Relationships among CCN spectra, vertical velocity and cloud microphysics in clean and polluted low stratus and cumuli (POST, MASE, RICO, ICE-T)

A Tale of Four Aircraft Field Projects

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Physics of Stratocumulus Tops (POST)

July-August, 2008, NSF, CIRPAS Twin Otter

Marine Stratus/Stratocumulus Experiment (MASE)

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

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

POST– clean to polluted and intermediate conditions

MASE—always polluted

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

project	N	$N_{1\%}$ (cm^{-3})	N_c (cm^{-3})	W (m/s)	σ_w (m/s)	S_{eff} (%)	k @ S_{eff}
RICO	16	106	89	1.13	0.85	0.64	0.38
ICE-T	15	203	164	0.81	0.84	0.84	0.16
POST	34	280	190	0.02	0.53	0.61	0.52
MASE	50	634	240	0.01	0.15	0.19	0.82

Project averages of 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,

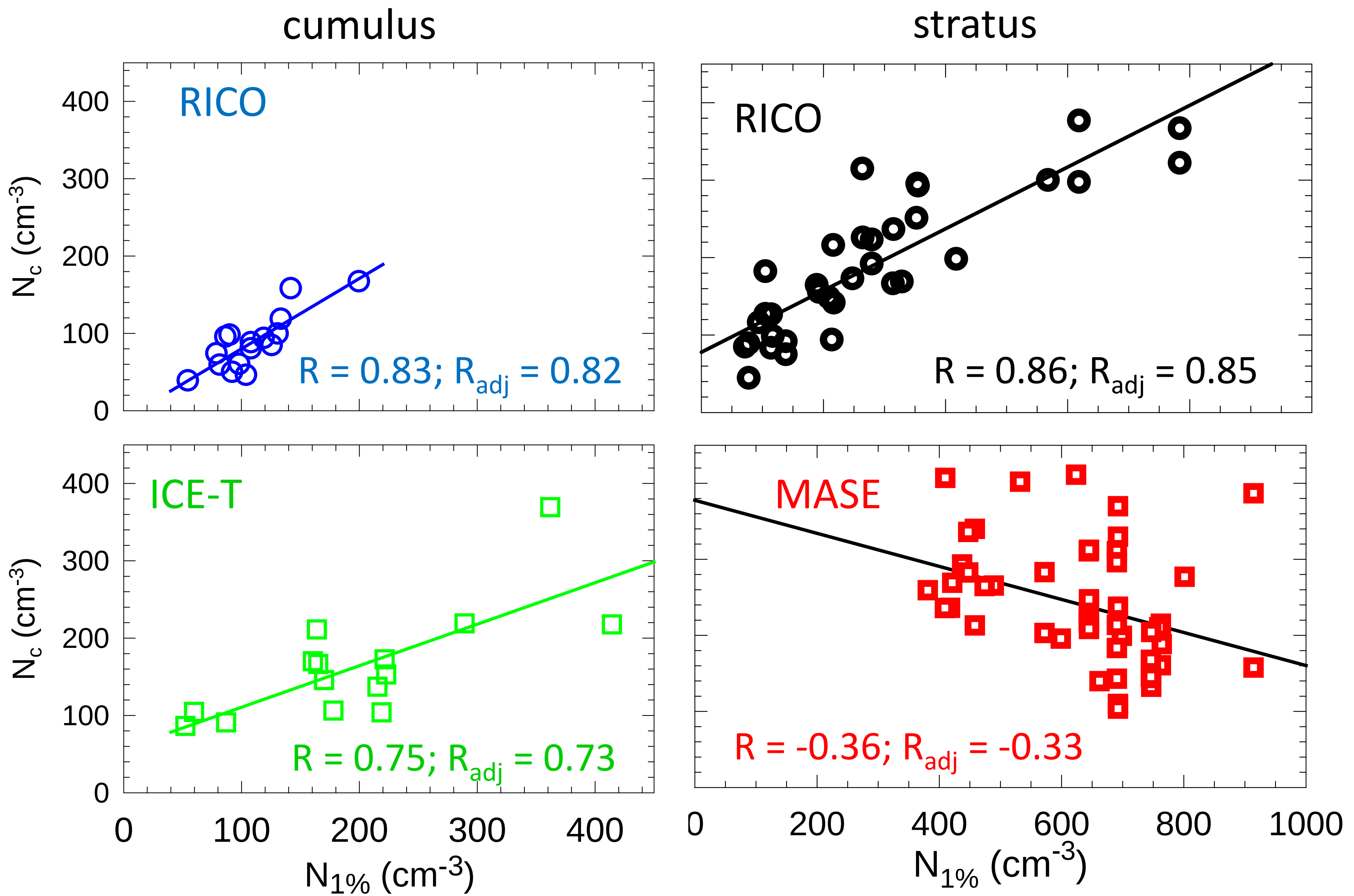
N_c is cloud droplet concentration,

W is mean vertical velocity,

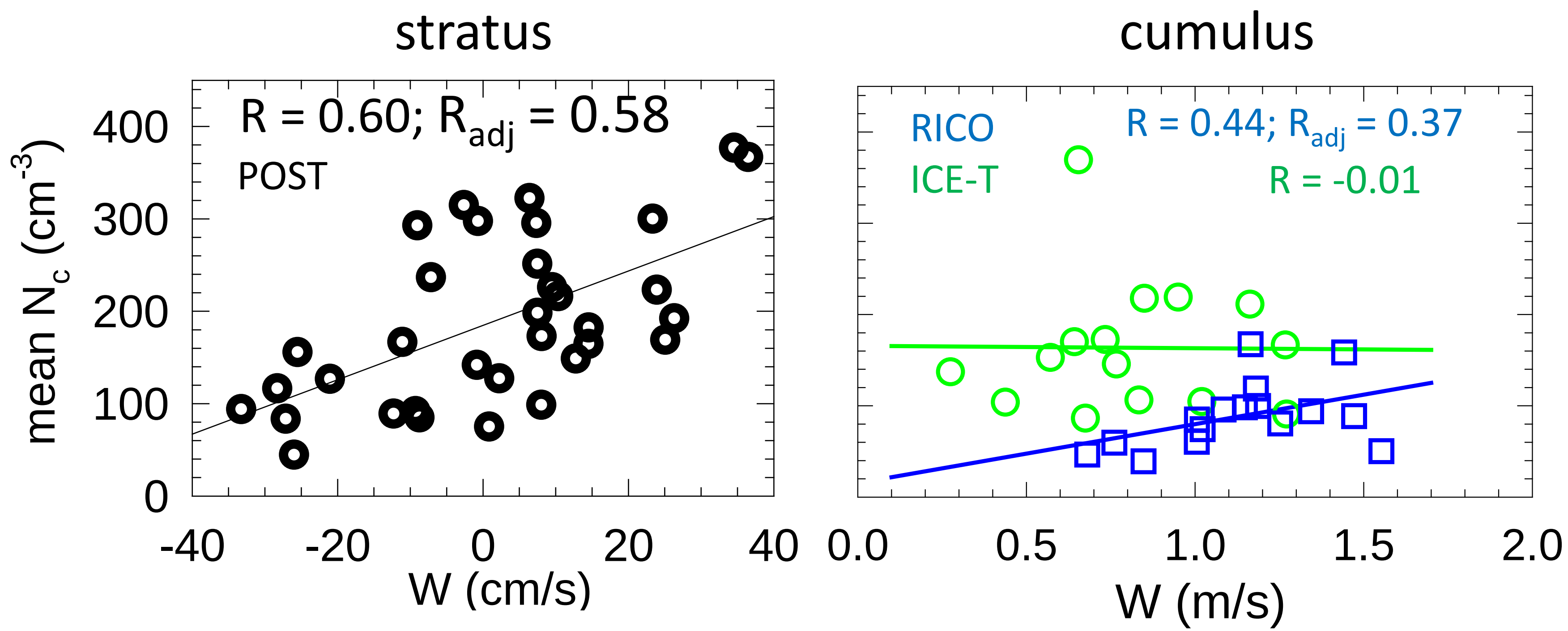
σ_w is standard deviation of W (W_{sd}),

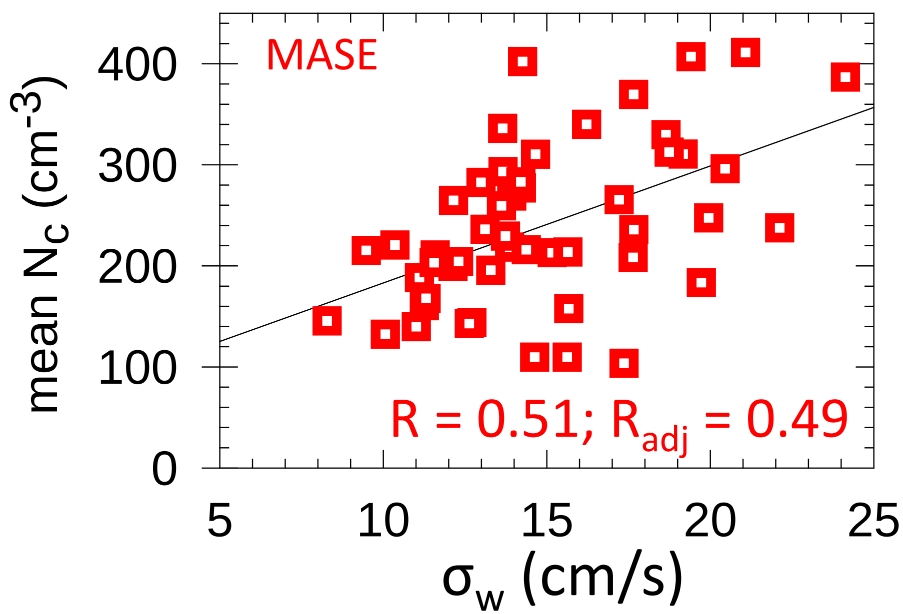
S_{eff} is mean effective supersaturation of the clouds as determined by the S for which CCN concentration, $N_{CCN}(S)$ equaled N_c.

