CCN and vertical velocity influences on droplet concentrations; multiple regressions

A Tale of Two two (four) Aircraft Field Projects

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Rain in Cumulus over the Ocean (RICO)

December-January, 2004-05, NSF, NCAR C-130

ICE in Clouds Experiment-Tropical (ICE-T)

July, 2011, NSF, NCAR C-130

Same location northeast Caribbean, opposite seasons, similar small cumulus clouds

RICO—clean

ICE-T—double concentrations of RICO

Marine Stratus/Stratocumulus Experiment (MASE)

July, 2005, DOE, Gulfstream-1, G-1

Physics of Stratocumulus Tops (POST)

July-August, 2008, NSF, CIRPAS Twin Otter

Same location off central California coast, same season, summer, and same stratus clouds,

MASE—always polluted

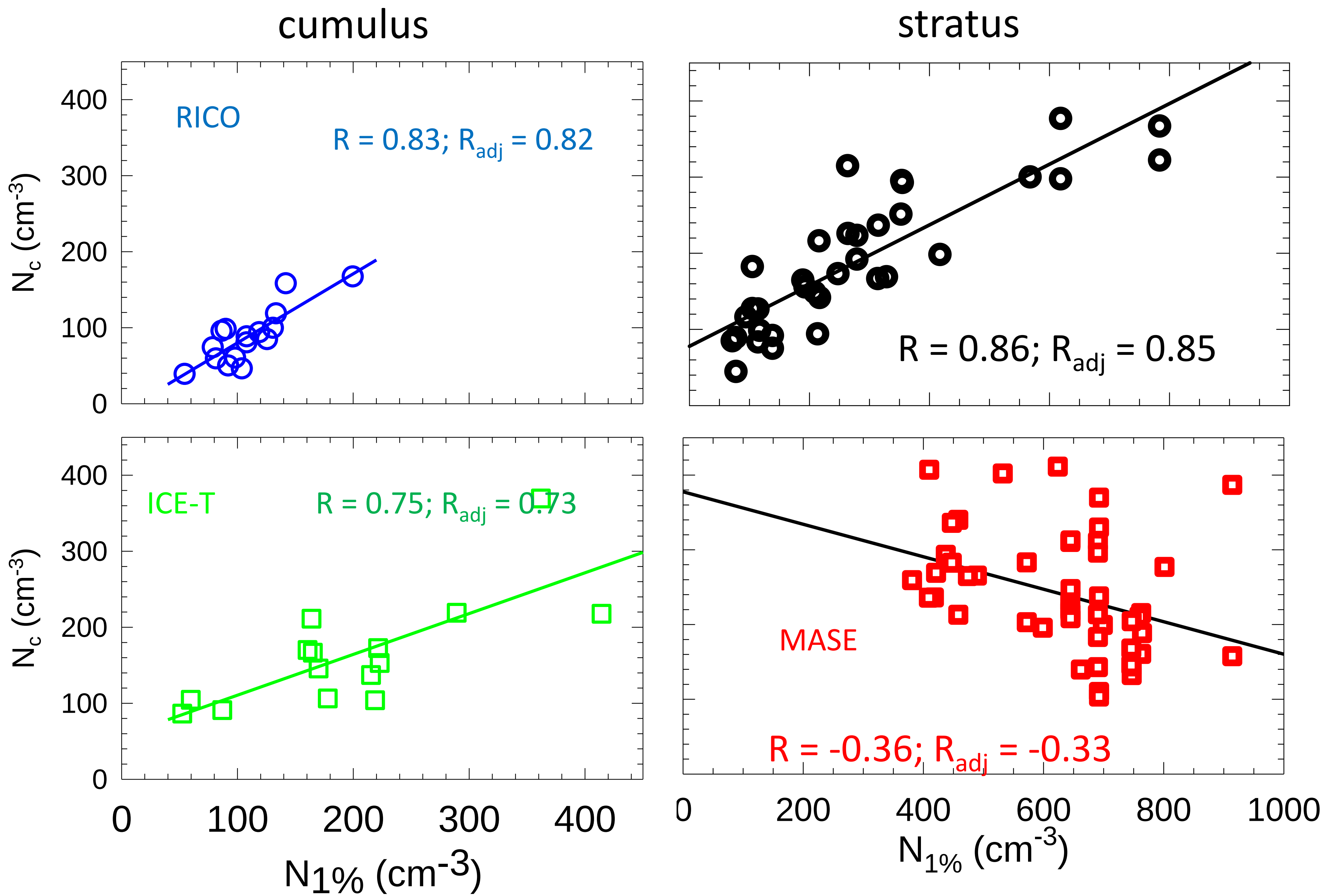
POST– clean to polluted and intermediate conditions

Low altitudes only < 2km for ICE-T; < 900m RICO

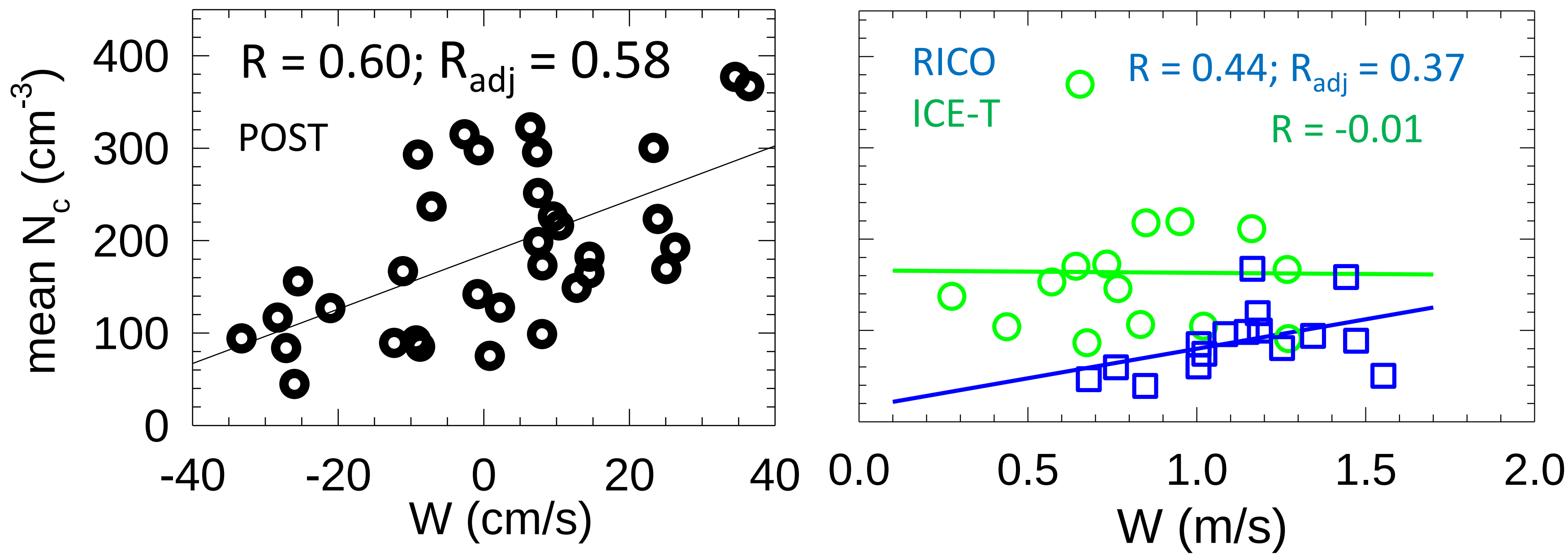
project	N	$N_{1\%}$ (cm^{-3})	N_c (cm^{-3})	W (m/s)	σ_w (m/s)	alt (m)	cb (m)	LWC (g/m^3)	MD (μm)	S_{eff} (%)
RICO	16	106	89	1.13	0.85	777	596	0.18	15.2	0.64
ICE-T	15	203	164	0.81	0.84	867	590	0.30	14.6	0.84
POST	34	280	190	0.02	0.53	408	209	0.30	13.8	0.61
MASE	50	634	240	0.01	0.15	312	100	0.23	10.7	0.19

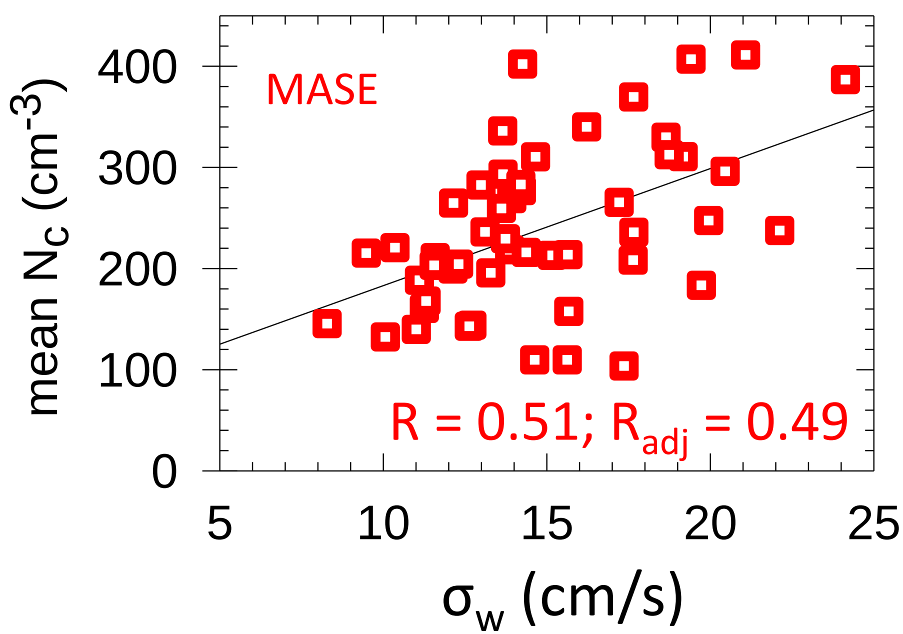
Flight averages: the threshold for cloud consideration is liquid water content (LWC) 0.1 g/m^3. N is number of "flights", $N_{1\%}$ is CCN conc. at 1% S, N_c is cloud droplet concentration, W is mean vertical velocity, σ_w is standard deviation of W (W_{sd}), alt is mean altitude of cloud measurements, cb is mean altitude of cloud base, h_b = alt-cb, LWC is mean liquid water content, MD is mean diameter of cloud droplets, σ is standard deviation of droplet spectra (droplet spectral width, i.e. variability of droplet sizes), S_{eff} is mean effective supersaturation of the clouds as determined by the S for which CCN concentration, $N_{CCN}(S)$ equaled N_c.

