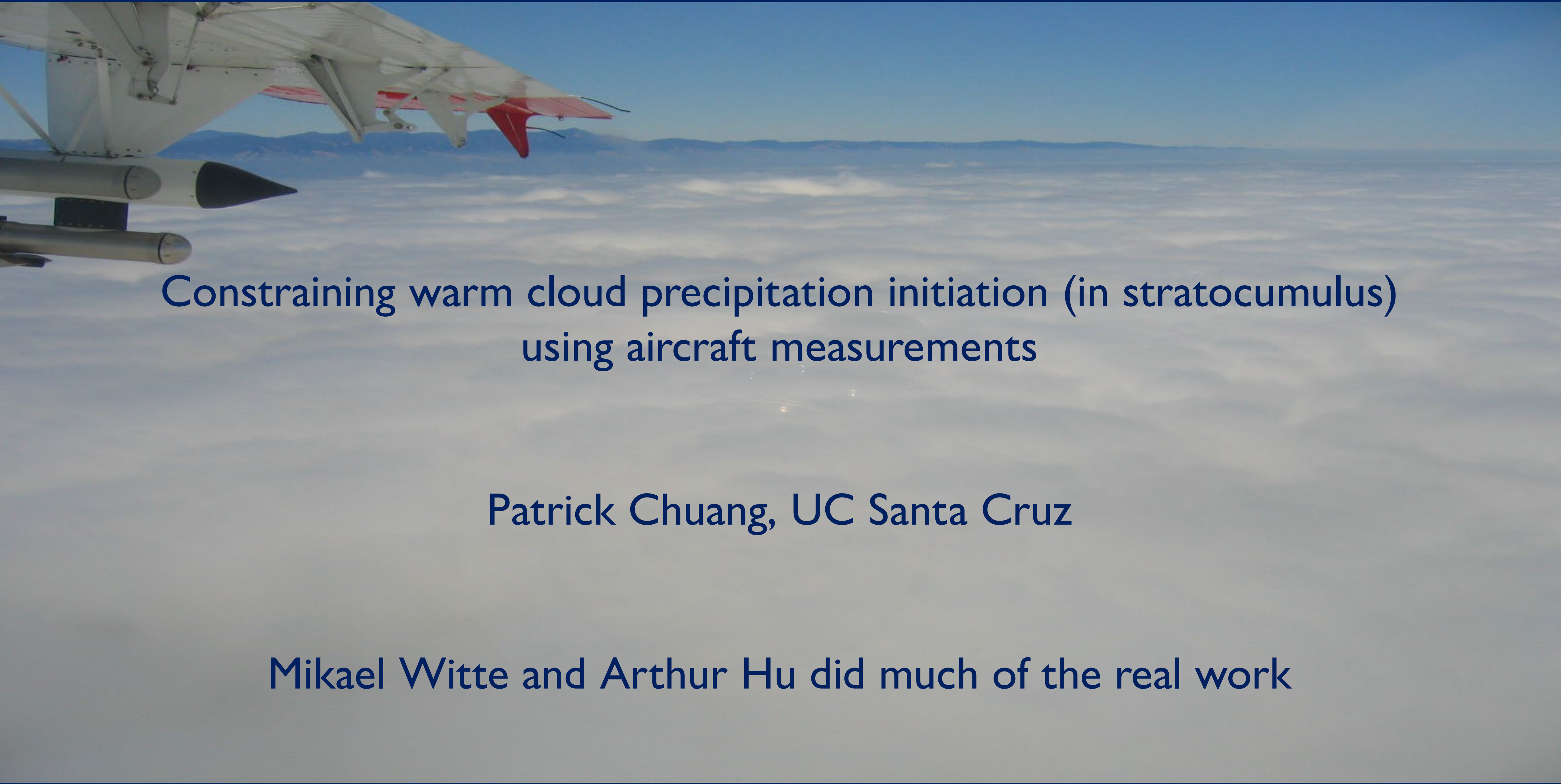

Constraining warm cloud precipitation initiation (in stratocumulus) using aircraft measurements

Patrick Chuang, UC Santa Cruz

Mikael Witte and Arthur Hu did much of the real work

Can we observe microphysics? How are observations being used to improve microphysics?

Can we directly measure process rates in real clouds from aircraft?

Probably not – requires observing the same system at two different times, with an intelligent choice of Δt.

However, we can quantitatively test representations of microphysical processes, which allows us to rule out those representations that are inconsistent with observations.

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RMetS
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Estimating collision–coalescence rates from *in situ* observations of marine stratocumulus

Mikael K. Witte,[a*] Orlando Ayala,[b] Lian-Ping Wang,[c] Andreas Bott[d] and Patrick Y. Chuang[a]

[a]*Earth and Planetary Sciences, University of California Santa Cruz, Santa Cruz, USA*
[b]*Engineering Technology Department, Old Dominion University, Norfolk, VA, USA*
[c]*Department of Mechanical Engineering, University of Delaware, Newark, USA*
[d]*Meteorological Institute, University of Bonn, Germany*

*Correspondence to: M. K. Witte, National Center for Atmospheric Research, Boulder, CO, USA. E-mail: mkwitte@ucar.edu

Questions

- How fast do collisions occur in real clouds (stratocumulus)?
- How well does theory explain these rates?
- Can turbulence bridge this gap?

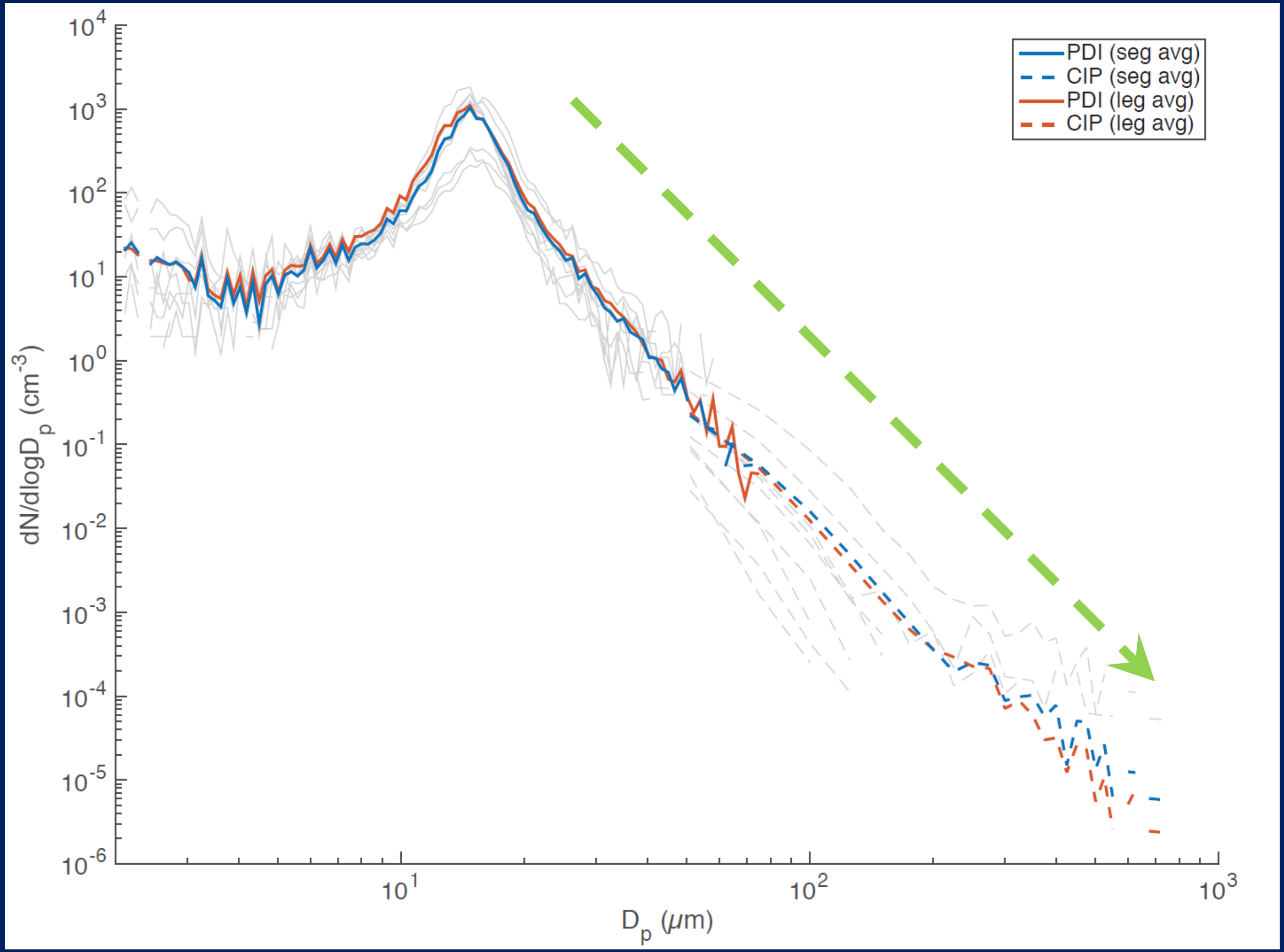
Overarching premise

Start with observed drop size distribution at cloud top (no more than 40 m from cloud top).

Assume that condensational growth produces drops of a limited size.

Drops larger than this size are assumed to be collisionally produced

Assume that collisional growth is at steady state.



