

Warm rain and climate:

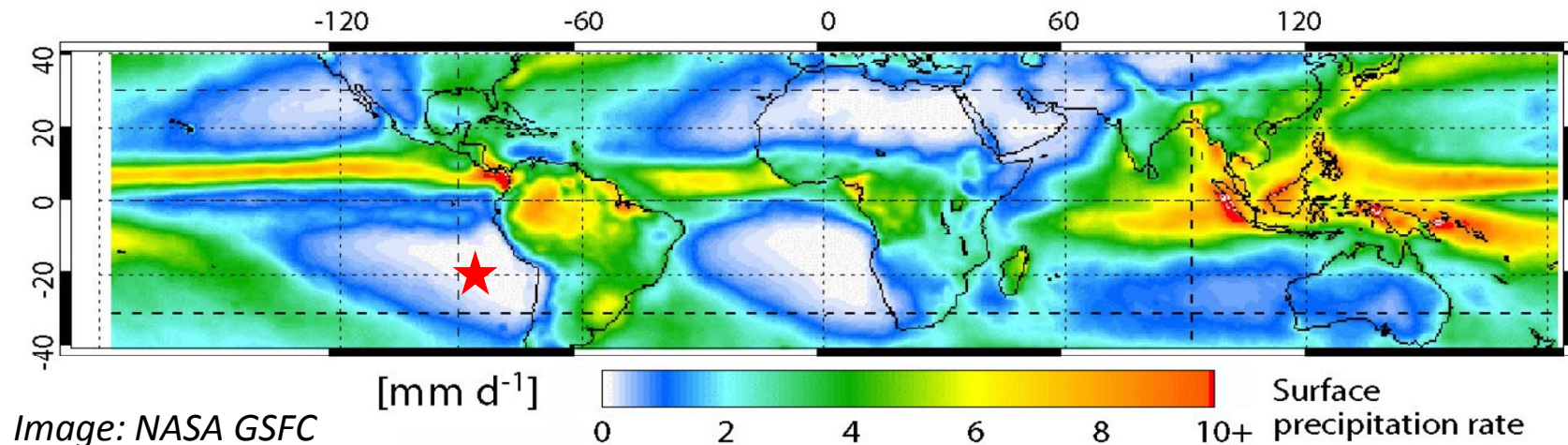
VOCALS, CloudSat, Models



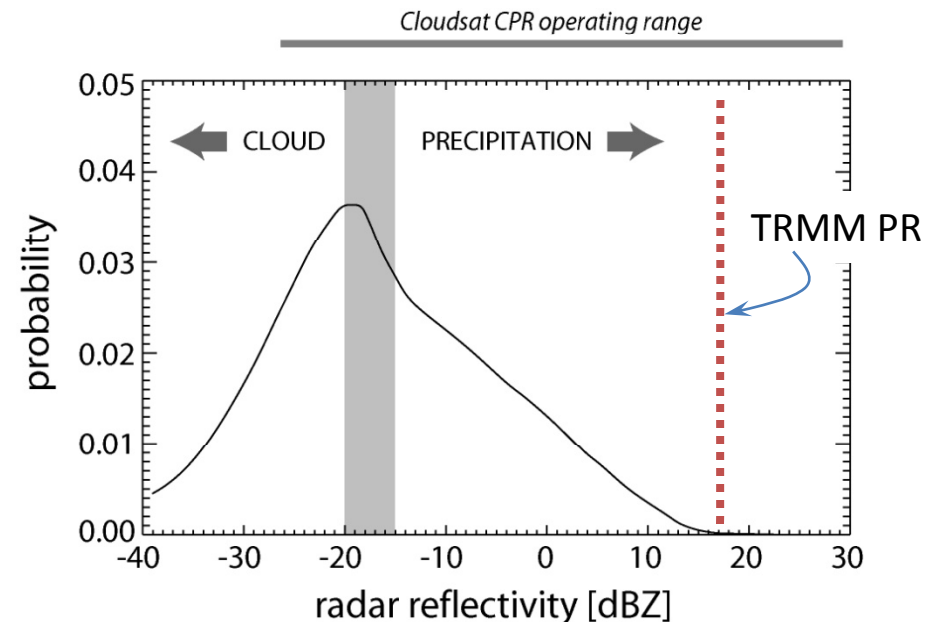
Robert Wood

University of Washington

Warm rain – a missing climatology

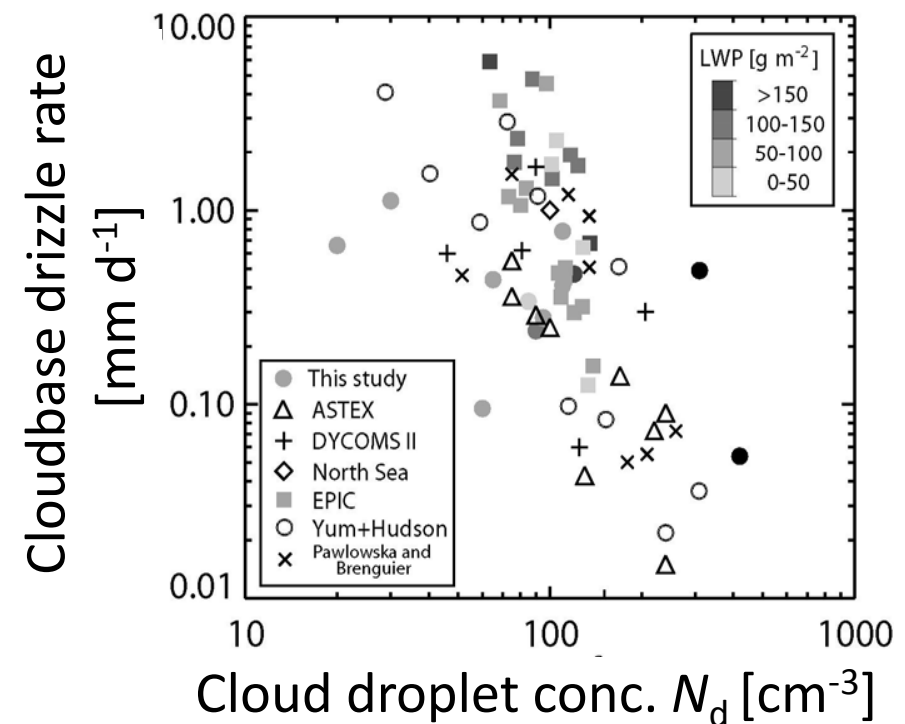


- Shipboard remote-sensing shows frequent precipitation from shallow clouds
- Many echoes below detection limit of current satellite sensors (passive or active)



Warm rain – macrophysical vs microphysical control

- In shallow stratocumulus-topped MBLs ($z_i < 1500$ m) recent studies indicate a dependence of drizzle rate upon cloud droplet concentration (see right)
- In deeper trade wind boundary layers no definitive relationship between precipitation rate and microphysics has been observed (e.g. Nuijens et al. 2009)



R. Wood, *J. Atmos. Sci.* (2005)

Warm rain – why do we care?

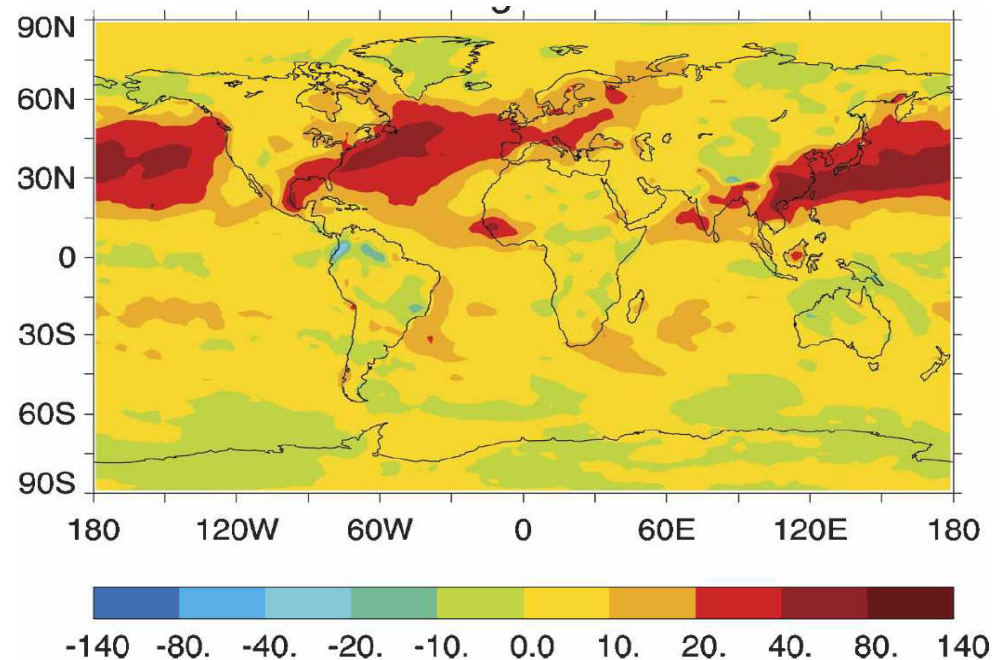
- GCMs estimate that:

1st AIE: -0.5 to -1.9 W m⁻²

2nd AIE: -0.3 to -1.4 W m⁻²

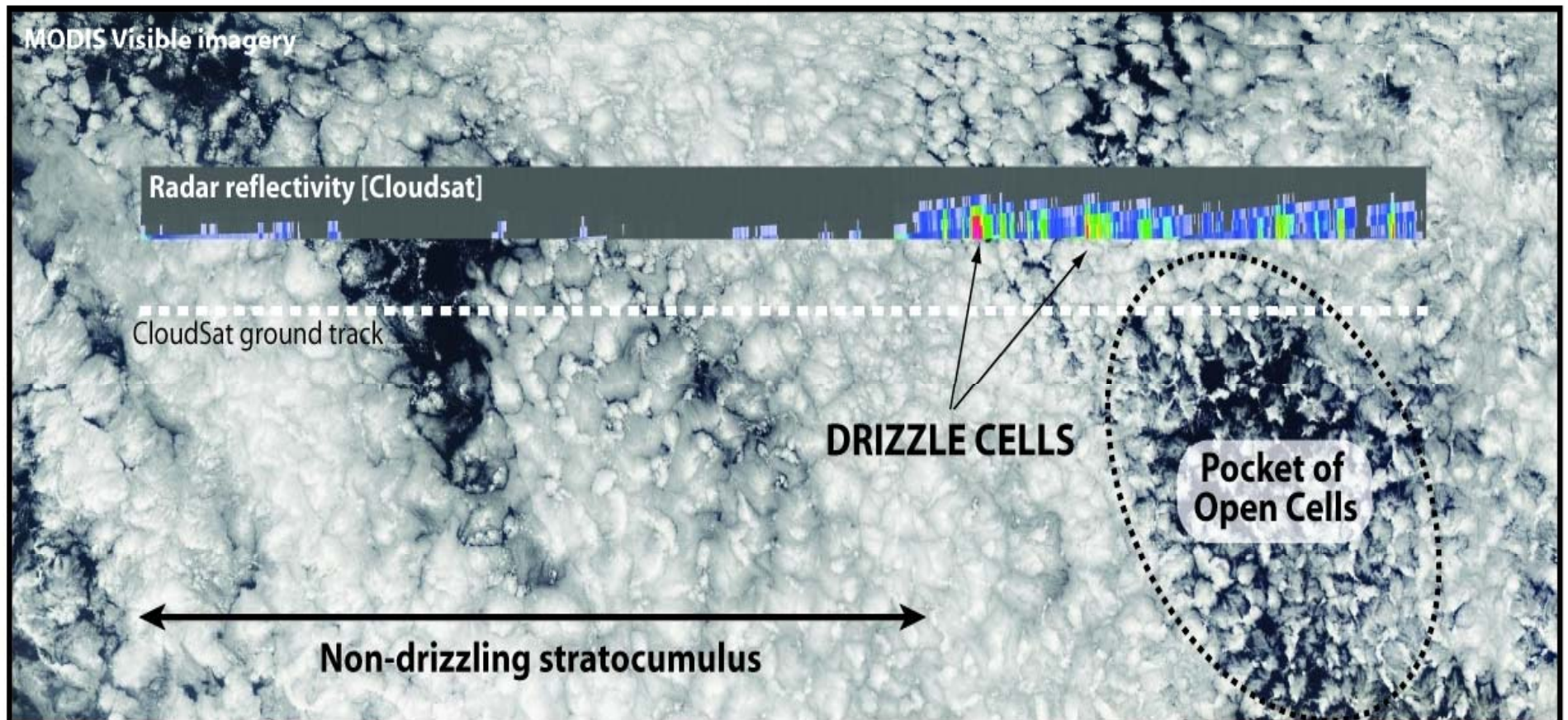
} Lohmann and Feichter (2005)

Change in LWP [g m⁻²]
estimated using the GFDL AM2:
Ming et al. (2008)



Warm rain rate and its sensitivity to aerosols/microphysics is important and unknown

CloudSat now observes drizzle



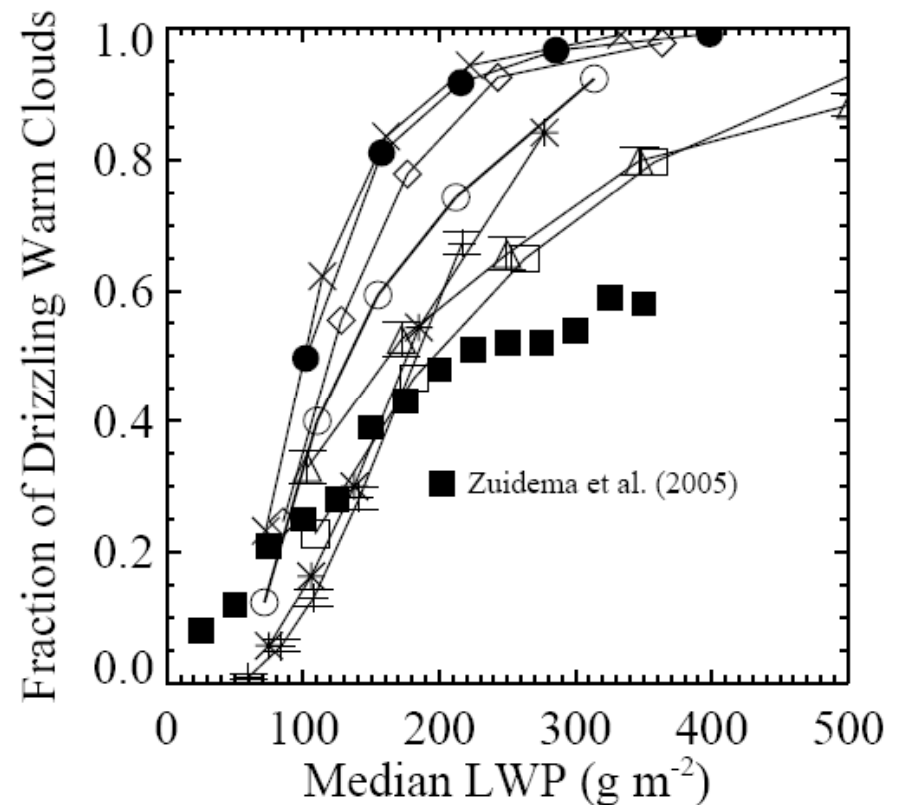
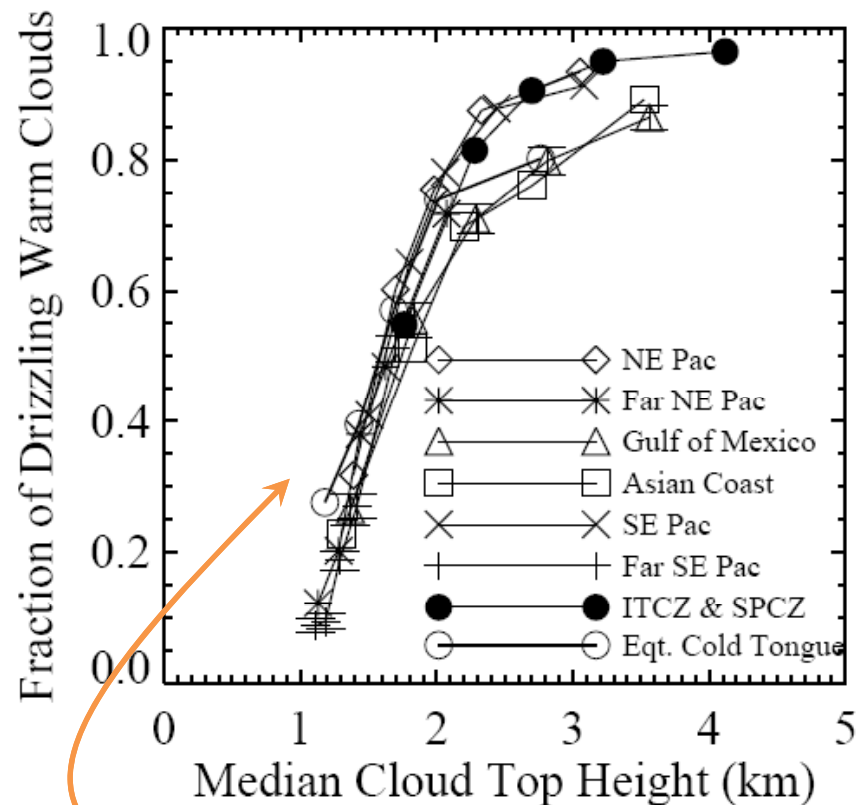
SE Pacific

Data/Methods

- Collocated CloudSat and Aqua-MODIS data:
 - Daytime data only (~13:30 local)
 - Warm clouds
- MODIS used to estimate LWP and N_d :
 - N_d using method of Bennartz (2007), assuming adiabatic vertical cloud profile
- CloudSat used to determine maximum Z in column. Classify > -15 dBZ as precipitating.

