Mesoscale Organization of Trade Cumulus Cloud Fields Buffers The Net Radiative Effect of Microphysical Variability

Pouriya Alinaghi
With
Franziska Glassmeier and Pier Siebesma

Cloud SW cooling is substantially compensated by their LW warming.

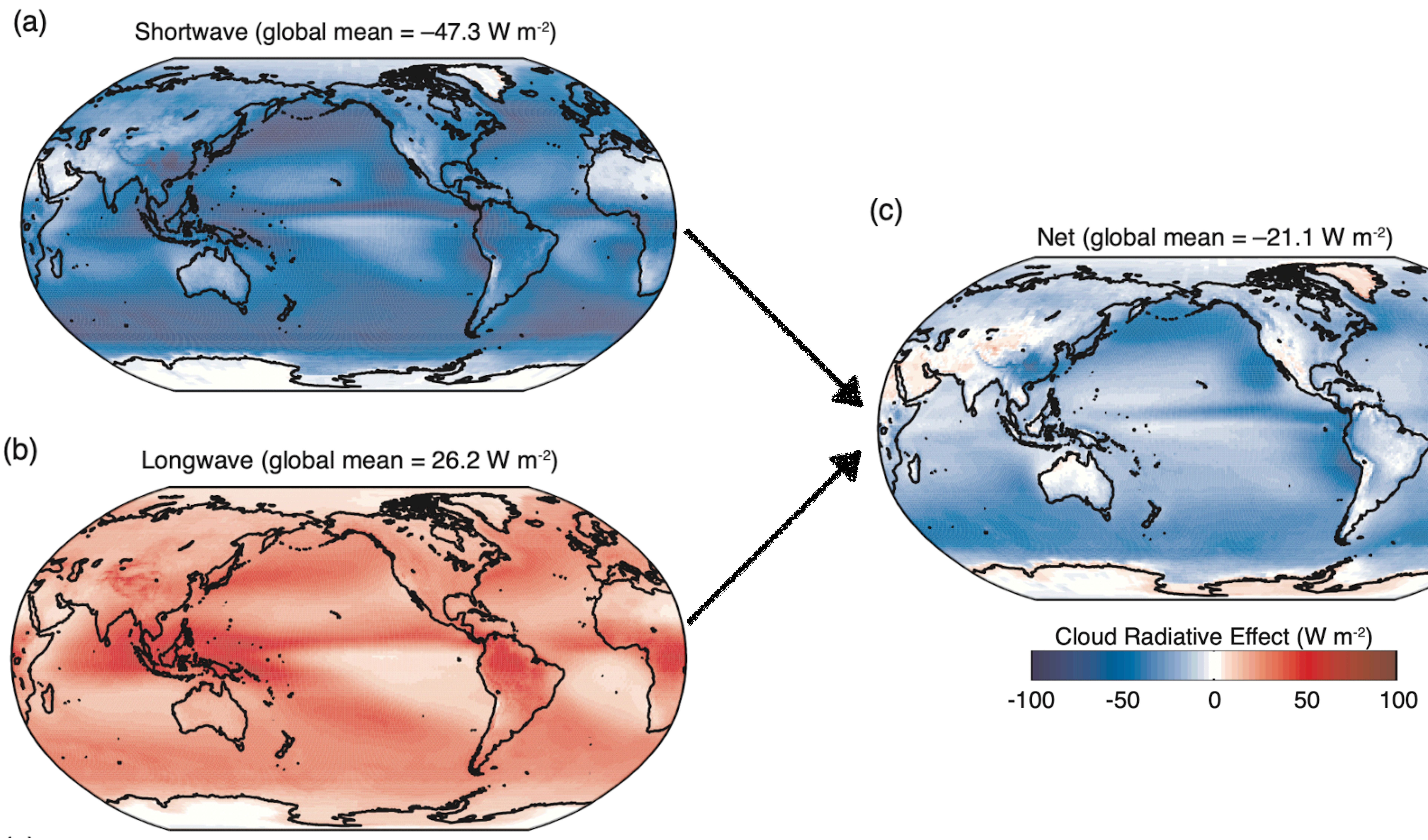
Motivation

Data

Methods

Results

Discussions & Conclusions



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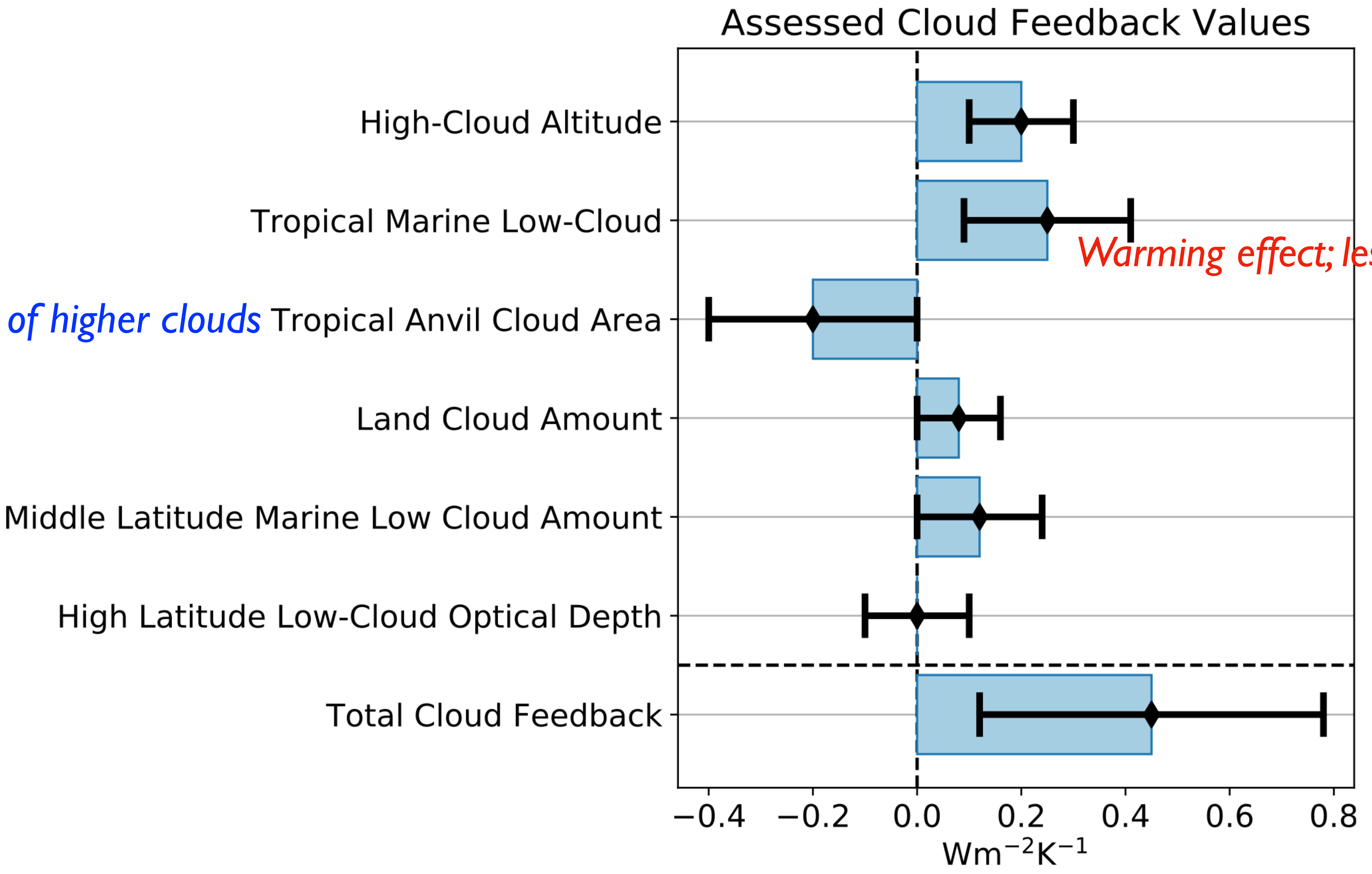
AR5, Chapter 7

Cloud feedback has compensating contributions.



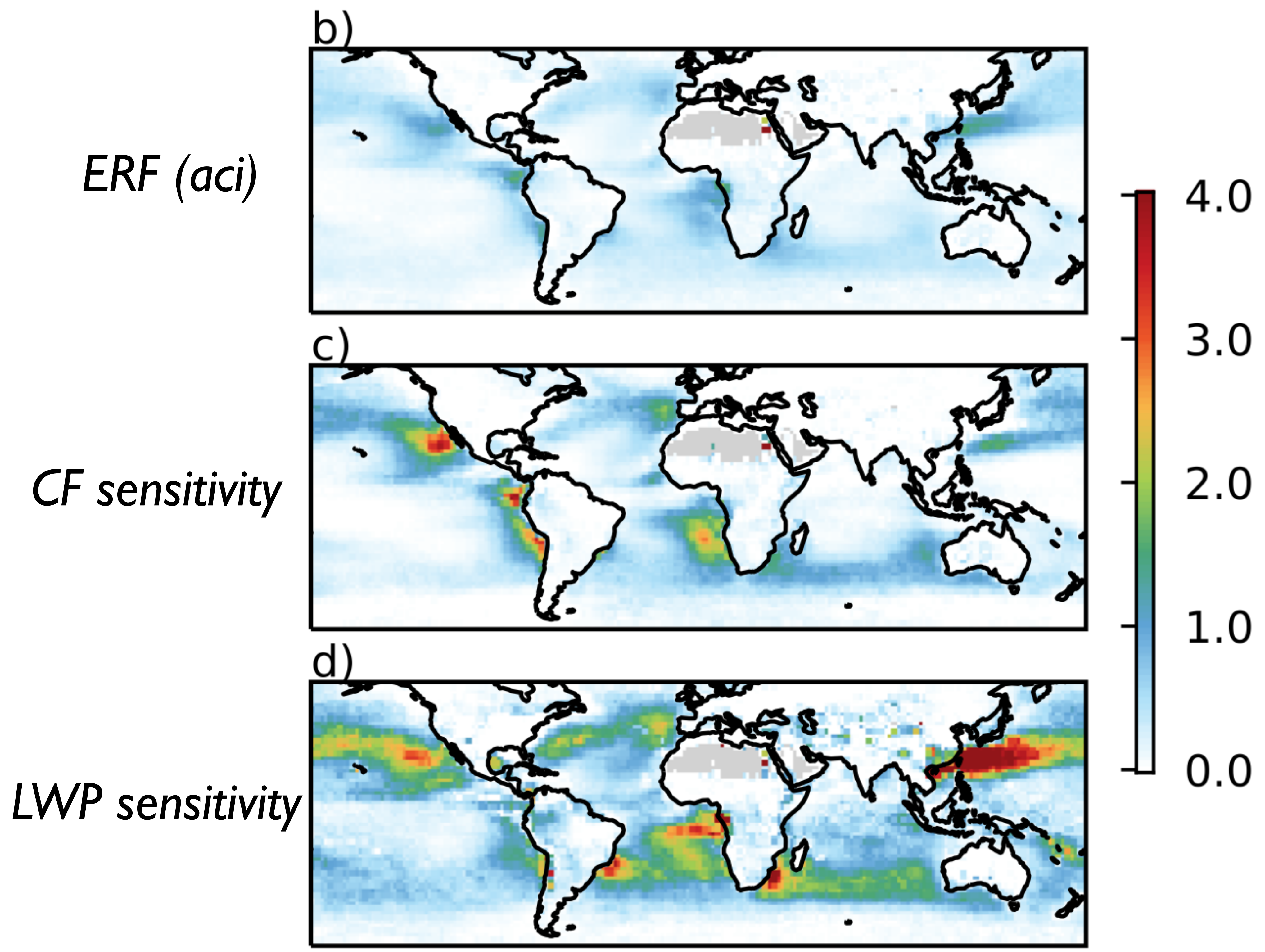
Warming effect; less reflection of low clouds

Cooling effect; less emission of higher clouds

Sherwood et al. (2020)

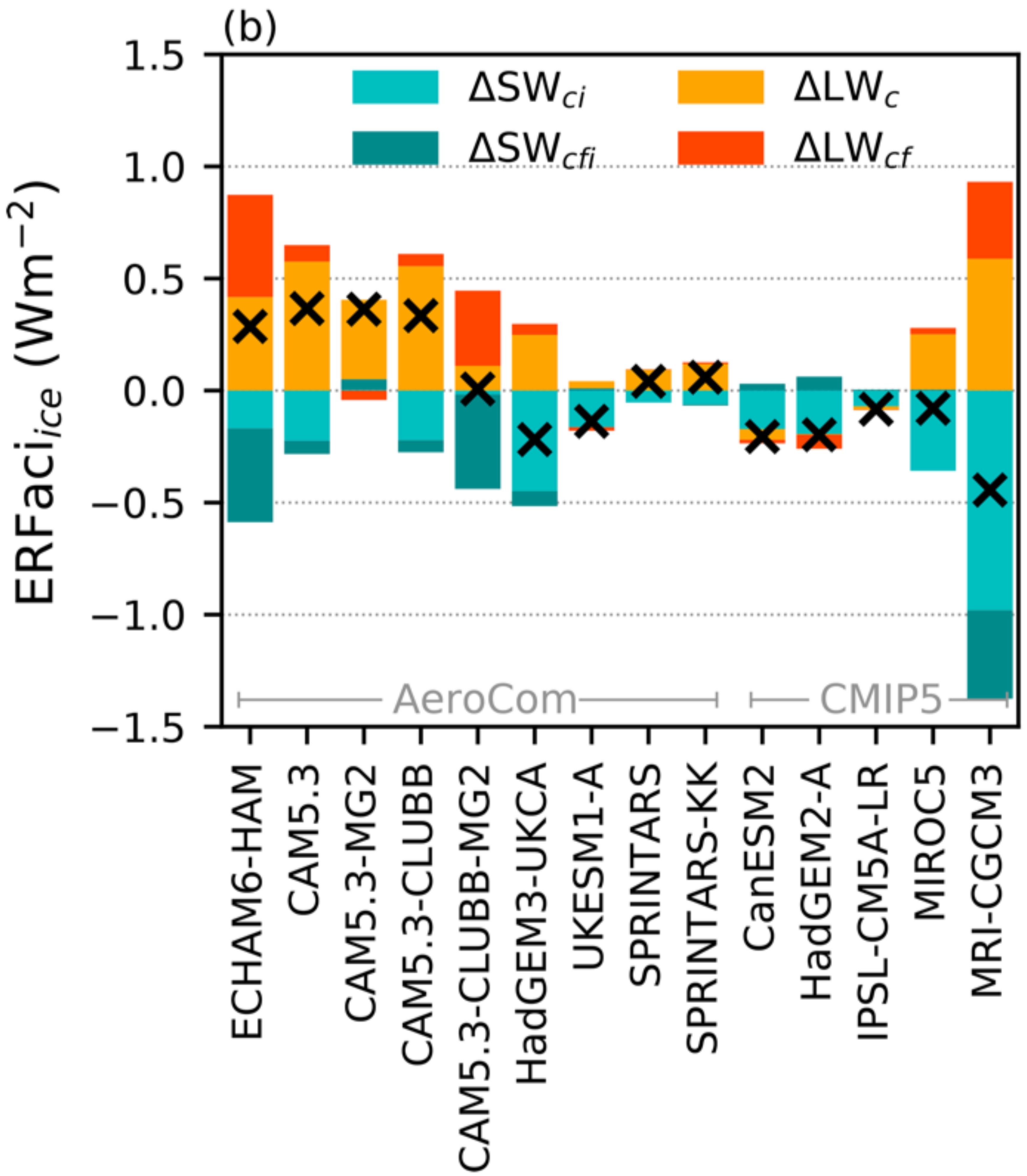
Effective radiative forcing due to aerosol-cloud interactions has two opposing effects.

Cooling effect on liquid clouds



Bellouin et al. (2020)

Warming effect on ice clouds



Gryspeerdt et al. (2020)

SW-LW compensation occurs at the level of individual cloud fields.

$$SW\ CRE = f(CF, COD)$$

$$LW\ CRE = f(CF, CTT) \approx f(CF, CTH)$$

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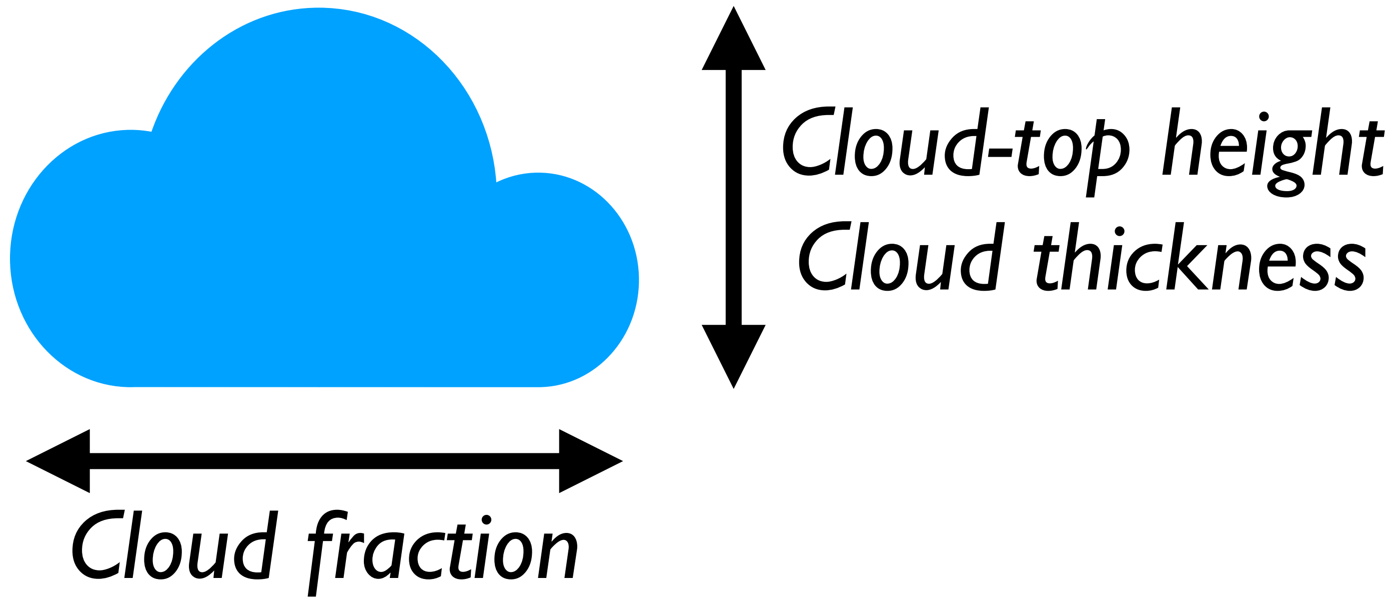

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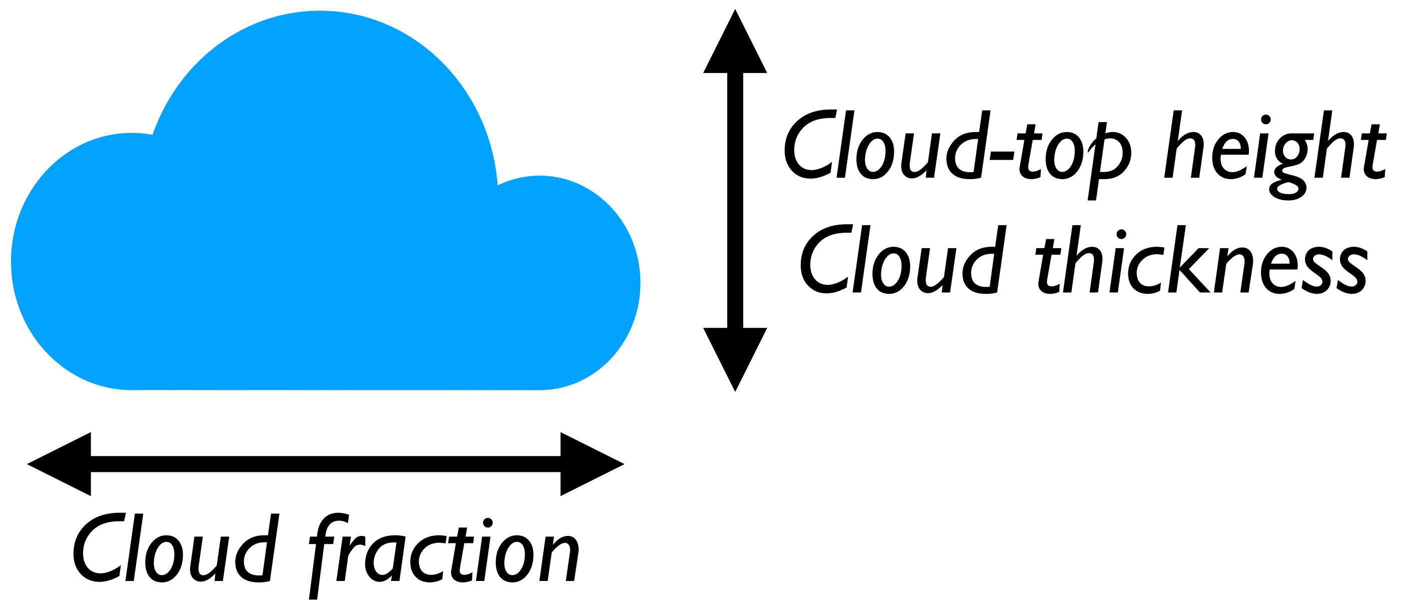

Clouds' horizontal and vertical dimensions do not independently respond to cloud-controlling factors

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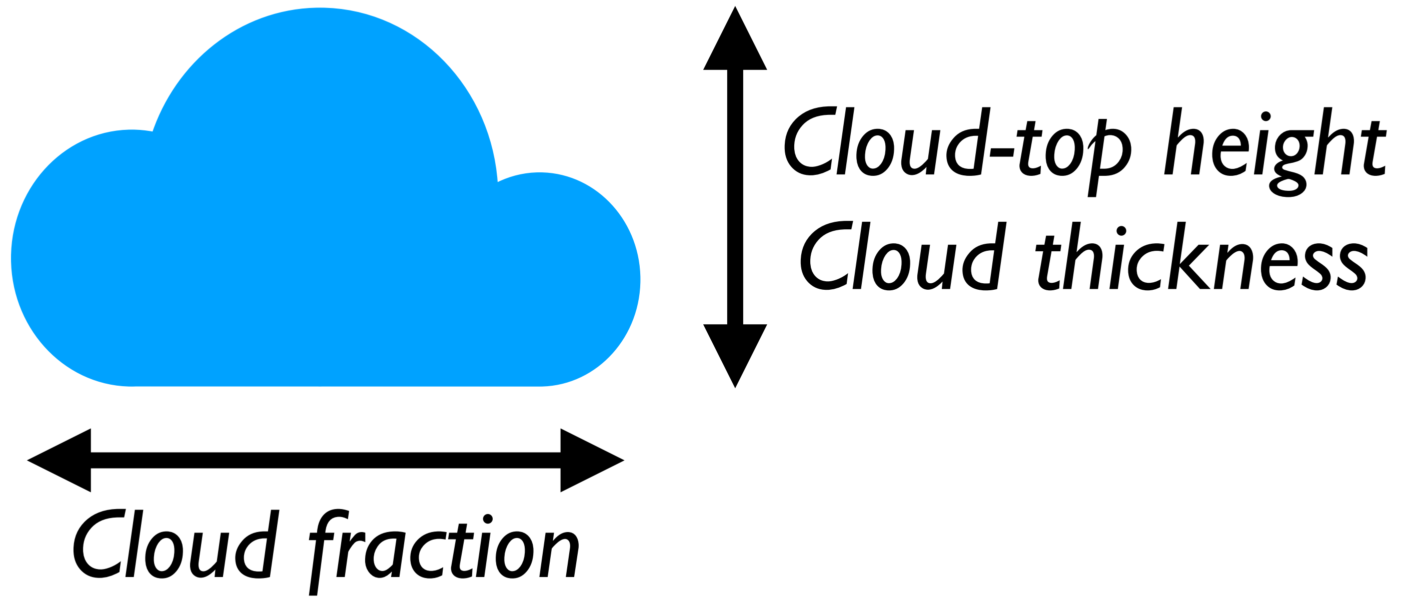
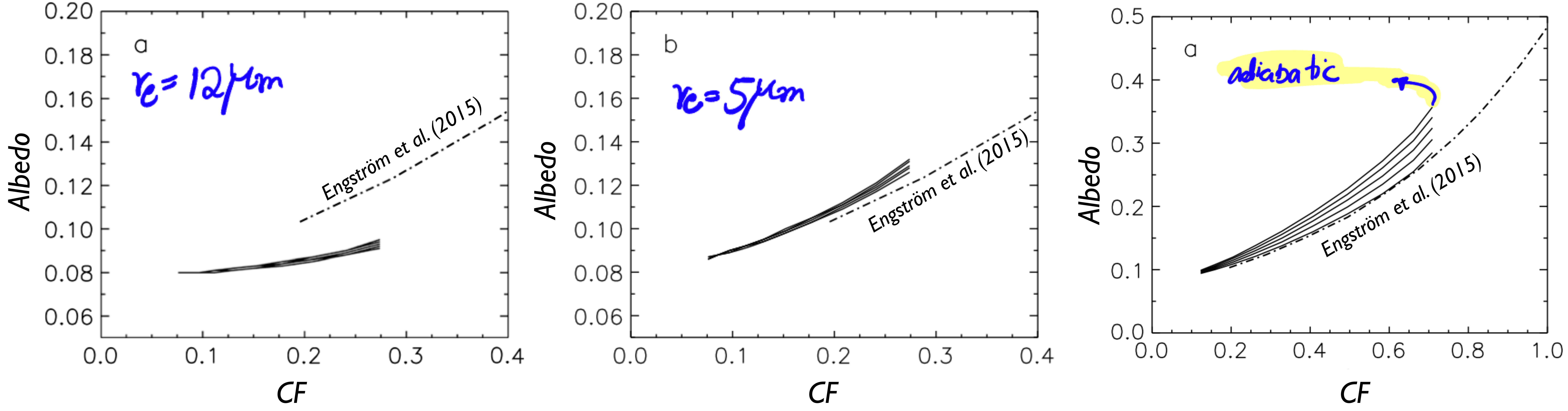


Clouds' horizontal and vertical dimensions do not independently respond to cloud-controlling factors

Example: albedo-cloud-fraction

Effective radius

Adiabaticity



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Feingold et al. (2017)

What's the effect of organization on cloud radiative effect?

