Low Free Tropospheric Static Stability Controls on Tropical Convection in Moist Environments*

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*Powell (2019): Observing possible thermodynamic controls on tropical rainfall in moist environments. *JAS*, **76**, 3737–3751, doi:10.1175/2019-JAS-D-0144.1

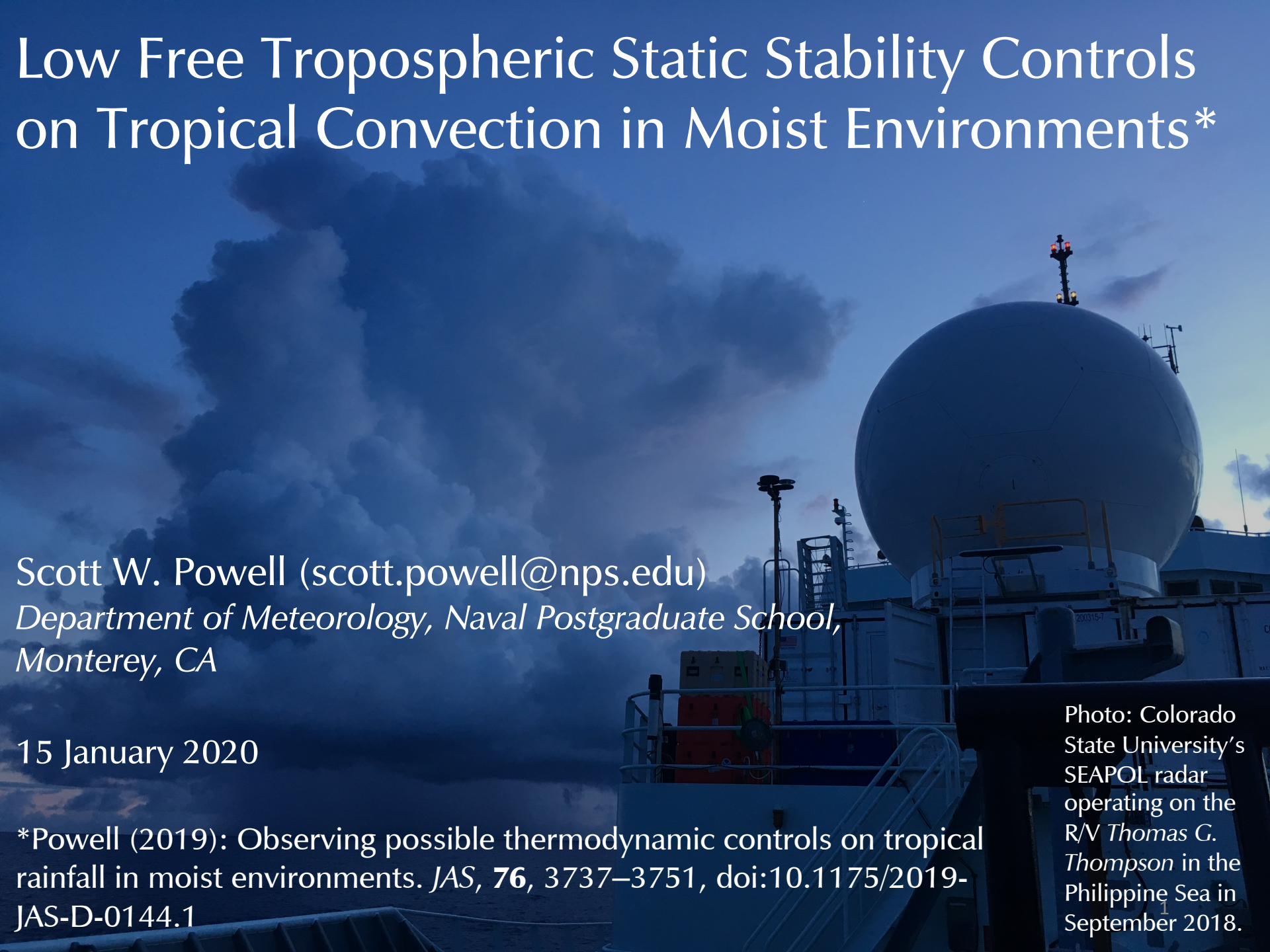
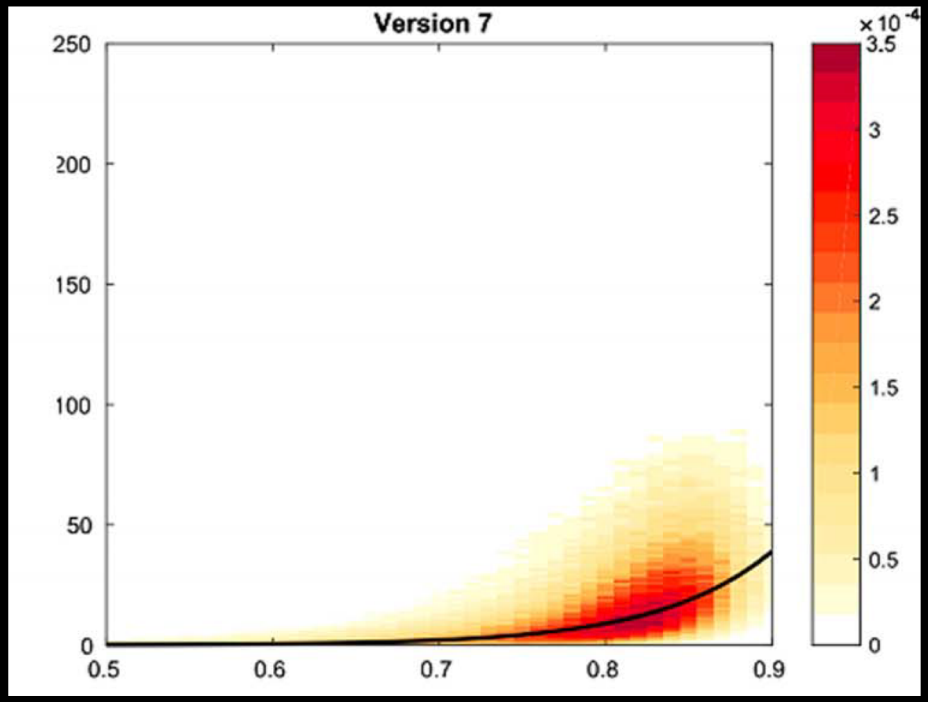
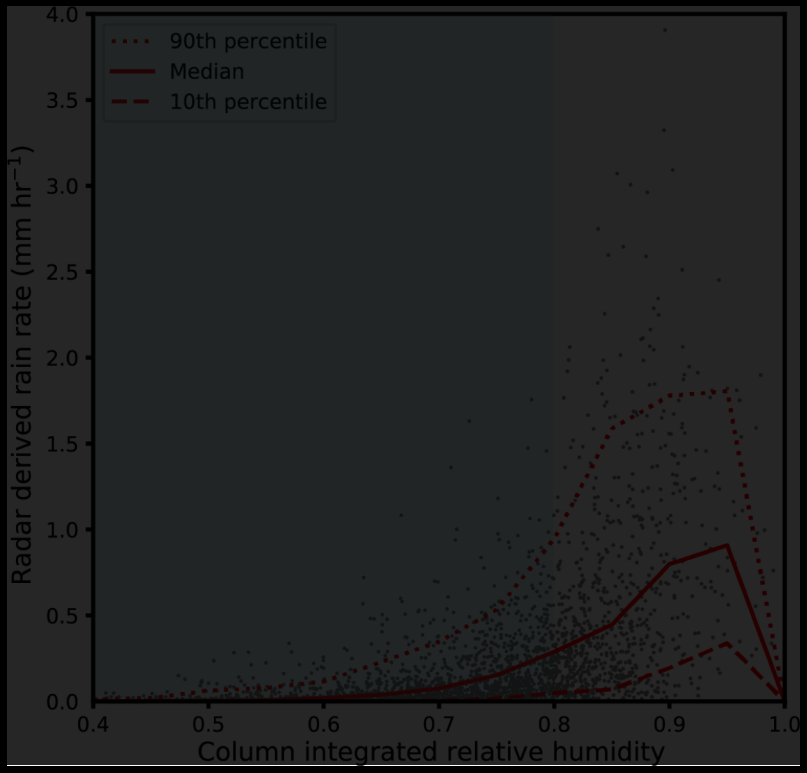


Photo: Colorado State University's SEAPOL radar operating on the R/V *Thomas G. Thompson* in the Philippine Sea in September 2018.

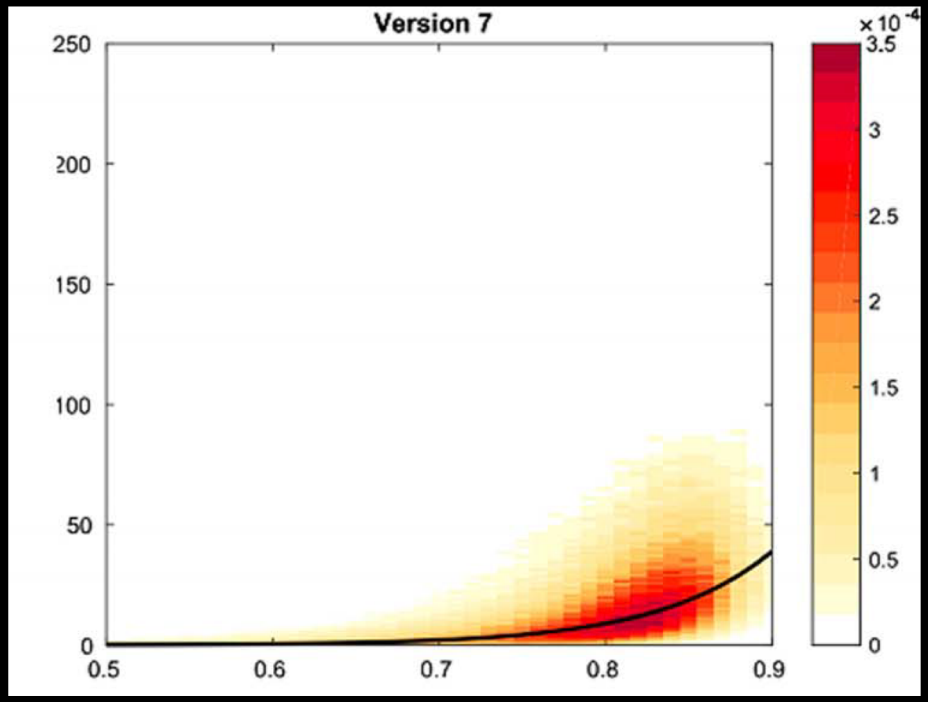
Rushley et al. (2018)





Derived from satellite-based derivations of relative humidity and rainfall

Rushley et al. (2018)



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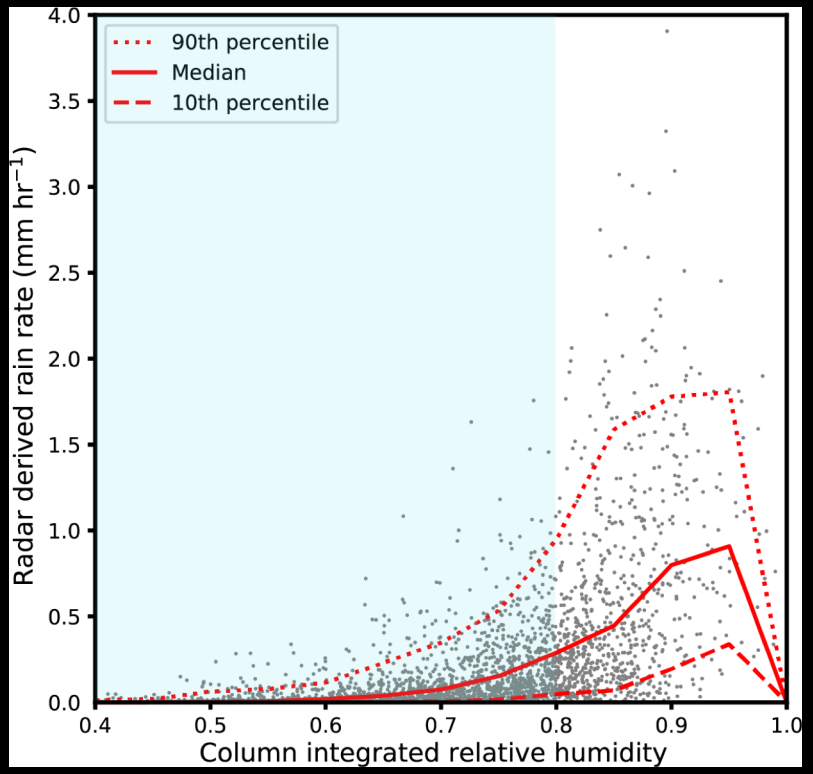
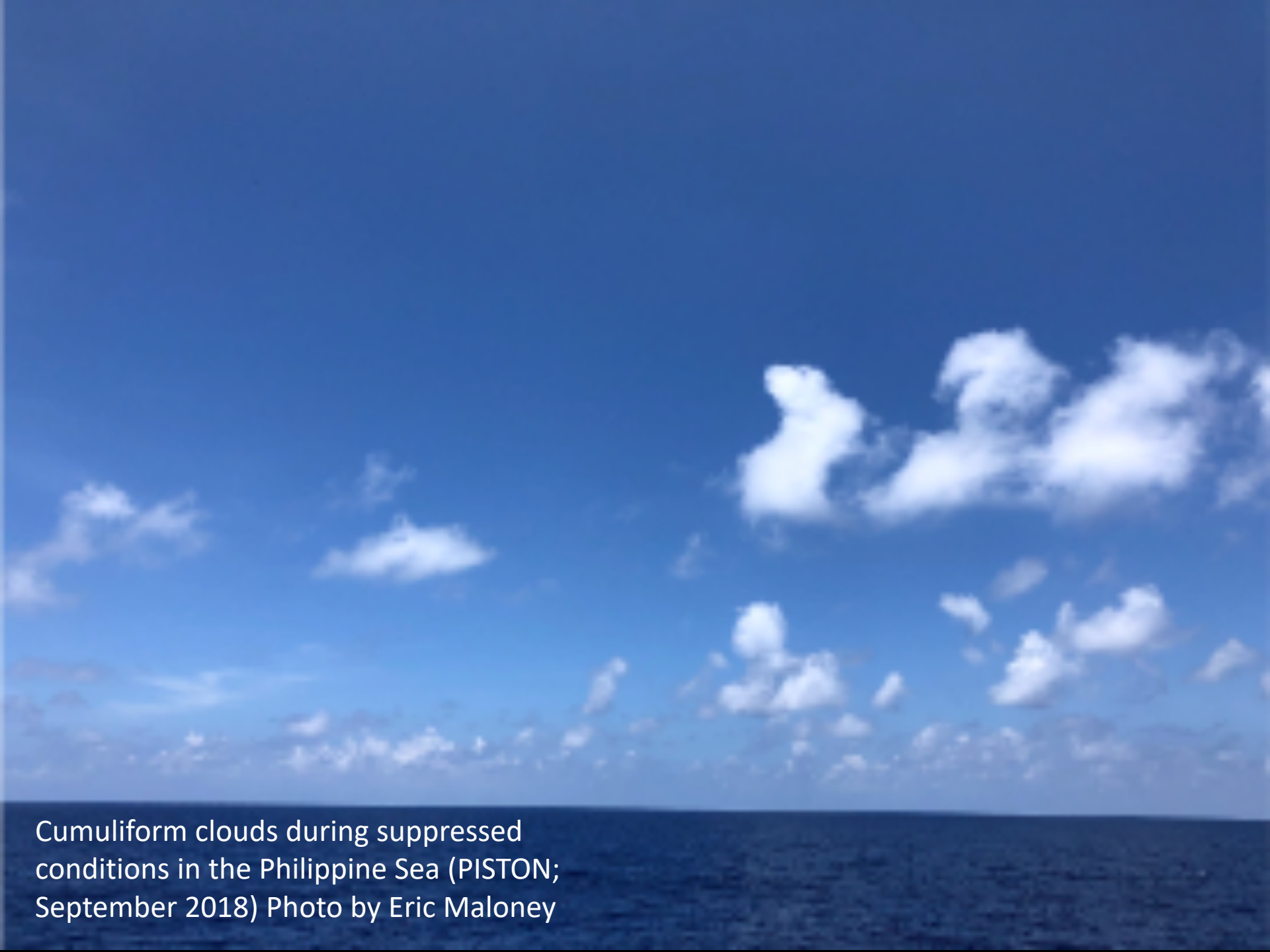