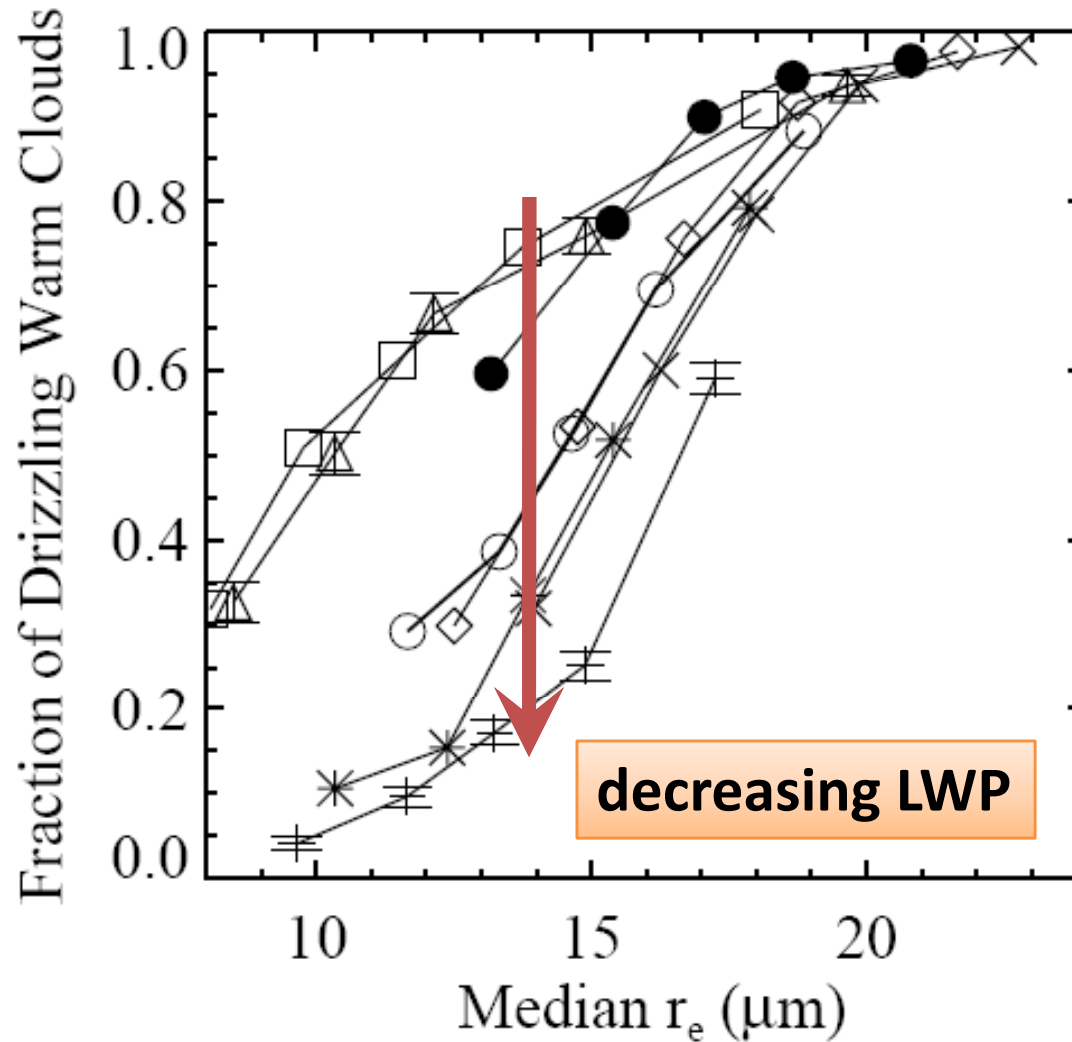


Fraction of clouds that are drizzling (> -15 dBZ)



qualitatively consistent with Byers and Hall (1955)

Effective radius not unique determinant of precipitation



Heuristic model

- **Goals:**
 - Attempt to reproduce salient features of A-Train data
 - Minimal physics necessary
- **Continuous collection model:**
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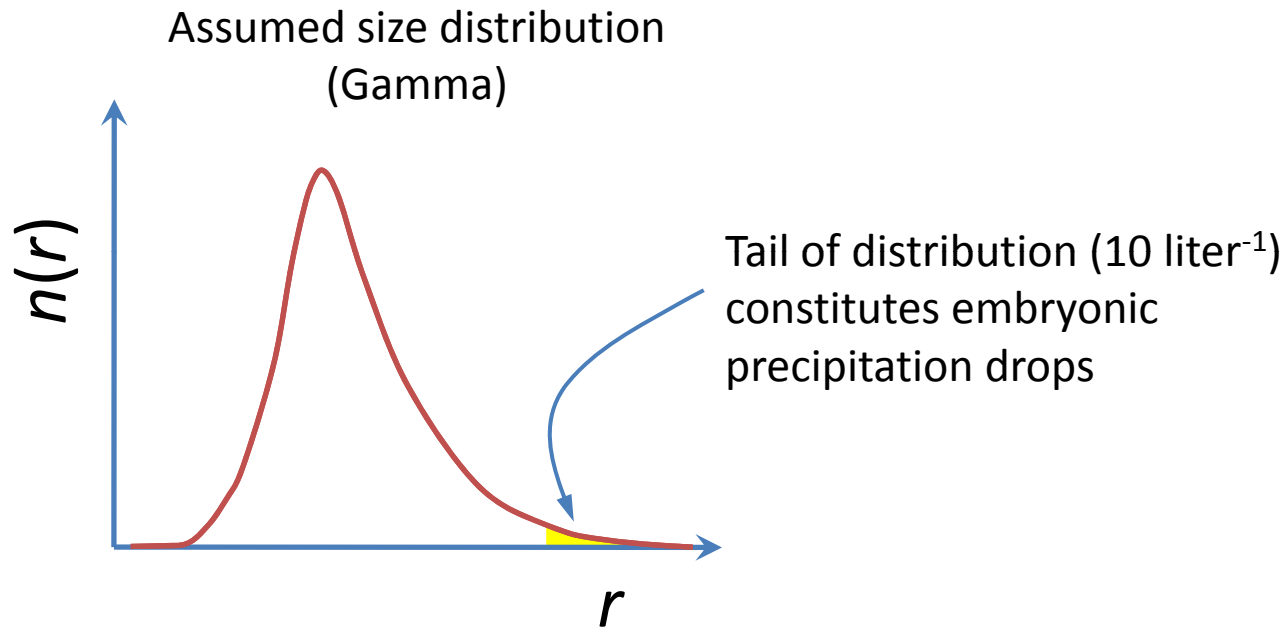
Model cloud structure

- Subadiabatic to represent entrainment effects in precipitating trade-cumulus
- Adiabaticity parameter f_{ad} decreases with height z above cloud base

$$f_{\text{ad}} = z_0 / (z_0 + z)$$

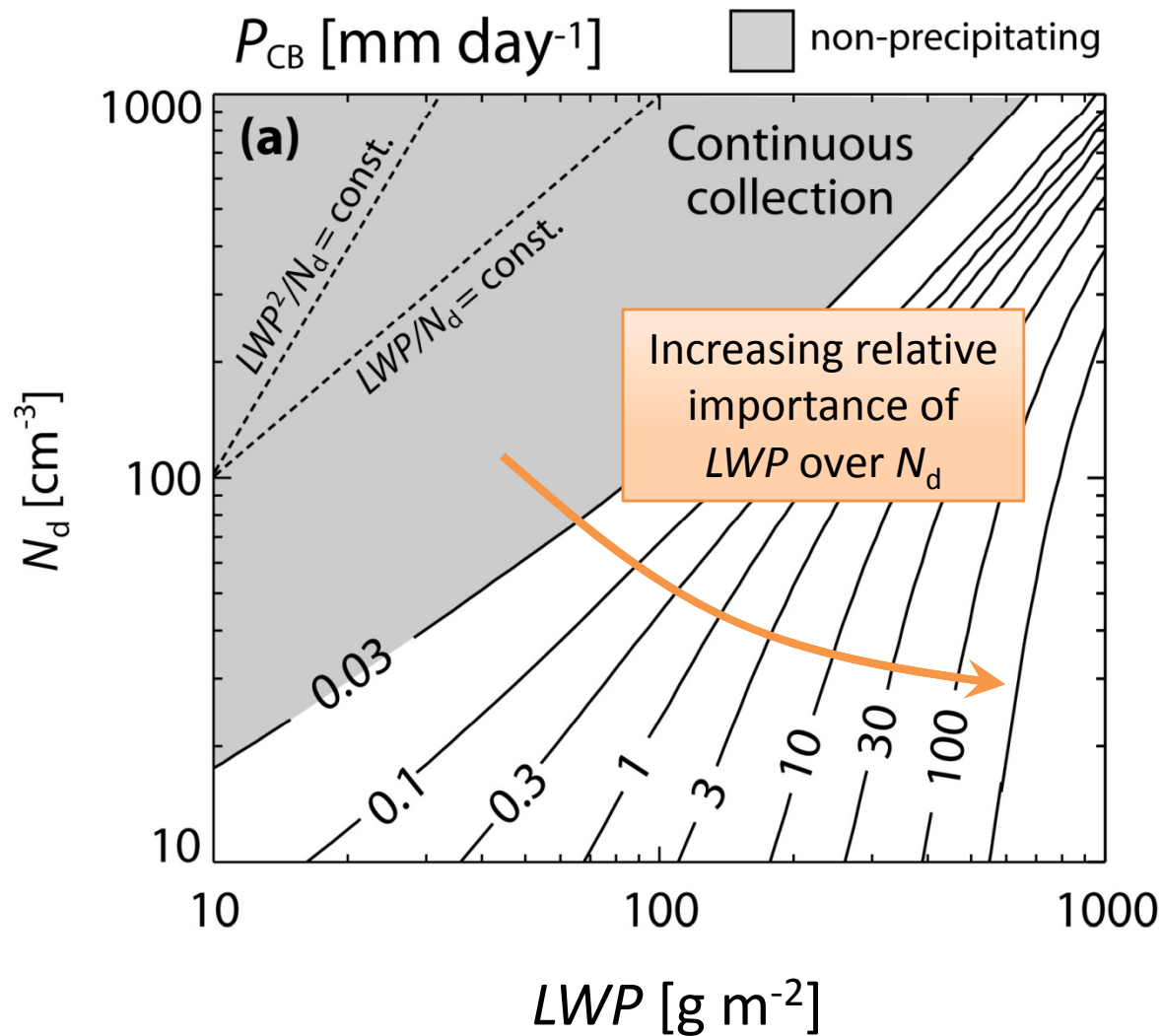
- Adiabaticity height scale $z_0 = 500$ m (estimated from RICO observations)
- Gives liquid water content as a function of height

Precipitation embryos



Gamma distribution of cloud drops determined from LWC
at cloud top and cloud droplet concentration

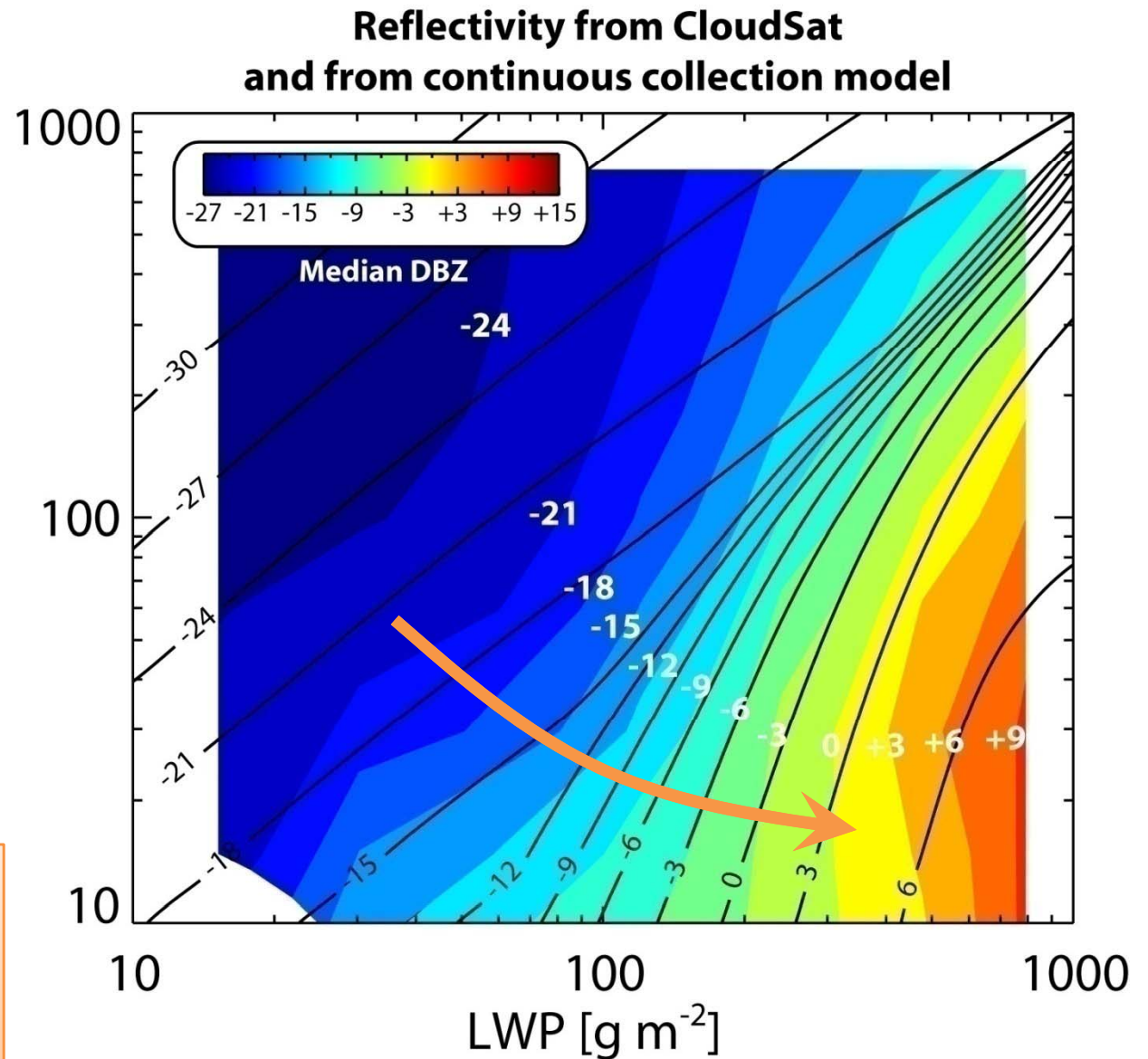
Microphysics vs macrophysics



Rain rate-to-reflectivity (94 GHz)

- Several steps need to be taken to compare model with CloudSat:
 - (1) Use model assumed precipitation DSD to determine radar reflectivity in Rayleigh limit
 - (2) Mie correction for 94 GHz reflectivity (Bohren-Huffman)
 - (3) Attenuate model 94 GHz reflectivity using two-way attenuation correction of 8.3 dBZ mm^{-1} of cloud liquid water (Lhermitte 1990)

Reflectivity in [LWP , N_d] space

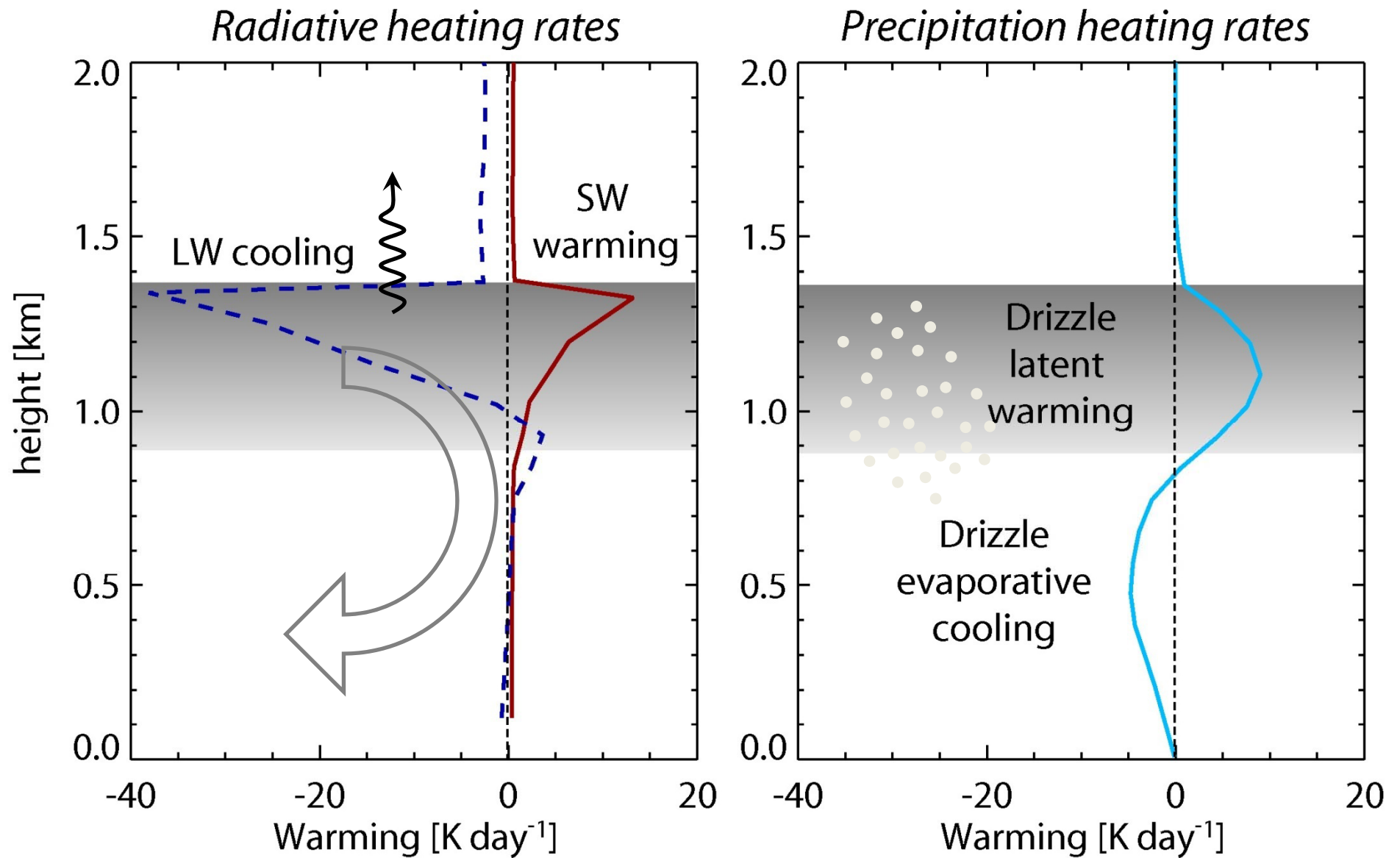


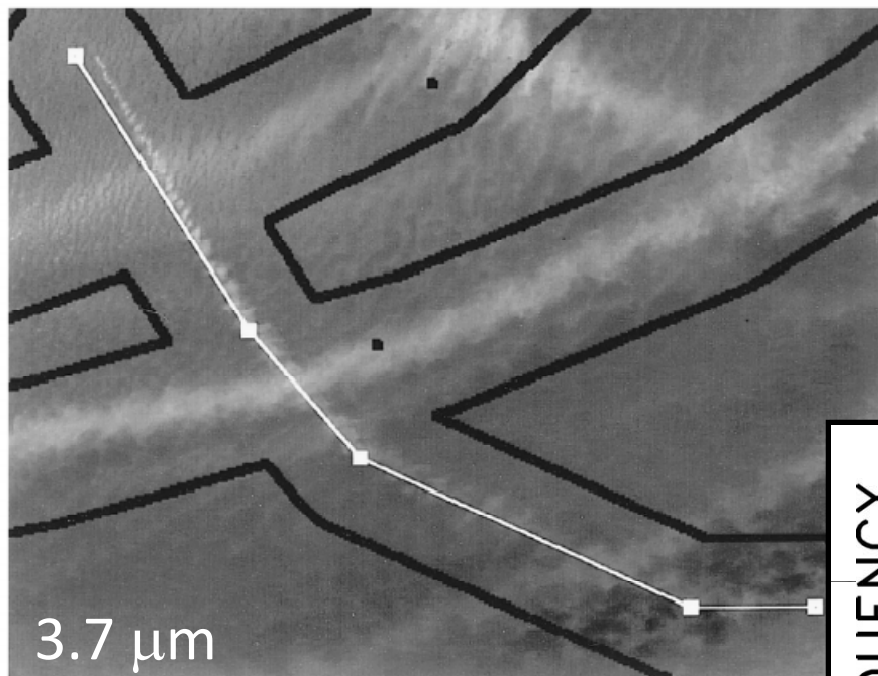
Increasing relative
importance of LWP
over N_d at high
rainrates

see also Suzuki and Stephens (2008)

**Warm rain, cloud structure
and dynamics**

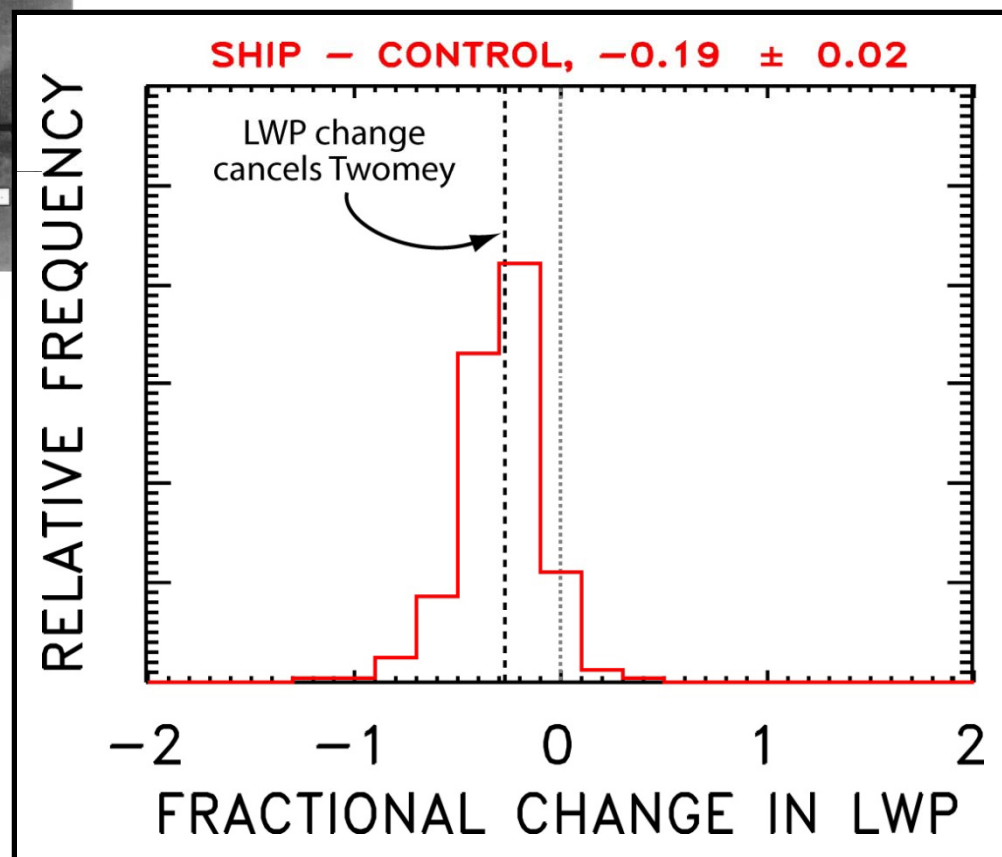
Drizzle affects MBL dynamics





Shiptrack surprises!