Shallow Cumuli

Stratocumulus Clouds

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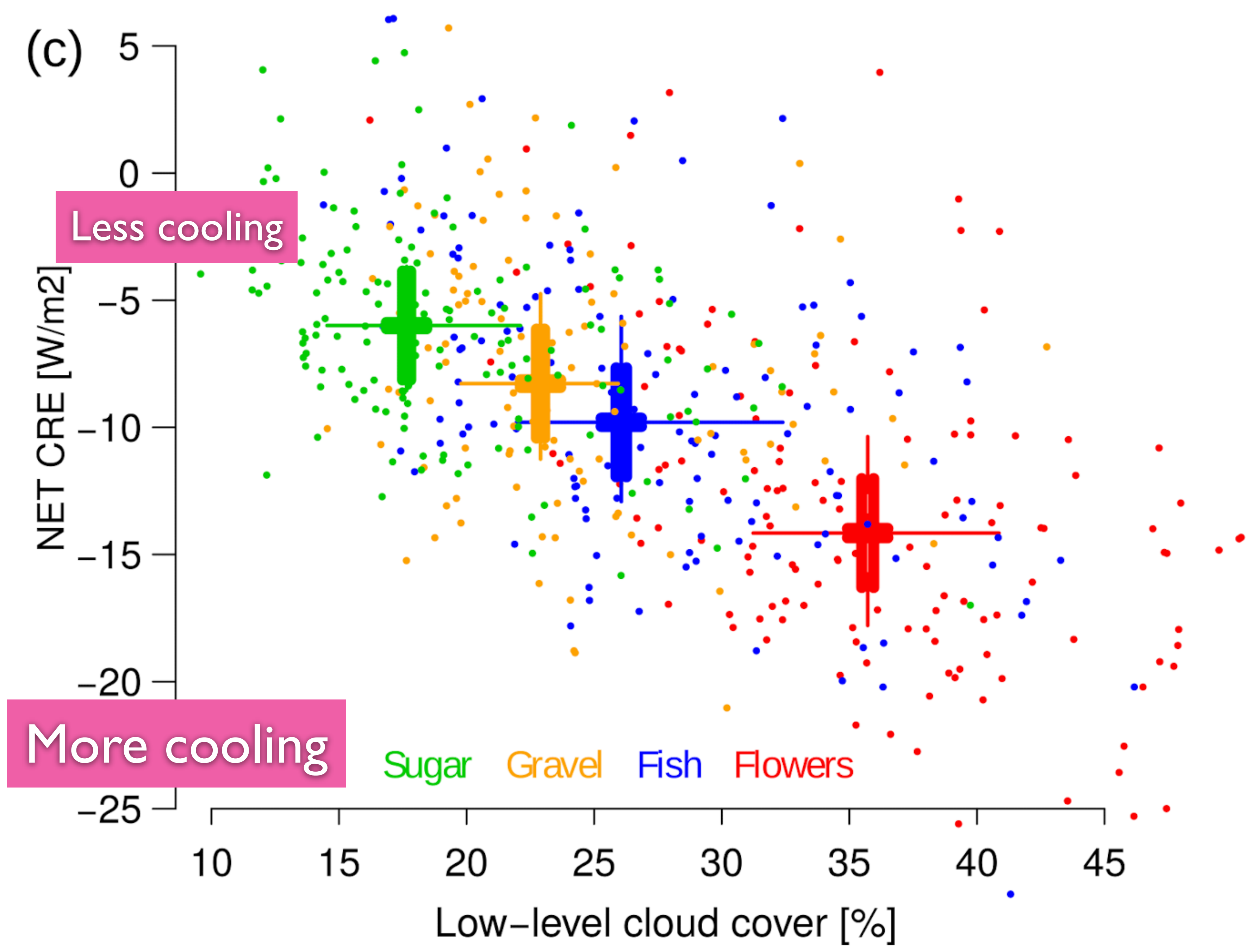
Bony et al, (2020), satellite:



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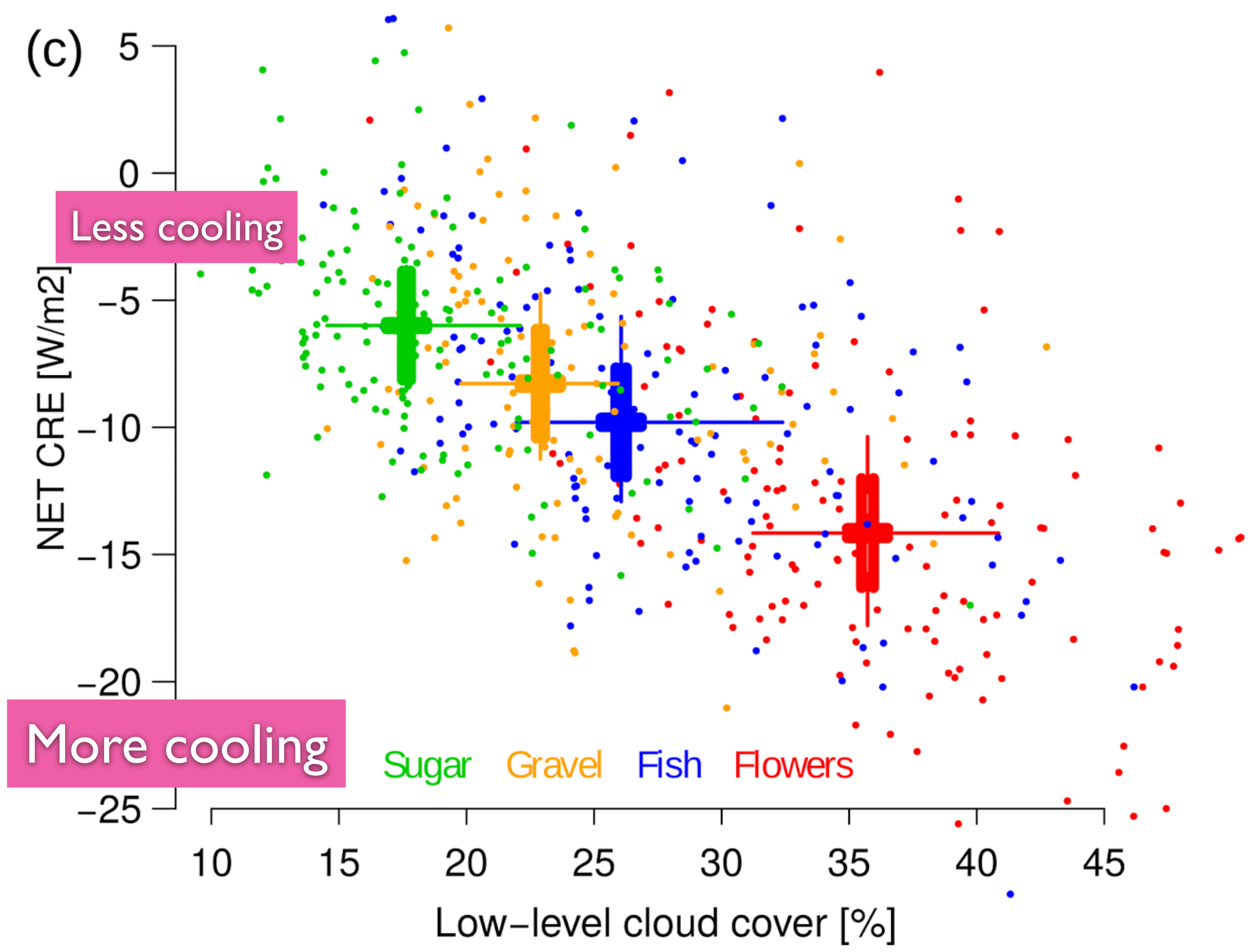
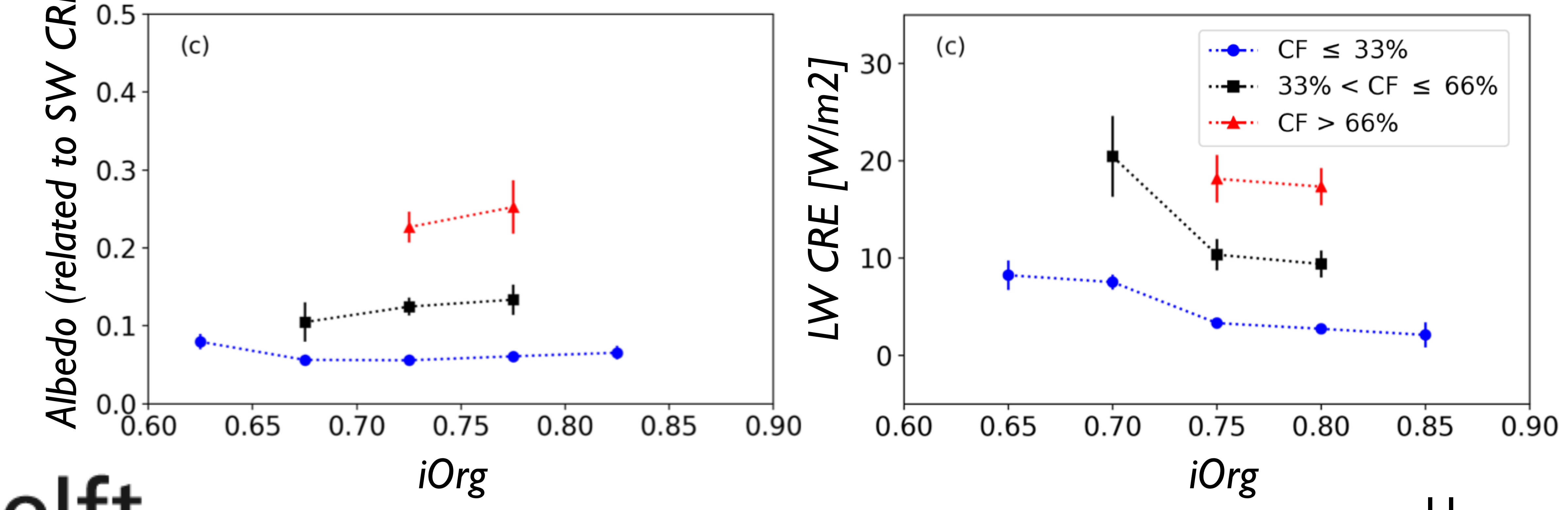


Luebke et al. (2022), satellite and EUREC4A observations:



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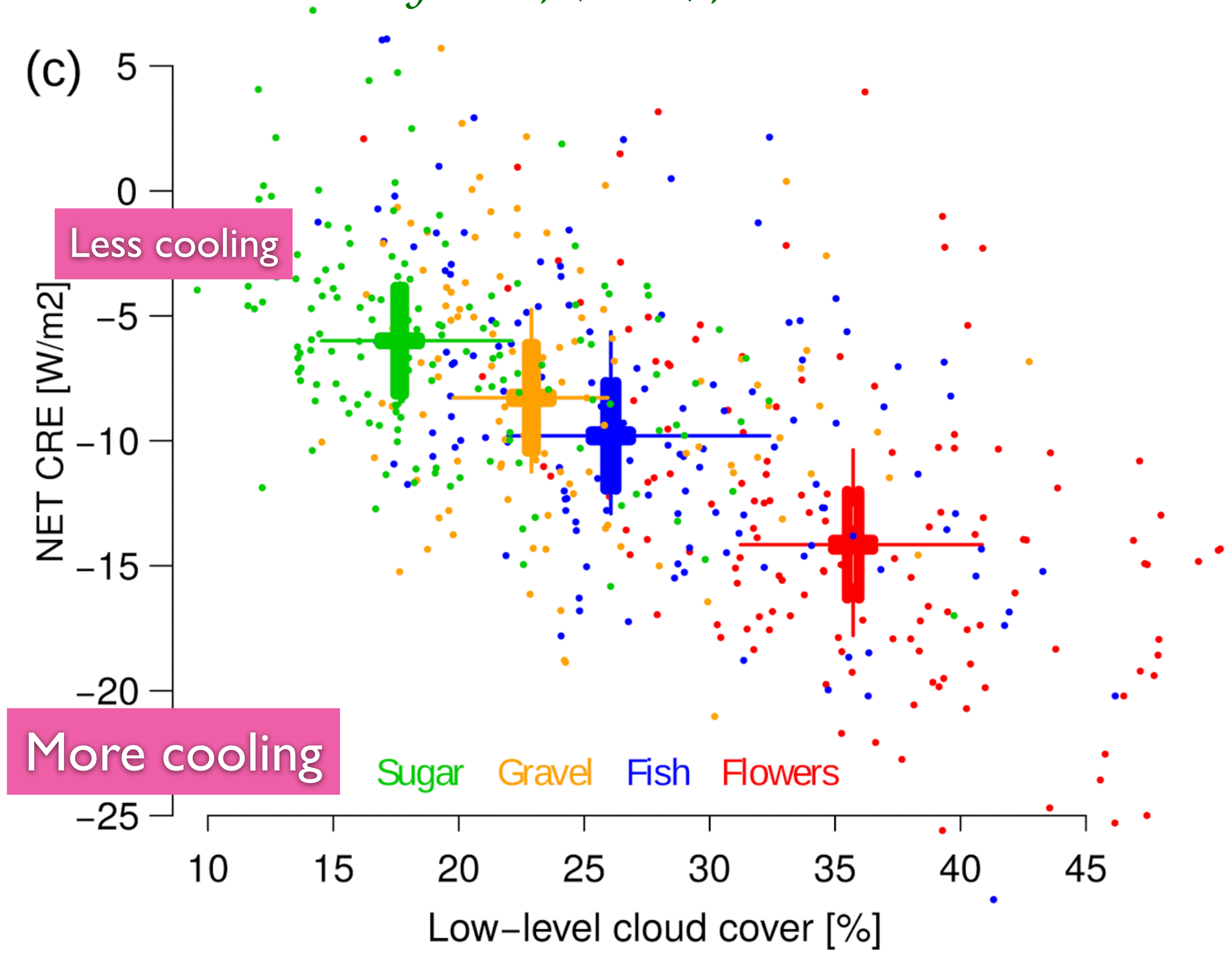

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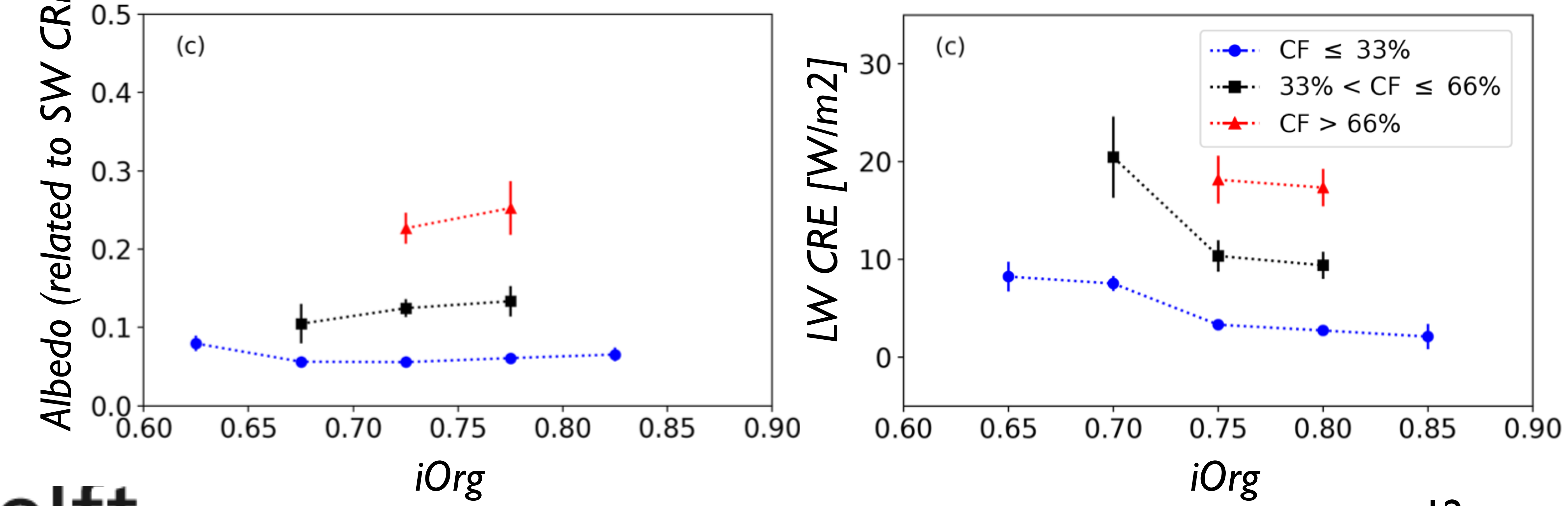

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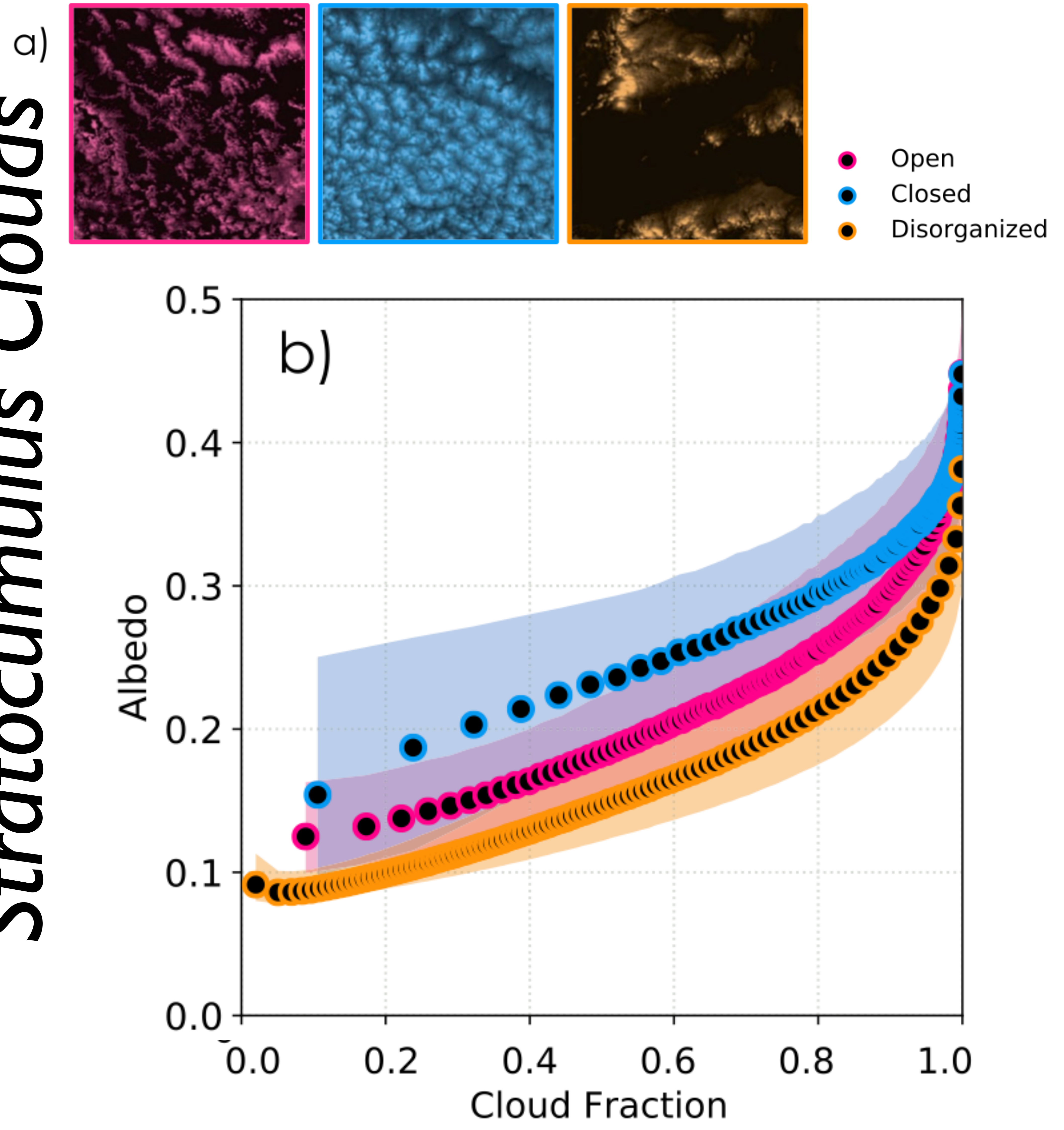

McCoy et al. (2023), satellites

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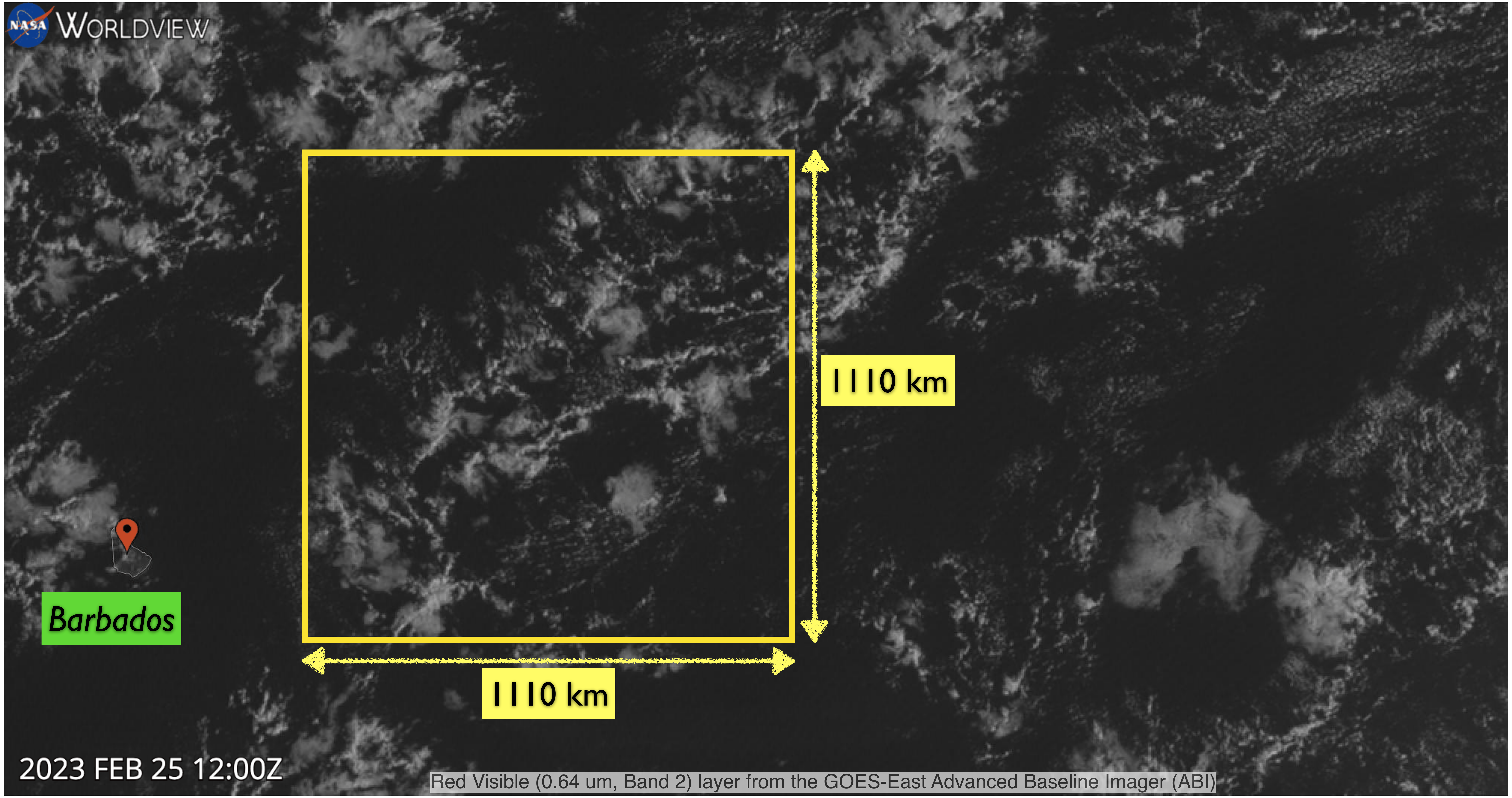
Focus: shallow cumuli

Subtropical ocean
East of Barbados
48-58 W, 20-30 N
2002-2020 Dec-May



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Outline

1. How is horizontal organization linked to cloud vertical properties?

2. How is organization related to microphysics?

3. How do 1&2 shape the response of net CRE to microphysical variability?

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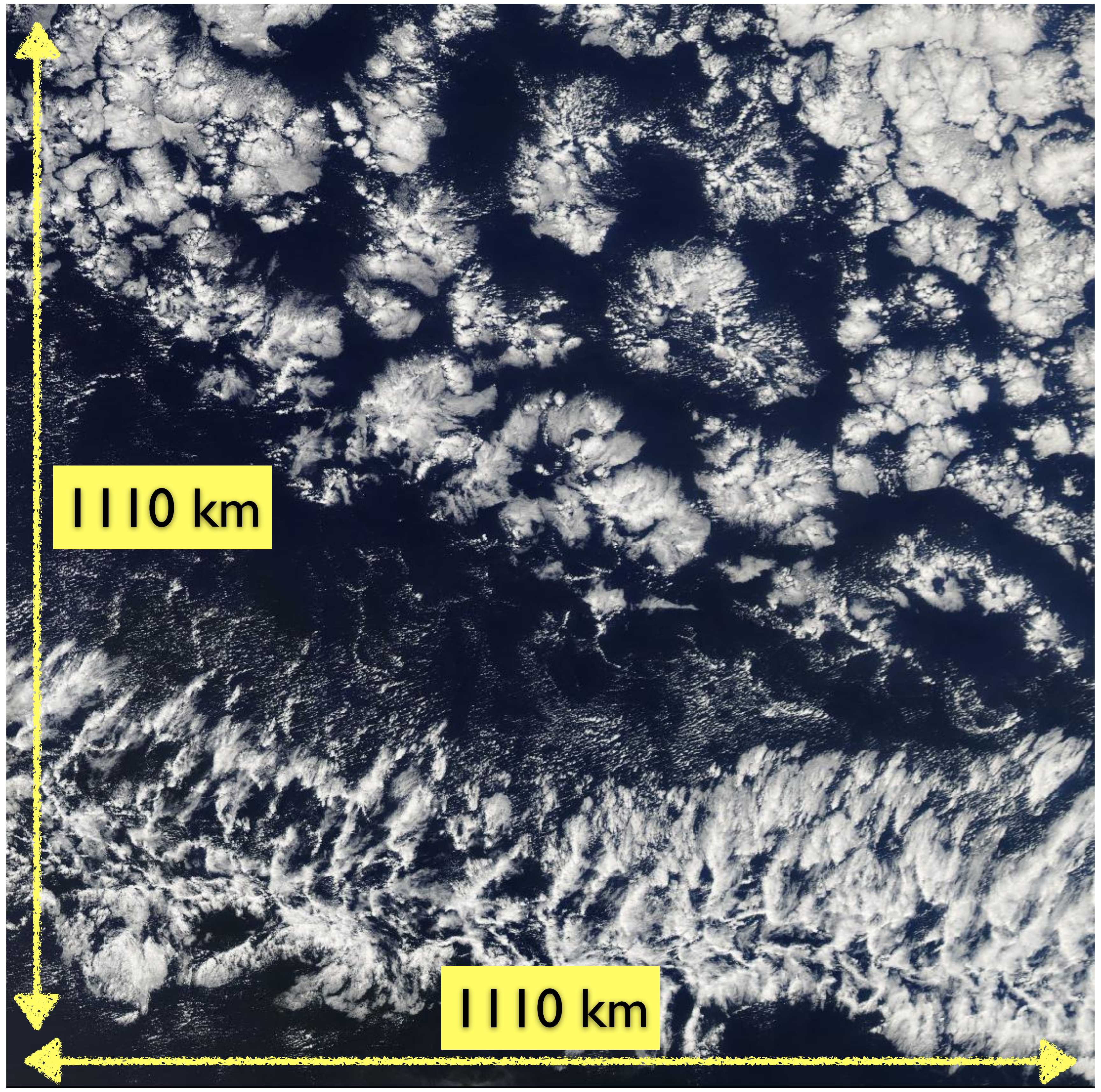
Radiation, organization, and microphysics variables