Method

$$\frac{dn_j}{dt} = k_{j-1} n_0 n_{j-1} - k_j n_0 n_j$$

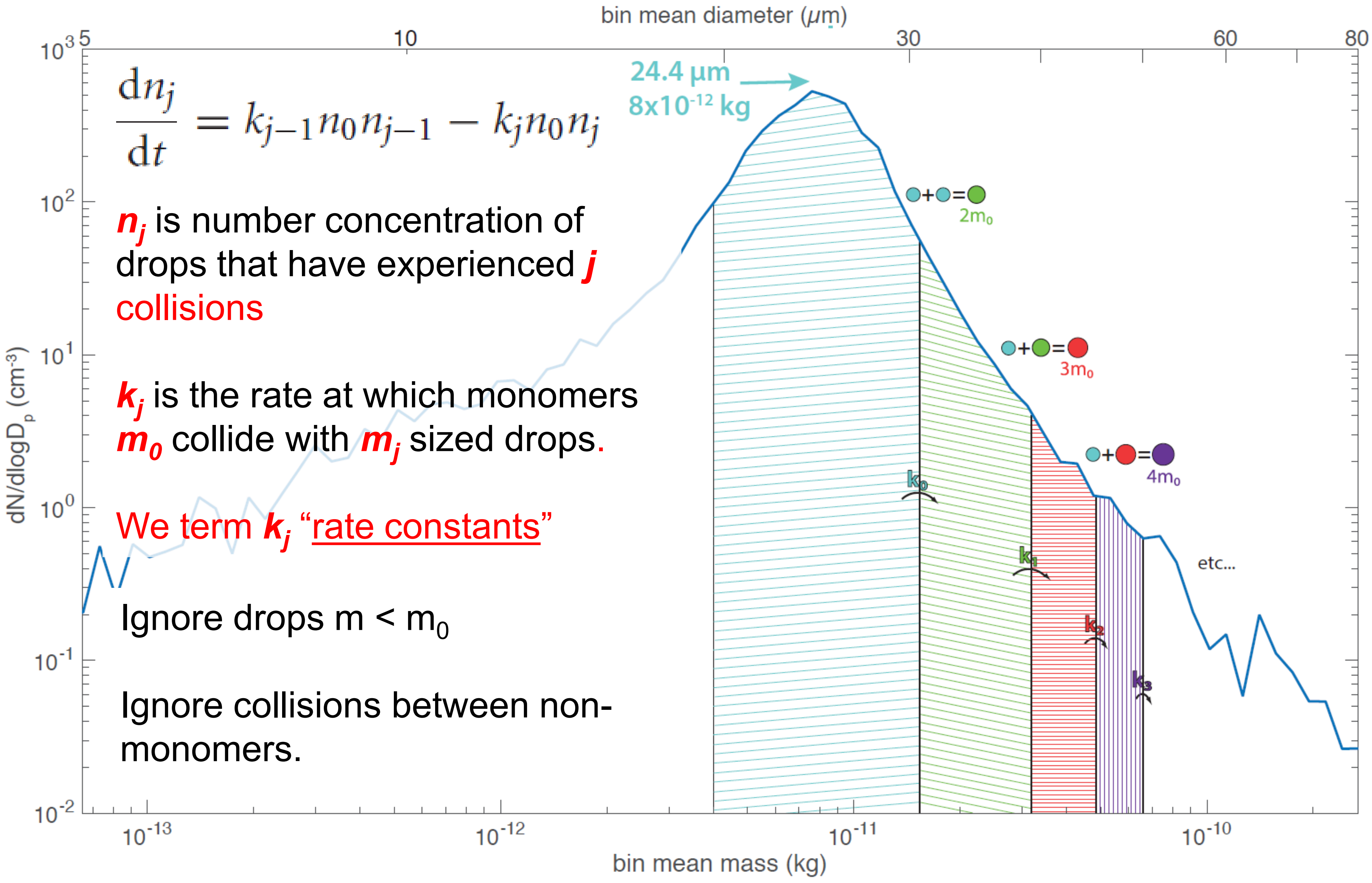
n_j is number concentration of drops that have experienced ***j*** collisions

k_j is the rate at which monomers ***m_0*** collide with ***m_j*** sized drops.

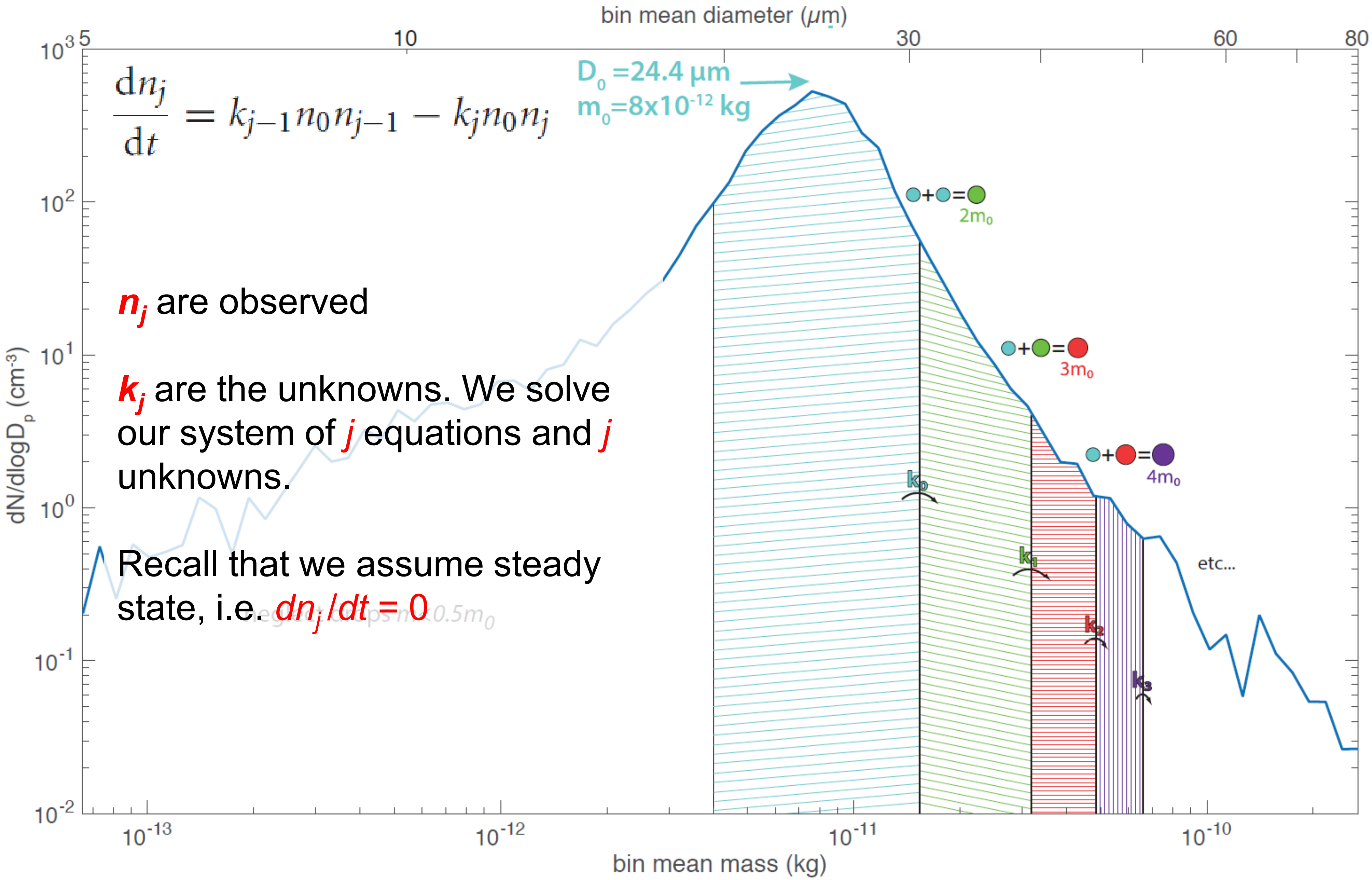
We term ***k_j*** "rate constants"

Ignore drops $m < m_0$

Ignore collisions between non-monomers.



Method



$$\frac{dn_j}{dt} = k_{j-1} n_0 n_{j-1} - k_j n_0 n_j$$

n_j are observed

k_j are the unknowns. We solve our system of j equations and j unknowns.

Recall that we assume steady state, i.e. $dn_j/dt = 0$

Is the steady state assumption valid?

Is the assumption of monomer-only collisions valid?

Why do we use the terminology “rate constants”?

Is the steady state assumption valid?

Is the assumption of monomer-only collisions valid?

Why do we use the terminology “rate constants”?

It must be true that some of our cases are not at steady state.

In some cases, the number of larger drops is decreasing with time, so the rates inferred here are overestimates.

But in other cases, the number of larger drops is increasing with time, so the rates inferred here are underestimates.

Thus, steady state is reasonable in the mean – but for any individual case, yields uncertainty.

Is the steady state assumption valid?

Is the assumption of monomer-only collisions valid?

Why do we use the terminology “rate constants”?

Good to within 30%, which is small relative to discrepancies from “theory” that we find in this study (see paper for more details).

Is the steady state assumption valid?

Is the assumption of monomer-only collisions valid?

Why do we use the terminology "rate constants"?

We often refer to "kernels" for discussing collision-coalescence rates.

However, "kernels" apply at a local scale (~ at a length scale where the drops have a reasonable probability of colliding with each other).