- Liquid water content in shiptracks is typically *reduced* compared with surrounding cloud
- Clear refutation of Albrecht's hypothesis

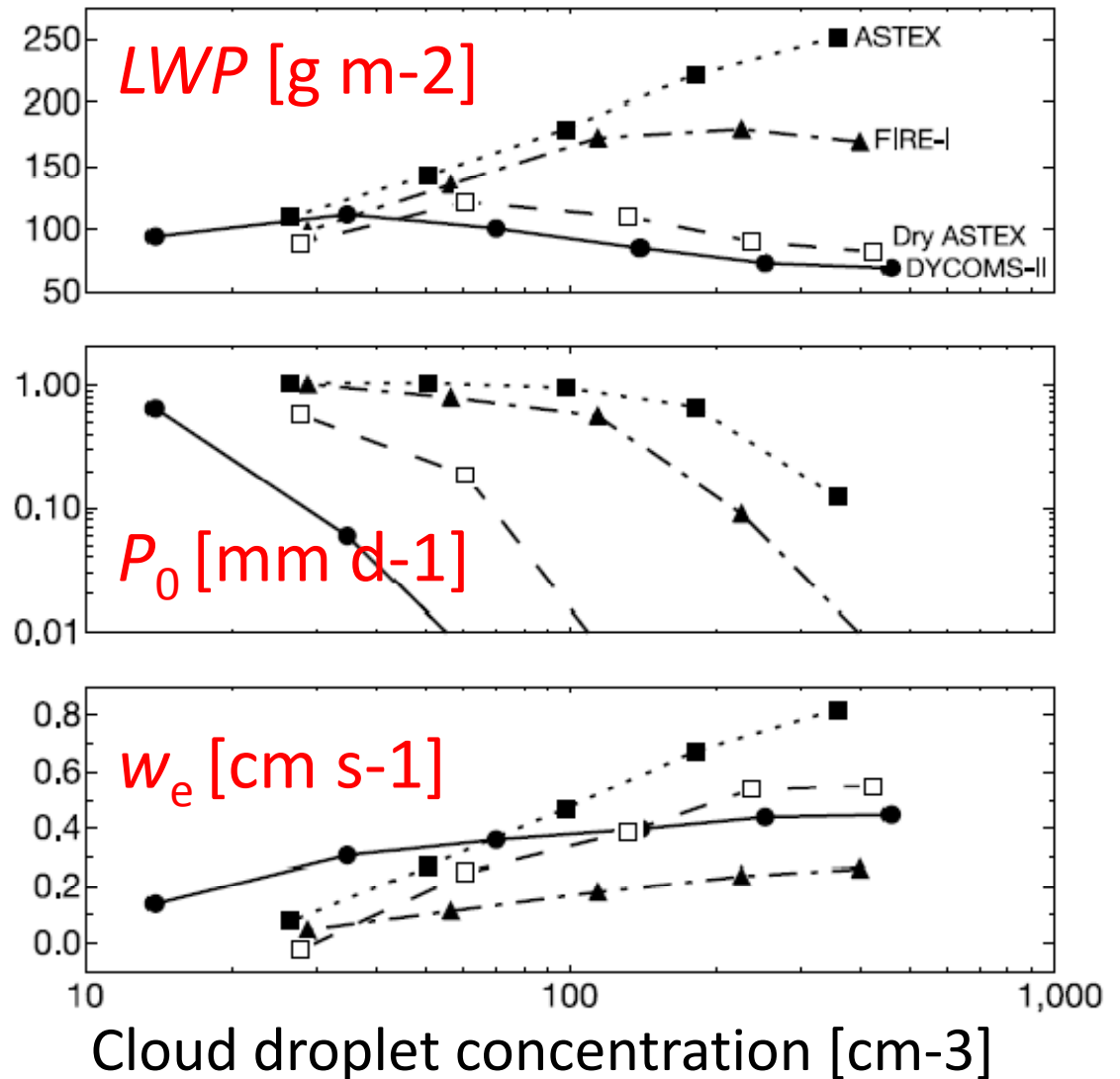


courtesy Jim Coakley, see Coakley and Walsh (2002)

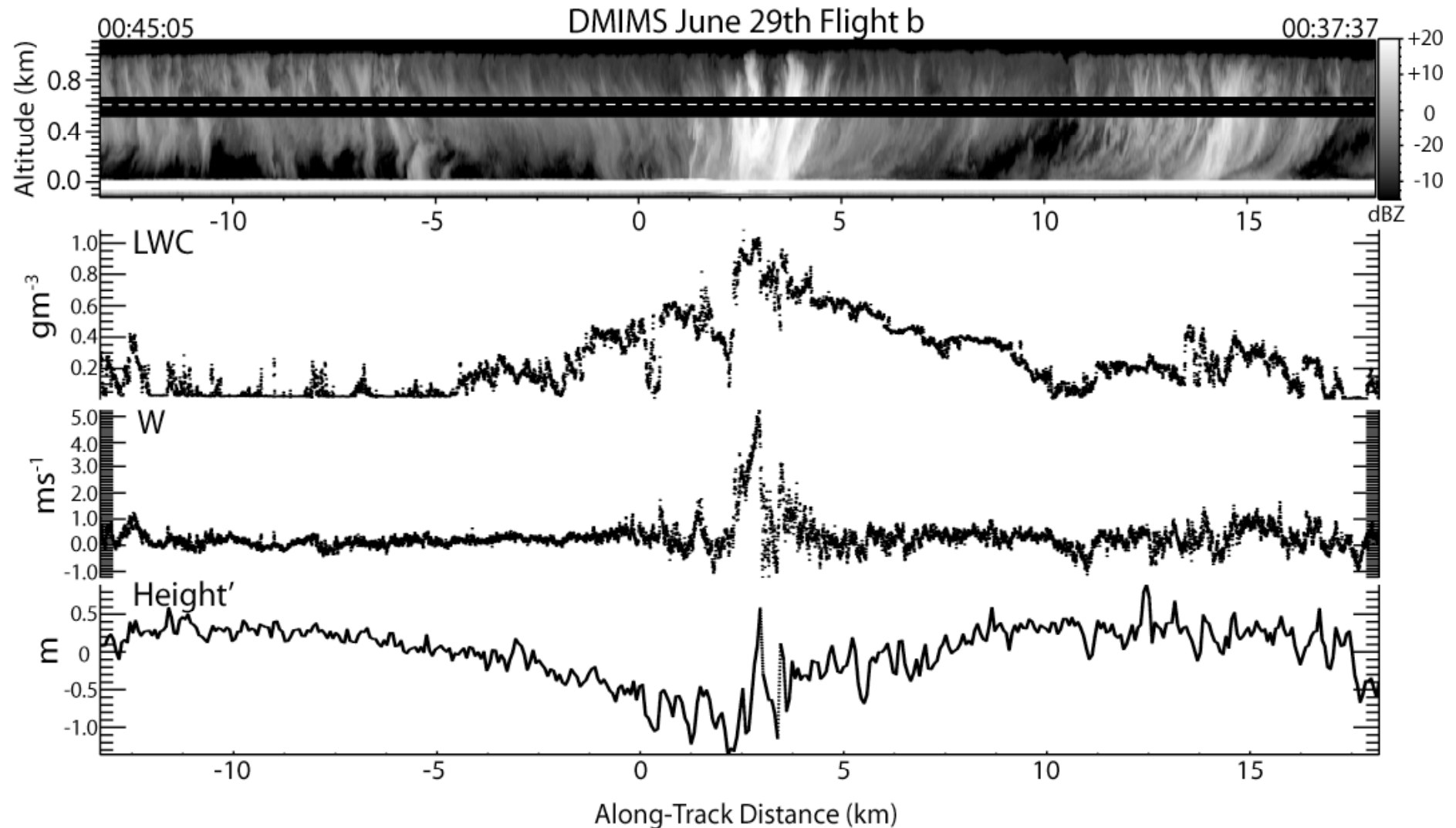
LES results

- Impact of aerosols simulated by varying N_d
- Increased $N_d \Rightarrow$ Reduced precipitation $\Rightarrow$ increased TKE $\Rightarrow$ increased entrainment w_e
- Changes in w_e can sometimes result in cloud thinning (reduced LWP)
- Also noted by Jiang et al. (2002)

Ackerman et al. (2004)

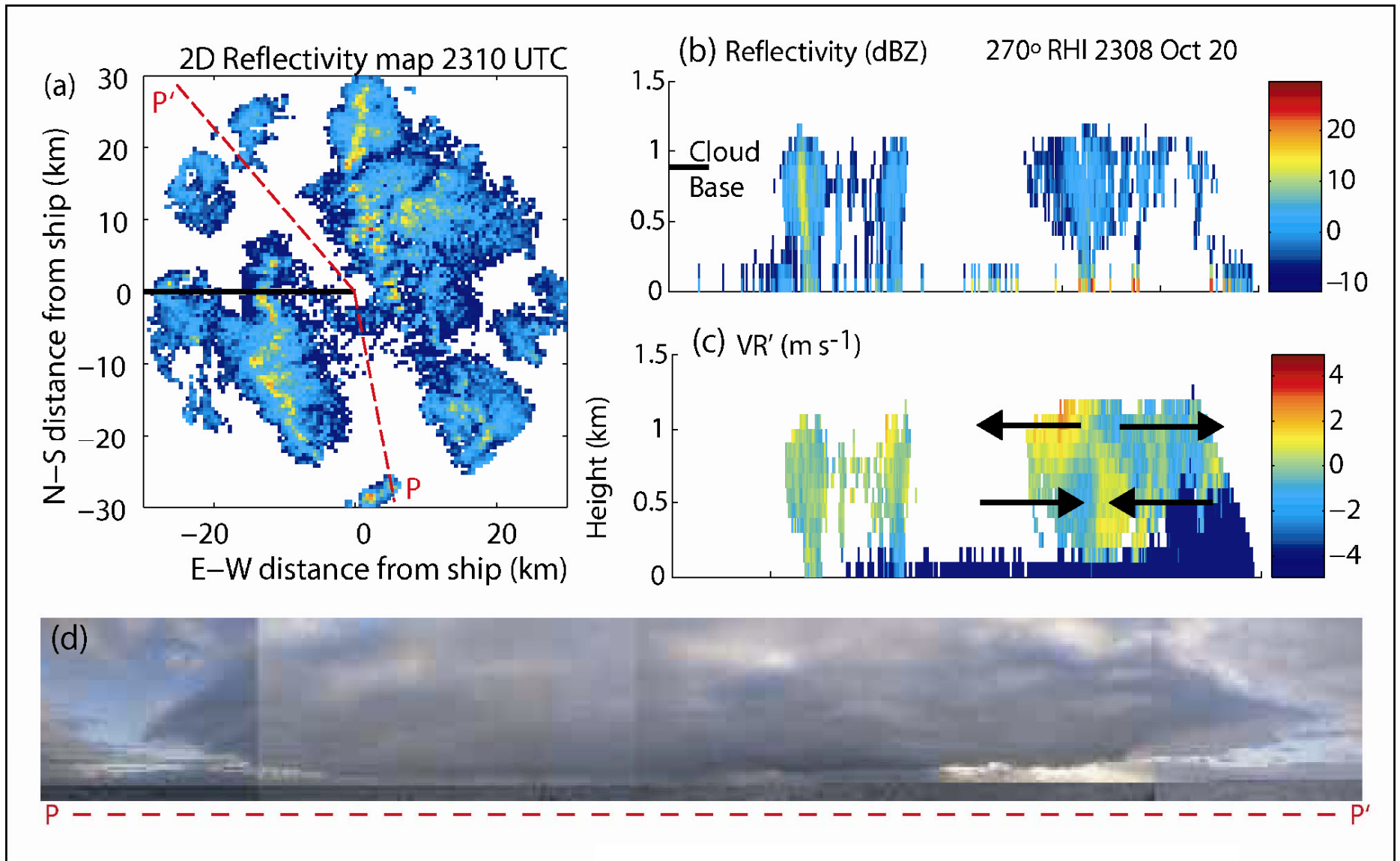


Drizzle and mesoscale cellularity

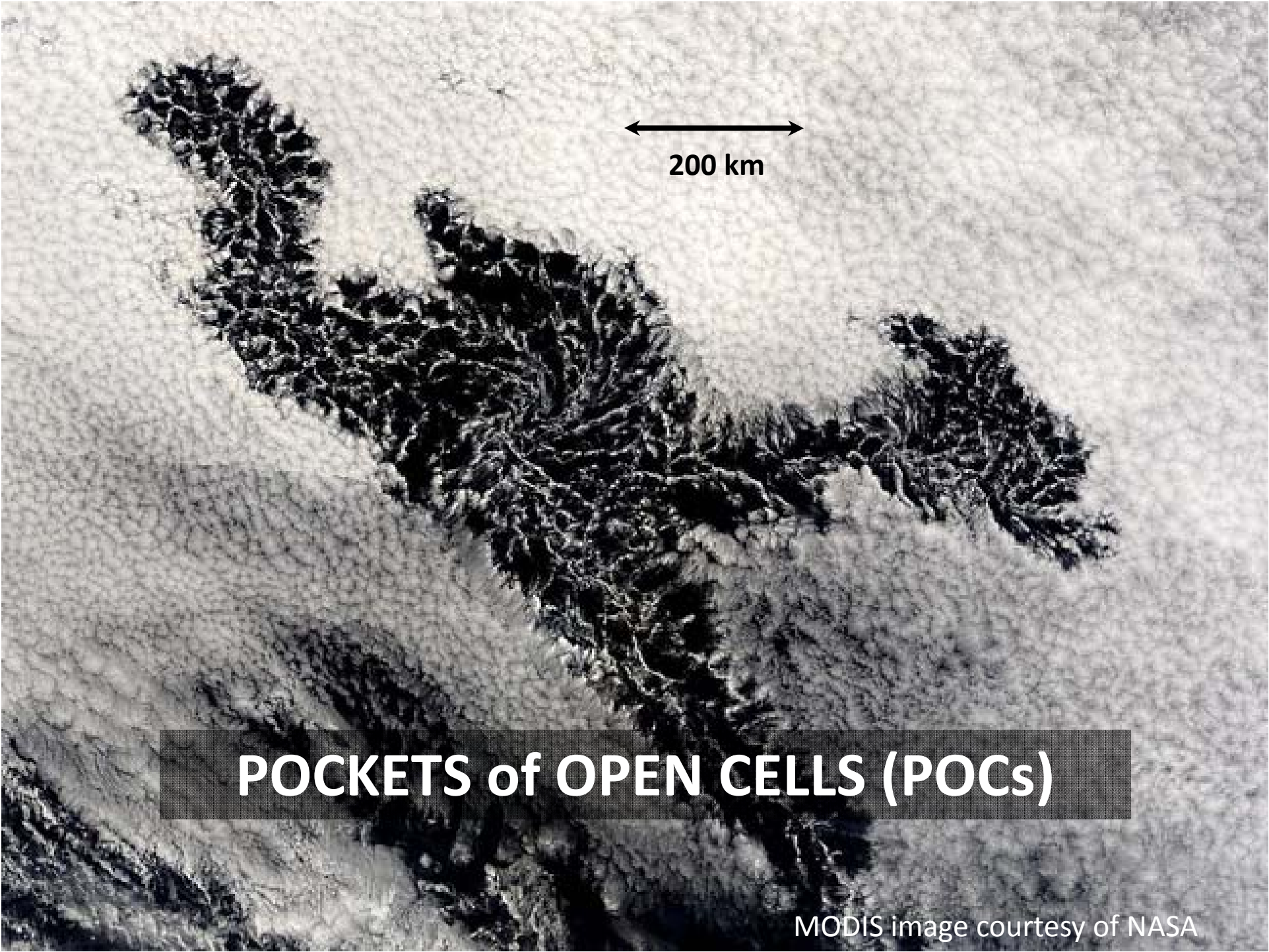


courtesy Dave Leon, U of Wyoming

Drizzle and cellularity



Comstock et al. (2007, Mon Wea Rev)



