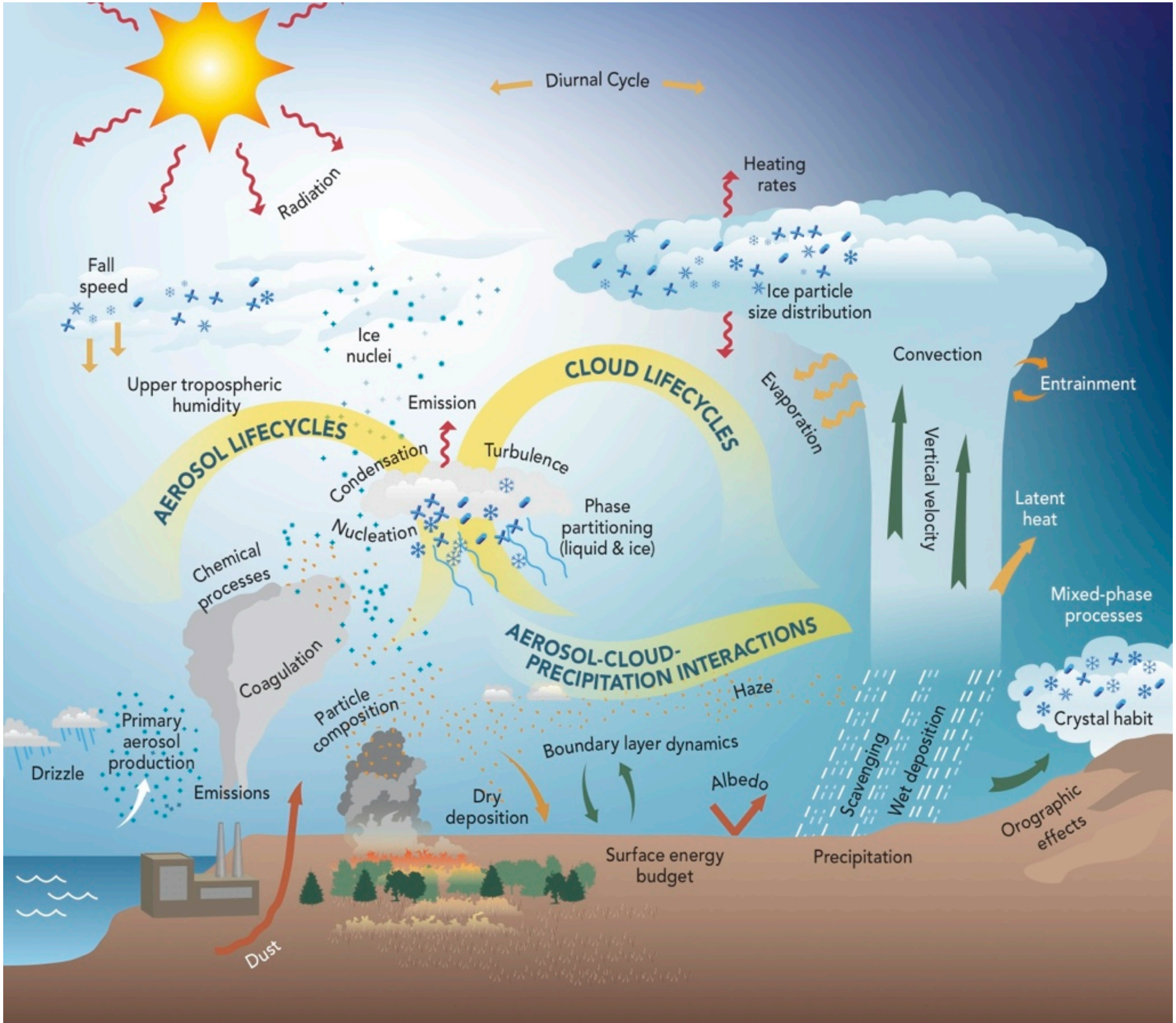
Evaluation of Aerosol-Cloud Interactions in the GISS-E2 GCM Using ARM Observations

Gijs de Boer[1,2,3], Surabi Menon[3], Susanna Bauer[4,5], Tami Toto[6], Andrew Vogelmann[6], Maureen Cribb[7]

(1) CIRES (2) NOAA (3) Berkeley Lab (4) NASA

(5) The Earth Institute Columbia University (6) Brookhaven National Laboratory (7) University of Maryland

Introduction



Simulations

GISS-2E Simulations:

•Global simulation from 2002-2009, nudged by winds from MERRA reanalysis

• 30 minute model time step

• 2° x 2.5° resolution, 40 vertical layers

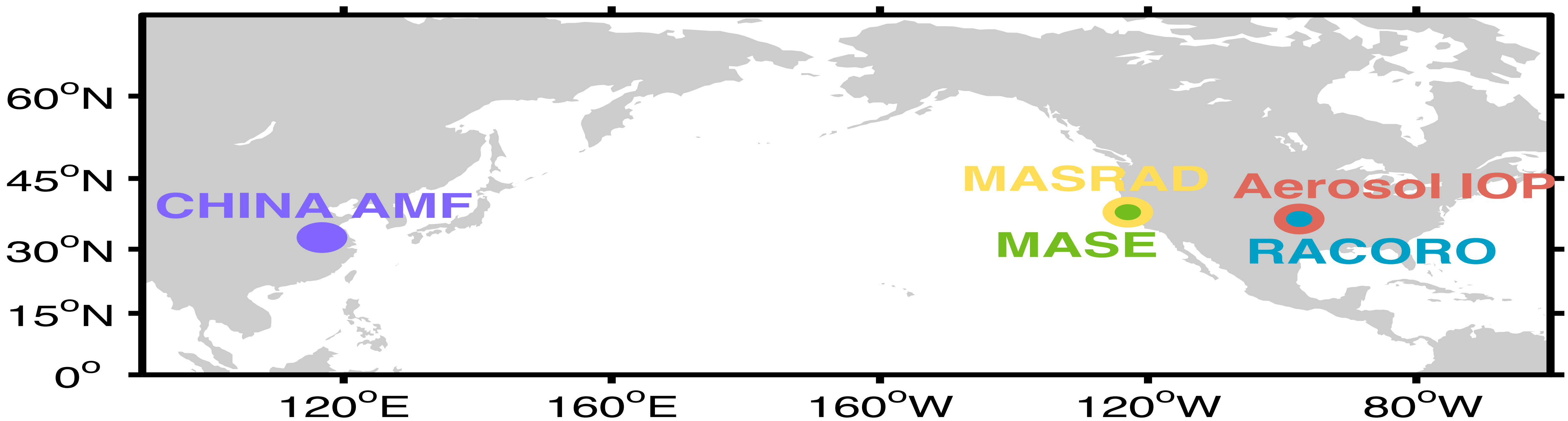
• GISS-E2 is coupled to MATRIX aerosol microphysics and chemistry (Bauer et al. 2008 [ACP] and 2010 [ACP])

• First Indirect Effect only (just through activation based on aerosol concentration) (Menon et al., 2010 [ACP])

• Cloud droplet activation through Köhler theory for stratiform clouds and parameterized for cumulus clouds

• First rounds of simulations have been completed -- more are currently underway.

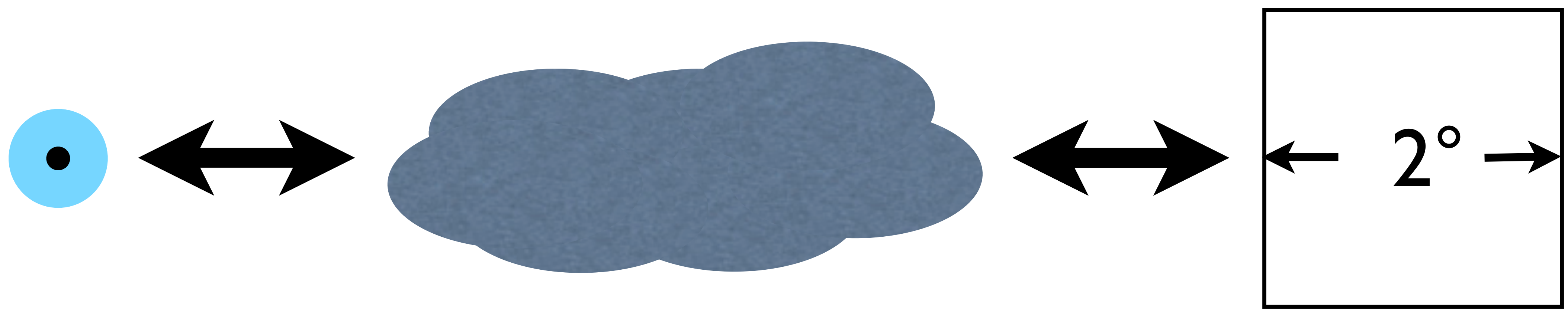
Measurement Campaigns



Campaign	Location	Dates	Key Measurements
Aerosol IOP	SGP	05/2003	Sfc. CCN, Sfc. CN, LWP, AOD, Aerosol/ Cloud Profiles, Sfc. Meteorology
MASRAD	Pt. Reyes, CA	03-09/2005	Sfc. CCN, LWP, AOD, Cloud OD, Sfc. Meteorology
MASE	Pt. Reyes, CA	07/2005	All MASRAD + profiles of aerosol and cloud information
AMF China	Shouxian, China	05-12/2008	Sfc. CCN, Sfc. CN, LWP, AOD, Cloud OD, Sfc. Meteorology
RACORO	SGP	02-06/2009	Sfc. CCN, Sfc. CN, LWP, AOD, Sfc. Meteorology, profiles of aerosol and cloud information

The Challenge

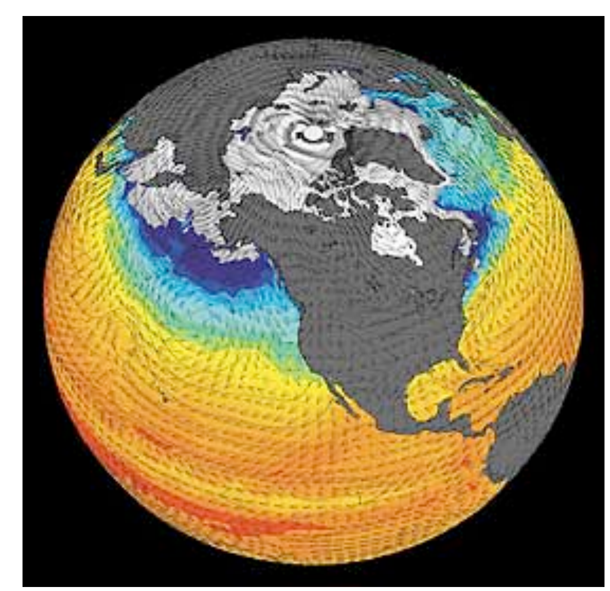
Taking localized measurements and applying them to the climate scale (see McComiskey and Feingold, 2012 [ACP]).



Process Scale

Bulk Scale

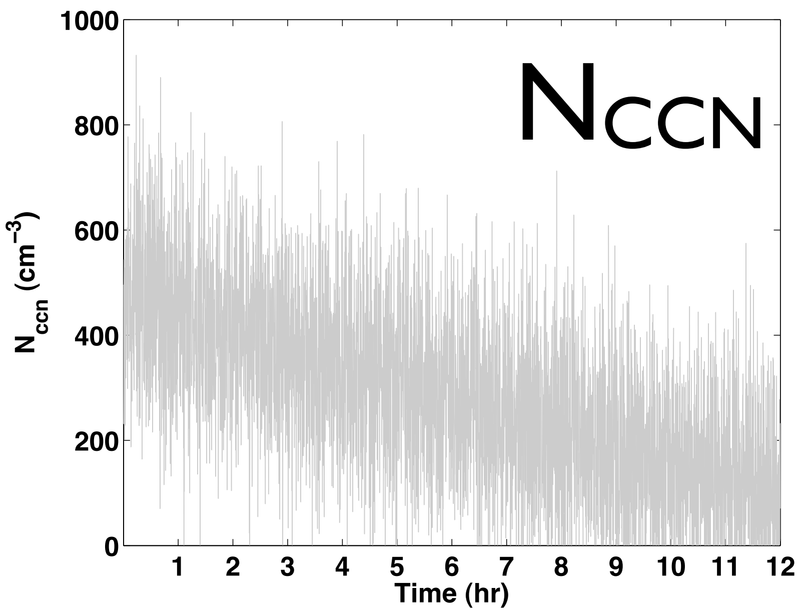
GCM Scale

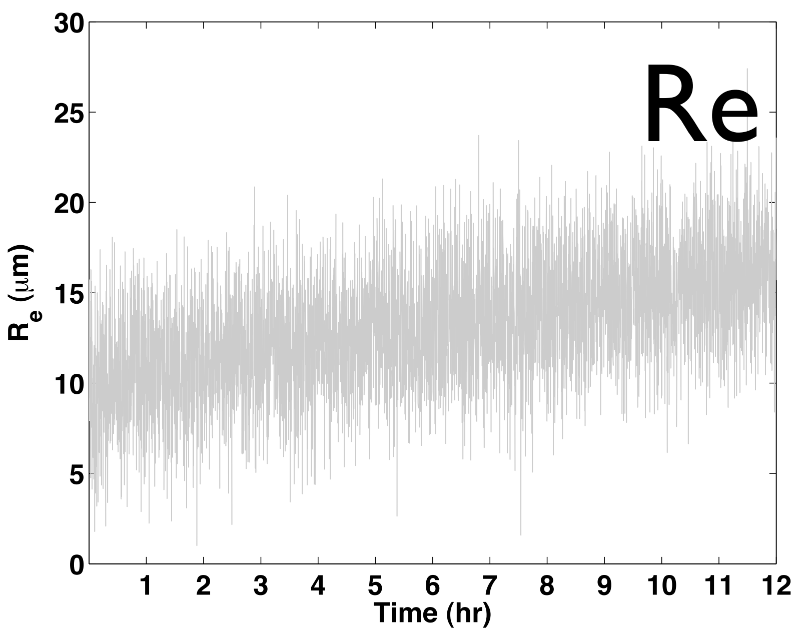


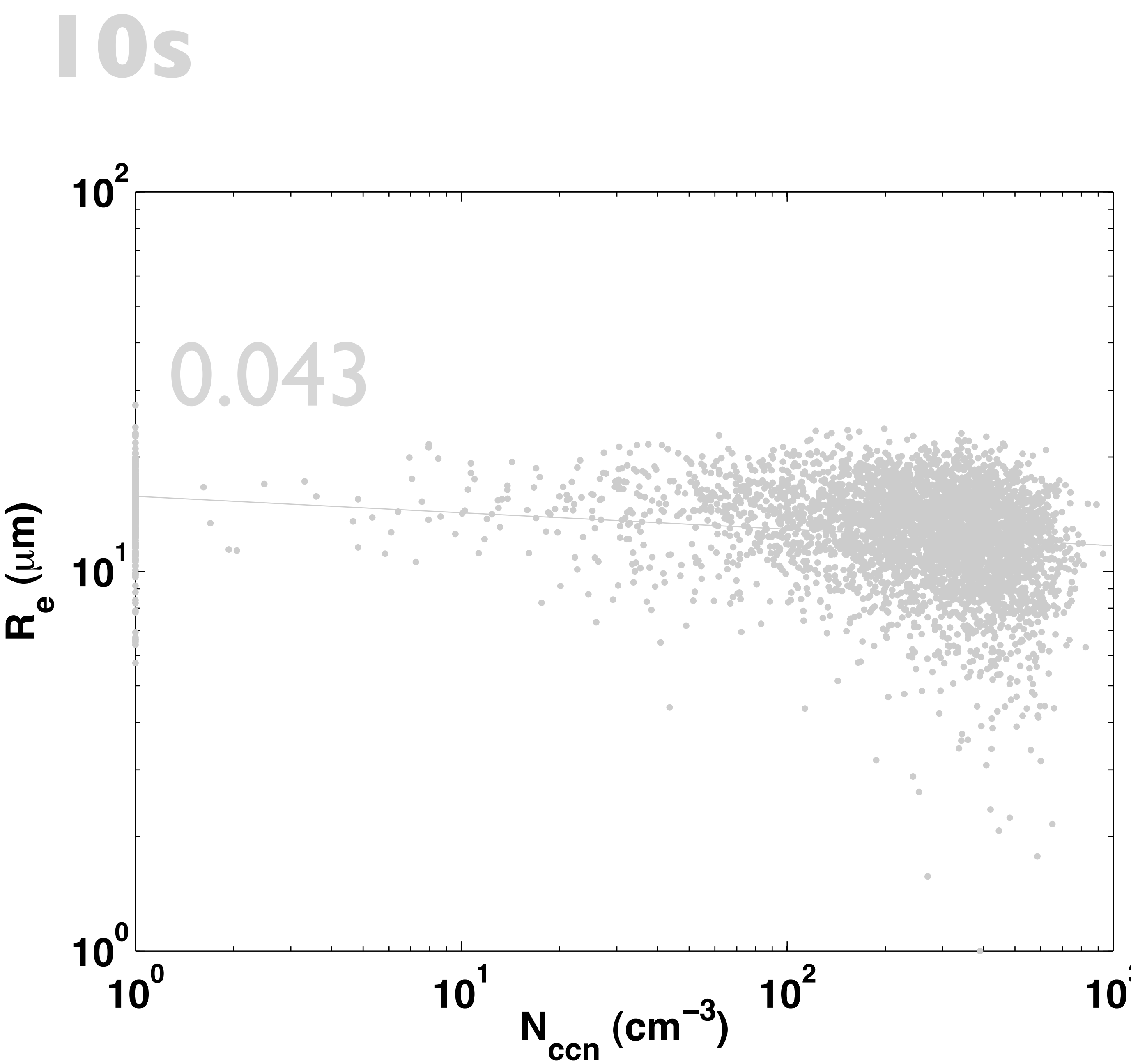
The Challenge

$$ACI_\tau = -\frac{\partial \ln r_e}{\partial \ln N_{CCN}}\bigg|_{LWC}$$

(McComiskey et al., 2009 [JGR])