Hudson and Noble, 2013: CCN and vertical velocity influences on droplet concentrations and supersaturations in clean and polluted stratus clouds. JAS, in press.



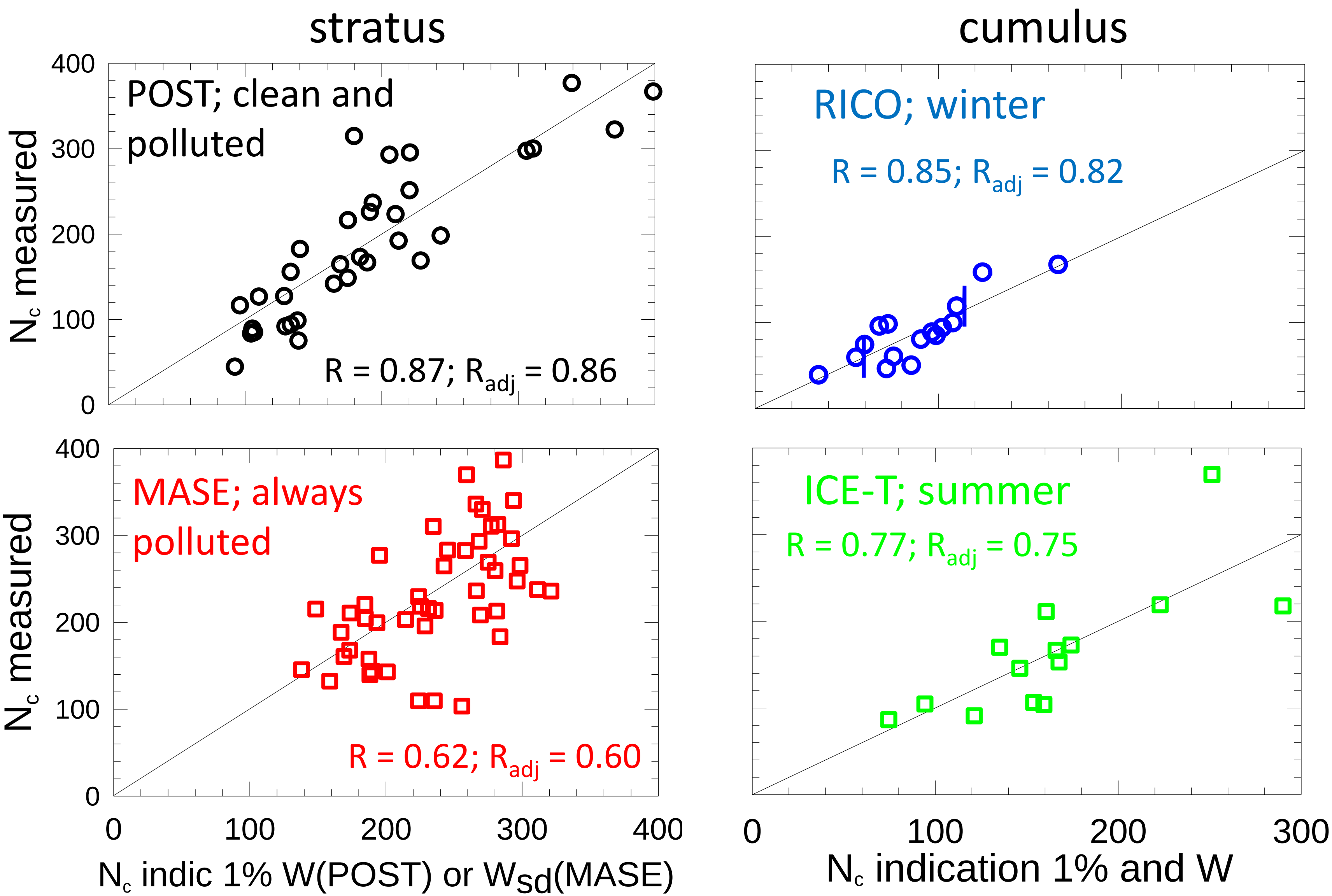
Single regressions between low altitude flight-averaged droplet concentrations (N_c) and below cloud CCN concentrations at 1% supersaturation ($N_{1\%}$)

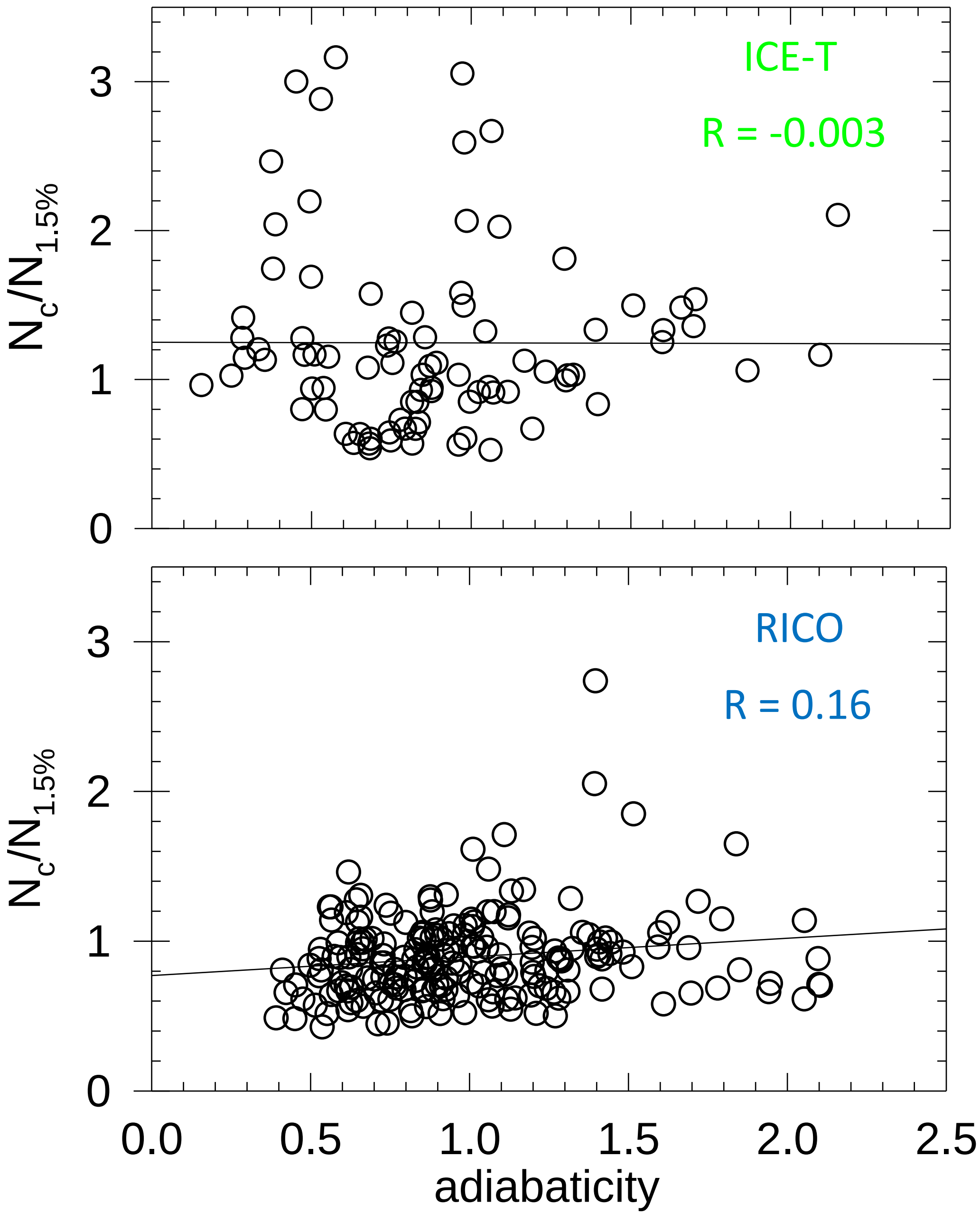




Regressions of flight-averaged droplet concentrations (N_c) against in-cloud vertical velocity (W) or standard deviation of W (σ_w).

