UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Cloud Microphysics Analysis From RACORO: How Indirect Effects and Mixing Mechanisms Impact Cloud Properties

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CAPI Breakout, 7 November 2013

Routine AAF Clouds with Low Optical Water Depths (CLOWD) Optical Radiative Observations (RACORO)

Vogelmann et al. (2012)

Where : in the vicinity of the ACRF SGP site, OK

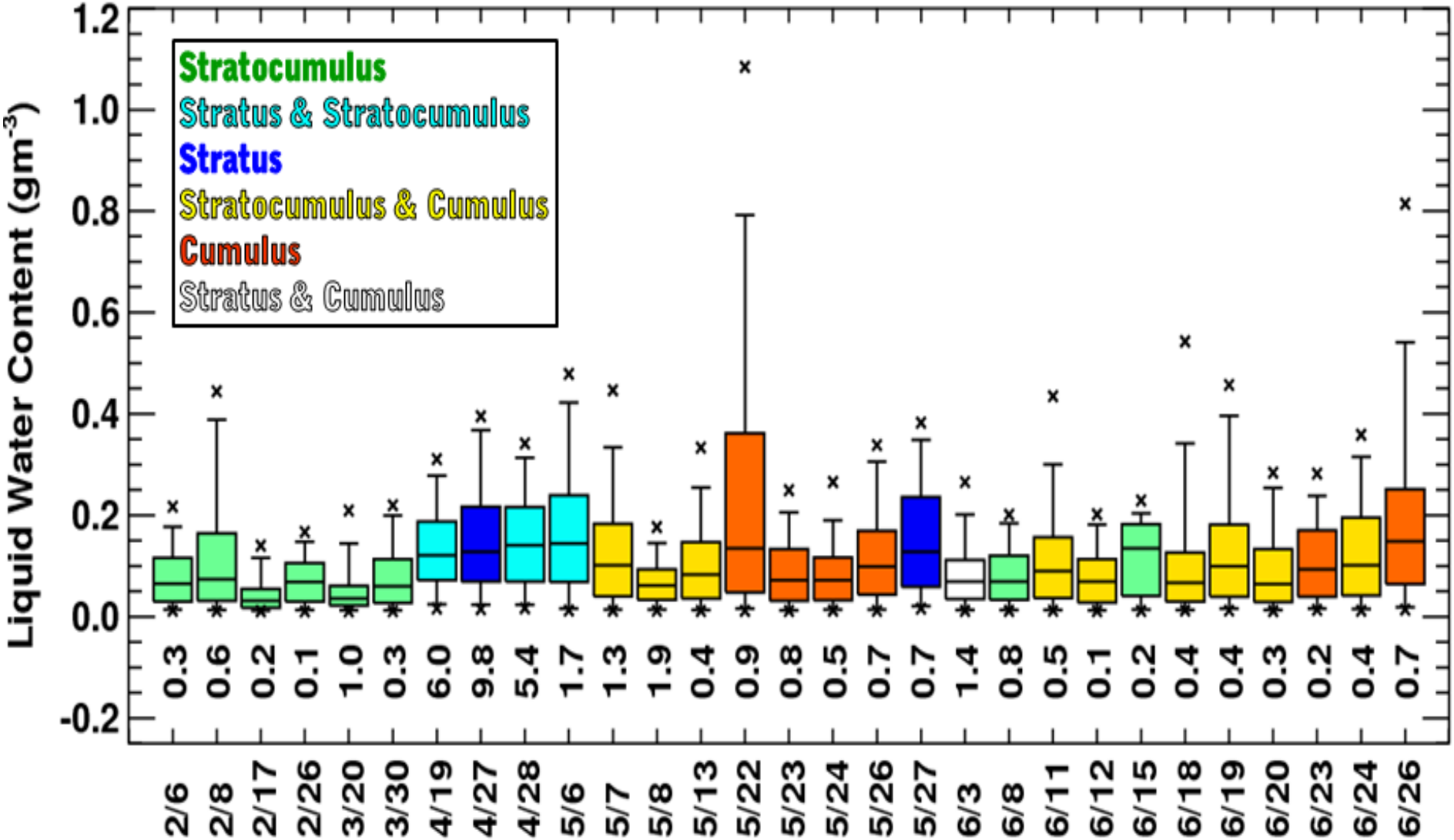
When : from January to June 2009

What : Routine measurements of aerosol, cloud , and radiative properties

Data : 260 hours flight time
=> 85 hours of shallow cumuli conditions
=> > 2,337 **cumuli sampled**

RACORO: 6 MONTHS FIELD CAMPAIGN !!!

Vogelmann et al., 2012, BAMS



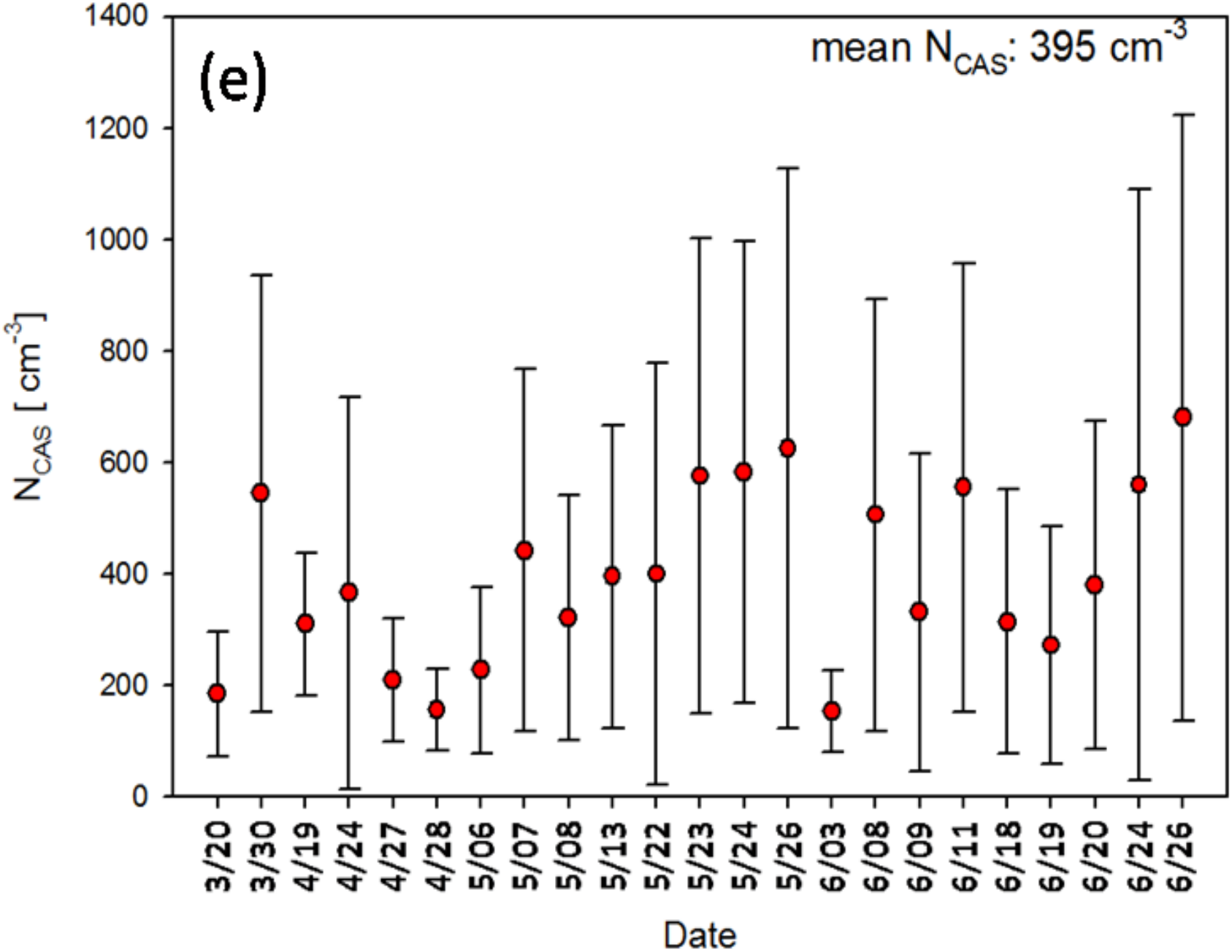

(e)
mean N_{CAS}: 395 cm^{-3}
N_{CAS} [cm^{-3}]
1400
1200
1000
800
600
400
200
0
3/20
3/30
4/19
4/24
4/27
4/28
5/06
5/07
5/08
5/13
5/22
5/23
5/24
5/26
6/03
6/08
6/09
6/11
6/18
6/19
6/20
6/24
6/26
Date

