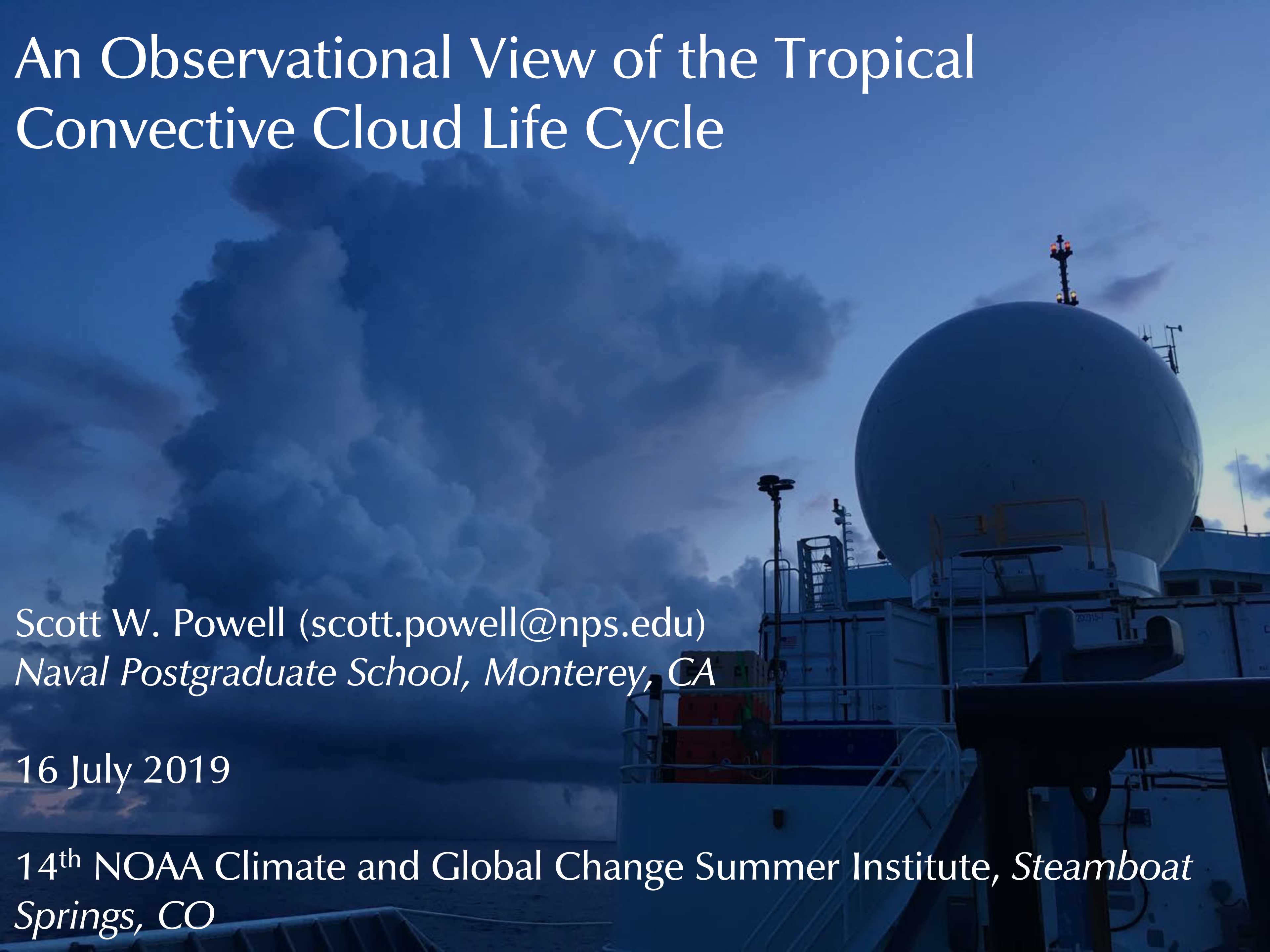
An Observational View of the Tropical Convective Cloud Life Cycle



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Dynamics and moist convection are intricately related through the thermodynamic equation.

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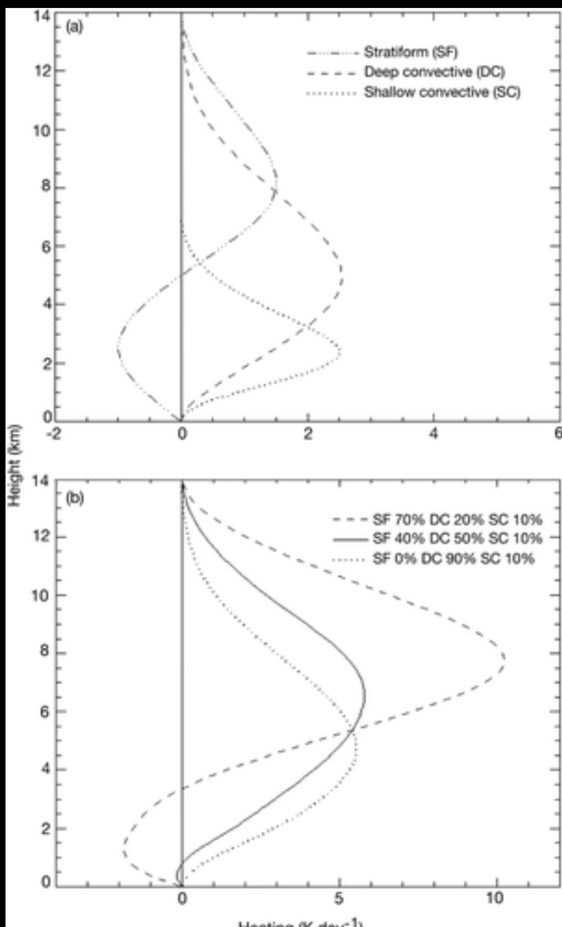
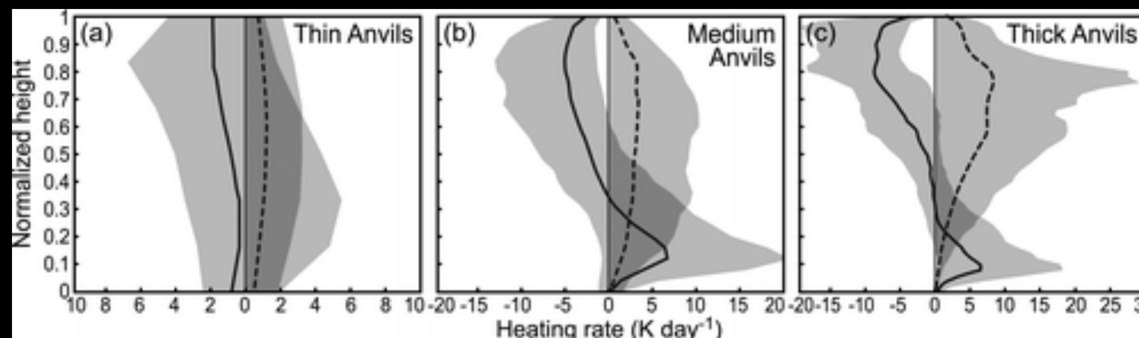
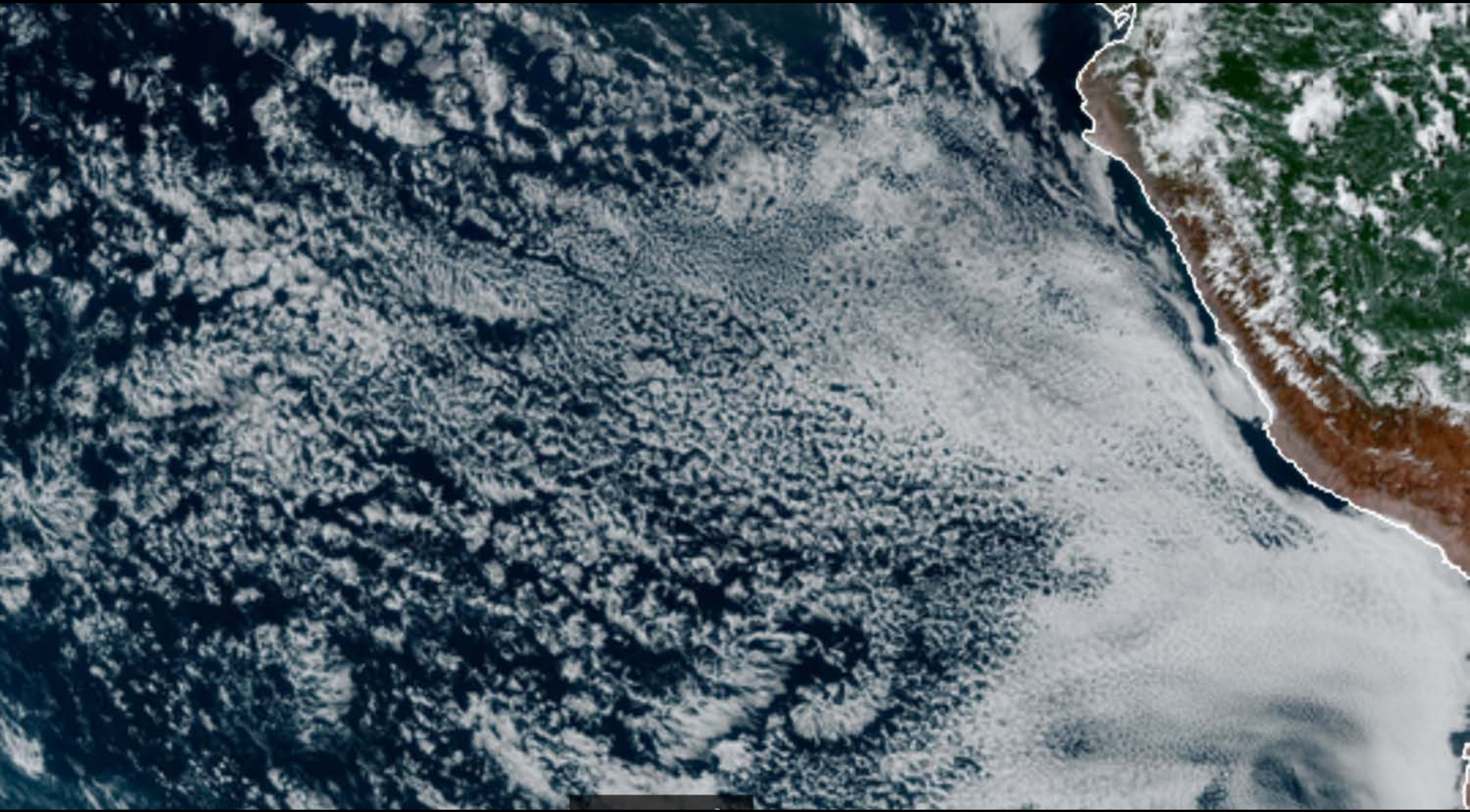