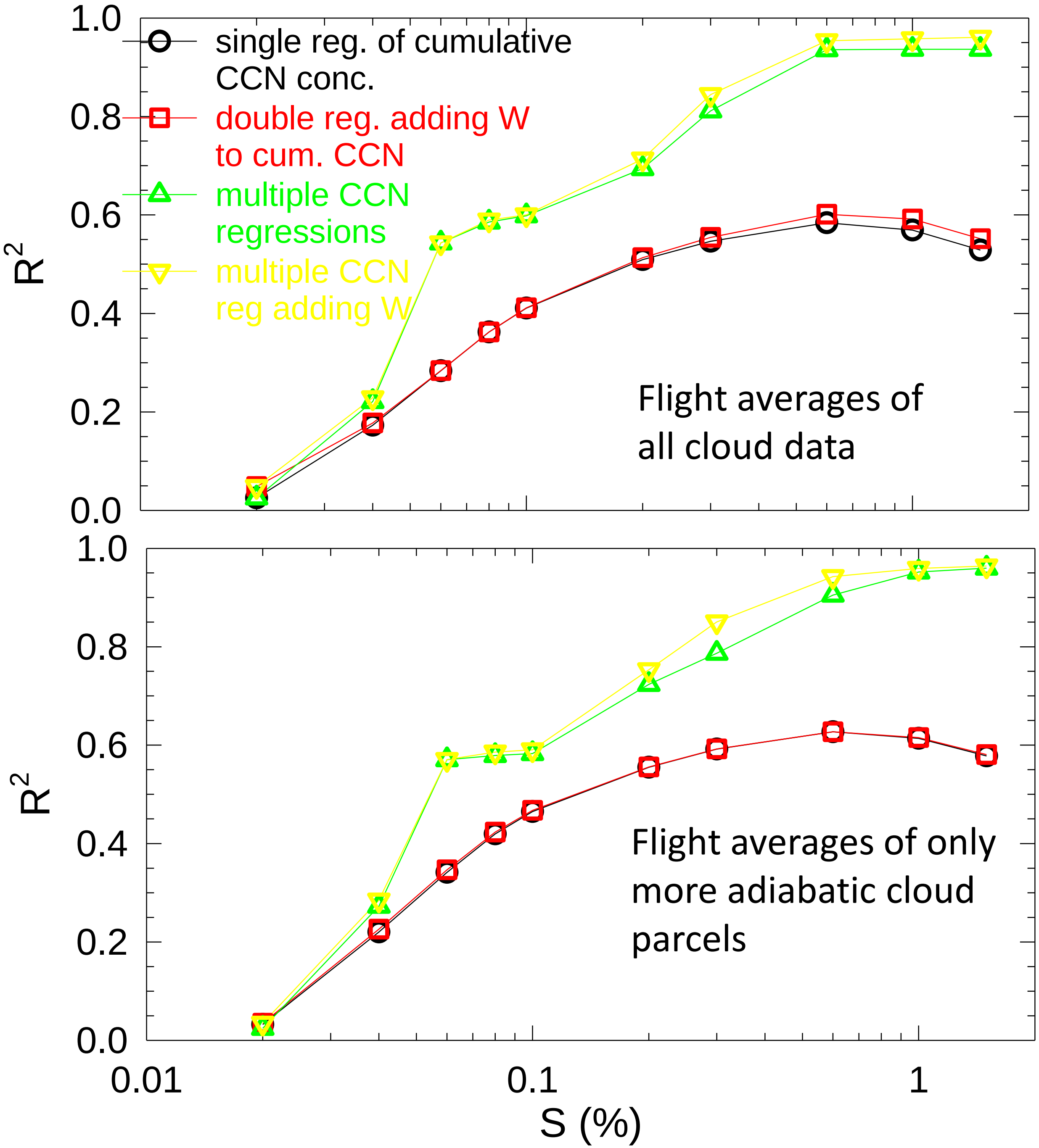
Double regressions of droplet concentrations (N_c) (cm^{-3}) from CCN at 1% S and W



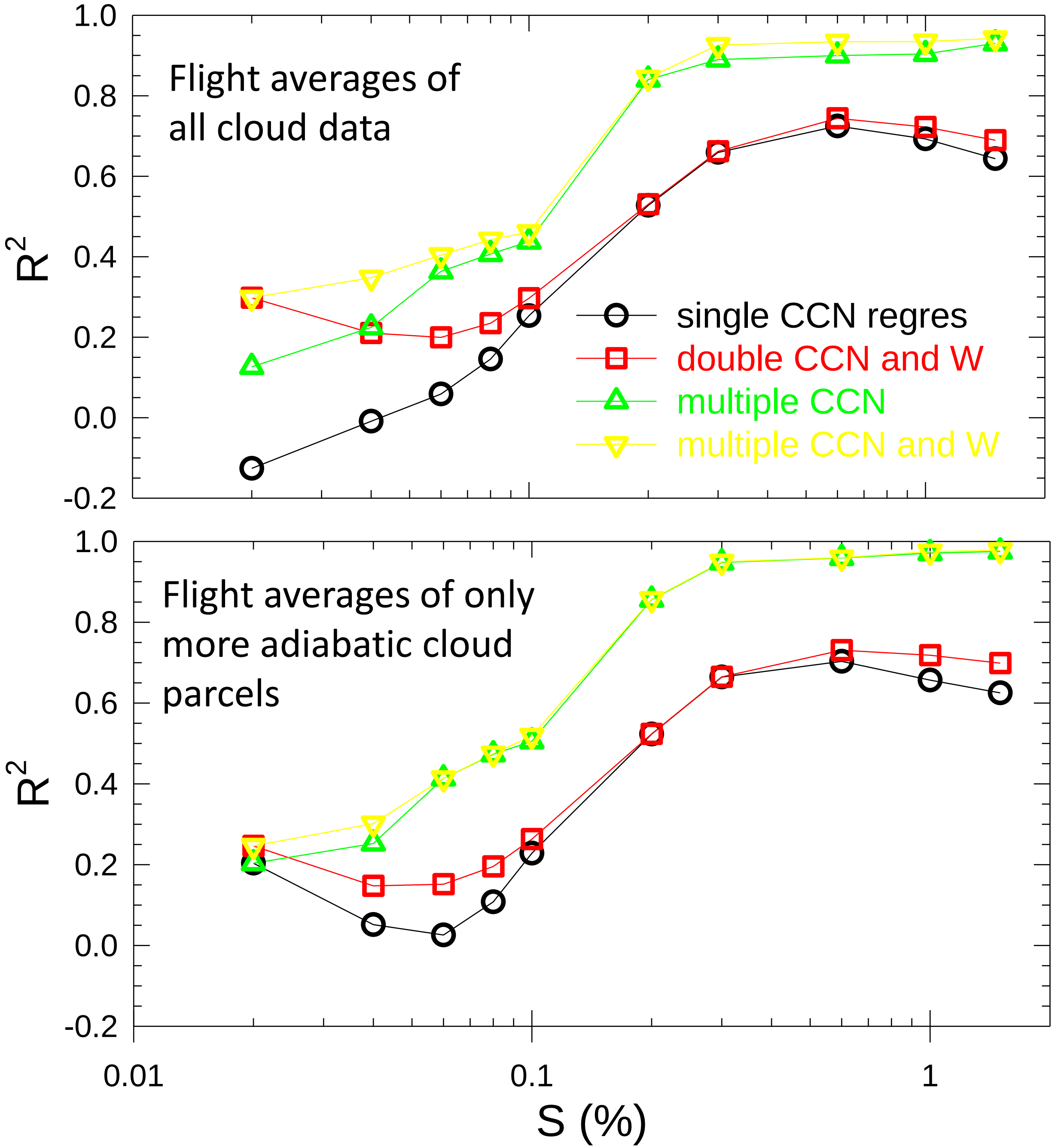


Adiabaticity;
How much is cloud diluted by entrainment, which reduces droplet concentration (N_c) and liquid water content (LWC). This could disrupt the relationship of N_c with CCN concentrations; especially if inhomogeneous mixing, which is random evaporation irrespective of droplet sizes. Homogeneous evaporation preferentially removes smaller droplets grown on smaller (lower S_c) CCN. So it just shifts the apparent cloud S lower but it preserves an effective S (S_{eff}).

ICE-T



50% higher N_c and LWC than flight averages



RICO

50% higher N_c and LWC than flight averages

Ezekiel, 1930

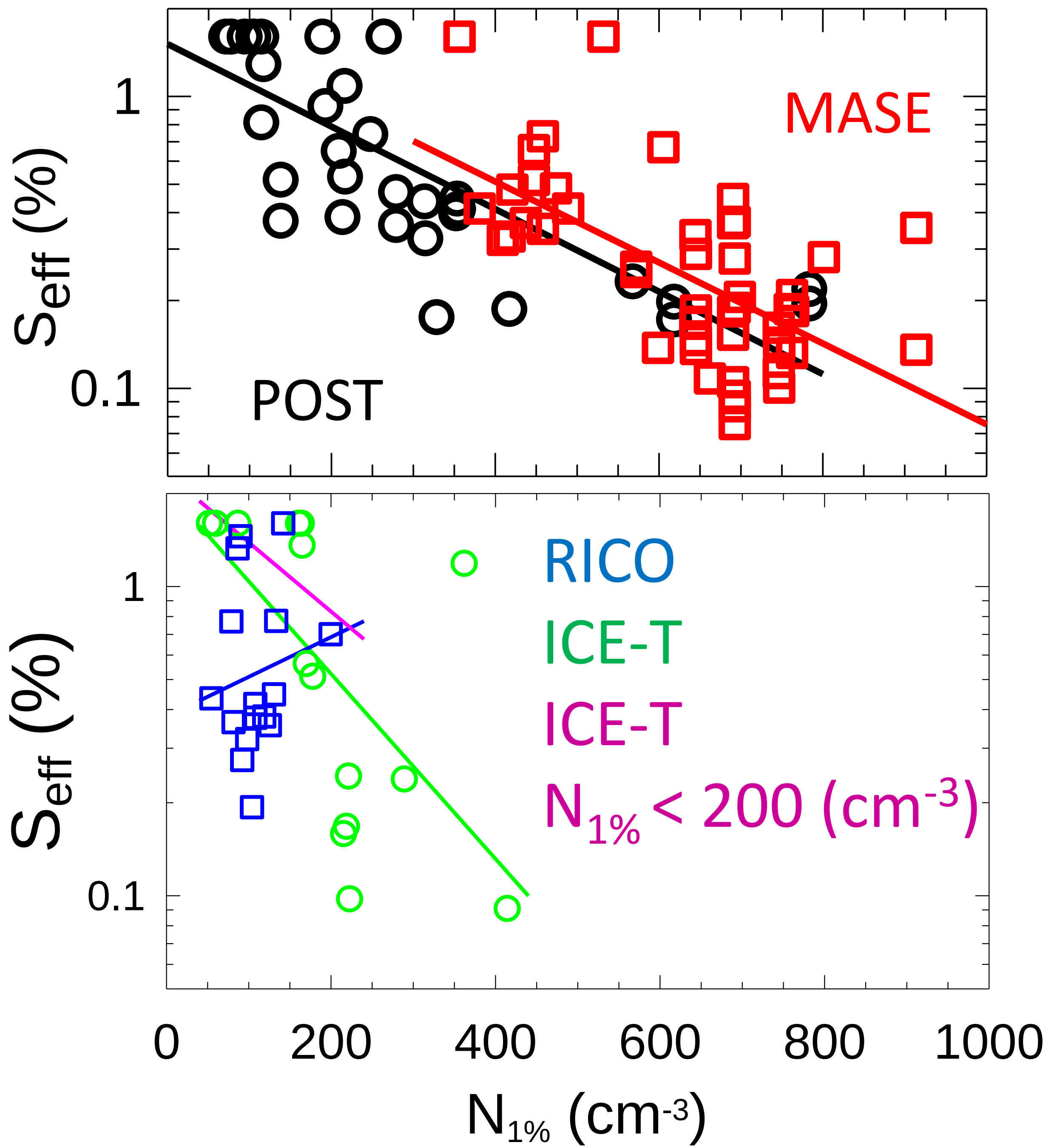
R^2_{adj} is essential for multiple regressions