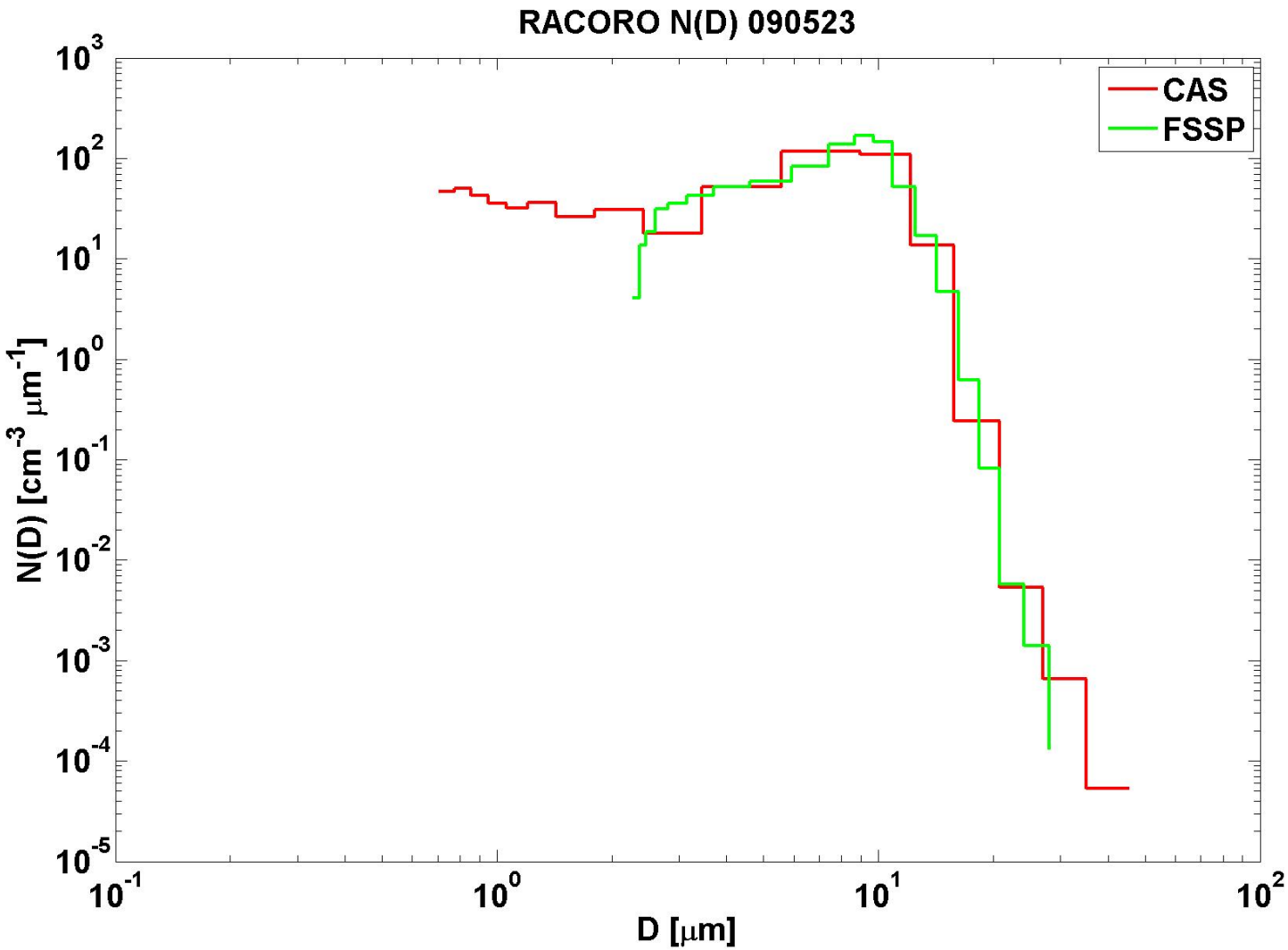
Table 2. RACORO multidisciplinary payload. Instrumentation listing is grouped by category given on the left. Radiometer viewing direction is indicated by ↑ (upward looking) and ↓ (downward looking). The last column indicates whether the measurement is relatively slow (S) or fast (F; usually 1 Hz or better). Brackets indicate paired measurements, where the faster measurements may help interpret the slower-response measurements (see text). For the dual-column CCN spectrometer (S/F), one column was fixed at 0.2% supersaturation (SS) and sampled at 1 Hz while the second column scanned through a range of SSs (0.2%, 0.28%, 0.4%, 0.57%, and 0.8%) in about 25 min.

	Measurement	Instrument	Speed
Cloud microphysics	LWC	Particle Volume Monitor-100A (Gerber Probe)	F
		Science Engineering Associates, Inc. (SEA) LWC probe (WCM-2000, LWC only)	F
	Drop size distribution	Forward Scattering Spectrometer Probe-100 (FSSP)	F
		Cloud and Aerosol Spectrometer (CAS)	F
		1D Cloud Imaging Probe (CIP)	F
		2D CIP	F
		2D Stereo Probe (2D-S)	F
	Cloud extinction	Cloud Integrating Nephelometer (CIN)	F
Radiation	Broadband irradiances	↑↓ shortwave Kipp & Zonen (a modified CM22)	S
		↑ Sunshine Pyranometer (SPN1)	F
		↑↓ longwave Kipp & Zonen (a modified CG4)	S
	Spectral radiances	↑↓ Infrared Thermometer (IRT)	F
		↑ or ↓ HydroRad-3 hyperspectral radiometer	F
	Spectral irradiances	↑↓ Multifilter Radiometer (MFR)	F
		↑↓ HydroRad-3 hyperspectral radiometer	F
Aerosol	CCN	Dual-column CCN spectrometer	S/F
	Size distribution	Differential Mobility Analyzer (DMA)	S
		Two condensation nuclei particle counters (CPCs)	F
		Ultrafine CPC (UFCPC)	F
		Passive Cavity Aerosol Spectrometer Probe (PCASP)	F
Atmospheric state	Temperature	Rosemount (primary) and Vaisala (backup)	F
	Water vapor	Two chilled-mirror hygrometers (EdgeTech, CR2)	S
		Diode Laser Hygrometer (DLH)	F
	Horizontal winds and updraft velocity	Determined from multiple aircraft sensors	F
	Conditions	Handheld photos	S
		DAQ flight images/video	F

- **Cloud droplet size distribution**

CAS (Cloud Aerosol Spectrometer)

FSSP (Forward Scattering Spectrometer Probe)