Radar/lidar-derived radiative heating in West African MCS cirrus anvil clouds (Powell et al. 2012)

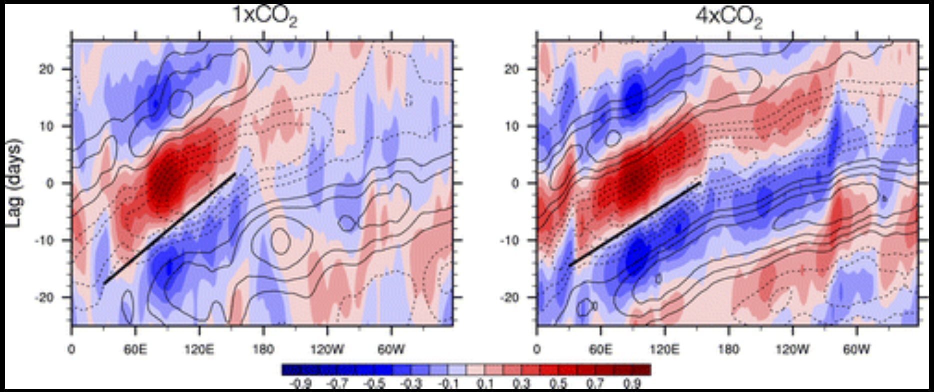
Idealized profiles of latent heating in convection (Schumacher et al. 2014)

GOES-16 (East Pacific 15 July)



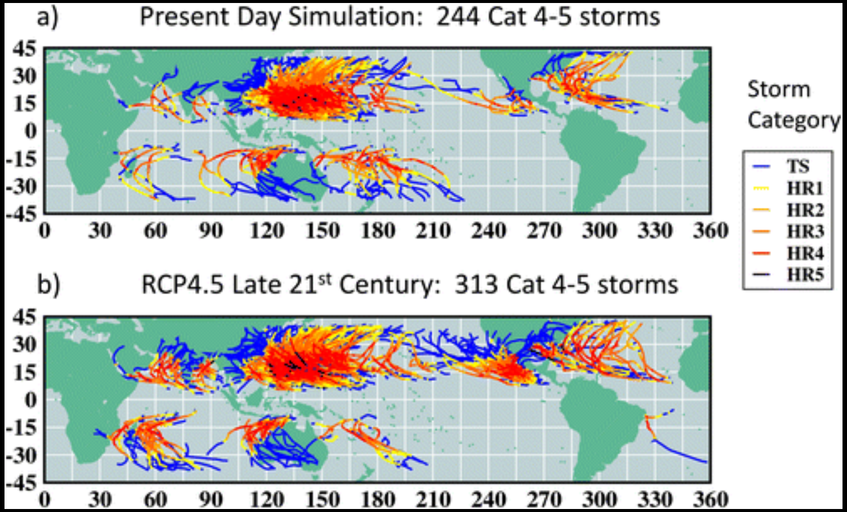
Himawari-8 (West Pacific 14 July)

Sub-seasonal variability of tropical precipitation increases in magnitude.

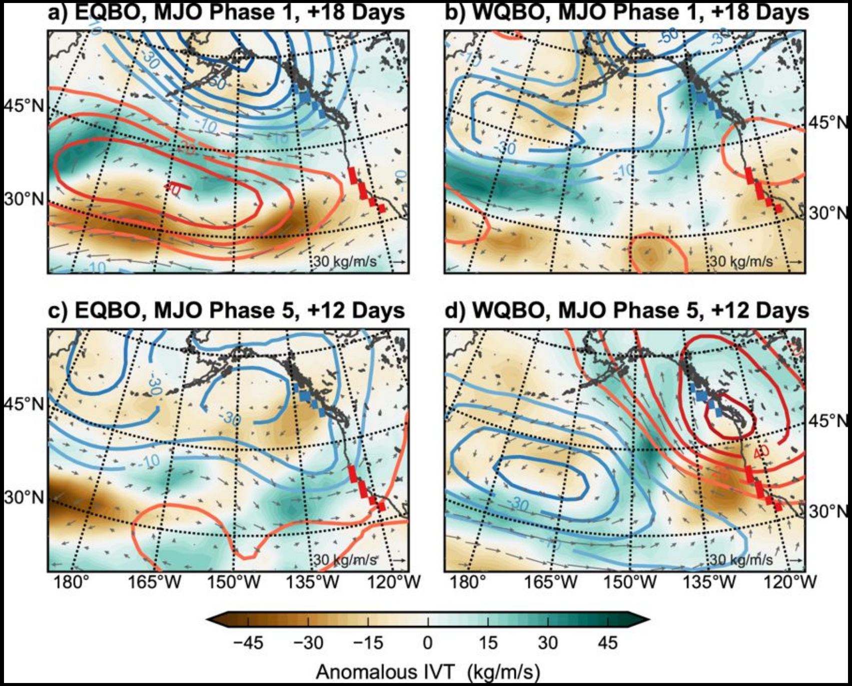


Arnold et al. (2015)

Tropical cyclone intensity increases.



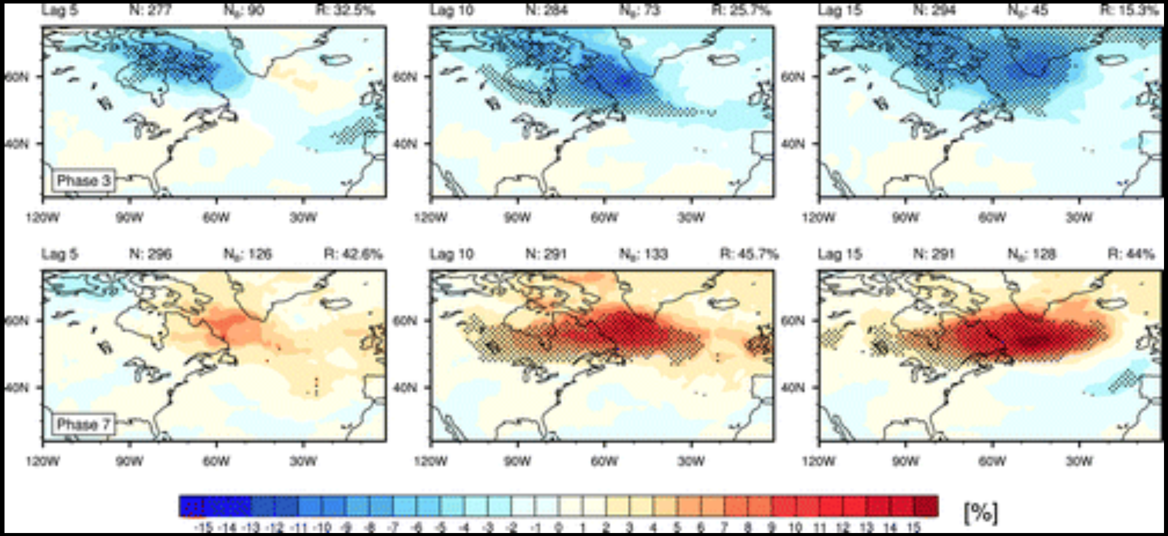
Knutson et al. (2015), but a result replicated by many studies