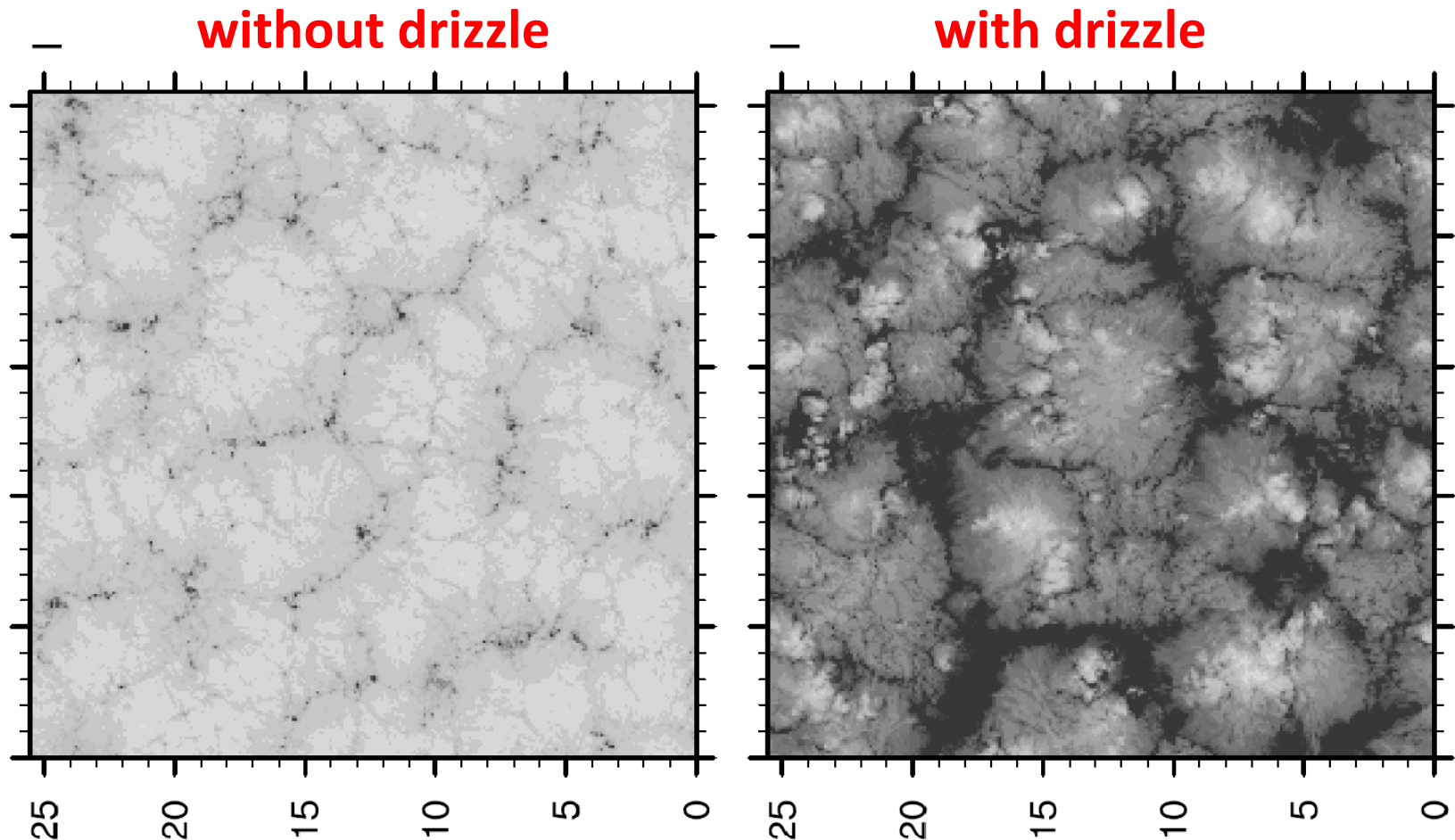
200 km

POCKETS of OPEN CELLS (POCs)

MODIS image courtesy of NASA

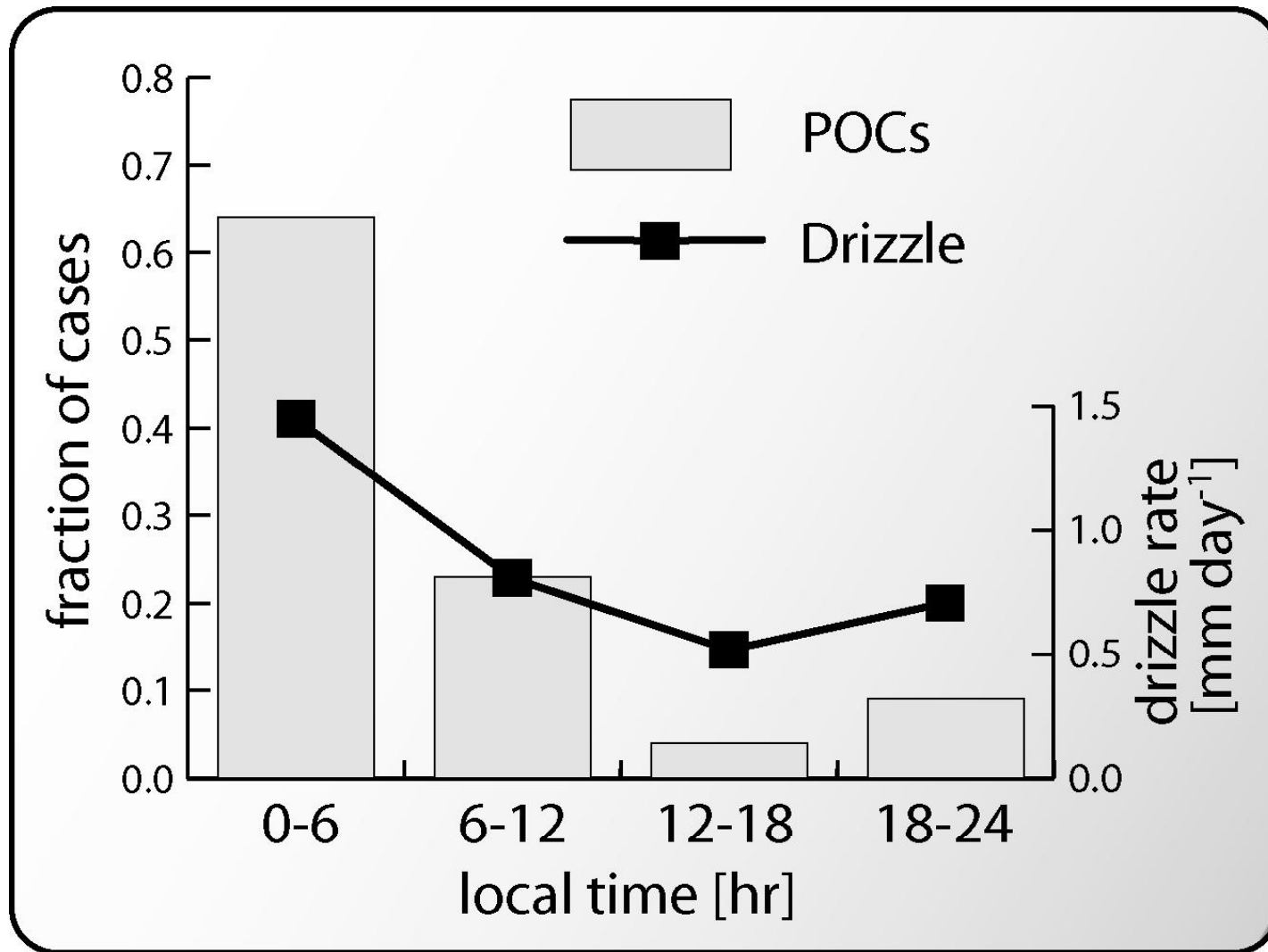
Drizzle and POCs

- Drizzle can exert important forcing on the MBL



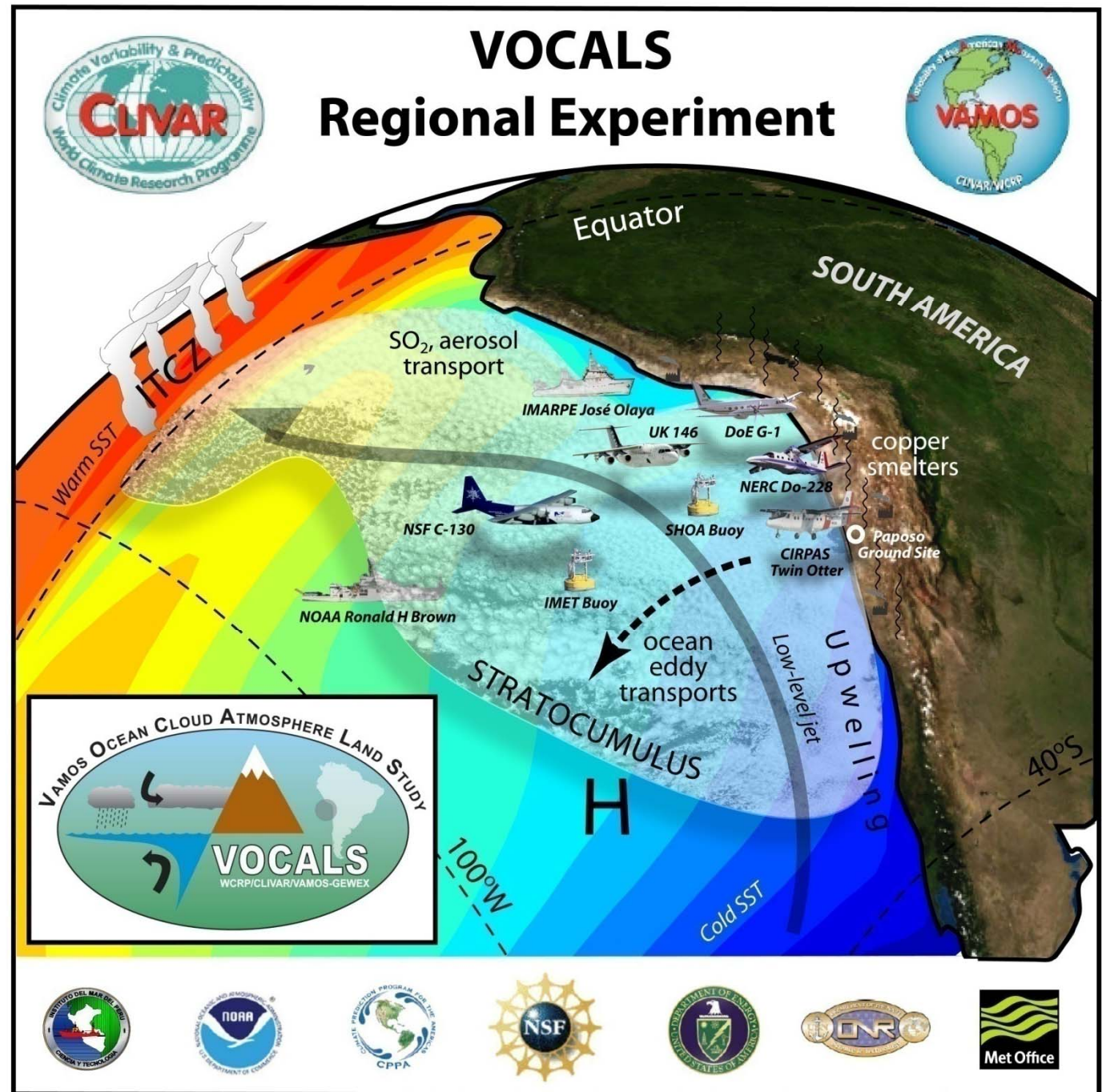
Savic-Jovcic and Stevens (2007)

POCs prefer to form at night



October-
November
2008

SE Pacific



VOCALS Regional Experiment (REx)

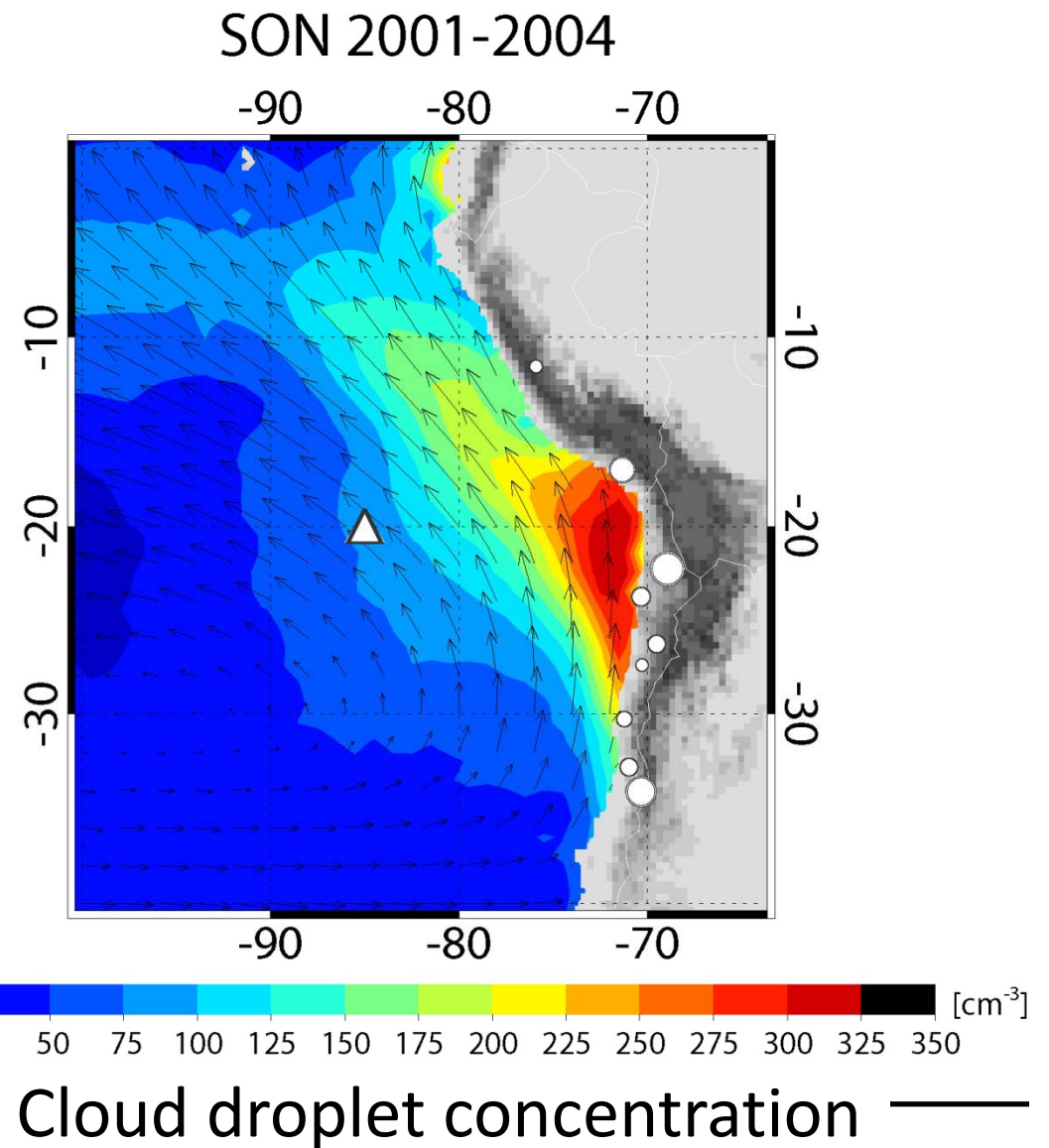
VOCALS-Rex will collect datasets required to address a set of issues that are organized into two broad themes:

- **Aerosol-cloud-drizzle interactions** in the marine boundary layer (MBL) and the physicochemical and spatiotemporal properties of aerosols
- **Chemical and physical couplings** between the upper ocean, the land, and the atmosphere.