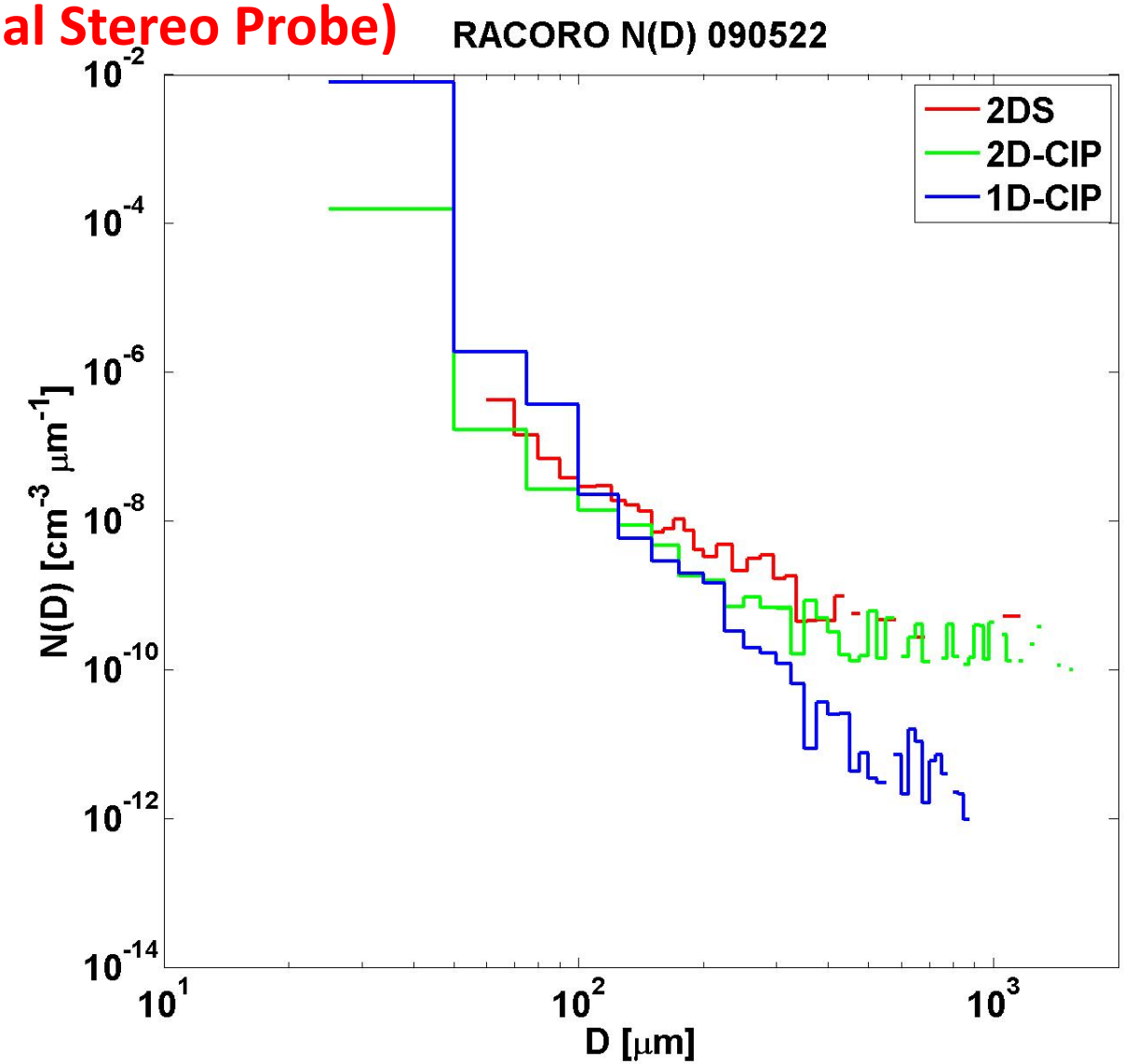


- **Cloud droplet size distribution**

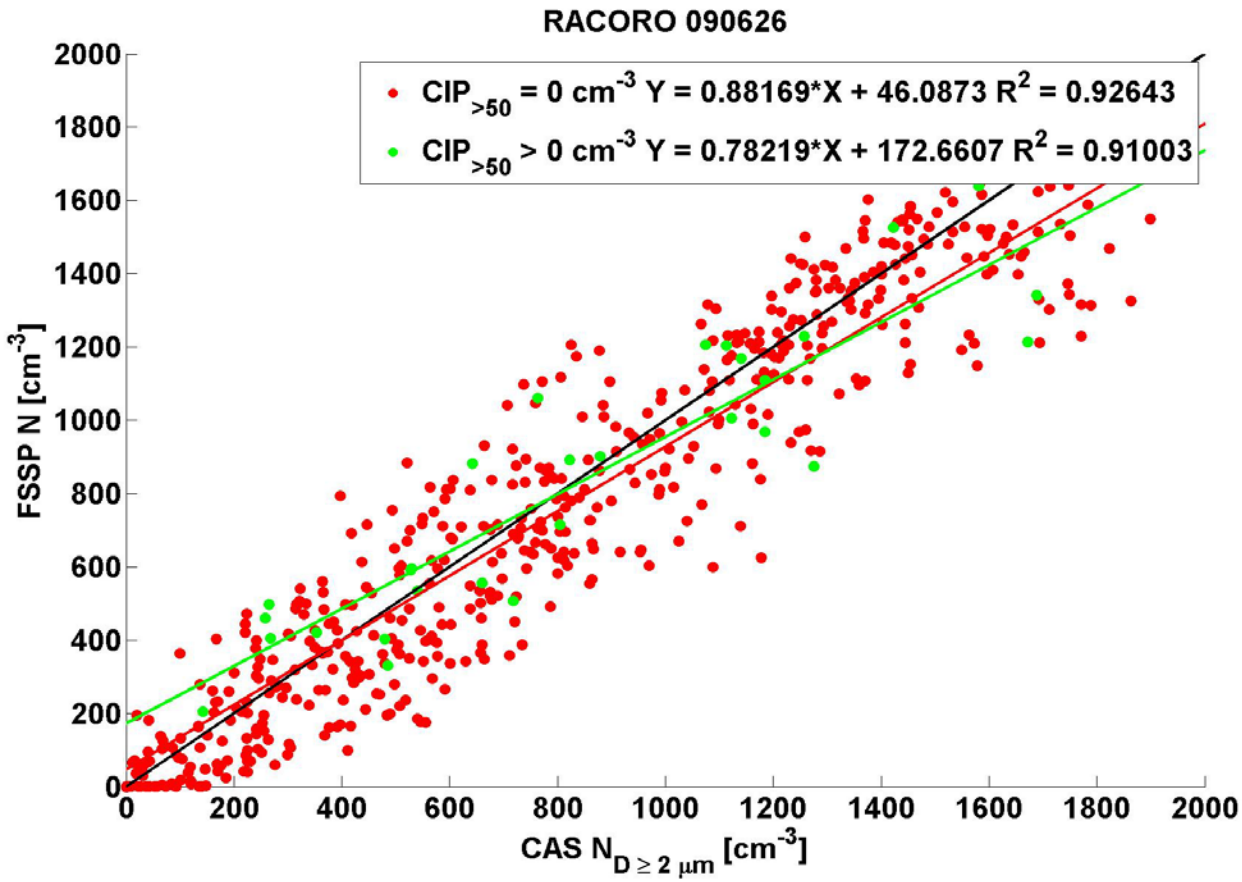
1DC (One Dimensional Cloud Probe)

2DC (Two Dimensional Cloud Probe)

2DS (Two Dimensional Stereo Probe)

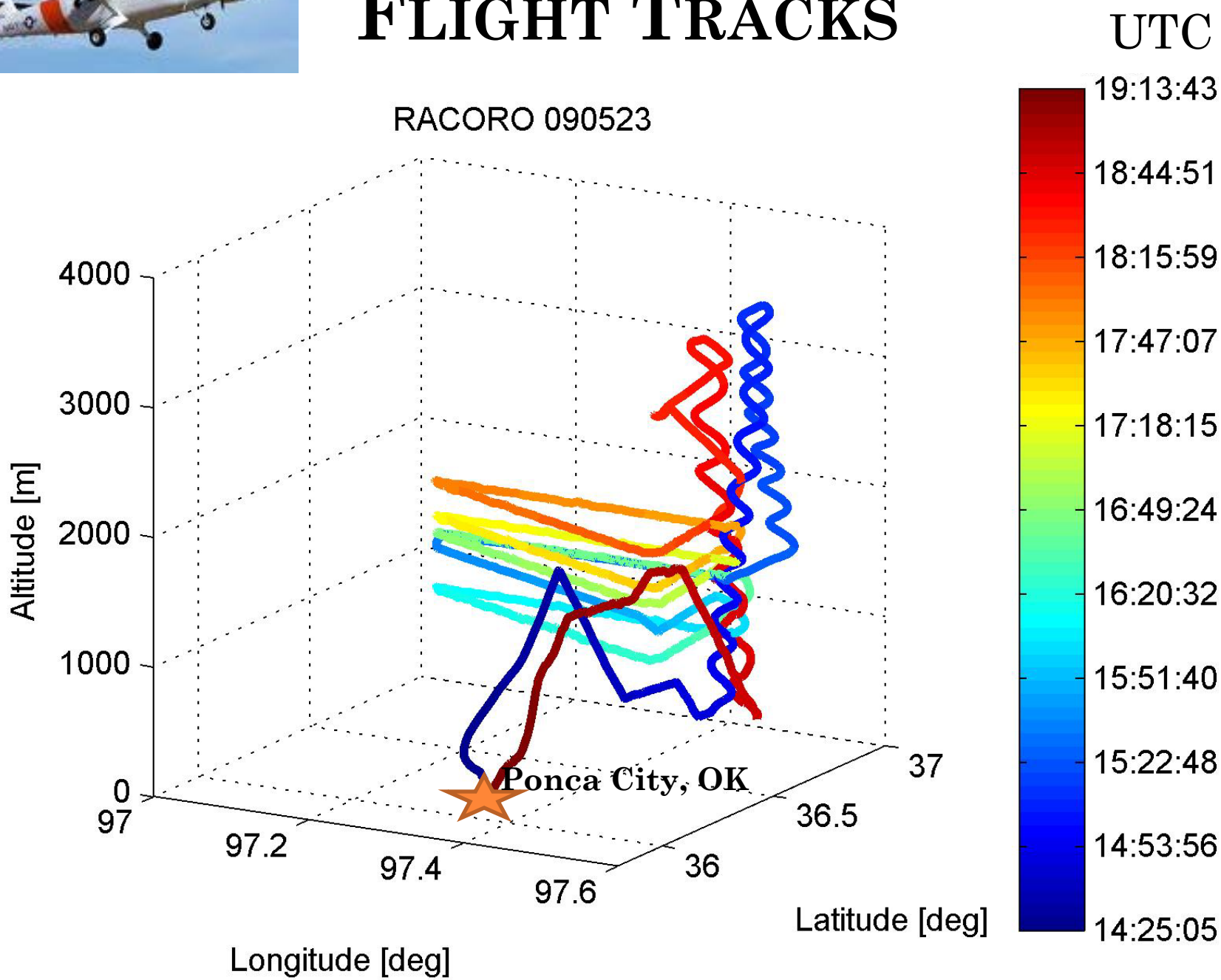


Value Added Data Product Developed



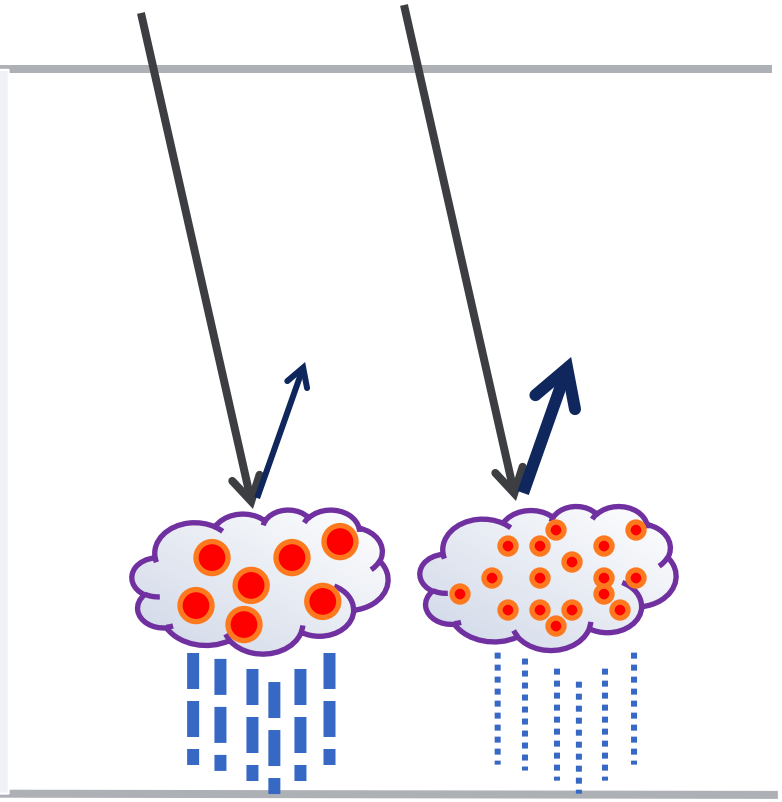
- **Compared N(D) from FSSP/CAS, from 1DC/2DC/2DS & against bulk water probes**
- **Removed spurious particles; looked for consistency**
- **Use CAS/1DC because calibration more stable and fewer spurious particles**