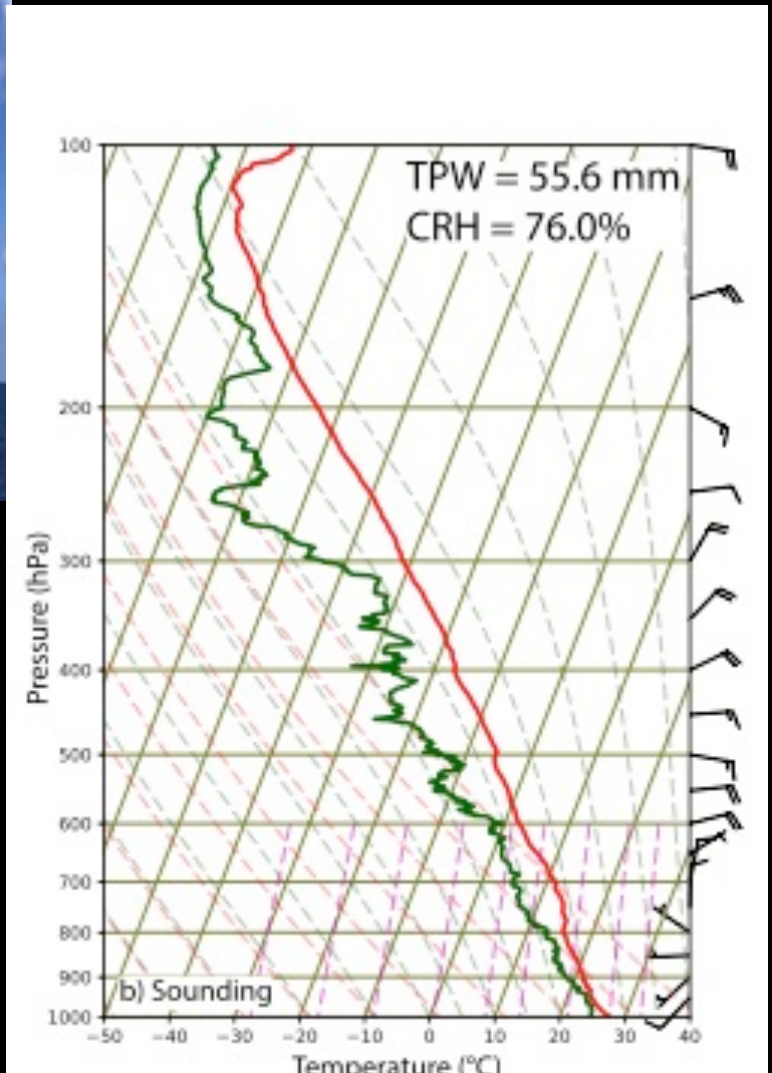
Derived from ground-based radar and rawinsonde

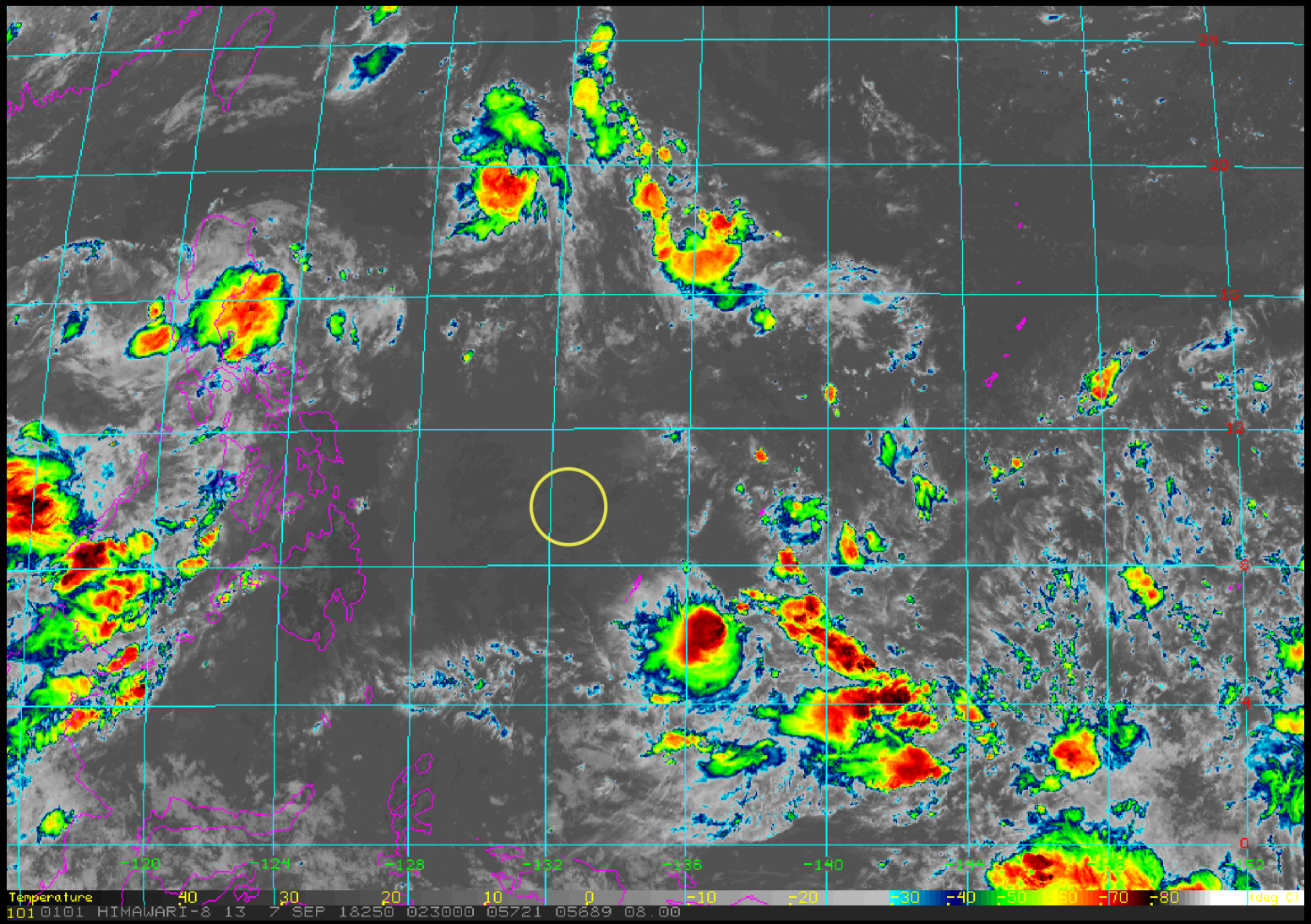


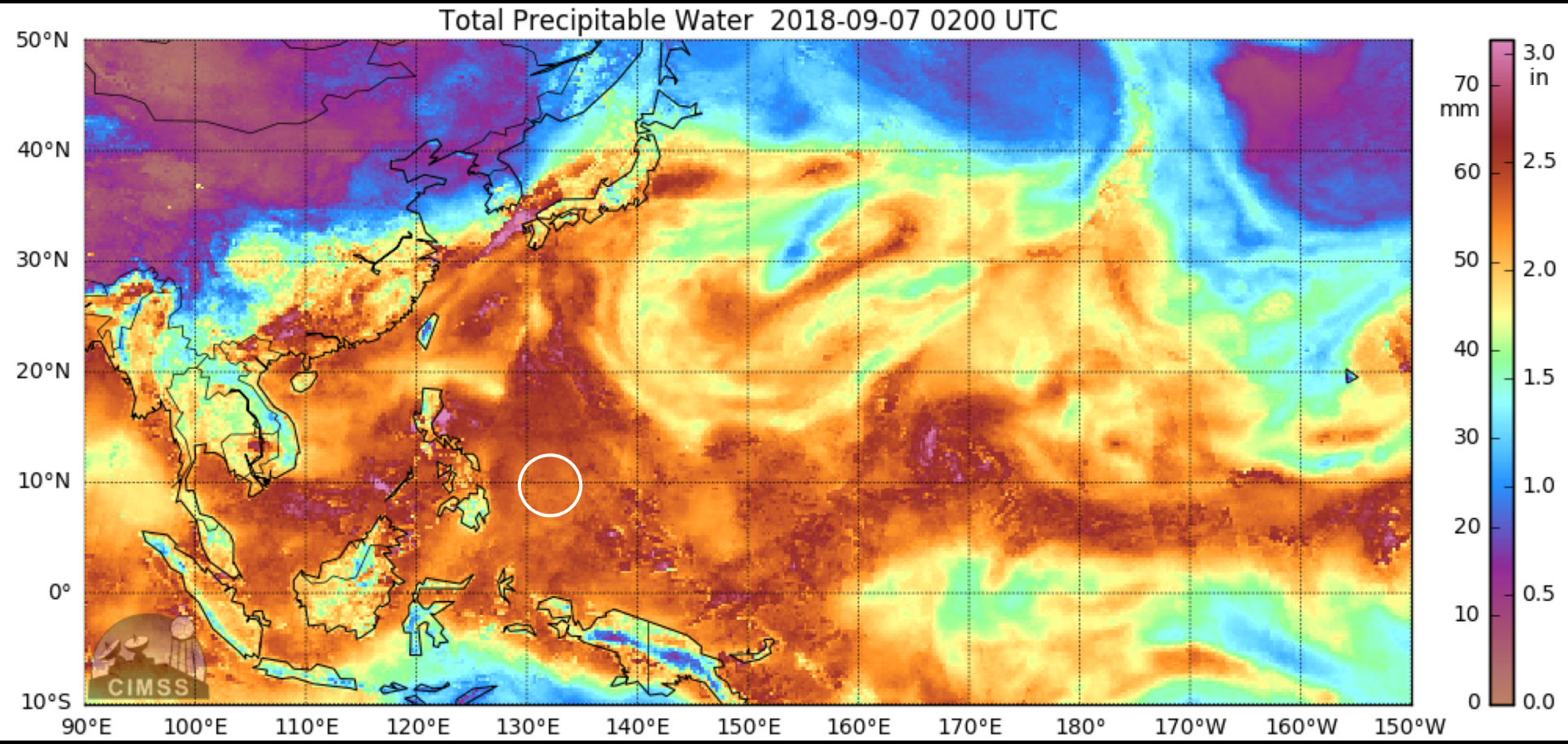
Cumuliform clouds during suppressed conditions in the Philippine Sea (PISTON; September 2018) Photo by Eric Maloney

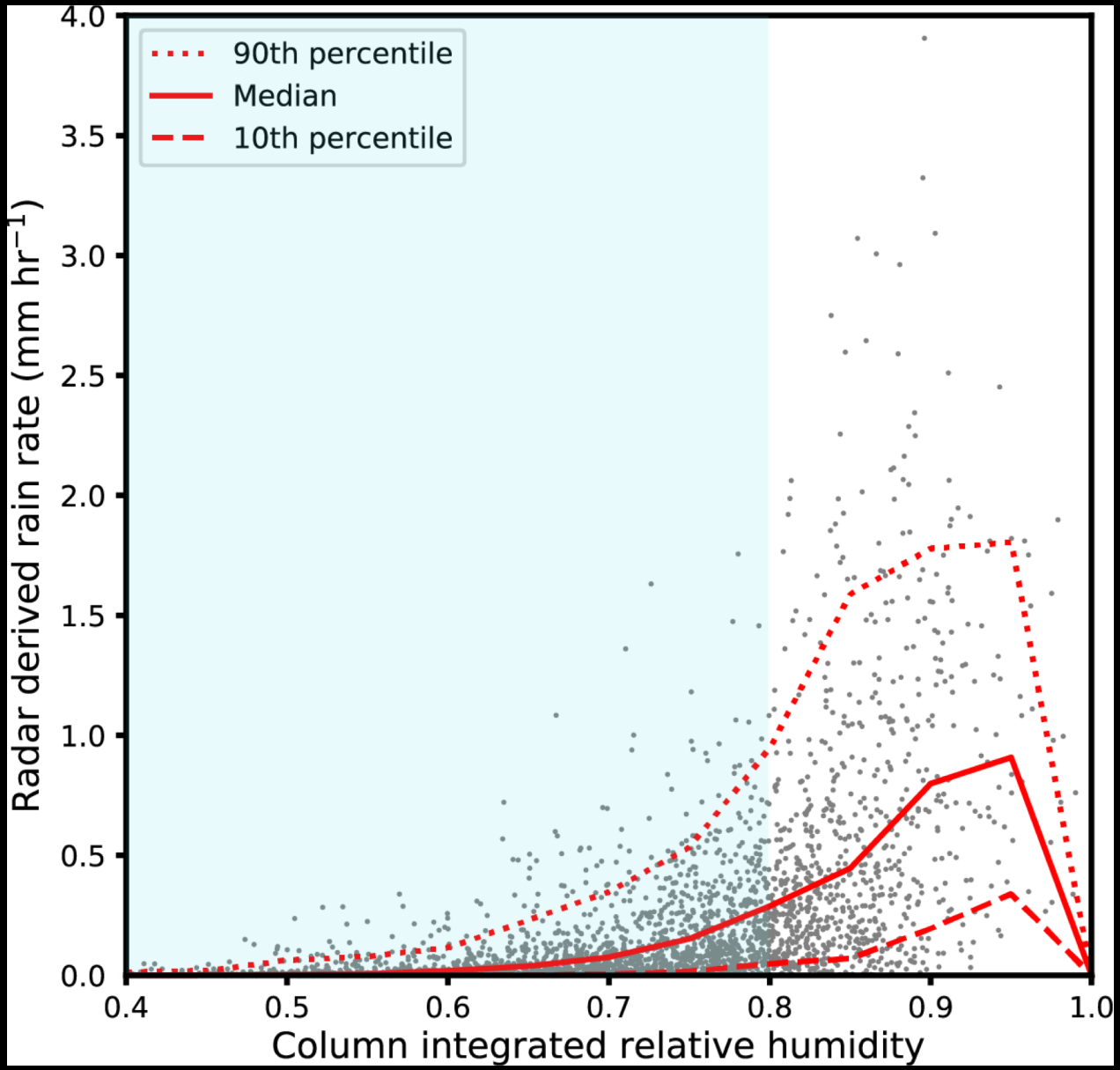
Cumuliform clouds during suppressed conditions in the Philippine Sea (PISTON 2018)