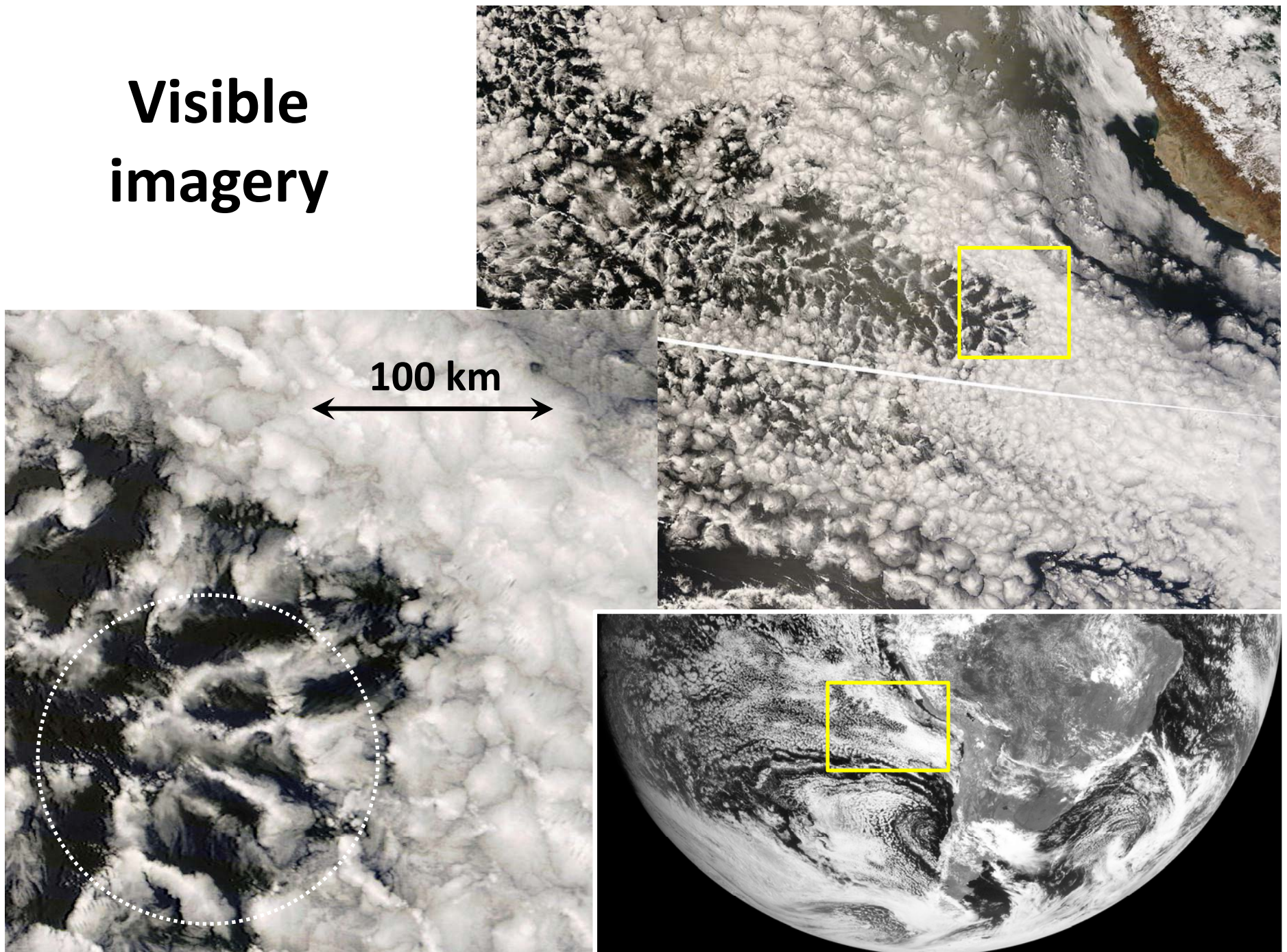


Aerosols and clouds

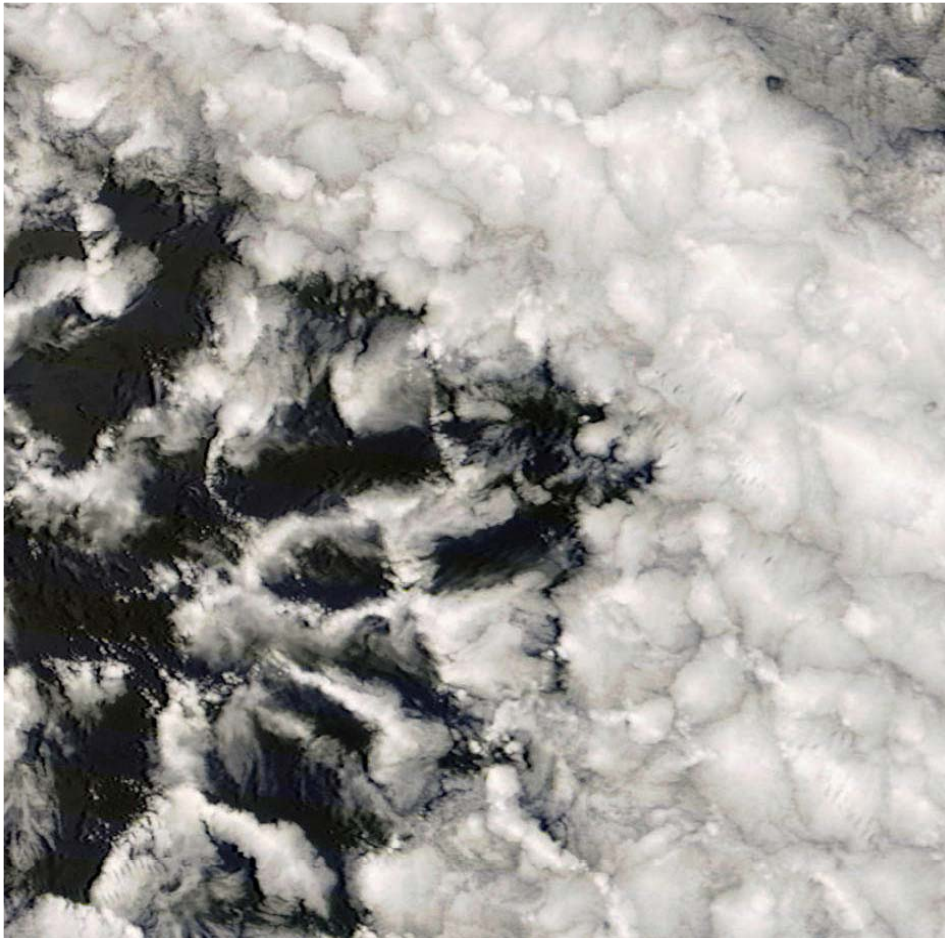
Chuquicamata, Chile



Visible imagery



October 27/28th 2008
POC Lagrangian - BAe-146 & NSF C-130

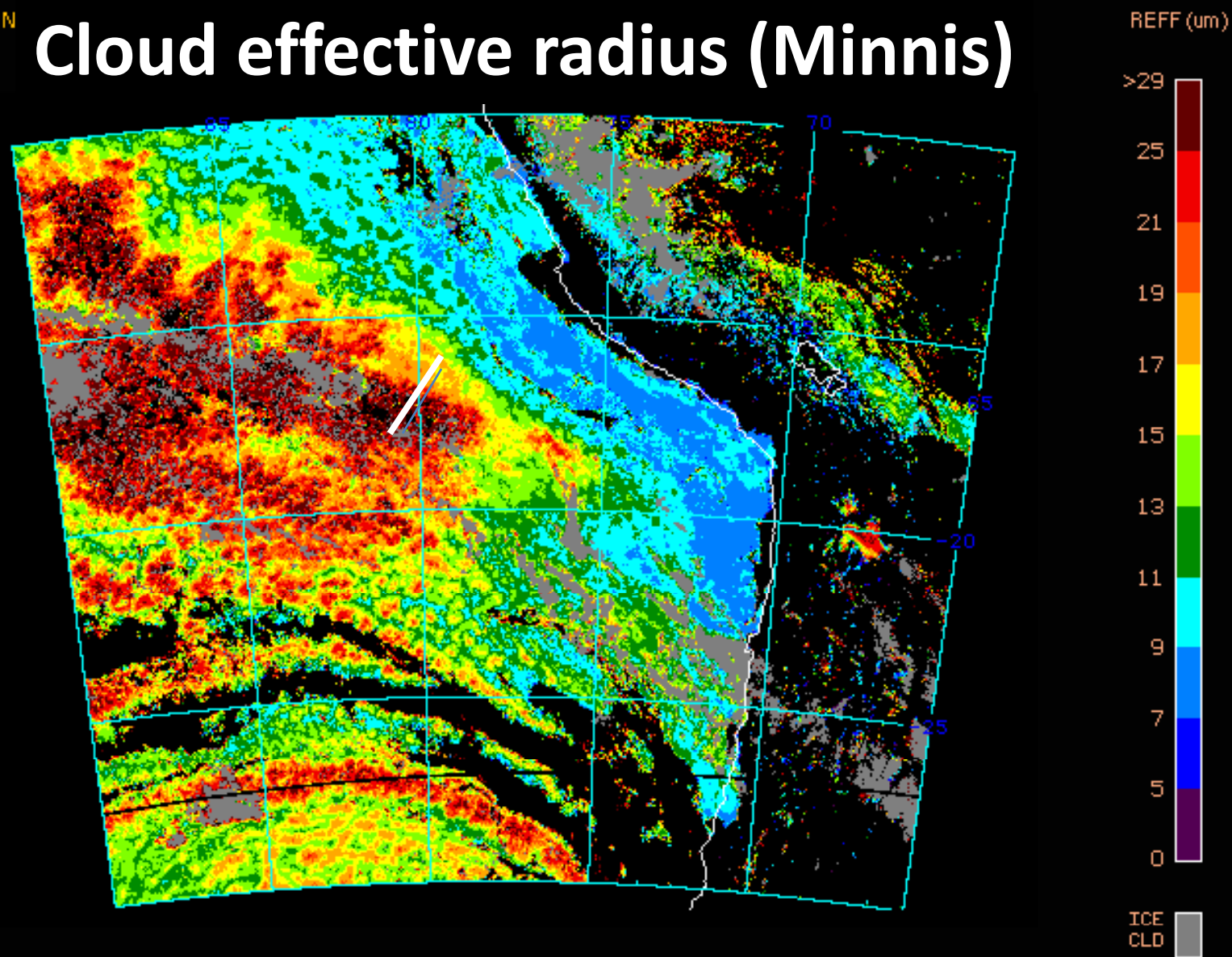


MODIS Terra, 250 m visible image



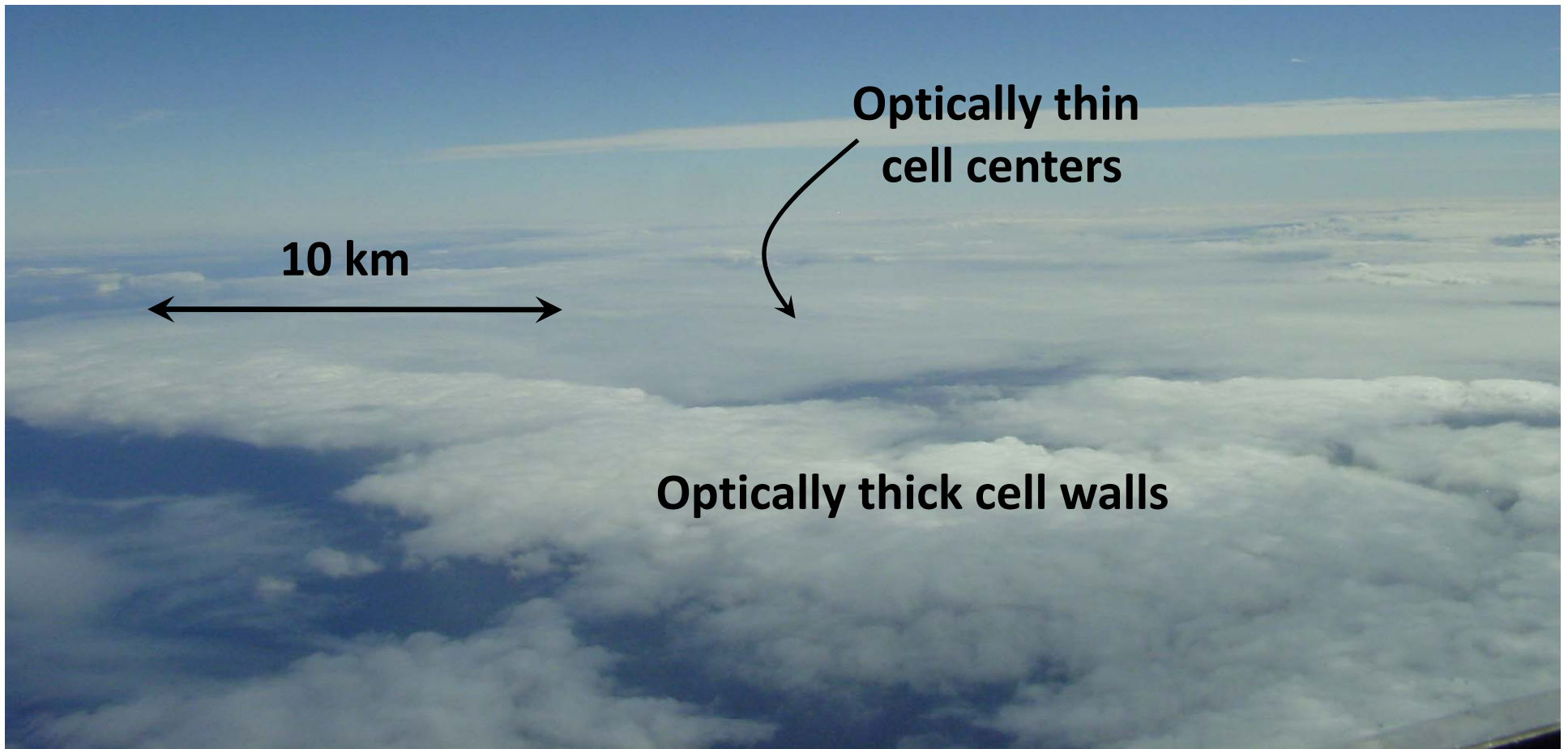
Photo from BAe-146, Hugh Coe

Cloud effective radius (Minnis)

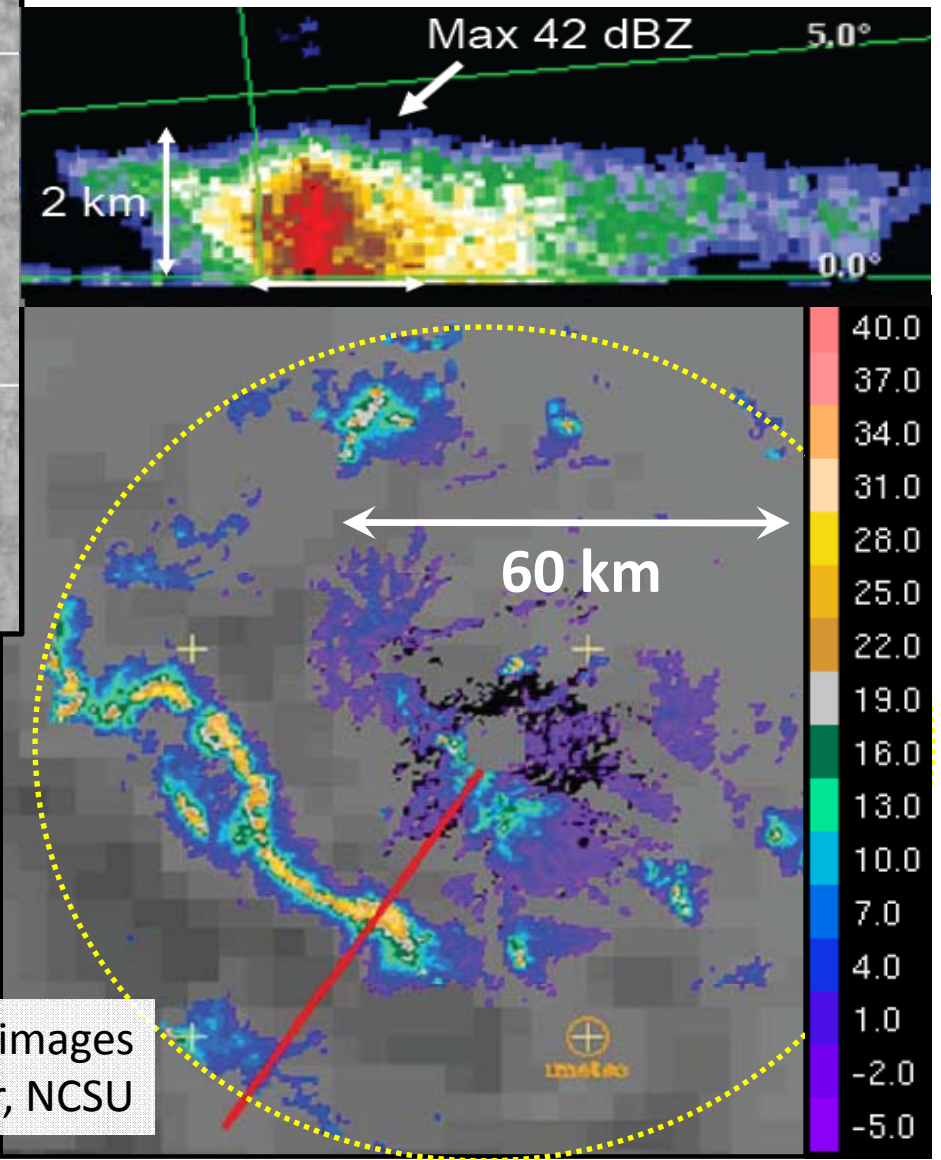
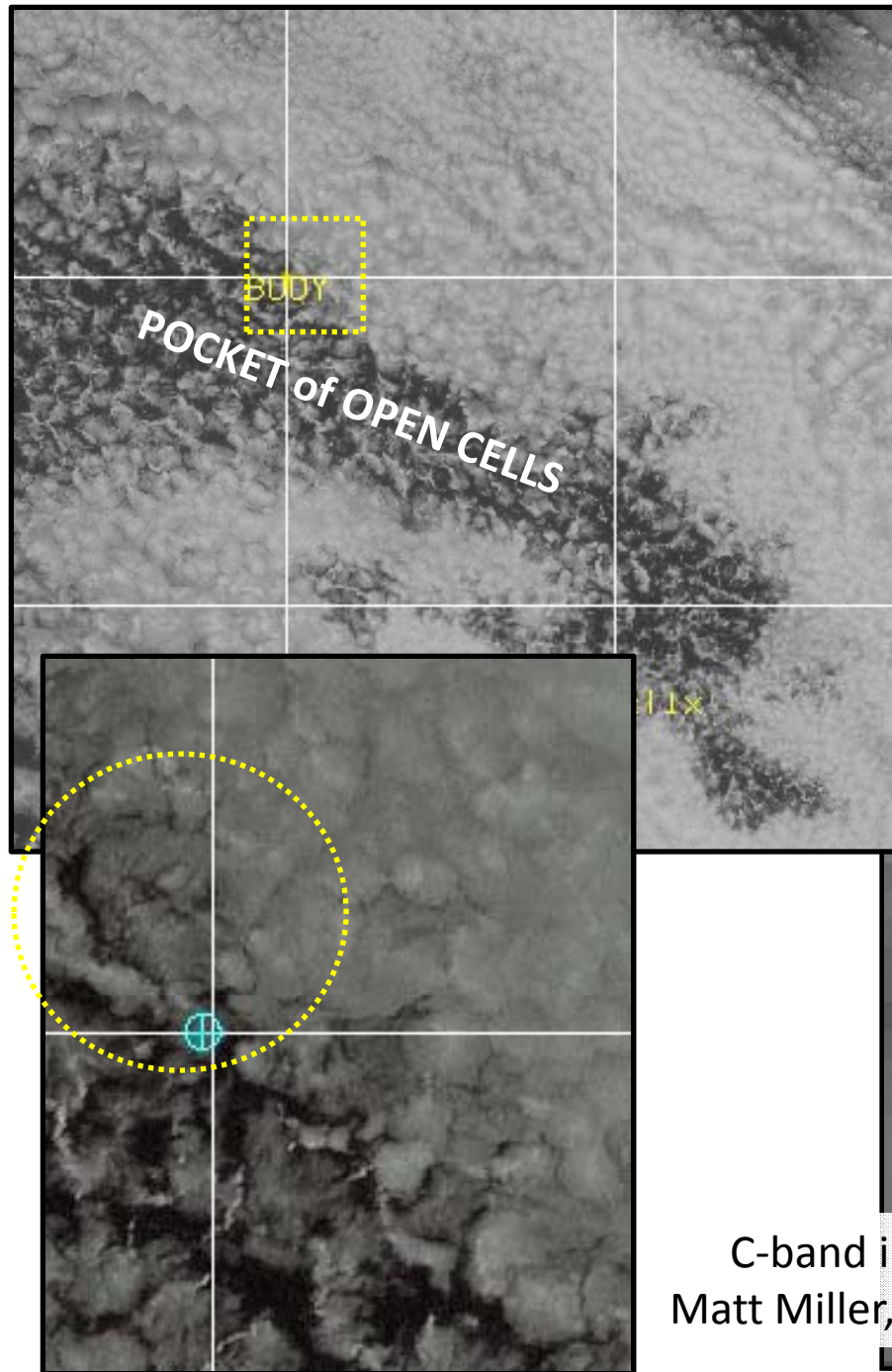


G10 EFFECTIVE WATER RADIUS OCT 28, 2008 14:15Z NASA LARC

OPEN CELL MORPHOLOGY

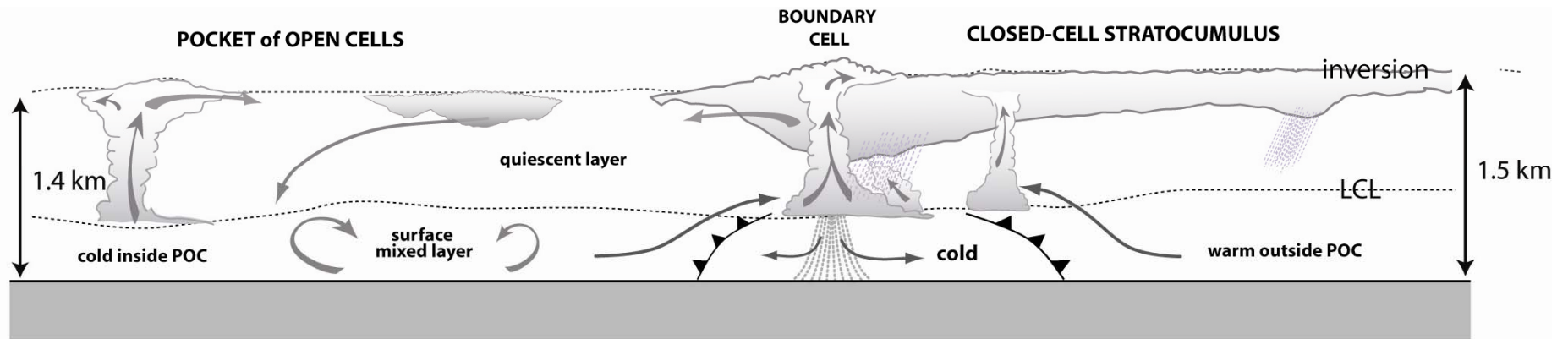


Boundary cells



C-band images
Matt Miller, NCSU

Conceptual model of POC edge



Decoupled MBL

Relatively well-mixed MBL

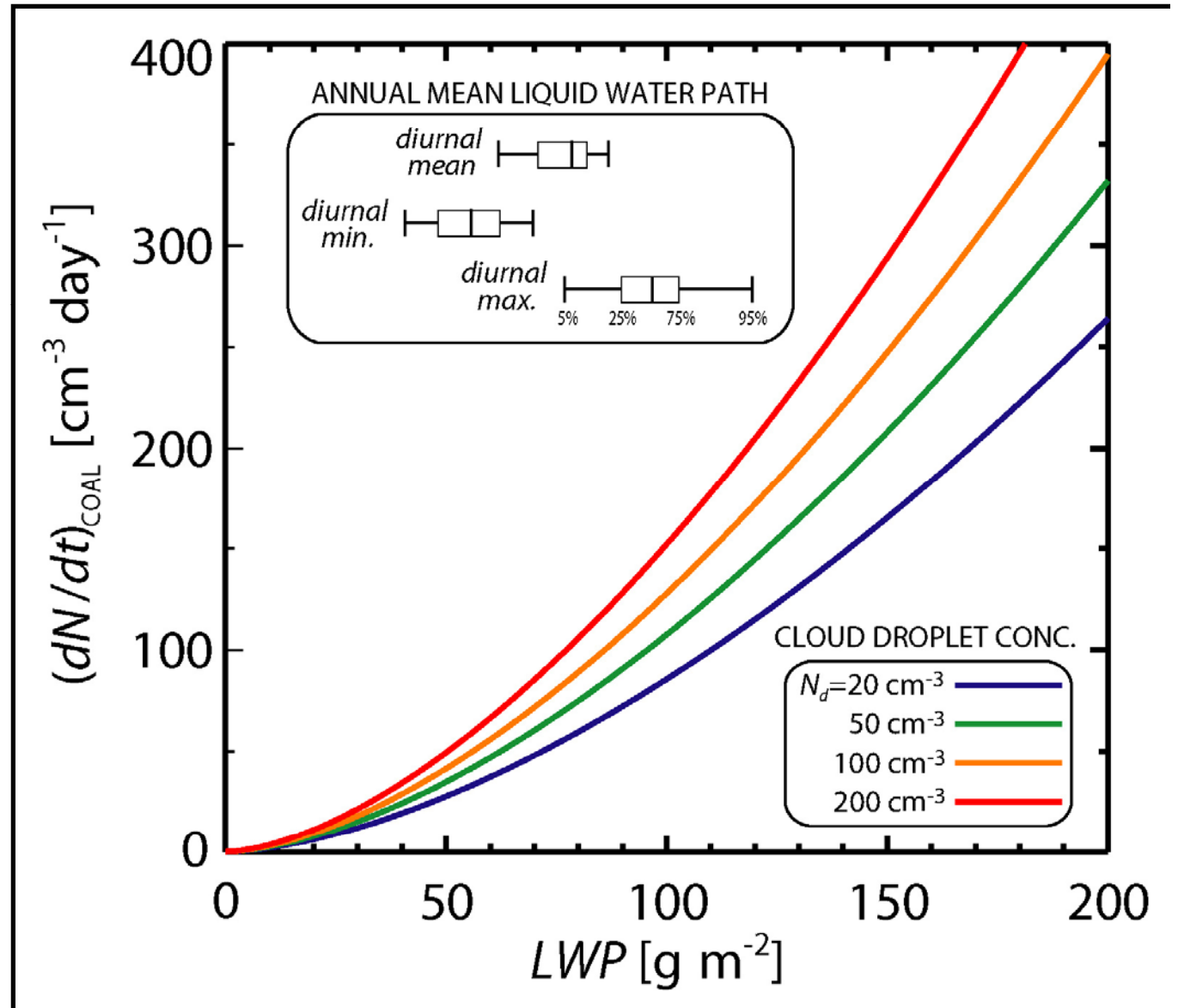
Extremely clean
[CN = 20-50 cm⁻³, CCN = 5-20 cm⁻³]