Flight Tracks



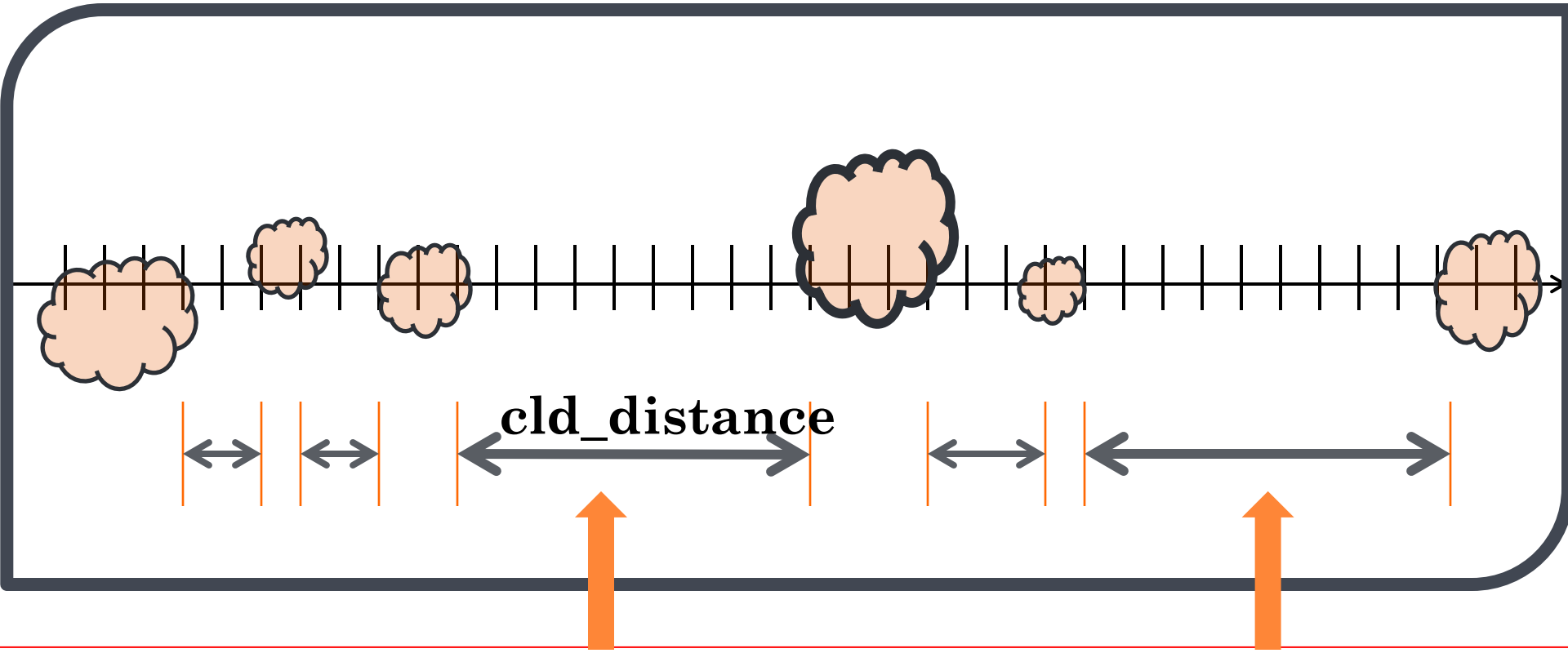
AEROSOL INDIRECT EFFECTS

- **Increase in aerosol concentrations**
- **Decrease in the size of cloud droplets**
- **Increase solar reflection**
- **Reduce the precipitation efficiency**
- **Increase in liquid water content**
- **Increase in cloud lifetime**



Methodology

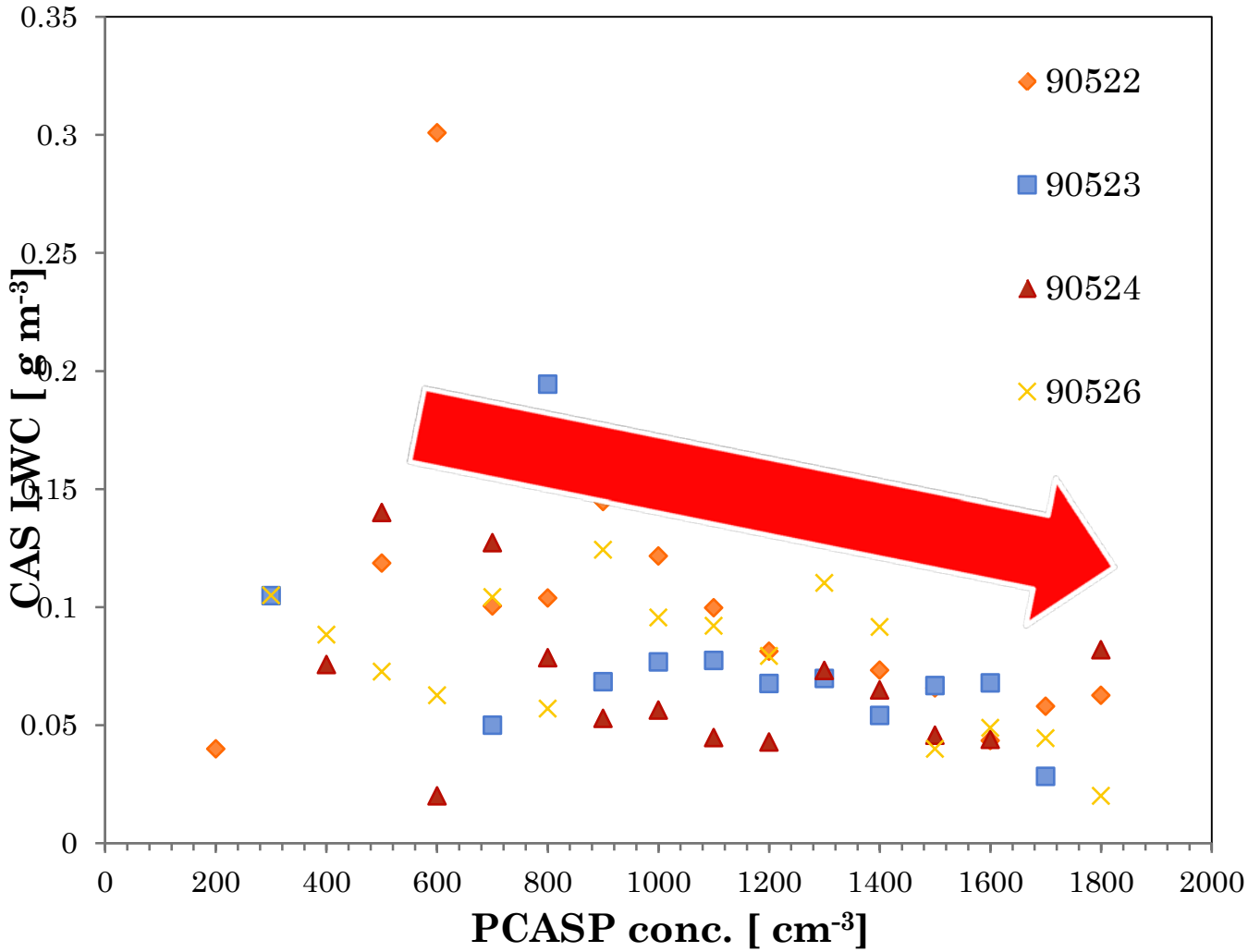
1. Determine average property of cloud; and
2. aerosol properties unperturbed by cloud field



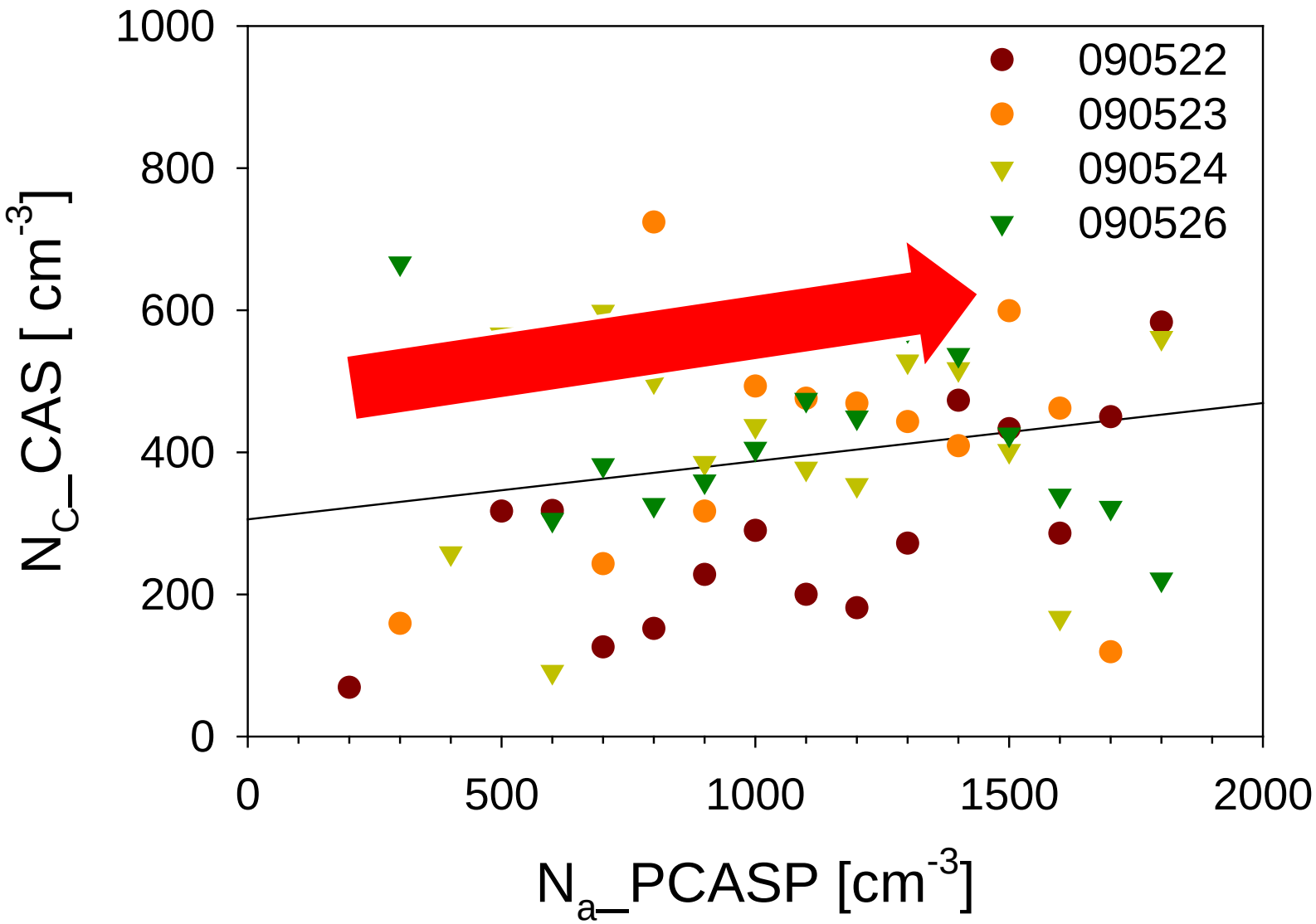
Only consider a cloud **<u>far enough away</u>** from nearest c