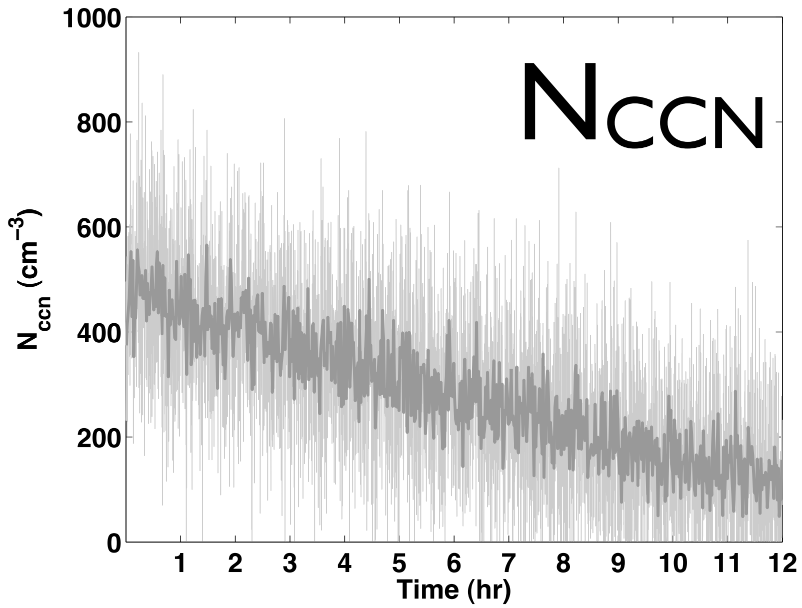


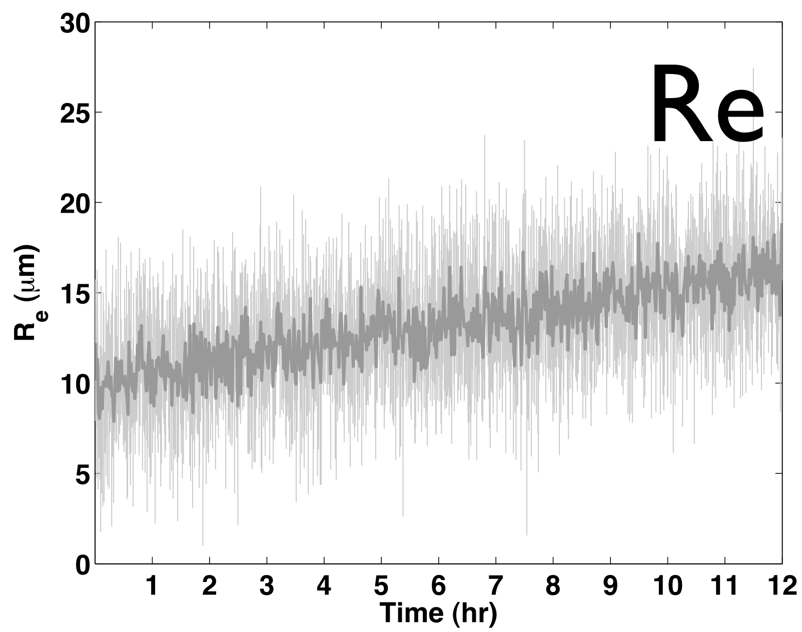
The Challenge

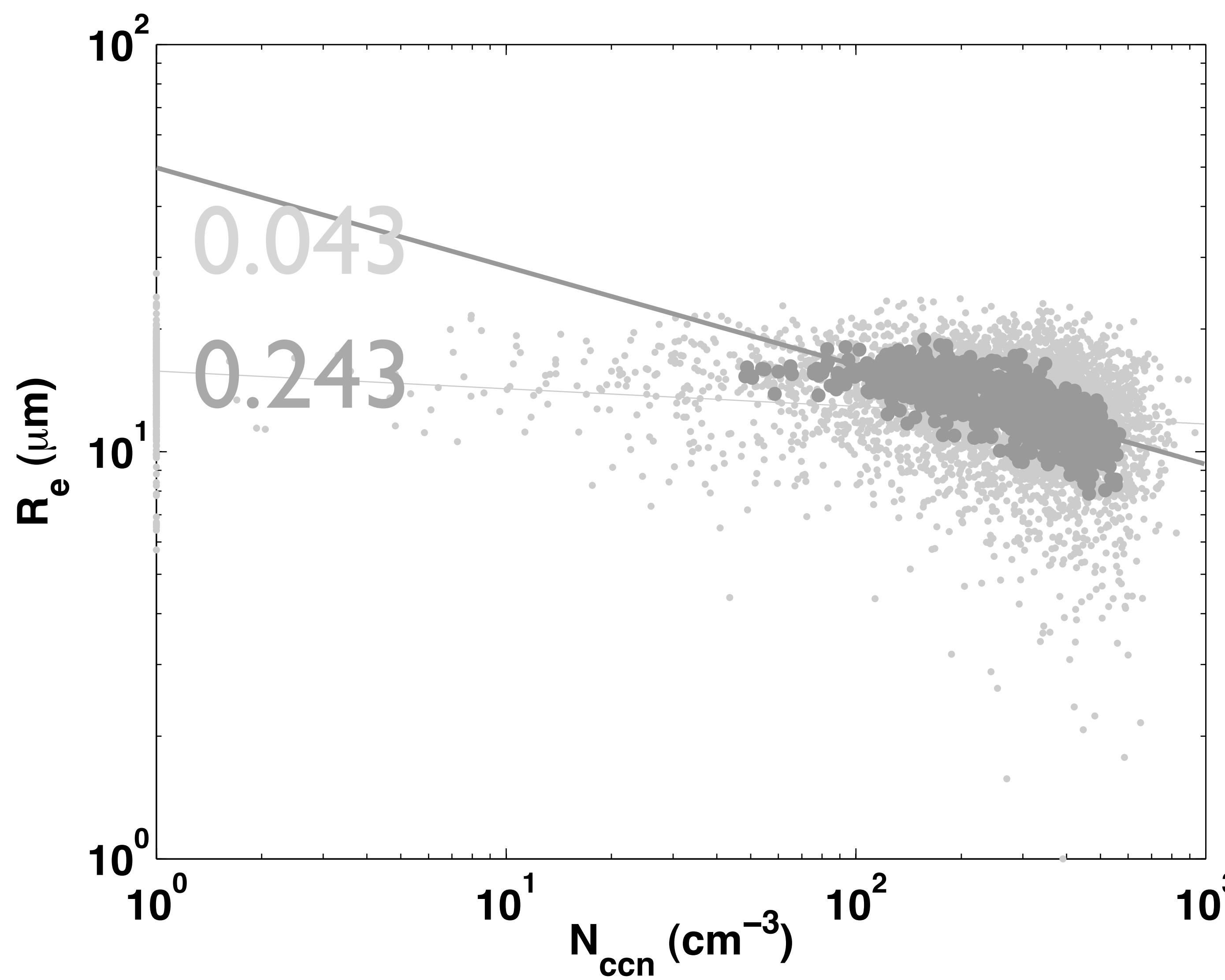
$$ACI_\tau = -\left.\frac{\partial \ln r_e}{\partial \ln N_{CCN}}\right|_{LWC}$$

(McComiskey et al., 2009 [JGR])

10s 1m



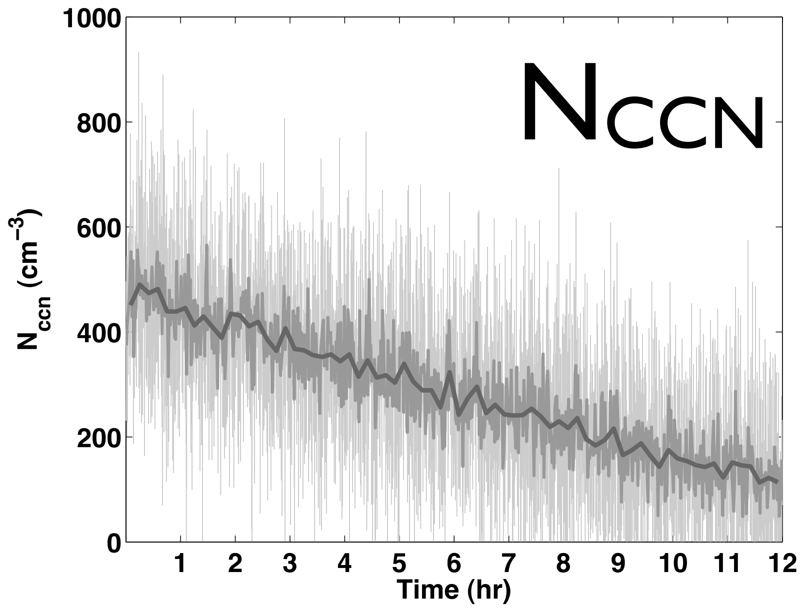


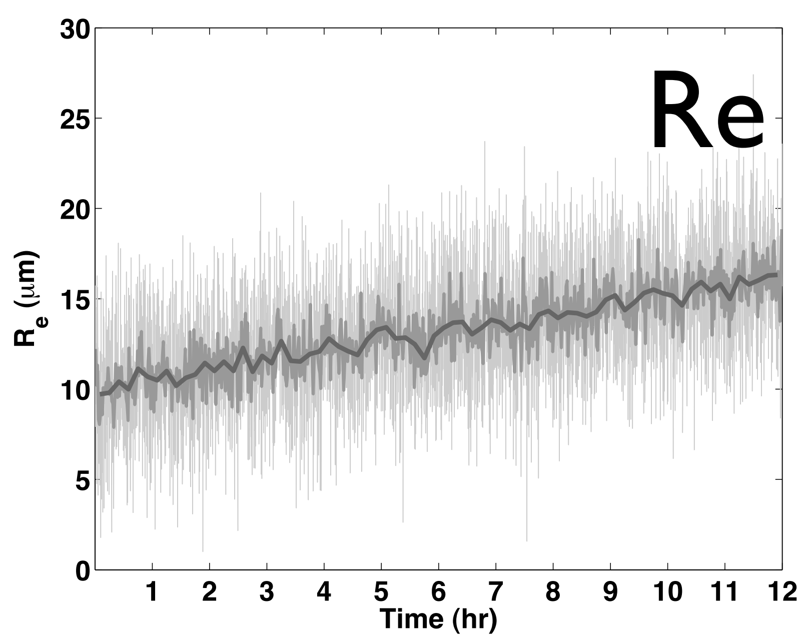


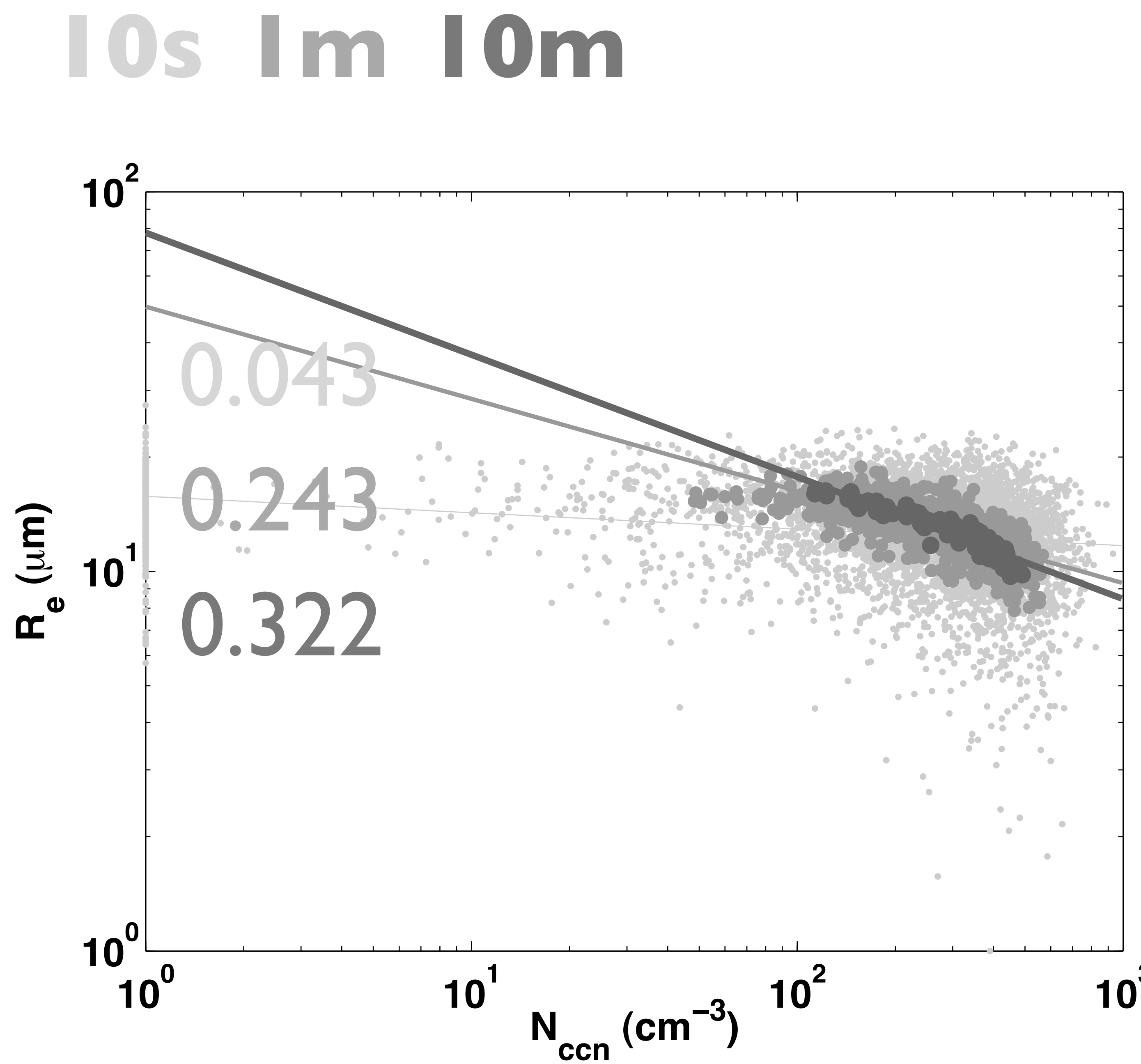
The Challenge

$$ACI_\tau = -\left.\frac{\partial \ln r_e}{\partial \ln N_{CCN}}\right|_{LWC}$$

(McComiskey et al., 2009 [JGR])



