions from CAM5 (J. Penner)

Compare autoconversion ratio in multiple global models (S. Ghan)

Add subgrid covariance between cloud water and rain to cloud microphysics in global models (H. Morrison)

Add prognostic precipitation to global models (H. Morrison, L. Donner)

Represent aerosol effects on shallow cumulus clouds in CAM5, including dependence on entrainment (G. Zhang, S. Ghan).

What is Missing?

- Some tasks have no one assigned
- Comparisons of simulations with measurements
- Measurements, analysis and modeling during transition from closed cell polluted conditions to open cell clean conditions (MAGIC2)

Cormorant: Complete Science Qs

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6) Can models using a hierarchy of scales adequately resolve the physical processes that control the formation and evolution of trade wind cumuli in the environs of the Galapagos Islands, including the large-scale cloud radiative impacts?