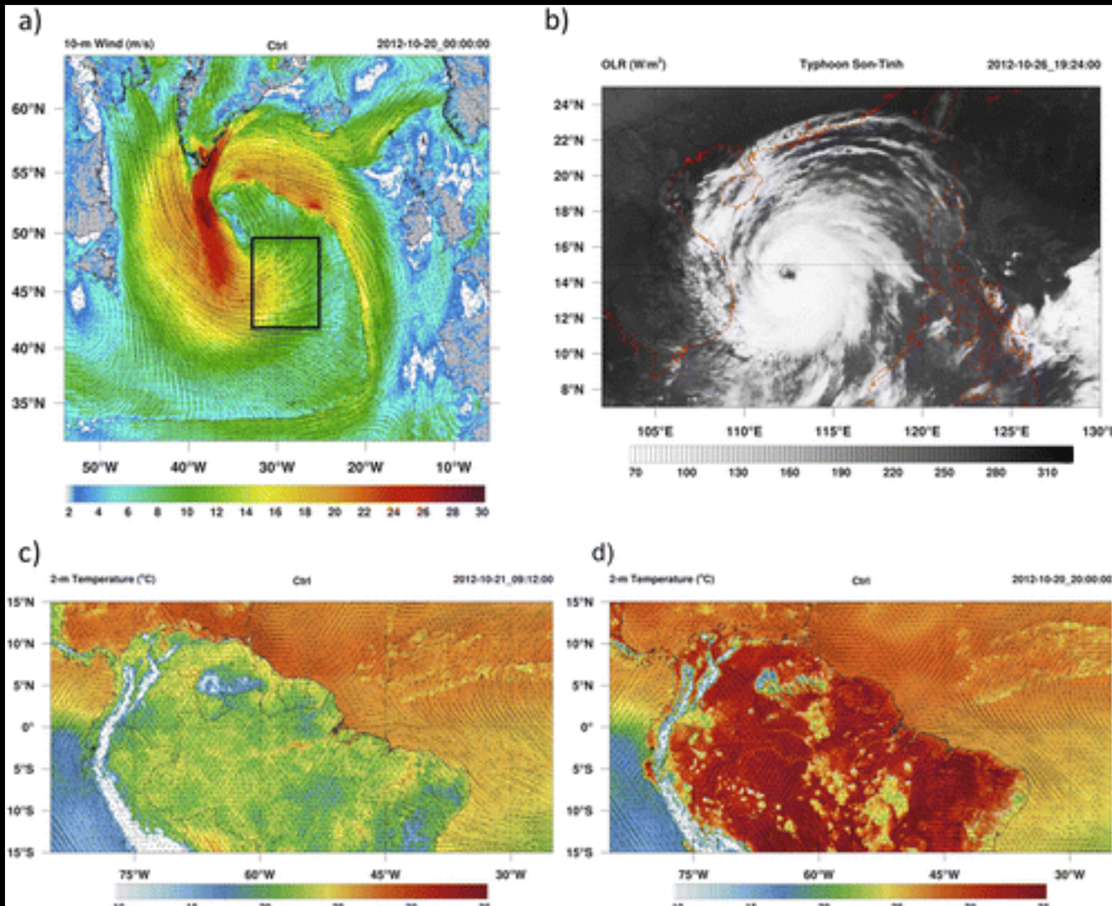


Deep convection in the tropics influences extratropical circulations, and therefore extreme weather events.

Henderson et al. (2016)

Mundhenk et al. (2018)





Weather forecast models have encroached onto “cloud-resolving” resolution. ECMWF runs operationally at 9 km grid spacing!

However, this is difficult for climate models that must integrate over long times.

Judt (2018); nominally 4 km grid spacing

Therefore, adequate modeling of tropical dynamics requires either 1) resolution of cloud-scale features or 2) accurate parameterization of these "sub-grid" scale cloud processes.

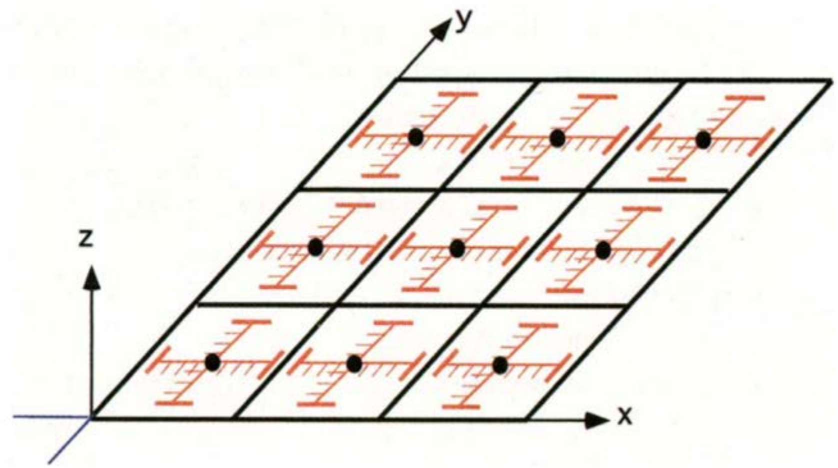
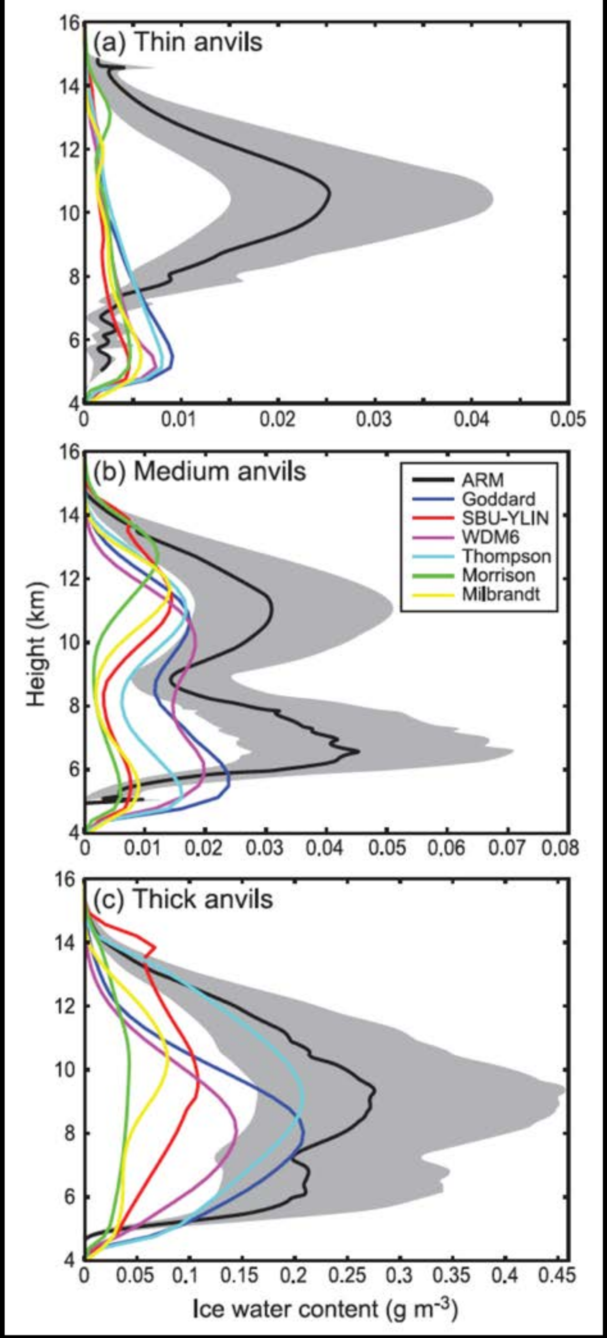
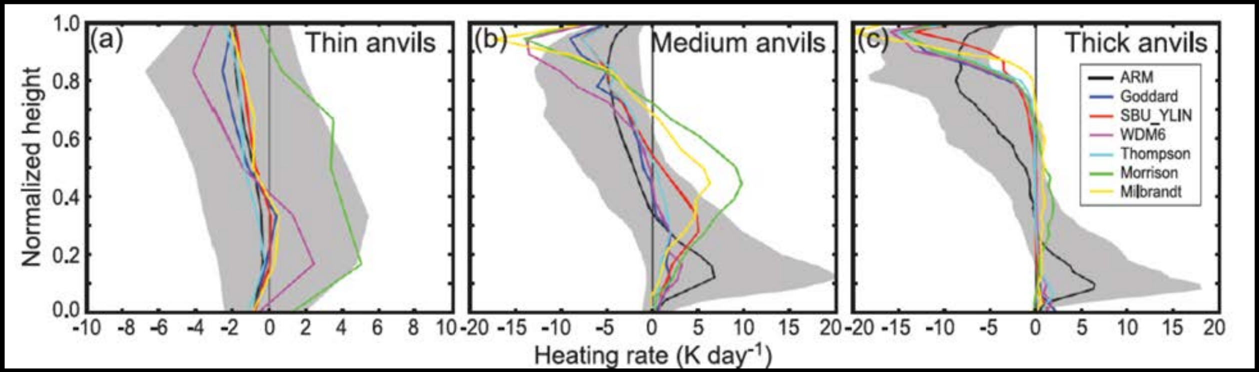


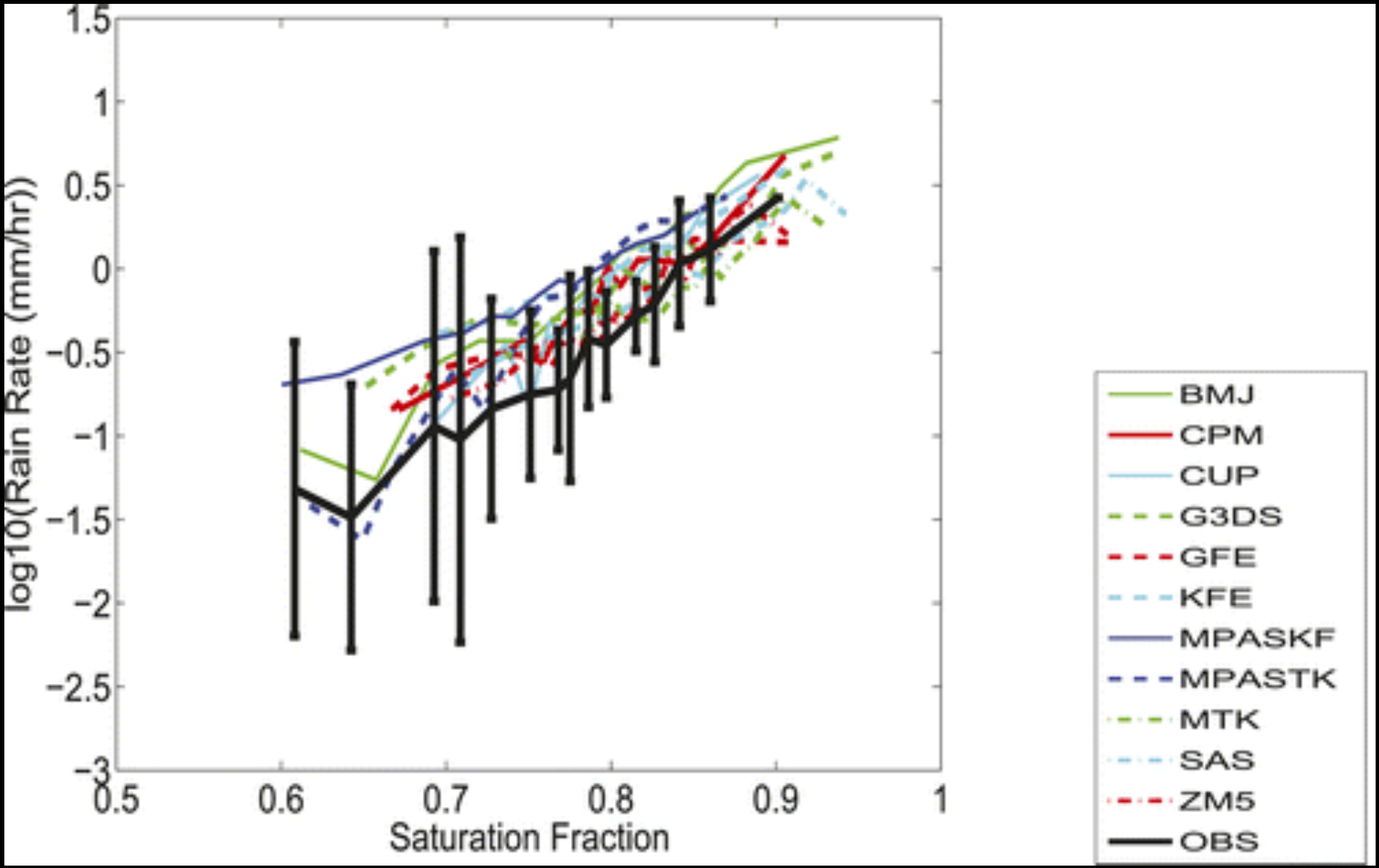
FIG. 17. An evolved version of the original superparameterization concept depicted in Fig. 16. Two CSRMs are embedded in each GCM grid box. They are oriented at right angles to each other. They have periodic boundary conditions, as before. At the point where the two high-resolution grids overlap, the CSRM is three-dimensional. Elsewhere, it is two-dimensional.