$$R^2_{adj} = 1 - (1-R^2)(n-1)/(n-p-1)$$

n is the number of data points
p is the number of parameters being regressed.

Adjusted R^2 are lower than R^2 because some of the greater R^2 of adding parameters is due to randomness and is an overprediction of the measurements due simply to the addition of more dimensions/parameters to the regressions.

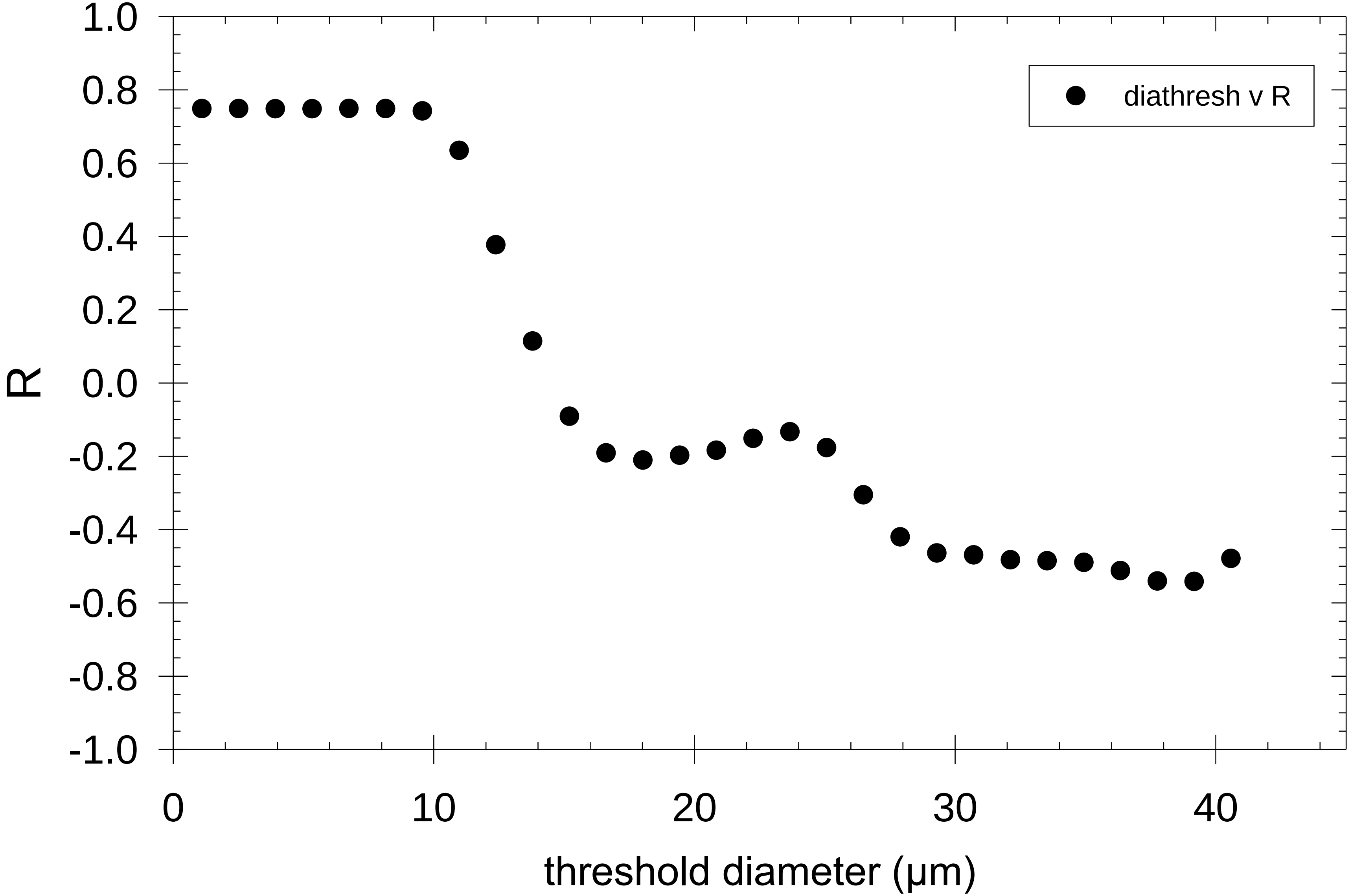
R^2_{adj} are a better alternative to significance levels even for single regressions [*Snyder and Lawson*, 1993].

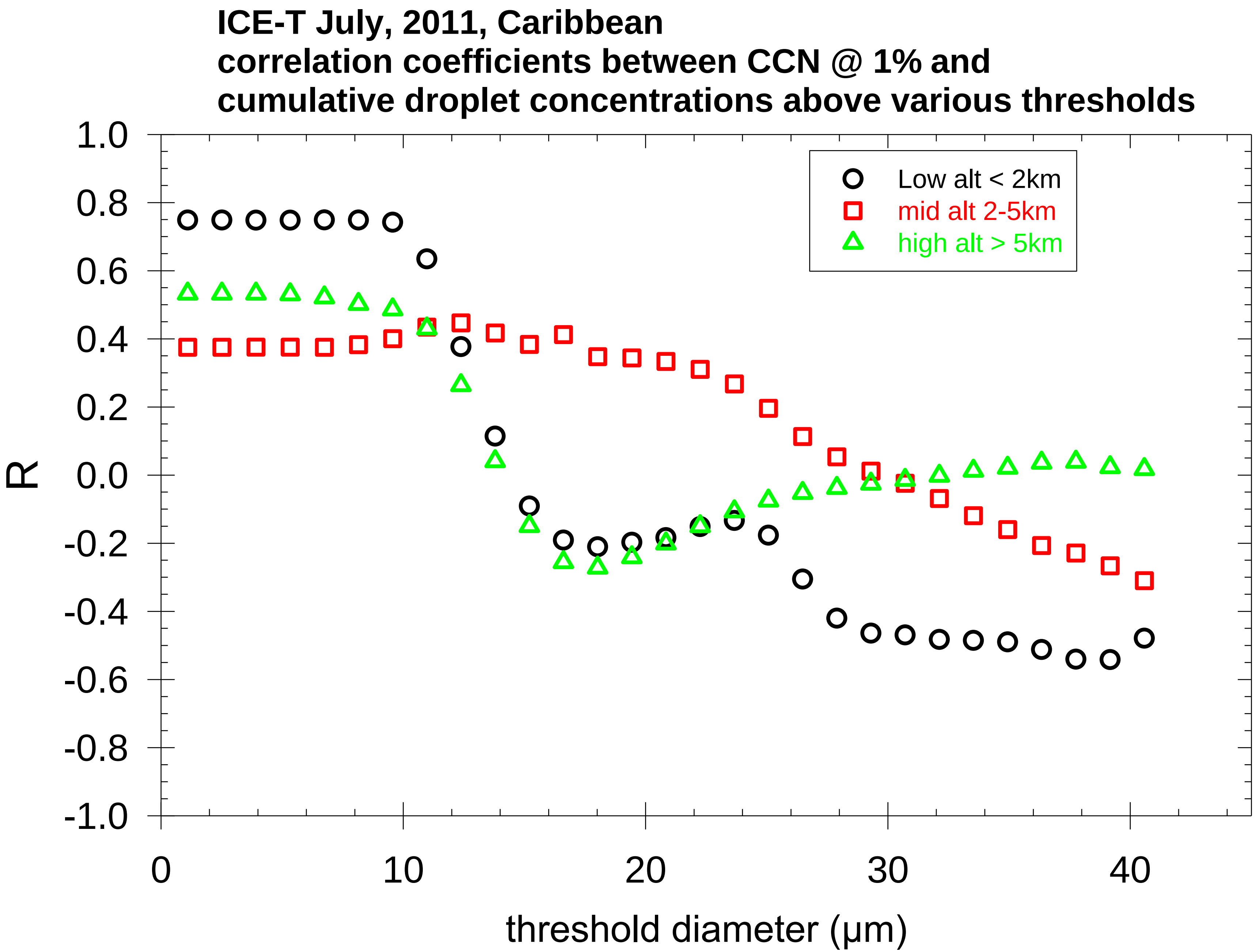


Effective cloud supersaturation, S_{eff}, is S for which $N_{CCN}(S)$ equals mean N_c