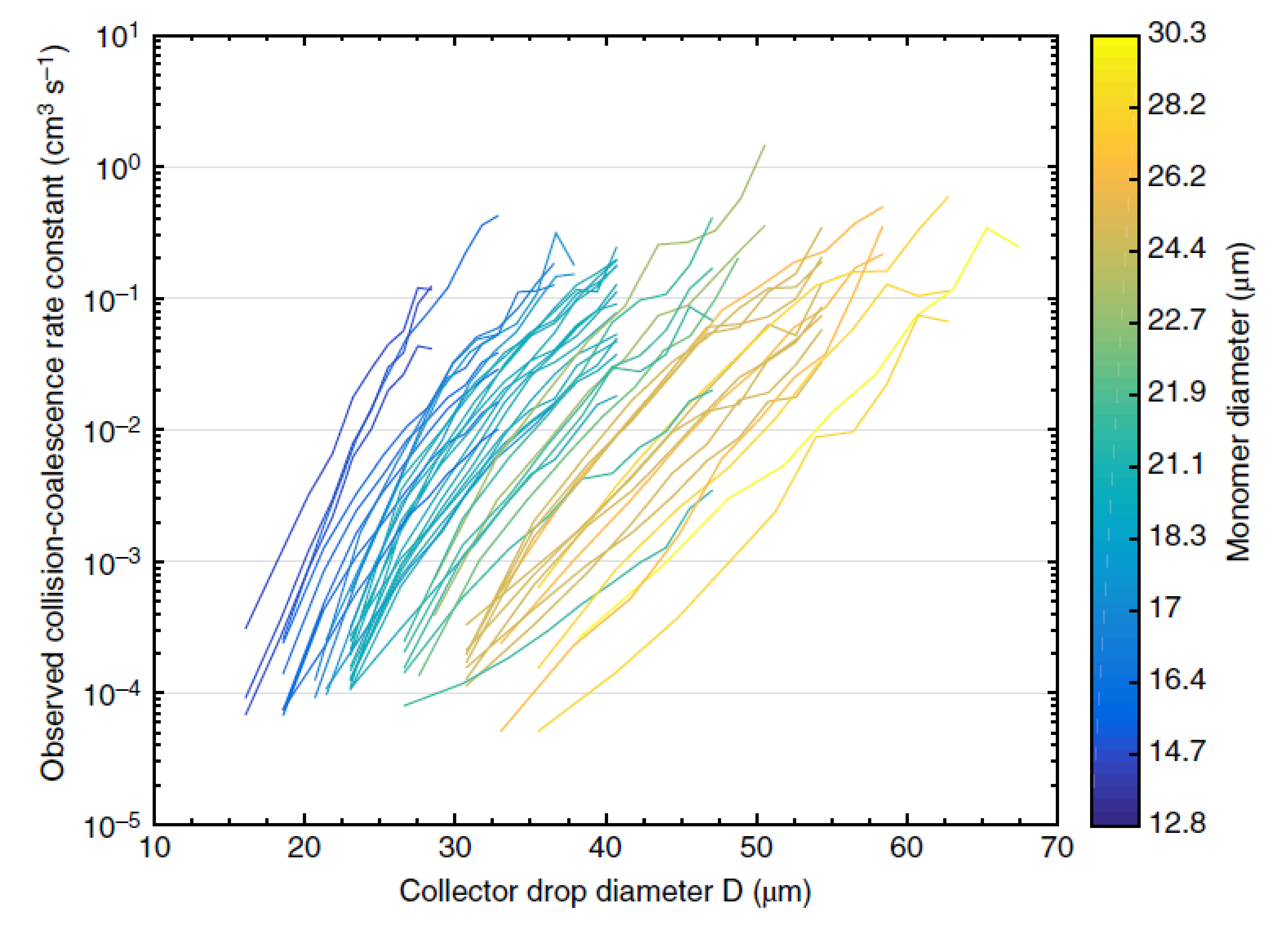
Here, we are using drop size distributions averaged over kms to 10s of km. Drops separated by these distances are very unlikely to meet.

Therefore, we adopt "rate constant" terminology (motivated by chemical reactions).

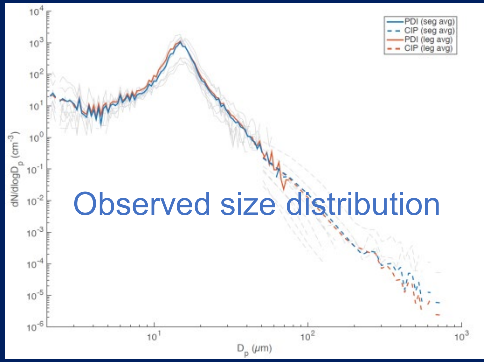
Results: rate constants

Rate constants increase as the collector drop size increases (as expected).

Rate constants also increase as the monomer diameter increases (also expected).



Method to compare with Hall kernel



1D stochastic collection box model w/ Hall kernel (Bott, 2000).

[For consistency: modify box model so only monomer collisions can occur.]

Output:
Rate constants $\boldsymbol{k_j}$ from the model assuming a well-mixed box.

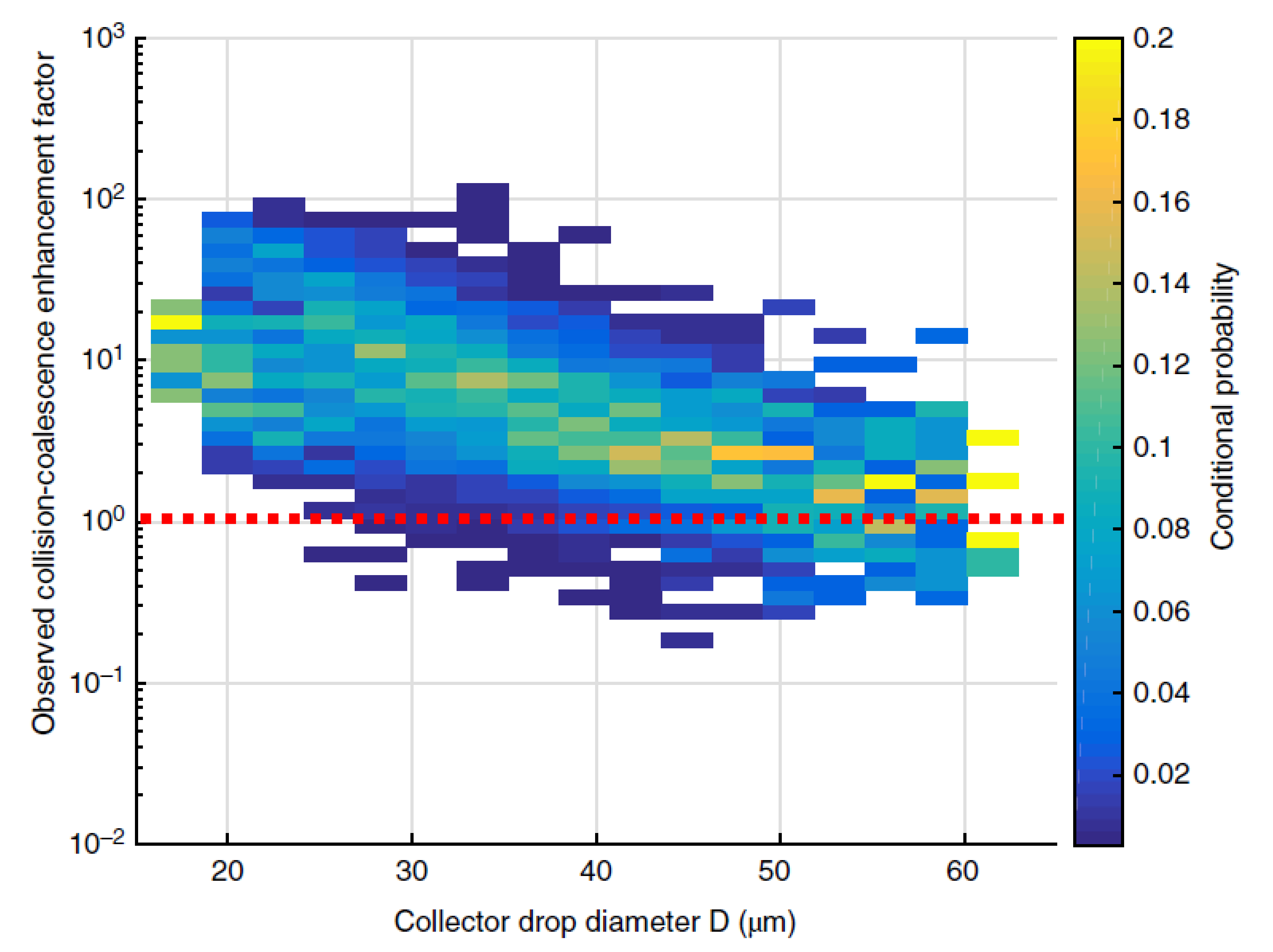
Results: Rate constants / Hall kernel (1.5 km averaged size distributions)

Rate constants > Hall kernel

Discrepancy is up to a factor of 30.

Discrepancy is larger for smaller collector drops (20 to 40 um)

Using a turbulent kernel with ε = 300 cm^2/s^3 reduces the discrepancy by a factor of ~2.



The physical explanation for this gap remains unclear.

- Averaging of small-scale inhomogeneity?
- Other growth processes (radiative cooling, stochastic condensation…)?
- Something else?

Implication for models?

We still have more work to do before we can confidently parameterize growth for precipitation initiation (collisional and otherwise).

Part 2: Learning about how large drops form by studying their environment

Work mostly done by Zhuoqun (Arthur) Hu (now at Columbia Univ.)