1519 cloud fields

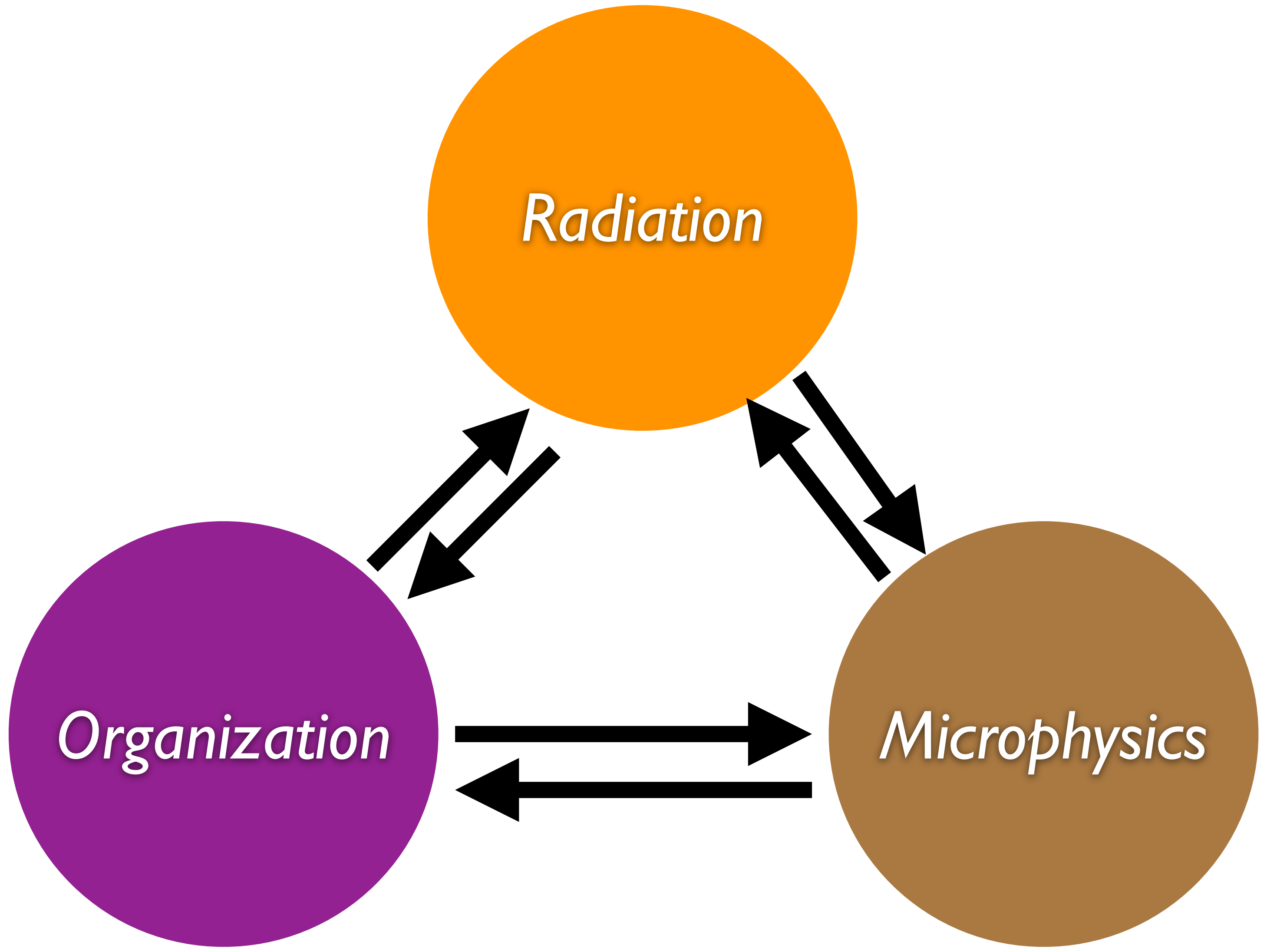
Reject fields with CTH > 4km (only shallow clouds)

1144 cloud fields

Reject fields with Reff < 14 μm (only precipitating clouds)

977 cloud fields

CERES
Radiative fluxes at the TOA:
Net cloud radiative effect (CRE)
Shortwave CRE (SW CRE)
Longwave CRE (LW CRE)



MODIS cloud mask
Organization metrics:
Cloud fraction (CF)
Degree of organization (iOrg)
Open-sky parameter (OS)
Cloud-top height (CTH)

CERES
Drop effective radius (Reff)

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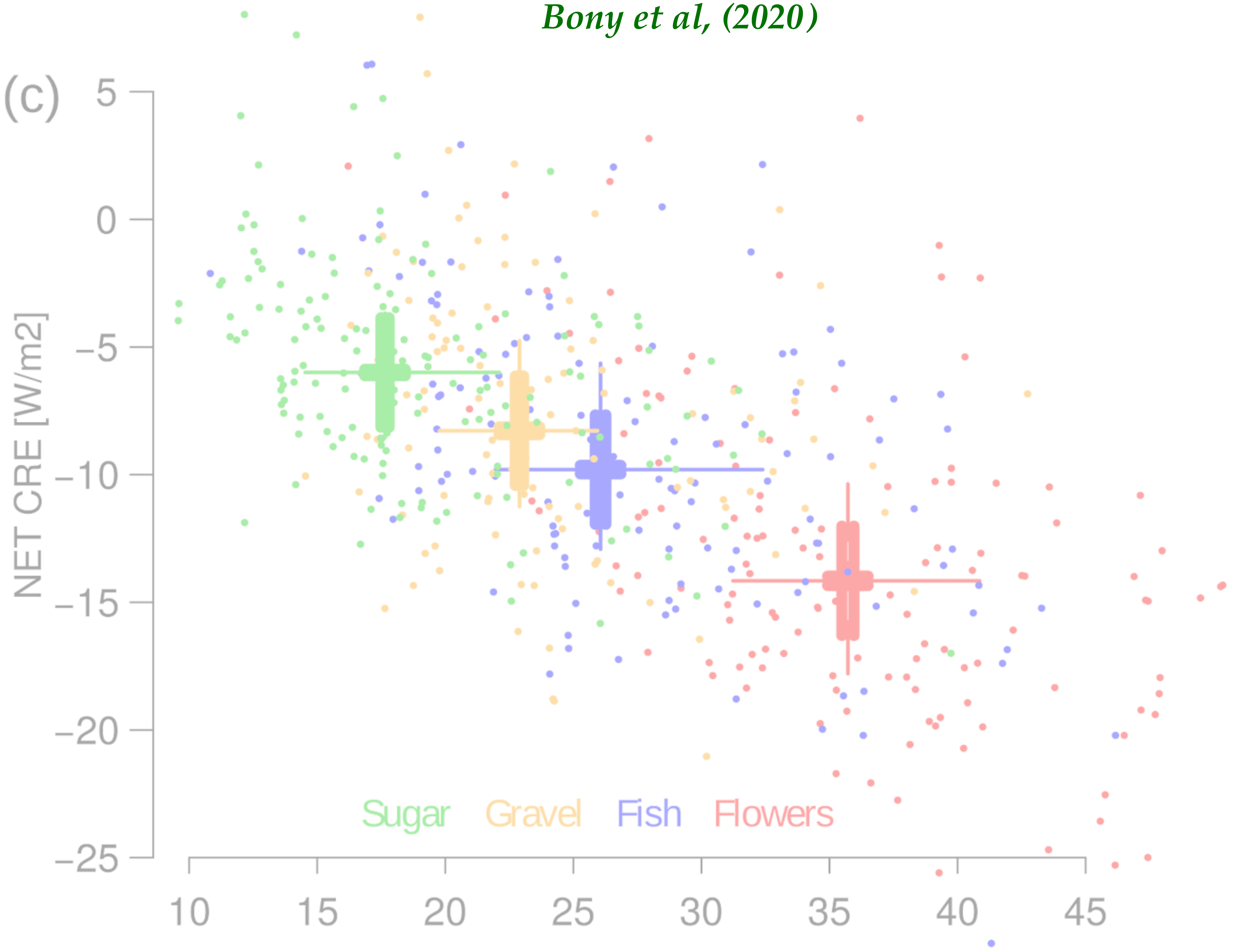
Schulz et al. (2021); Rosenfeld et al. (2012)

Janssens et al. (2021); Python package "cloudmetrics"

We eliminate the confounding effect of cloud fraction.

$$\ln X = c \times \ln \mathrm{CF} + \ln X \,|\, \ln \mathrm{CF}$$

Bony et al, (2020)



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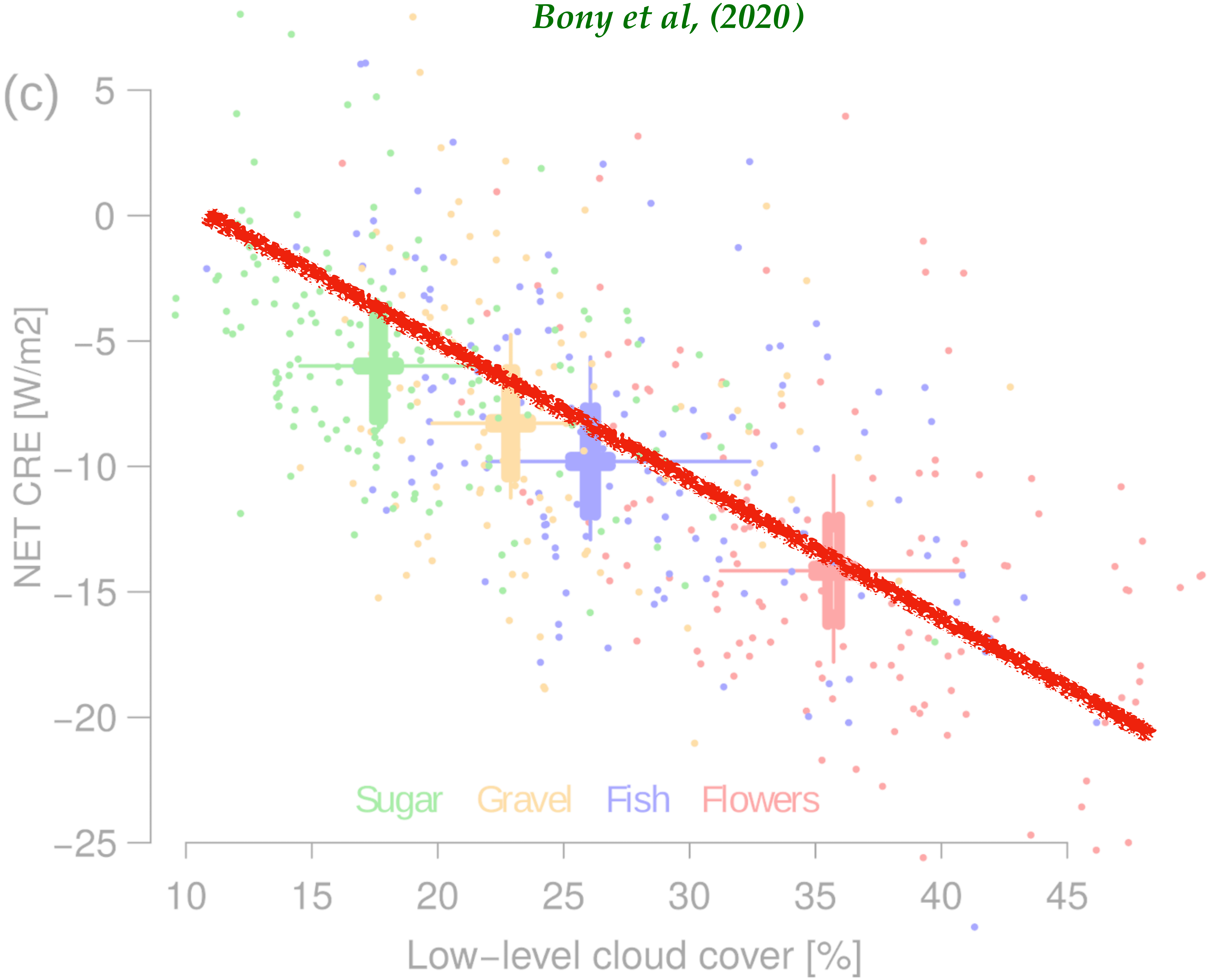

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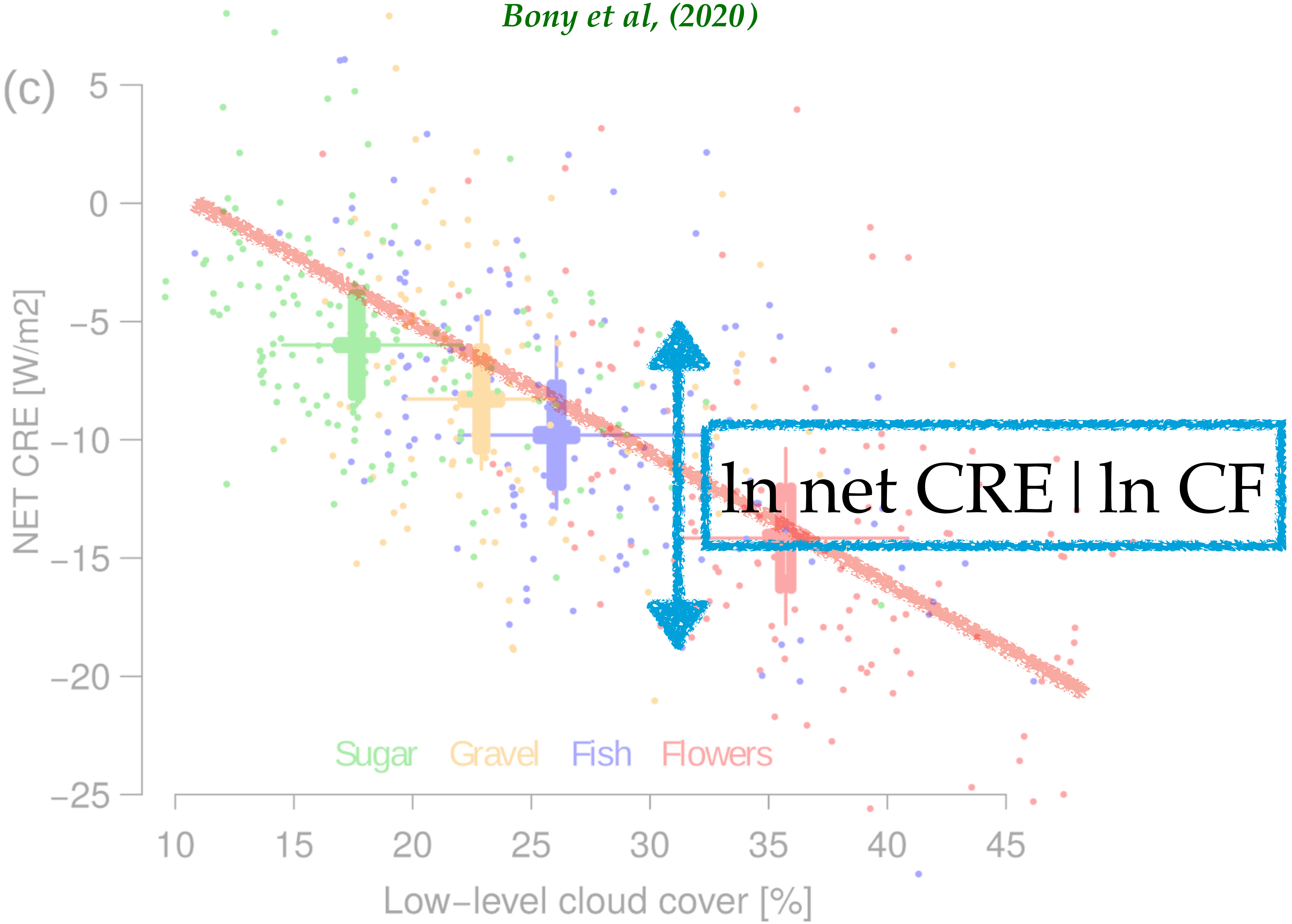

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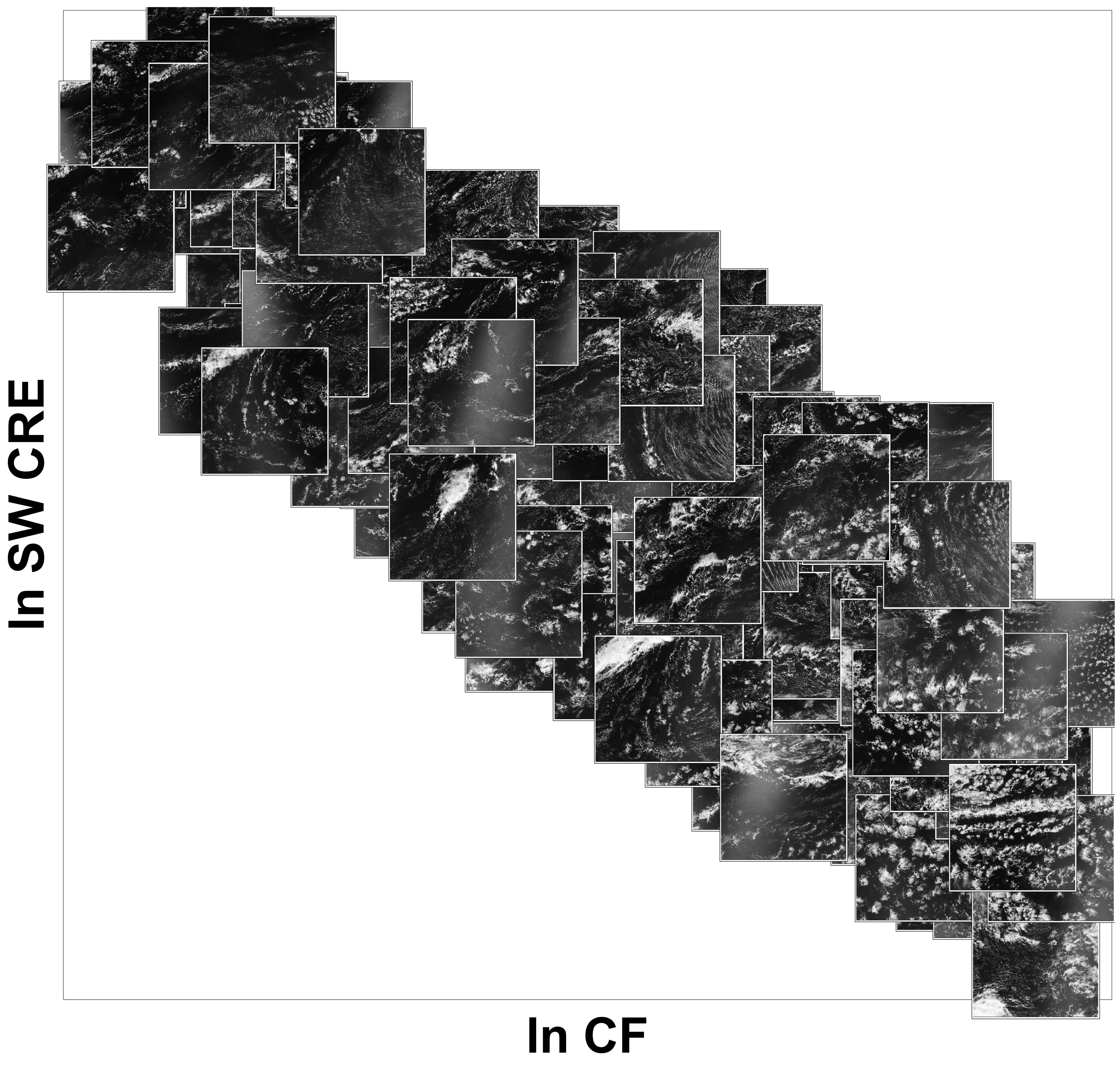
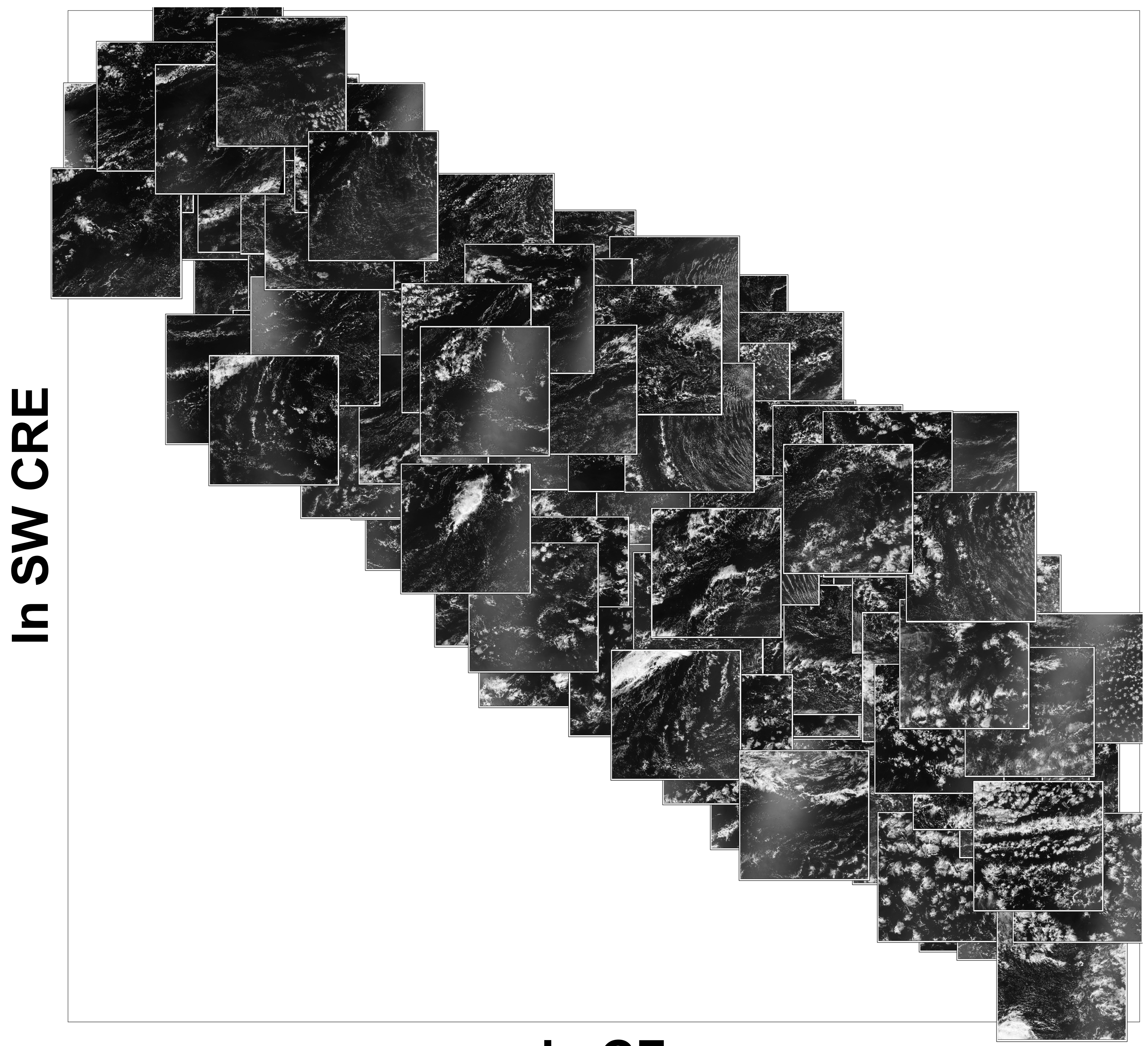
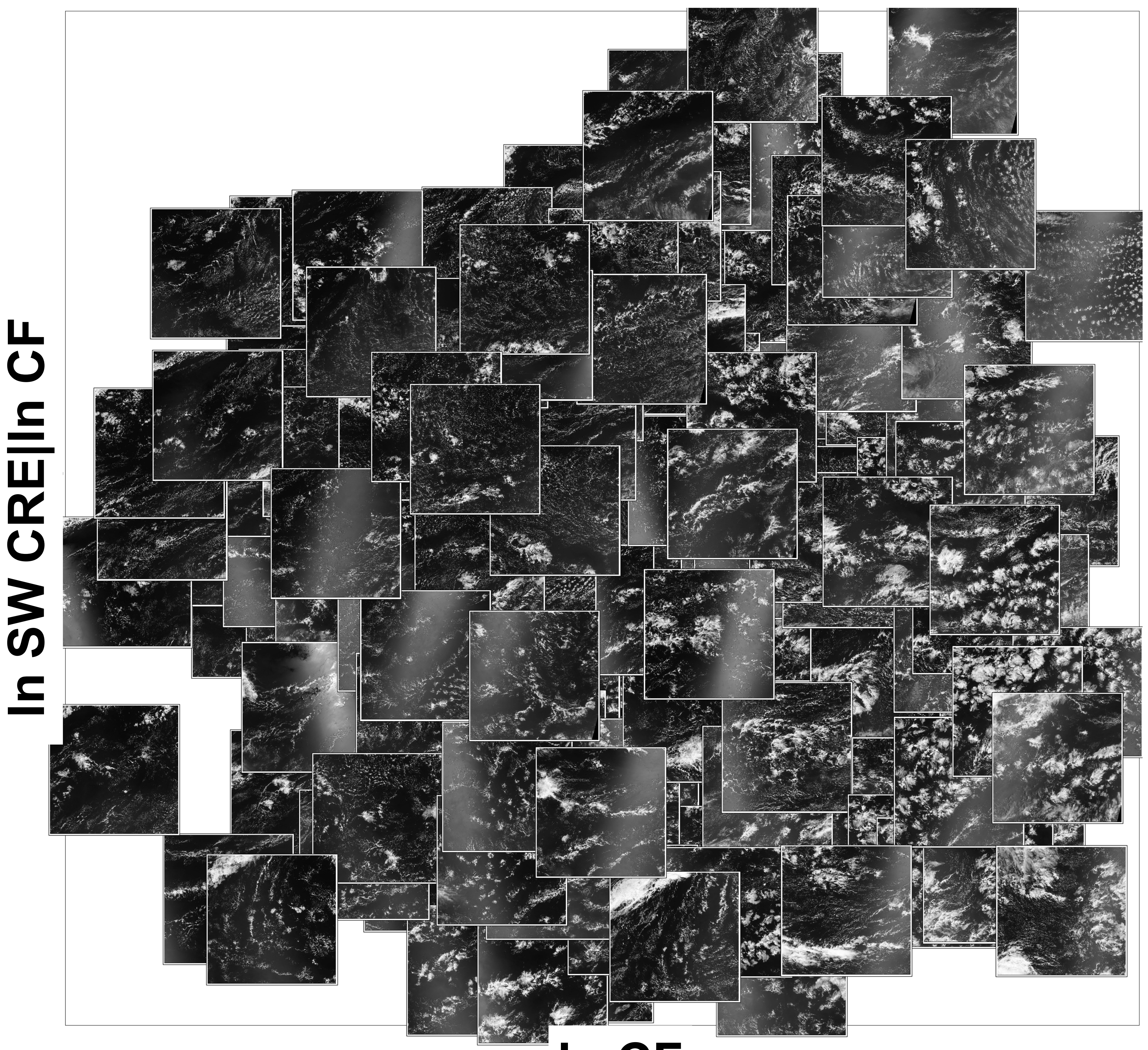
Let's consider the SW CRE-CF relationship.