Suppression of cloud S by pollution predicted by Twomey (1959)

ICE-T July, 2011, Caribbean
correlation coefficients between CCN @ 1% and
cumulative droplet concentrations above various thresholds




ICE-T July, 2011, Caribbean
correlation coefficients between CCN @ 1% and
cumulative droplet concentrations above various thresholds
Low alt < 2km
mid alt 2-5km
high alt > 5km
R
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0
10
20
30
40
threshold diameter (μm)

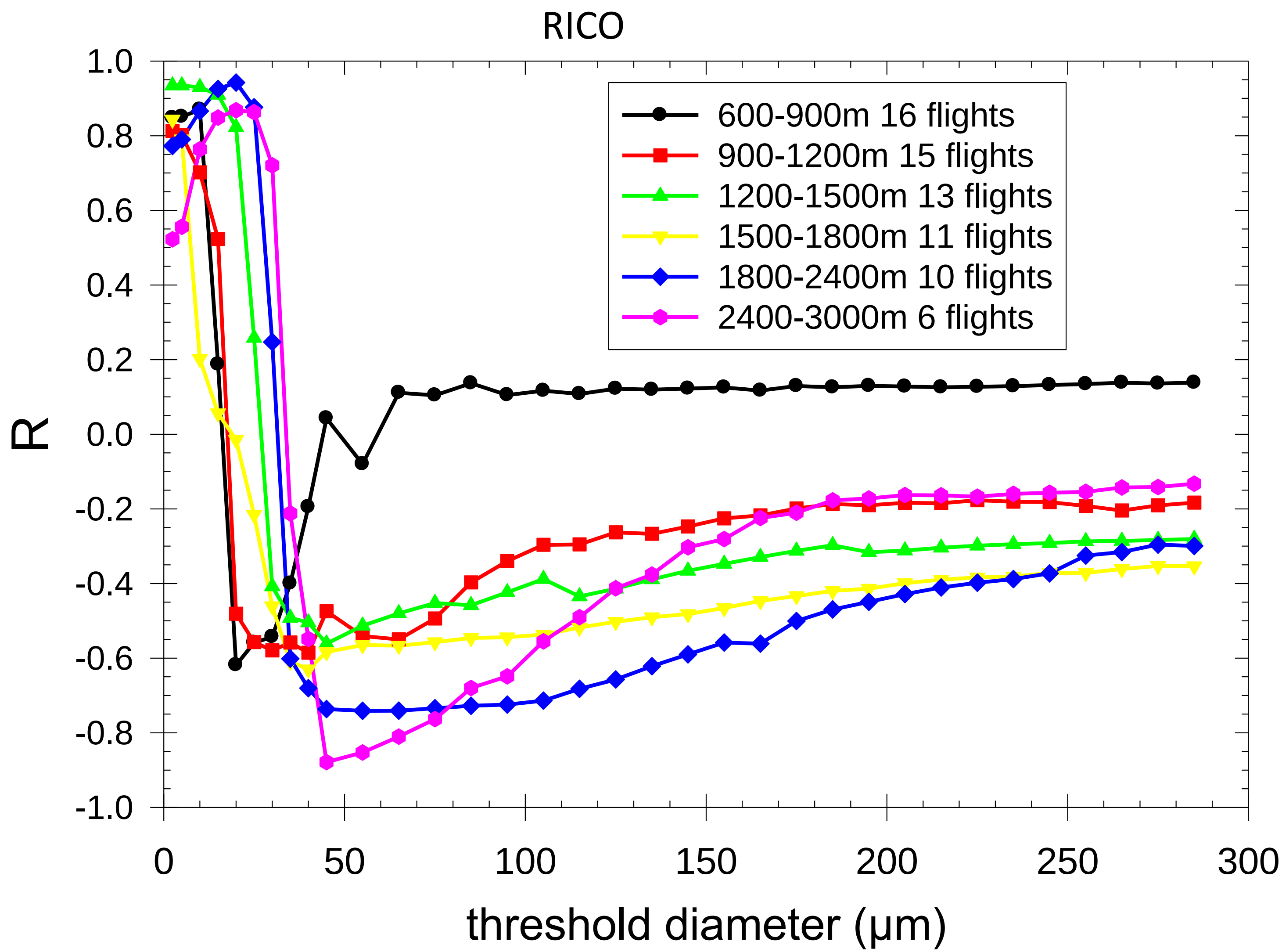
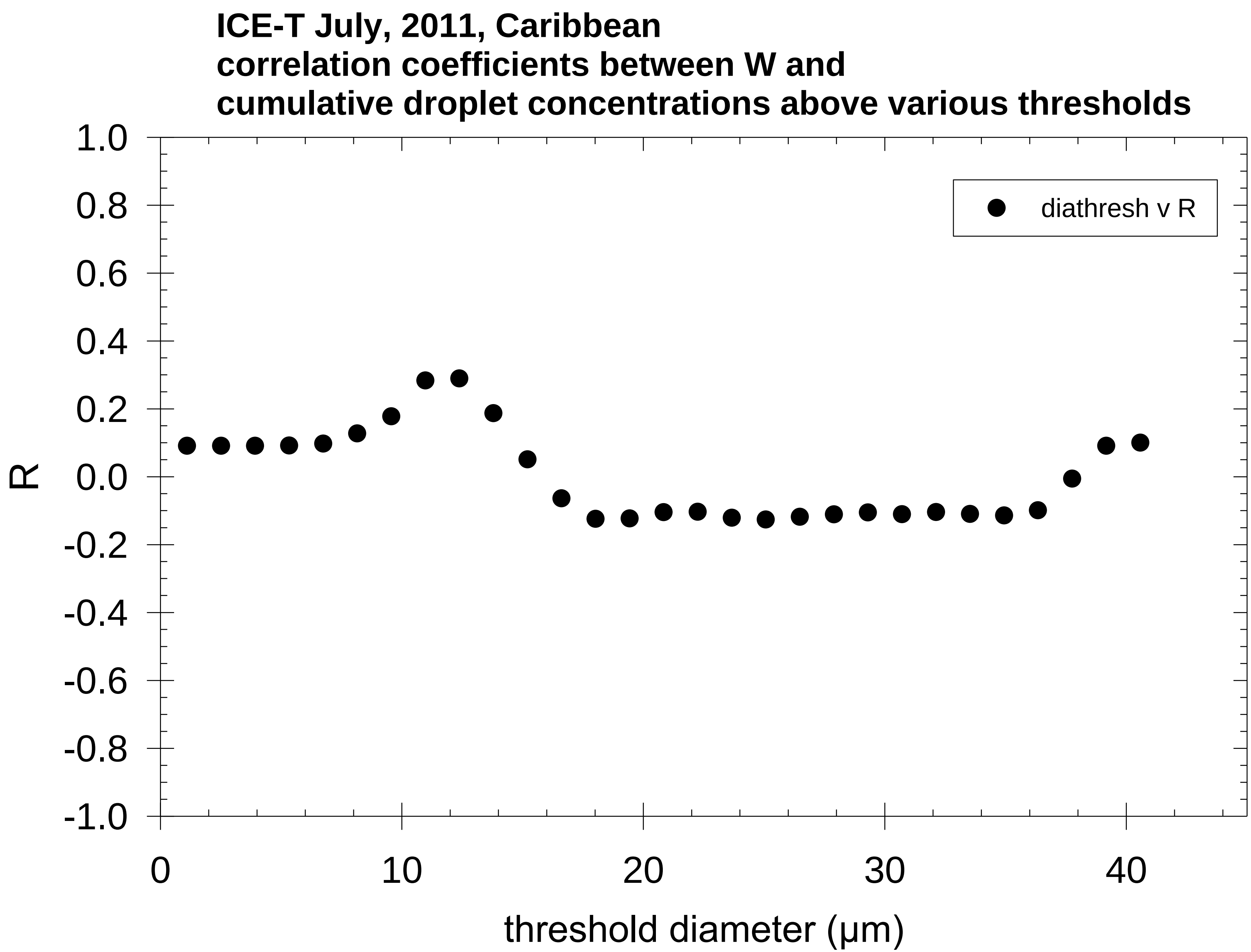
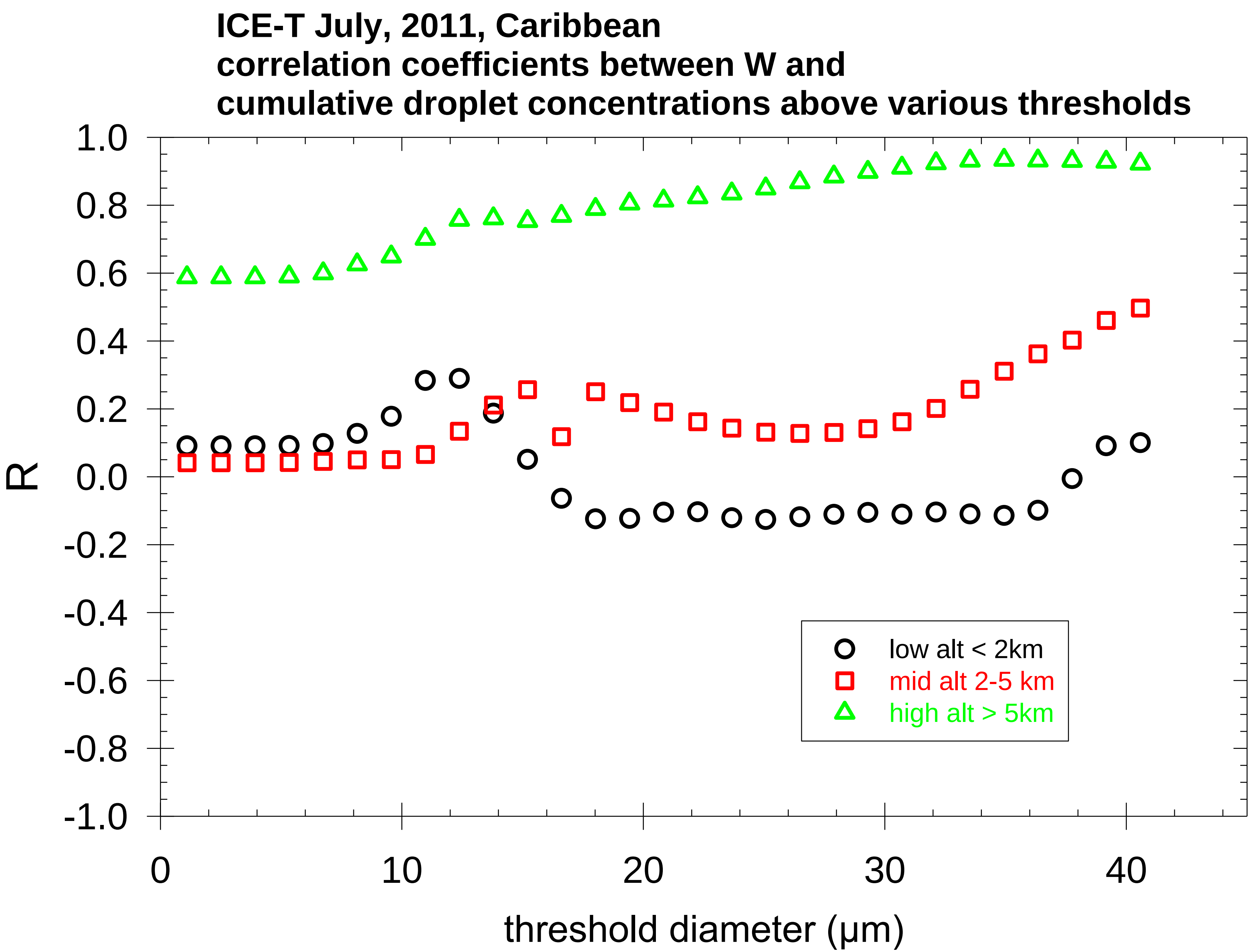