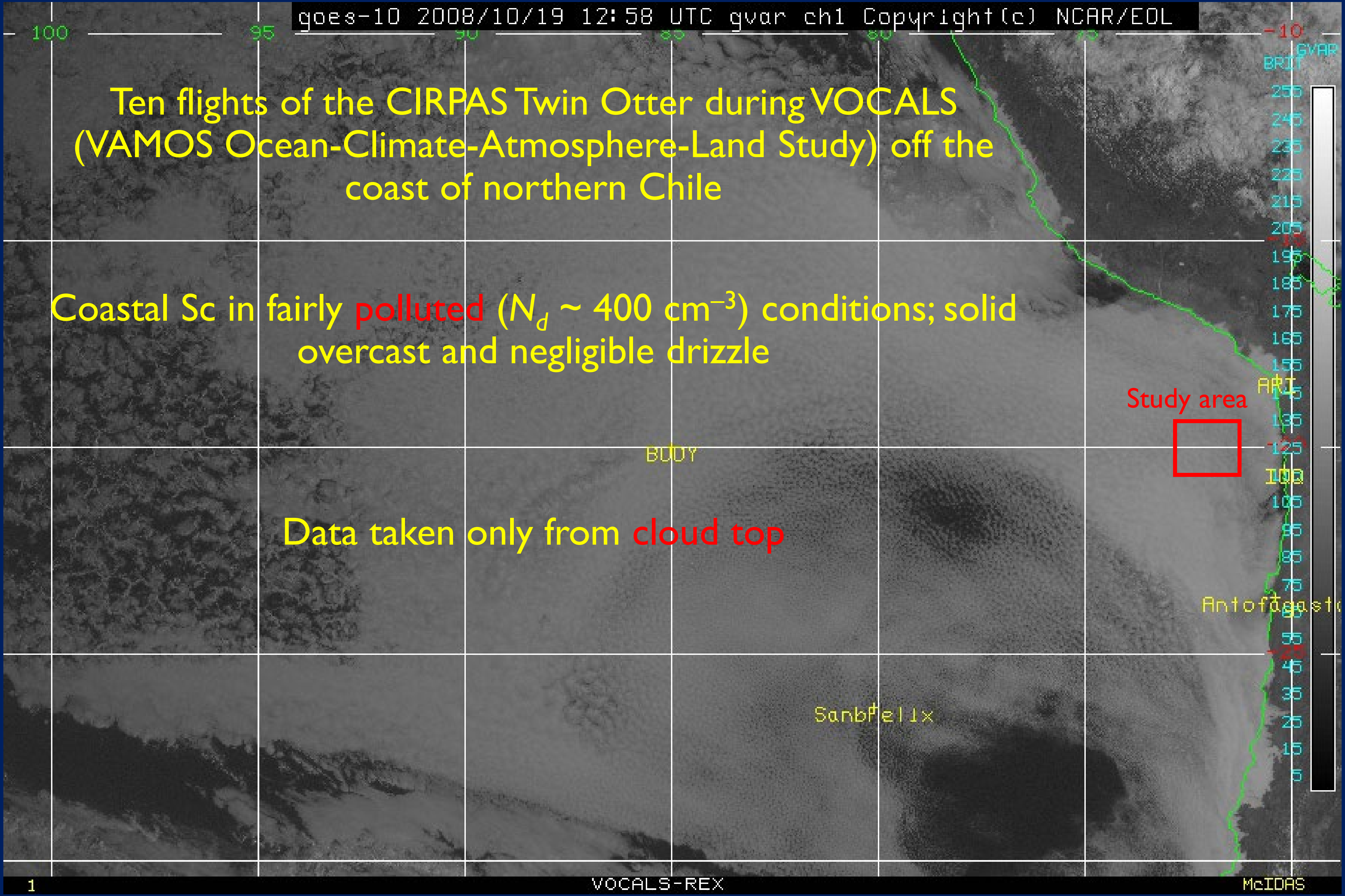
How does the environment surrounding large drops differ from typical drops?

What does this tell us about the processes that control cloud-top droplet growth?

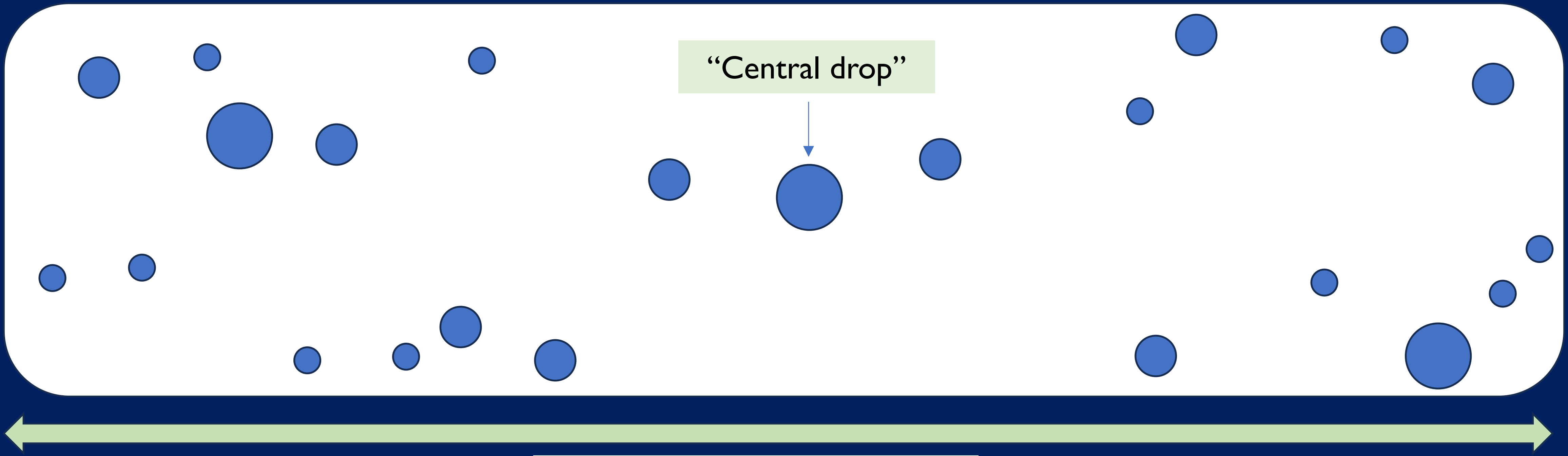
Ten flights of the CIRPAS Twin Otter during VOCALS (VAMOS Ocean-Climate-Atmosphere-Land Study) off the coast of northern Chile

Coastal Sc in fairly polluted (N_d ~ 400 cm^{-3}) conditions; solid overcast and negligible drizzle

Data taken only from cloud top



Defining the environment around each drop ("central drop")



Window for this central drop
(length 1.4 m to 55 m)

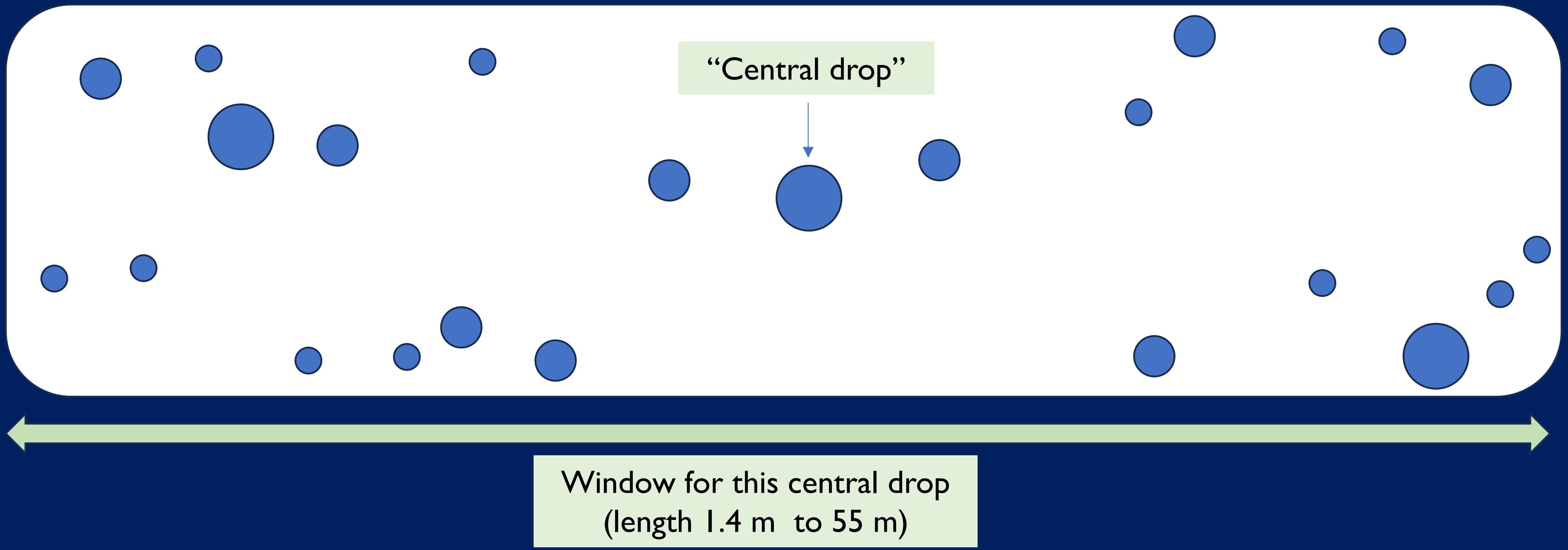
Characterizing the environment around each drop ("central drop")