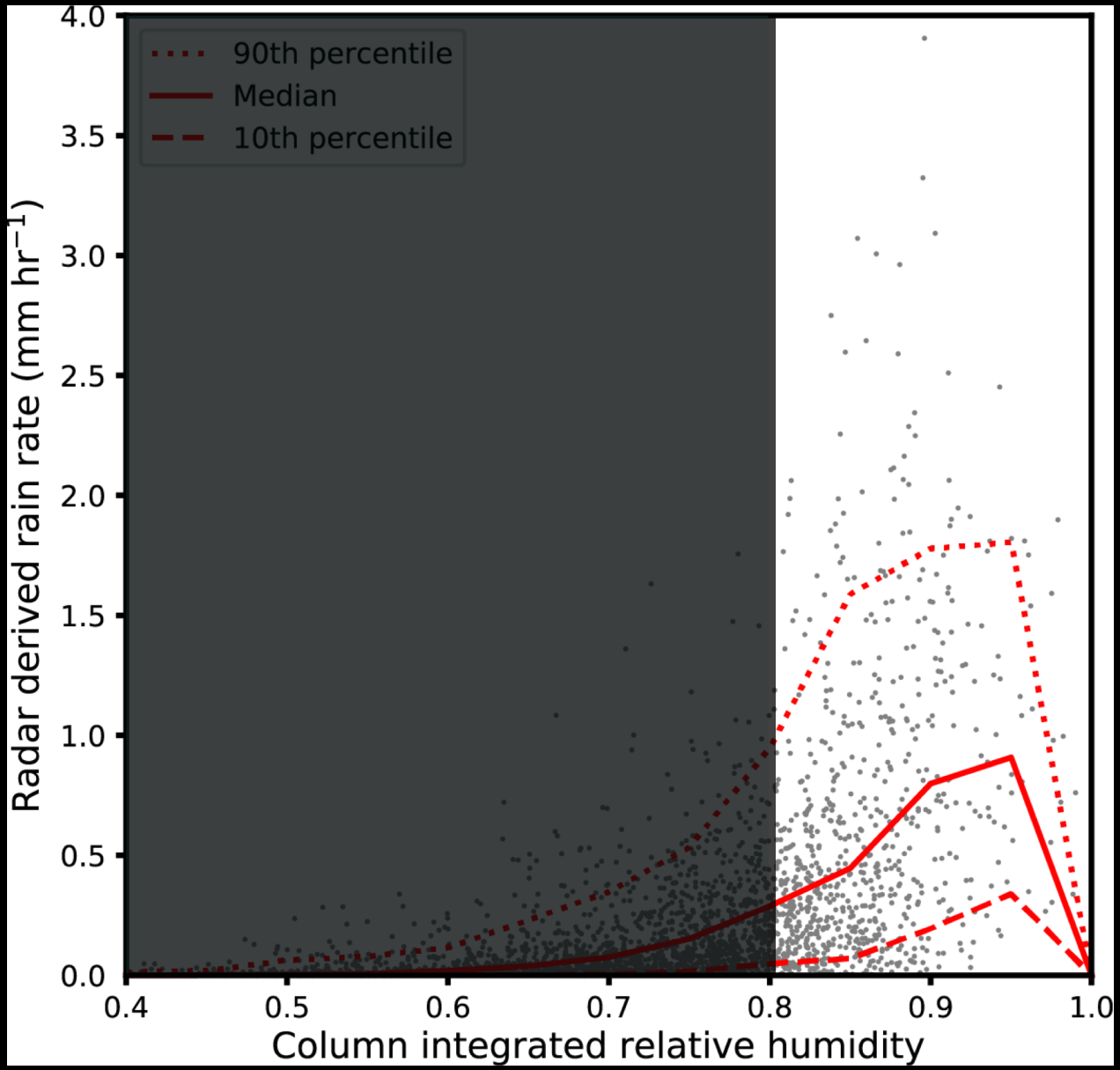
Sounding at the time the photo was taken

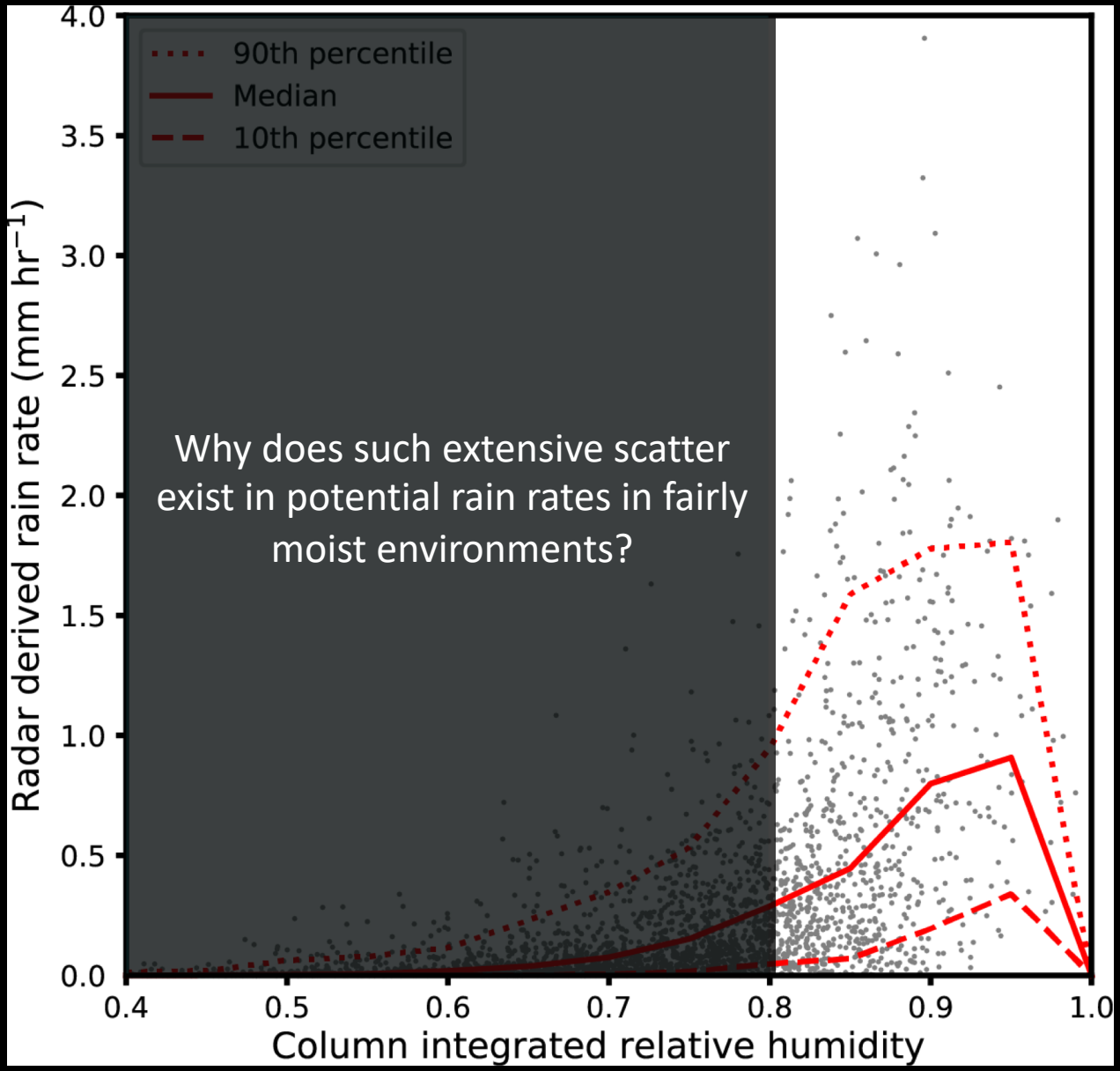


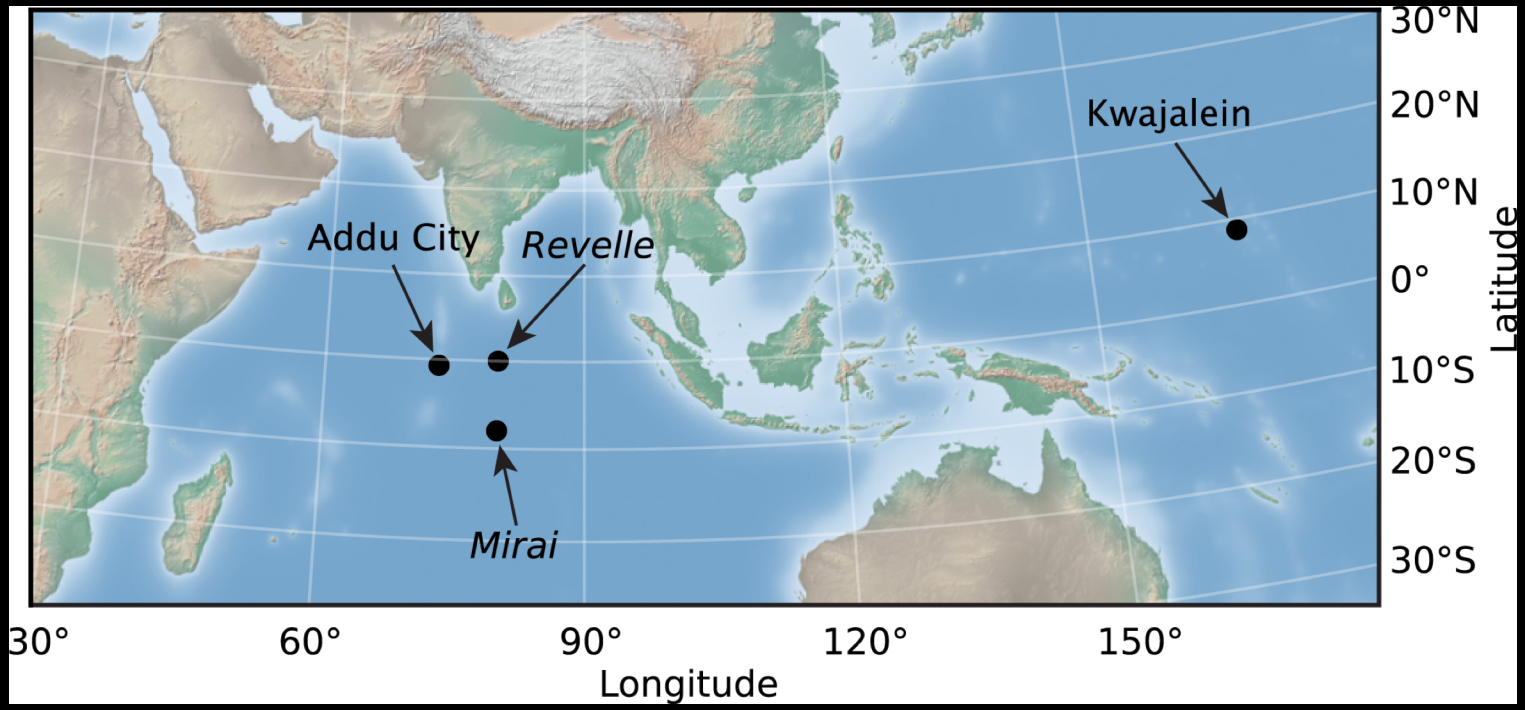

Temperature
40 30 20 10 0 -10 -20 -30 -40 -50 -60 -70 -80
101 0101 HIMAWARI-8 13 7 SEP 18250 023000 05721 05689 08.00

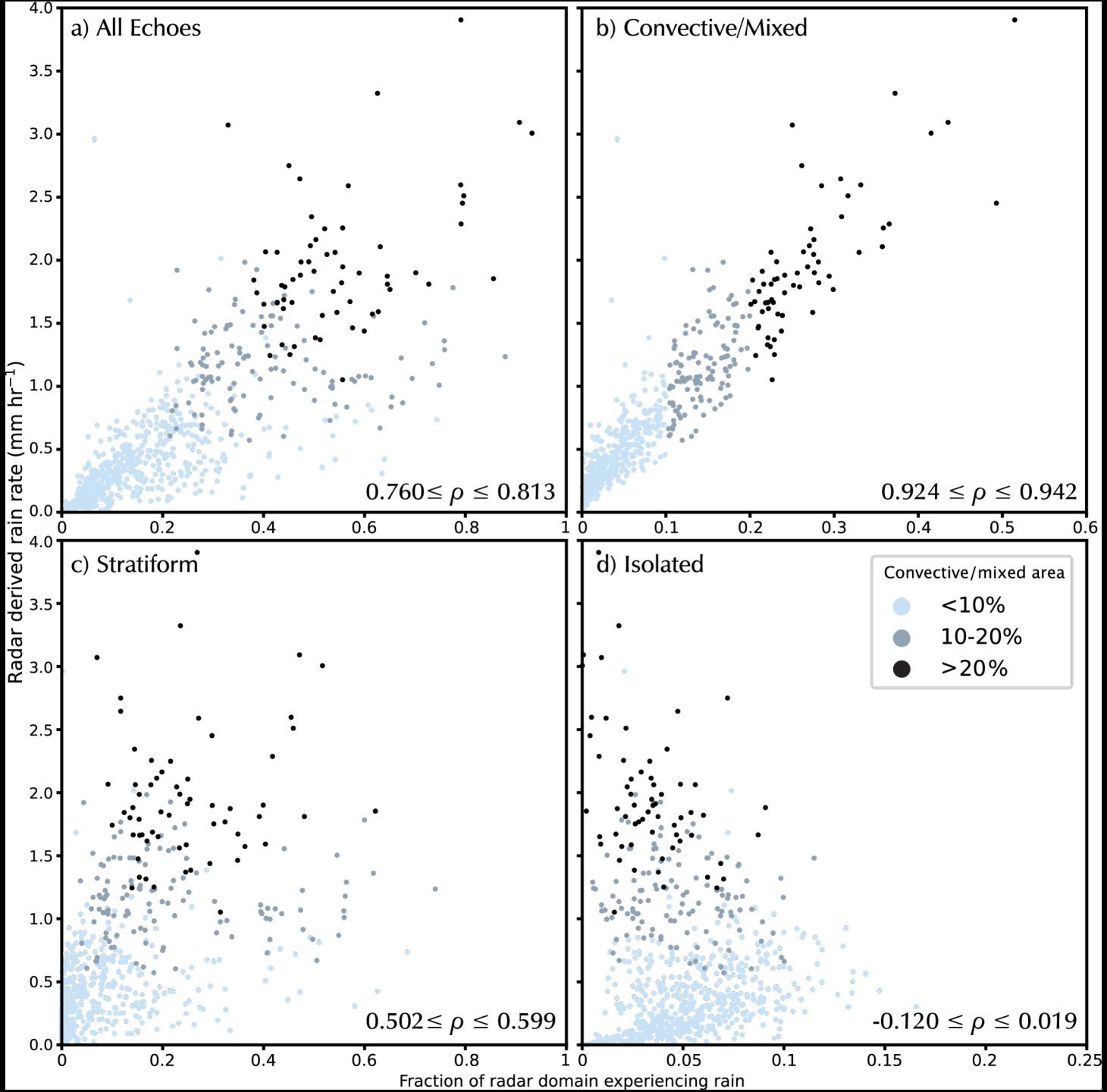

Total Precipitable Water 2018-09-07 0200 UTC
50°N
40°N
30°N
20°N
10°N
0°
10°S
90°E
100°E
110°E
120°E
130°E
140°E
150°E
160°E
170°E
180°
170°W
160°W
150°W
70
mm
60
50
40
30
20
10
0
3.0
in
2.5
2.0
1.5
1.0
0.5
0.0
CIMSS