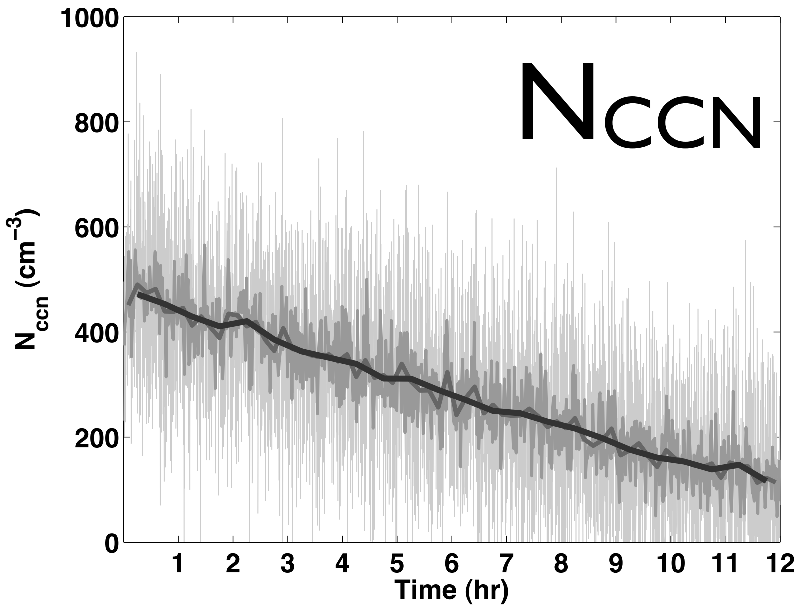


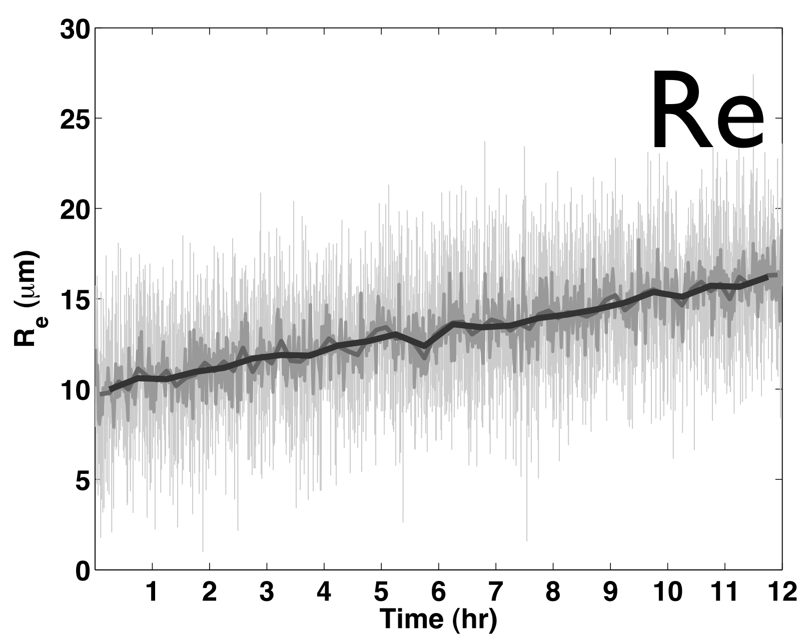


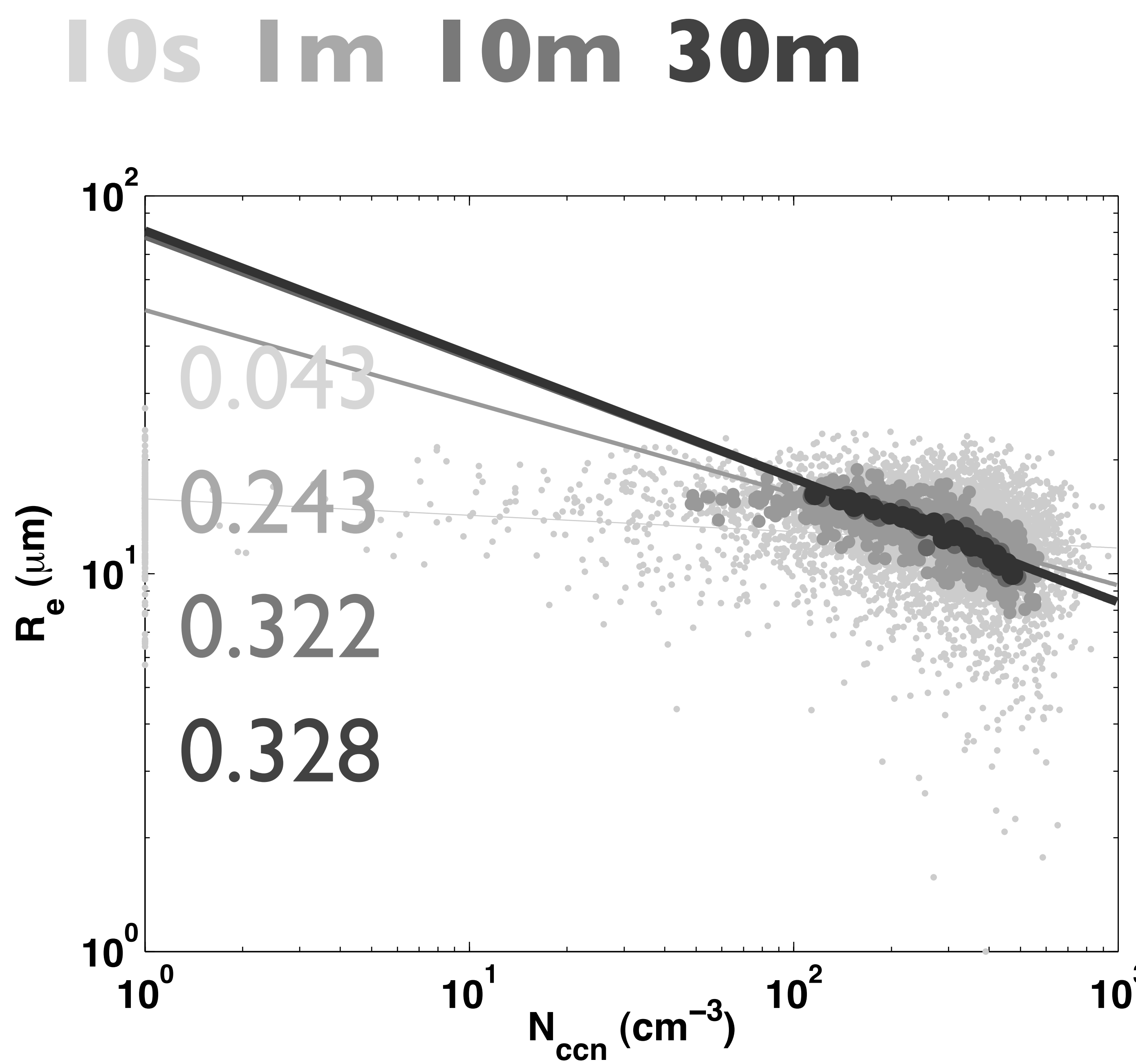
The Challenge

$$ACI_\tau = -\frac{\partial \ln r_e}{\partial \ln N_{CCN}}\bigg|_{LWC}$$

(McComiskey et al., 2009 [JGR])



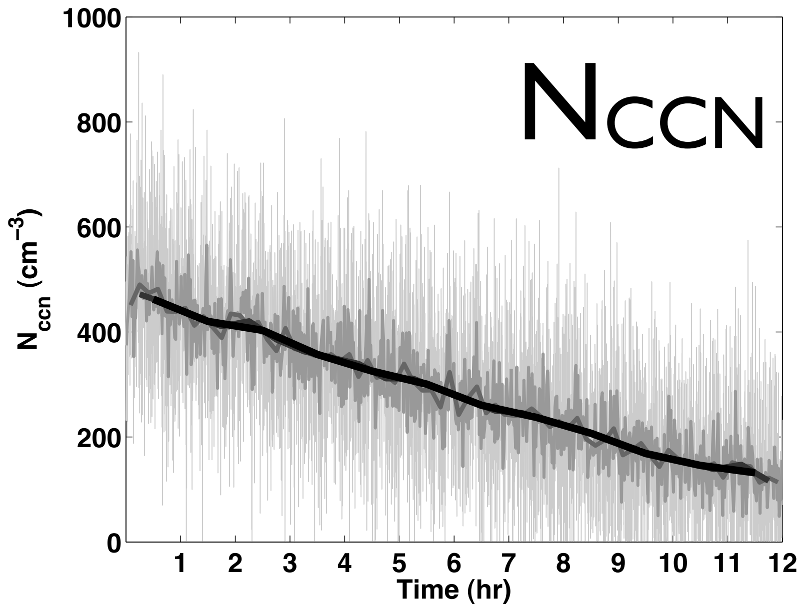


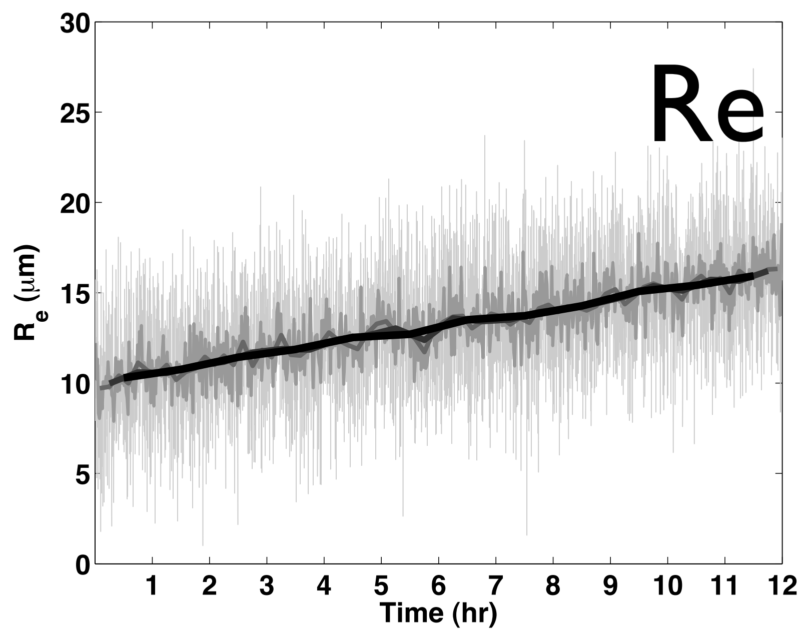


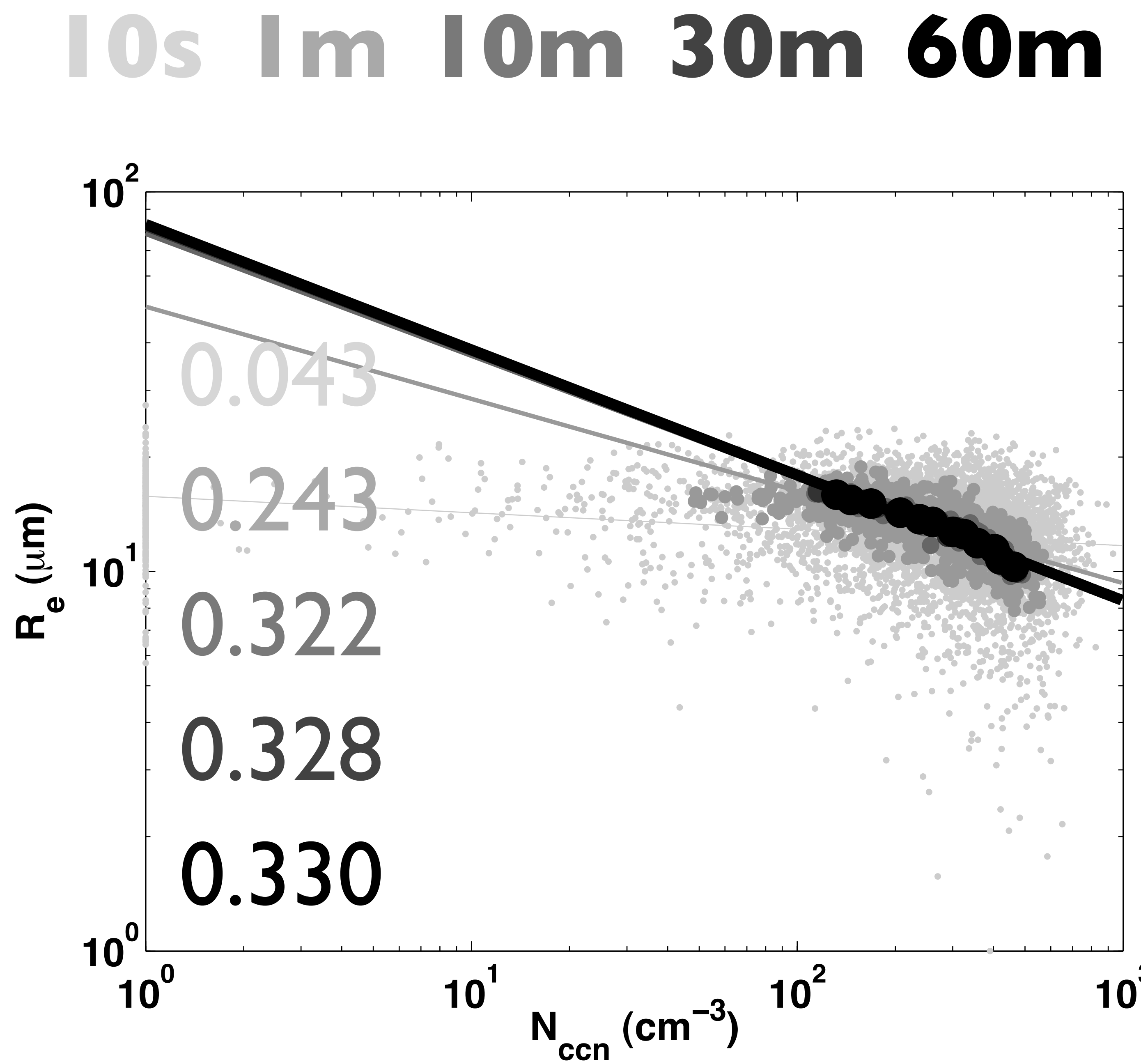
The Challenge

$$ACI_\tau = -\left.\frac{\partial \ln r_e}{\partial \ln N_{CCN}}\right|_{LWC}$$

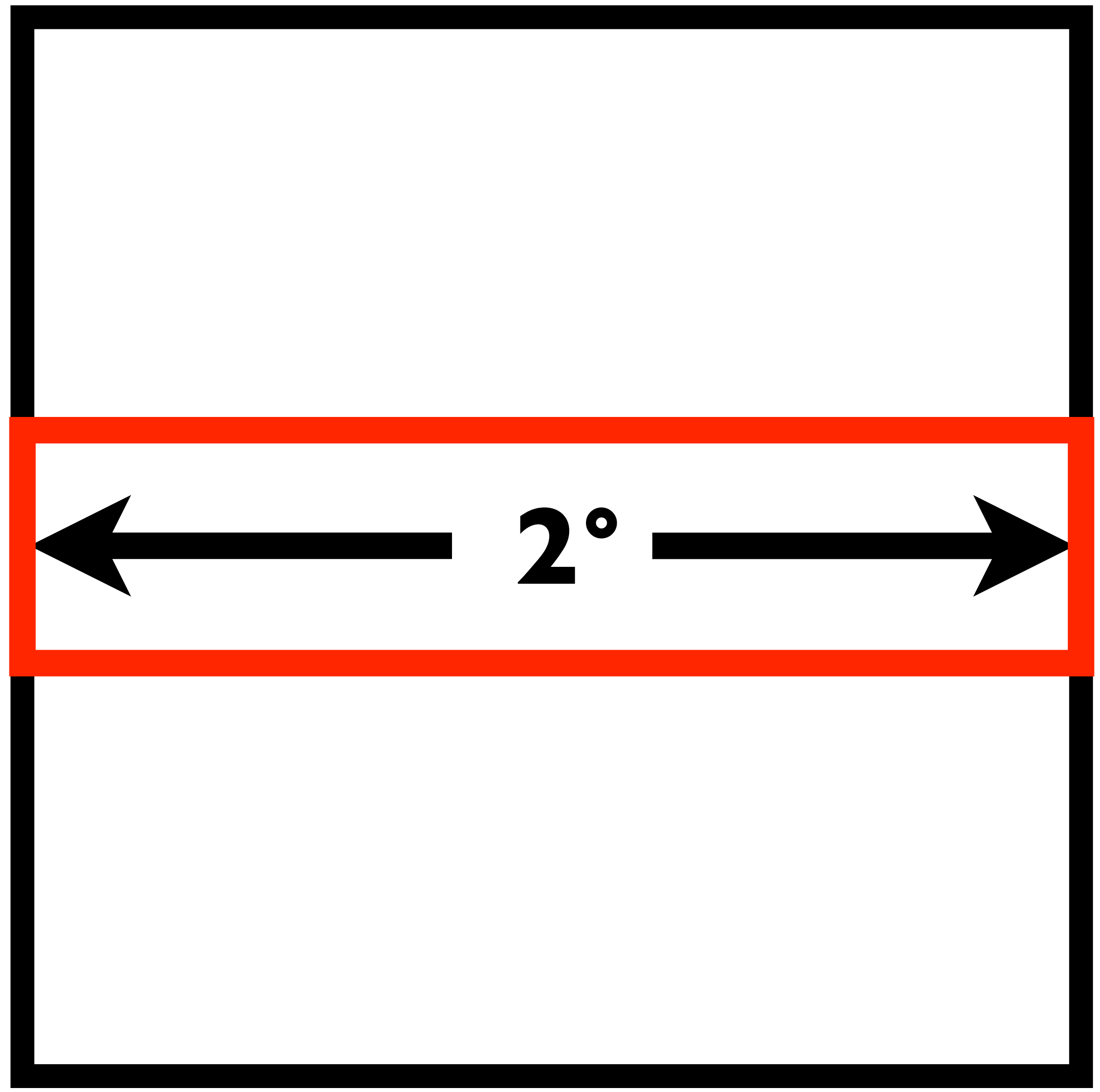
(McComiskey et al., 2009 [JGR])