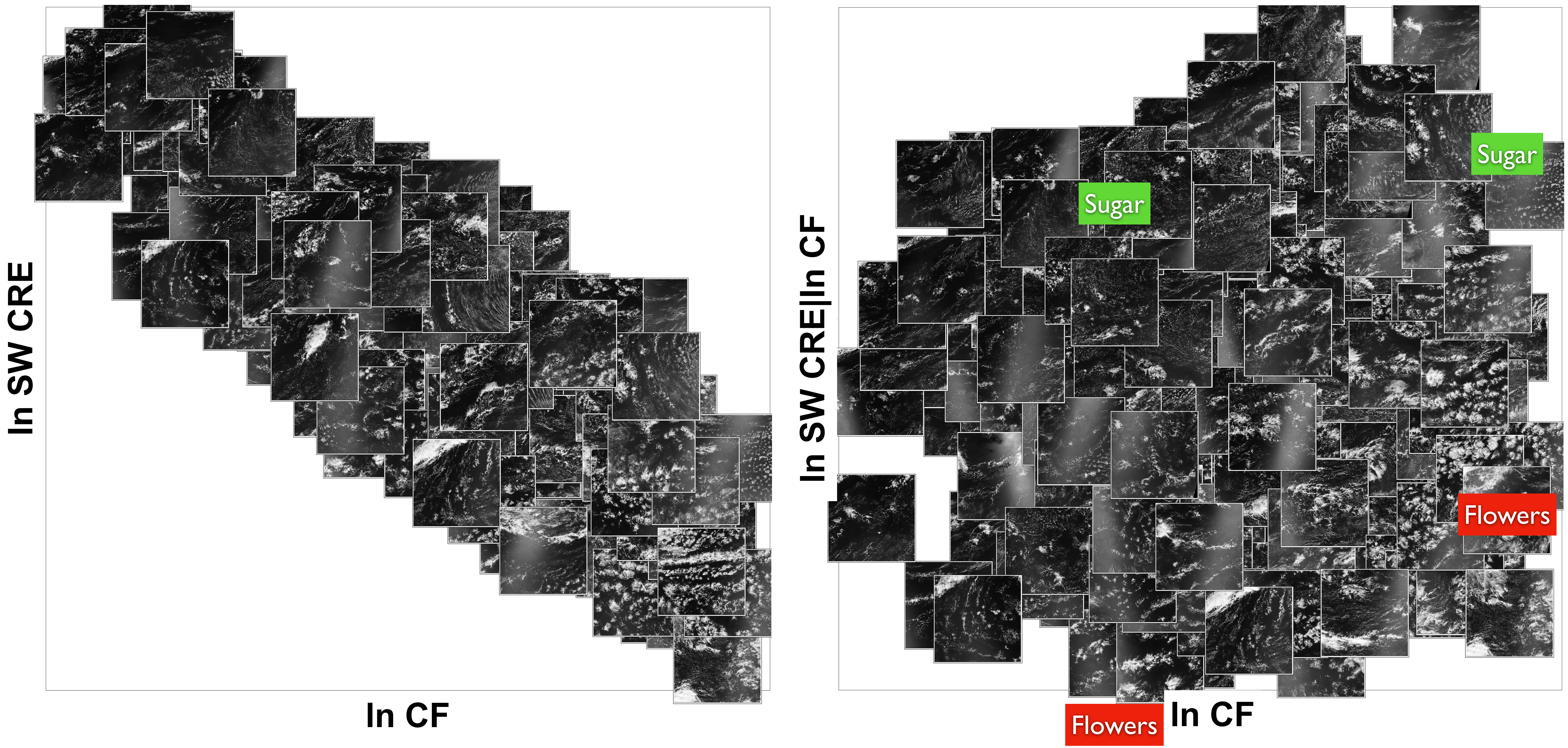


Having cloud fraction fixed, radiative effect varies.





Having cloud fraction fixed, pattern and radiative effect co-vary.



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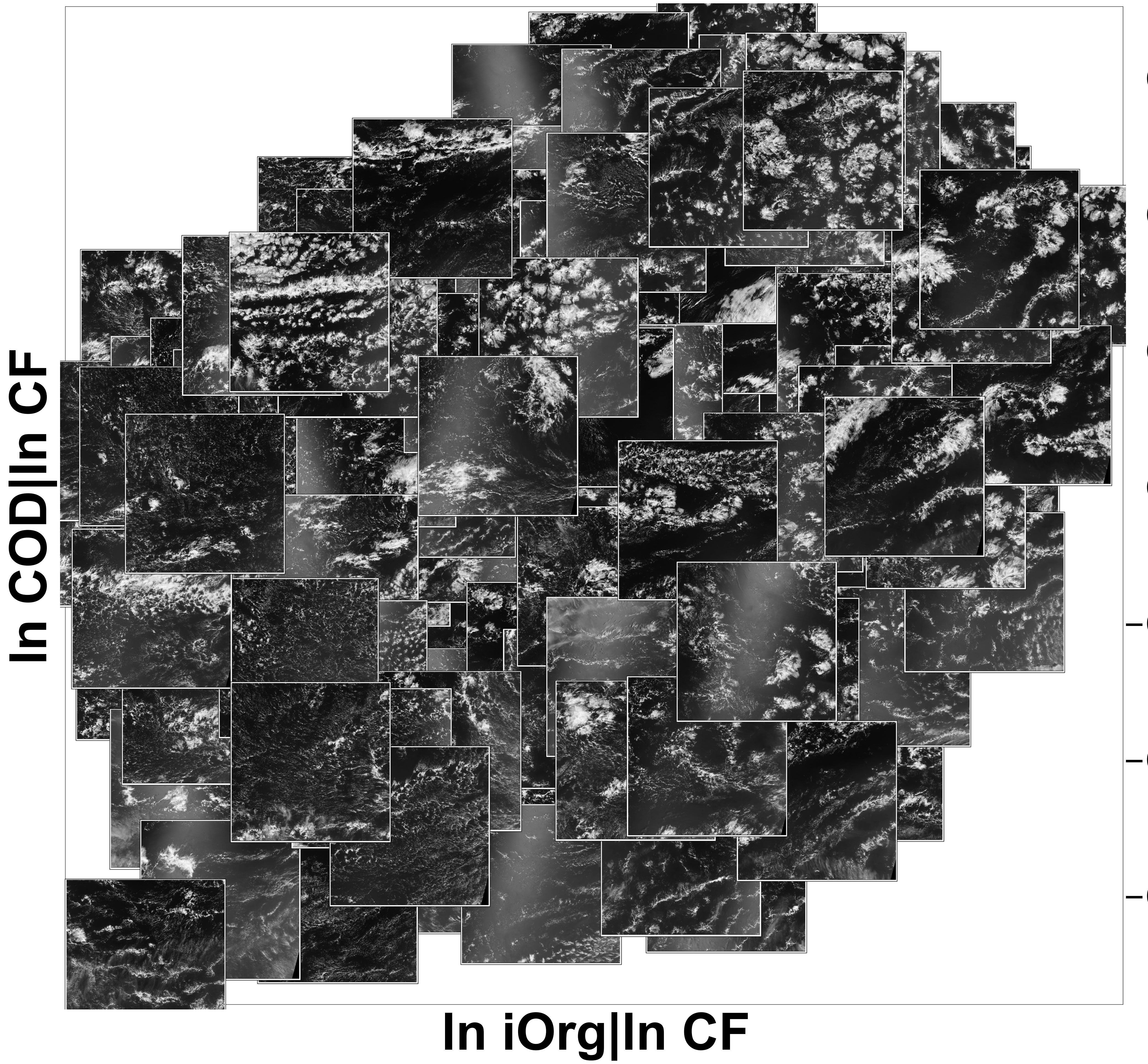
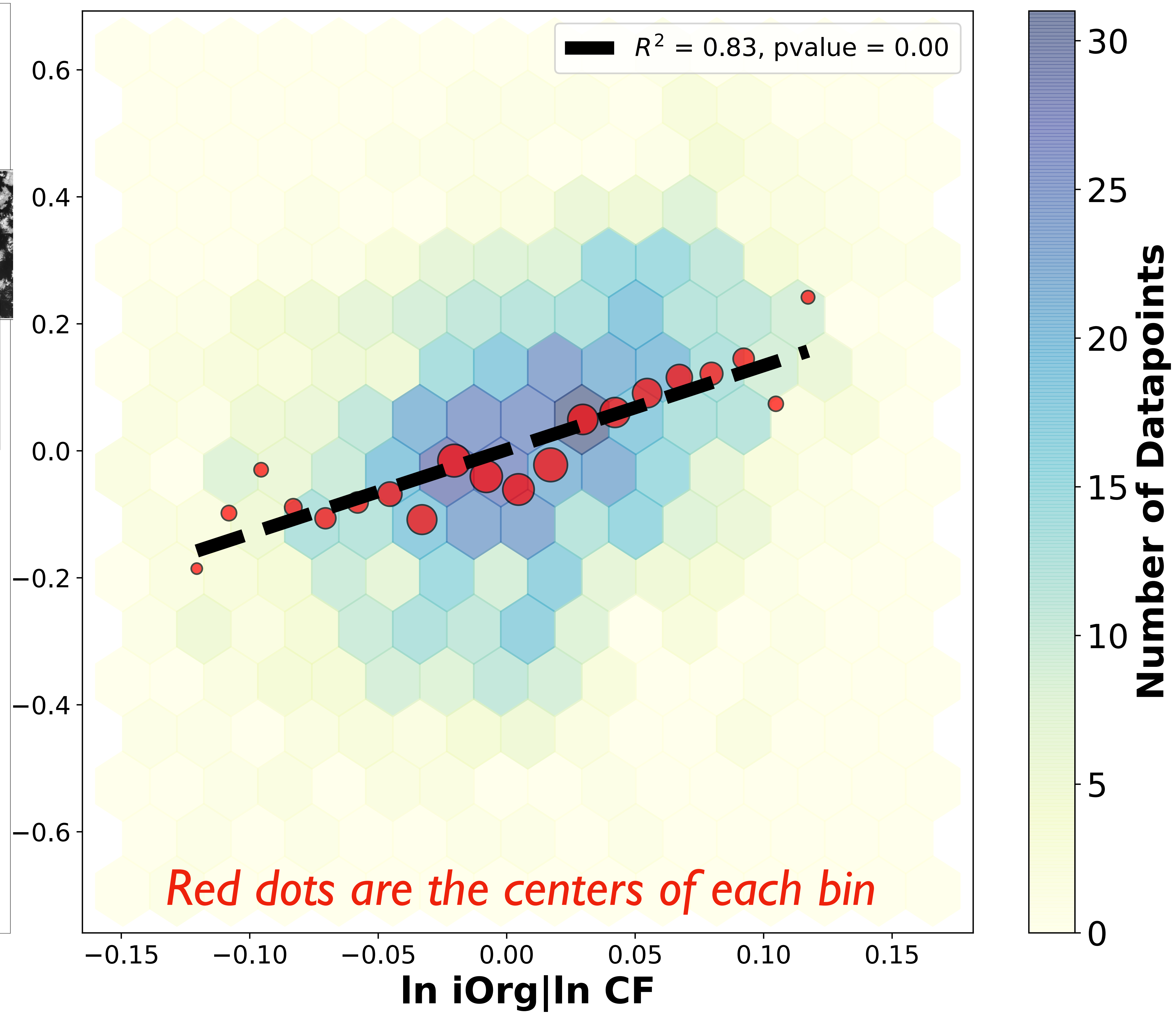
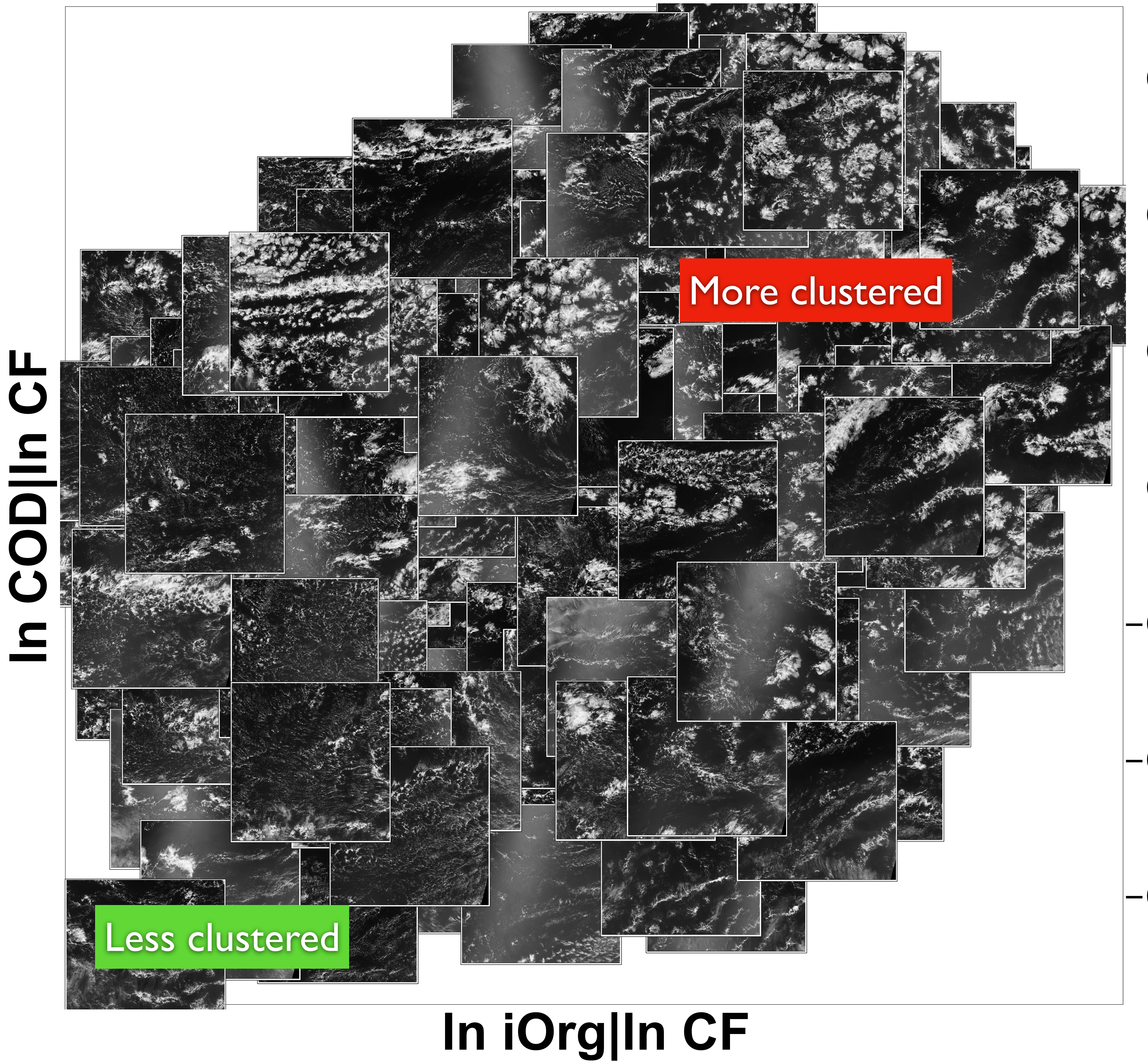
How is horizontal organization linked to cloud vertical properties?

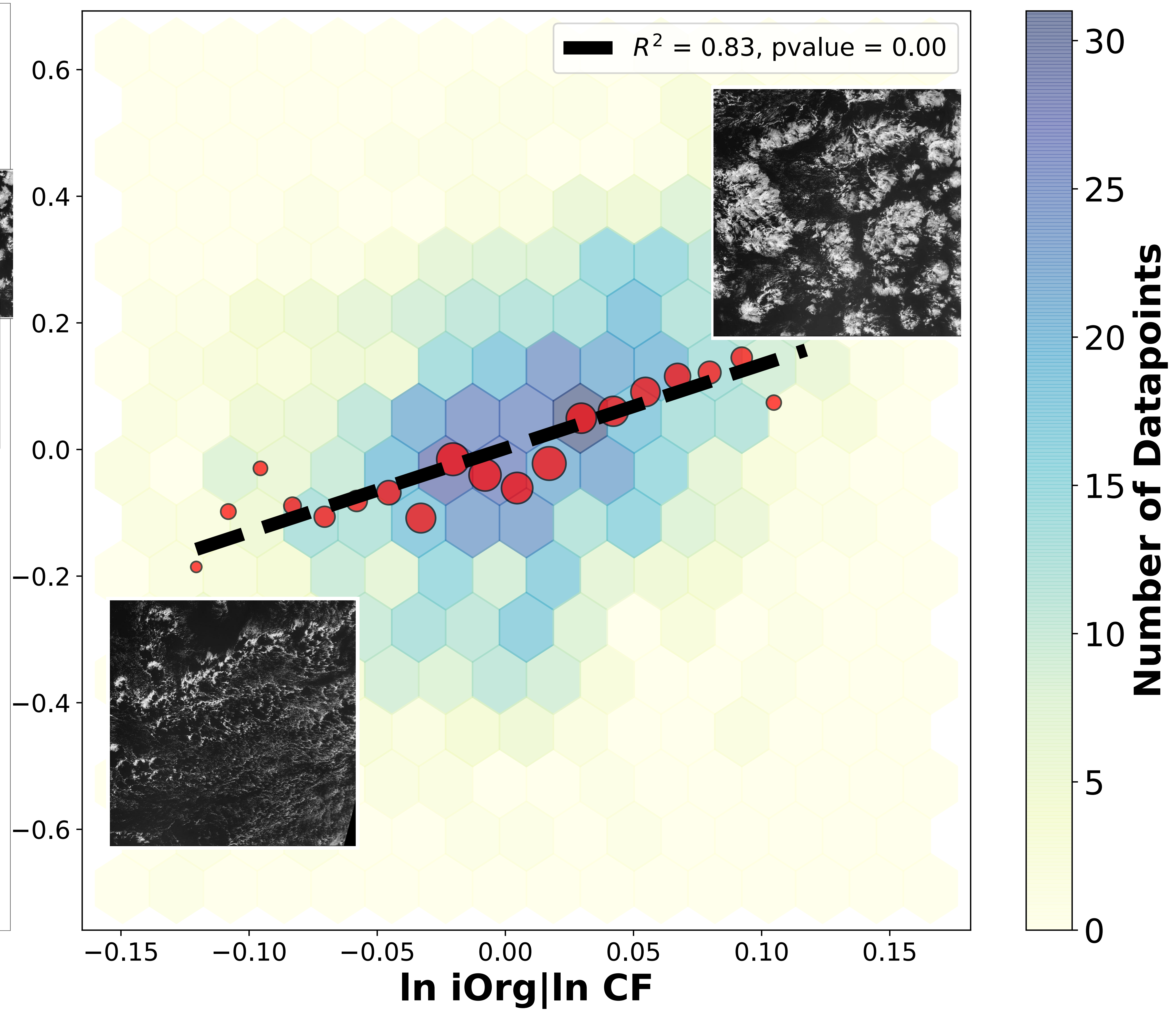
COD|CF and iOrg|CF are correlated.





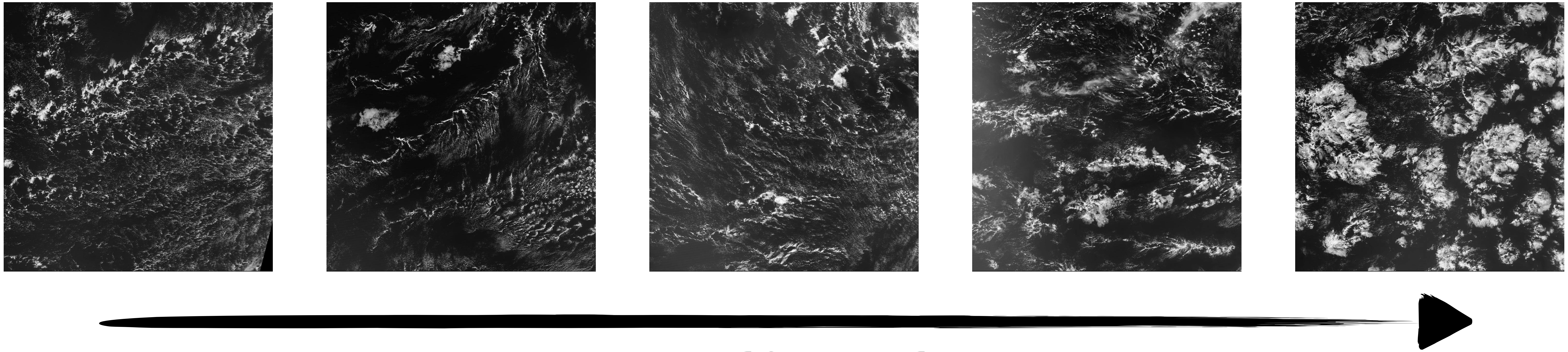
COD|CF and iOrg|CF are correlated — both measure clustering.





Interesting — cloud optical depth can measure pattern!

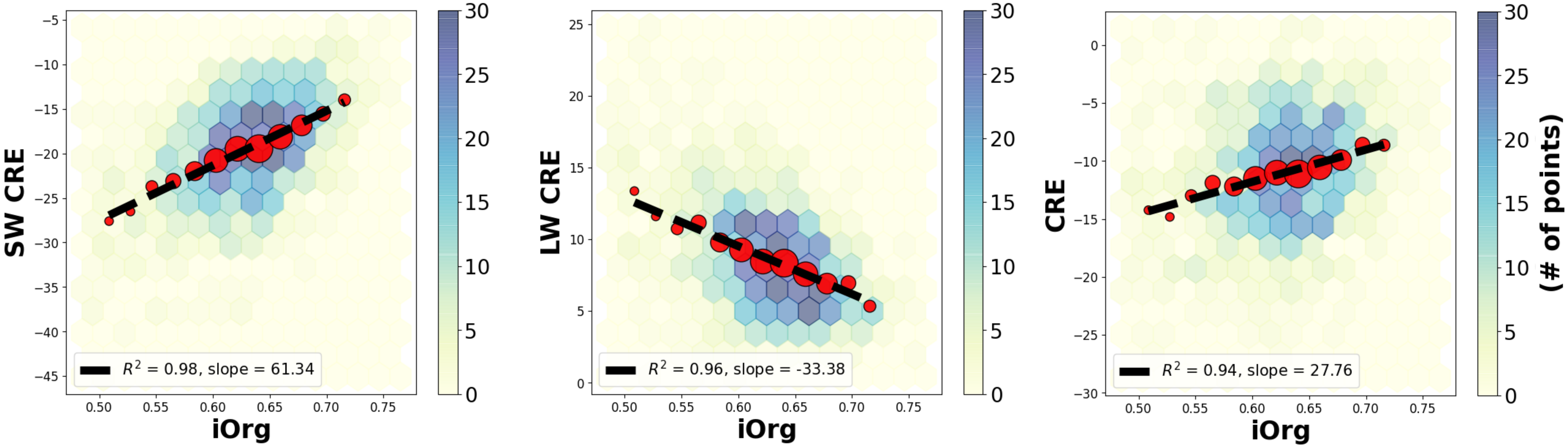
Clouds appear to be more ***clustered*** *when they are* ***optically thicker***



ln COD|ln CF

Having CF fixed, organization can explain 5 W/m2 of net CRE variability.