Randall et al. (2003)





Powell et al. (2012): Deficiencies in CRMs to replicate anvil radiative heating



Hagos et al. (2016): Models tend to rain excessively, especially at low column-integrated relative humidity.

What are some leading order problems for resolving convection—meaning independent (potentially) deep convective elements and organized convective systems?

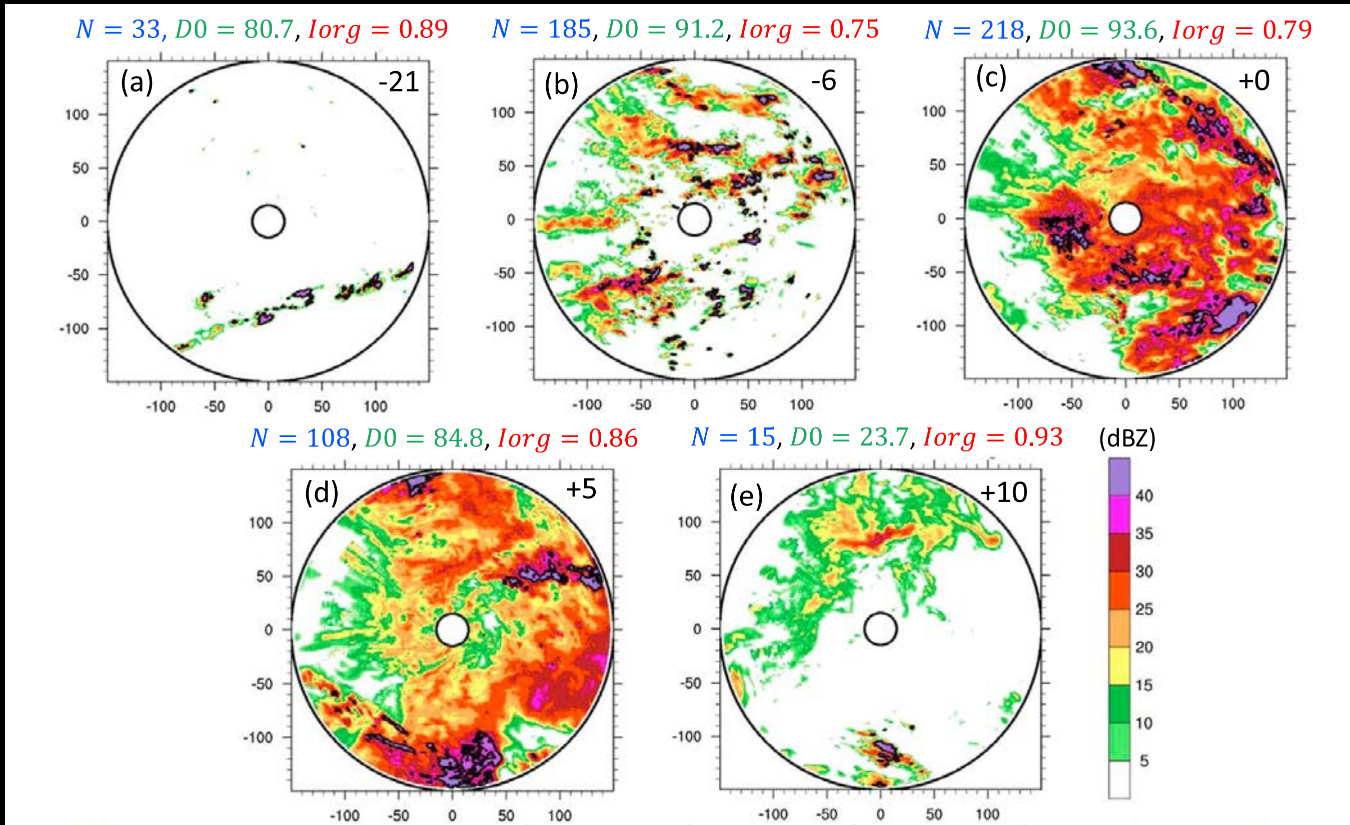
- Mesoscale organization: Depending on how one defines "organization", this can be quantified—a first step toward anchoring a model parameterization to observations.

- Cumuliform cloud structure: Microphysical processes, updraft velocities; basic properties of clouds such as their widths, updraft widths, locations of updrafts relative to their cores.

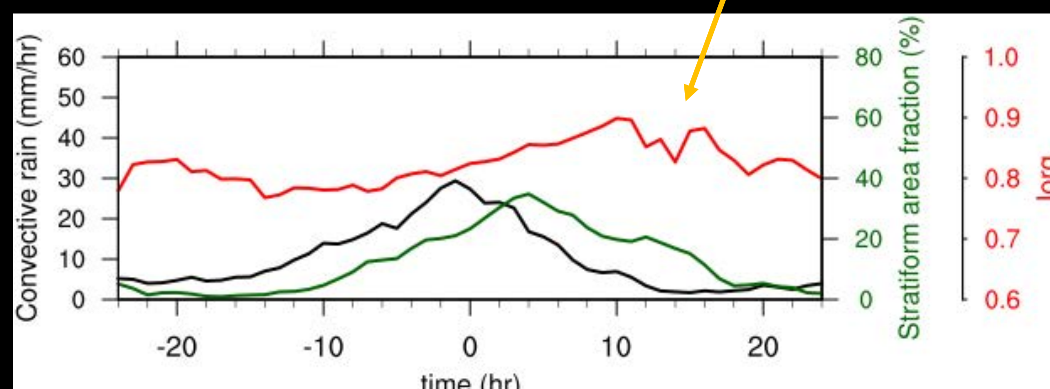
- Interactions between the clouds and their environment: What factors other that atmospheric moisture are of leading order importance for sustaining buoyant updrafts?

- Boundary layer parameterization: For example, what is the buoyancy flux from the ocean to the atmosphere?

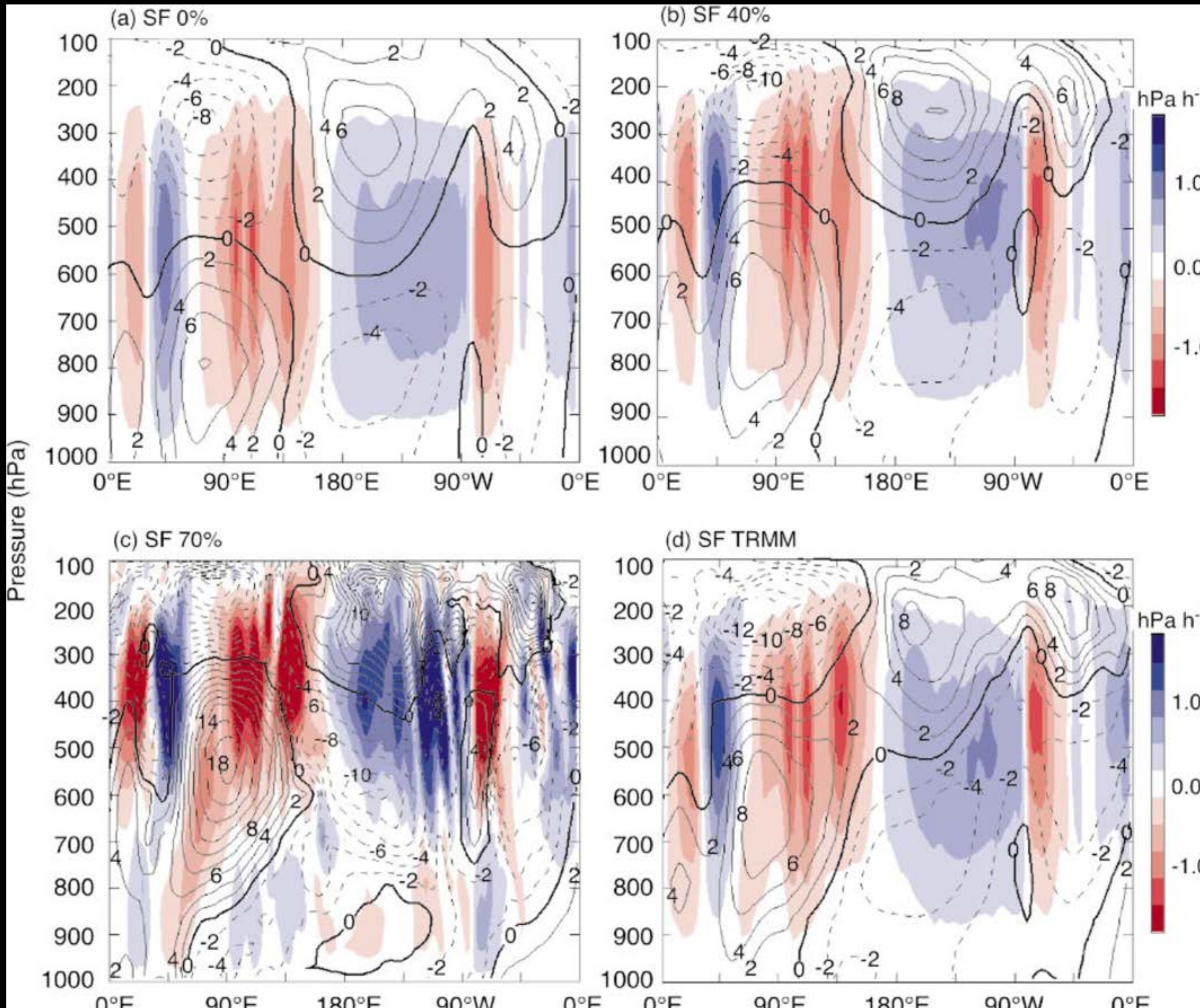
Cheng et al. (2018)