Moderately polluted
[CN = 500-1000 cm⁻³, CCN = 100 cm⁻³]



Coalescence and CCN depletion

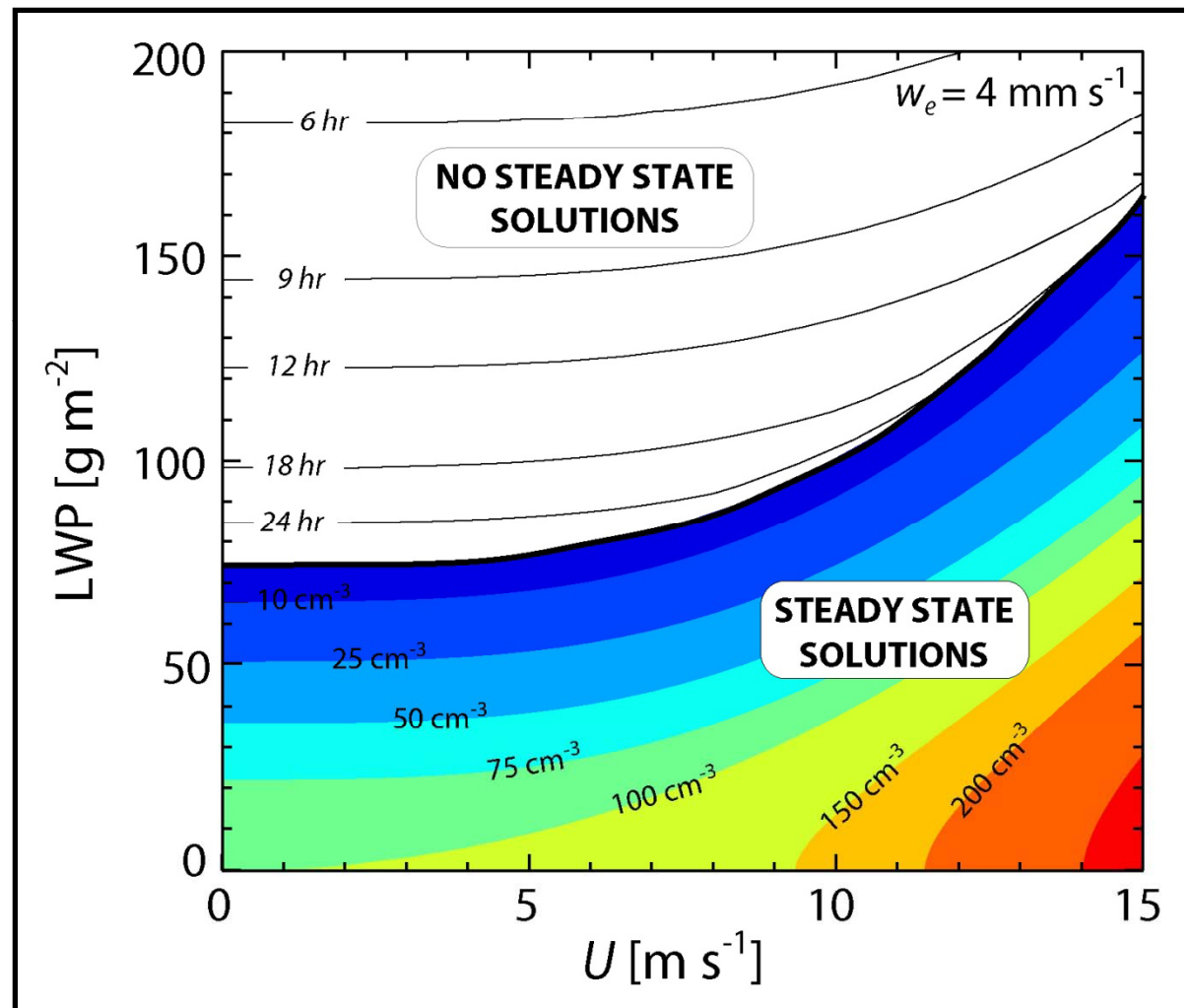
- Loss rate of CCN number concentration through coalescence
 $\propto LWP^2$



Steady-state cloud condensation nucleus (CCN) model

Assumptions:

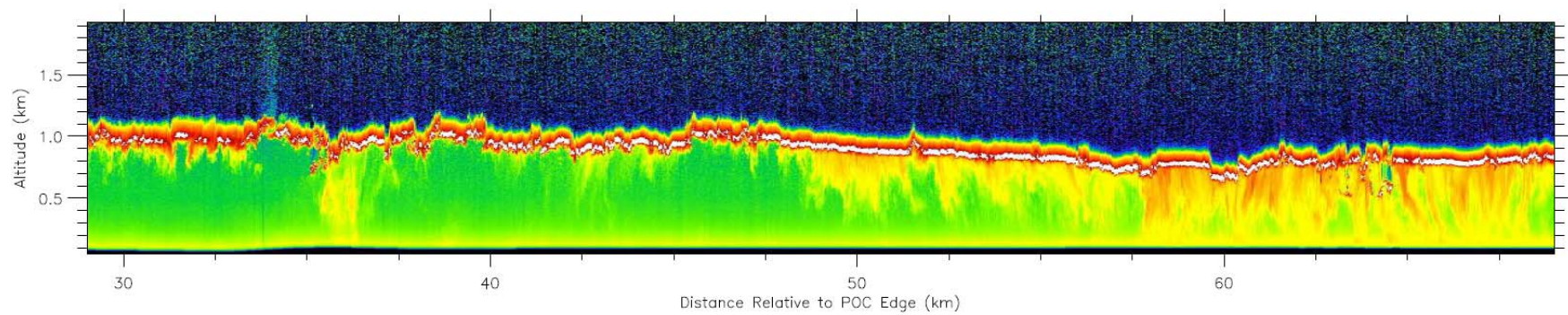
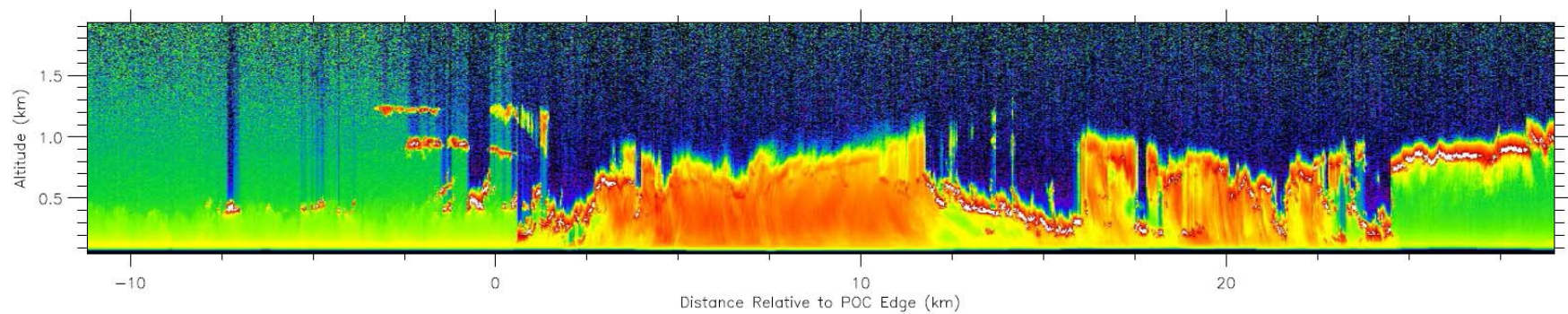
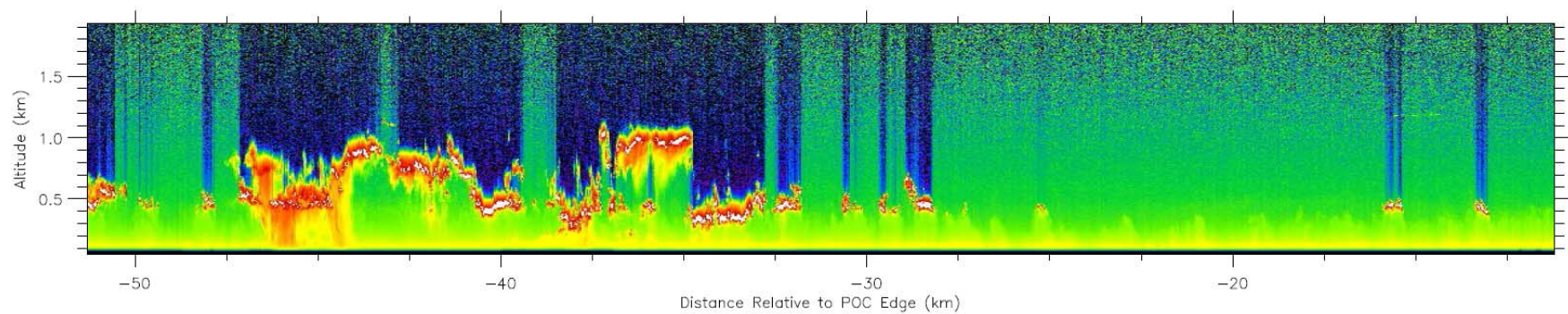
1. Wind-driven sea-salt production and entrainment of 100 cm^{-3} from free-troposphere are only aerosol sources.
2. Coalescence scavenging is the only loss term
3. Examine steady state solution for CCN concentration



Take-home messages

- Precipitation common in, and energetically important for, shallow marine boundary layers
- Precipitation rate is macrophysically-determined but can be influenced microphysically
- Precipitation important for organization of mesoscale structure in the stratocumulus-topped boundary layer
- Precipitation important for controlling aerosol population within the marine boundary layer



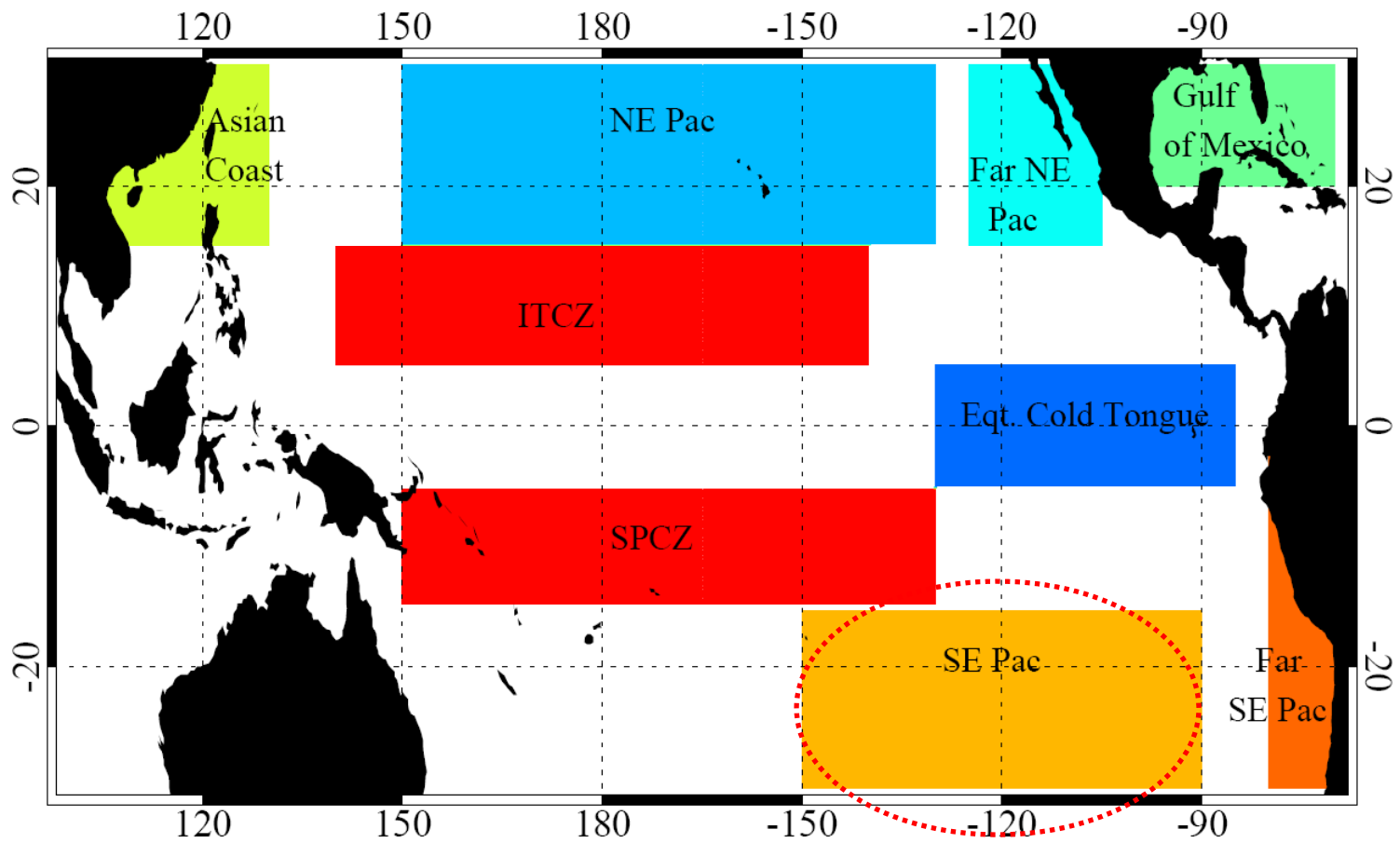




Data/Methods

- Collocated CloudSat (GEOPROF) and Aqua-MODIS (MOD06) data:
 - Daytime data only ($\sim 13:30$ local)
 - CloudSat cloud top height below freezing level
 - MODIS cloud top temperature $> 0^{\circ}\text{C}$
 - MODIS cloud optical depth $\tau > 3$
- MODIS used to estimate LWP and N_d :
 - LWP from standard MODIS cloud product
 - N_d using method of Bennartz (2007), assuming adiabatic vertical cloud profile
- CloudSat used to determine maximum Z in column. Classify > -15 dBZ as precipitating.

Regions Studied



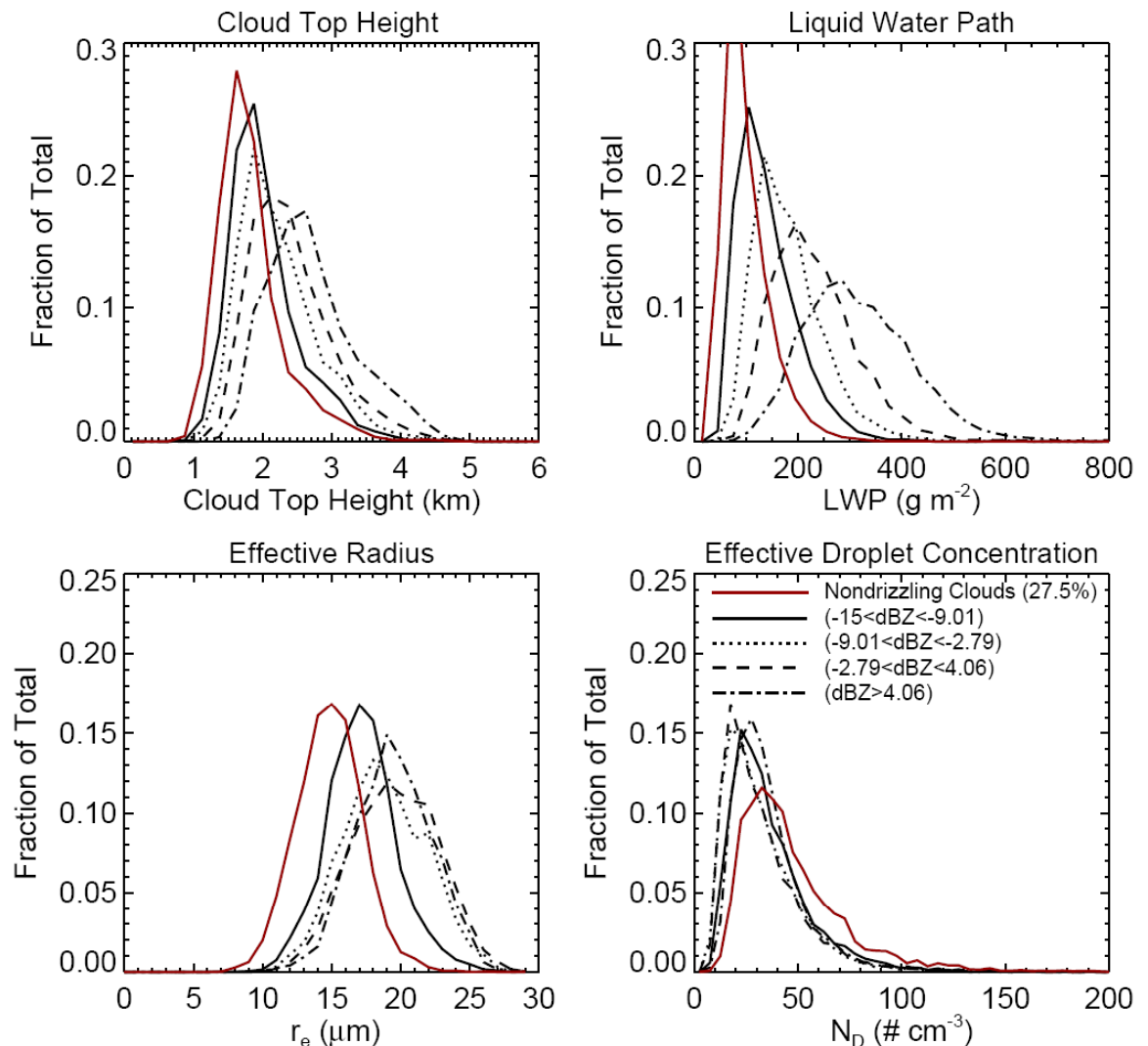
Cloud properties associated with different amounts of precipitation