Figure 5. Correlation coefficients (R) for 1% S CCN at 100m altitude versus cumulative drop(let) concentrations above various size thresholds within the specified altitude bands. This is the same data displayed in Figs. 3A and 4 but here displayed for each altitude band as a function of drop(let) sizes. As in those other figures the flights considered varied with altitude band and this may cause biases. The number of flights in each altitude range is shown in the legend.

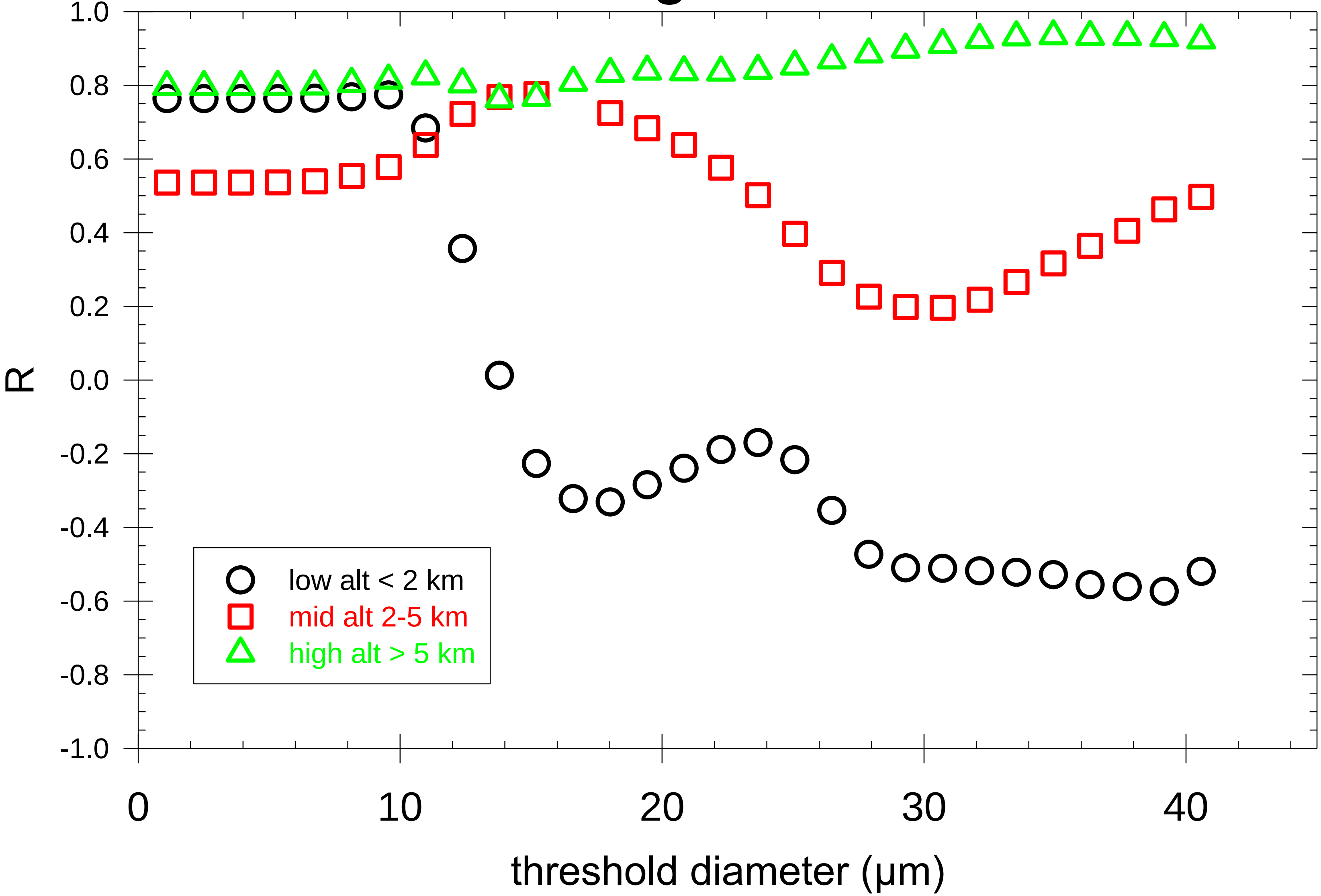

ICE-T July, 2011, Caribbean
correlation coefficients between W and
cumulative droplet concentrations above various thresholds
diathresh v R
R
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0
10
20
30
40
threshold diameter (μm)