Without removing CF-variability



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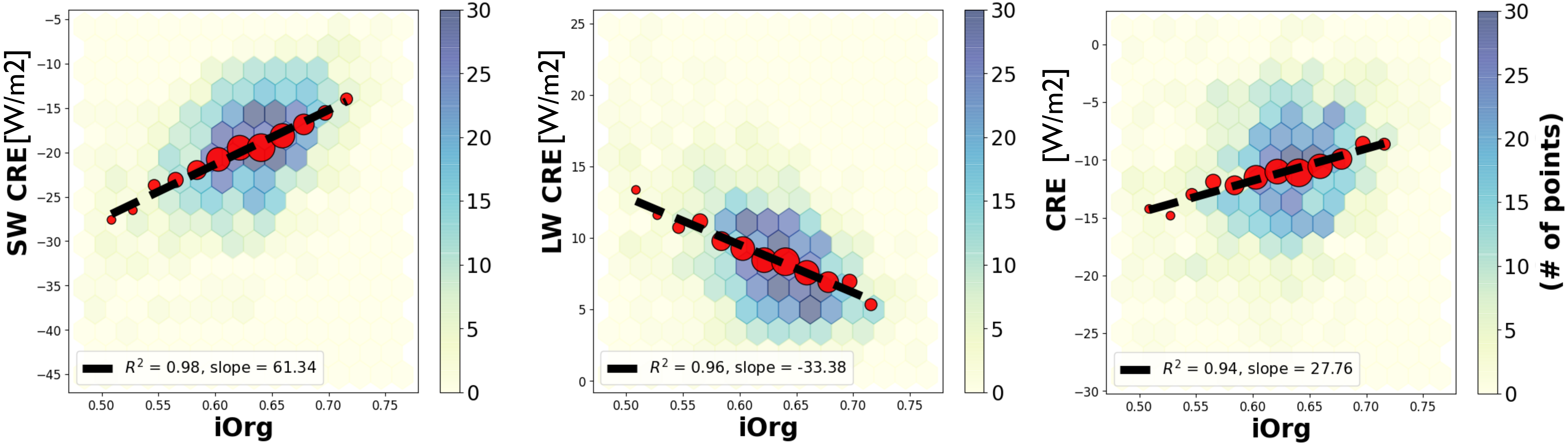

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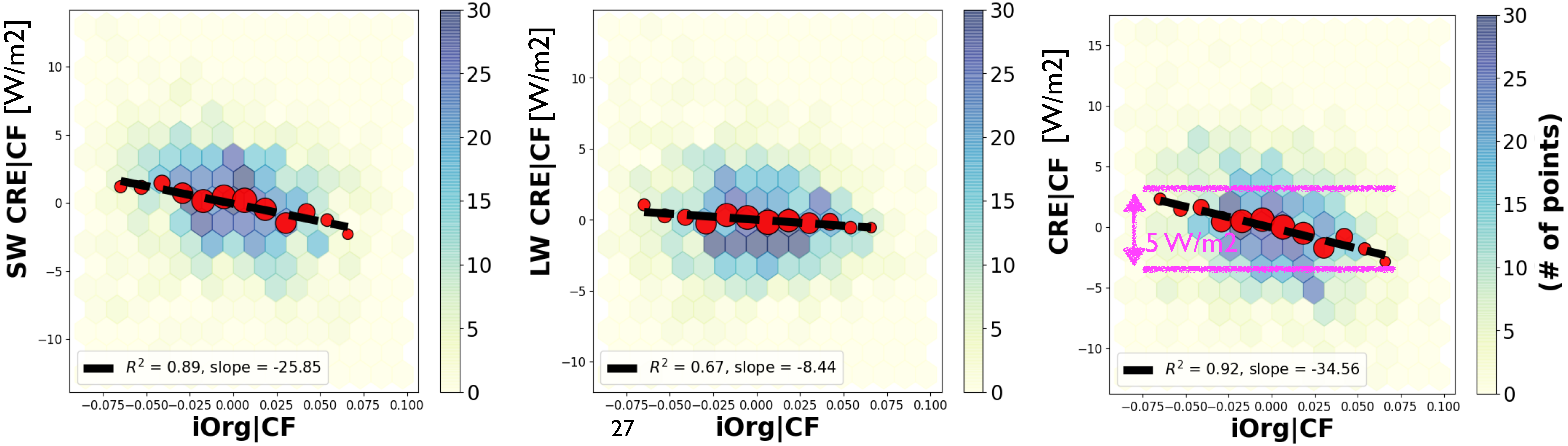

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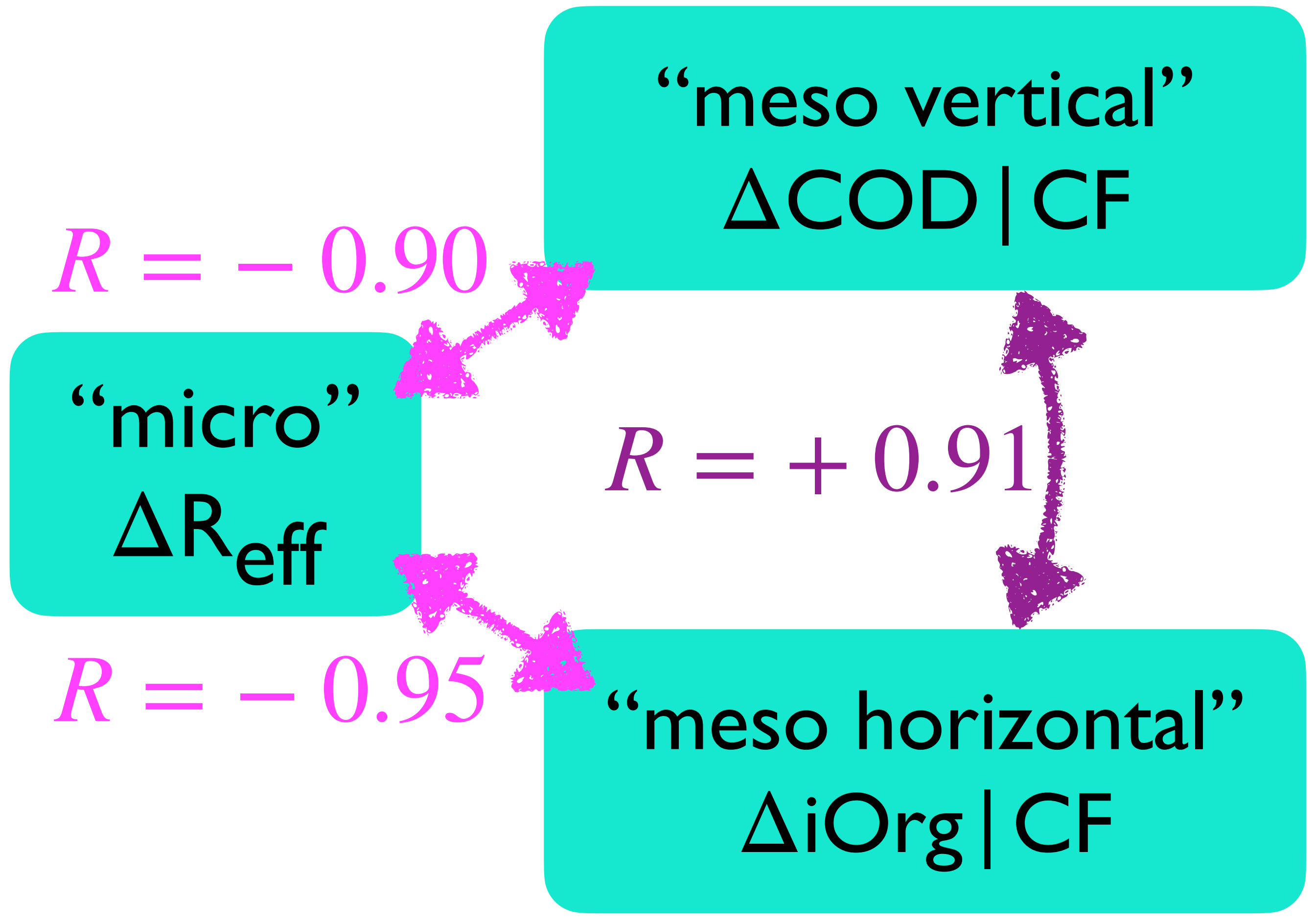
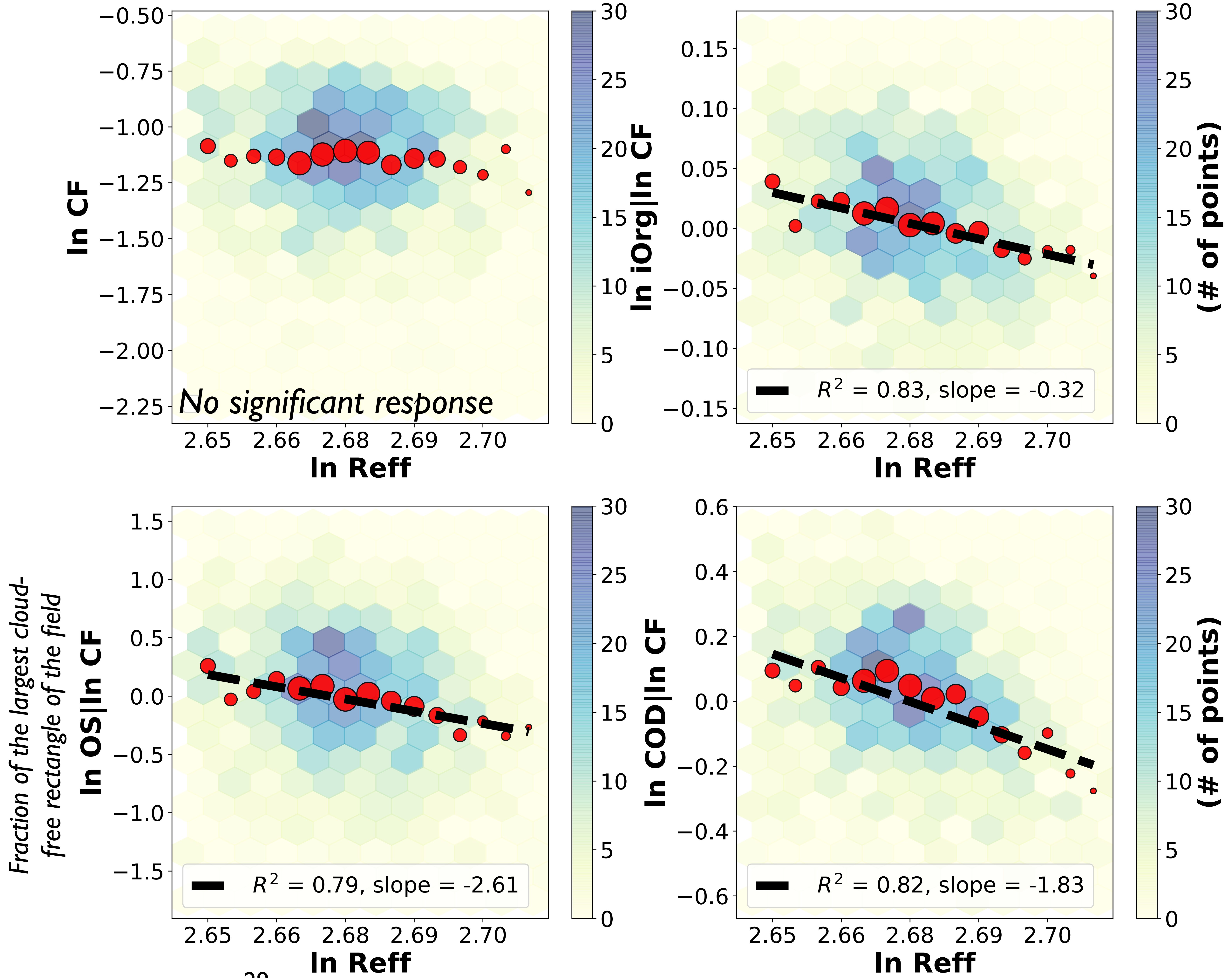
How is organization related to cloud microphysical properties?

Organization can serve as a proxy for microphysics.

Reff controls the height at which precipitation starts

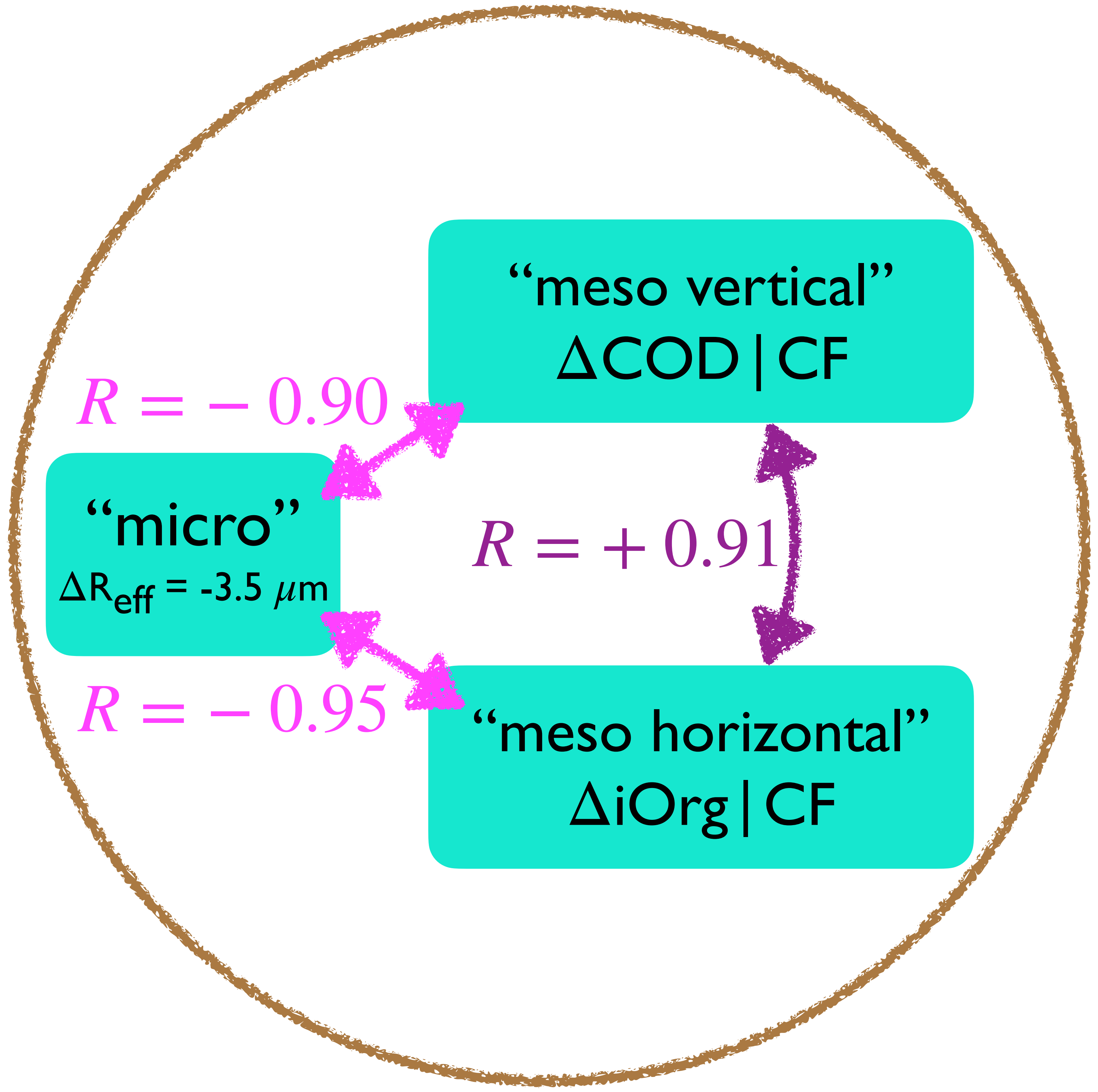
Precipitation potentially affects organization via cold pools





How does organization shape the response of net CRE to microphysical variability?

Organization buffers the microphysical variability of net CRE.



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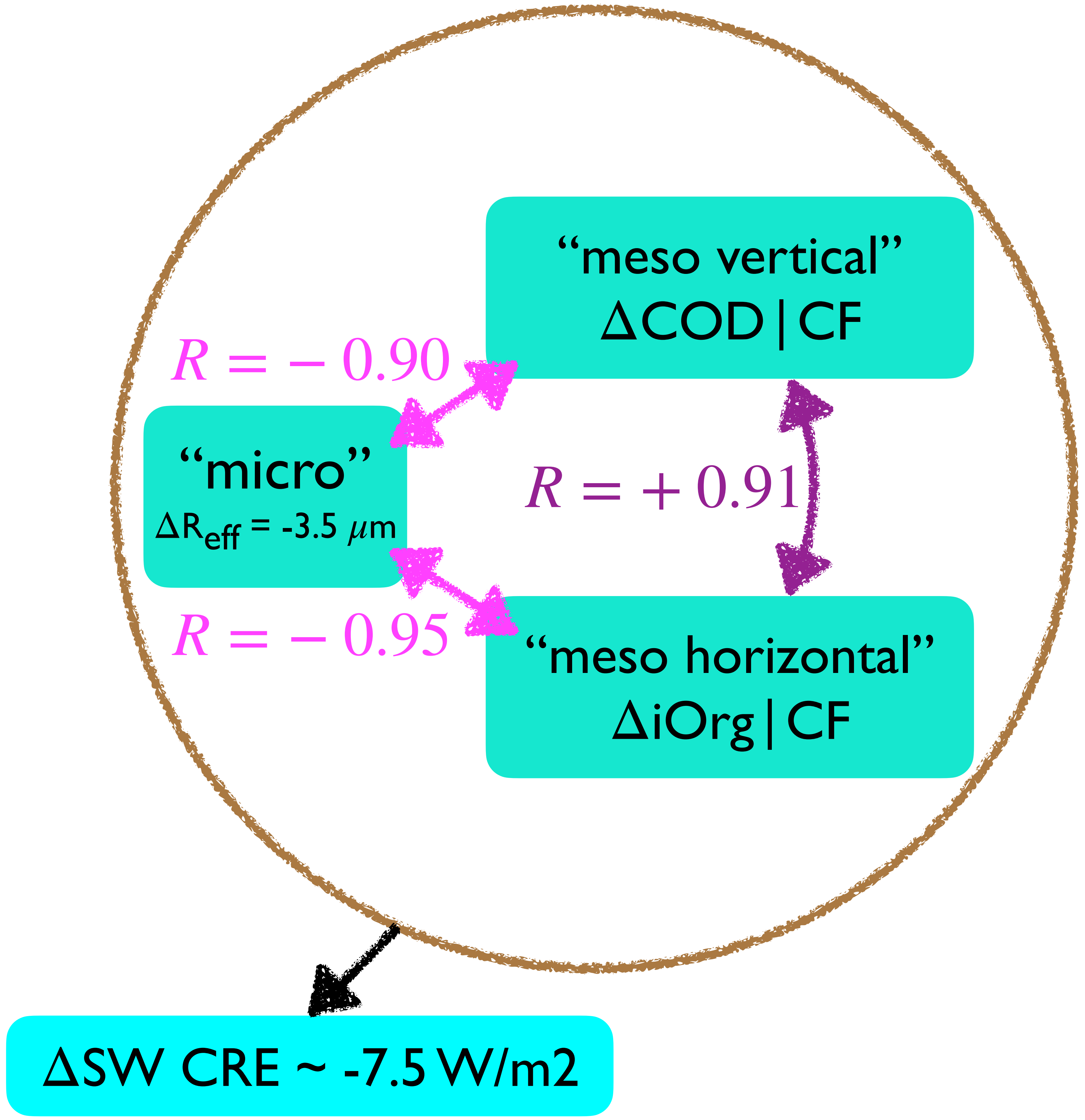

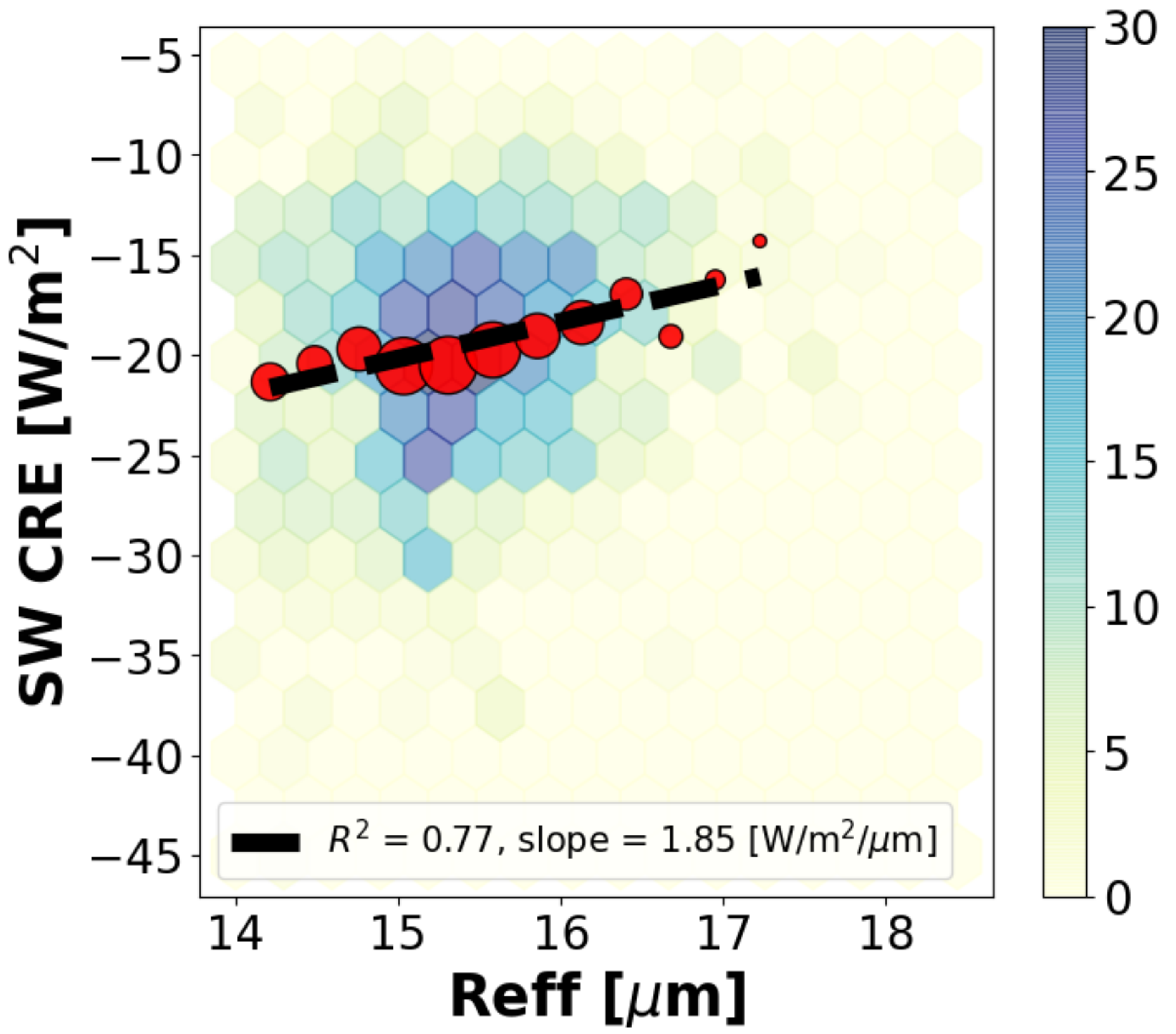

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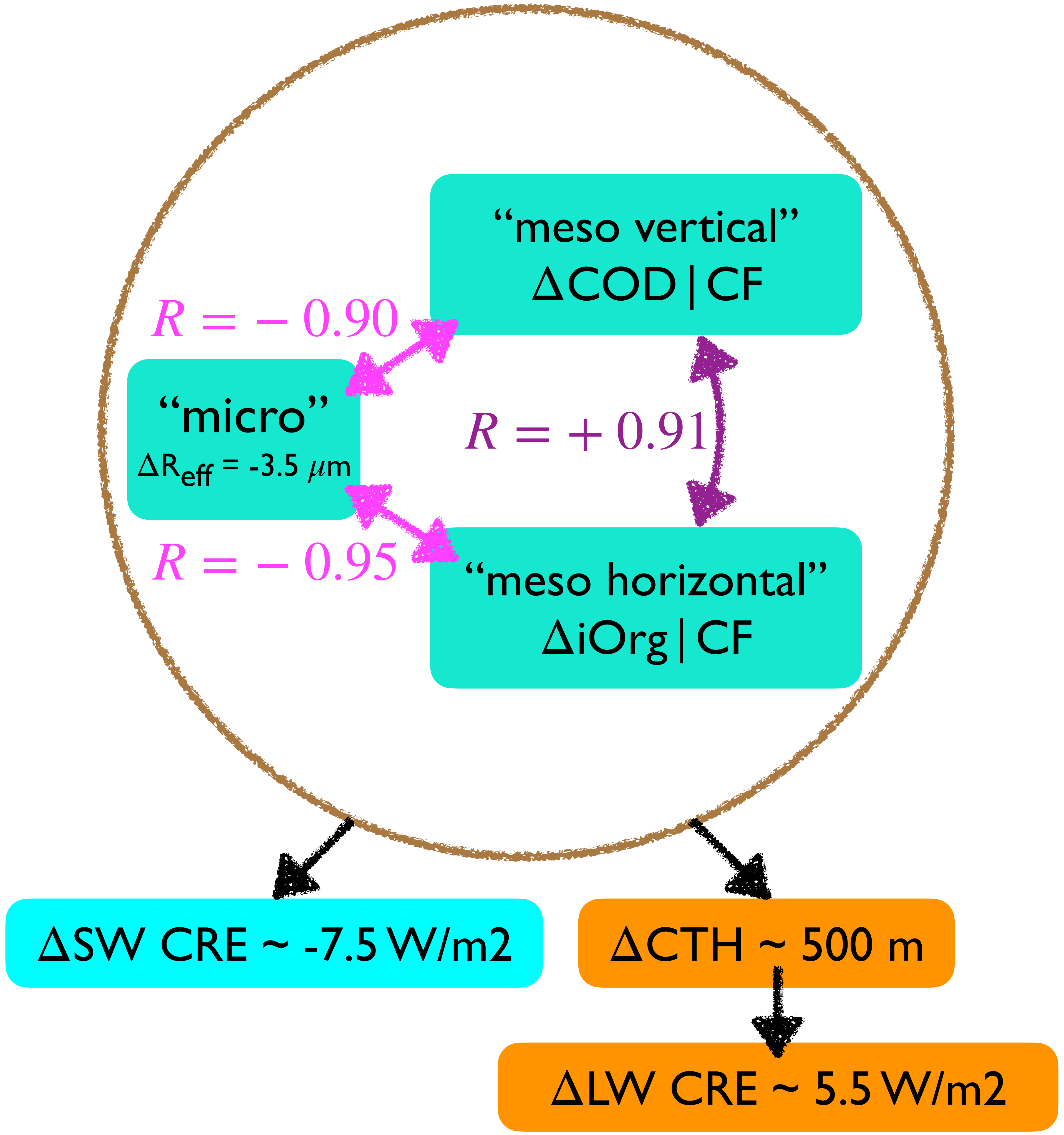