Aerosol concentration 150 m away from the nearest clou

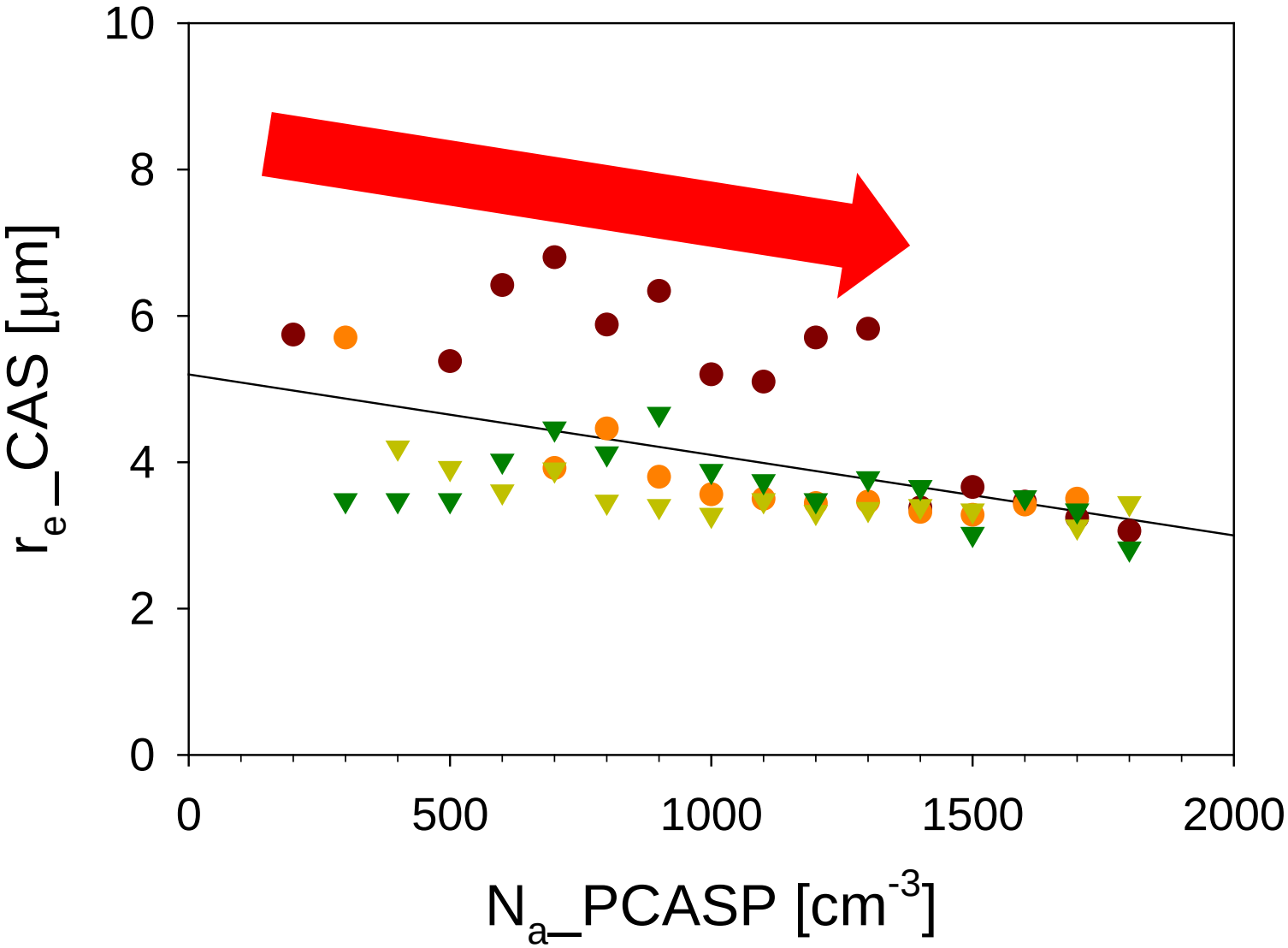
As N_{PCASP} ↑ , LWC →



As N_{PCASP} ↑ , N_{CAS} →



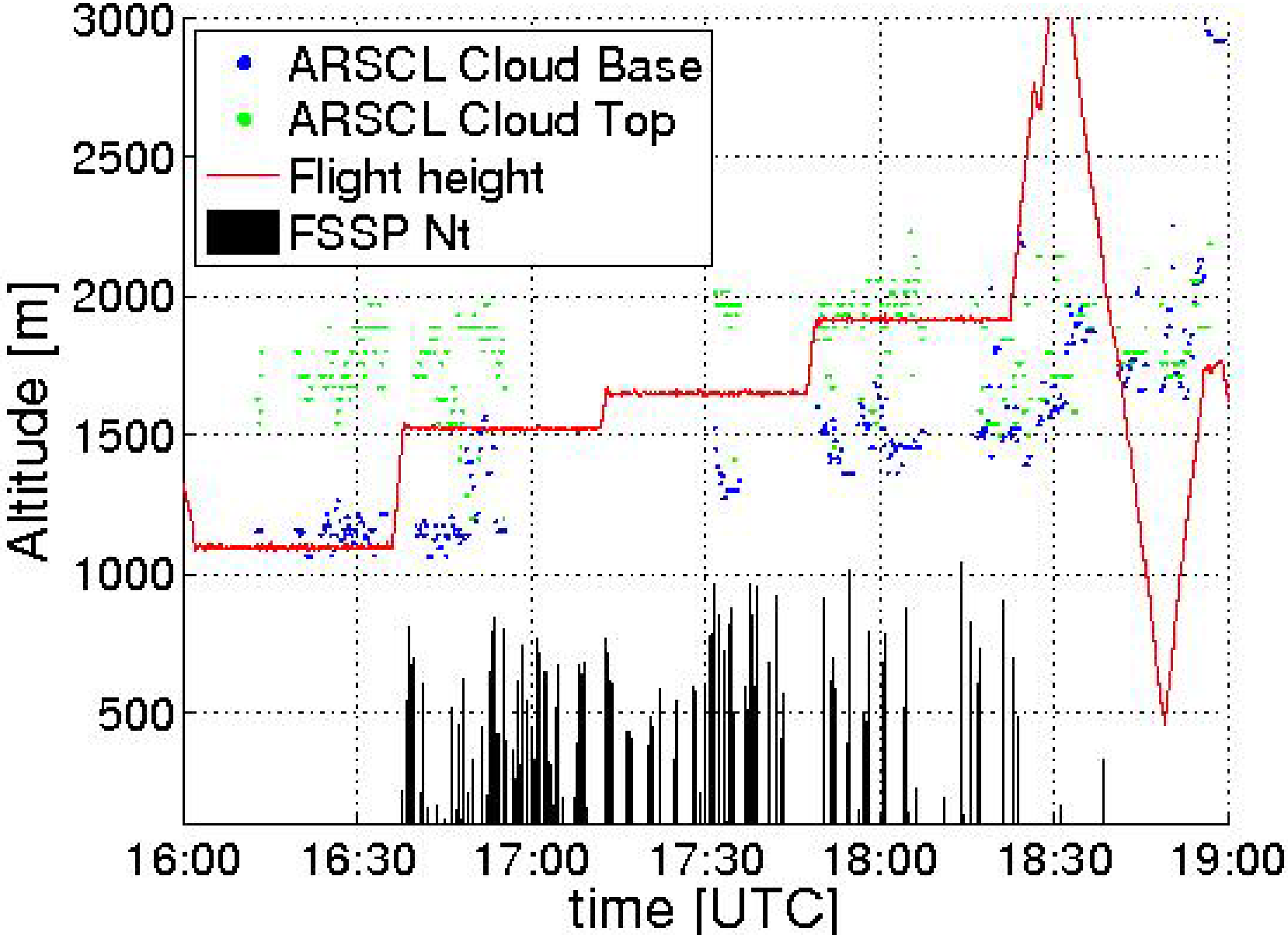
As N_{PCASP} ↑ , CAS r_{eff} →



As W_{MAX} ↑ , N_{CAS} ↑

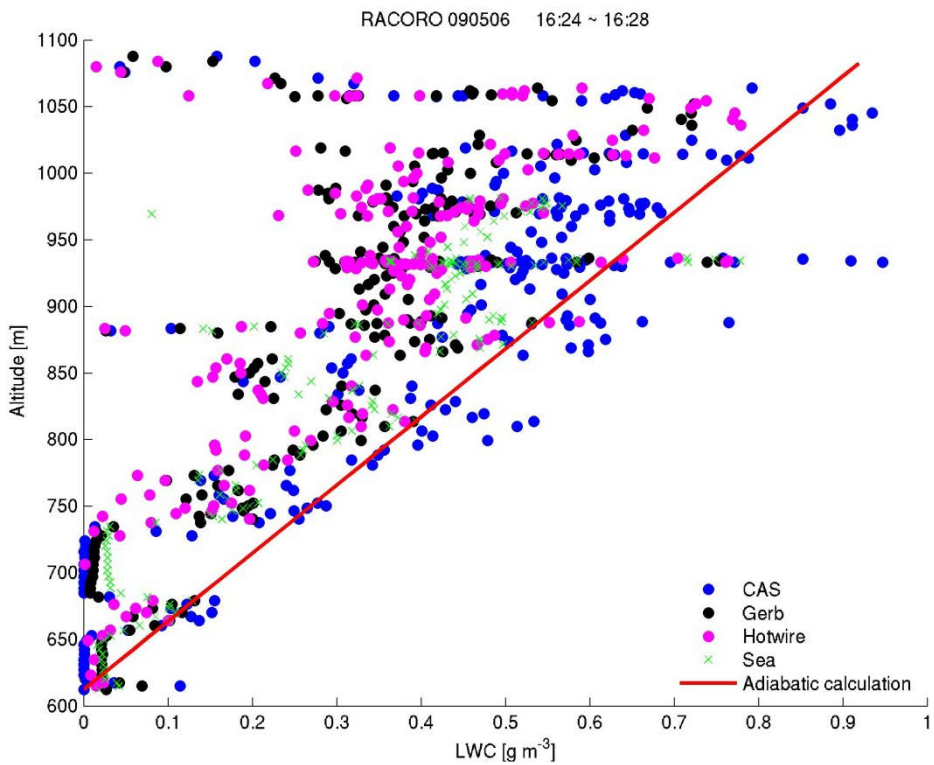
- As N_{PCASP} ↑ , N_{CAS} →
- AS N_{PCASP} ↑ , reff →
- As W_{MAX} ↑ , N_{CAS} ↑
- Vertical velocity is more dominant than aerosol effect in determining cloud droplet number concentration !