The Challenge

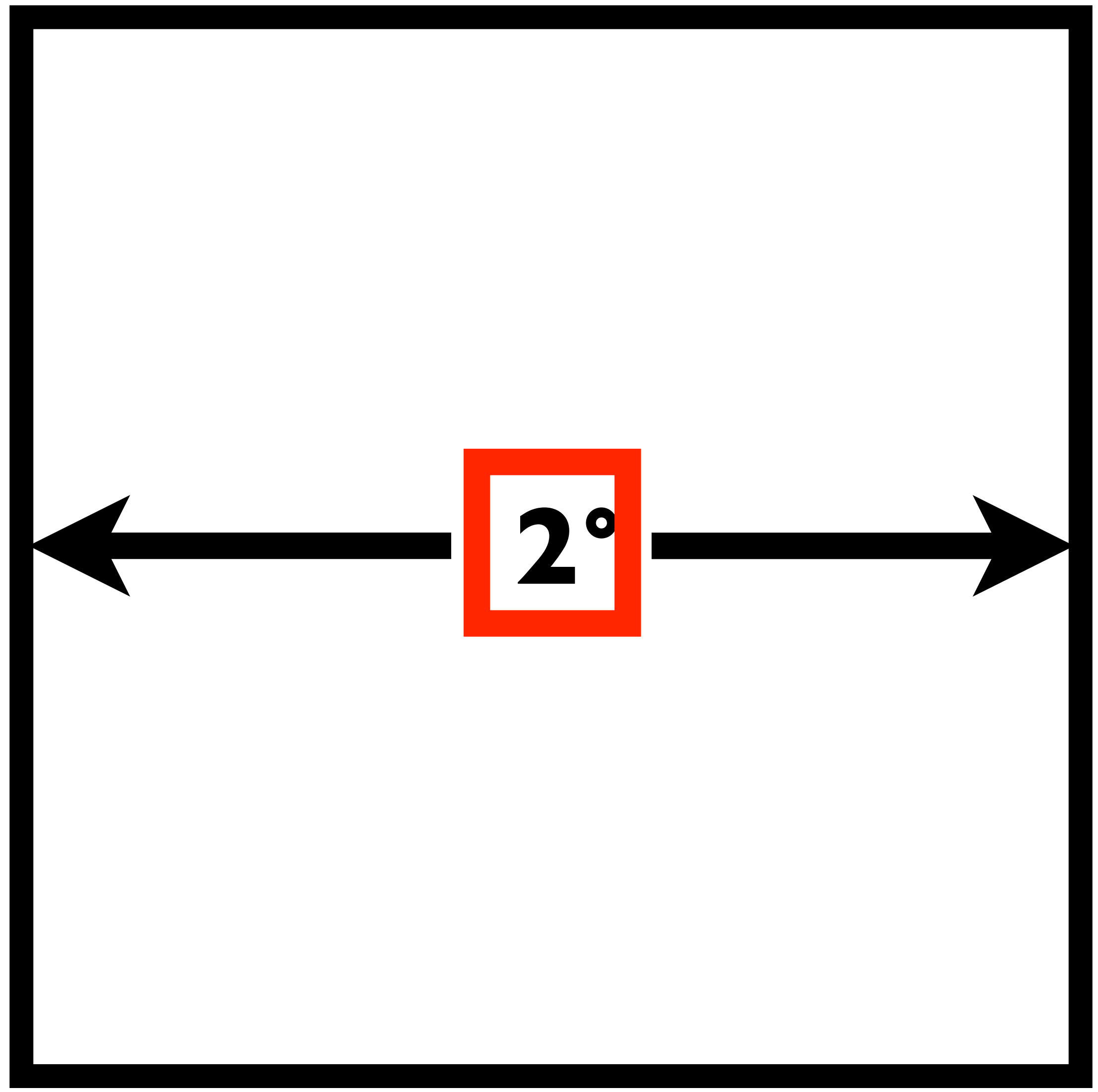


How do we cover the entire grid box at every time step?

• 2° is ~220 km, which means at 10 m/s we would need to average over roughly 6-7 hours.

• This assumes stationary atmosphere.

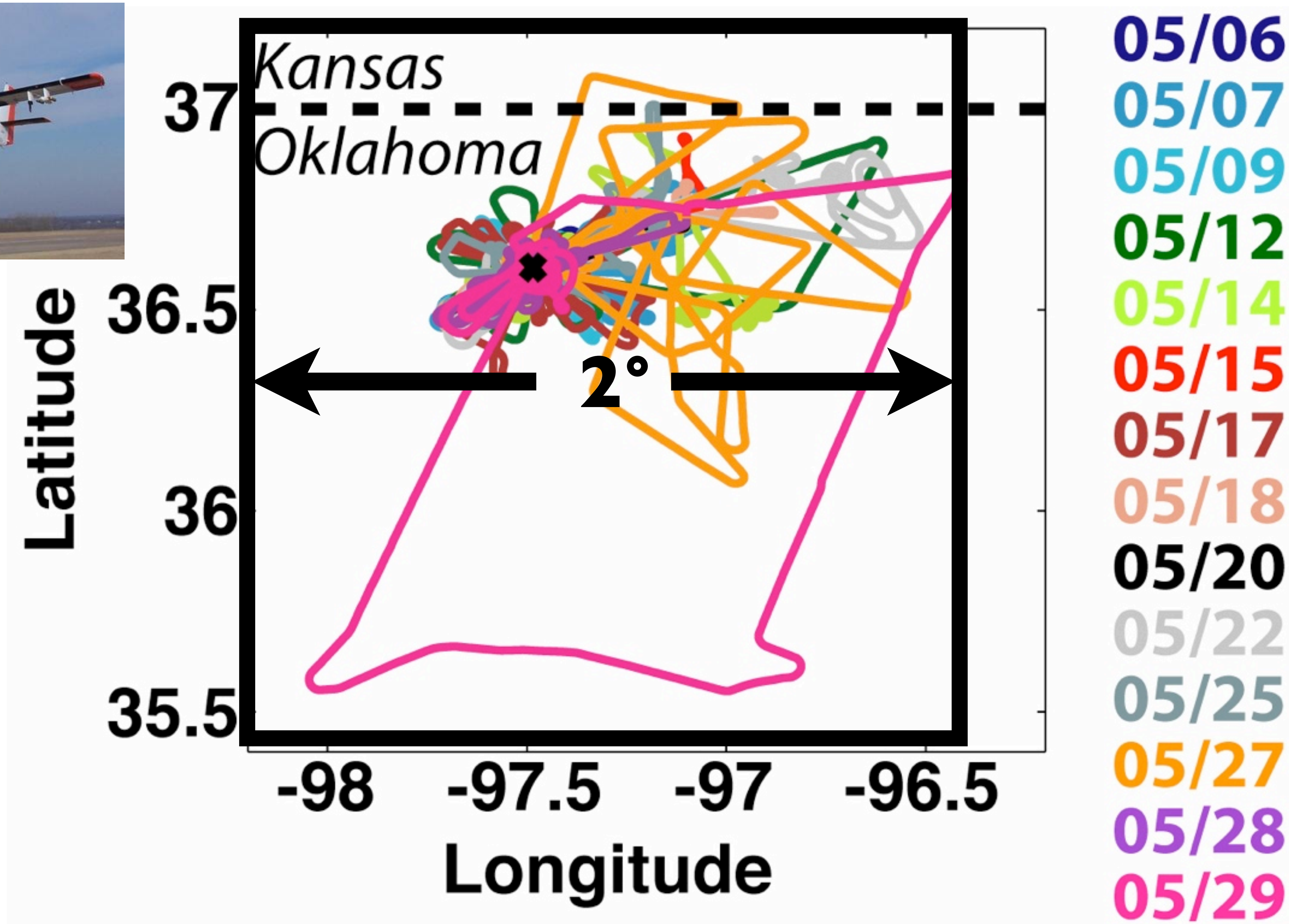
The Challenge



How do we cover the entire grid box at every time step?

- Alternatively we can look at shorter windows that still capture internal variability (~1 hour)
- This assumes limited sub-grid scale variability.

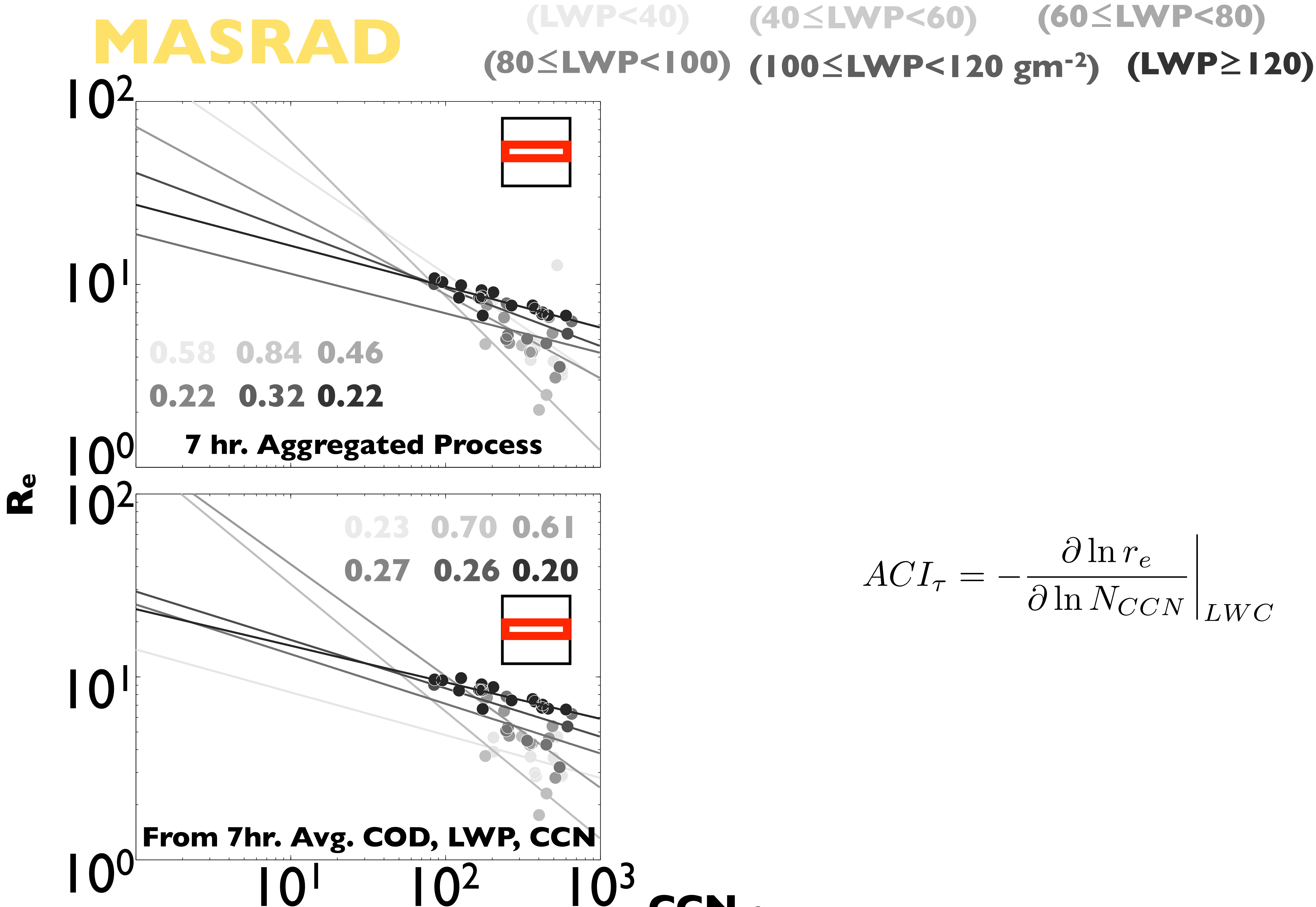
The Challenge



How do we cover the entire grid box at every time step?

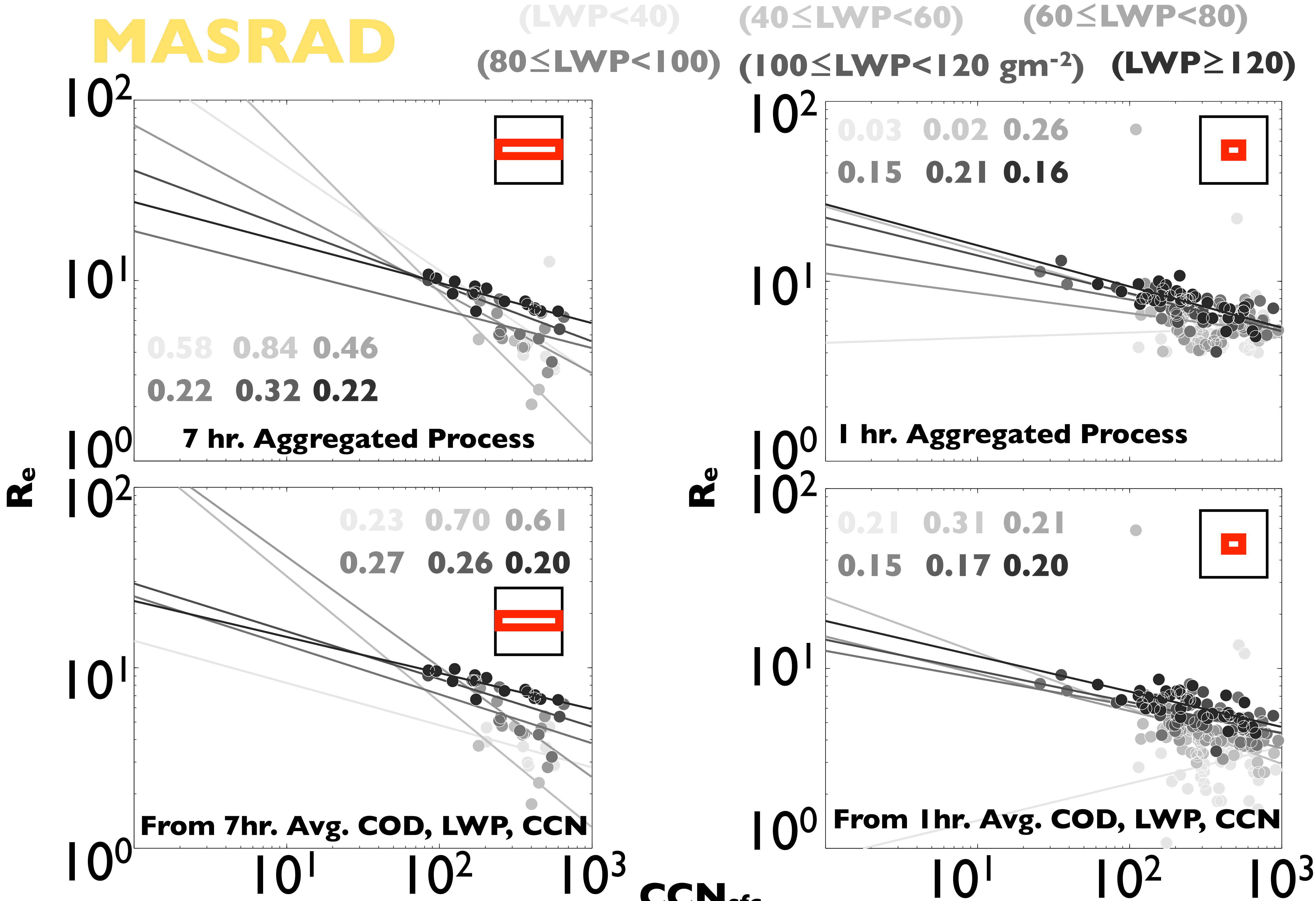
- We can sample a large area rapidly using aircraft.