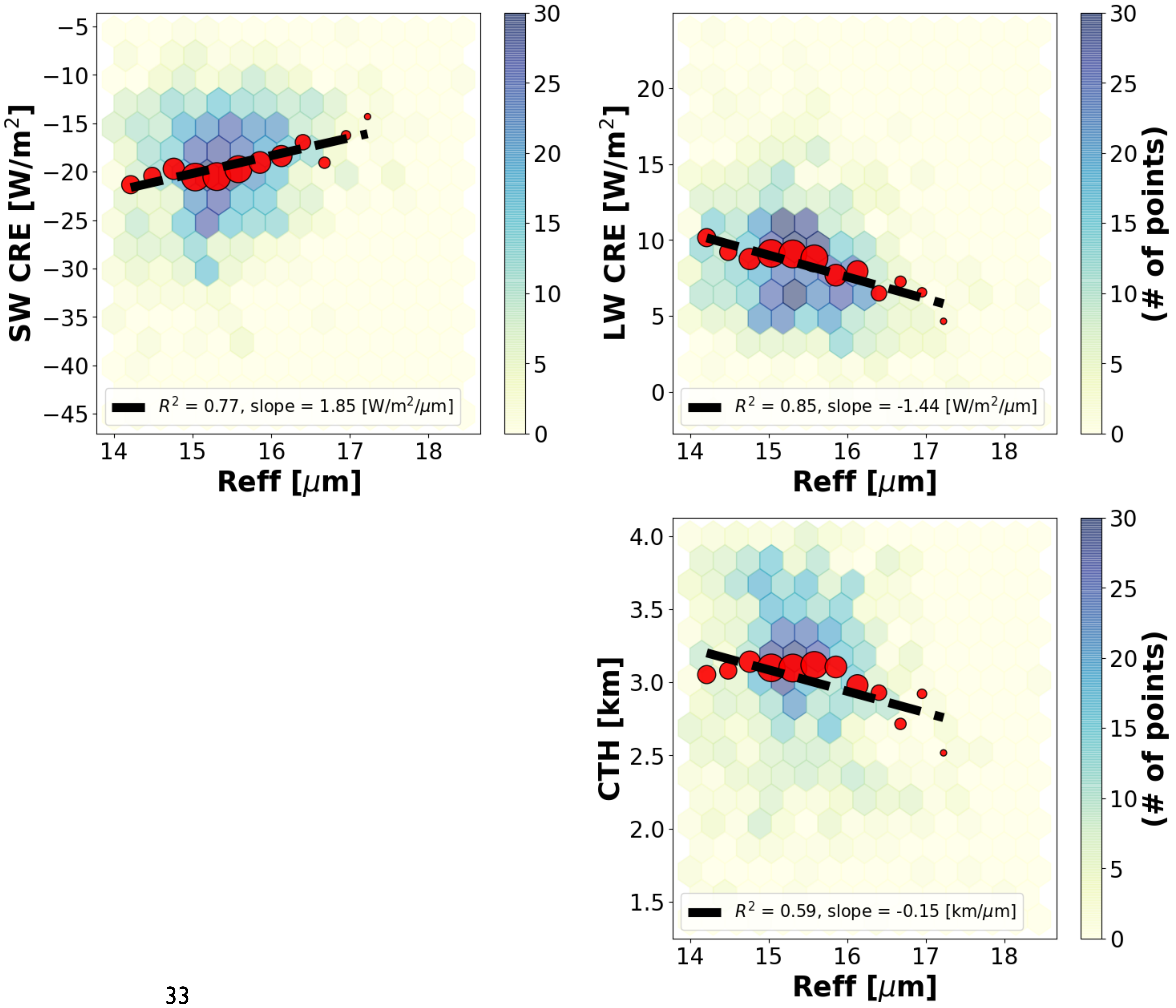

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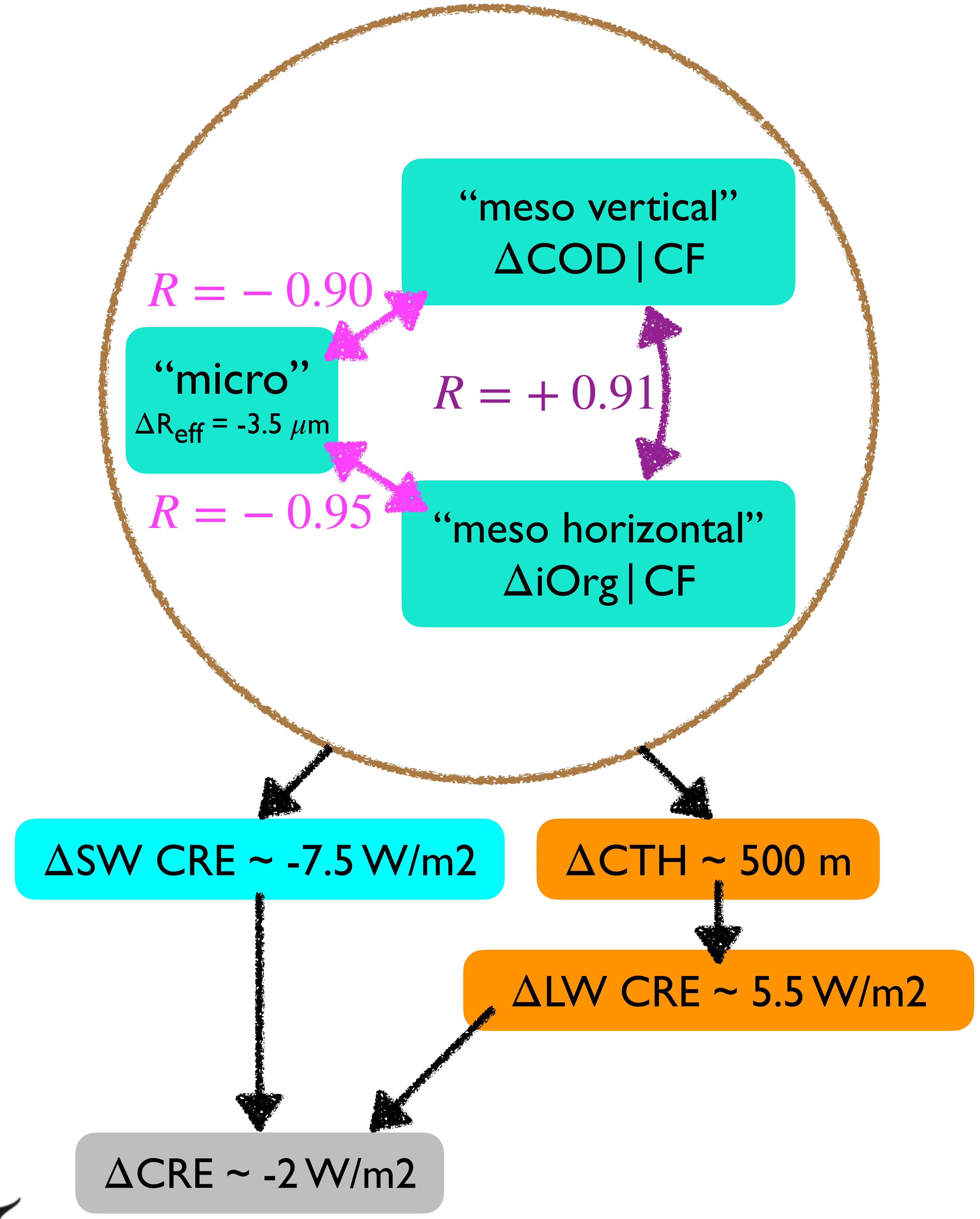

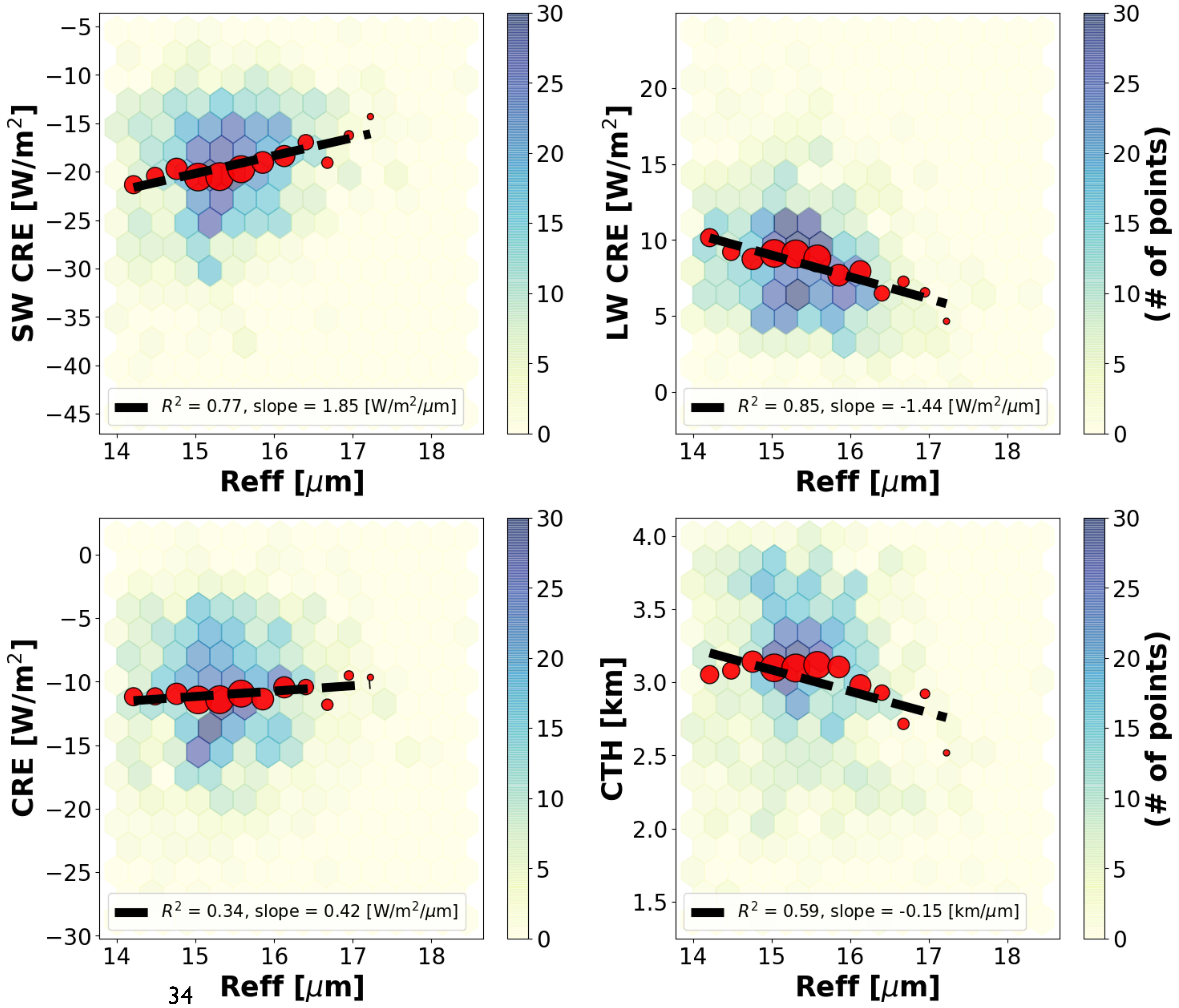

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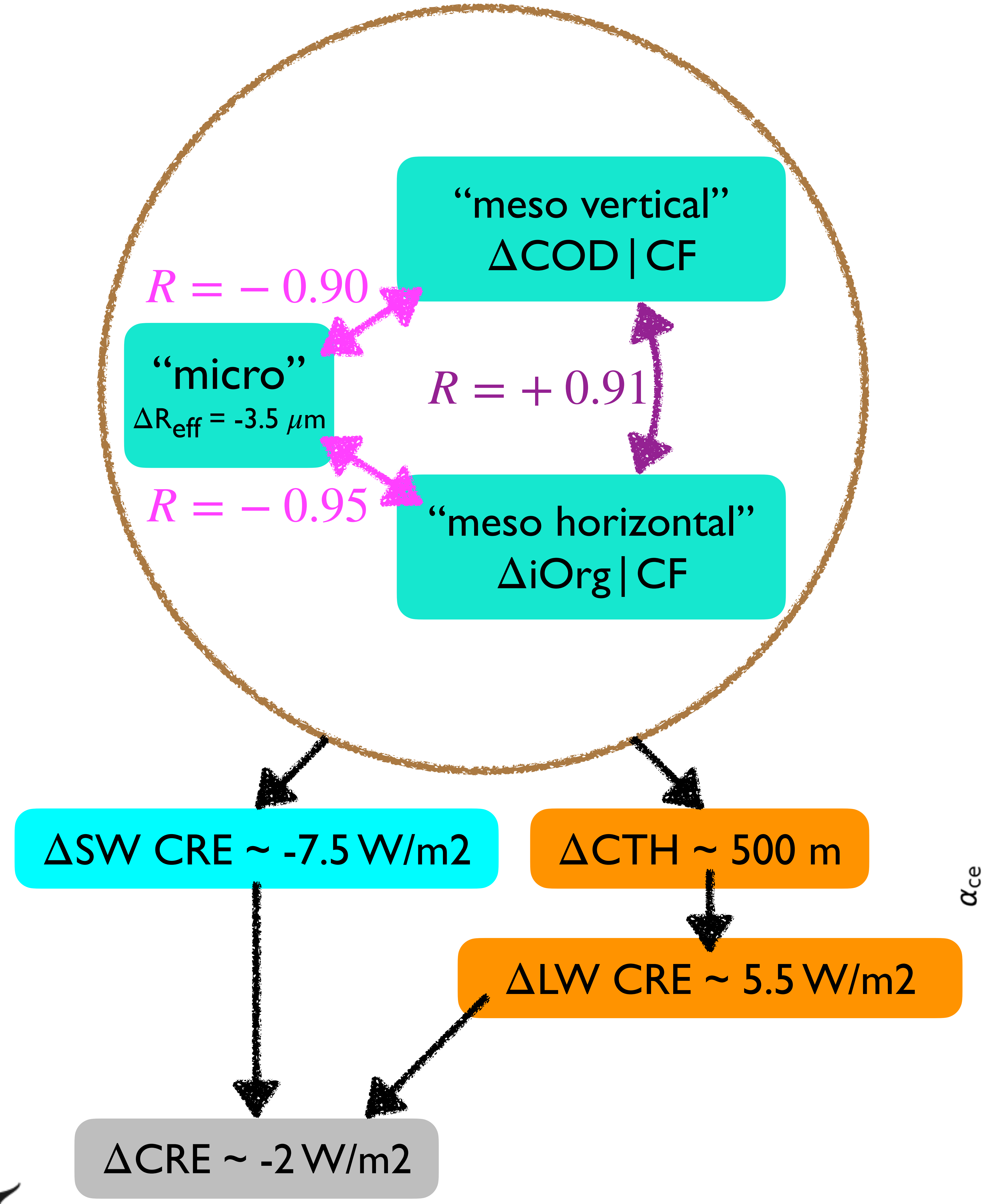

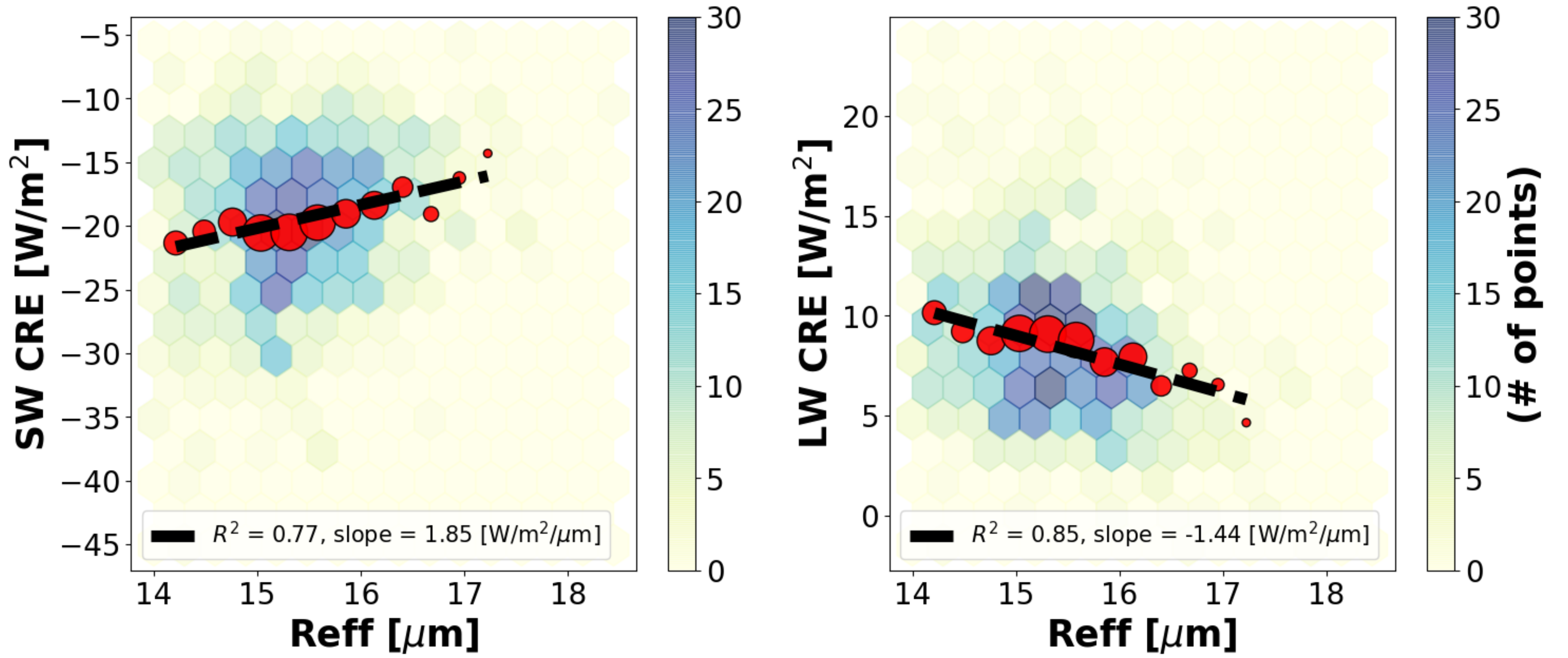

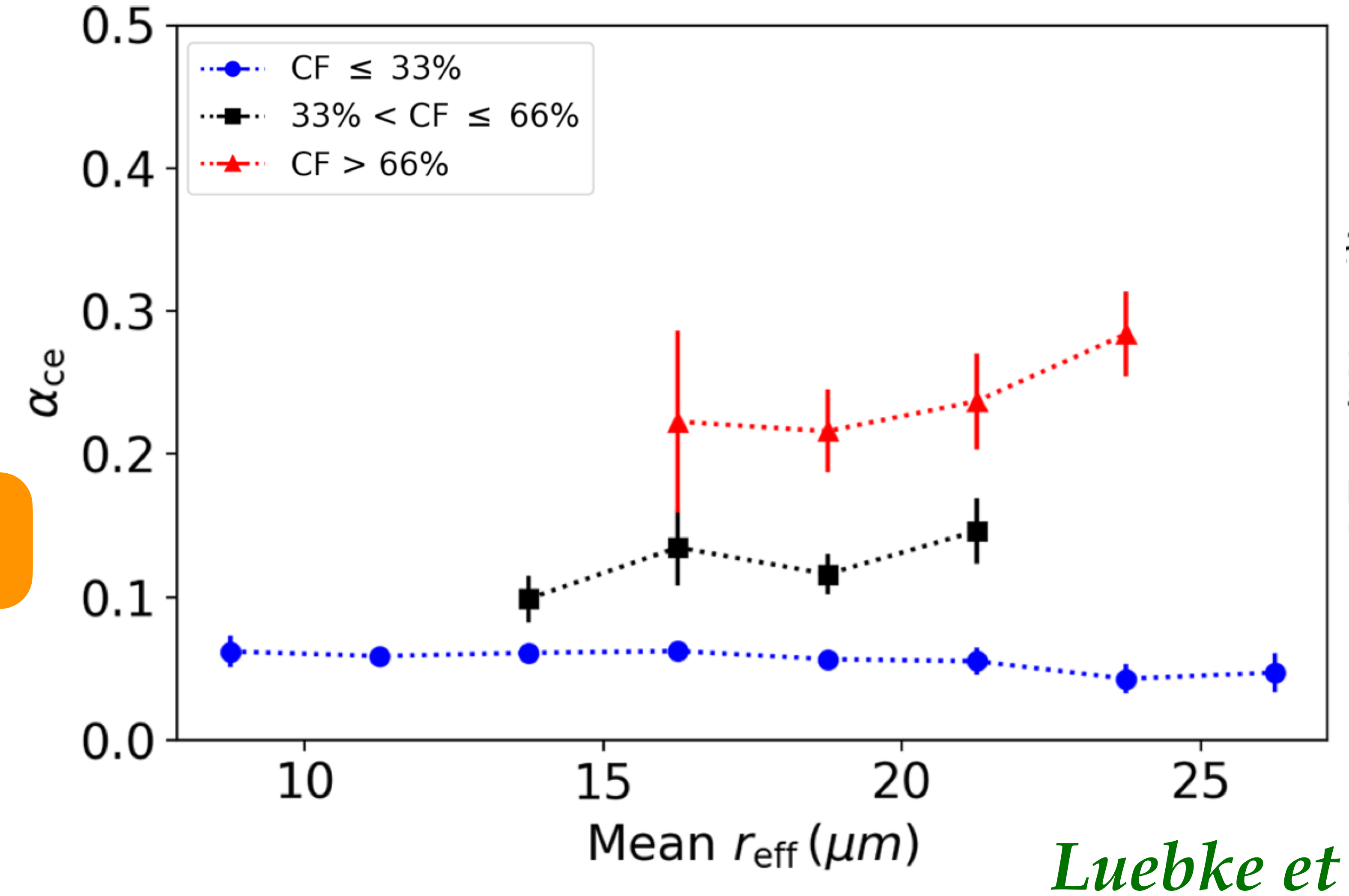

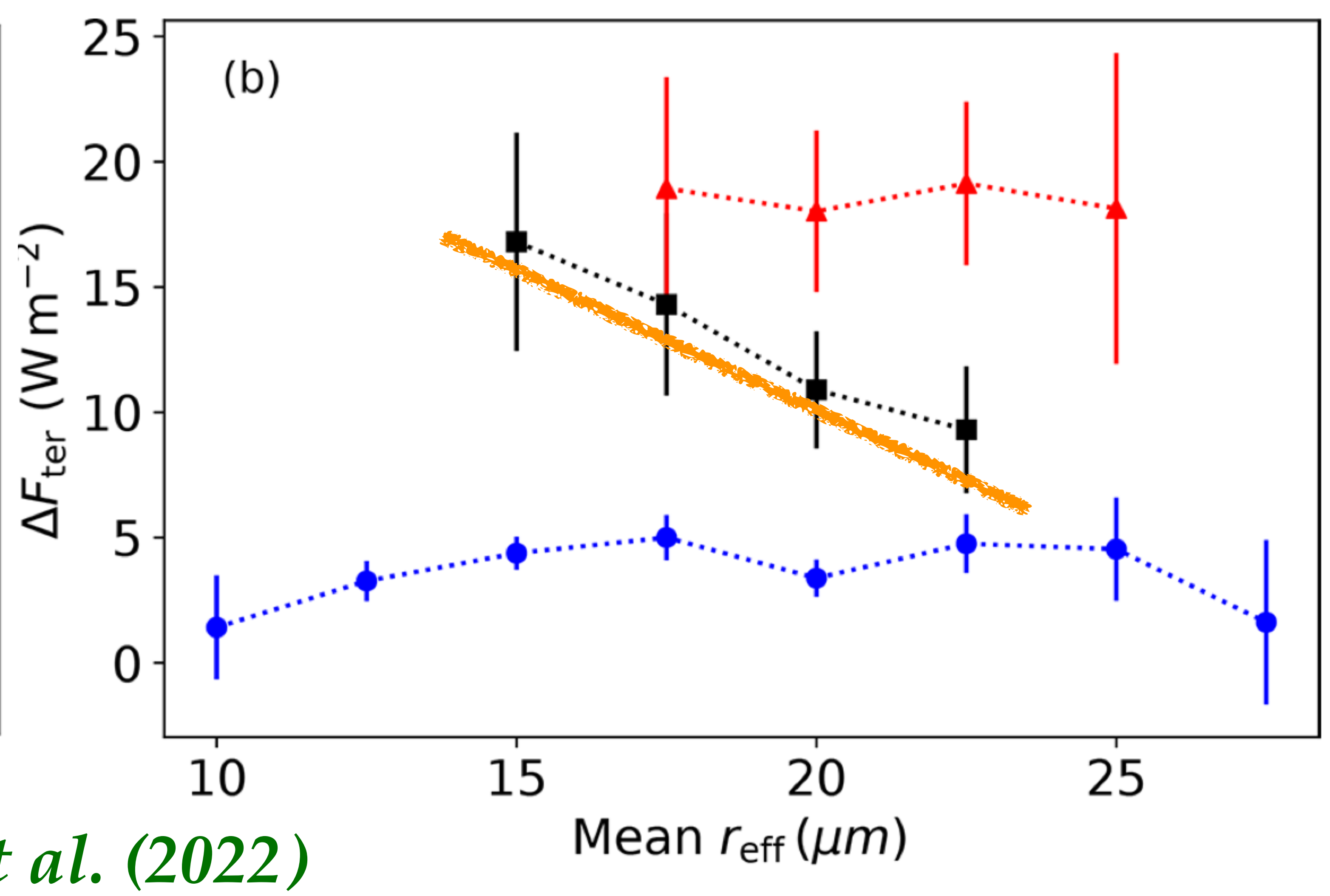

Luebke et al. (2022)