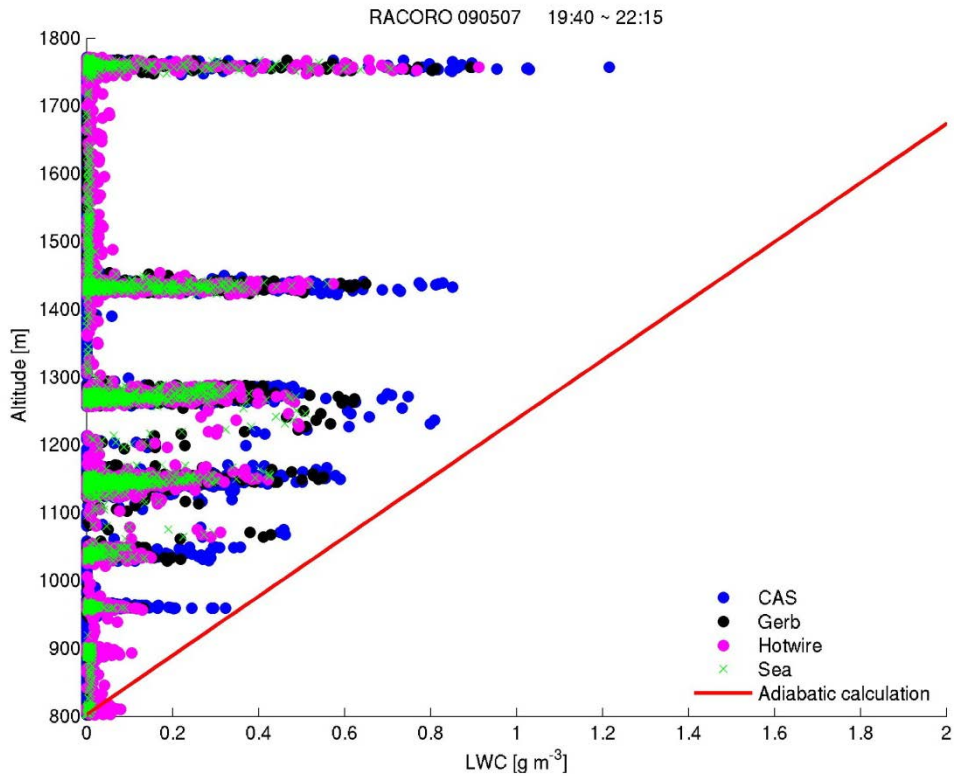
Cloud Base estimation



Adiabaticity (Ad / β / $AR_L = \frac{LWC}{LWC_{ad}}$)

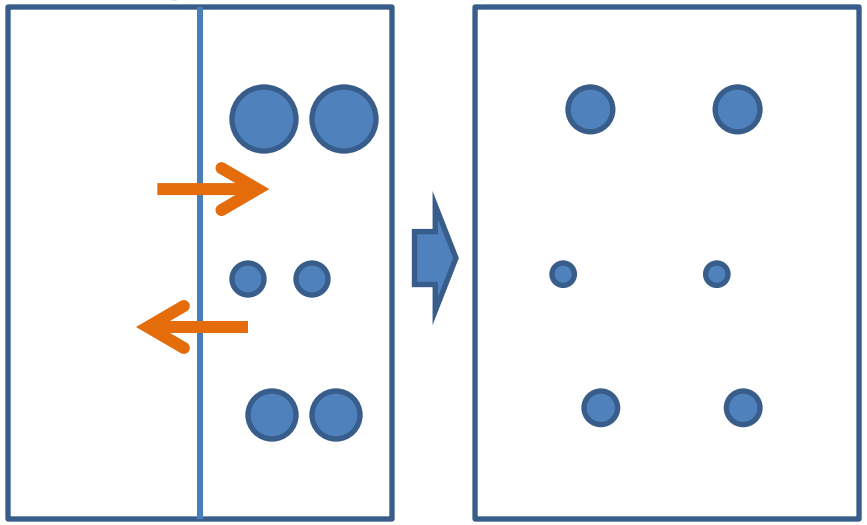
Shallow convective clouds are strongly diluted by entrainment



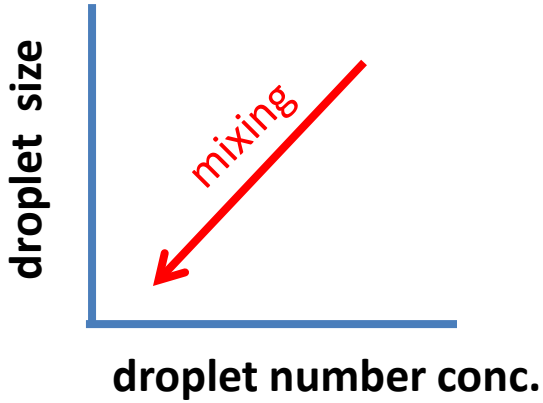


Homogeneous mixing

Mixing first & Evaporate later

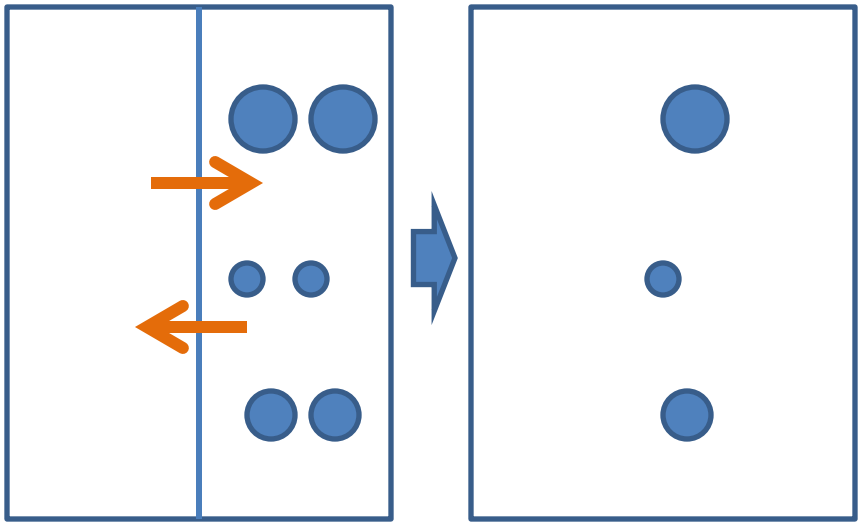


- The number concentration does not change/decreases.
- All droplets decrease their size because of evaporation

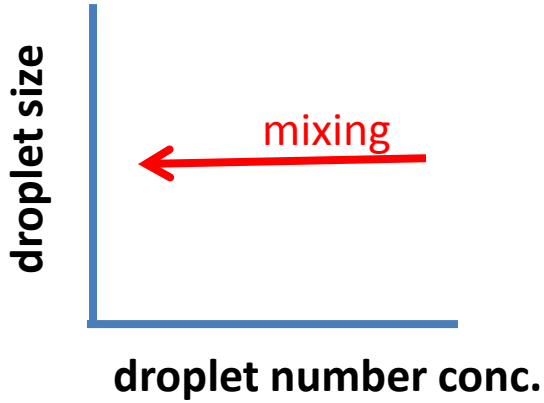


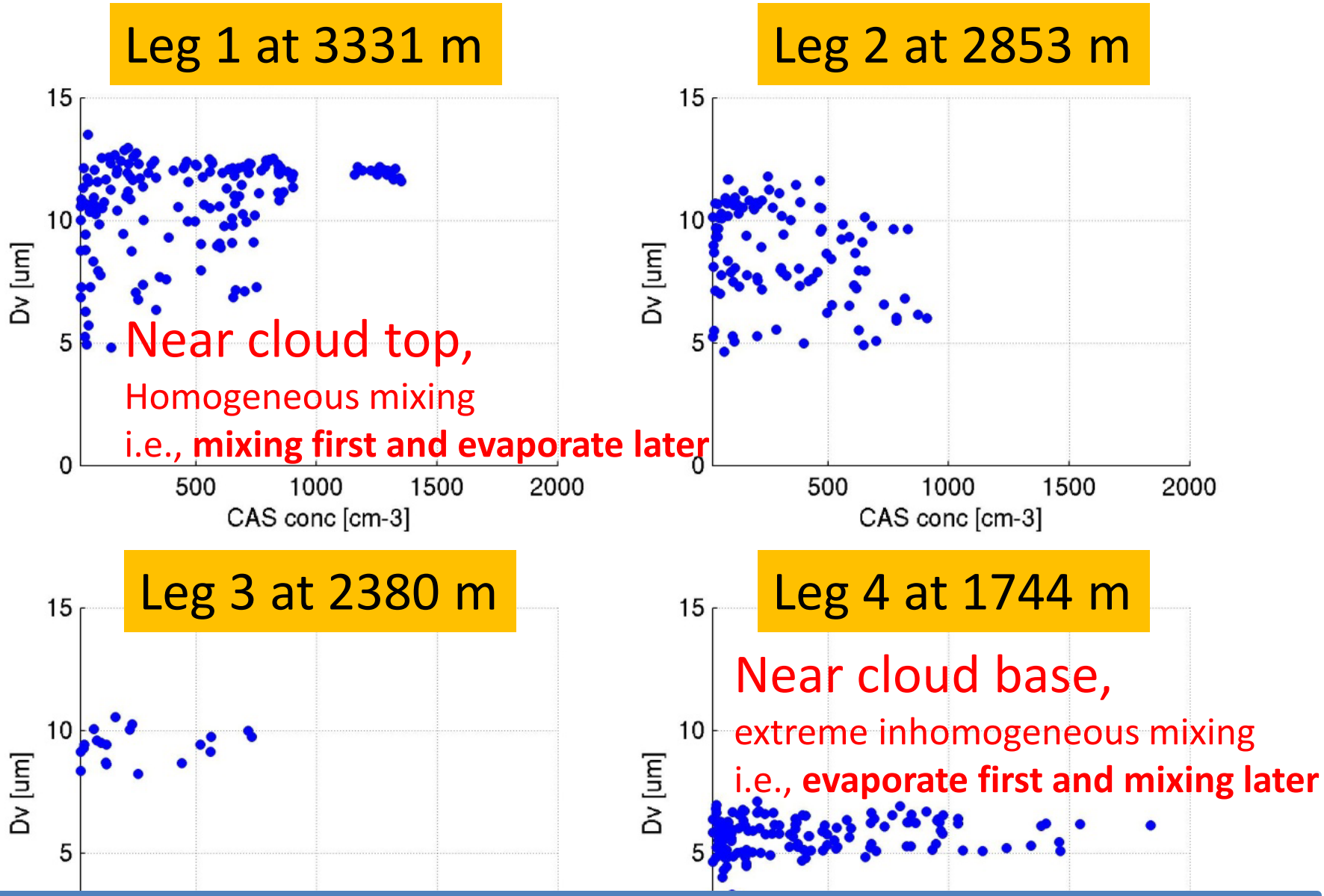
Inhomogeneous mixing

Evaporate first & Mixing later



- The number concentration decreases even more.
- The surviving droplets keep their size.