CCN_{sfc} - R_e

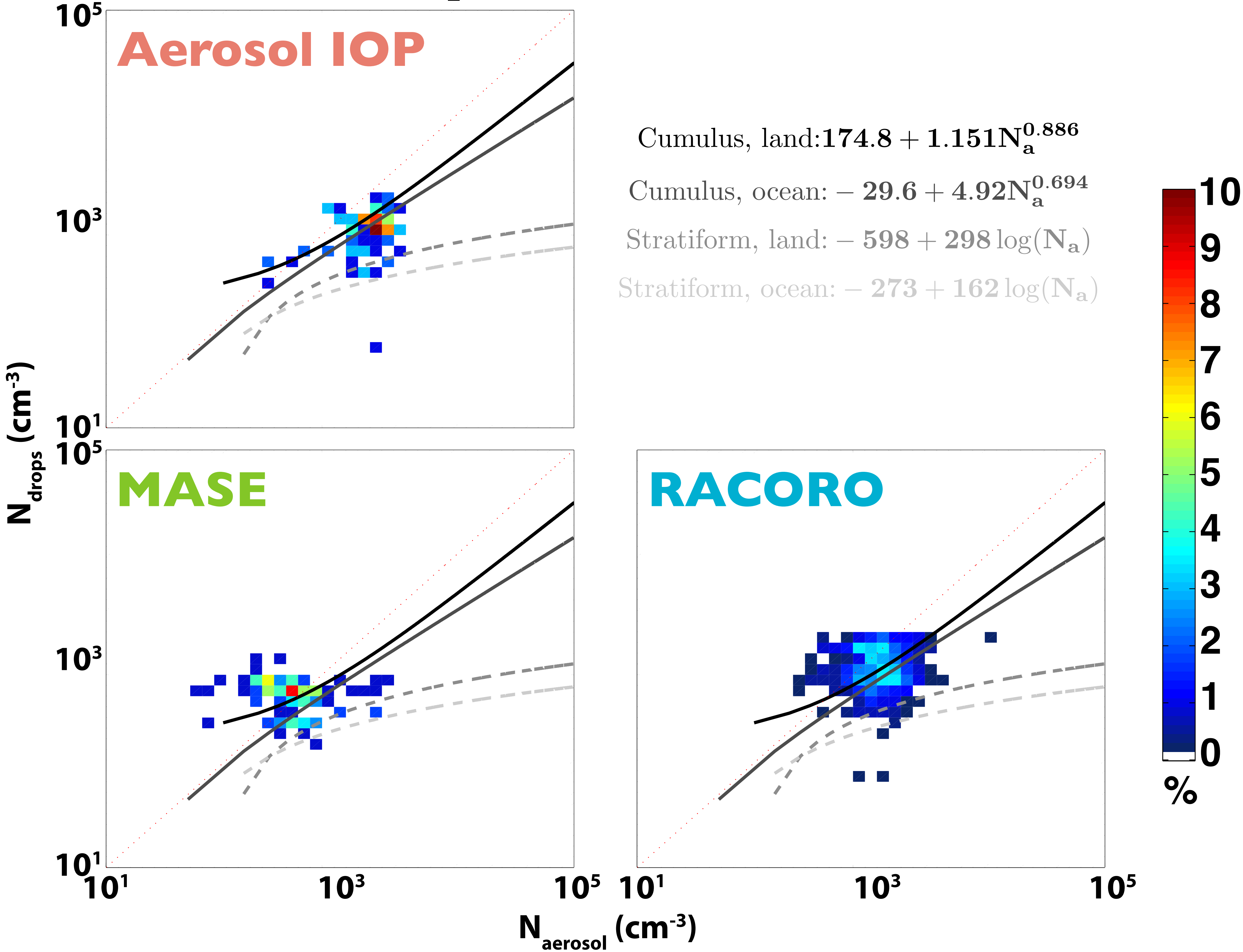


$$ACI_\tau = -\frac{\partial \ln r_e}{\partial \ln N_{CCN}}\bigg|_{LWC}$$

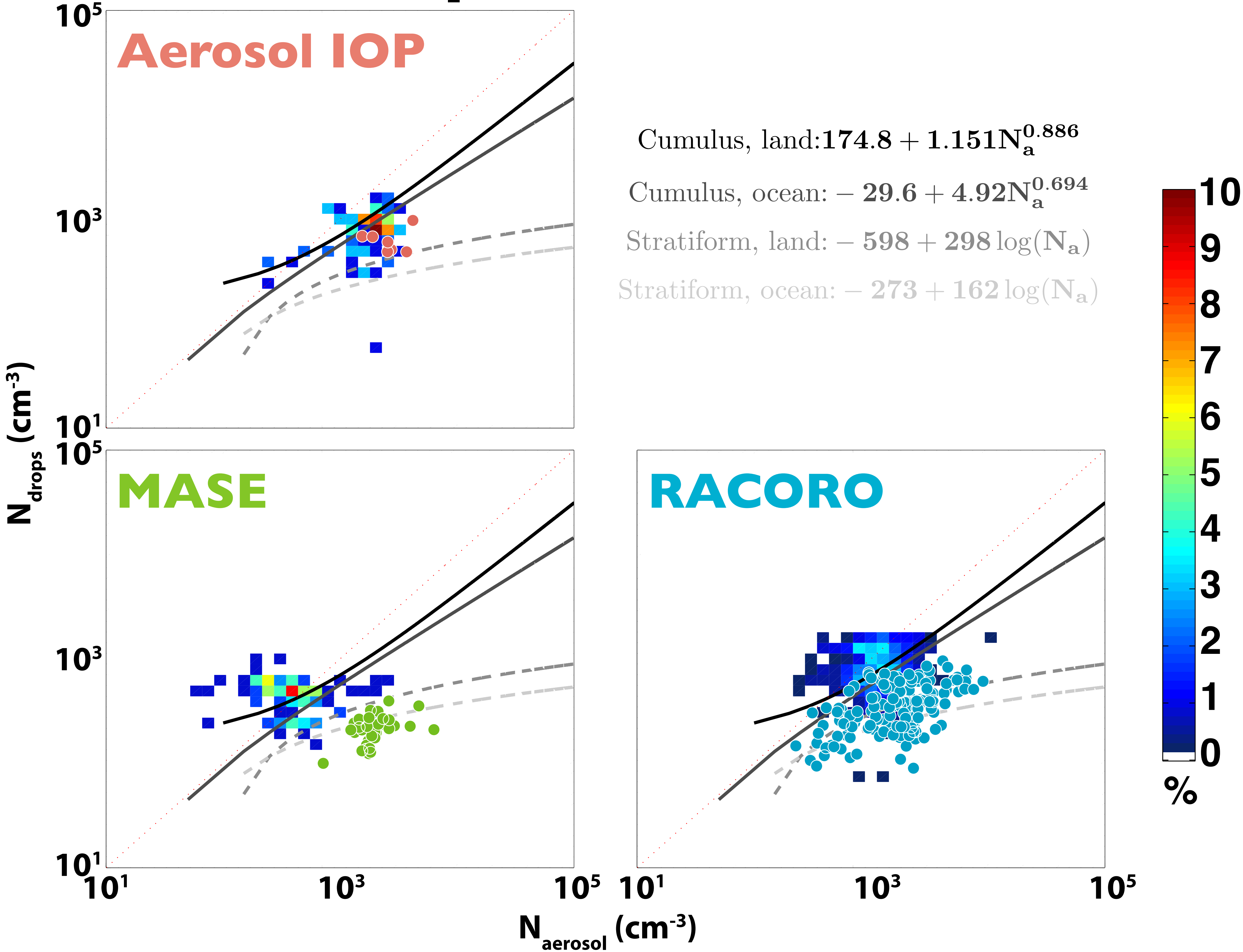
CCN$_{sfc}$ - R$_e$


MASRAD
(LWP<40) (40≤LWP<60) (60≤LWP<80)
(80≤LWP<100) (100≤LWP<120 gm⁻²) (LWP≥120)
0.58 0.84 0.46
0.22 0.32 0.22
7 hr. Aggregated Process
0.03 0.02 0.26
0.15 0.21 0.16
1 hr. Aggregated Process
0.23 0.70 0.61
0.27 0.26 0.20
From 7hr. Avg. COD, LWP, CCN
0.21 0.31 0.21
0.15 0.17 0.20
From 1hr. Avg. COD, LWP, CCN
Re
CCNsfc