Thermodynamics: Potential temperature q

Dynamics: vertical velocity w; vertical TKE $(w')^2$

Cloud: Liquid water content LWC; Drop concentration N_d

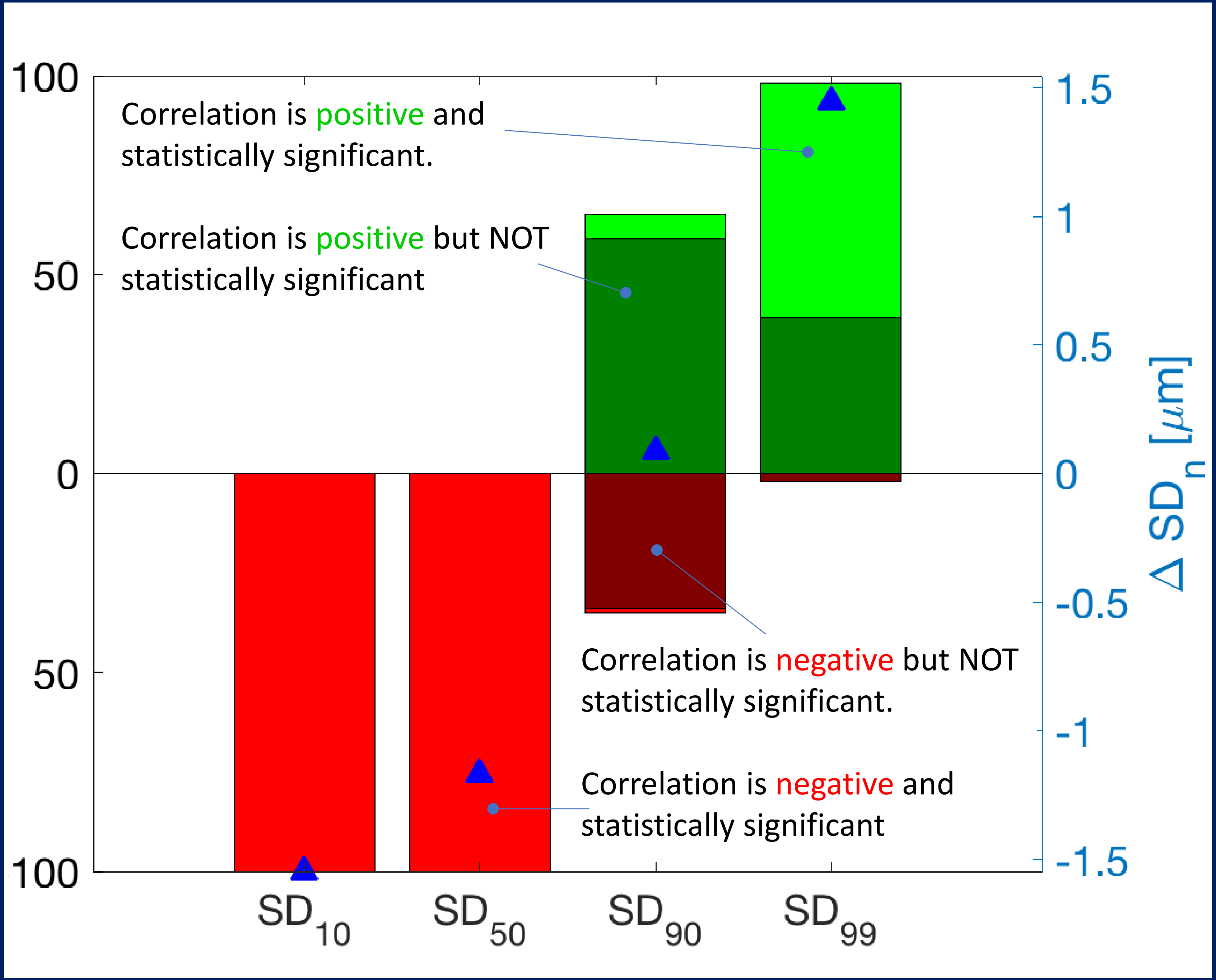
Size distribution: 10th, 50th, 90th, and 99th percentile diameters: SD_{10}, SD_{50}, SD_{90}, SD_{99}



Example result

100 trials for statistics

Compute correlation between large central drops and the environment (relative to small central drops).



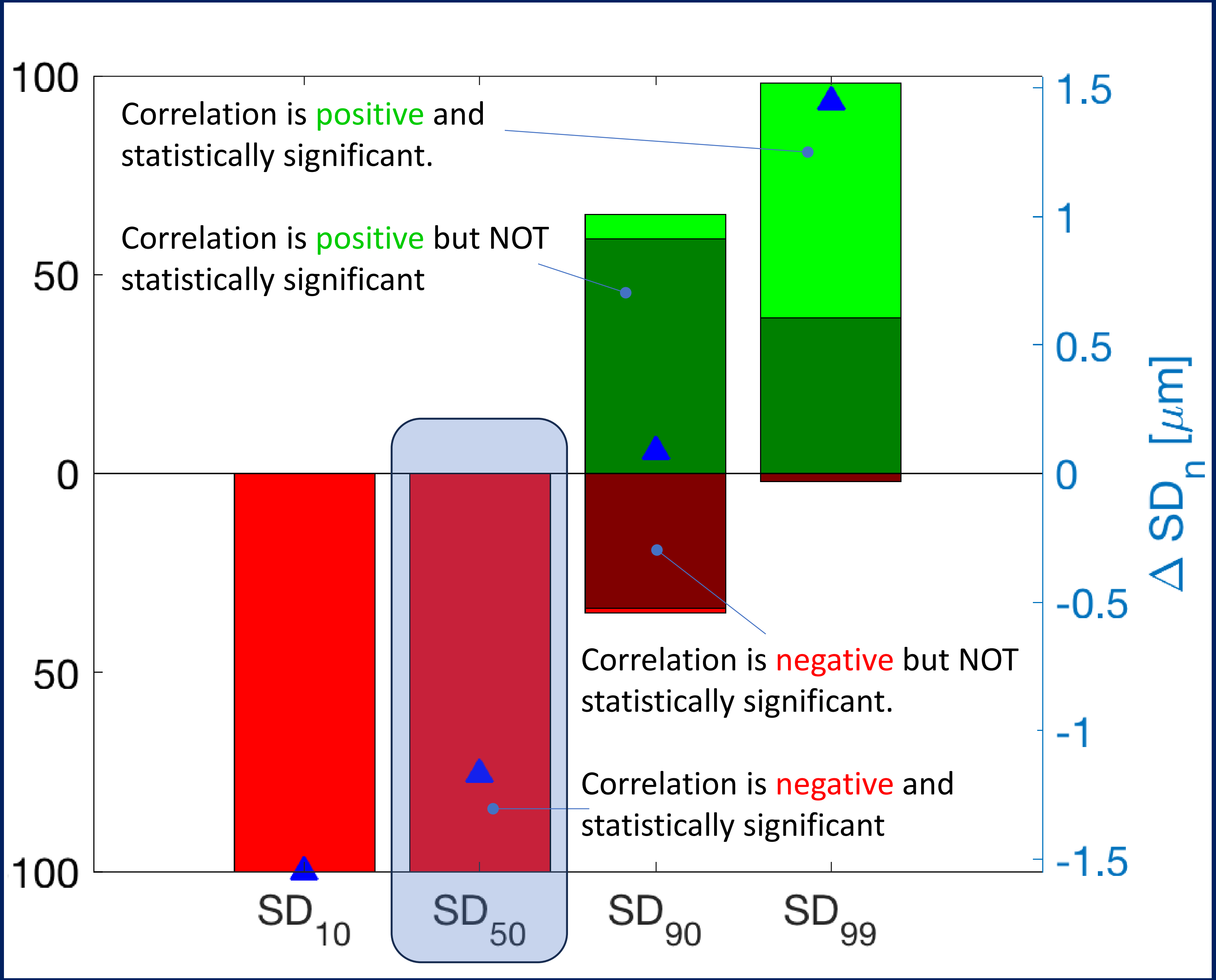
Example result

100 trials for statistics

Compute correlation between large central drops and the environment (relative to small central drops).

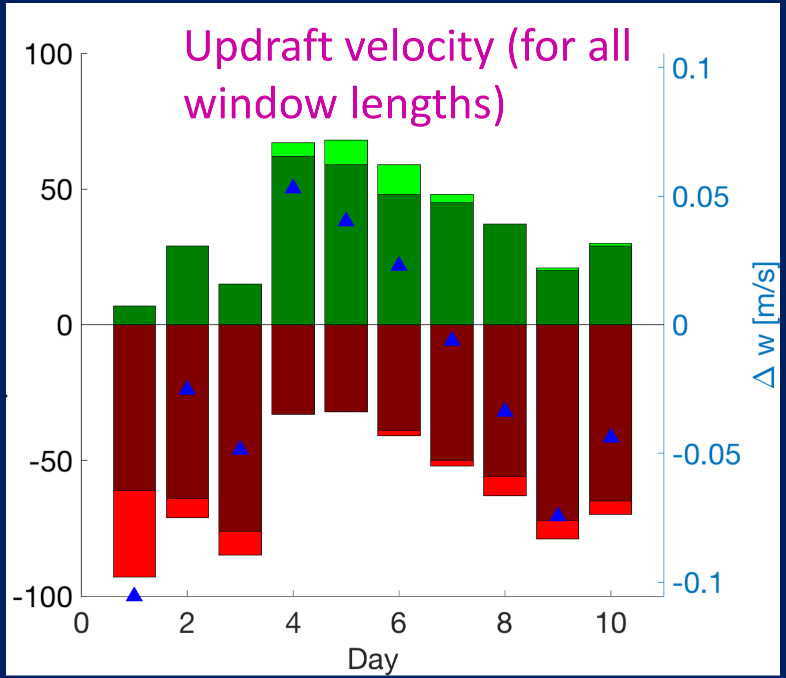
e.g. SD50: The median drop size in the window is negatively correlated with large central drops…

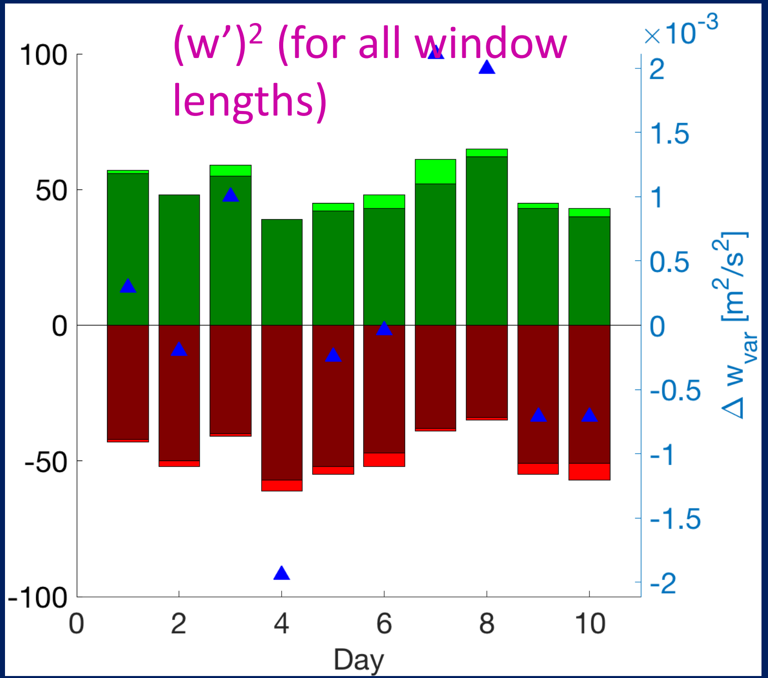
i.e. larger drops are found in environments with smaller median drop diameter.