SE Pacific

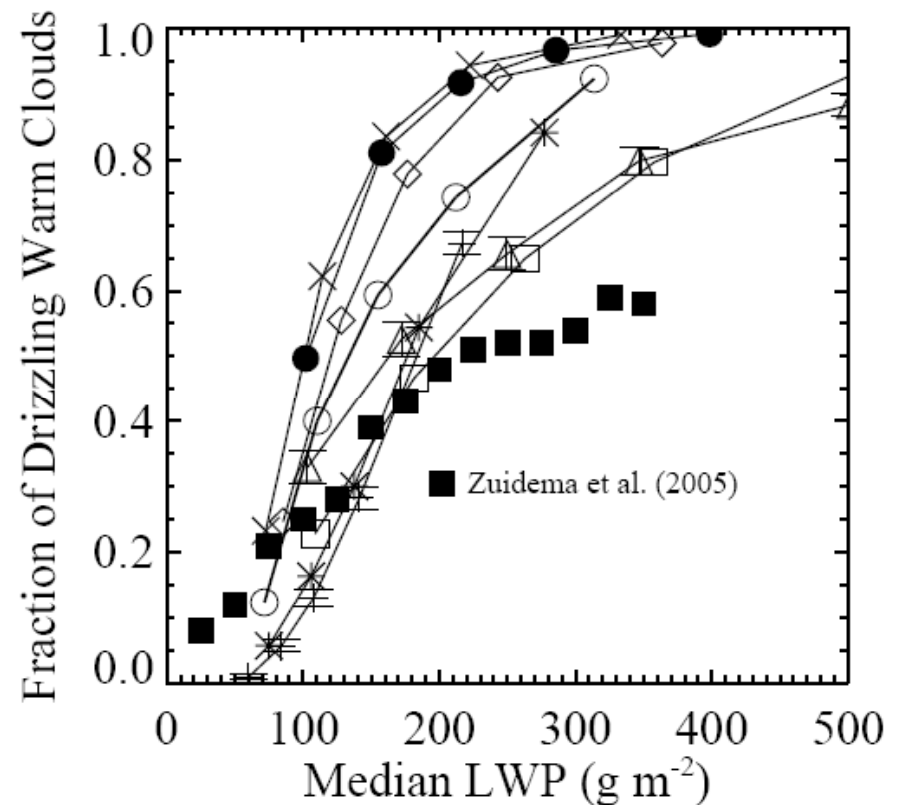
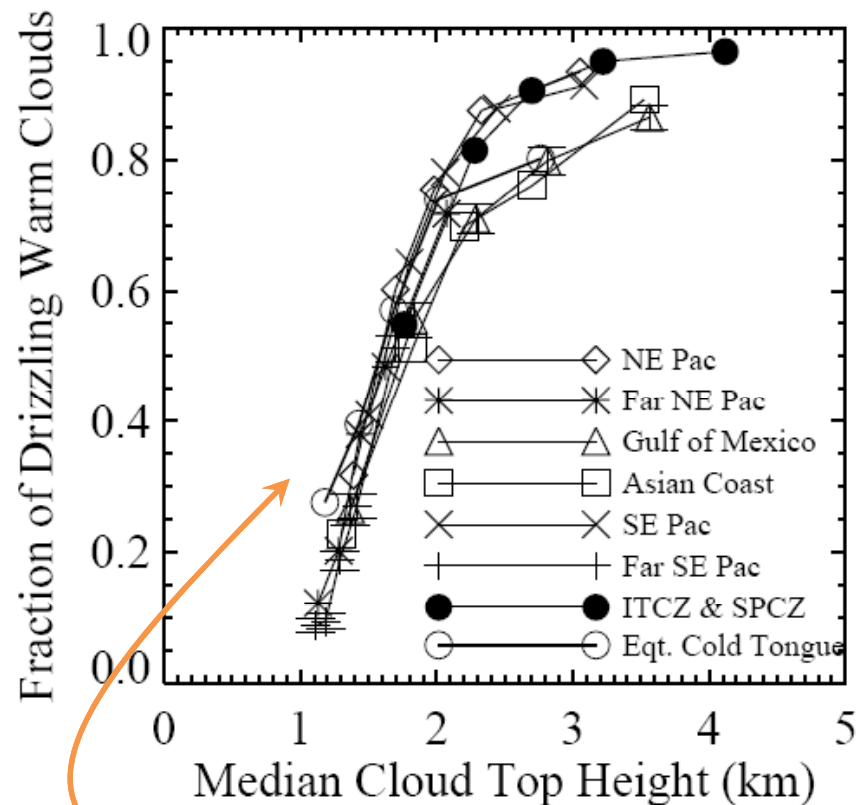
As clouds move from non-precipitating to precipitating:

(1) LWP and cloud top height show steady increases

(2) Microphysical parameters “saturate”

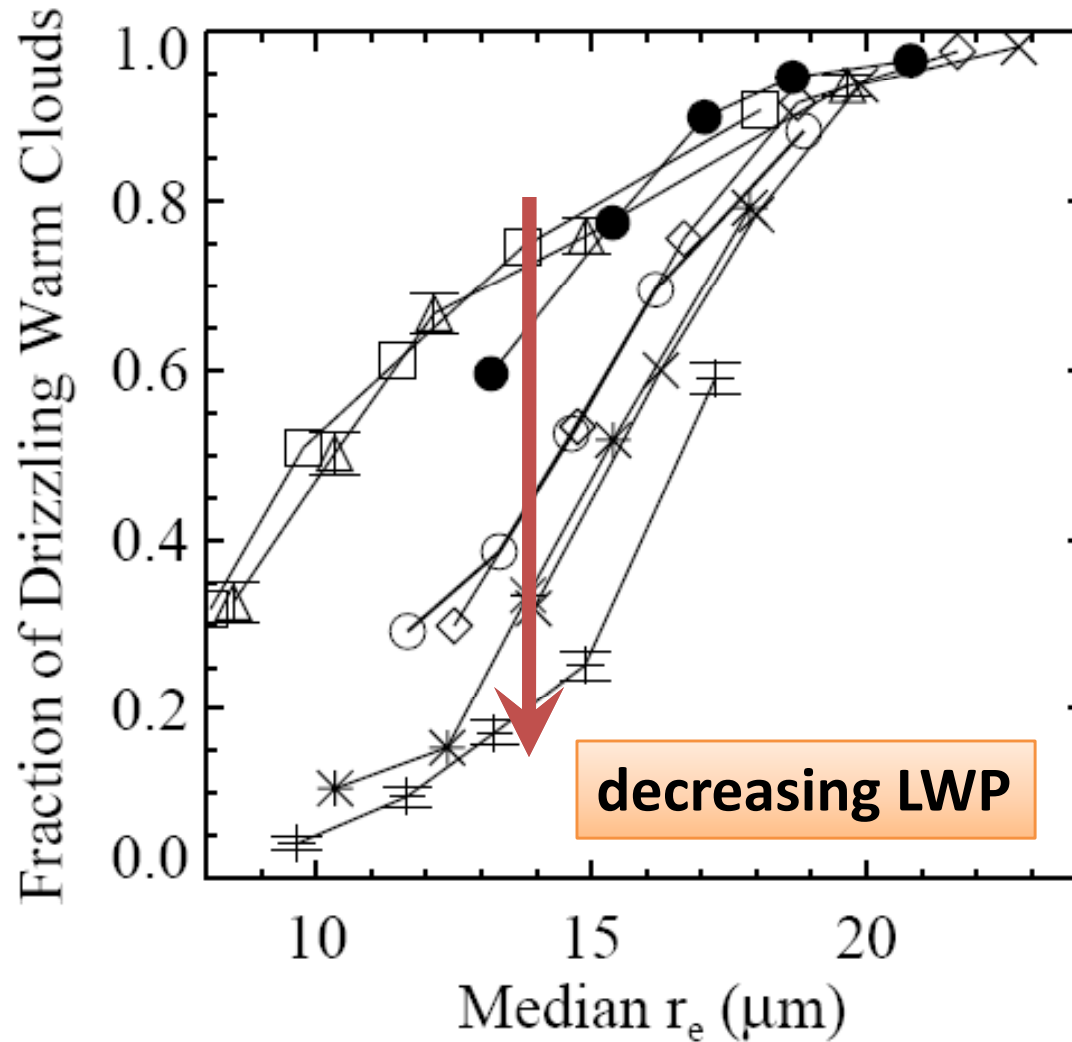


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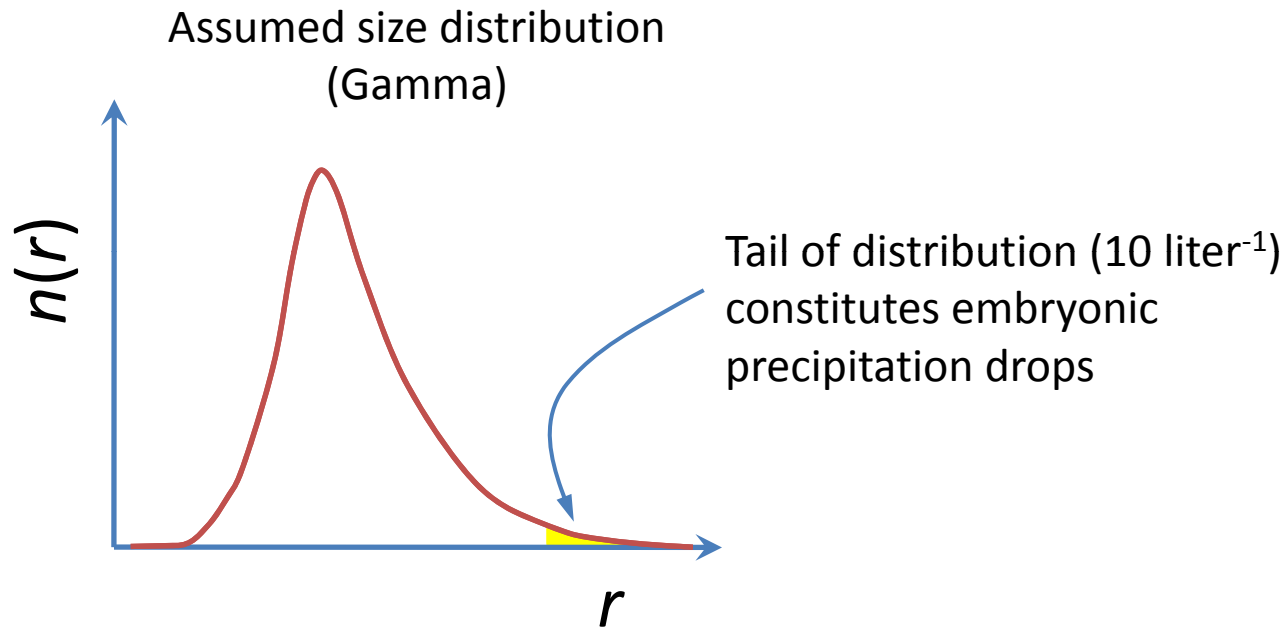
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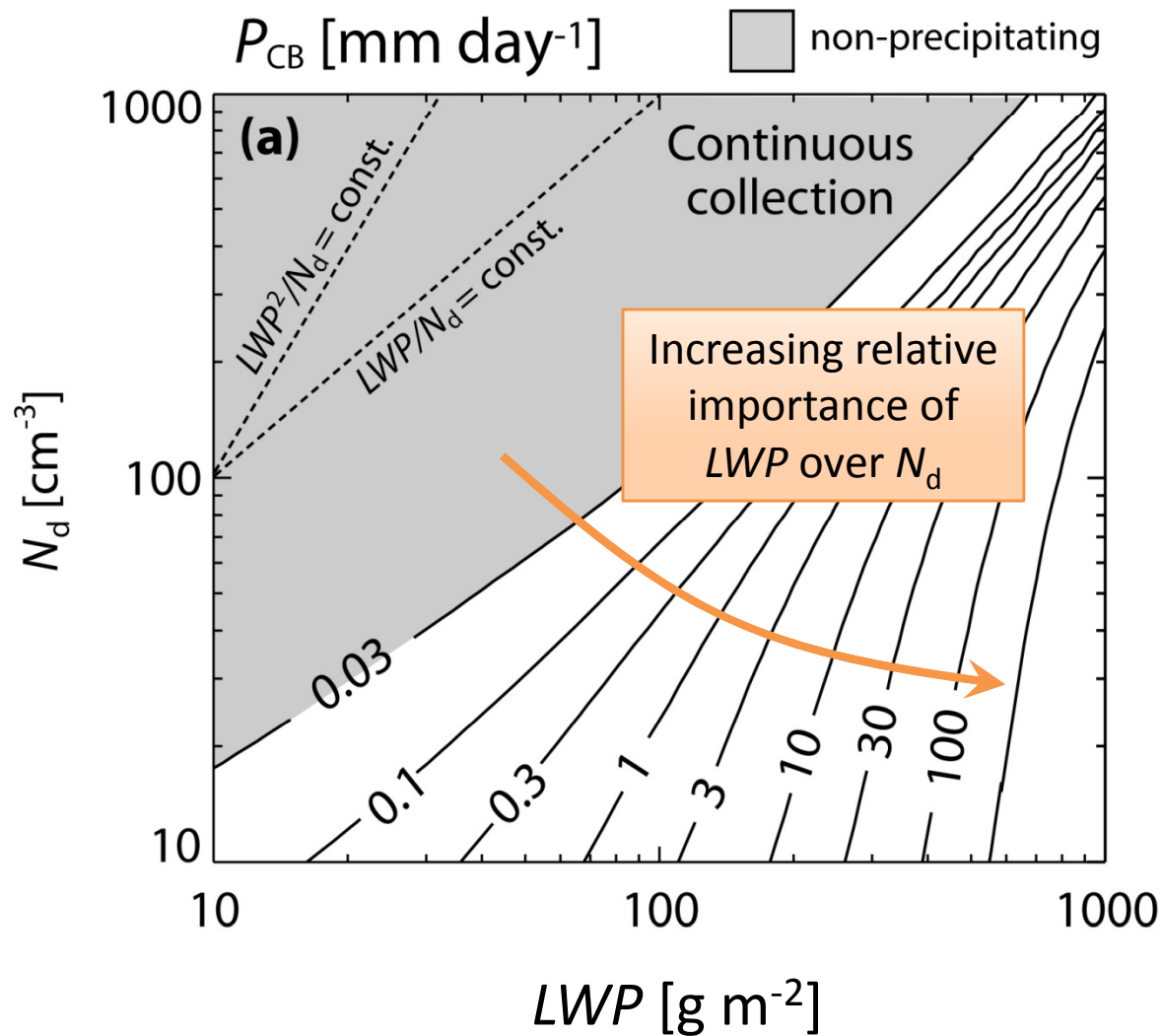
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Precipitation embryos



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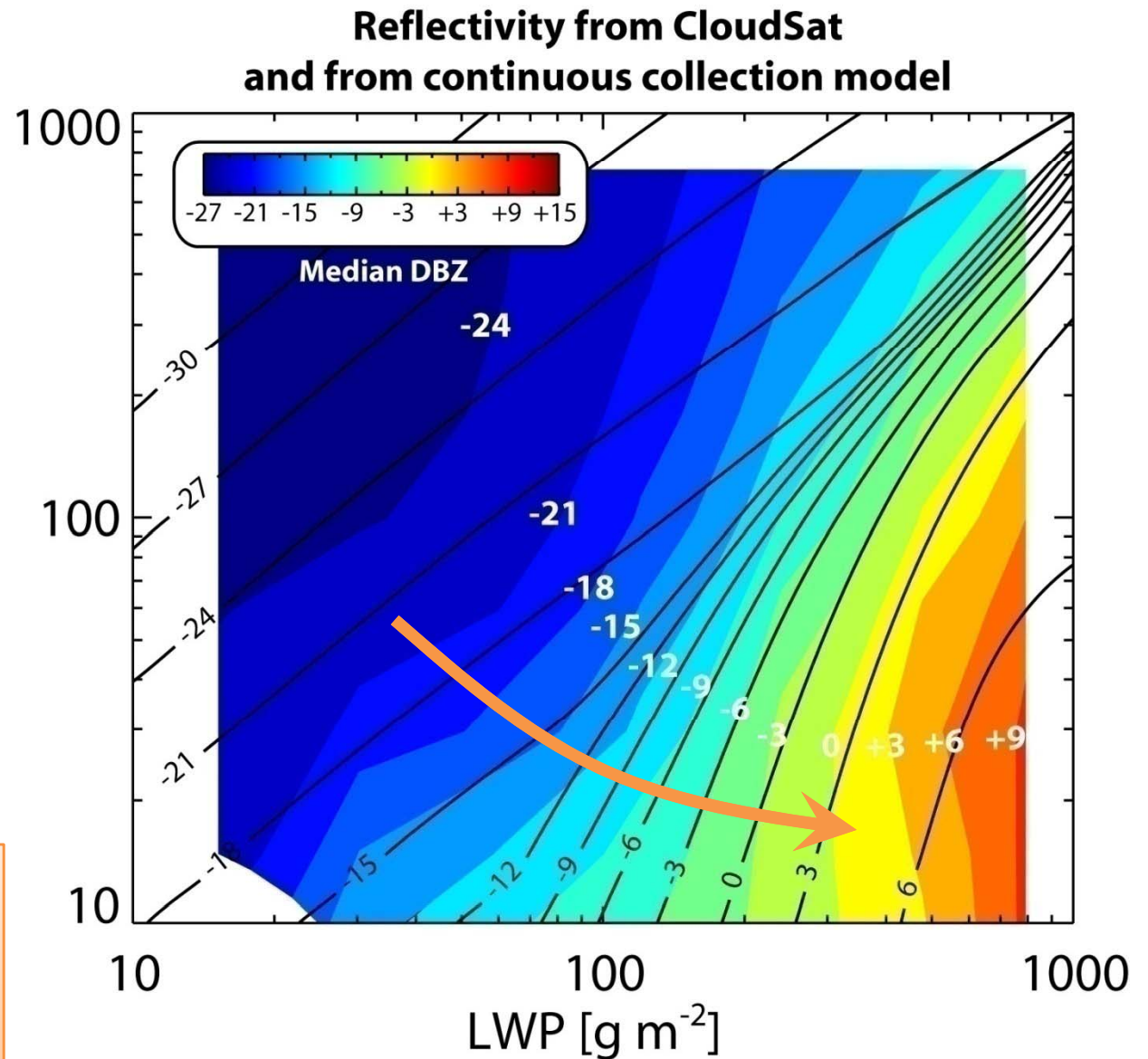
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Reflectivity in [LWP , N_d] space