✦ During **RACORO, in-situ data show that**

the mixing becomes more homogeneous with height !

Implication: Potential biases to radiative forcing associated with mixing types

- The impact of entrainment-mixing processes on cloud microphysics has been neglected in GCMs.
- GCM studies assumed homogeneous mixing.
- In Inhomogeneous mixing case, cloud droplet number concentration would be smaller than the original assumption, hence less cloud-top albedo in GCM will be induced.
- Assuming homogeneous mixing resulted in 2% - 7% optically thicker cloud than the inhomogeneous mixing type.

Chosson and Brenguier, 2007; Morrison and Grabowski, 2008; Hill et al., 2009

Conclusion

Take-home messages !

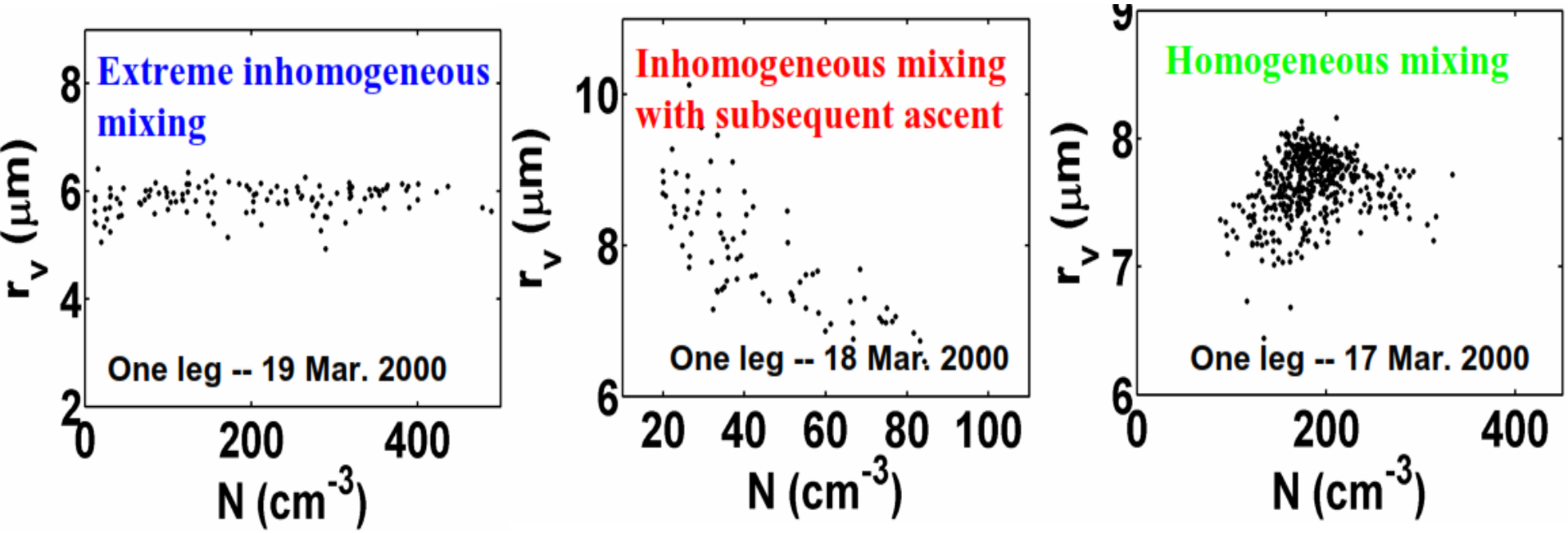
1. Value added cloud product available for RACORO.

2. For shallow cumuli, LWC decreases as N_a increases, different from classical 2nd aerosol indirect effect.

3. Updraft velocity dominant factor for cloud droplet activation. Dynamical effects stronger than aerosol effects.

4. Mixing becomes more homogeneous as height in cloud increases.

Entrainment - Mixing mechanisms



Yum, 1998; Lu and Liu, 2011

Cloud droplet spectral width (σ)

- As N_{CCN} ↗ , σ ↘ (negative correlation)

at high W in cumulus

- As N_{CCN} ↗ , σ ↗ (positive correlation)

at low W in stratocumulus

Hudson et al, JGR (2012)

Relative dispersion, $\varepsilon = \frac{\sigma}{\overline{D}}$

Liu and Daum(2002), in-situ FIRE, SOCEX, ACE1, ASTEX, SCMS

✓ ε increased as cloud drop number concentration increased.

Liu et al. (2006), adiabatic parcel model

✓ ε increased as cloud drop number concentration increased.

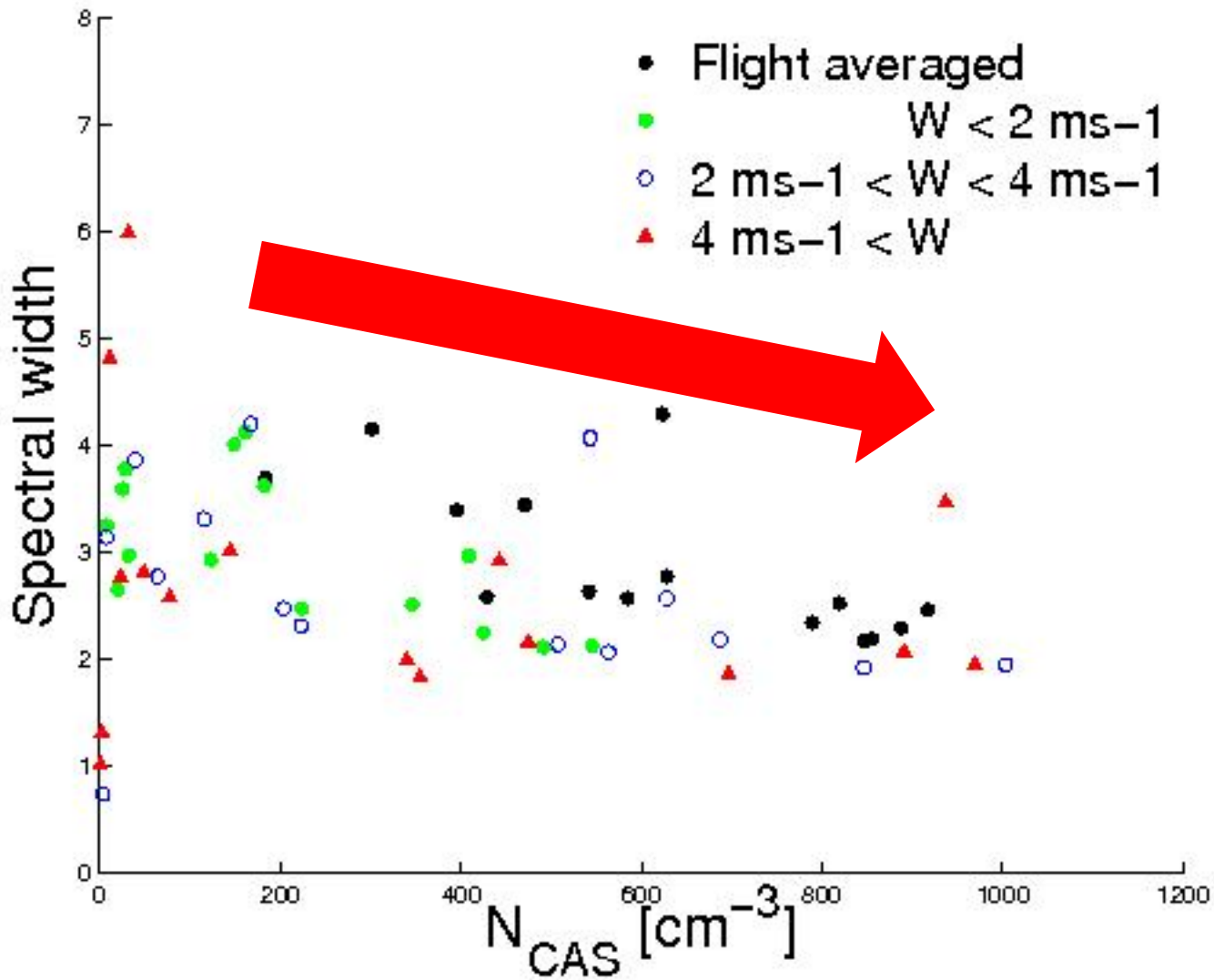
Lu and Seinfeld(2006), Lu et al.(2007), LES & MASE, marine stratus

✓ ε decreased with increasing aerosol number concentration.