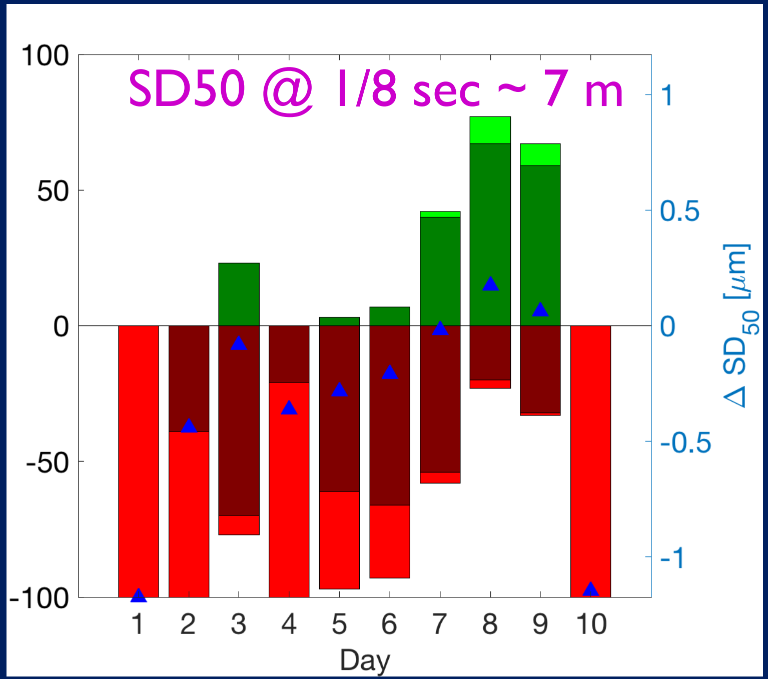


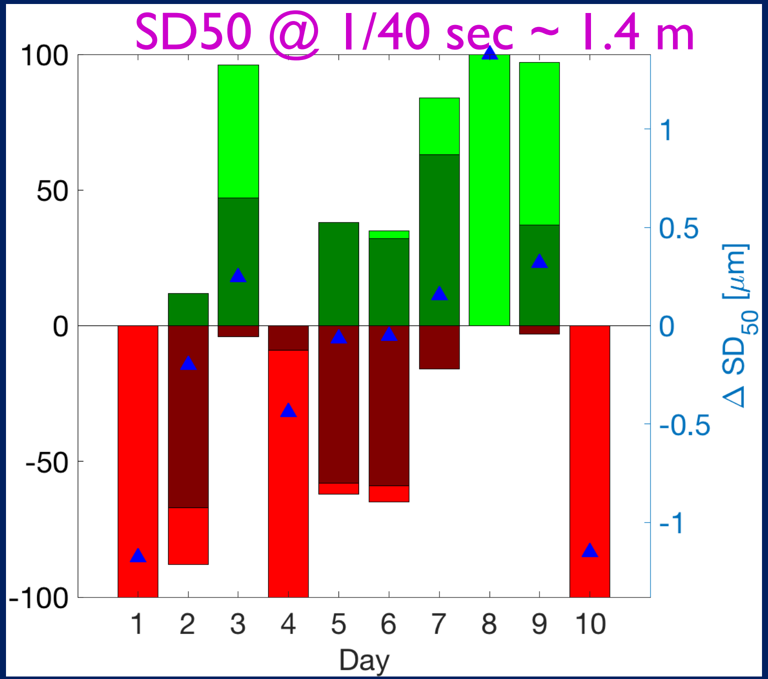
Examples of null results

No consistent, statistically significant correlations for all 10 flights





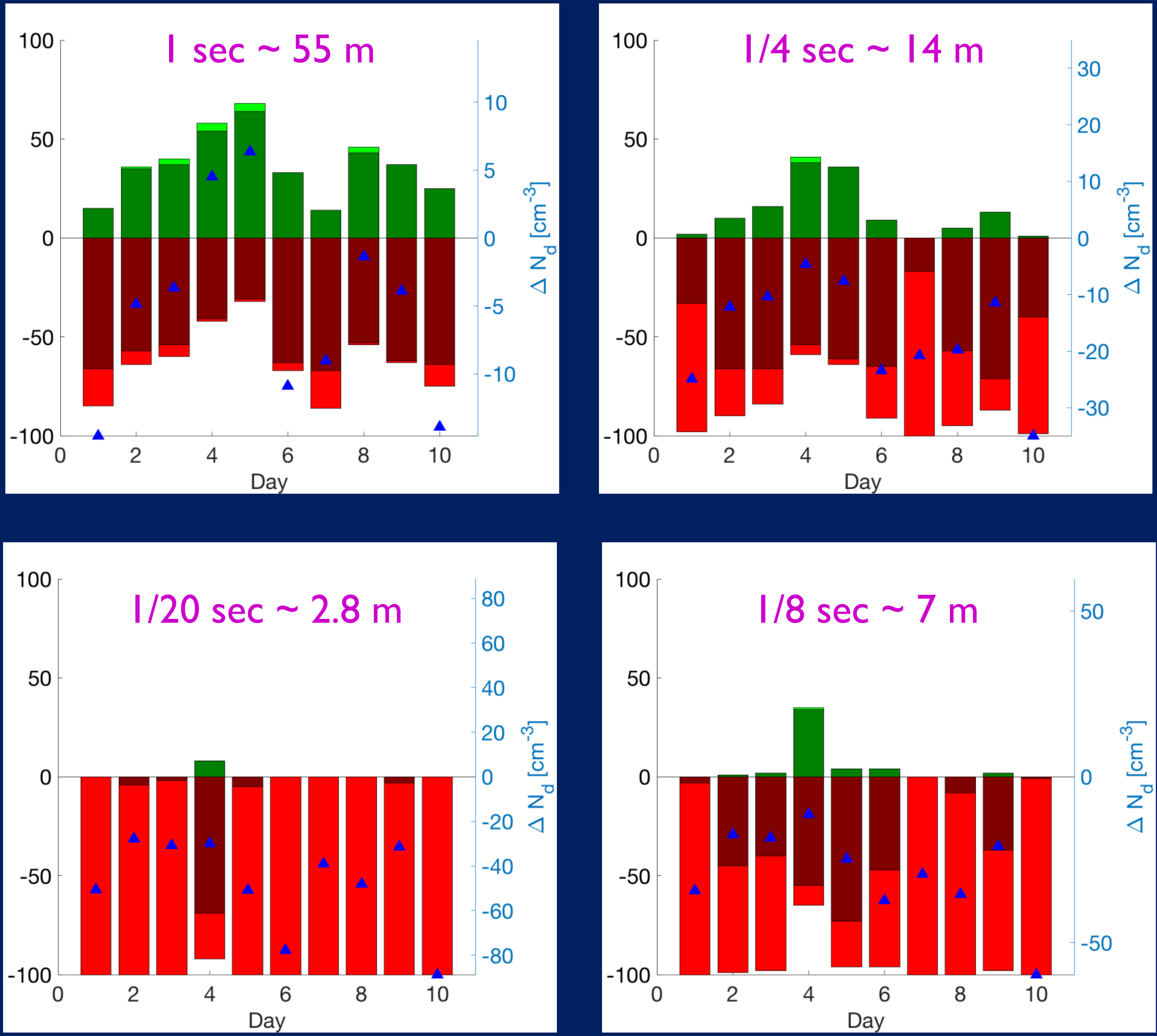




One variable (N_d) across 10 flight days for 4 different window lengths

Large windows: no statistically consistent correlations

1/20 sec window: Large drops are correlated with environments with lower N_d

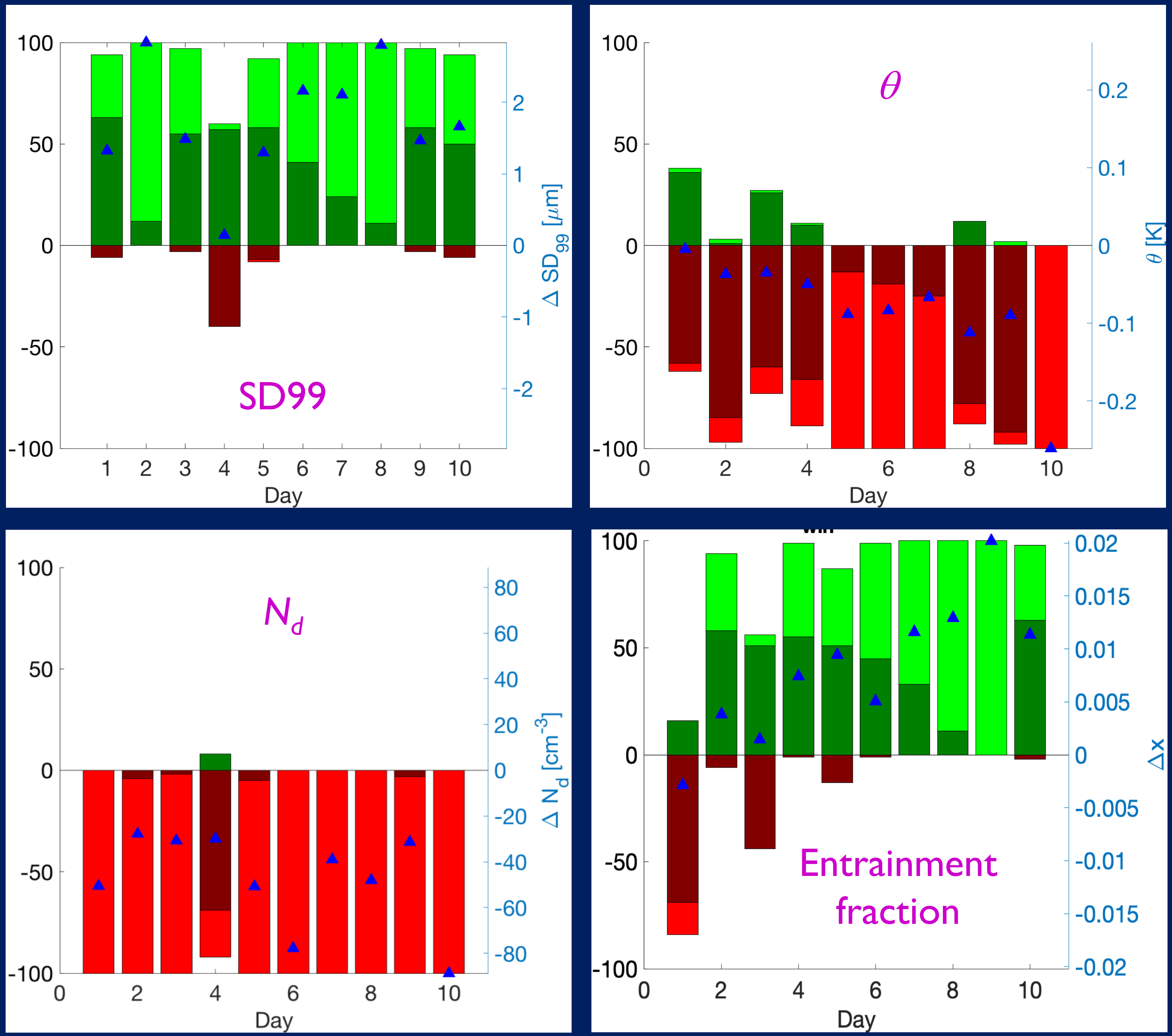


Statistically significant trends

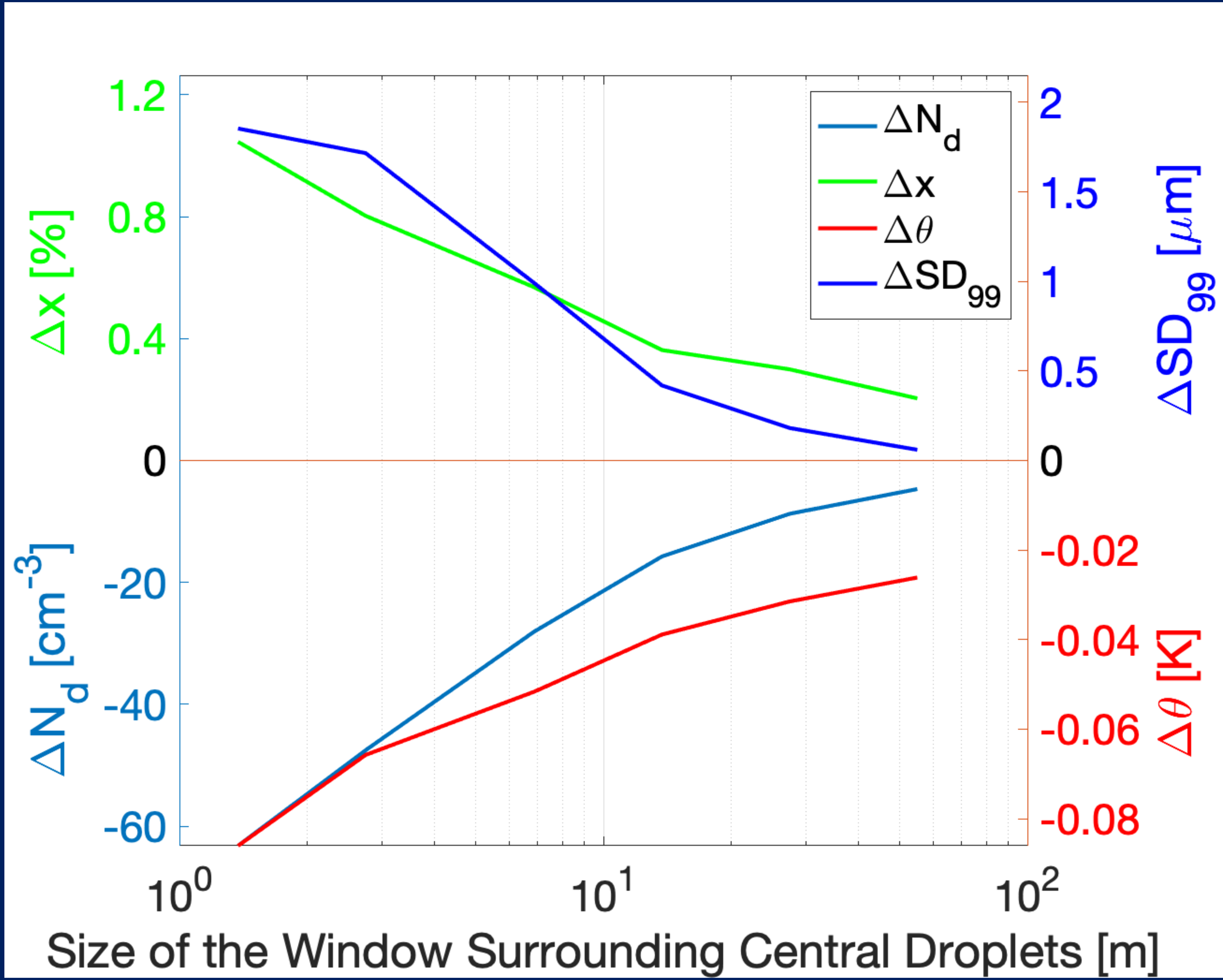
(all at 1/20 sec ~ 2.8 m)

Large drops are associated with:

- Other large drops (SD99)
- Cooler air (θ)
- Lower N_d (by 30 to 60 cm^{-3})
- More entrained air
- No change in LWC (not shown)



Environmental anomalies are larger as window size get smaller!



Synthesis and interpretation

Large drops are correlated with…

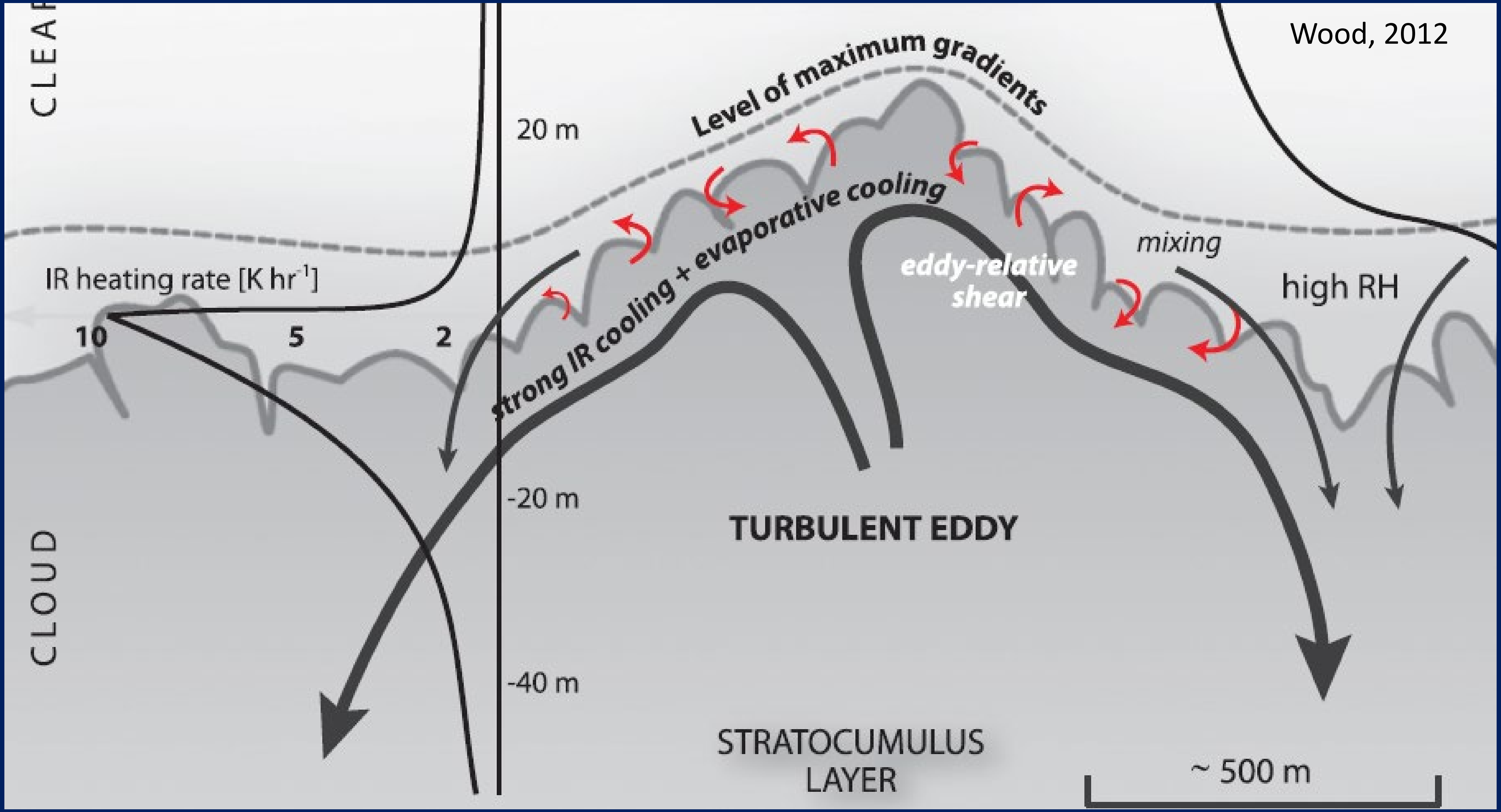
- Other large drops, smaller Nd & no change in LWC → collisional growth occurs in coherent volumes of air (with length scale < 1 m??)
- Implies that there are volumes of air or "lucky environments" where collisional growth is more probable → collisional growth is not purely stochastic