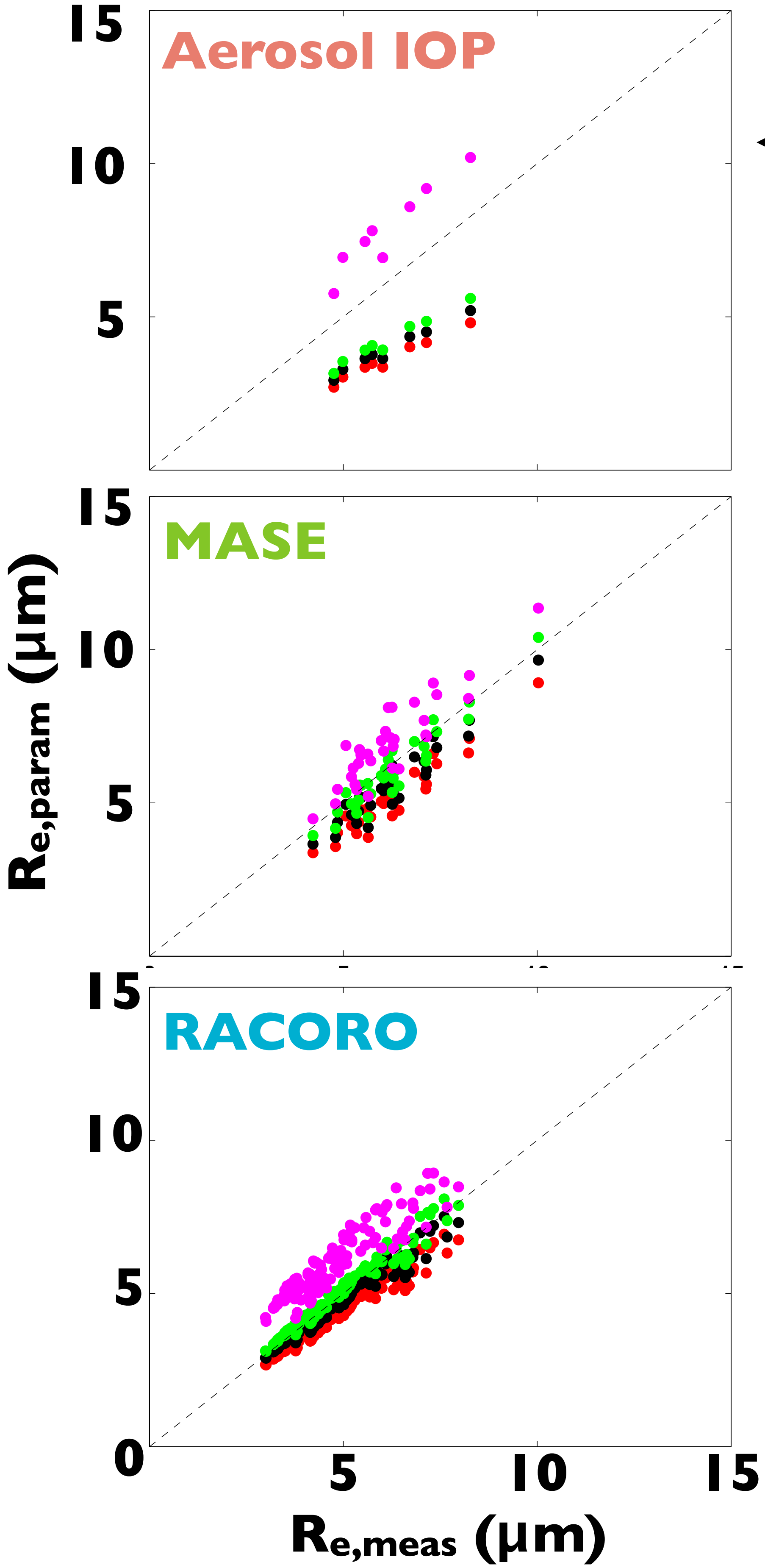
Droplet Activation



Droplet Activation



Effective Radius



Process Level

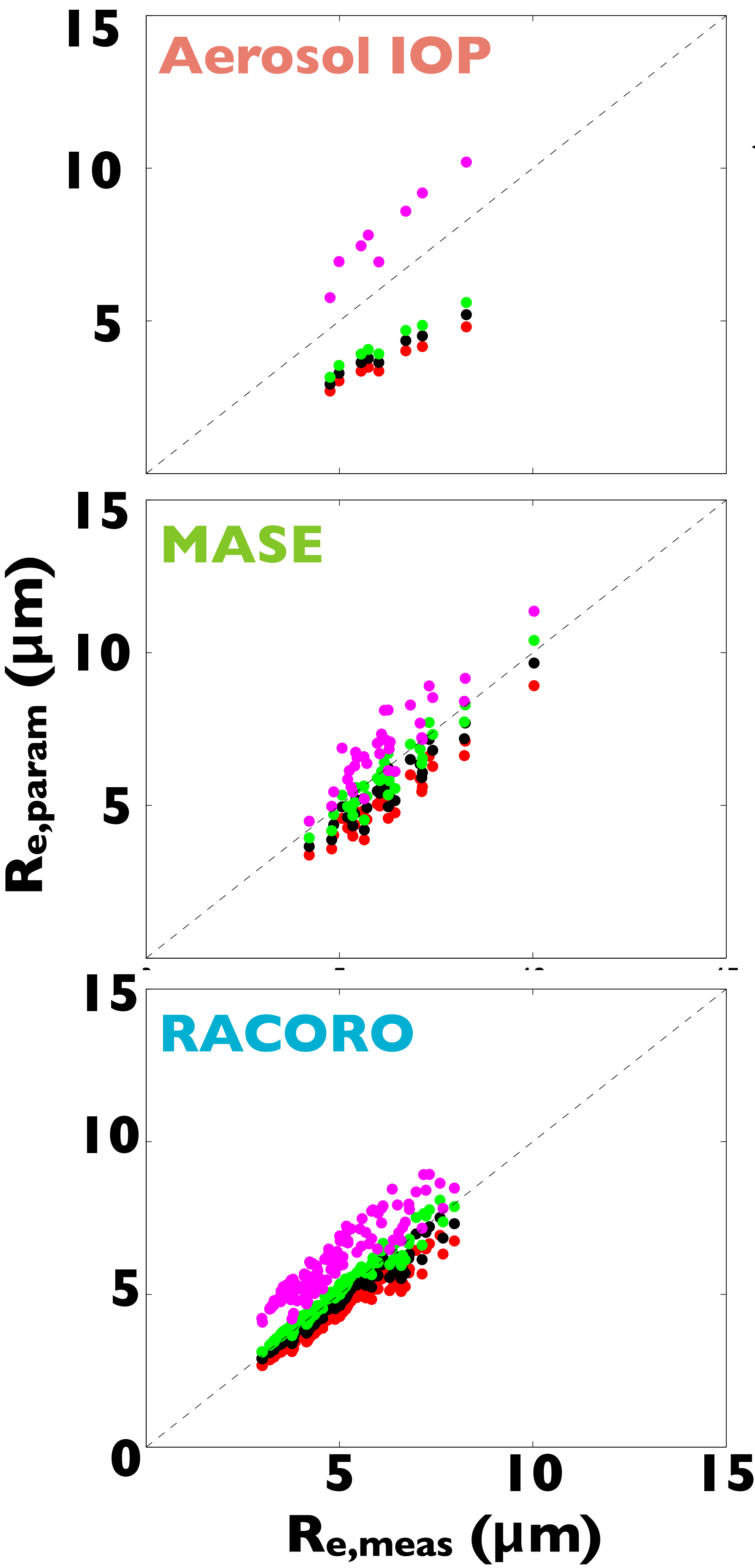
$$R_e = \beta R_v$$

$$R_e = 0.6 \left(\frac{LWC}{N_{liq}} \right)^{\frac{1}{3}}$$

$$R_e = 0.65 \left(\frac{LWC}{N_{liq}} \right)^{\frac{1}{3}}$$

$$R_e = 0.7 \left(\frac{LWC}{N_{liq}} \right)^{\frac{1}{3}}$$

Effective Radius



← Process Level

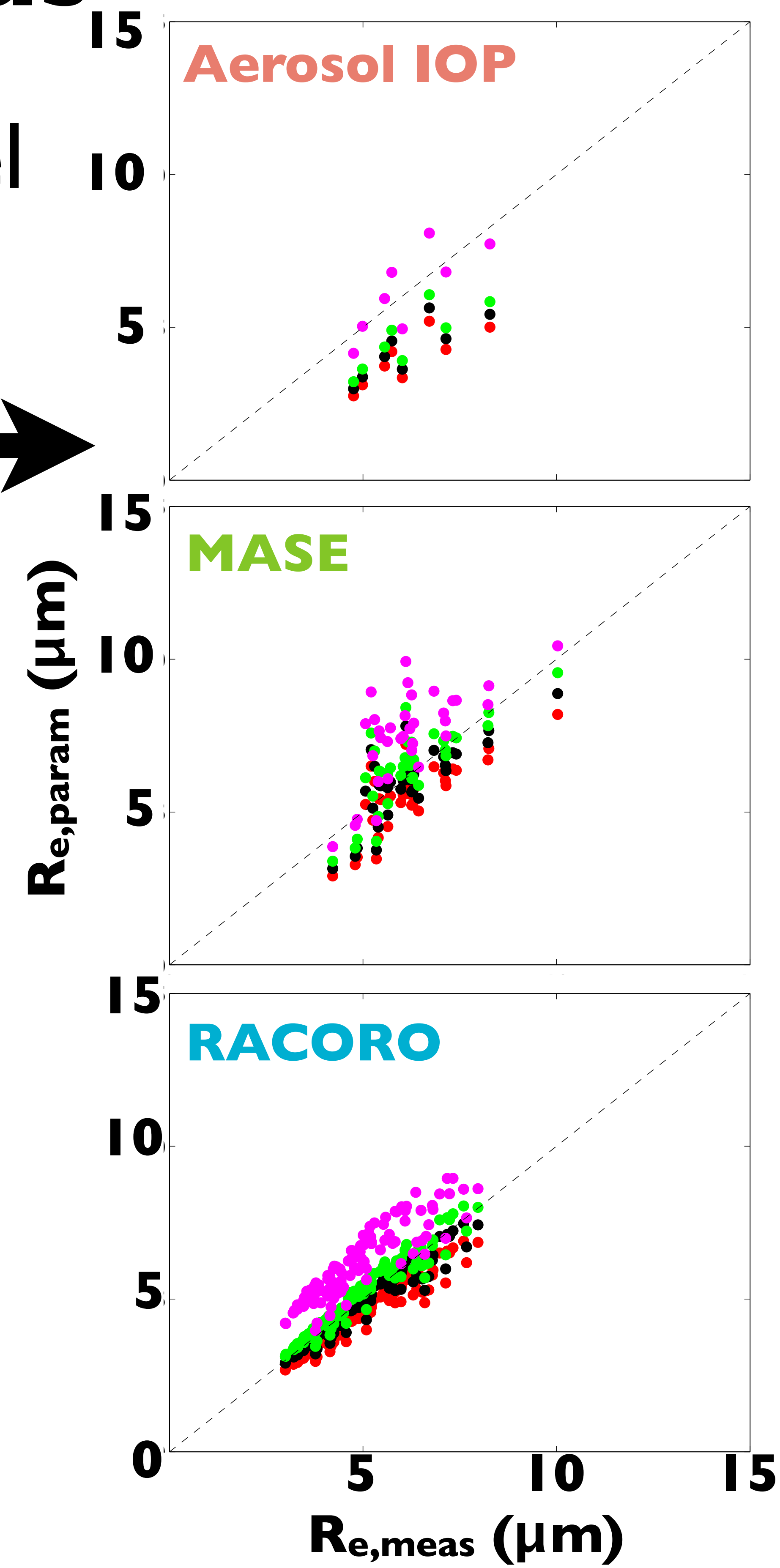
Gridscale Level →

$$R_e = \beta R_v$$

$$R_e = 0.6 \left(\frac{LWC}{N_{liq}}\right)^{\frac{1}{3}}$$

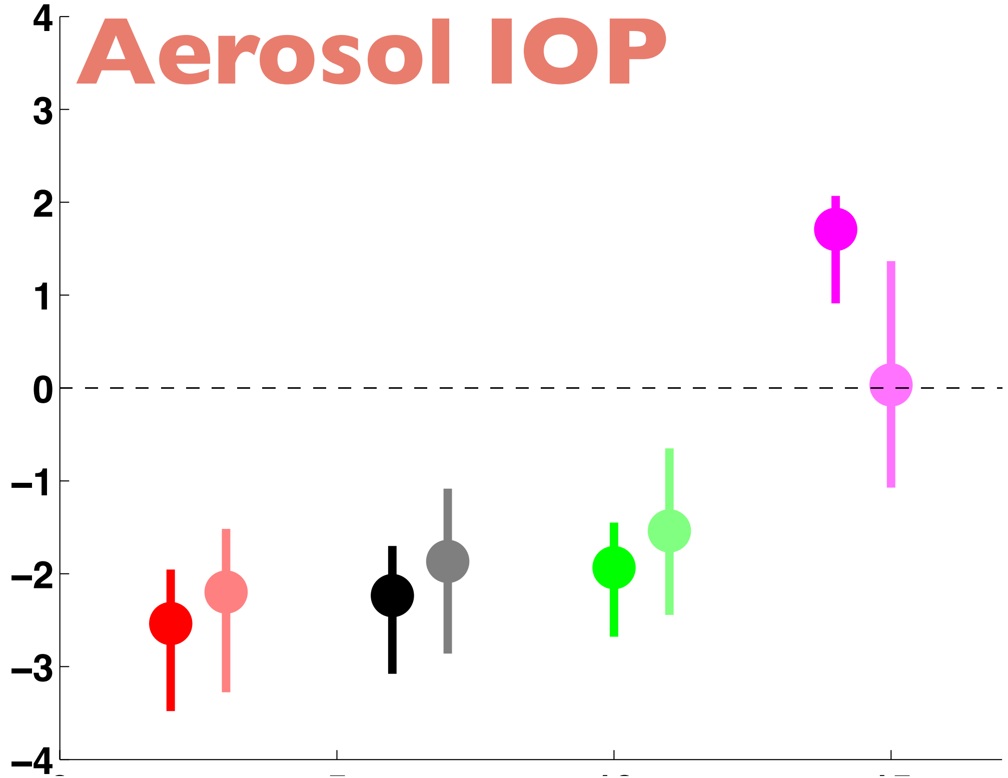
$$R_e = 0.65 \left(\frac{LWC}{N_{liq}}\right)^{\frac{1}{3}}$$

$$R_e = 0.7 \left(\frac{LWC}{N_{liq}}\right)^{\frac{1}{3}}$$



Effective Radius

Parameterization-Observation

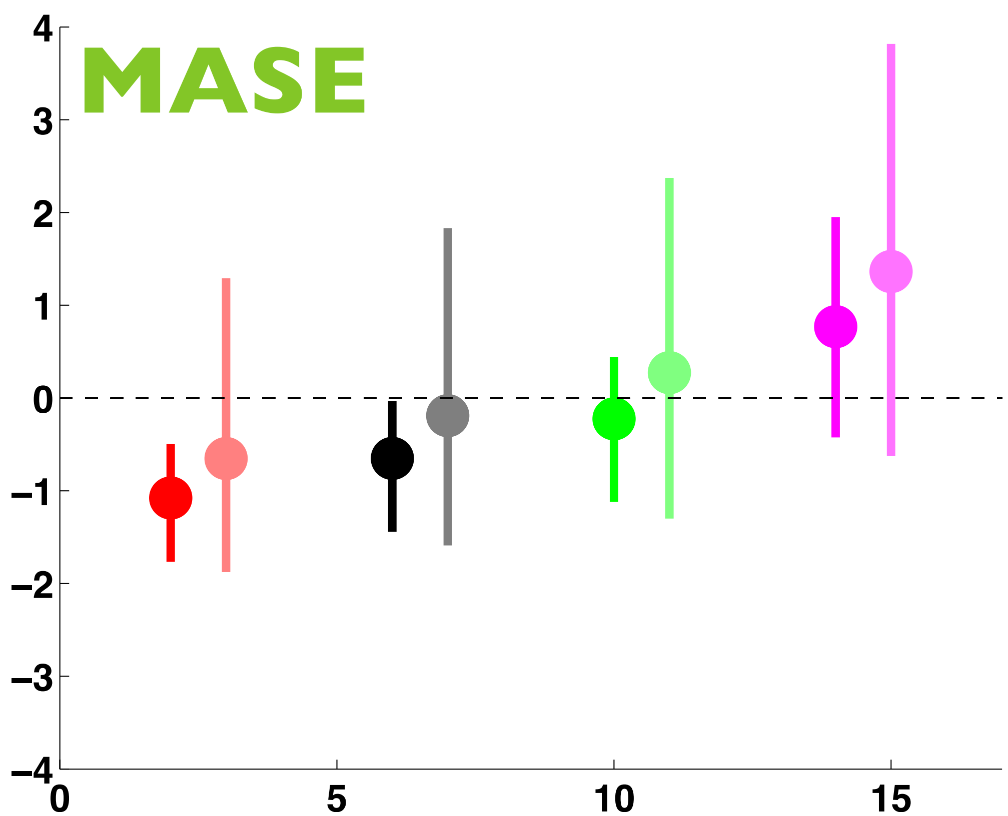


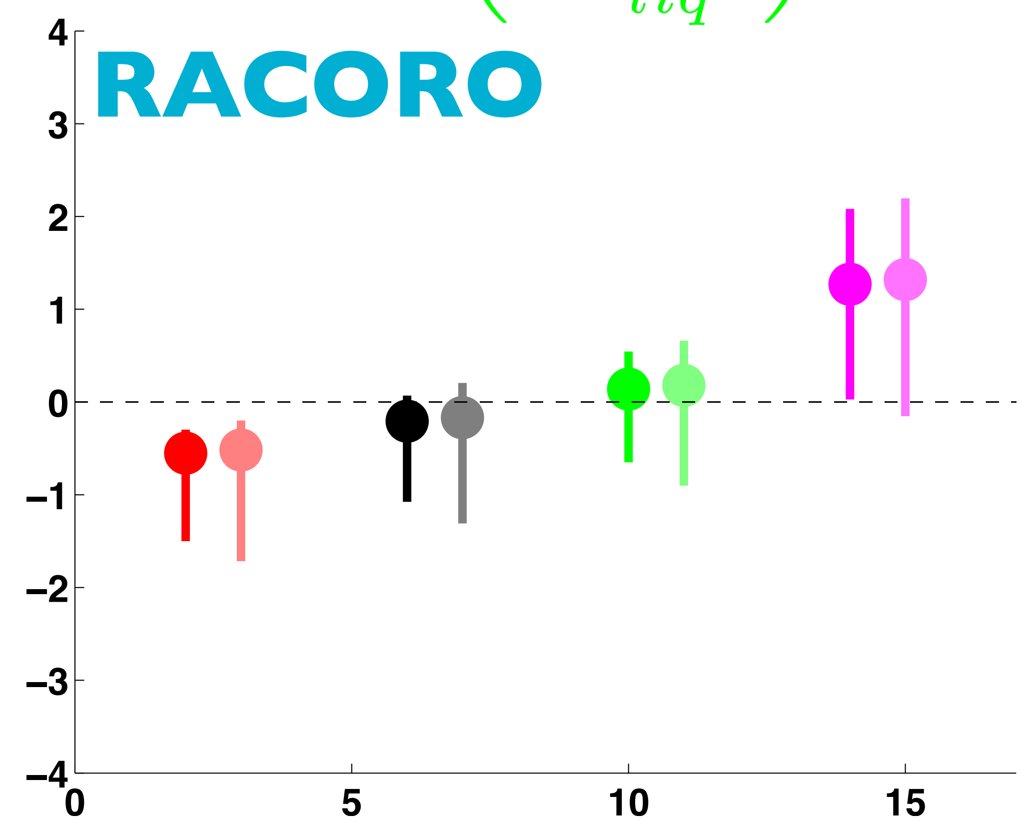
$$R_e = \beta R_v$$

$$R_e = 0.65 \left(\frac{LWC}{N_{liq}} \right)^{\frac{1}{3}}$$

$$R_e = 0.6 \left(\frac{LWC}{N_{liq}} \right)^{\frac{1}{3}}$$

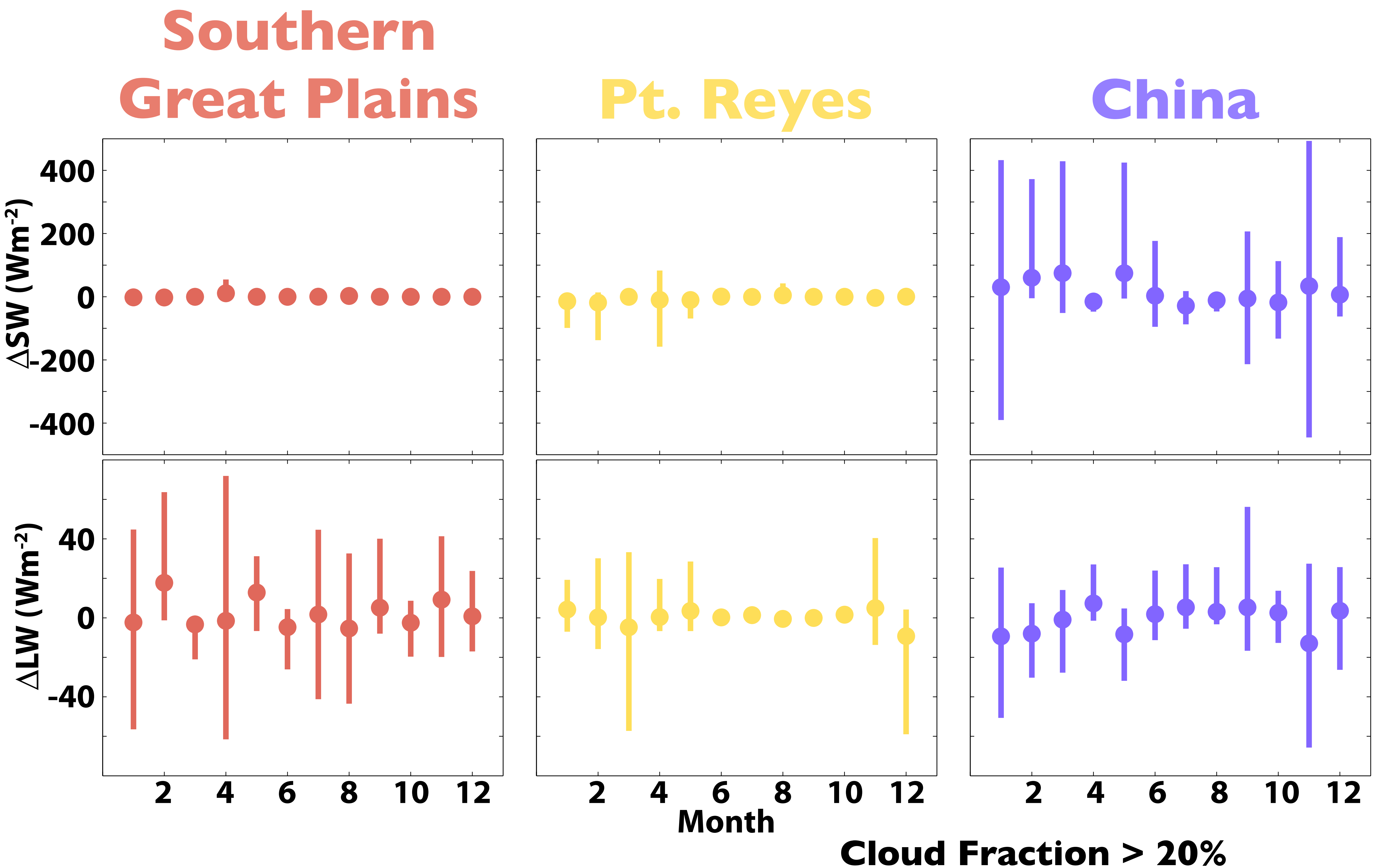
$$R_e = 0.7 \left(\frac{LWC}{N_{liq}} \right)^{\frac{1}{3}}$$





Process **Gridscale**

Global Impact



Summary

- The NASA GISS ModelE2 GCM is being evaluated using cloud and aerosol measurements from several ARM campaigns
- Issues of scale and sampling make a fair evaluation challenging as aggregation of measurements can result in altered (and sometimes non-physical!!) relationships
- These issues must continue to be addressed from the perspectives of observational campaign planning, simulation evaluation and parameterization development
- Scale-aware evaluation results in altered performance of specific parameterizations
- Minor changes to parameterizations may have large impacts on global climate

FUNDING:

U.S. DEPARTMENT OF ENERGY

FASTER
FAst-physics System TEstbed and Research

References

Bauer, S.E., S. Menon, D. Koch, T.C. Bond, and K. Tsigaridis (2010): A global modeling study on carbonaceous aerosol microphysical characteristics and radiative forcing. *Atmos. Chem. Phys.*, **10**, 7439-7456, doi:10.5194/acp-10-7439-2010.

Bauer, S.E., D. Wright, D. Koch, E.R. Lewis, R. McGraw, L.-S. Chang, S.E. Schwartz, and R. Ruedy (2008): MATRIX (Multiconfiguration Aerosol TRacker of mIXing state): An aerosol microphysical module for global atmospheric models. *Atmos. Chem. Phys.*, **8**, 6603-6035, doi:10.5194/acp-8-6003-2008.

Bower, K.N. and T.W. Choularton (1992): A parameterization of the effective radius of ice-free clouds for use in global climate models, *Atmos. Res.*, **27**, 305-339.

Liu, Y., and P. Daum (2002), Anthropogenic aerosols: Indirect warming effect from dispersion forcing, *Nature*, **419**, 580–581.

Liu, Y., and P. Daum (2000), Spectral dispersion of cloud droplet size distributions and the parameterization of cloud droplet effective radius, *Geophys. Res. Lett.*, **27**, 1903-1906.

Martin, G.M., D.W. Johnson, and A. Spice (1994): The measurement and paramterization of effective radius of droplets in warm stratocumulus clouds, *J. Atmos. Sci.*, **51**, 1823-1842.

McComiskey, A. and G. Feingold (2012): The scale problem in quantifying aerosol indirect effects, *Atmos. Chem. Phys.*, **12**, 1031-1049.

McComiskey, A., G. Feingold, A. S. Frisch, D. D. Turner, M. A. Miller, J. C. Chiu, Q. Min, and J. A. Ogren (2009), An assessment of aerosol-cloud interactions in marine stratus clouds based on surface remote sensing, *J. Geophys. Res.*, **114**, D09203, doi: 10.1029/2008JD011006.