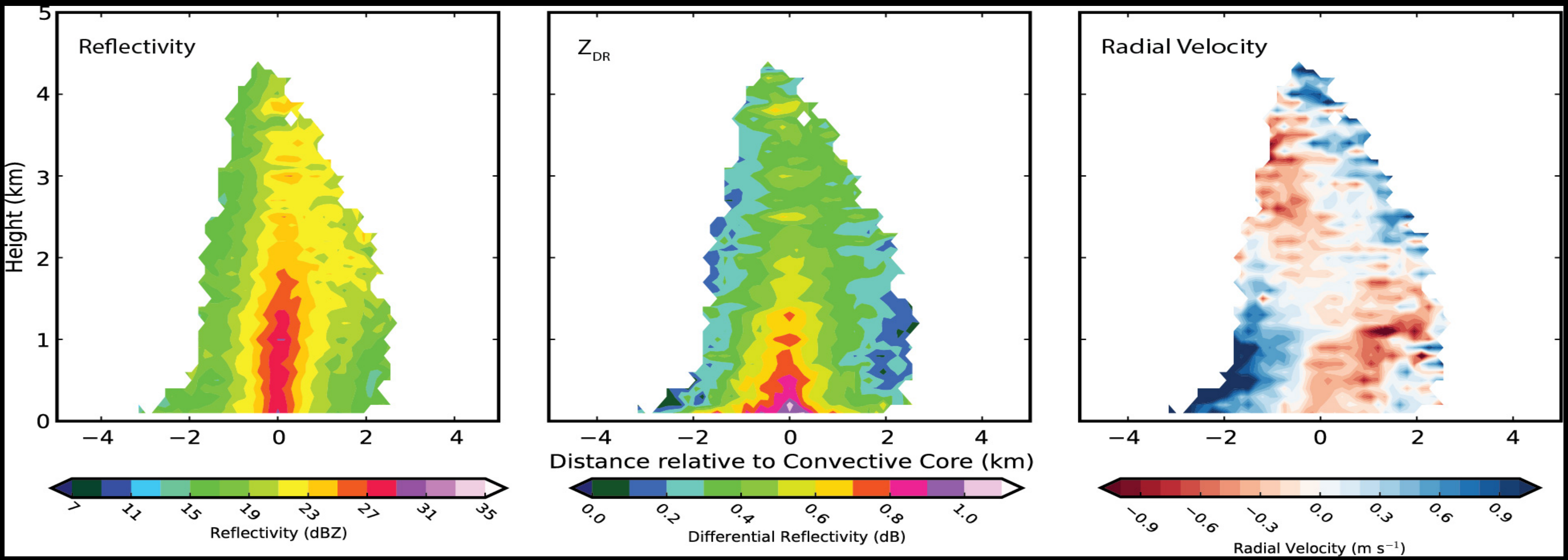
Maximum "organization" of convection maximizes in a mature stage of cloud life cycle.

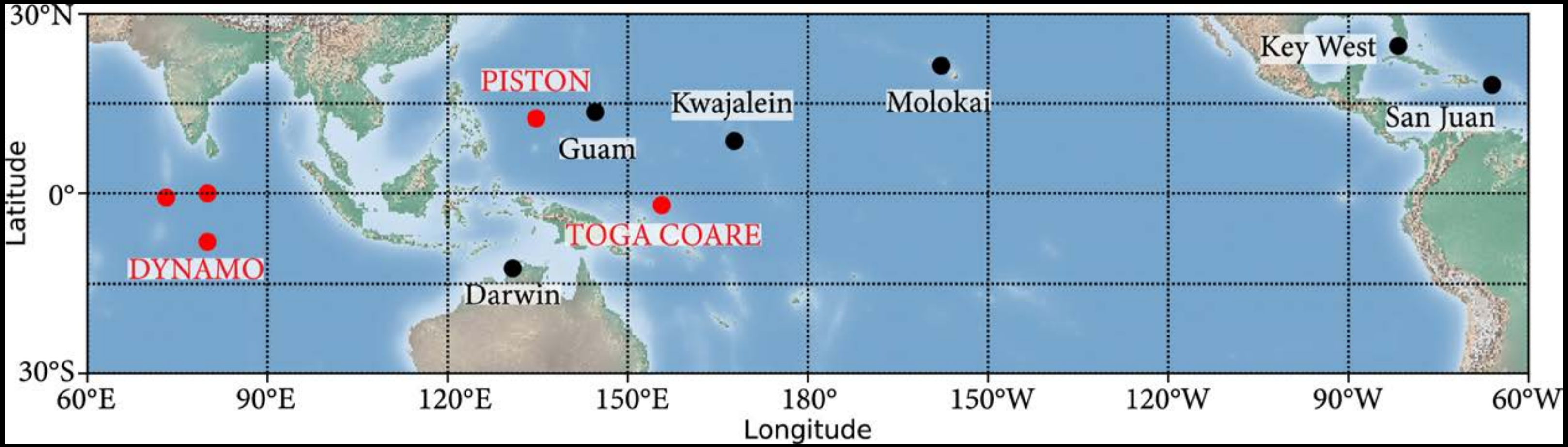


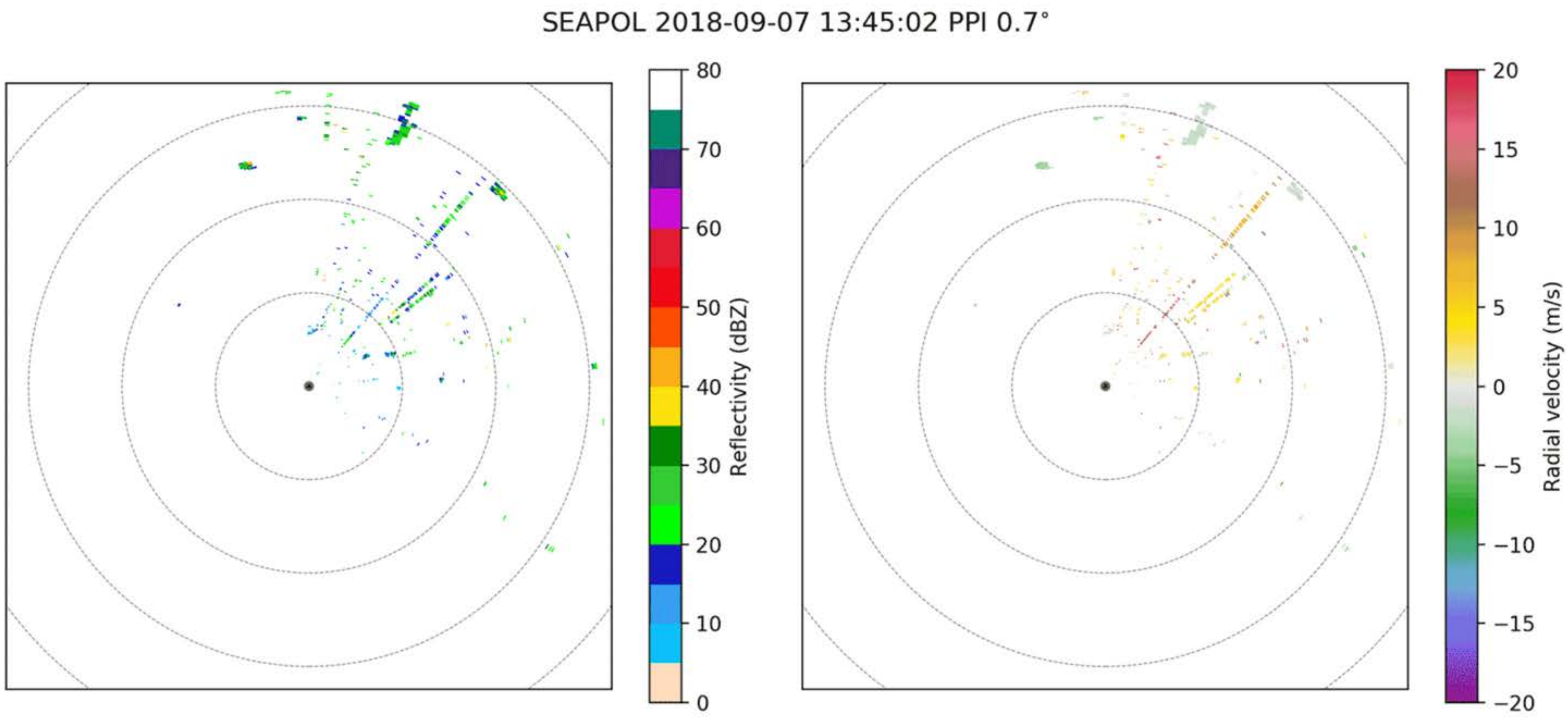
Stratiform rain fraction in model is very important for accurate representation of circulation.