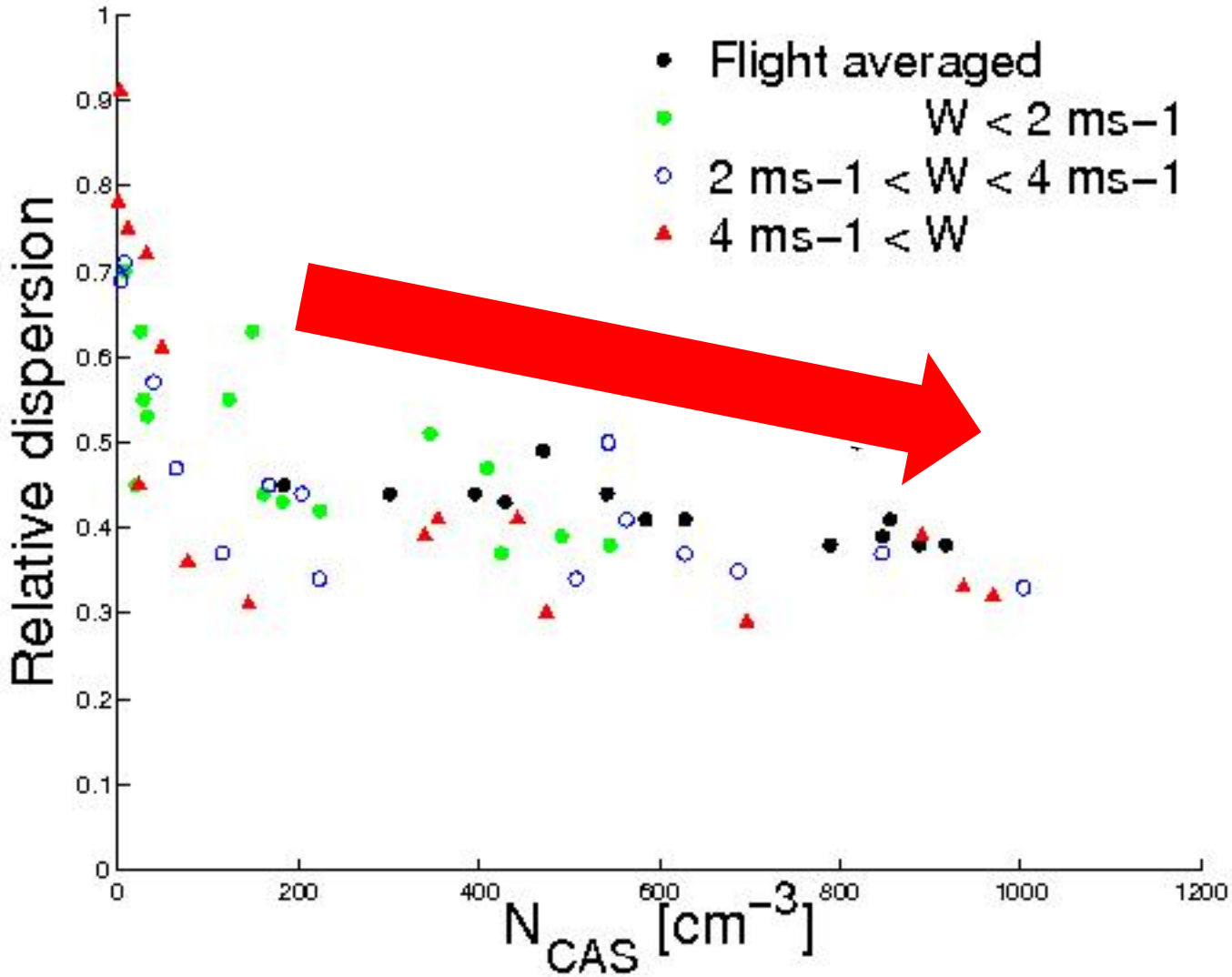
Hudson et al.(2012), in-situ RICO

✓ ε decreased with increasing aerosol number concentration.

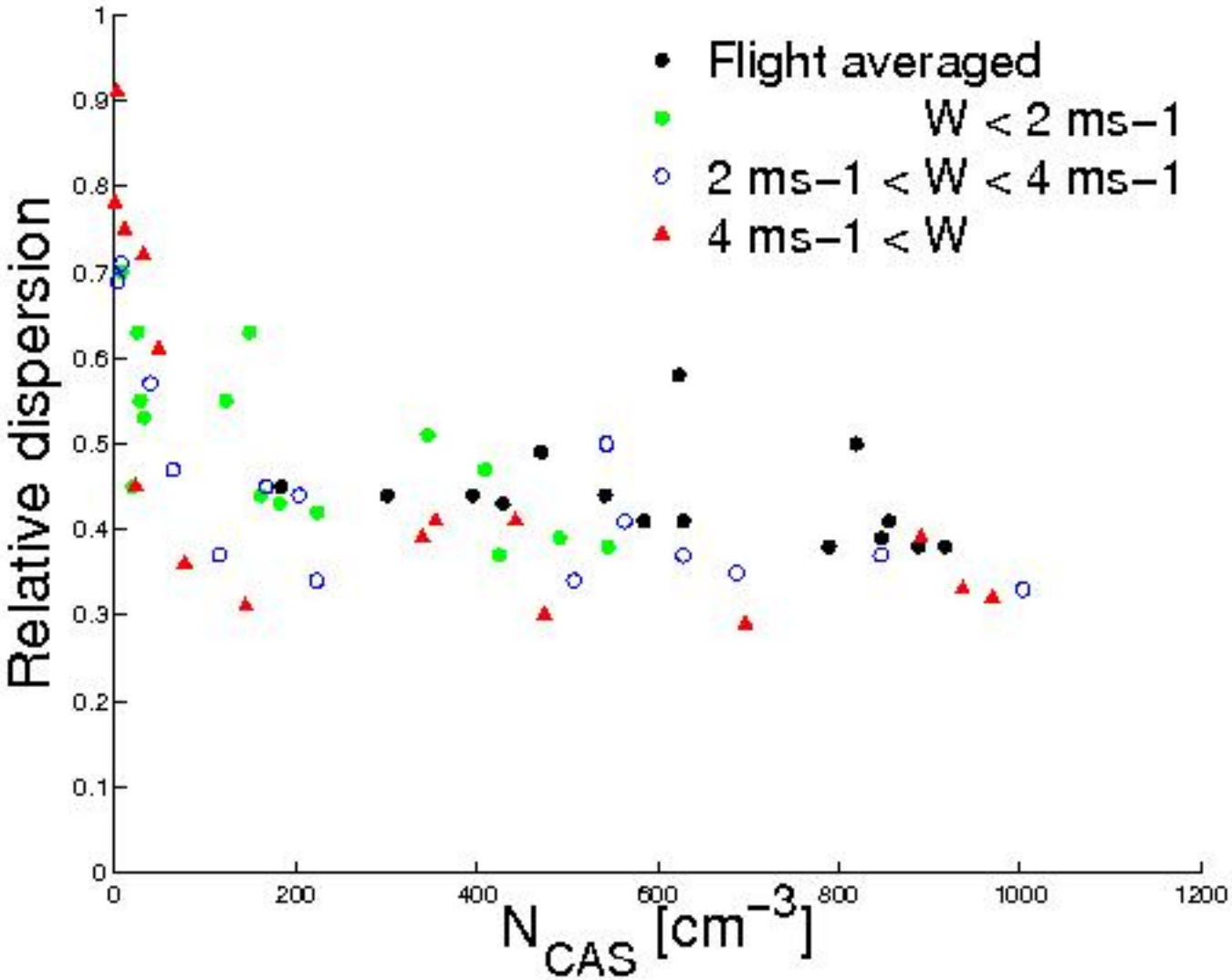
σ – N_{CAS} relationship with vertical velocity restriction



Relative dispersion, $\varepsilon = \frac{\sigma}{\overline{D}}$



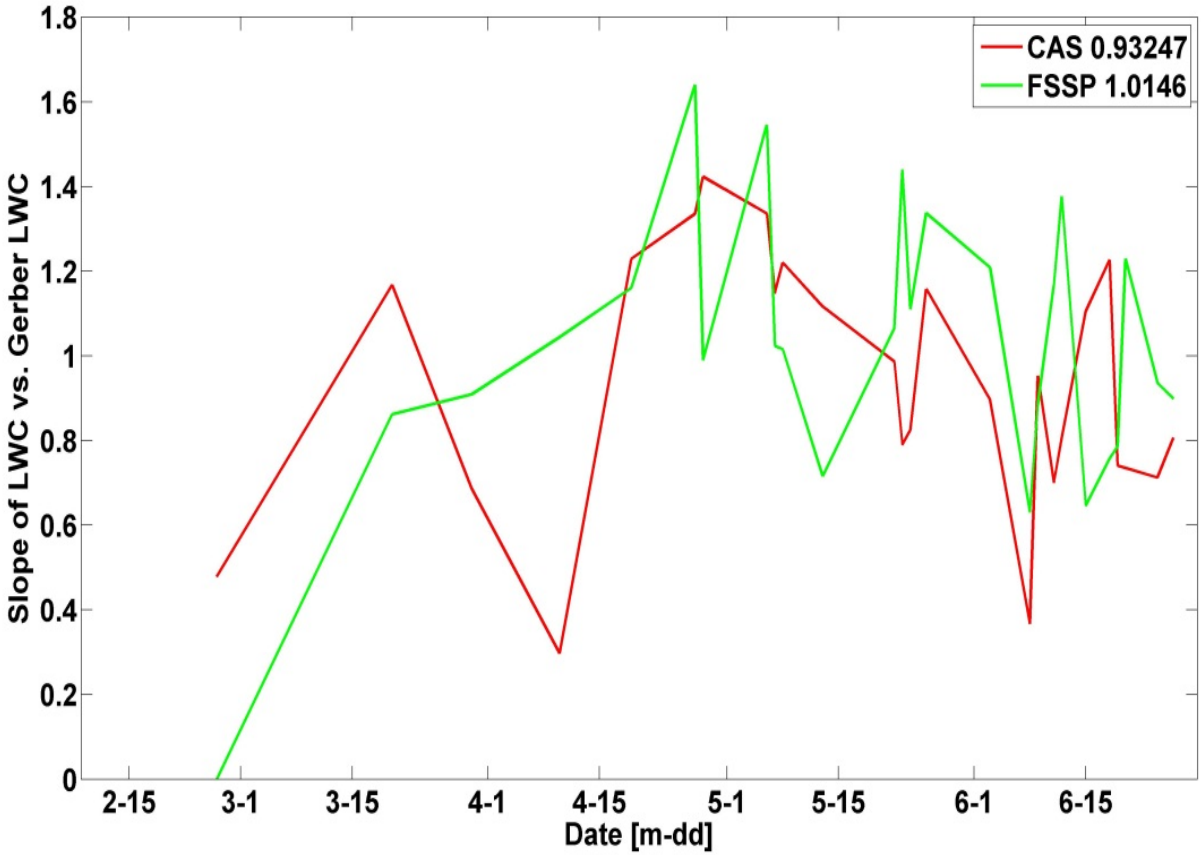
$\varepsilon - N_{CAS}$ relationship with vertical velocity restriction



RACORO I

Instrument	Measur
UFCPC	Na
CPC	
PCASP	N(D)
FSSP	
CAS (CAPS)	
1-D CIP (CAPS)	
2-D CIP	N(D), ima
2DS	
Gerber probe	Bulk LW
SEA probe	
Hot-wire	

Value Added Data Product Developed



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- **Removed spurious particles; looked for consistency**
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Questions

1. For shallow cumuli over land, how do droplet concentration, effective radius (r_{eff}), LWC, vertical velocity inside cloud, and droplet spectra change with increasing aerosol concentration?

2. What physical processes explain the mechanisms by which these changes occur?