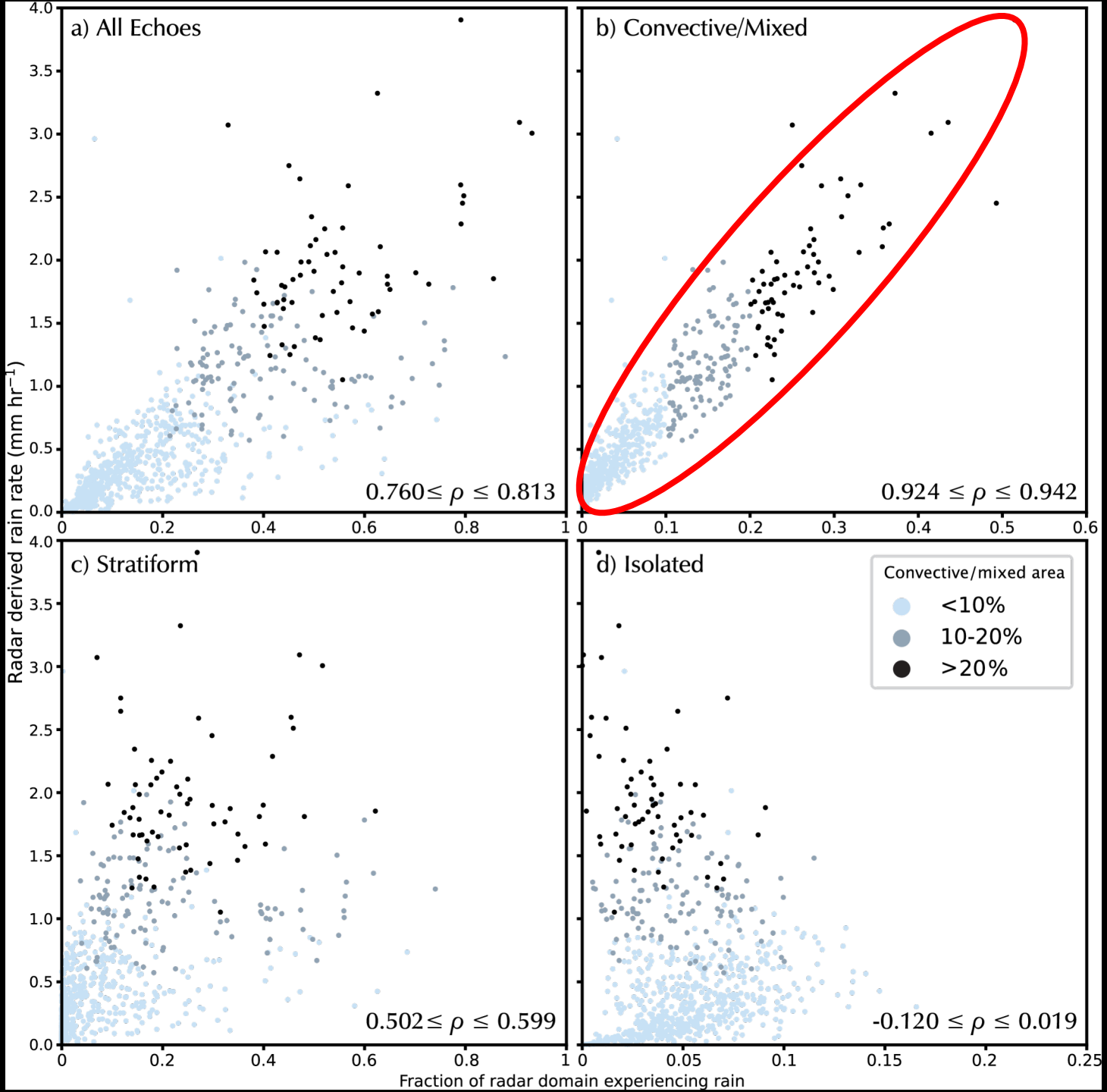

90th percentile
Median
10th percentile
Radar derived rain rate (mm hr^{-1})
Column integrated relative humidity
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.4
0.5
0.6
0.7
0.8
0.9
1.0


90th percentile
Median
10th percentile
Radar derived rain rate (mm hr^{-1})
Column integrated relative humidity
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.4
0.5
0.6
0.7
0.8
0.9
1.0


90th percentile
Median
10th percentile
Why does such extensive scatter exist in potential rain rates in fairly moist environments?
Radar derived rain rate (mm hr^{-1})
Column integrated relative humidity
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.4
0.5
0.6
0.7
0.8
0.9
1.0


Kwajalein
Addu City
Revelle
Mirai
30°N
20°N
10°N
0°
10°S
20°S
30°S
Latitude
30°
60°
90°
120°
150°
Longitude


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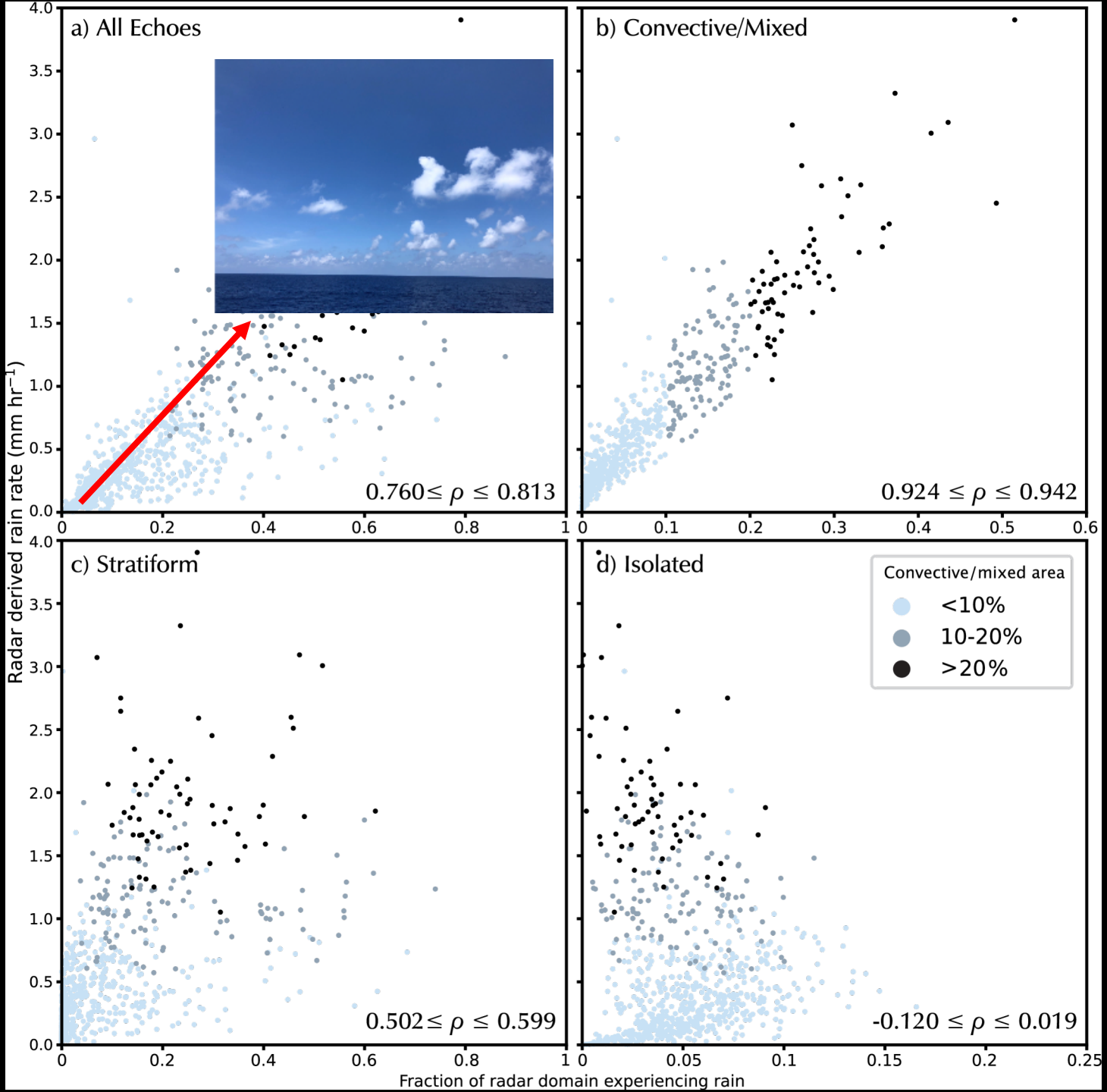
a) All Echoes
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Radar derived rain rate (mm hr^{-1})
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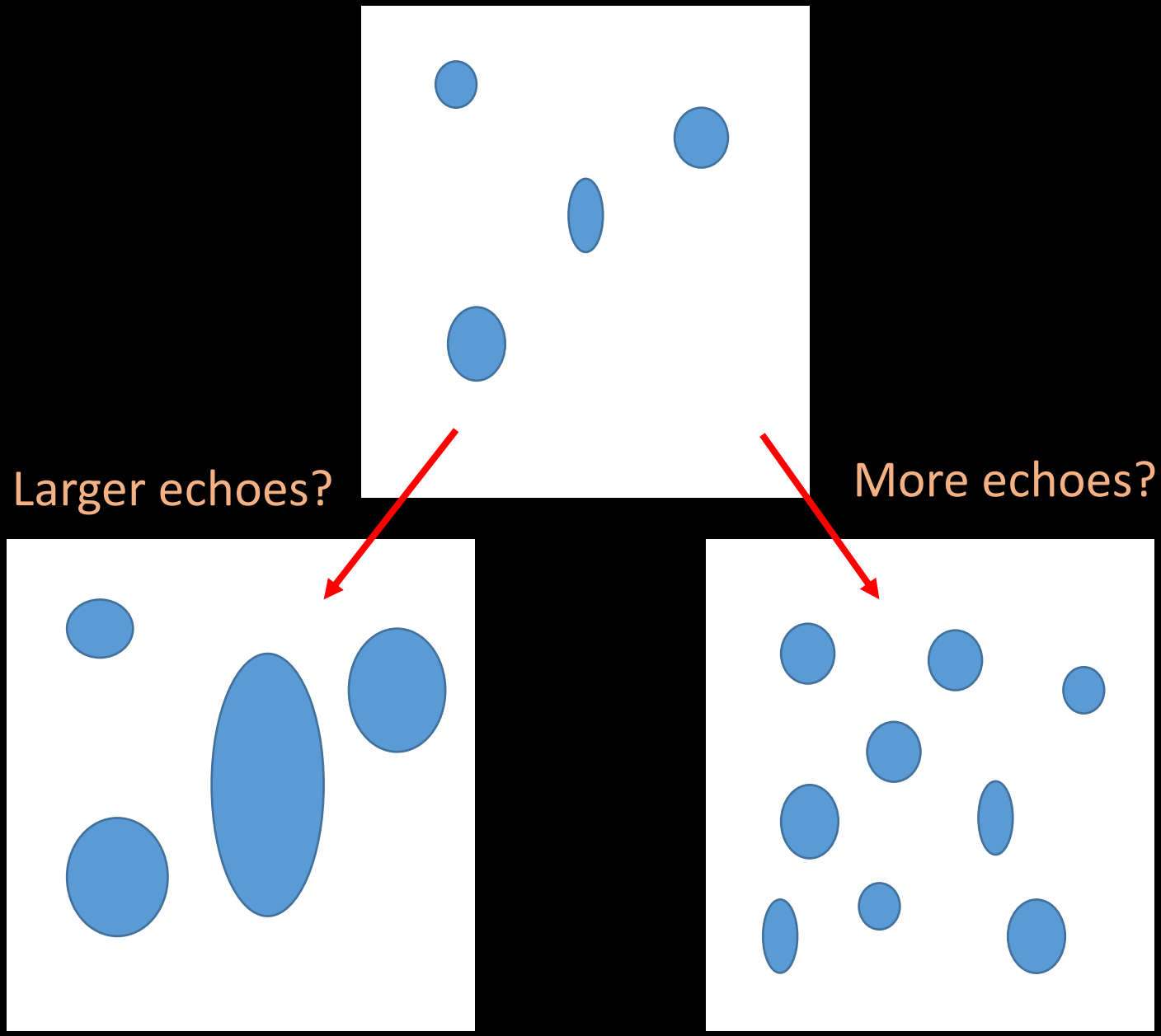
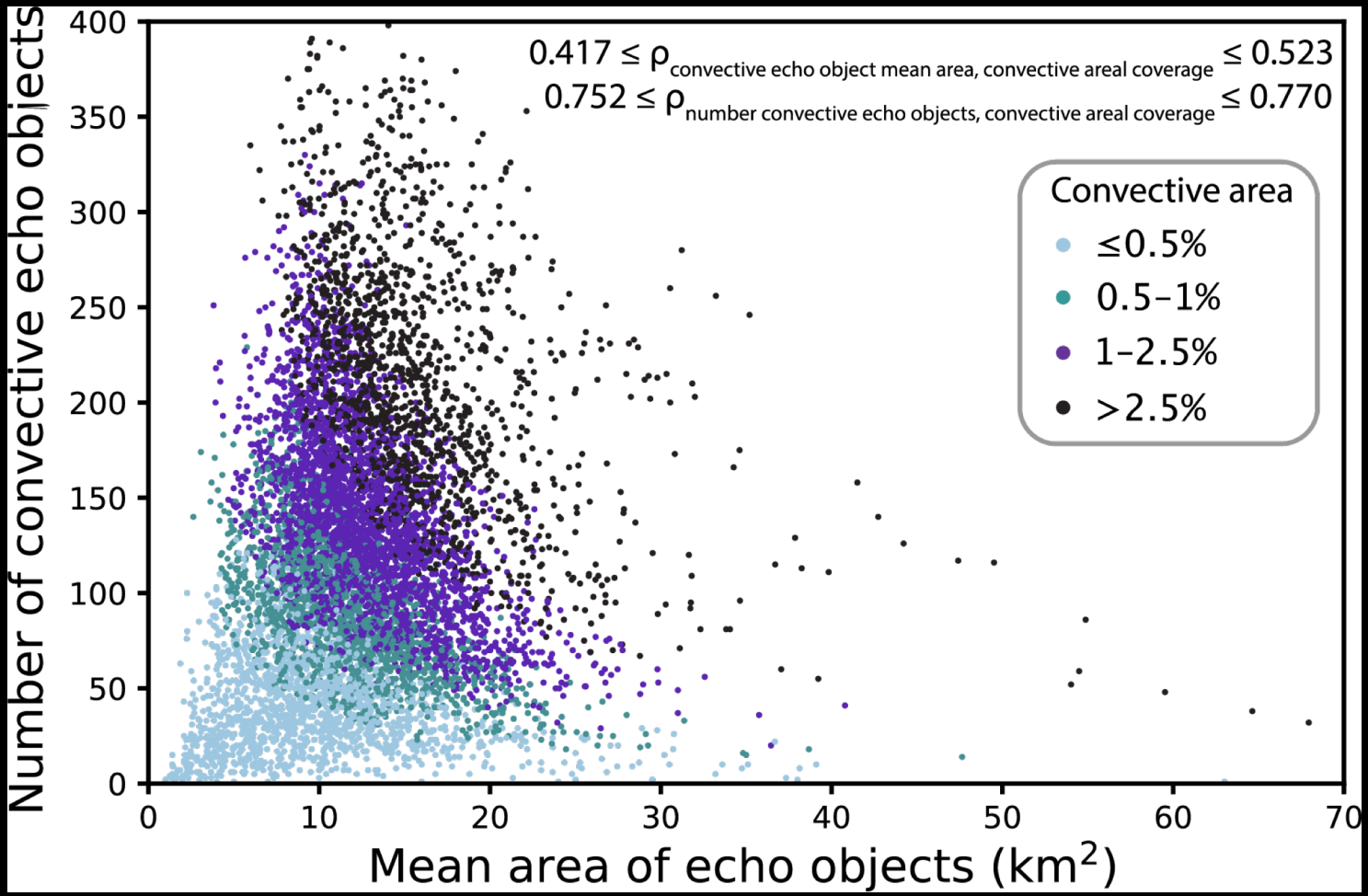
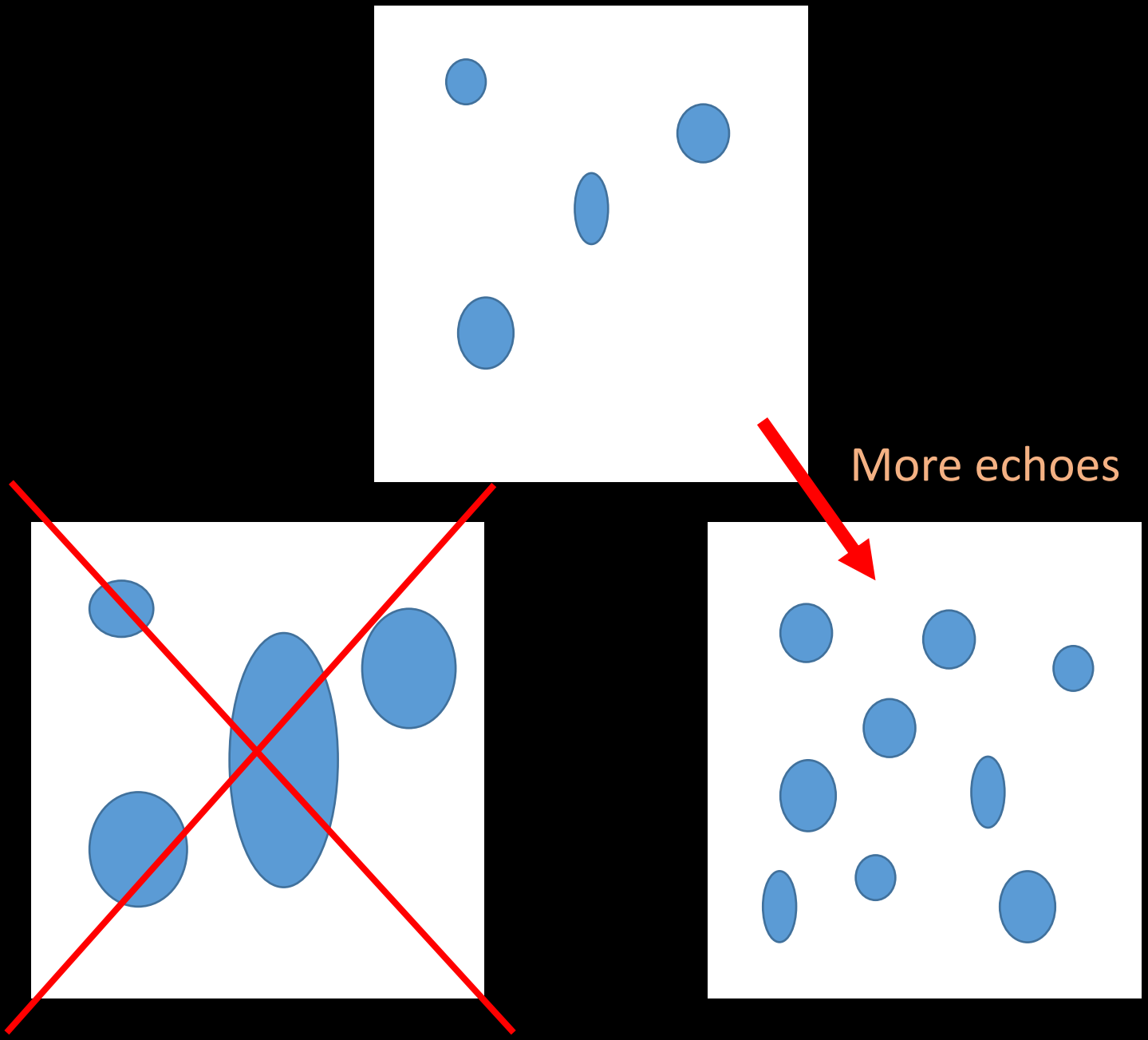
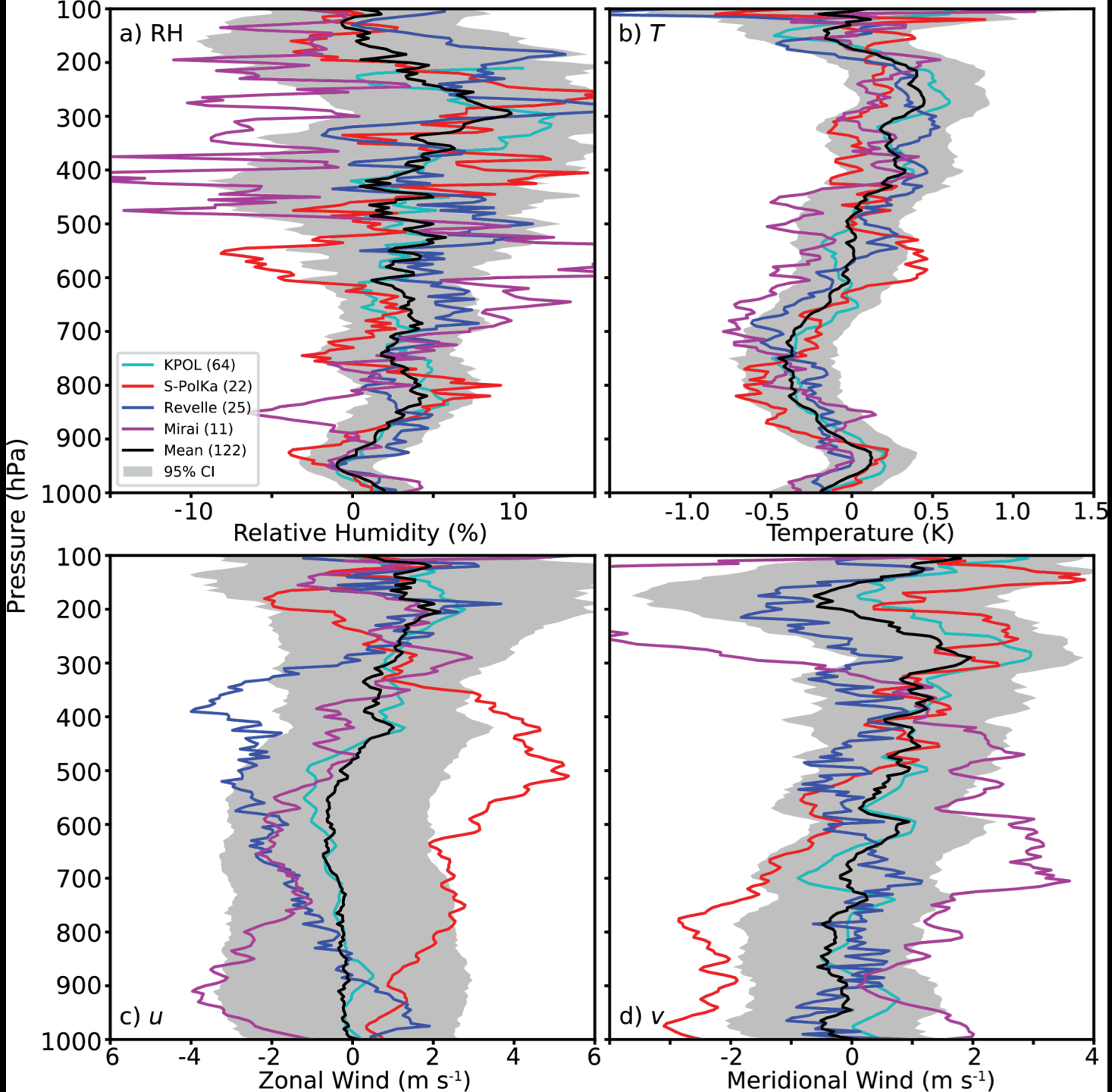