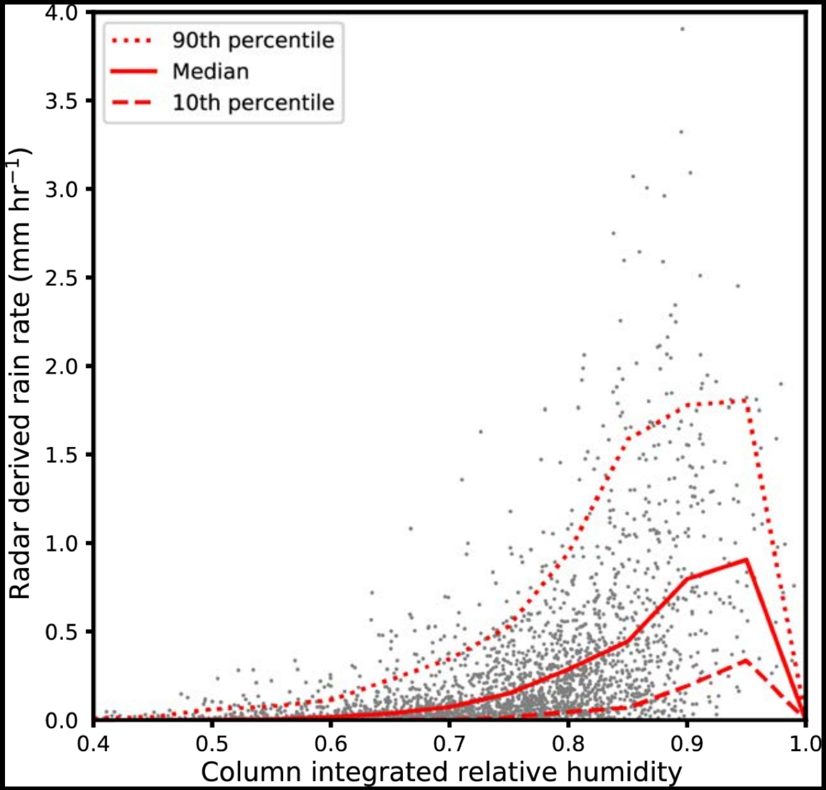
Schumacher et al. (2004)


Reflectivity
Z_{DR}
Radial Velocity
Height (km)
Distance relative to Convective Core (km)
Reflectivity (dBZ)
Differential Reflectivity (dB)
Radial Velocity (m s^{-1})

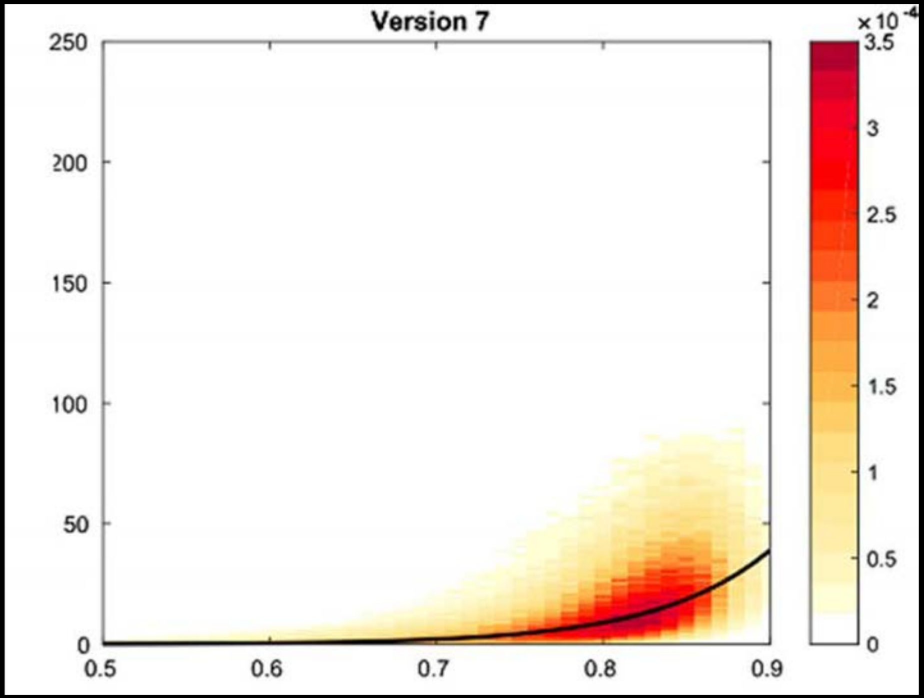

30°N
30°S
0°
Latitude
60°E
90°E
120°E
150°E
180°
150°W
120°W
90°W
60°W
Longitude
PISTON
Guam
Kwajalein
Molokai
Key West
San Juan
DYNAMO
TOGA COARE
Darwin

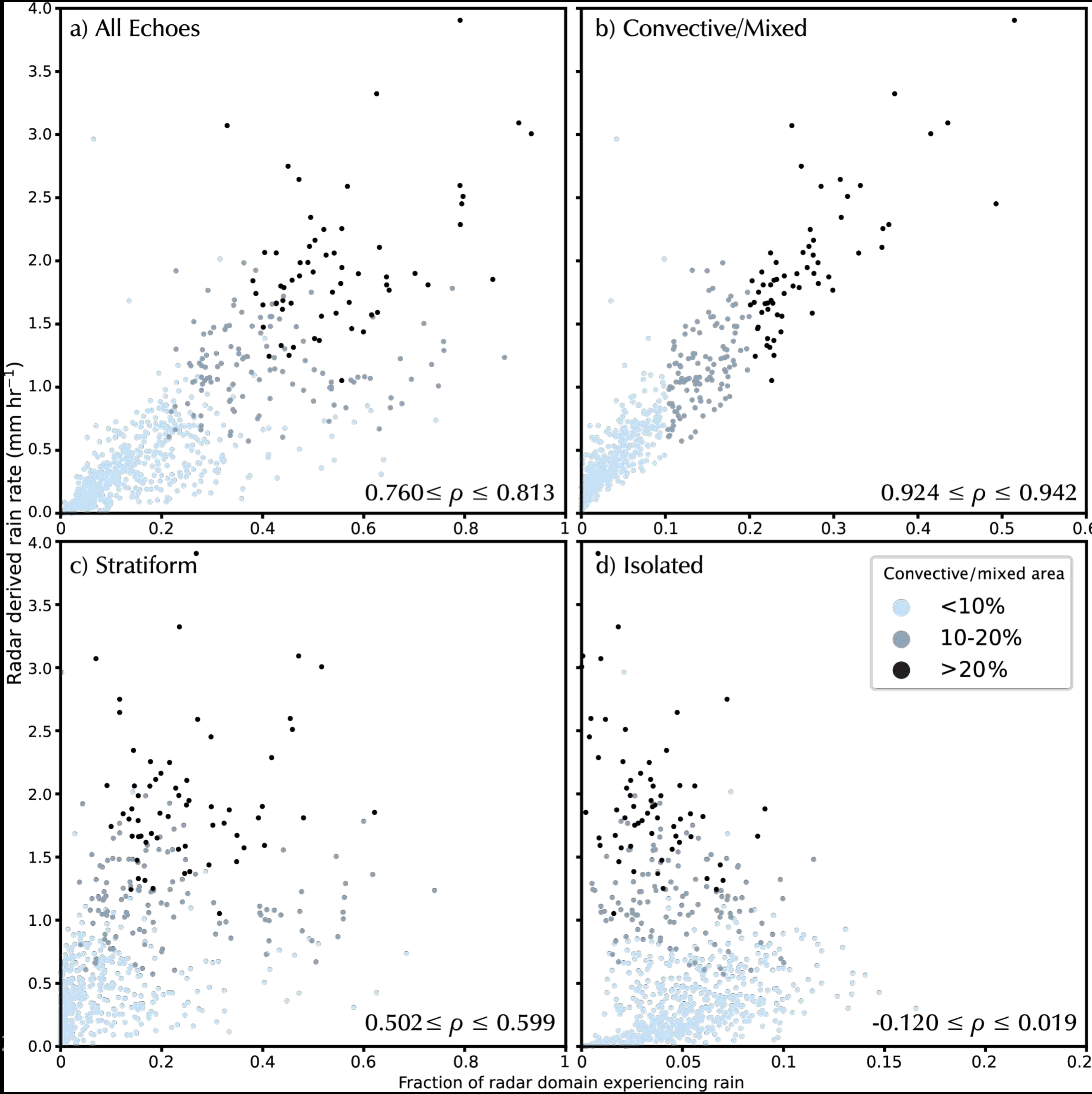

SEAPOL 2018-09-07 13:45:02 PPI 0.7°
Reflectivity (dBZ)
0
10
20
30
40
50
60
70
80
Radial velocity (m/s)
−20
−15
−10
−5
0
5
10
15
20