Synthesis and interpretation

Large drops are correlated with…

- Other large drops, smaller Nd & no change in LWC → collisional growth occurs in coherent volumes of air (with length scale < 1 m??)
- Implies that there are volumes of air or "lucky environments" where collisional growth is more probable → collisional growth is not purely stochastic
- Cooler air & more entrained air → air parcel residing for more time near cloud top (radiative cooling + entrainment)
- Signatures do not appear to be fully compatible with other mechanisms, e.g. stochastic condensation; condensation induced by radiative cooling; turbulence-enhanced collisions… but does not rule these out as parallel mechanisms

These are all proxies for time at cloud top



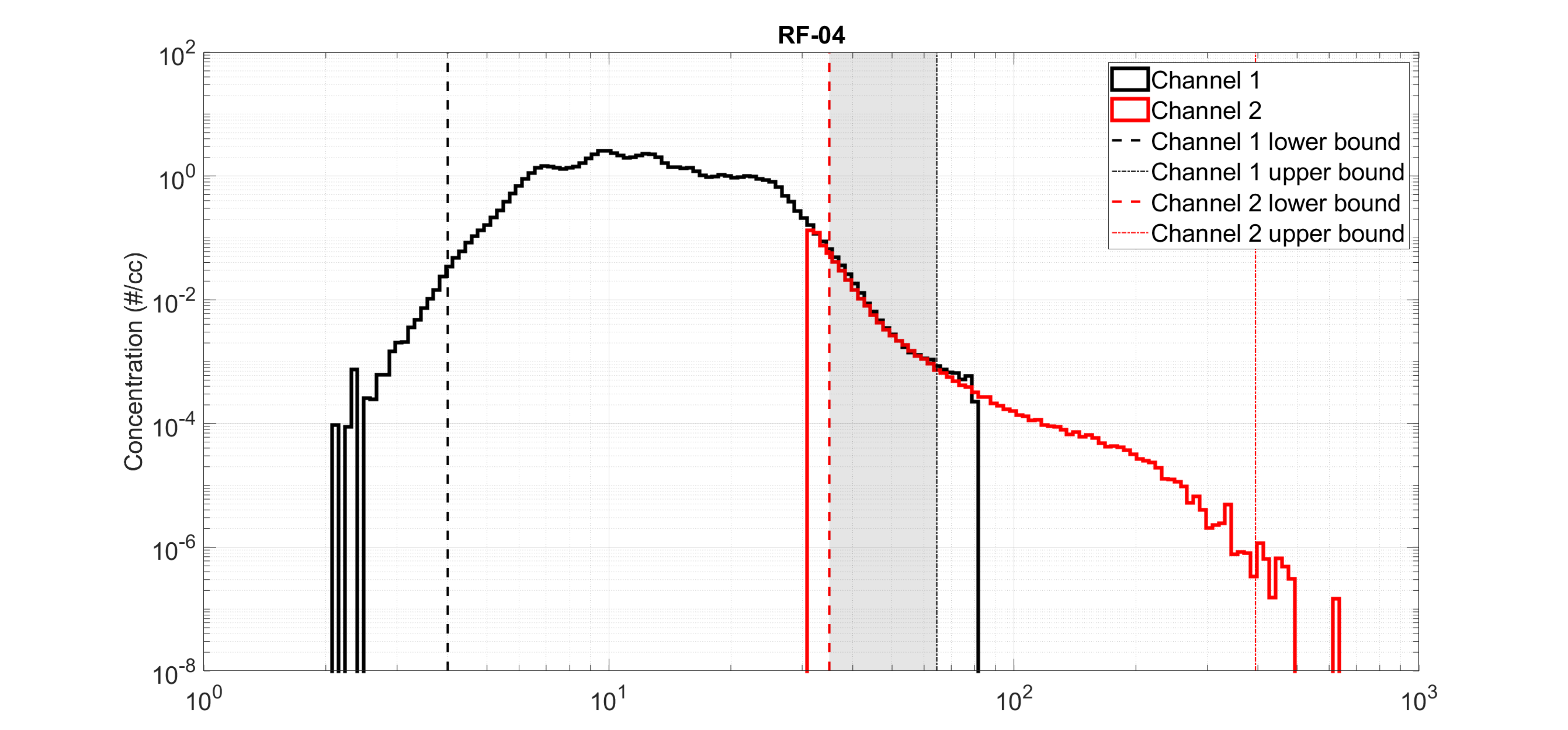
Implications for models

Good news: collision-coalescence in Sc is not random. We suspect time is the most important ingredient.

Bad news: the length scale (<1 m!?) associated with the longest times is too small to be directly represented in (most) models → How to parameterize?

Can we observe microphysics?

Requires good observations! Latest 2-channel Phase Doppler Interferometer (Artium Technologies) can measure drops from ~3 um to ~800 um in a single package.

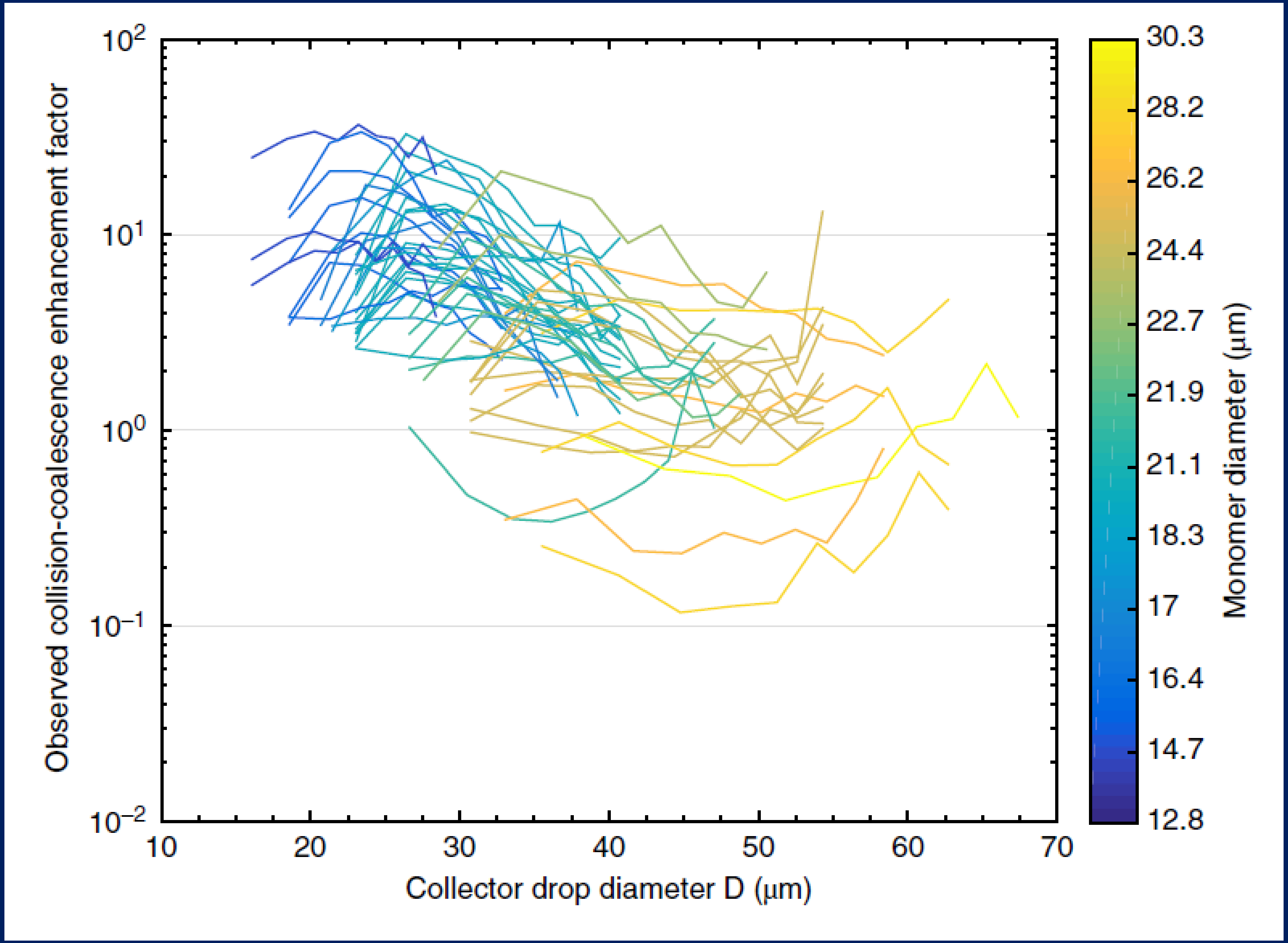


Thank you!

Anyone interested in collaborating on aircraft cloud microphysical data, please feel free to reach out!

pchuang@ucsc.edu

Extra slides – rate constant / Hall kernel (30 km average)



Extra slides – with turbulence 300 cm2/s3