Larger echoes?
More echoes?

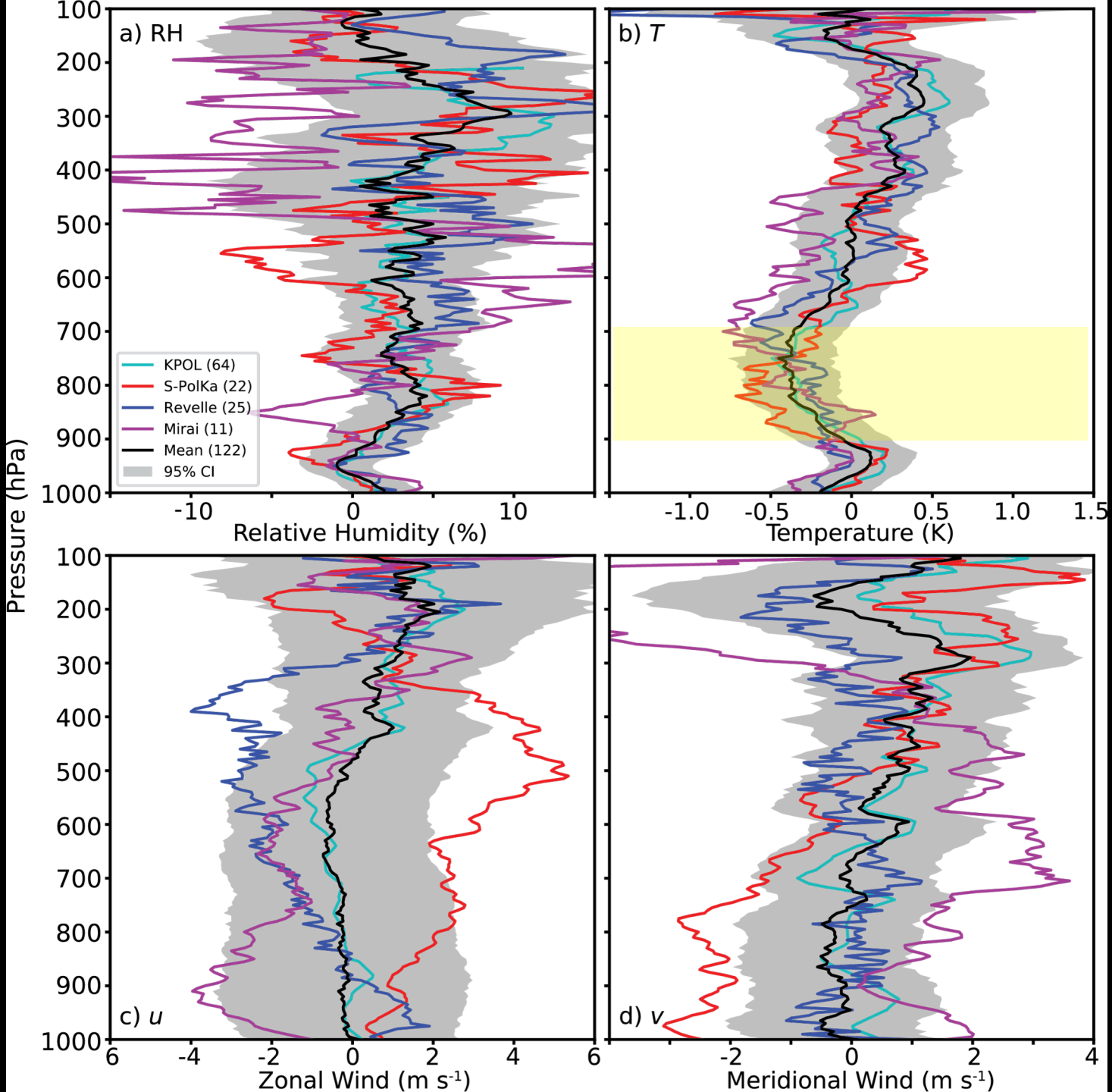

$0.417 \leq \rho_{\text{convective echo object mean area, convective areal coverage}} \leq 0.523$
$0.752 \leq \rho_{\text{number convective echo objects, convective areal coverage}} \leq 0.770$
Convective area
≤0.5%
0.5–1%
1–2.5%
>2.5%
Number of convective echo objects
Mean area of echo objects (km²)
0
50
100
150
200
250
300
350
400
0
10
20
30
40
50
60
70


More echoes

Differences in soundings between upper and lower quartiles of convective rainfall



Differences in soundings between upper and lower quartiles of convective rainfall



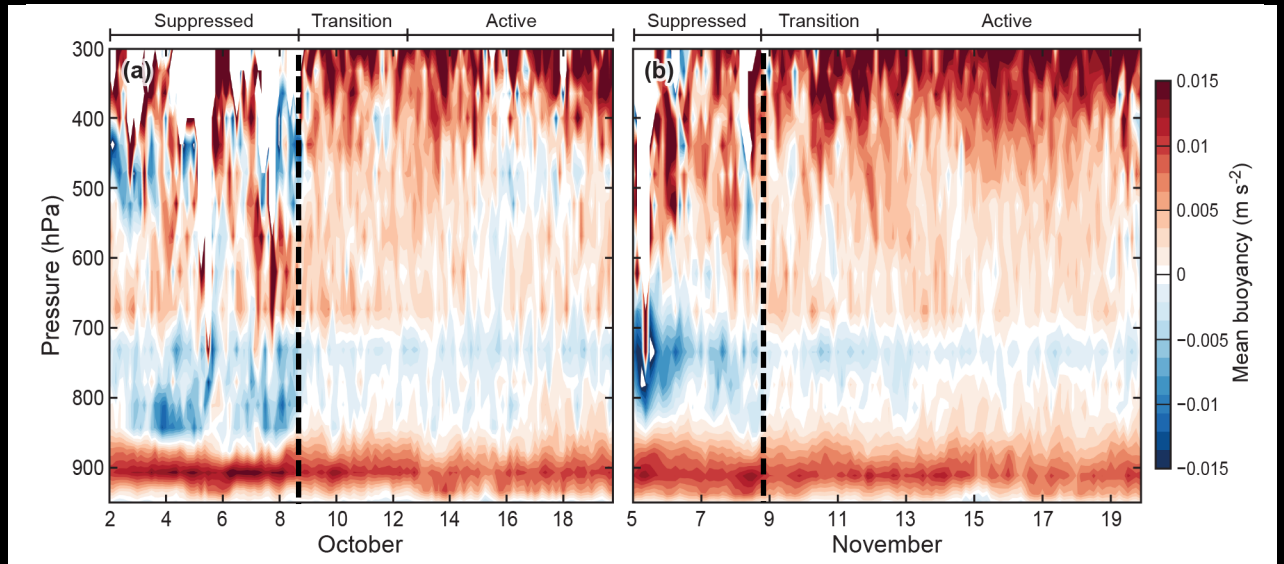
Conclusions

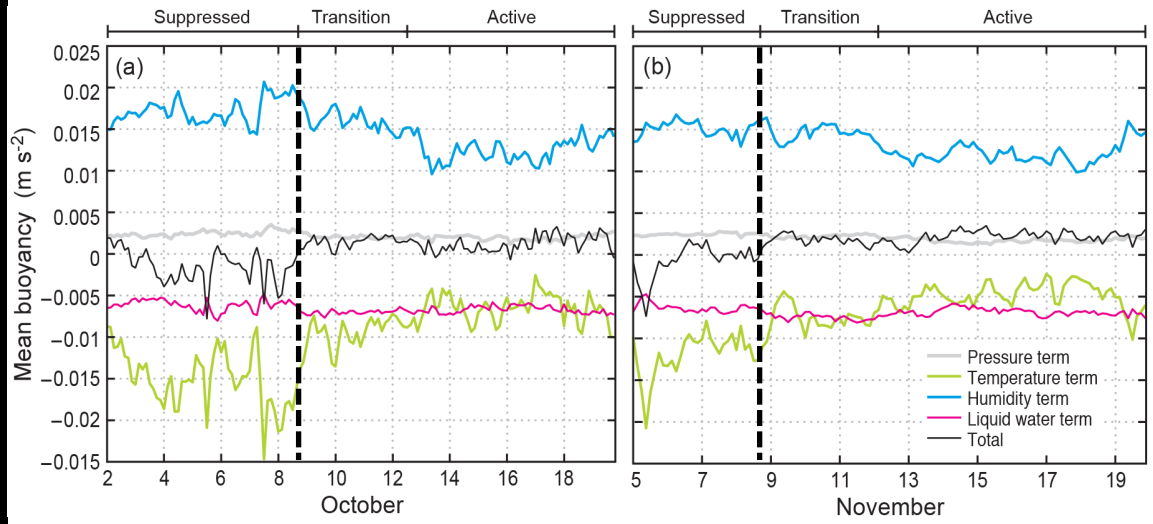
- Ample water vapor ($\geq$ about 55 mm TPW) is typically a *necessary but insufficient* condition for tropical, marine deep convection.
- When the atmosphere is moist, rainfall is controlled more by the number than the size of convective elements.
- Lapse rate in the lower free troposphere appears to be related to rainfall when CRH $\geq$ 80%, but the correlation is weak.
- What change in vertical motion (e.g. for MJO initiation) is required to cause a large enough change in LFT temperature to support deep convective onset?