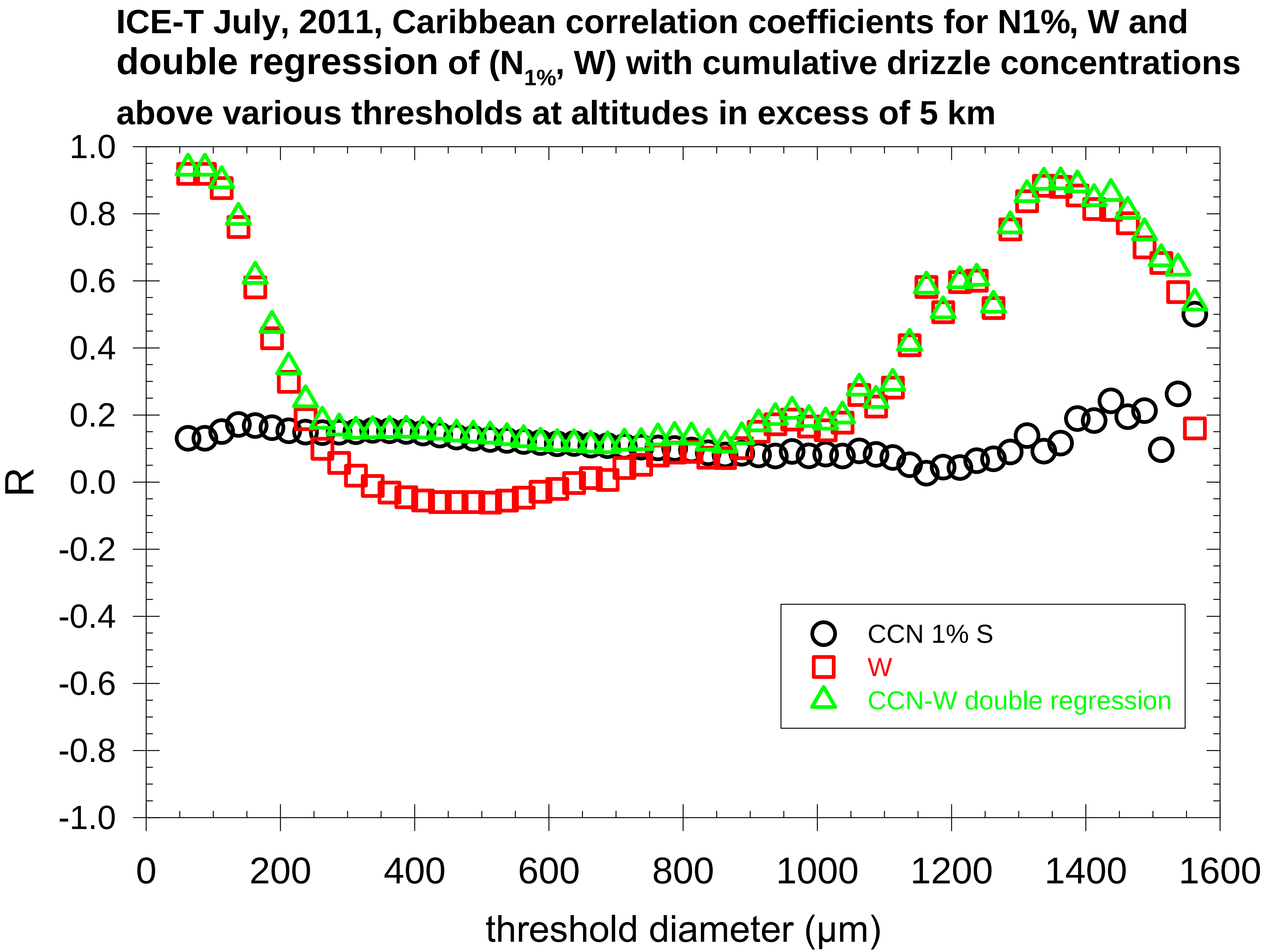


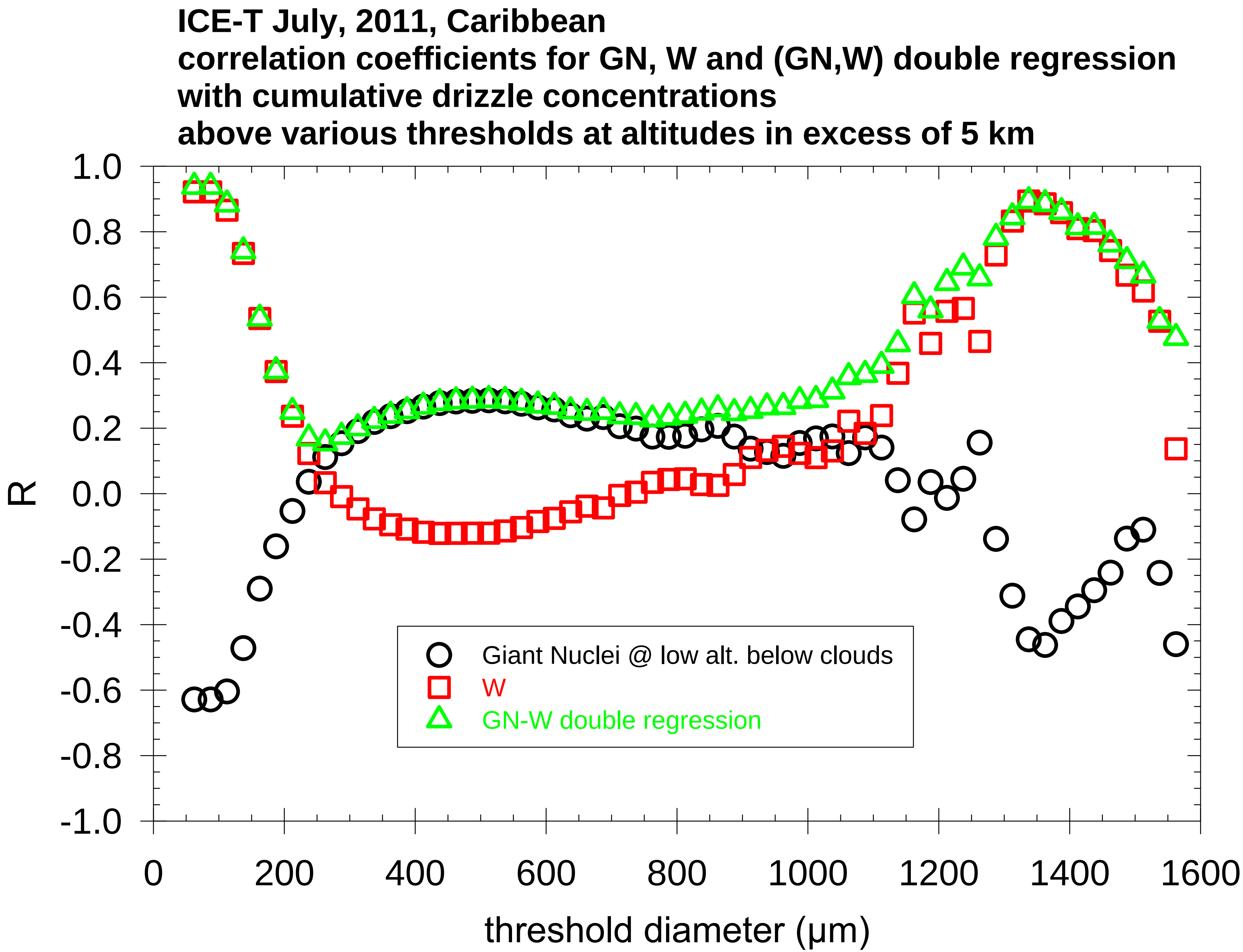
ICE-T July, 2011, Caribbean
correlation coefficients between W and
cumulative droplet concentrations above various thresholds
R
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0
10
20
30
40
threshold diameter (μm)
low alt < 2km
mid alt 2-5 km
high alt > 5km

ICE-T July, 2011, Caribbean
correlation coefficients for cumulative droplet concentrations
above various thresholds at various altitudes for CCN and W