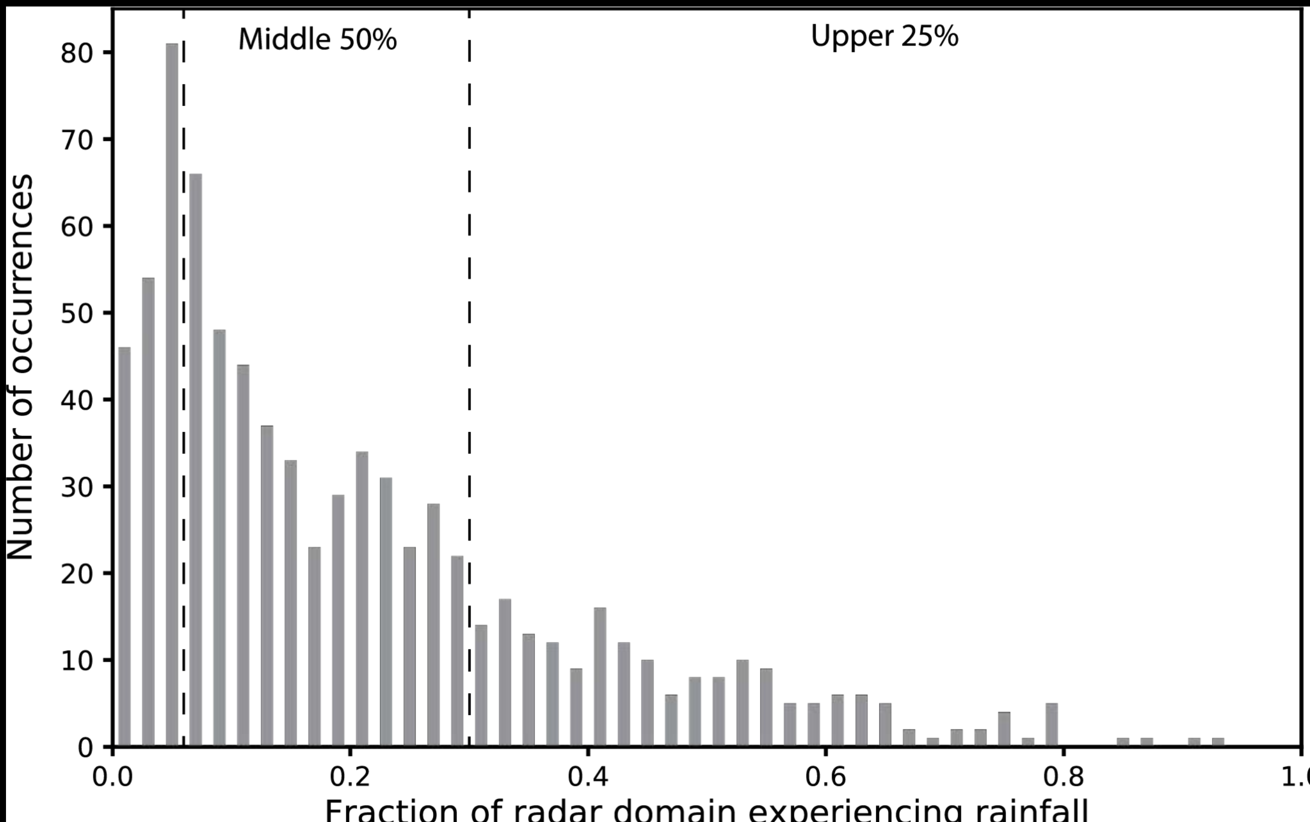
Powell (2019)

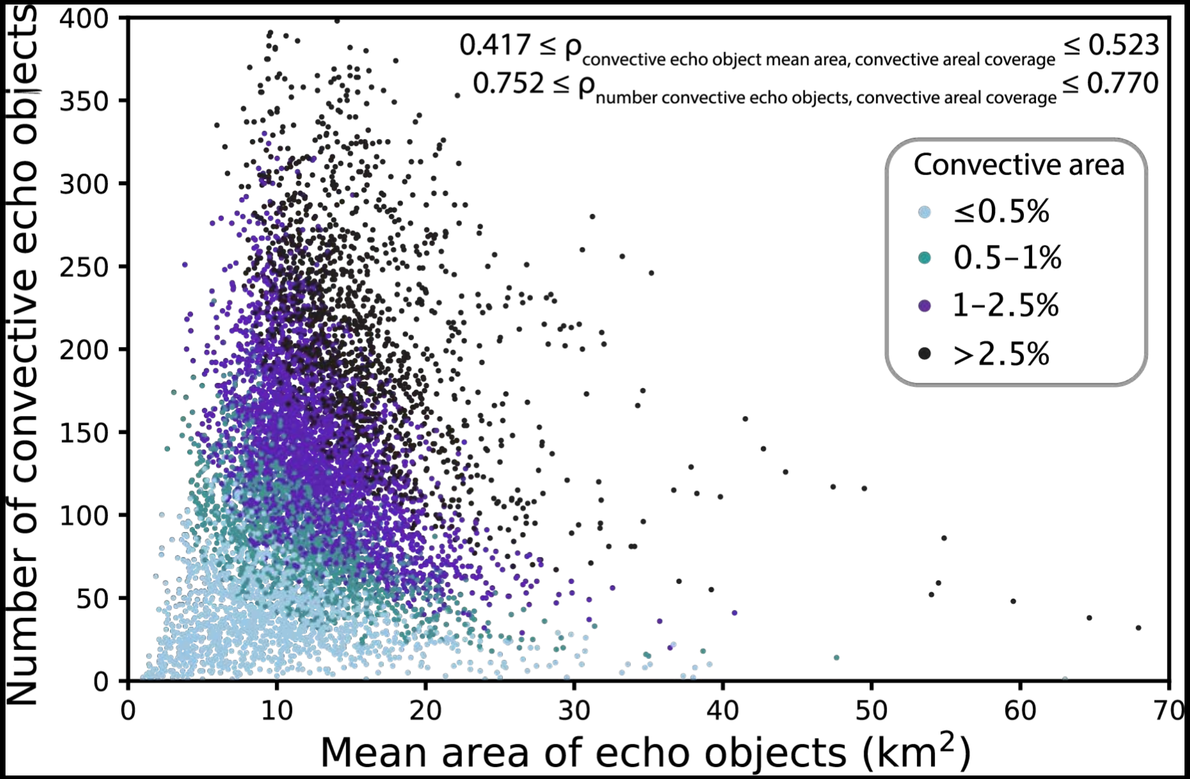


Rushley et al. (2018)

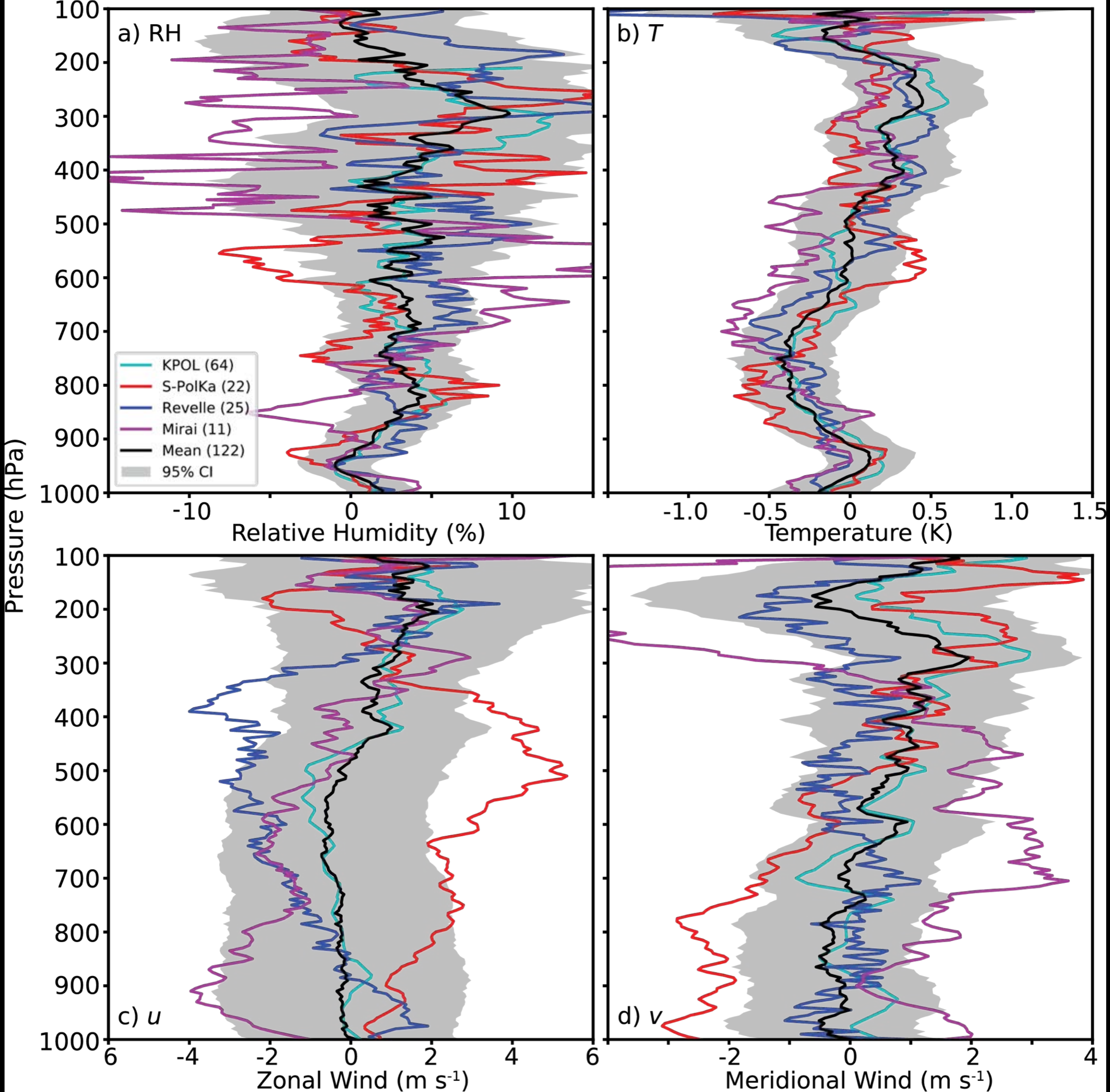



a) All Echoes
0.760≤ ρ ≤ 0.813
b) Convective/Mixed
0.924 ≤ ρ ≤ 0.942
c) Stratiform
0.502≤ ρ ≤ 0.599
d) Isolated
-0.120 ≤ ρ ≤ 0.019
Convective/mixed area
<10%
10-20%
>20%
Radar derived rain rate (mm hr⁻¹)
Fraction of radar domain experiencing rain