The End

Extra Slides

Individual terms in buoyancy equation: Mean in 700-850 mb layer

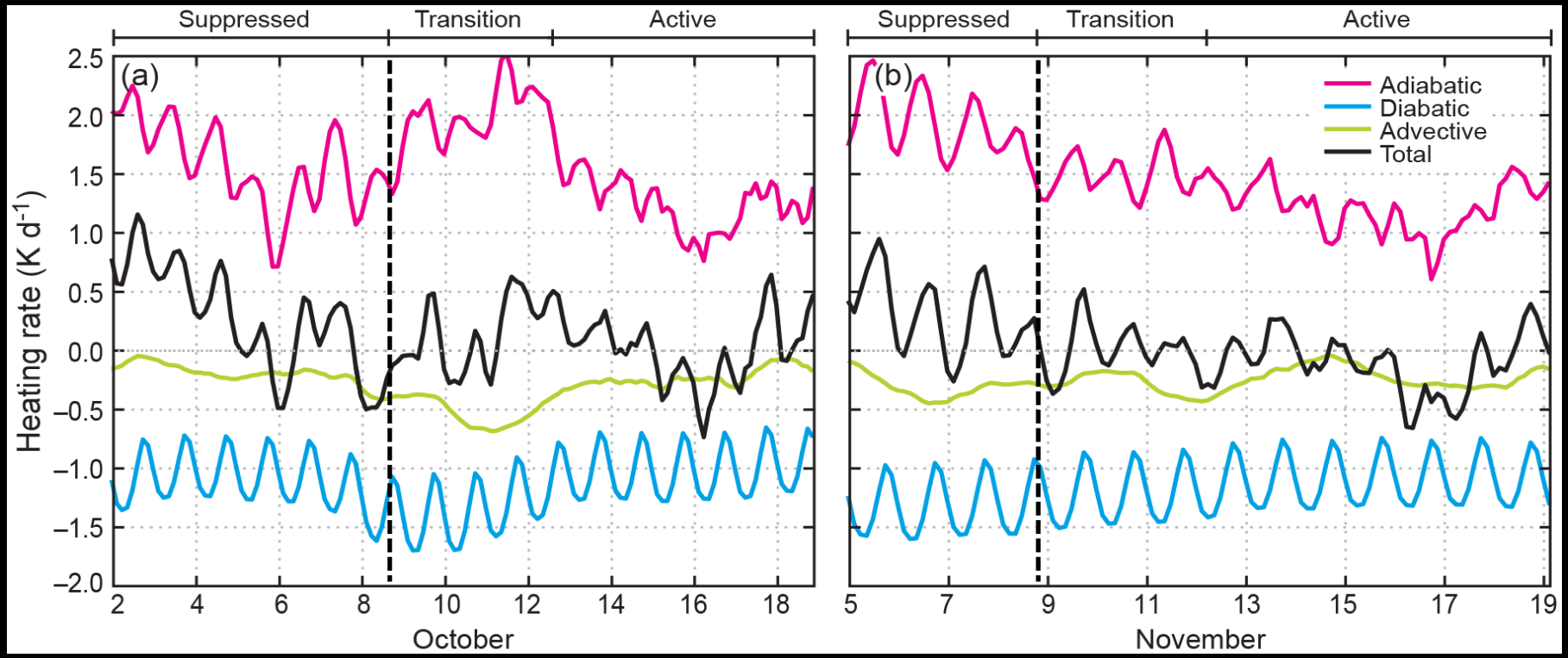




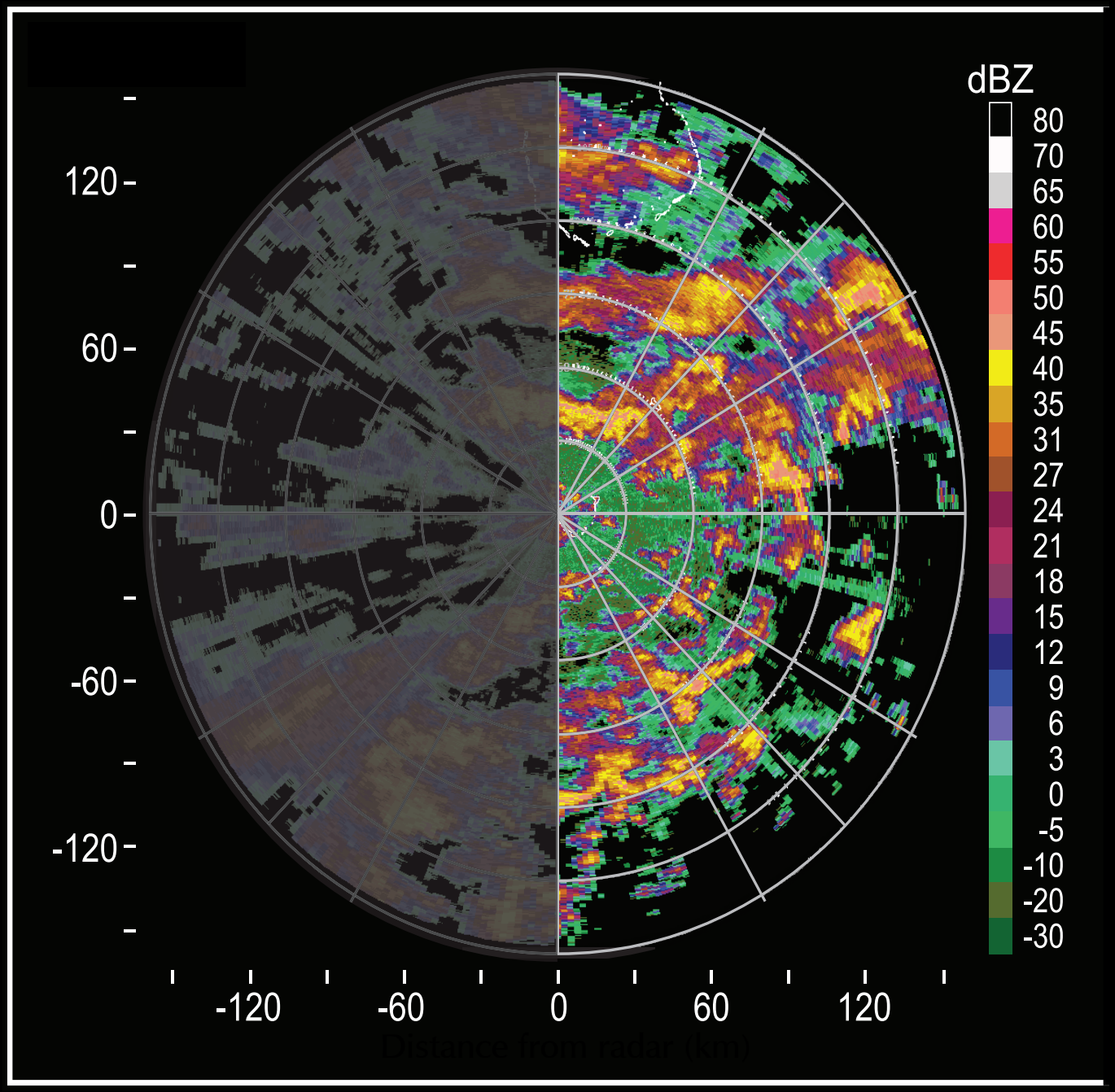
$$B \approx g\left(\underbrace{\frac{T^*}{T_e}}_{Temperature} - \overbrace{\frac{p^*}{p_e}}^{Pressure} + \underbrace{0.608\left(w^*\right)}_{Vapor} - \overbrace{w_H}^{Hydrometeor} \right)$$

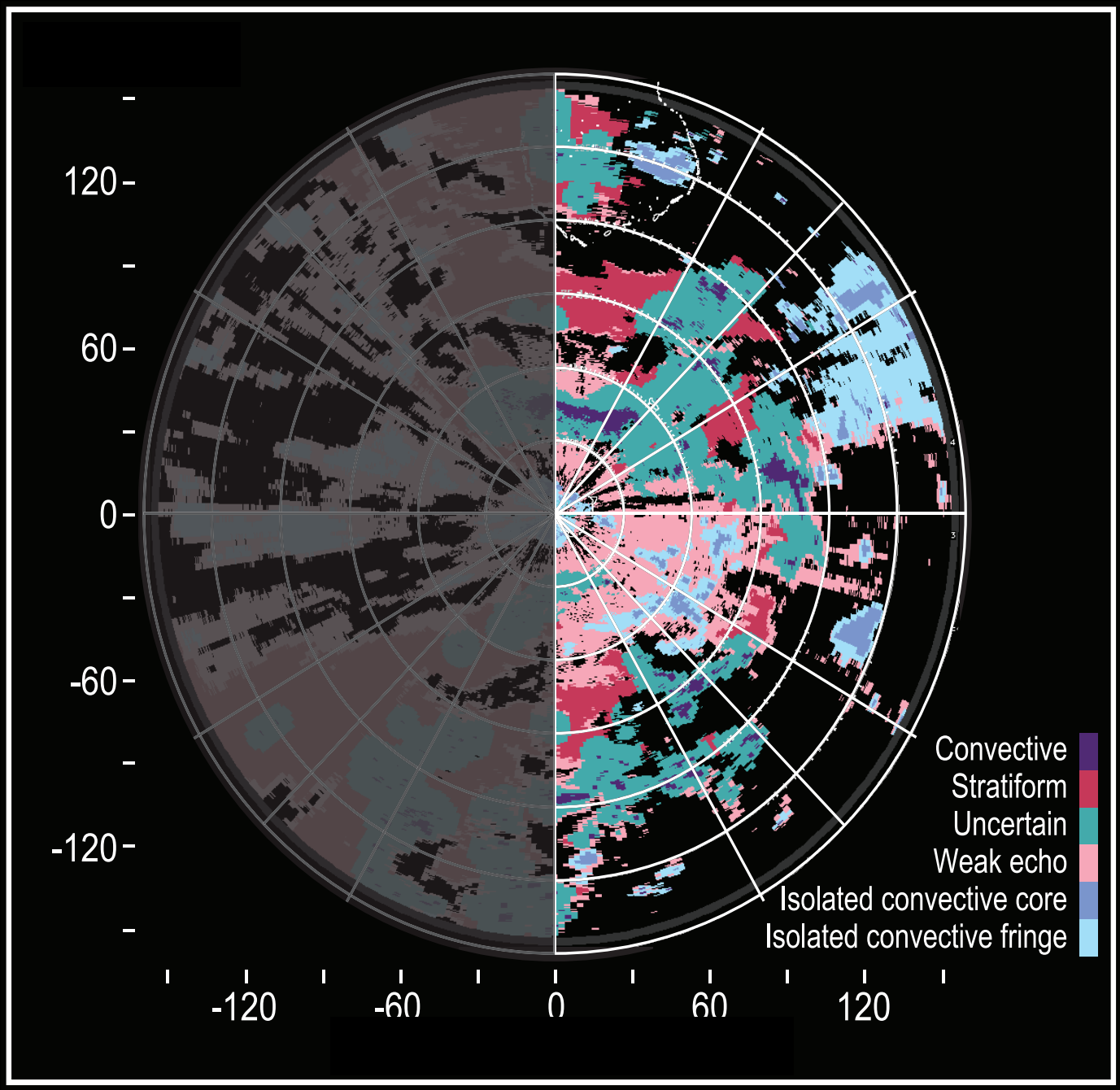
Green Gray Blue Red

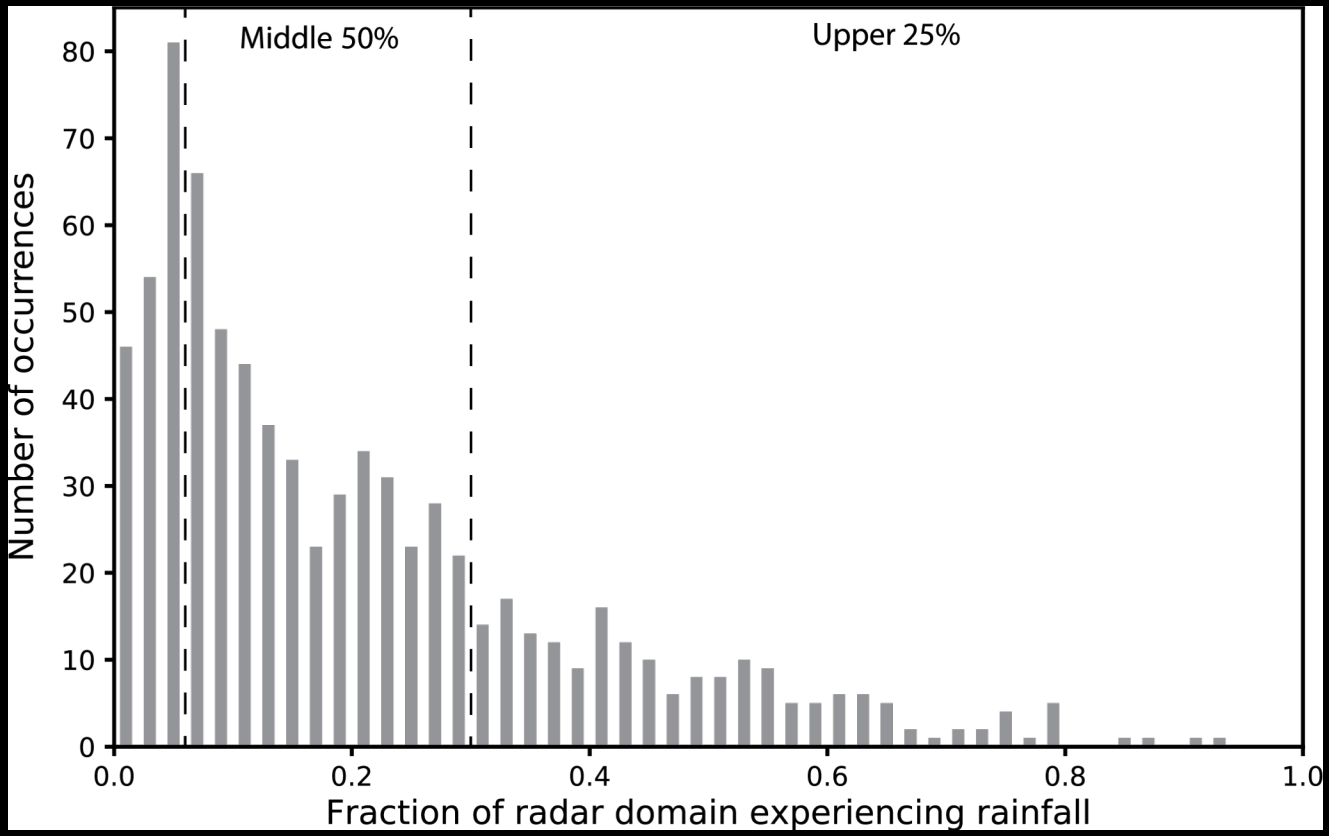
Temperature tendency at 700-850 hPa in clear-air