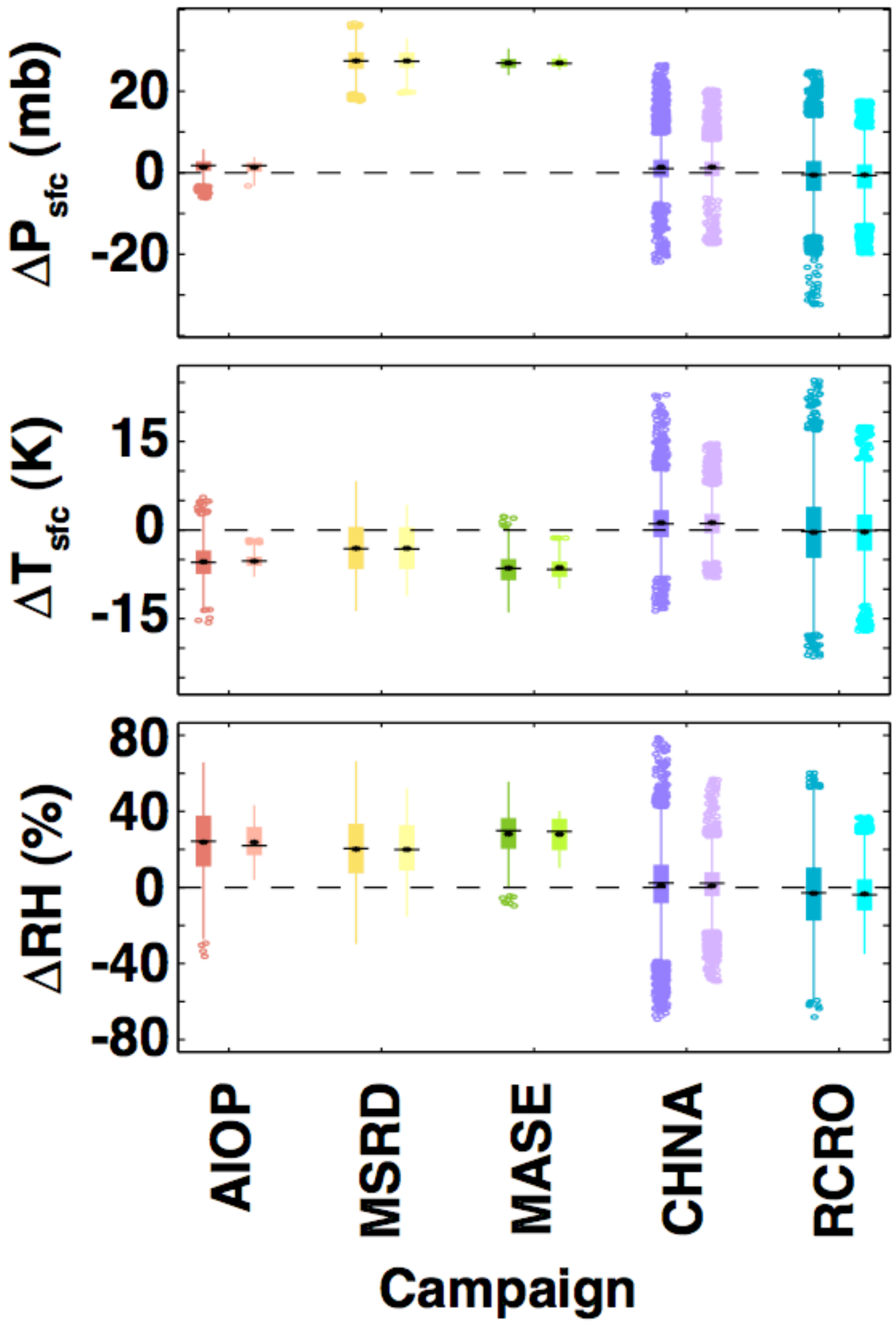
Menon, S., A.D. Del Genio, Y. Kaufman, R. Bennartz, D. Koch, N. Loeb and D. Orlikowski (2008): Analyzing signatures of aerosol-cloud interactions from satellite retrievals and the GISS GCM to constrain the aerosol indirect effect, *J. Geophys. Res.*, **113**, D14S22, doi:10.1029/2007JD009442.

Menon, S., D. Koch, G. Beig, S. Sahu, J. Fasullo and D. Orlikowski (2010): Black carbon aerosols and the third polar ice cap, *Atmos. Chem. Phys.* , 10, 4559-4571

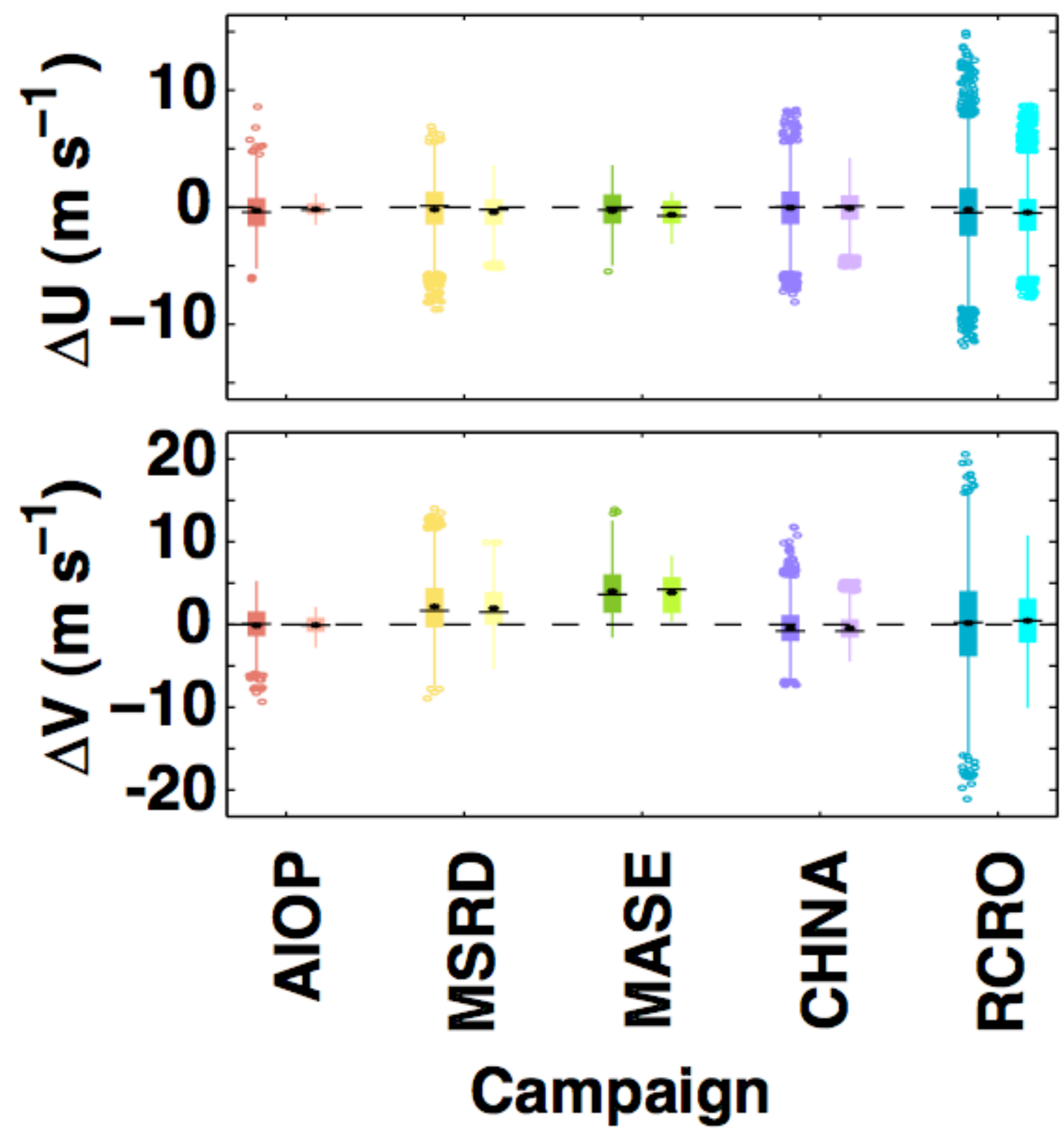
Extra Slides

|
|
v

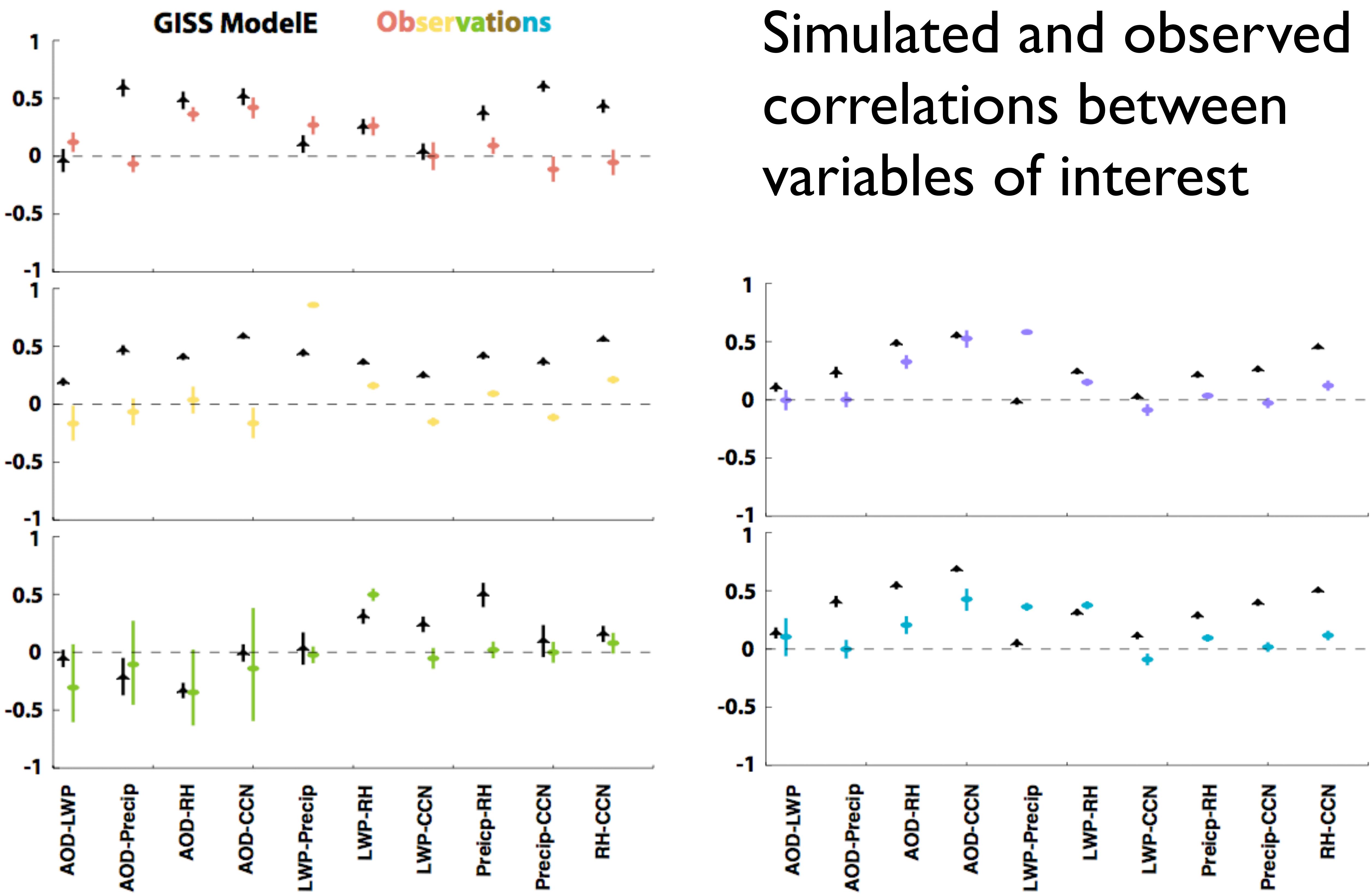
Meteorology



Differences between observed and simulated meteorological quantities

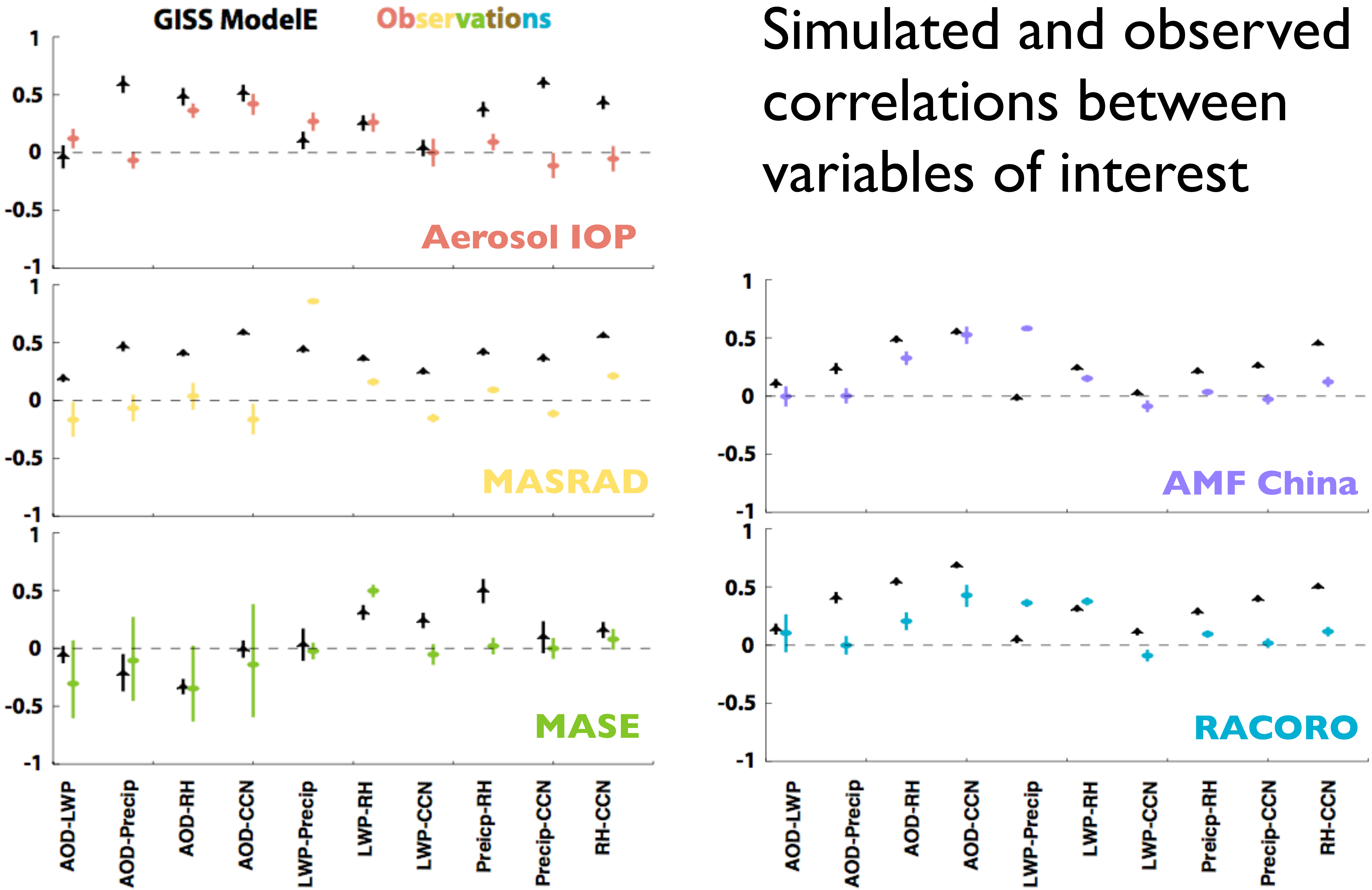


Correlations



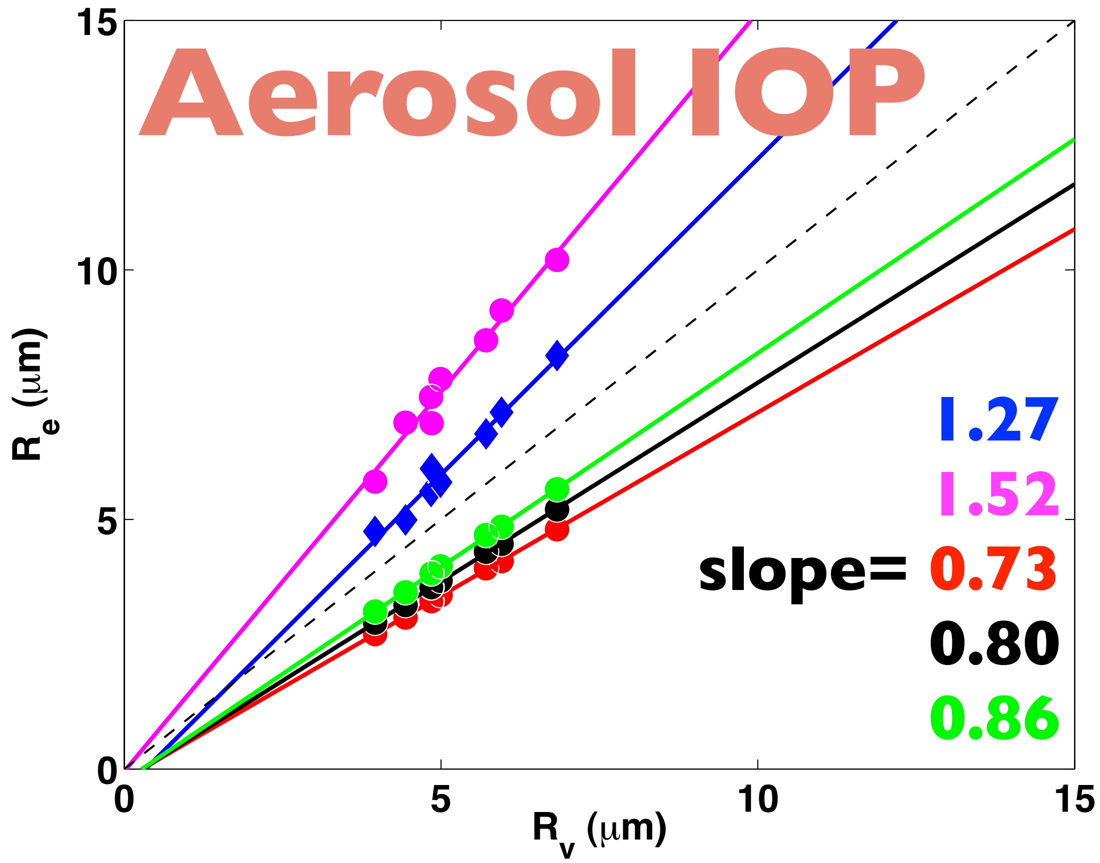
Simulated and observed correlations between variables of interest