1. Free tropospheric water vapor could be a confounding factor

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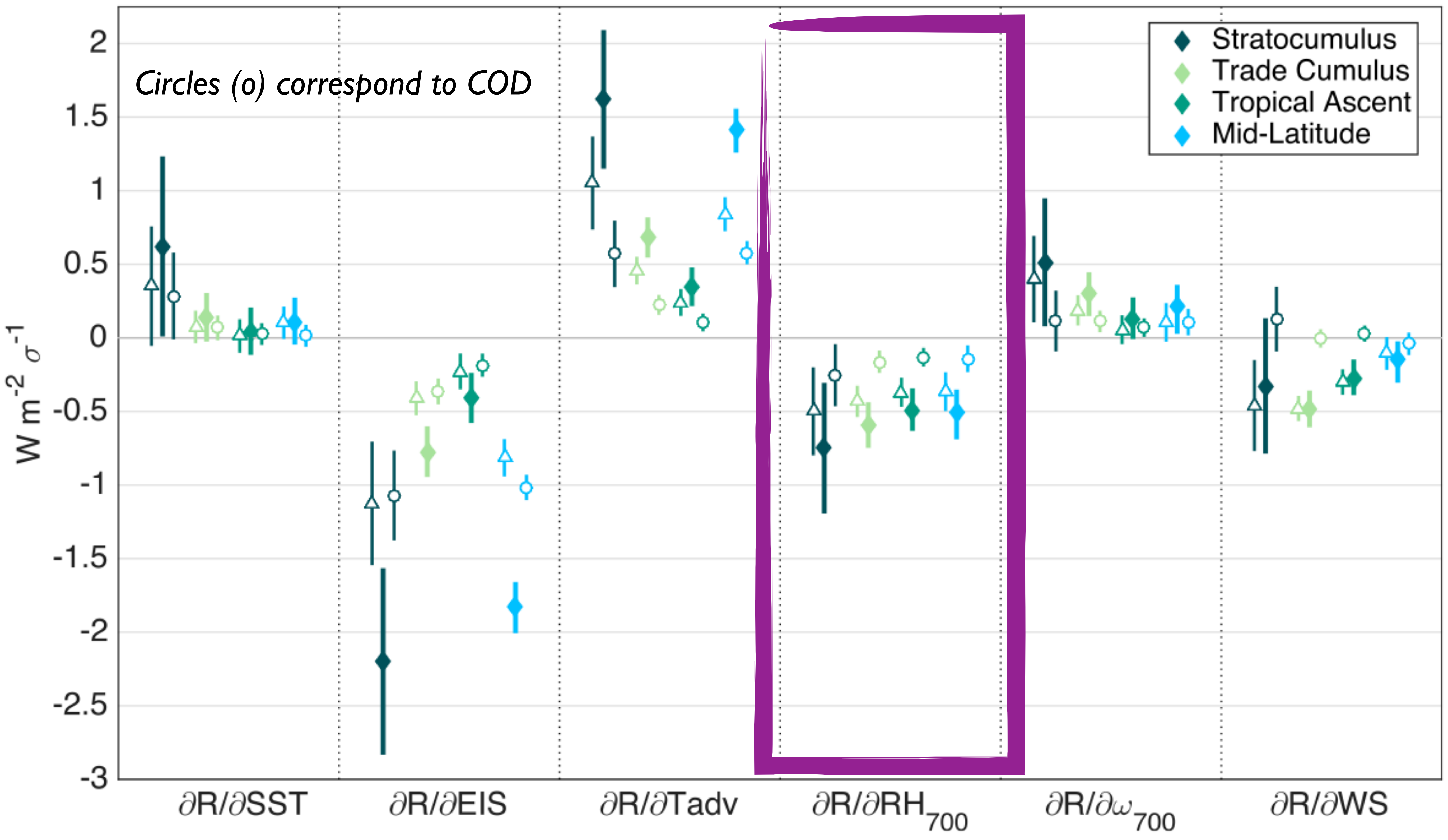

Trade cumuli COD is not (very) sensitive to free tropospheric humidity

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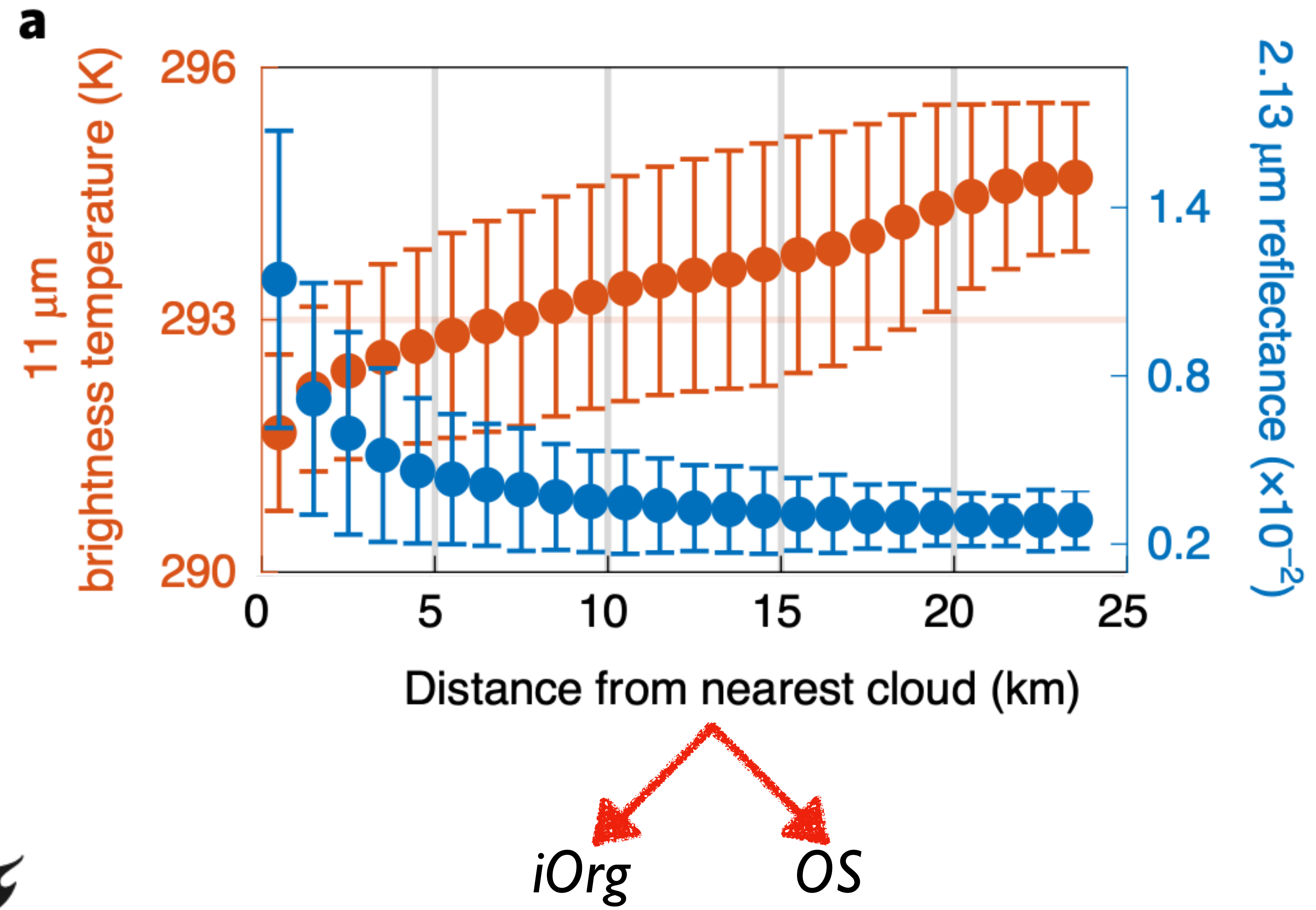
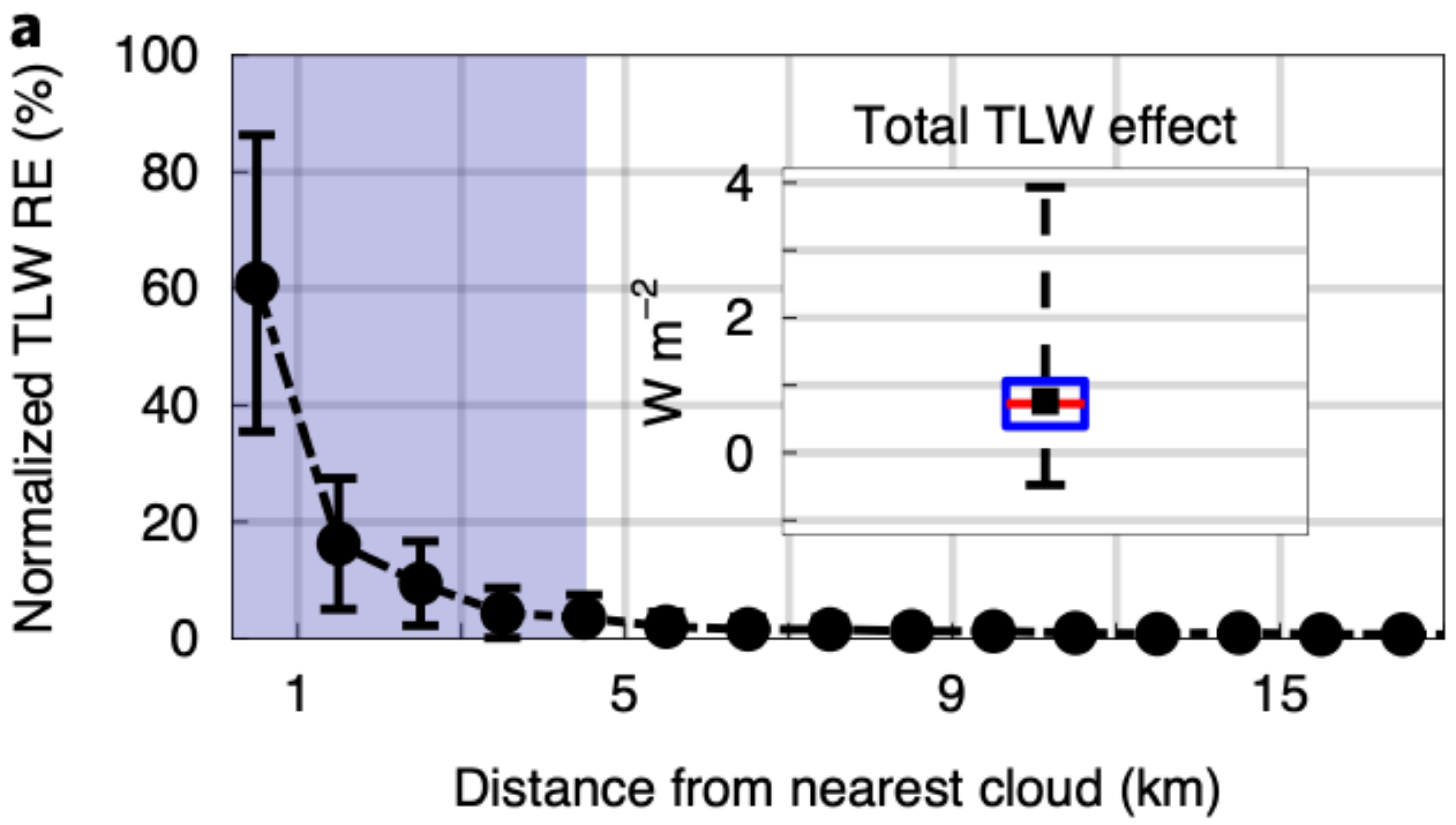
Scott et al. (2020)

2. Cloud twilight zone: neither clear nor cloudy

With increasing the distance between cloud objects
Reflectance/cooling decreases
Emission decreases; more warming



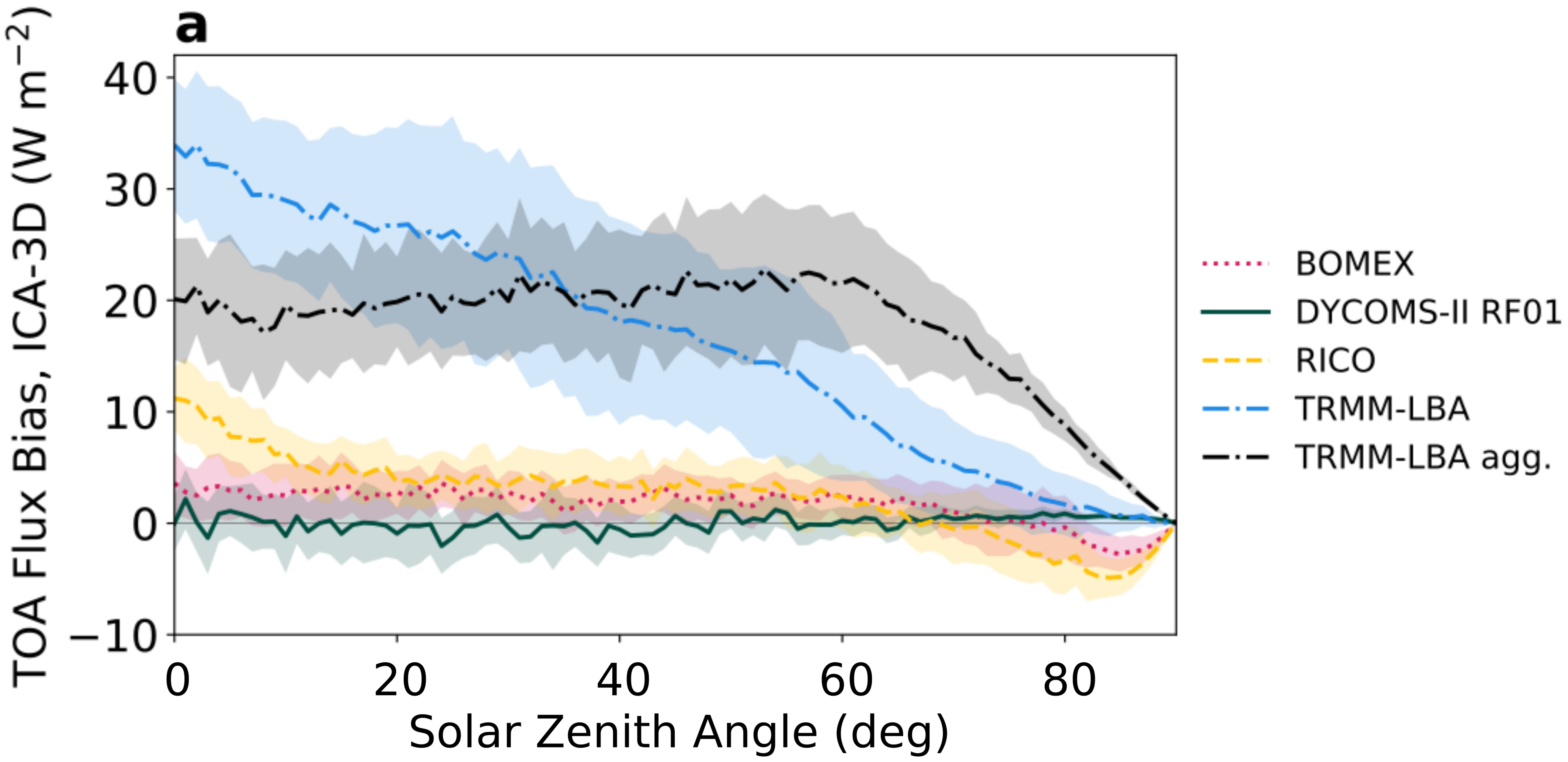
0.75 W/m2 seems negligible compared to ~5 W/m2 LW CRE variability wrt Reff.
So, radiative effect from twilight zone effect might not be significant.



Eytan et al. (2020)

3. Three-dimensional SW cloud radiative effects

Not significant for both BOMEX and RICO cases.



Singer et al. (2021)

Aerosols?

Effective radius (Reff) depends on:

- *aerosol abundance*
- *meteorological conditions; updraft strength and cloud depths*

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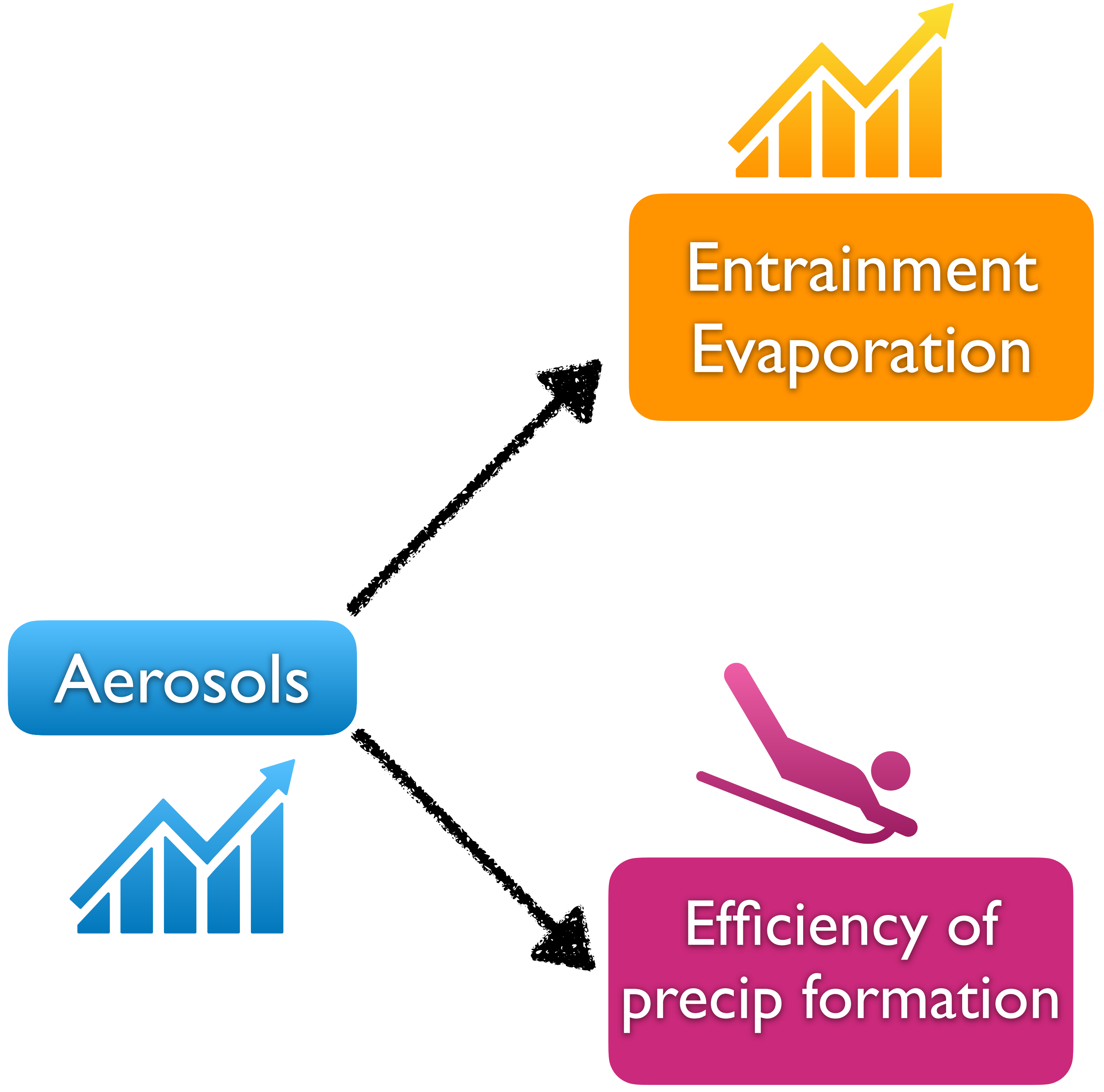

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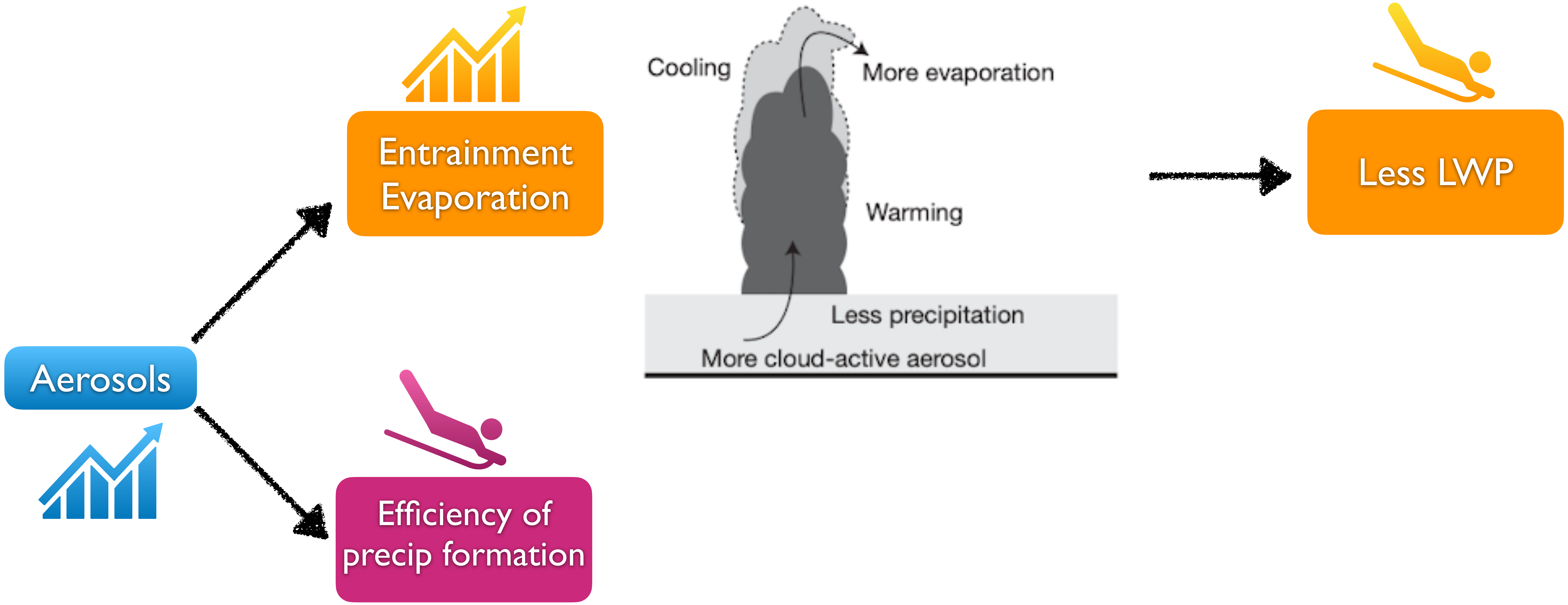

Stevens and Feingold (2009)

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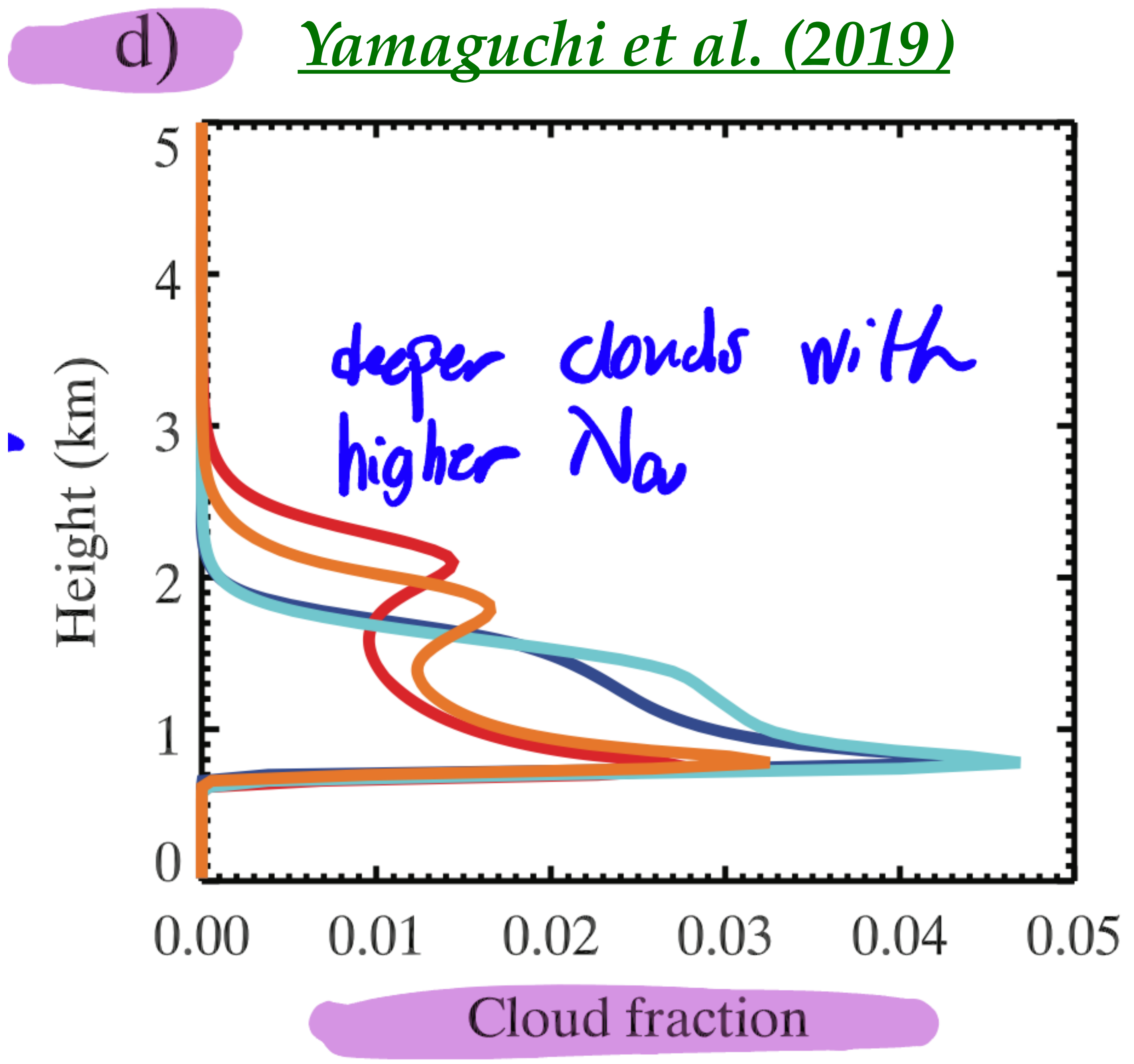