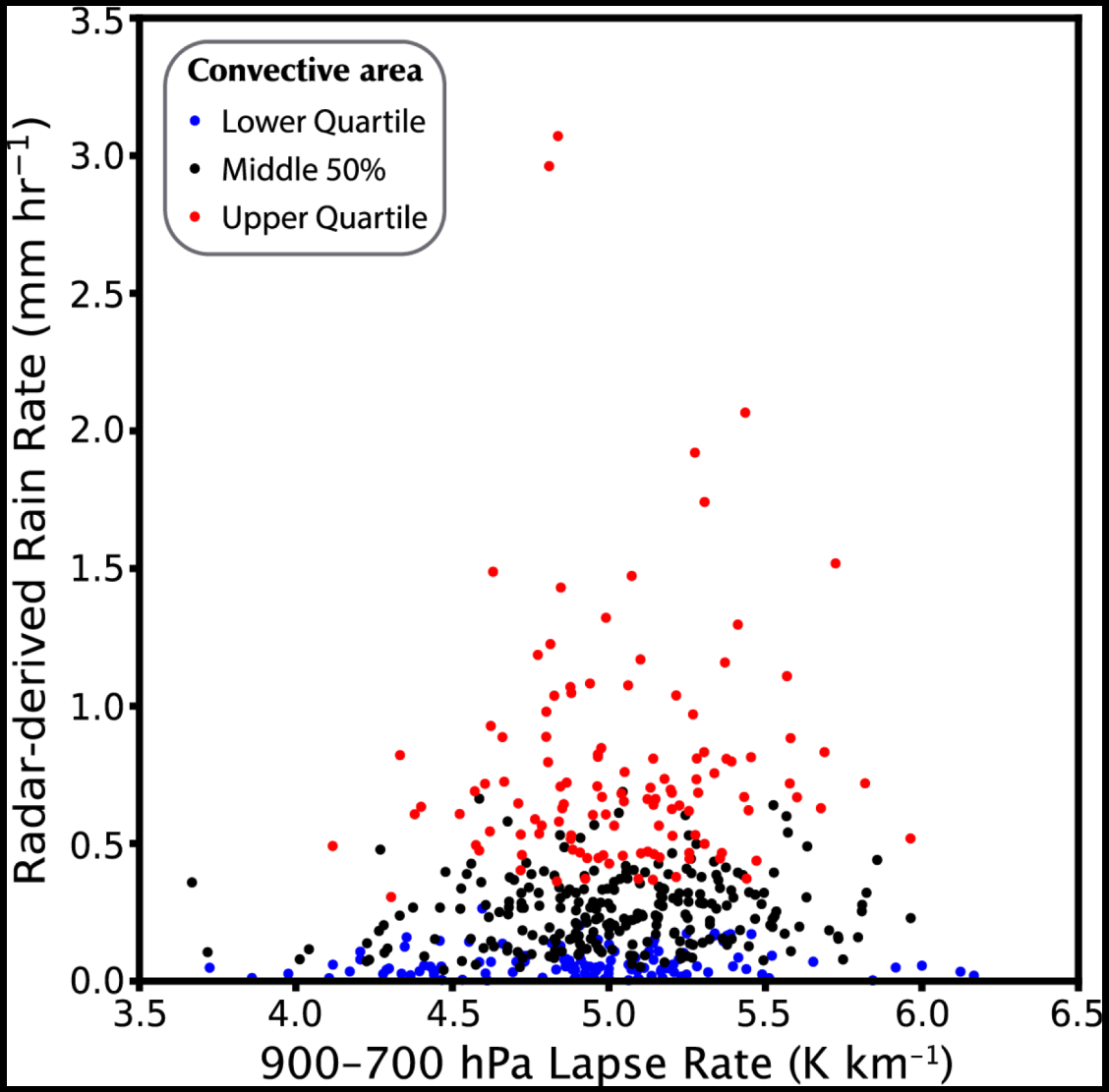


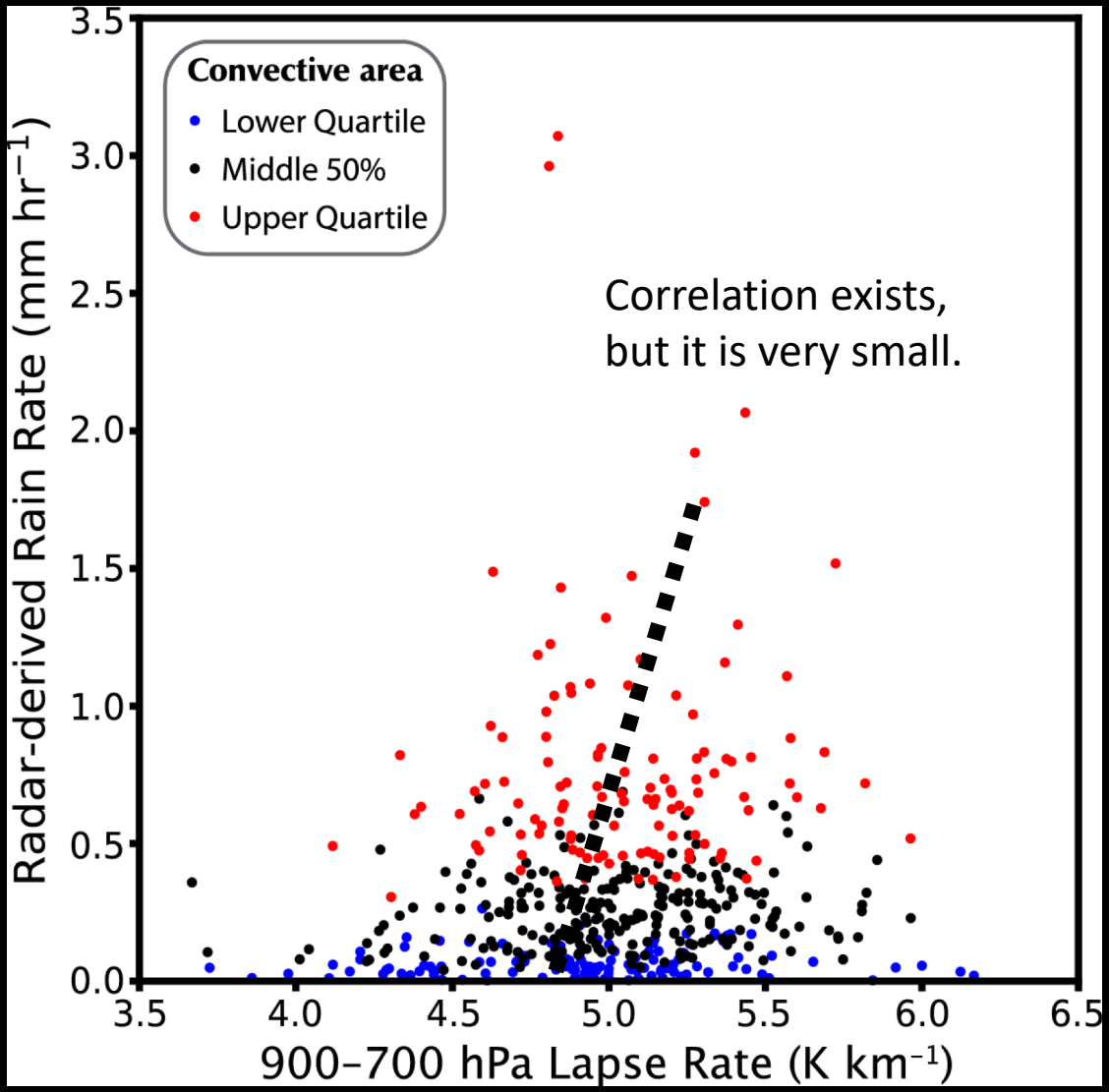
$$\frac{\partial T}{\partial t} = \underbrace{-\mathbf{u}_h \cdot \nabla T}_{advective} \overbrace{-w\left(\frac{g}{c_p} + \Gamma\right)}^{adiabatic} + \underbrace{\frac{J}{c_p}}_{diabatic}$$


dBZ
80
70
65
60
55
50
45
40
35
31
27
24
21
18
15
12
9
6
3
0
-5
-10
-20
-30
120
60
0
-60
-120
-120
-60
0
60
120
Distance from radar (km)

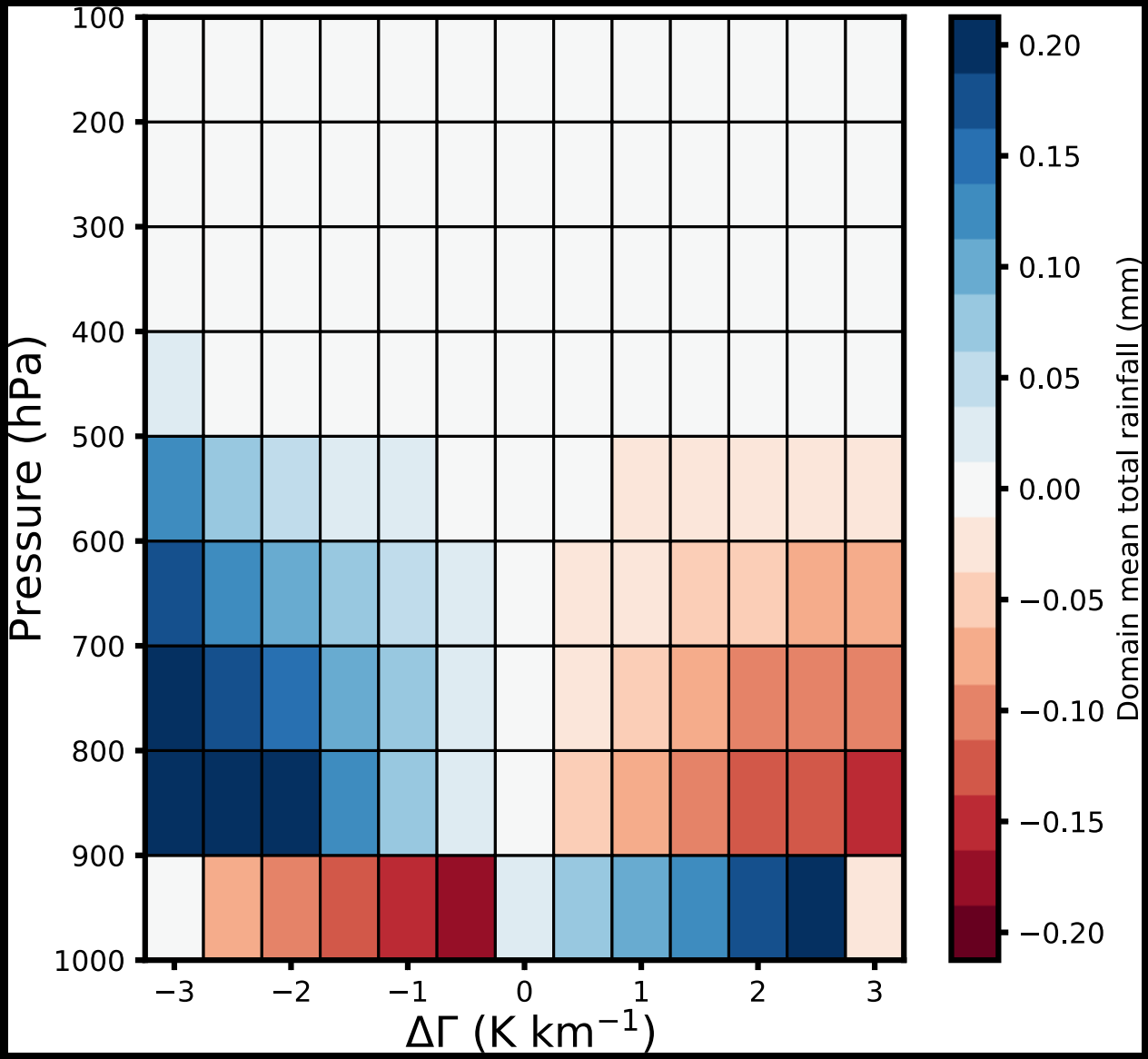

120
60
0
-60
-120
-120
-60
0
60
120
Convective
Stratiform
Uncertain
Weak echo
Isolated convective core
Isolated convective fringe

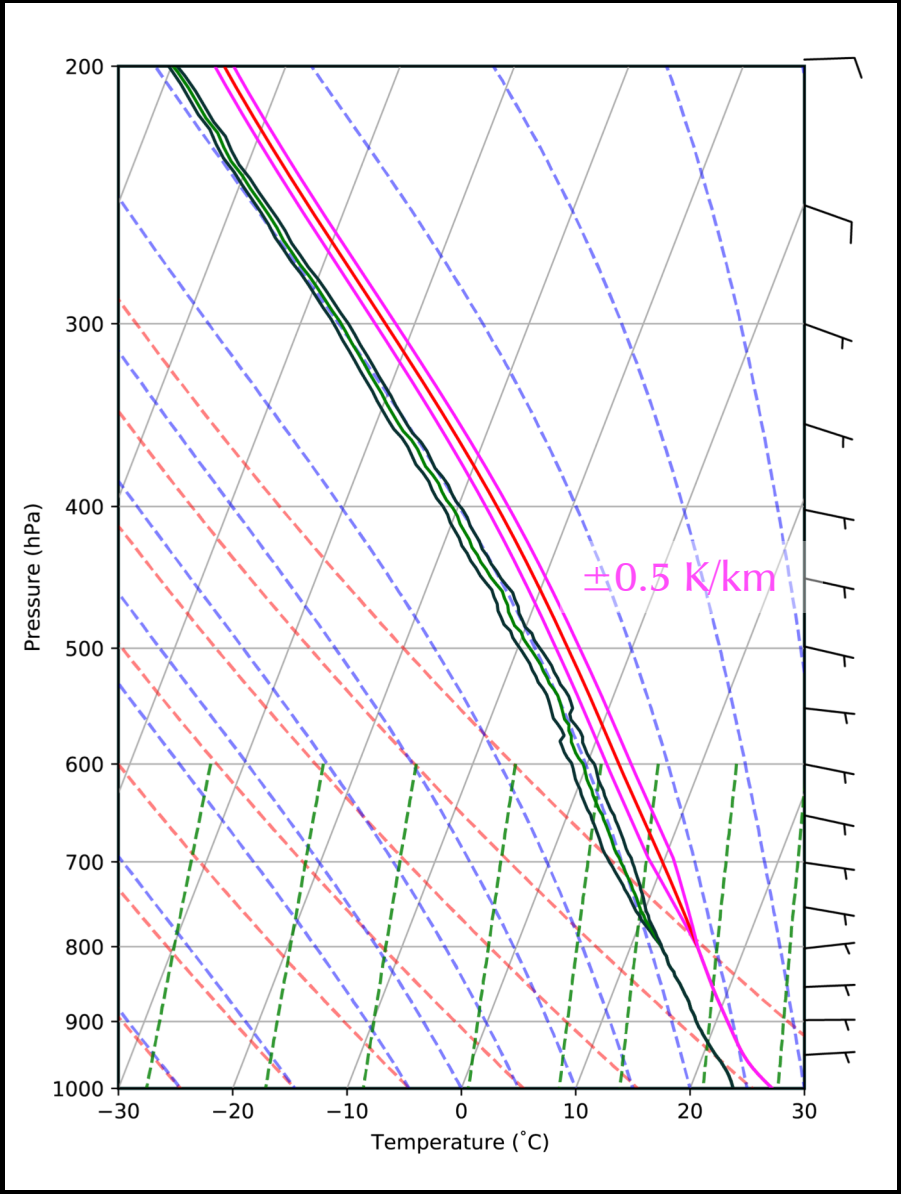

Middle 50%
Upper 25%
Number of occurrences
0
10
20
30
40
50
60
70
80
0.0
0.2
0.4
0.6
0.8
1.0
Fraction of radar domain experiencing rainfall