Correlations



Simulated and observed correlations between variables of interest

Effective Radius



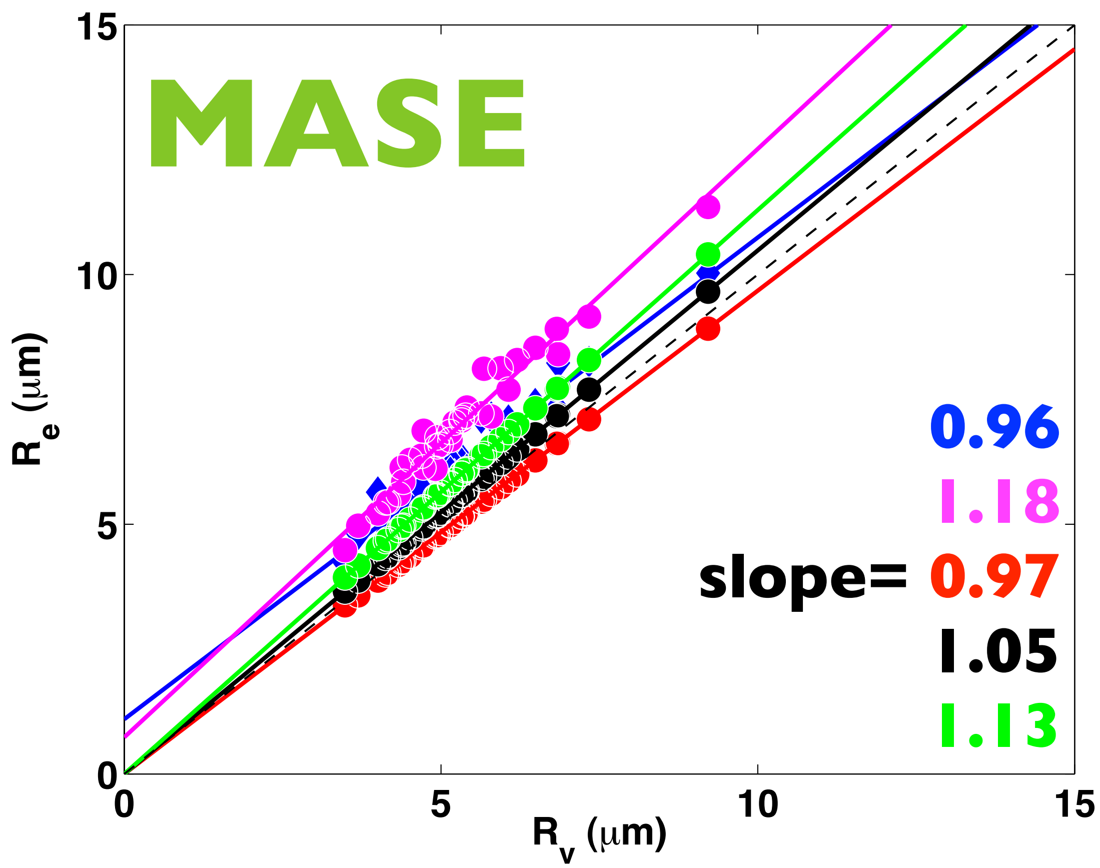
Measured R_e

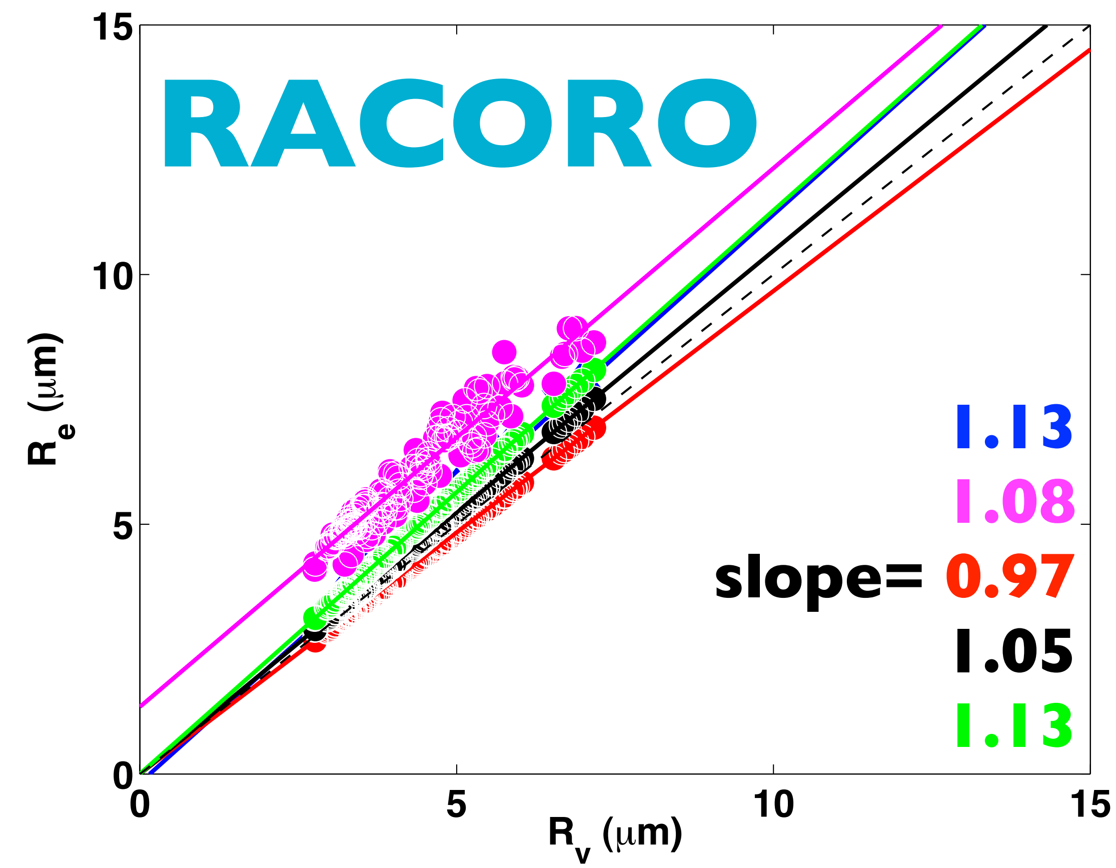
$R_e = \beta R_v$

$R_e = 0.6\ (LWC/N)^{1/3}$

$R_e = 0.65\ (LWC/N)^{1/3}$

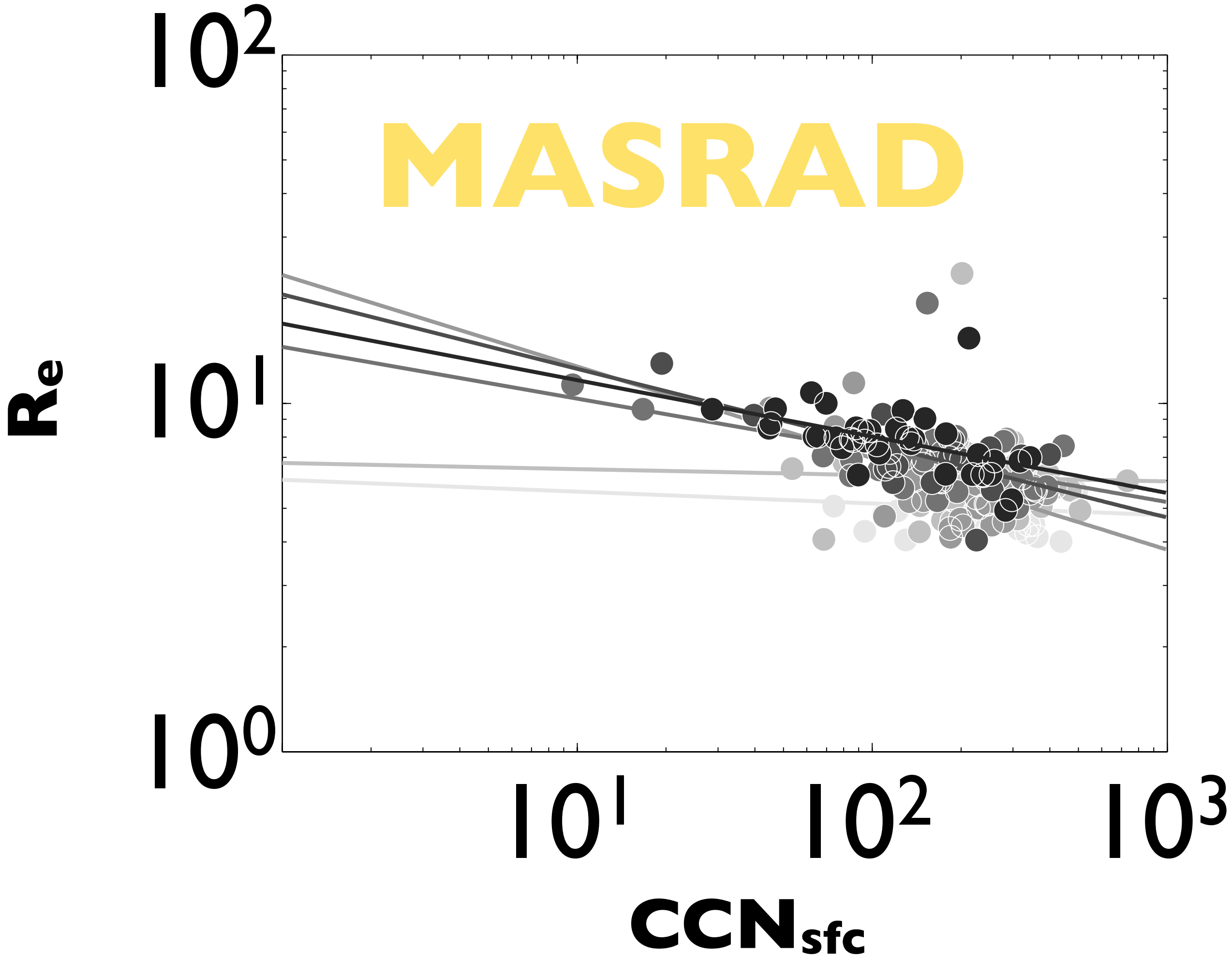
$R_e = 0.7\ (LWC/N)^{1/3}$

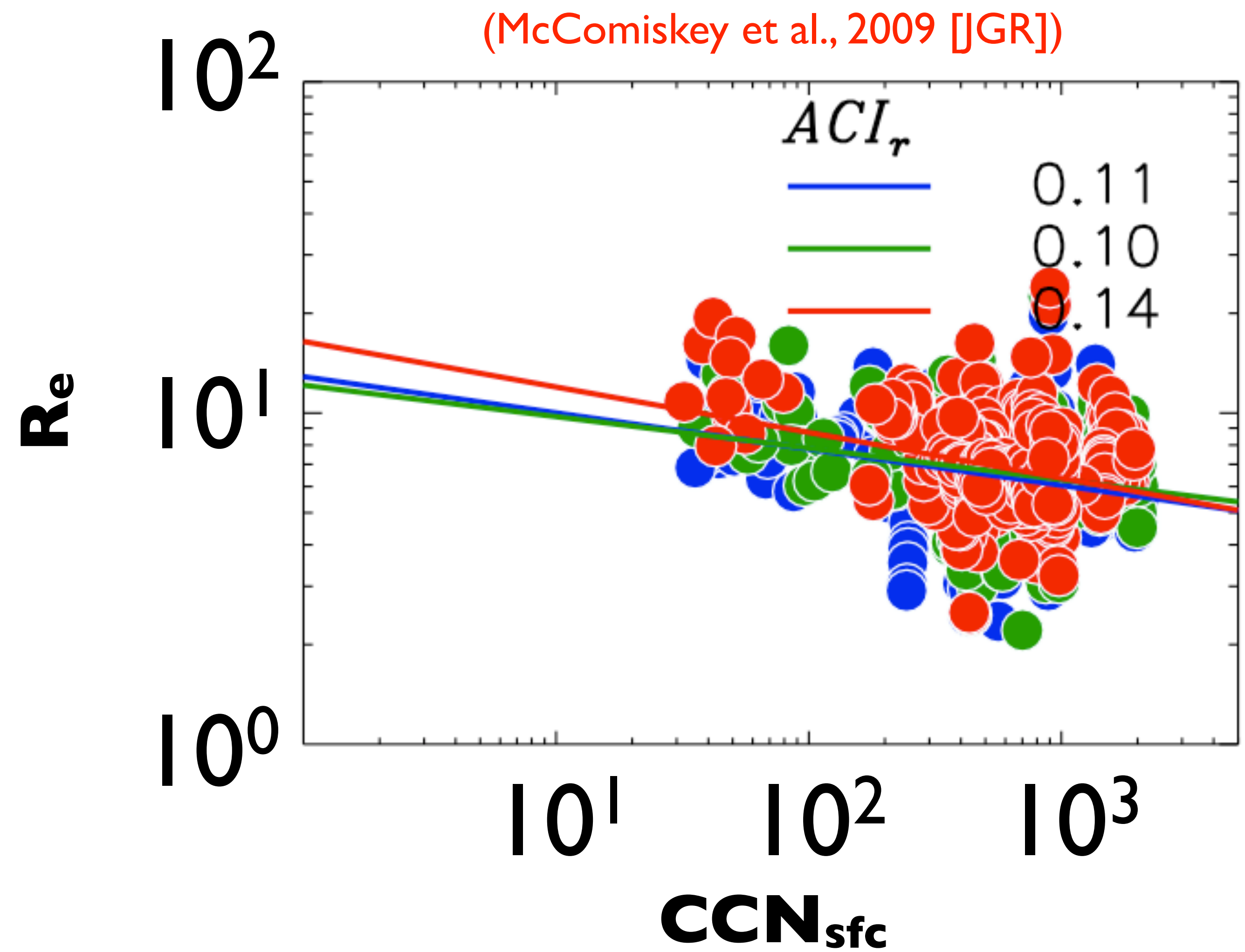




$$ACI_\tau = -\left.\frac{\partial \ln r_e}{\partial \ln N_{CCN}}\right|_{LWC}$$

CCN_{sfc} - R_e





0.03 (LWP<40)

0.02 (40≤LWP<60)

0.26 (60≤LWP<80)

0.15 (80≤LWP<100)

0.21 (100≤LWP<120 gm^{-2})

0.16 (LWP≥120)

0.11 (107≤LWP<118)

0.10 (118≤LWP<130 gm^{-2})

0.14 (130≤LWP<143 gm^{-2})

Effective Radius

$$R_e = \frac{\int_{r_1}^{r_2} \pi r^3 n(r) dr}{\int_{r_1}^{r_2} \pi r^2 n(r) dr}$$

Effective Radius

$$R_e = \frac{\int_{r_1}^{r_2} \pi r^3 n(r) dr}{\int_{r_1}^{r_2} \pi r^2 n(r) dr}$$

$$R_e = \alpha \left(\frac{LWC}{N_{liq}} \right)^{\frac{1}{3}}$$

α= 62.04 (Bower and Choularton, 1992 [Atmos. Res.])

66.83 (Martin et al., 1994 [JAS])

70.89

Effective Radius

$$R_e = \frac{\int_{r_1}^{r_2} \pi r^3 n(r) dr}{\int_{r_1}^{r_2} \pi r^2 n(r) dr}$$

$$R_e = \alpha \left(\frac{LWC}{N_{liq}} \right)^{\frac{1}{3}}$$

α= 62.04 (Bower and Choularton, 1992 [Atmos. Res.])

66.83

70.89 (Martin et al., 1994 [JAS])

$$R_e = \beta R_v \qquad R_v = \left(\frac{3LWC}{4N_{liq}\pi\rho_l} \right)^{\frac{1}{3}}$$

(Liu and Daum, 2002 [Nature])

$$\beta = \frac{\left(1 + 2\left(1 - 0.7exp\left(-0.003N_{liq}\right)\right)^2\right)^{\frac{2}{3}}}{\left(1 + 2\left(1 - 0.7exp\left(-0.003N_{liq}\right)\right)^2\right)^{\frac{1}{3}}}$$