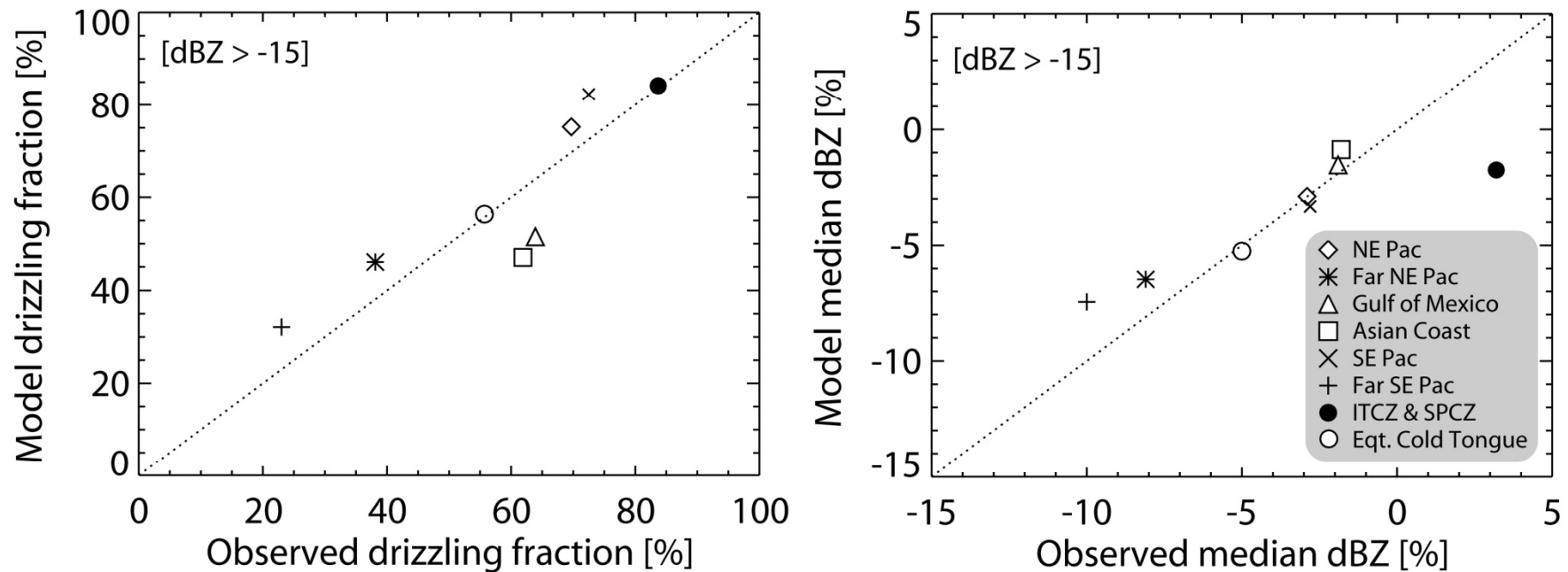


Increasing relative
importance of LWP
over N_d at high
rainrates

see also Suzuki and Stephens (2008)

CloudSat: colors
Model: lines

Model vs Obs drizzle fraction and intensity



Given $[LWP, N_d]$ joint pdf, model can determine the drizzling fraction and intensity of drizzle in each region

Understanding the model behavior

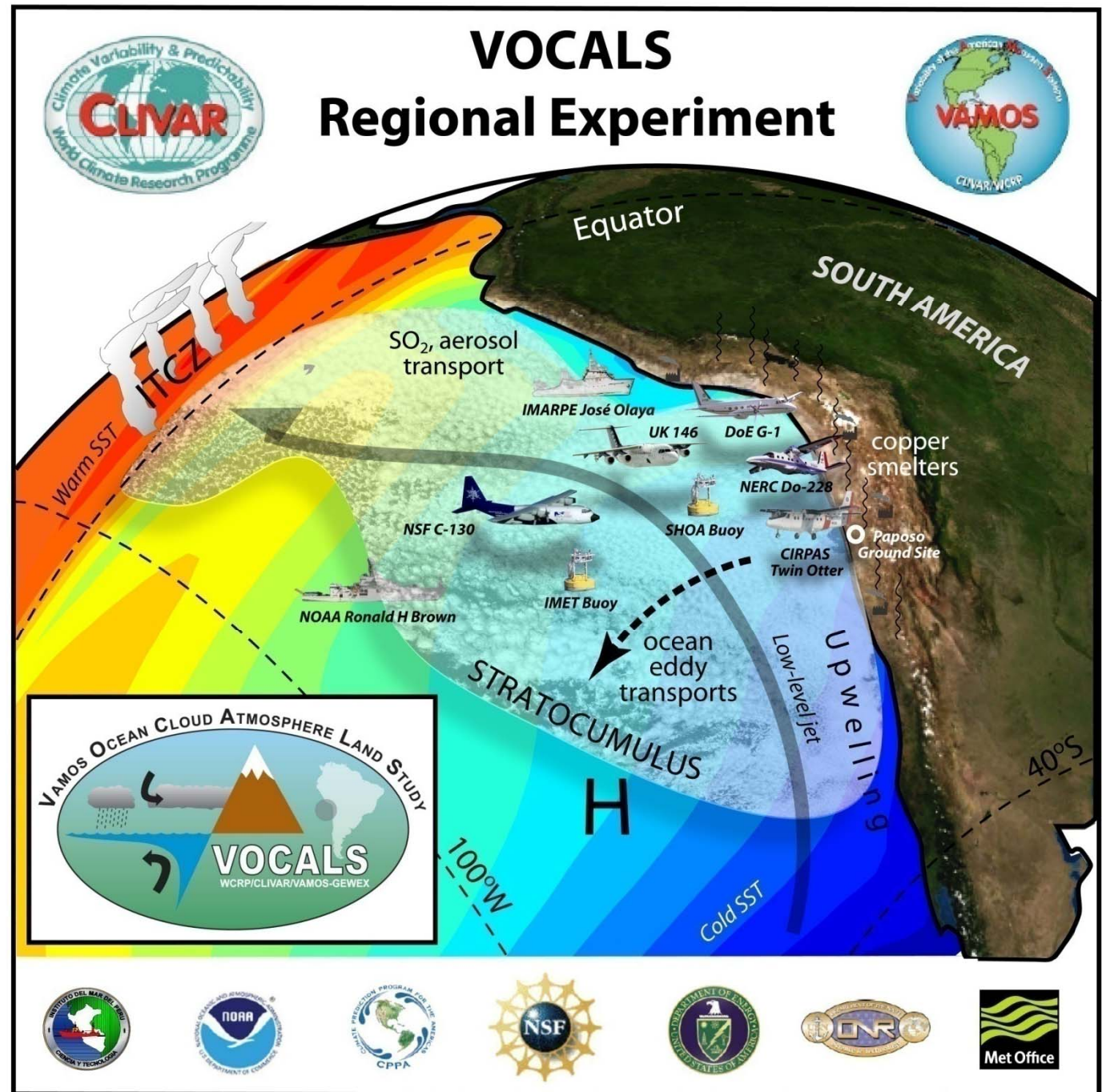
- Precipitation drop embryo formation
 - depends very strongly upon microphysics (N_d)
- Accretion
 - primarily limited by availability of cloud liquid water (not microphysics)
- Clouds in which accretion dominates (thicker clouds, higher LWP) show reduced sensitivity to N_d

Conclusions

- Observations and simple heuristic model show decreasing relative importance of microphysics as precipitation rate in warm clouds increases
- Broadly consistent with field observations (DYCOMS, ACE-2, EPIC, RICO)
- Implications for aerosol-cloud-precipitation interactions

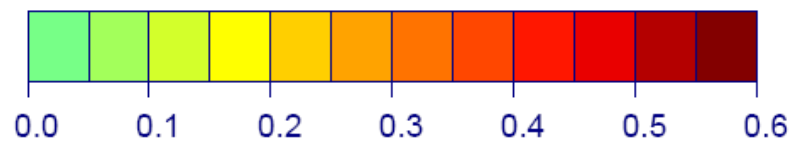
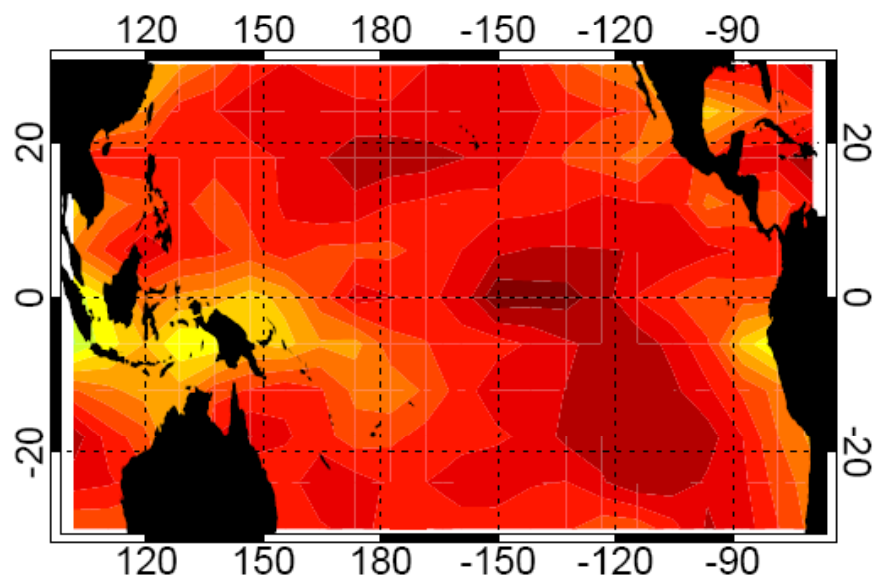
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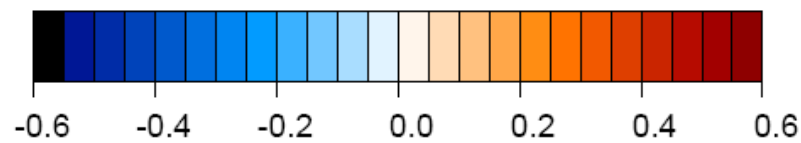
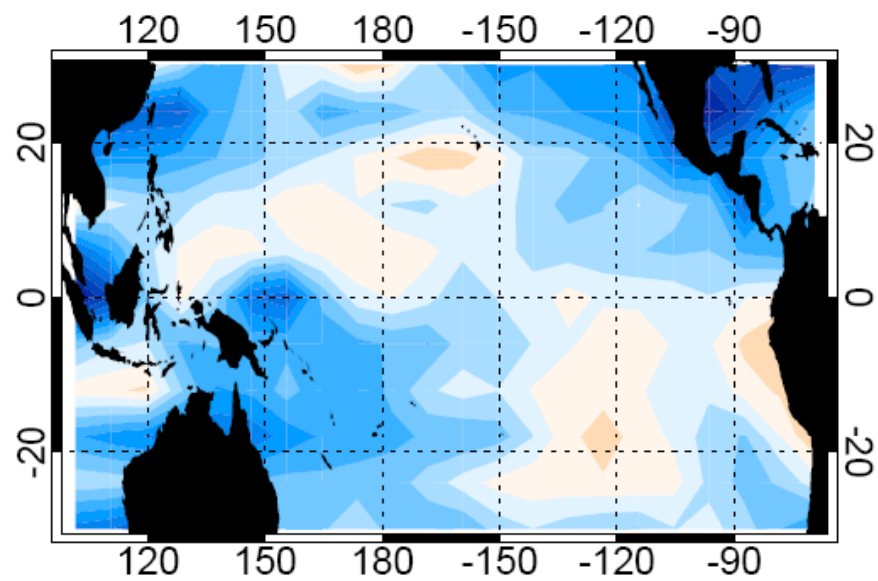


VOCALS-CloudSat

- VOCALS will yield a unique dataset detailing the properties of clouds, aerosols, and precipitation in the largest stratocumulus sheet on Earth
- Development/testing of CloudSat/CALIPSO/A-Train retrievals of light precipitation and MBL microphysical and macrophysical structure
- Near-surface issues
 - technical: surface clutter
 - physical: evaporation of drizzle



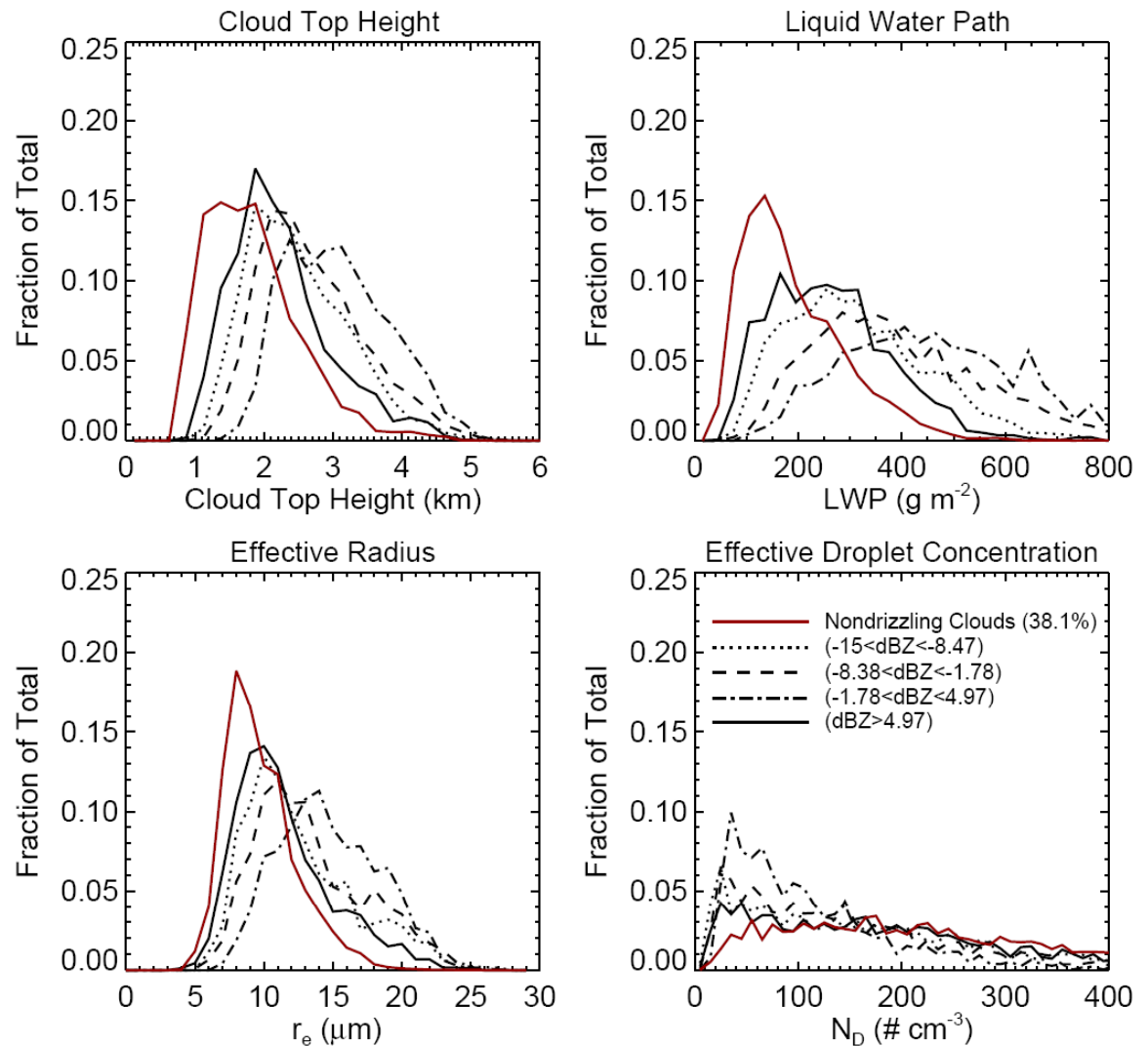
$\Delta\text{LWP}/\text{LWP}$



$\Delta N_D/N_D$

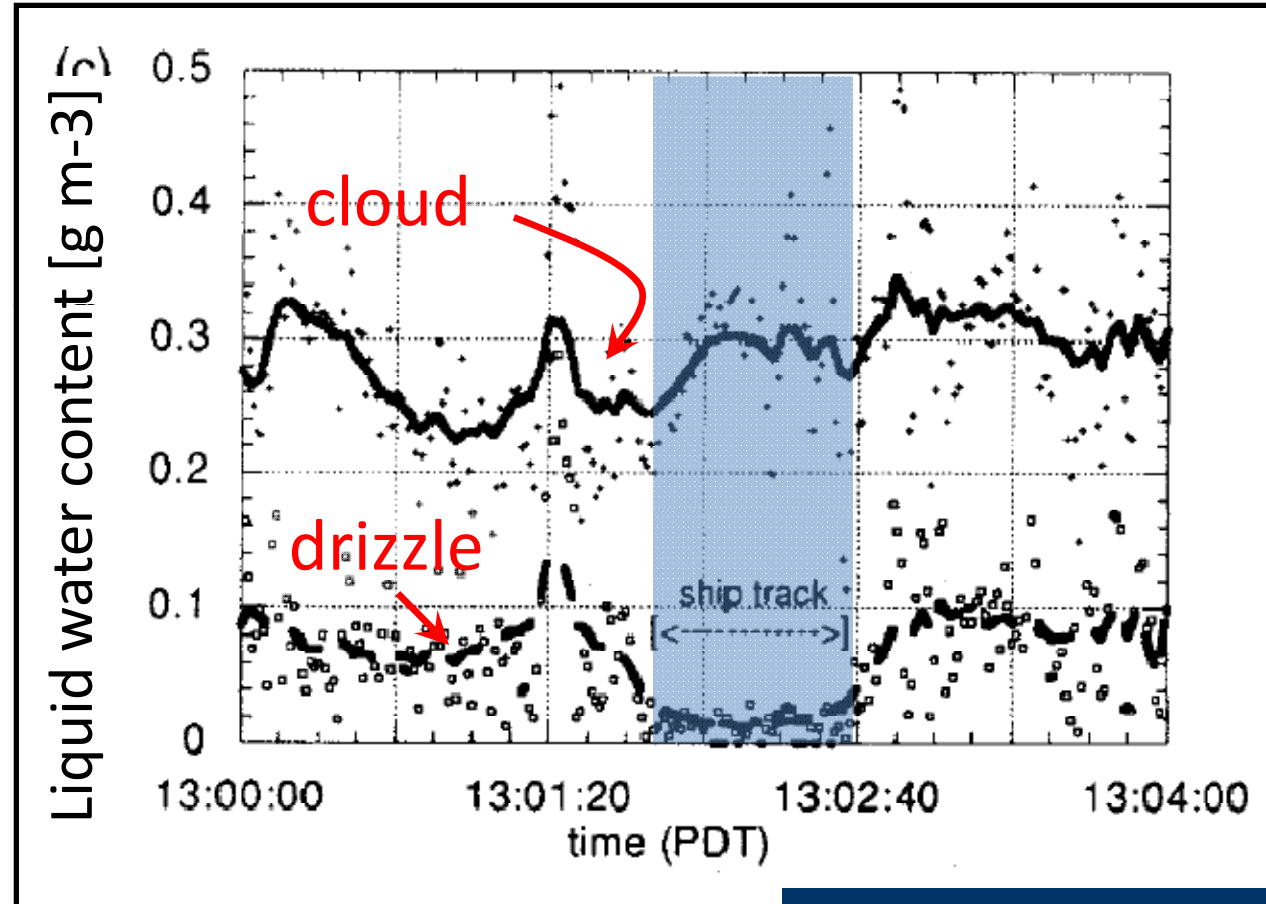
Cloud properties associated with different amounts of precipitation

Asian Coast



Drizzle suppression in shiptracks

- Drizzle is frequently found to be suppressed in shiptracks
- So what's wrong with Albrecht's hypothesis?



Ferek et al. 2000