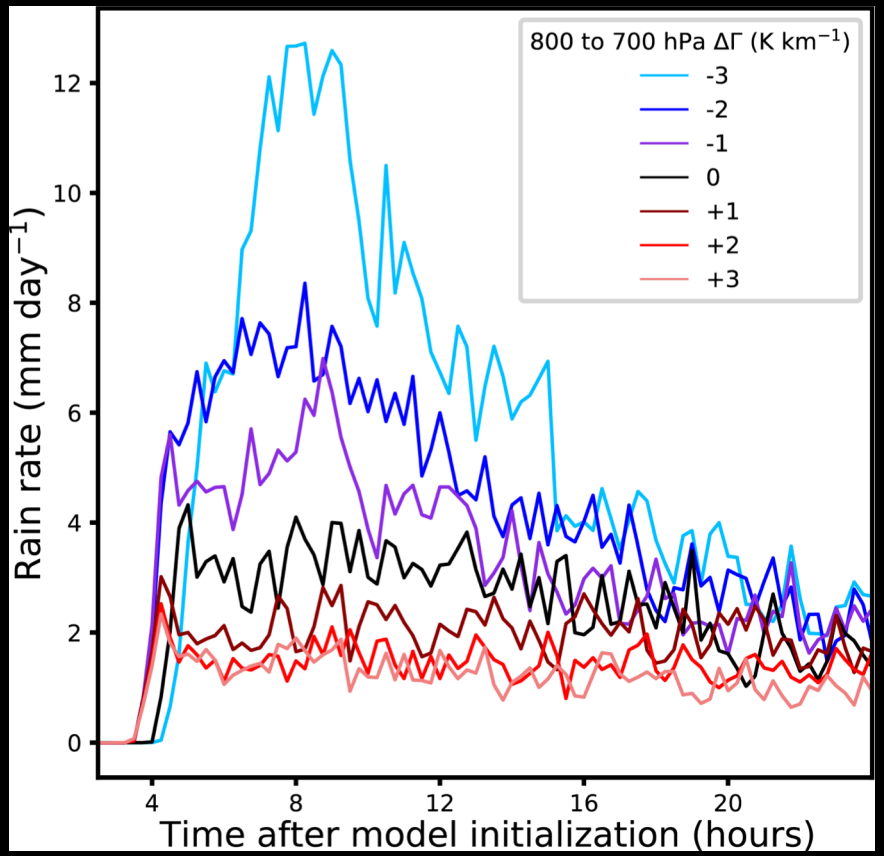

Convective area
Lower Quartile
Middle 50%
Upper Quartile
Radar-derived Rain Rate (mm hr^{-1})
900–700 hPa Lapse Rate (K km^{-1})
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5

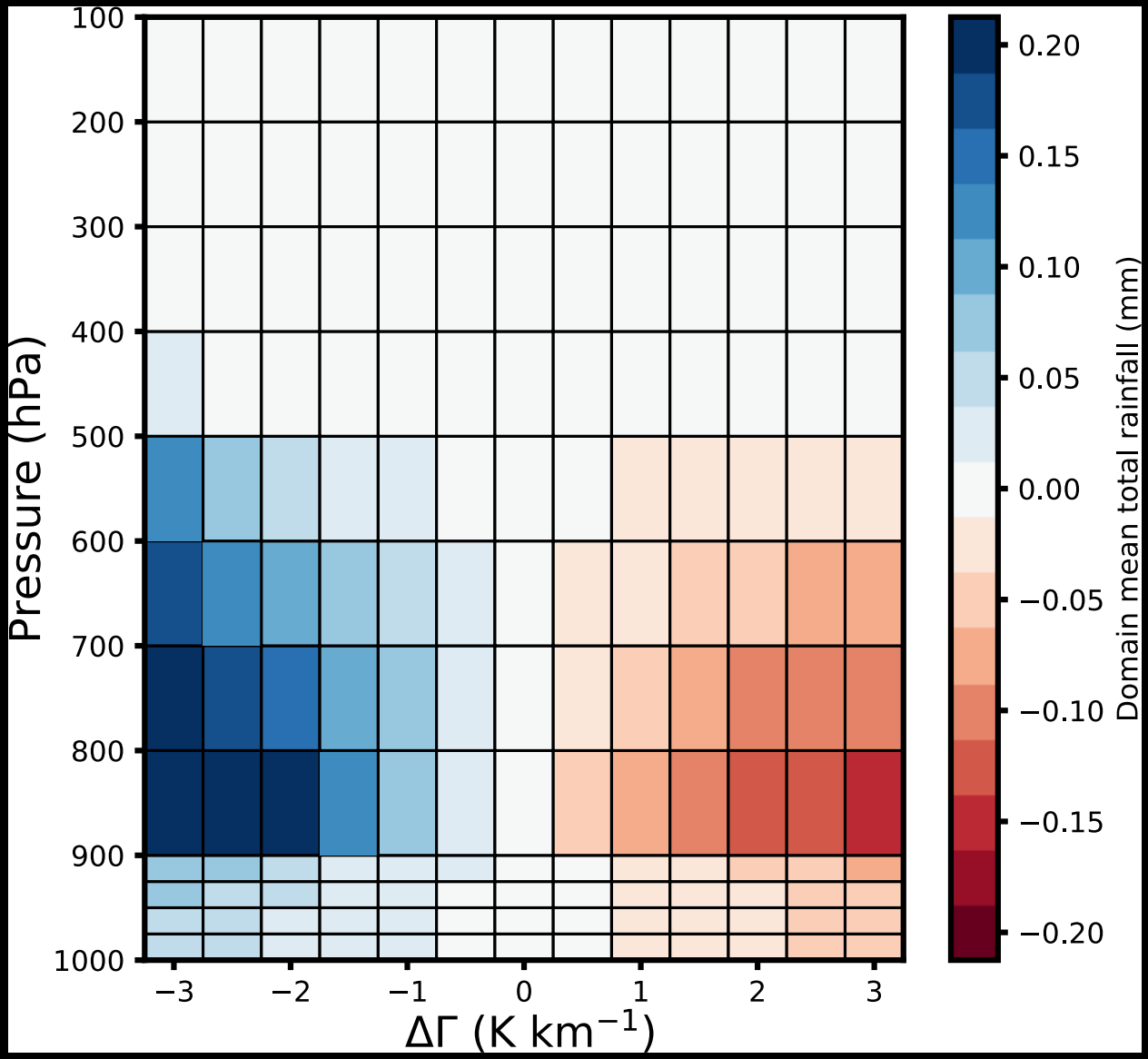

Convective area
Lower Quartile
Middle 50%
Upper Quartile
Correlation exists,
but it is very small.
Radar-derived Rain Rate (mm hr^{-1})
900–700 hPa Lapse Rate (K km^{-1})
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
3.5
4.0
4.5
5.0
5.5
6.0
6.5

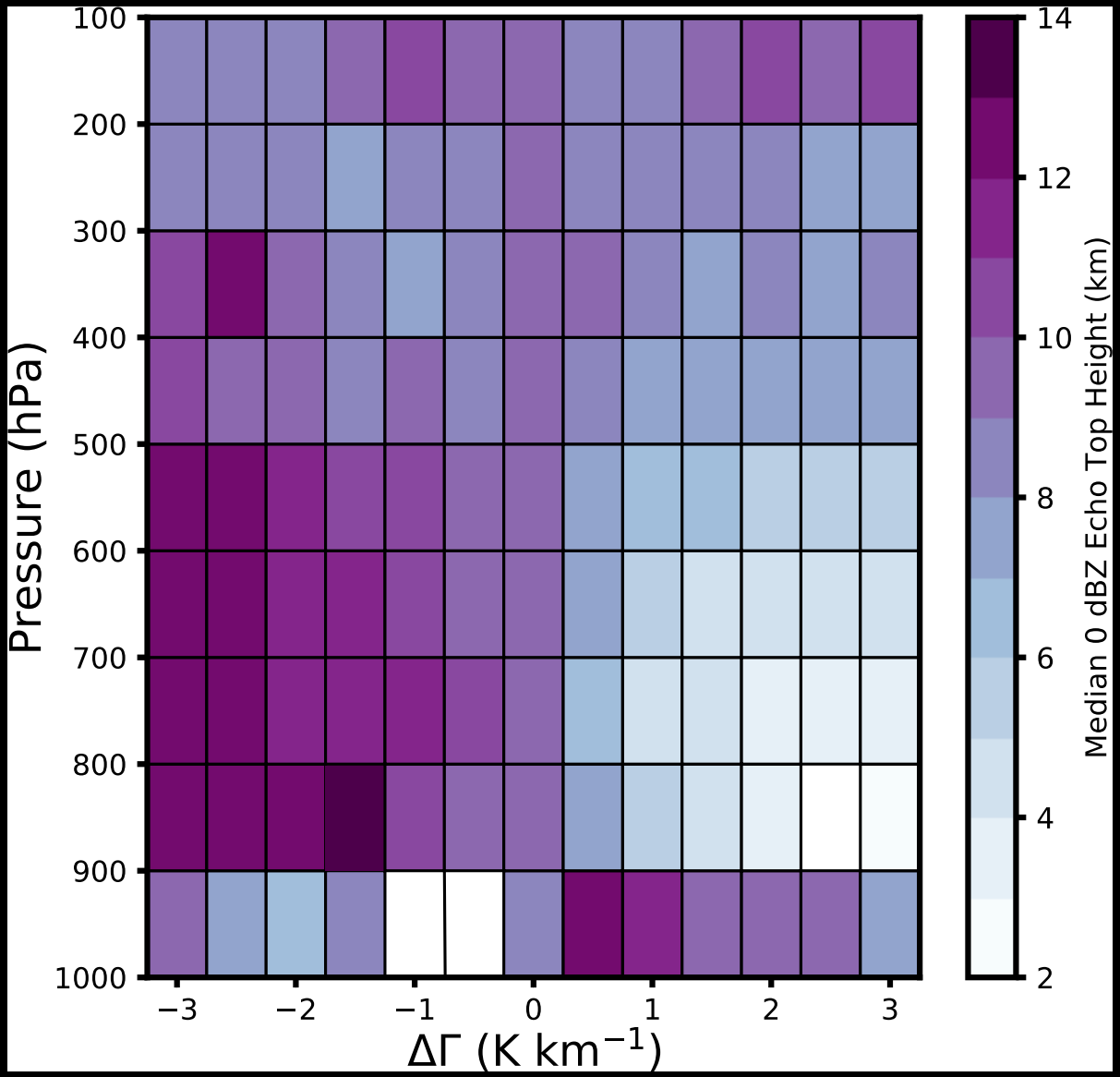
CM1 Simulations

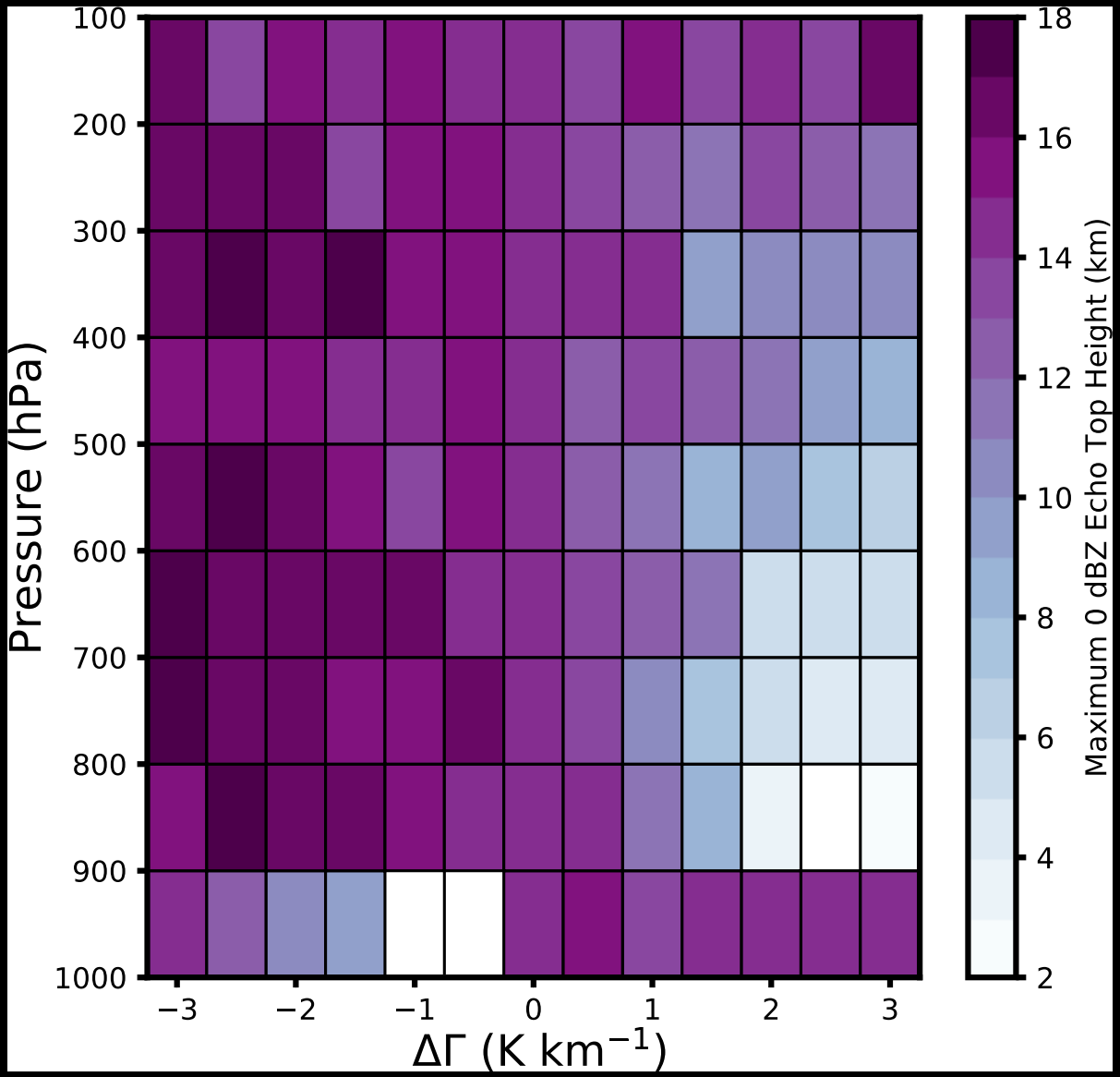

Pressure (hPa)
100
200
300
400
500
600
700
800
900
1000
−3
−2
−1
0
1
2
3
ΔΓ (K km^{-1})
Domain mean total rainfall (mm)
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20


200
300
400
500
600
700
800
900
1000
Pressure (hPa)
−30
−20
−10
0
10
20
30
Temperature (˚C)
±0.5 K/km


800 to 700 hPa ΔΓ (K km^{-1})
-3
-2
-1
0
+1
+2
+3
Rain rate (mm day^{-1})
0
2
4
6
8
10
12
4
8
12
16
20
Time after model initialization (hours)


Pressure (hPa)
100
200
300
400
500
600
700
800
900
1000
−3
−2
−1
0
1
2
3
ΔΓ (K km^{-1})
Domain mean total rainfall (mm)
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20


Pressure (hPa)
100
200
300
400
500
600
700
800
900
1000
−3
−2
−1
0
1
2
3
ΔΓ (K km^{-1})
Median 0 dBZ Echo Top Height (km)
14
12
10
8
6
4
2


Pressure (hPa)
100
200
300
400
500
600
700
800
900
1000
−3
−2
−1
0
1
2
3
ΔΓ (K km^{-1})
Maximum 0 dBZ Echo Top Height (km)
18
16
14
12
10
8
6
4
2