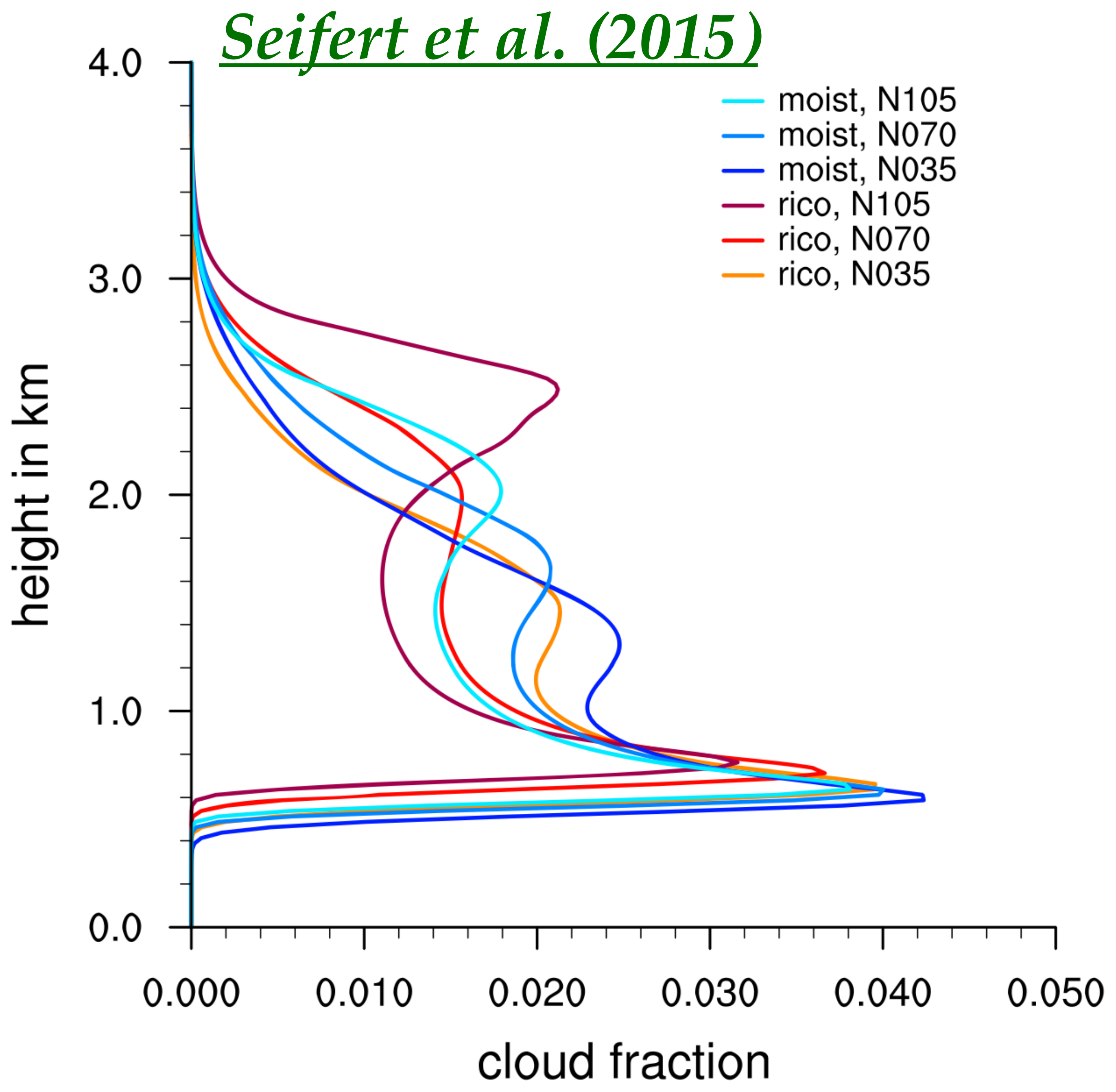

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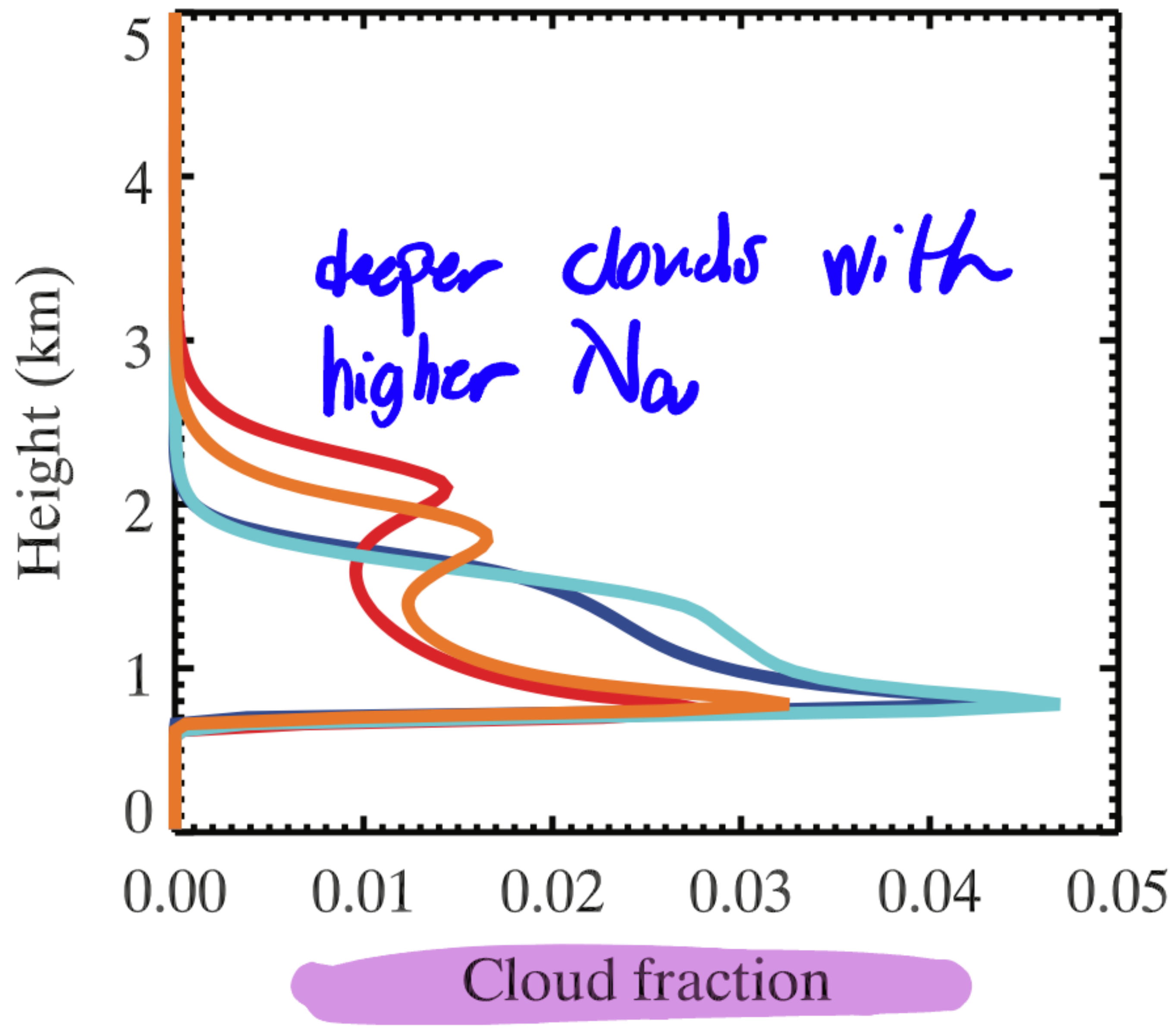
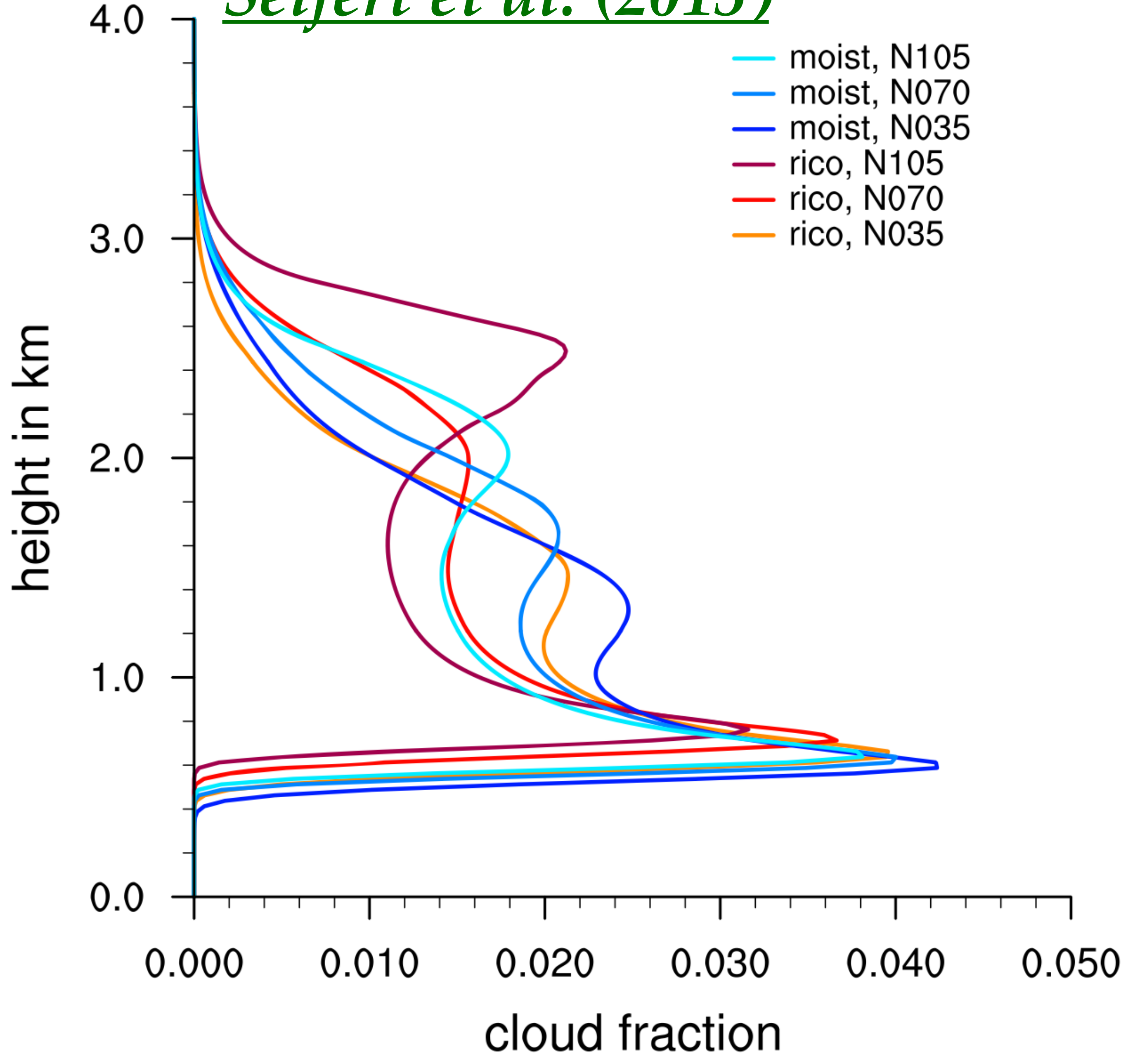
d) Yamaguchi et al. (2019)



Seifert et al. (2015)



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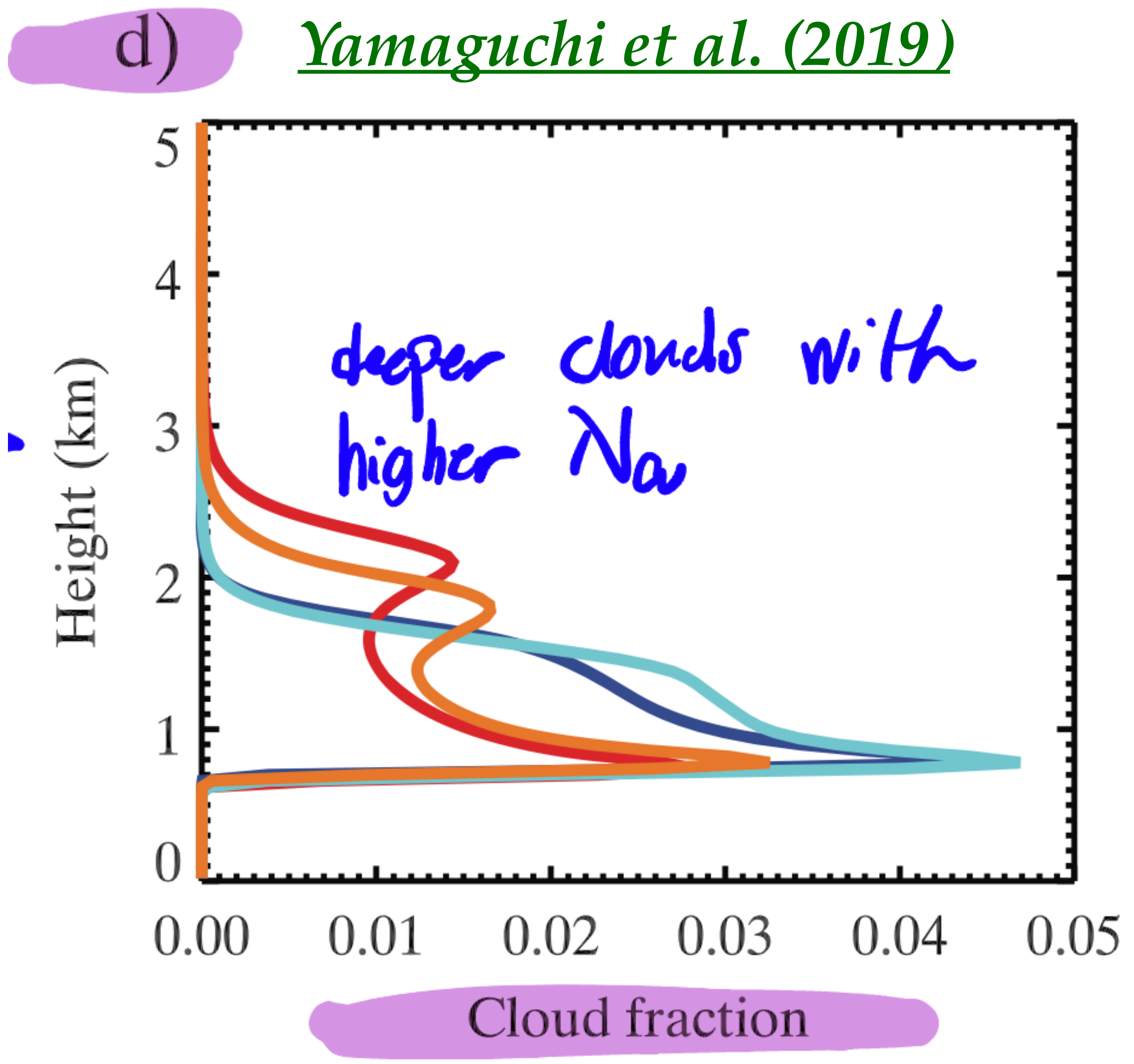
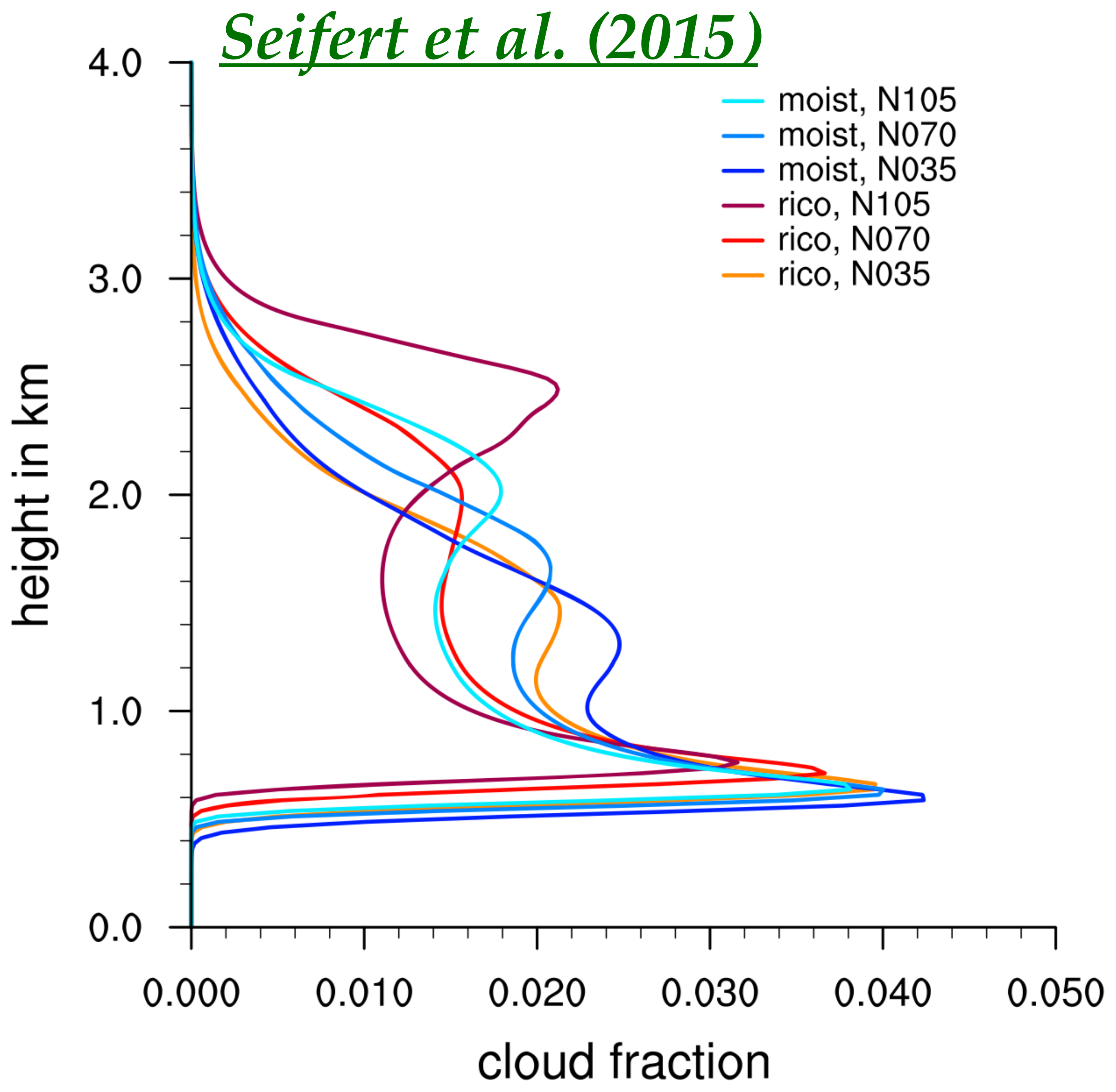
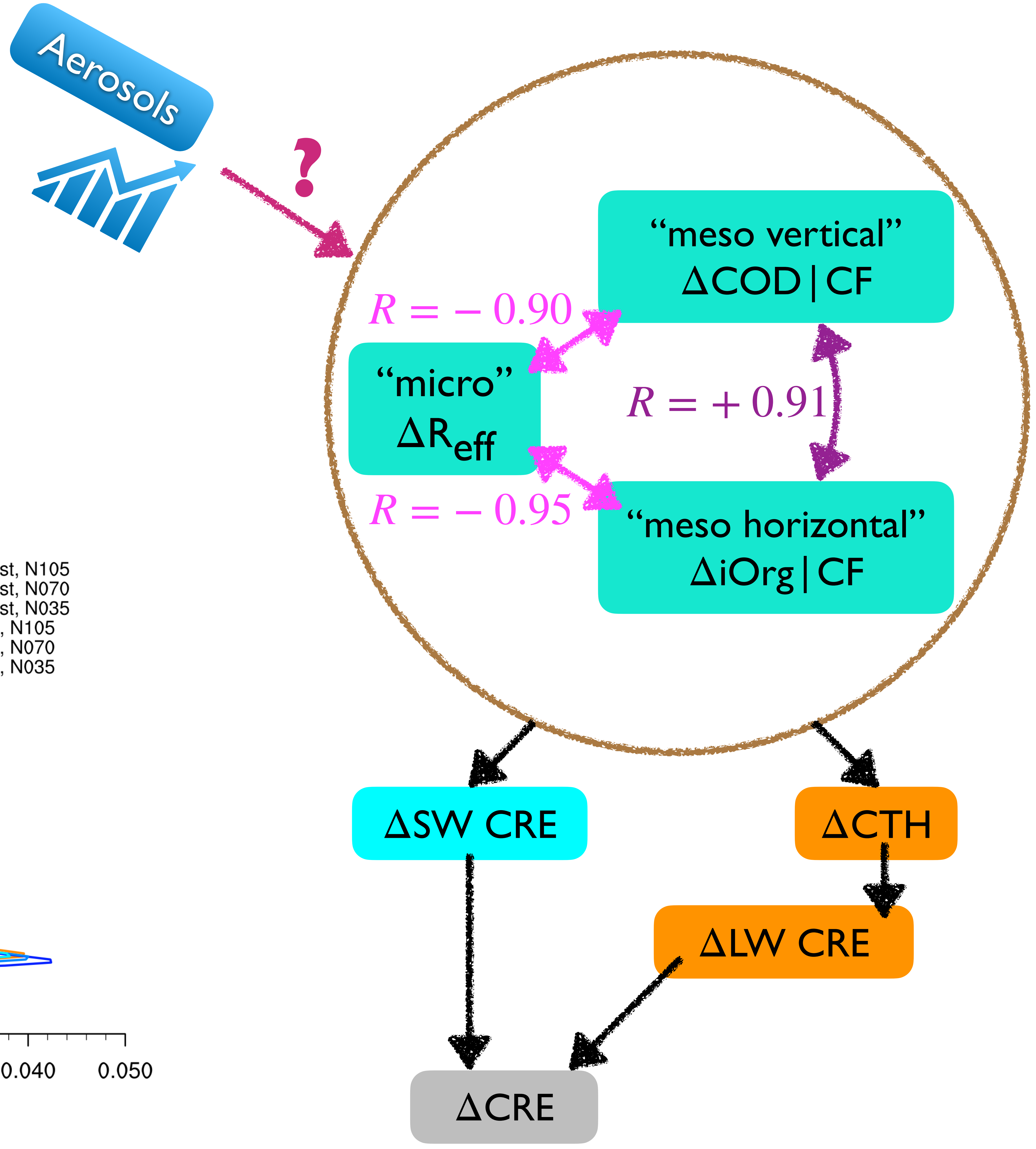


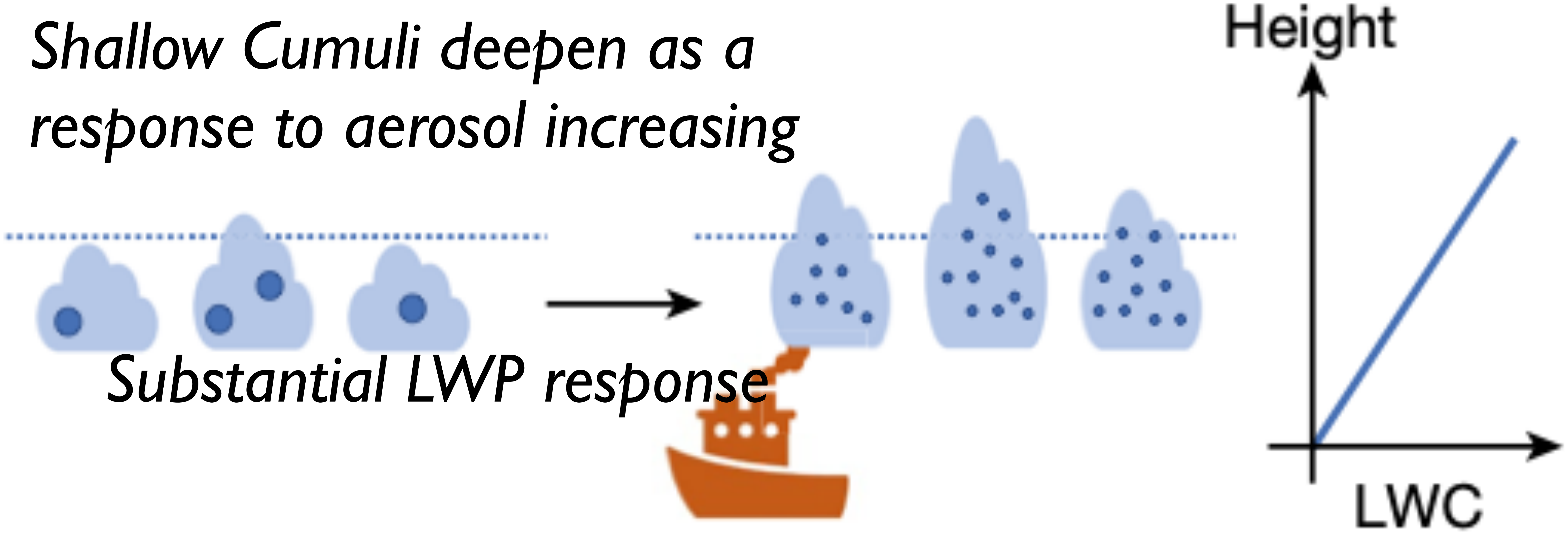




Aerosols?

Our results are consistent with a recent observational study on effect of invisible ship tracks on liquid clouds

Shallow Cumuli deepen as a response to aerosol increasing



Substantial LWP response

Manshausen et al. (2022)

Motivation

Data

Methods

Results

Discussions & Conclusions

Conclusion

- *Cloud patterns influence the radiative effects through changes in not only cloud cover but also cloud optical depth.*
- *Trade cumuli are optically thicker when they are more clustered.*
- *Controlling cloud fraction, iOrg variability (0.15) can explain 5 W/m2 variability in net CRE.*
- *Organization can serve as a proxy for microphysical state of clouds.*
- Δ*Reff ~ -3.5*μ*m:* Δ*CF ~ 0,* Δ*ln(iOrg) ~ 0.1,* Δ*thickness ~ 500m,* Δ*SW CRE ~ -7.5 W/m2,* Δ*LW CRE ~ 5W/m2,* Δ*net CRE ~ 2W/m2.*
- *Cumuli organization buffers the response of net cloud radiative effect to microphysical perturbations.*

Thanks for your attention!