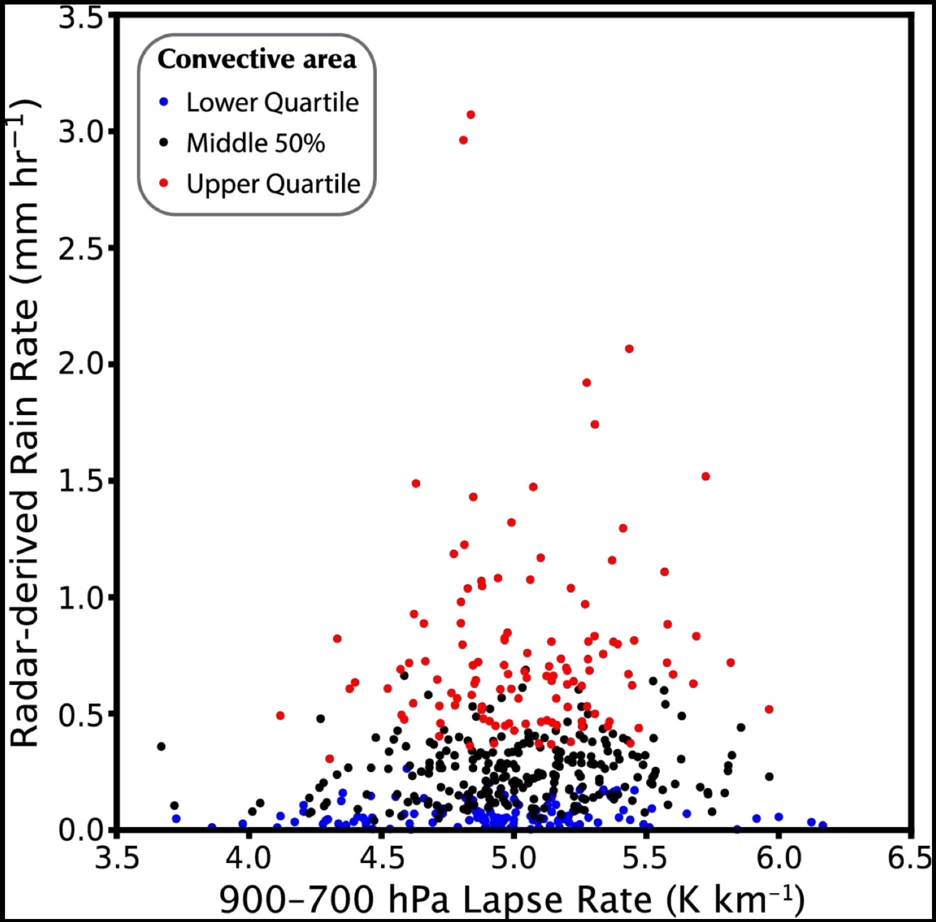

Middle 50%
Upper 25%
Number of occurrences
Fraction of radar domain experiencing rainfall
0
10
20
30
40
50
60
70
80
0.0
0.2
0.4
0.6
0.8
1.0



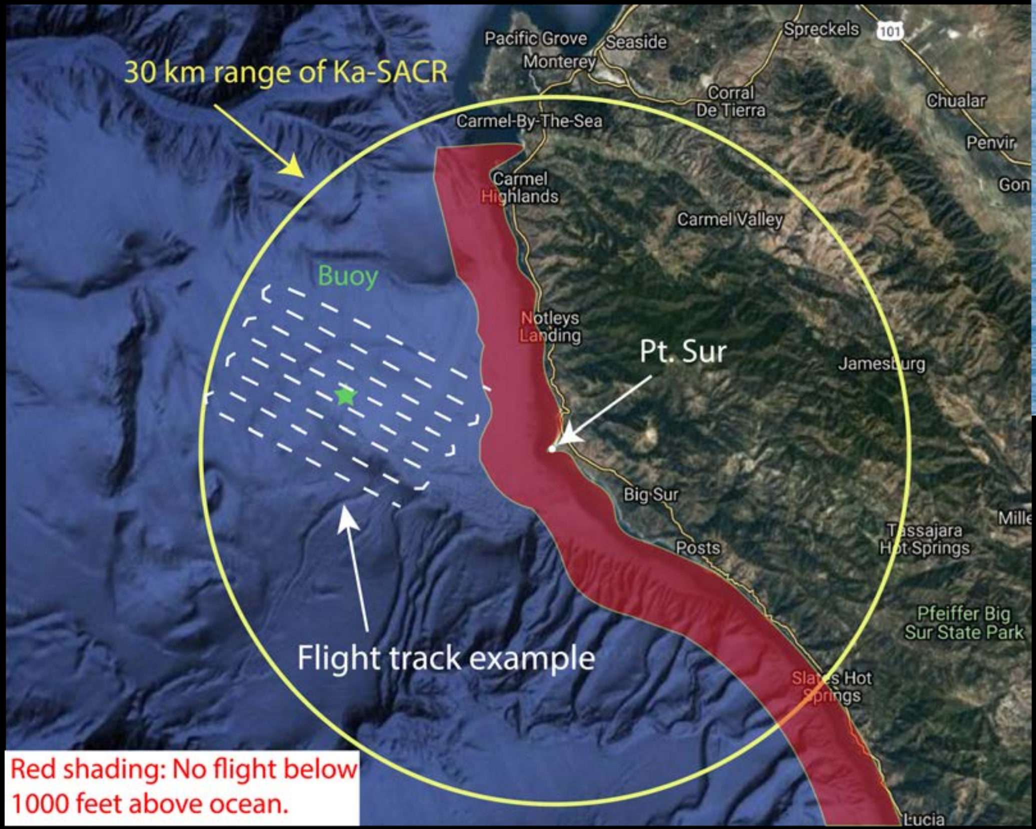
$0.417 \leq \rho_{\text{convective echo object mean area, convective areal coverage}} \leq 0.523$
$0.752 \leq \rho_{\text{number convective echo objects, convective areal coverage}} \leq 0.770$
Convective area
≤0.5%
0.5–1%
1–2.5%
>2.5%
Number of convective echo objects
0
50
100
150
200
250
300
350
400
0
10
20
30
40
50
60
70
Mean area of echo objects (km^2)



a) RH
b) T
c) u
d) v
KPOL (64)
S-PolKa (22)
Revelle (25)
Mirai (11)
Mean (122)
95% CI
Pressure (hPa)
100
200
300
400
500
600
700
800
900
1000
-10
0
10
Relative Humidity (%)
-1.0
-0.5
0
0.5
1.0
1.5
Temperature (K)
6
-4
-2
0
2
4
6
Zonal Wind (m s-1)
-2
0
2
4
Meridional Wind (m s-1)


Convective area
Lower Quartile
Middle 50%
Upper Quartile
Radar-derived Rain Rate (mm hr^{-1})
900–700 hPa Lapse Rate (K km^{-1})
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5

California Aircraft Littoral Investigation of Convection over Ocean (**CALICO**) January–February 2020 (planned)



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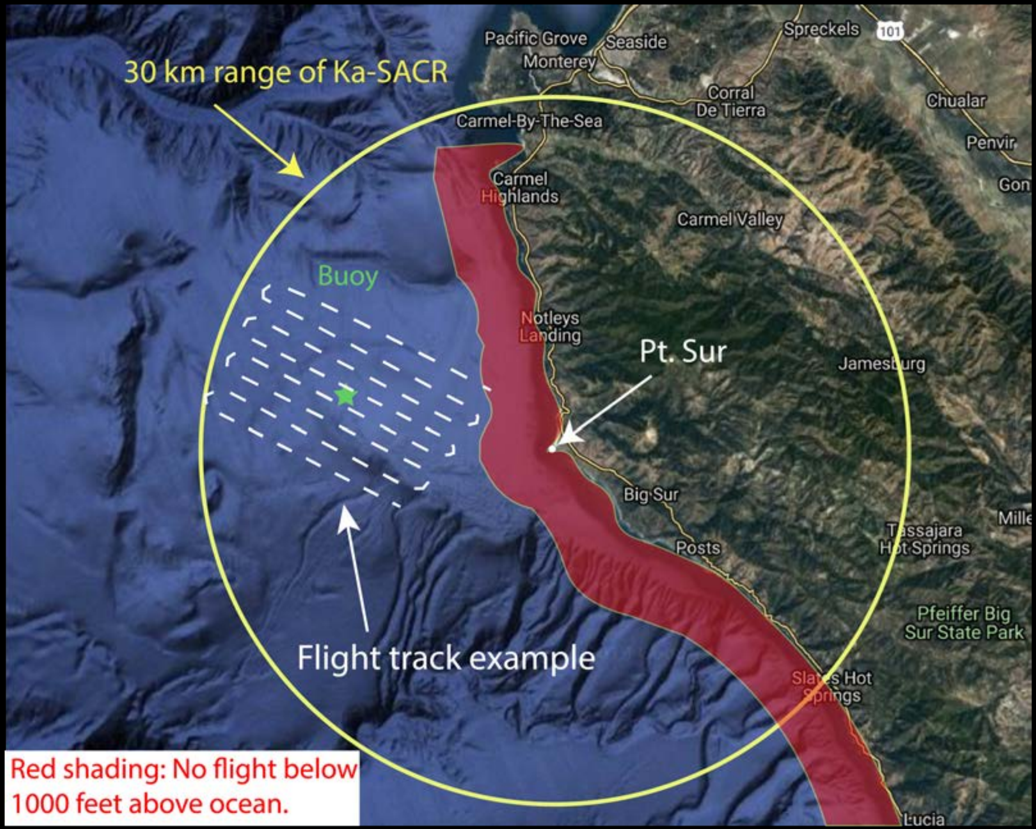

The free tropospheric selection hypothesis: Free-tropospheric humidity and temperature and low-level wind shear determine which boundary layer thermals "survive" entrainment of unsaturated air to become clouds.

The boundary layer selection hypothesis: Variations in boundary layer temperature/moisture and wind determine the size and spatial distribution of thermals.

Where do our observations go from here?