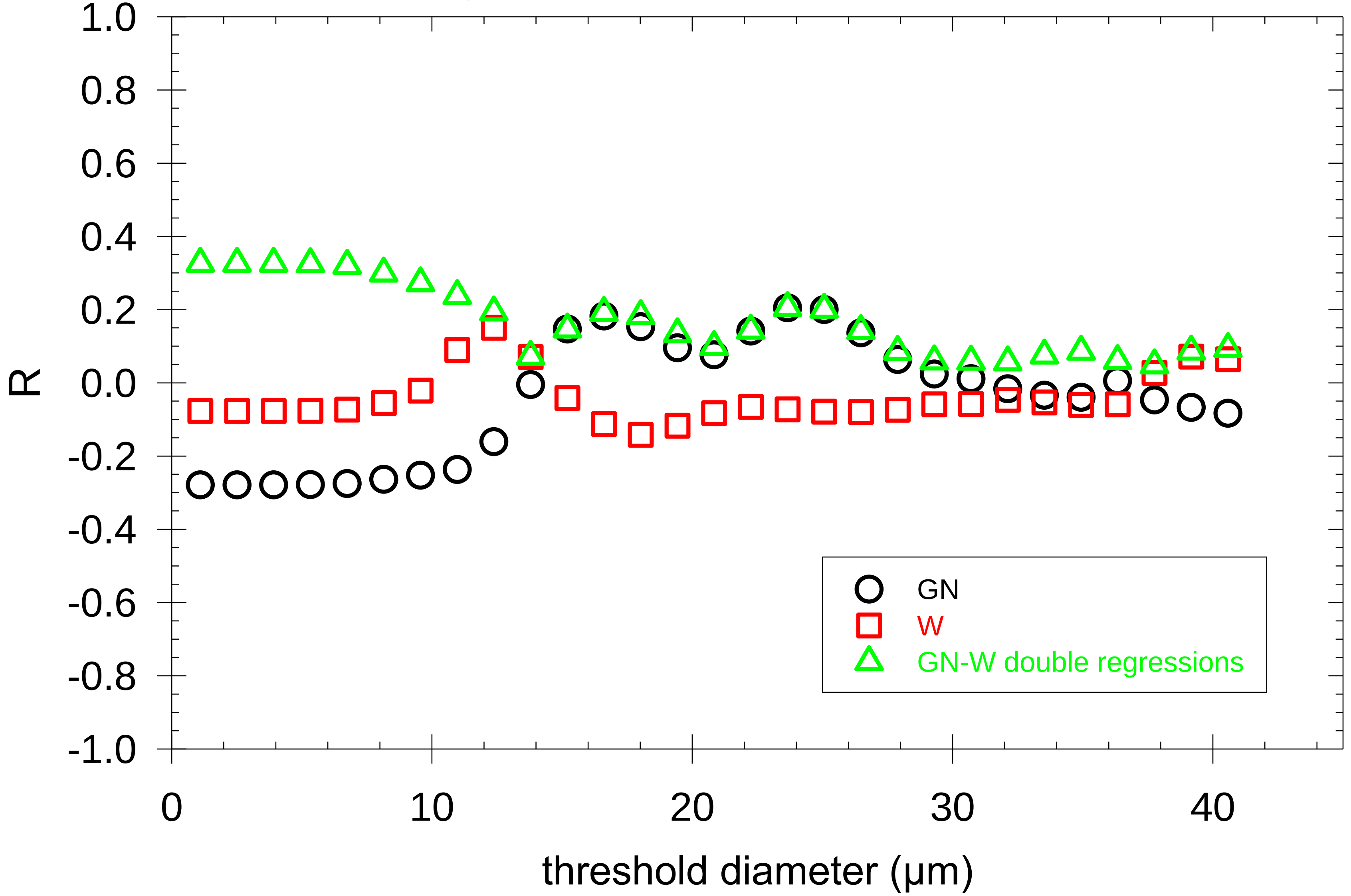
double regressions

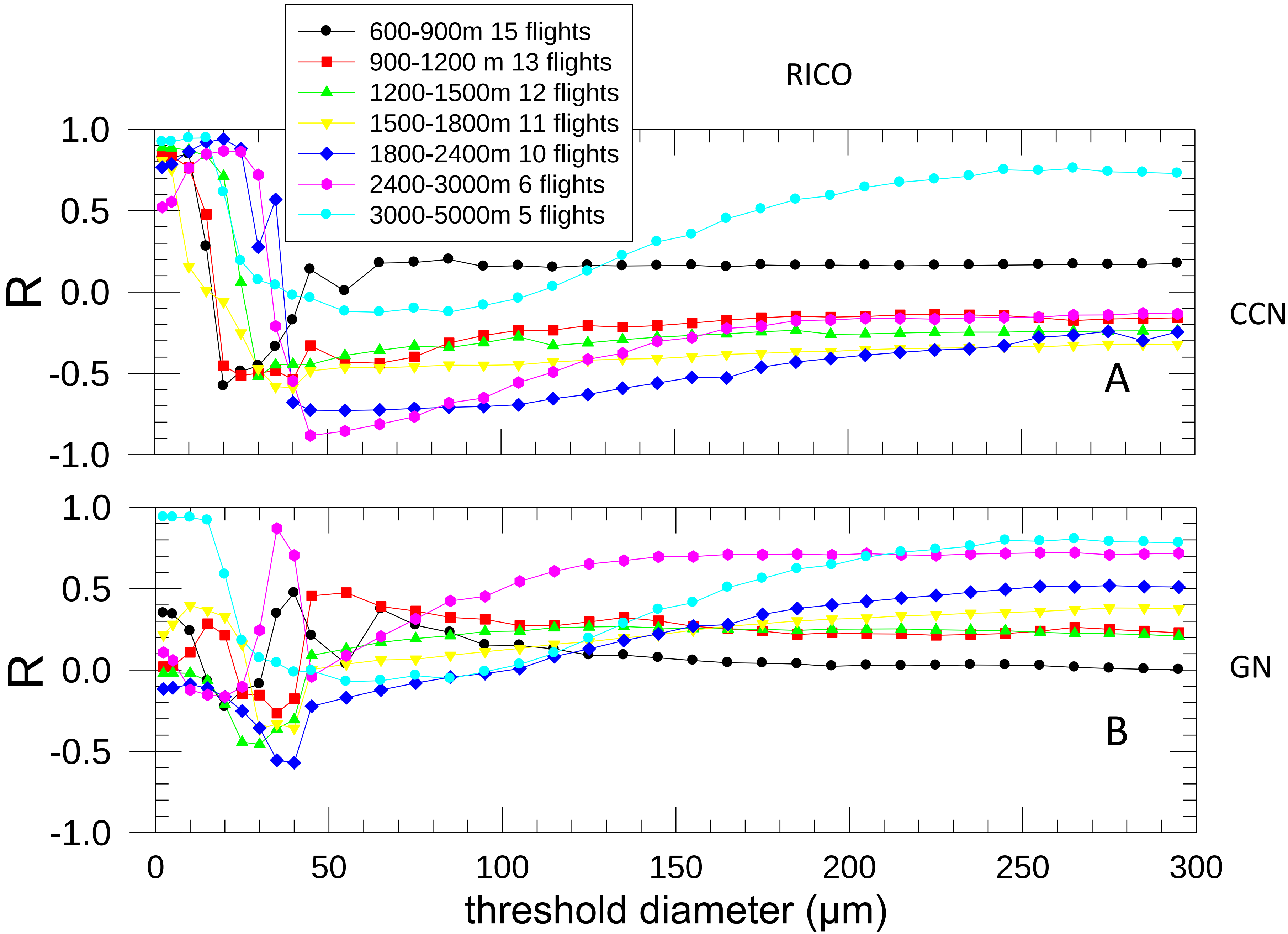



ICE-T July, 2011, Caribbean correlation coefficients for N1%, W and double regression of (N1%, W) with cumulative drizzle concentrations above various thresholds at altitudes in excess of 5 km
R
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0
200
400
600
800
1000
1200
1400
1600
threshold diameter (µm)
CCN 1% S
W
CCN-W double regression

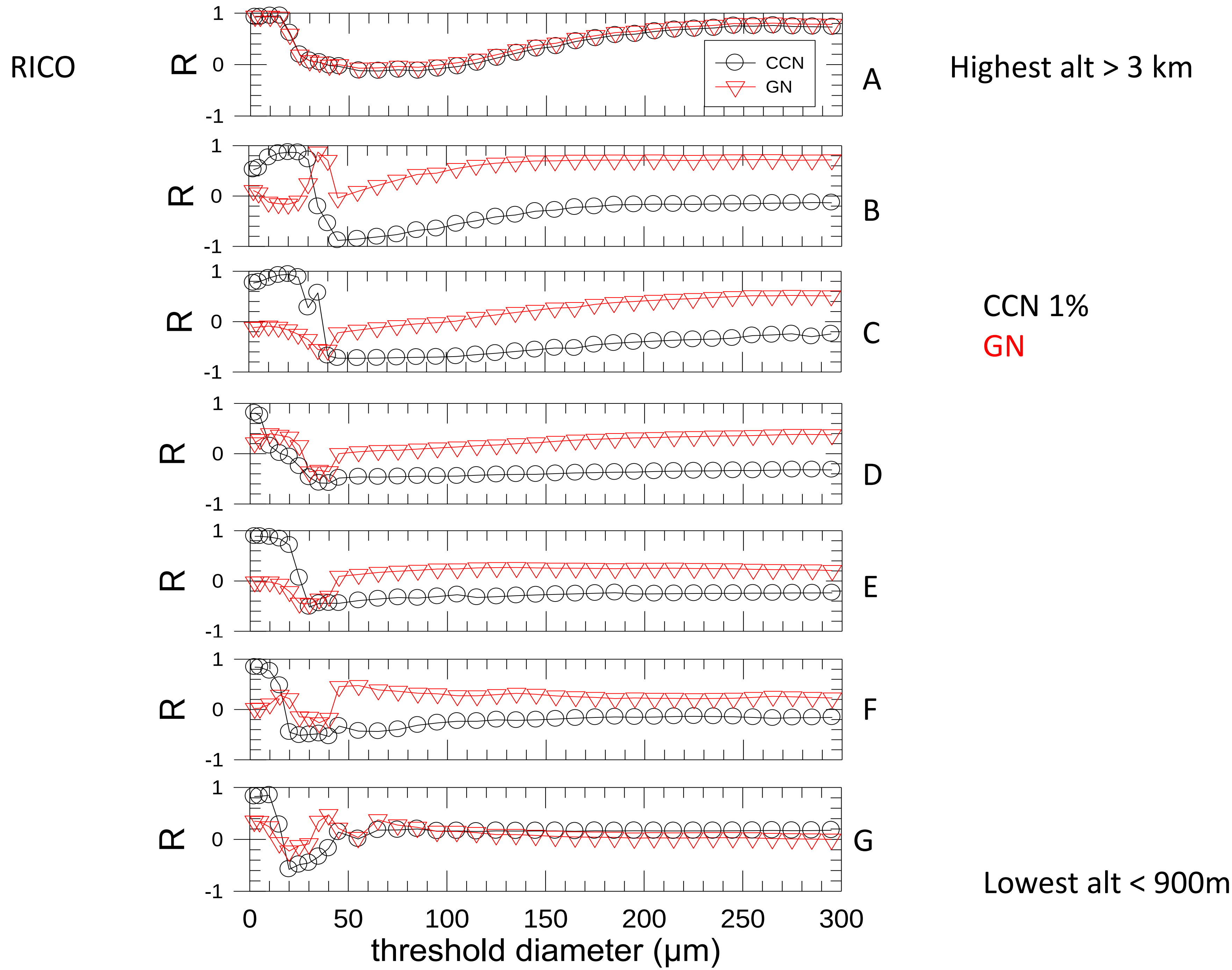

ICE-T July, 2011, Caribbean
correlation coefficients for GN, W and (GN,W) double regression
with cumulative drizzle concentrations
above various thresholds at altitudes in excess of 5 km
R
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0
200
400
600
800
1000
1200
1400
1600
threshold diameter (µm)
Giant Nuclei @ low alt. below clouds
W
GN-W double regression

ICE-T July, 2011, Caribbean
correlation coefficients for cumulative droplet concentrations above various thresholds at low altitudes for GN and W and double regression of (GN, W) with cum. droplet conc.





600-900m 15 flights
900-1200 m 13 flights
1200-1500m 12 flights
1500-1800m 11 flights
1800-2400m 10 flights
2400-3000m 6 flights
3000-5000m 5 flights
RICO
1.0
0.5
0.0
-0.5
-1.0
R
CCN
A
GN
B
0
50
100
150
200
250
300
threshold diameter (μm)



RICO
Highest alt > 3 km
CCN 1%
GN
Lowest alt < 900m
CCN
GN
A
B
C
D
E
F
G
R
1
0
-1
0
50
100
150
200
250
300
threshold diameter (μm)

Conclusions and Summary

Factor of 2 higher N_{CCN} and N_c summer (ICE-T) than winter (RICO)

At low altitudes N_{CCN} dominates W for determining N_c

At high altitudes W dominates N_{CCN} for determining N_c

W positively correlated with N_{CCN} in RICO but not ICE-T

increases R of N_{CCN} and W with N_c, in RICO but not ICE-T

but then double regression does not improve RICO

but does improve ICE-T

More adiabatic cloud parcel Nc are higher but not much better correlated with N_{CCN}

Multiple CCN regression are much better than single correlations

As in stratus, cloud S is suppressed by higher N_{CCN} in ICE-T but not RICO?

In ICE-T even for same range as RICO

Higher cloud S in ICE-T than RICO

W related to some high alt drizzle

GN not related to N_c at low alt

GN related to high alt drizzle in RICO but not ICE-T

Hudson and Noble about to be submitted to JGR

"Seasonal contrasts of CCN and low altitude microphysics of northeastern Caribbean small cumuli; and comparisons with stratus"

ICE-T and RICO and comparisons with POST and MASE