k is the log-log slope of cumulative CCN spectrum at S_{eff}



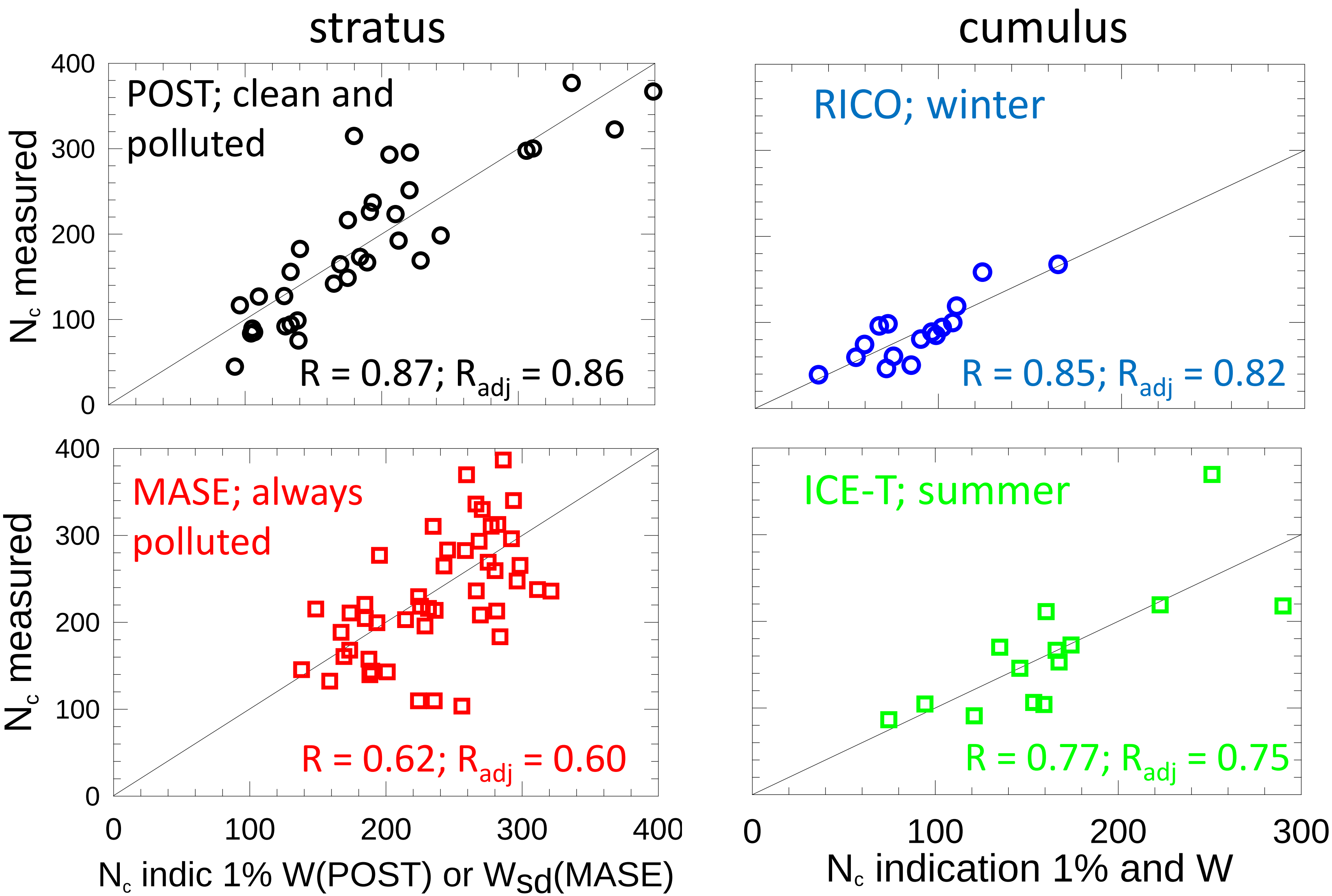
Single regressions between low altitude flight-averaged droplet concentrations (N_c) and below cloud CCN concentrations at 1% supersaturation ($N_{1\%}$)

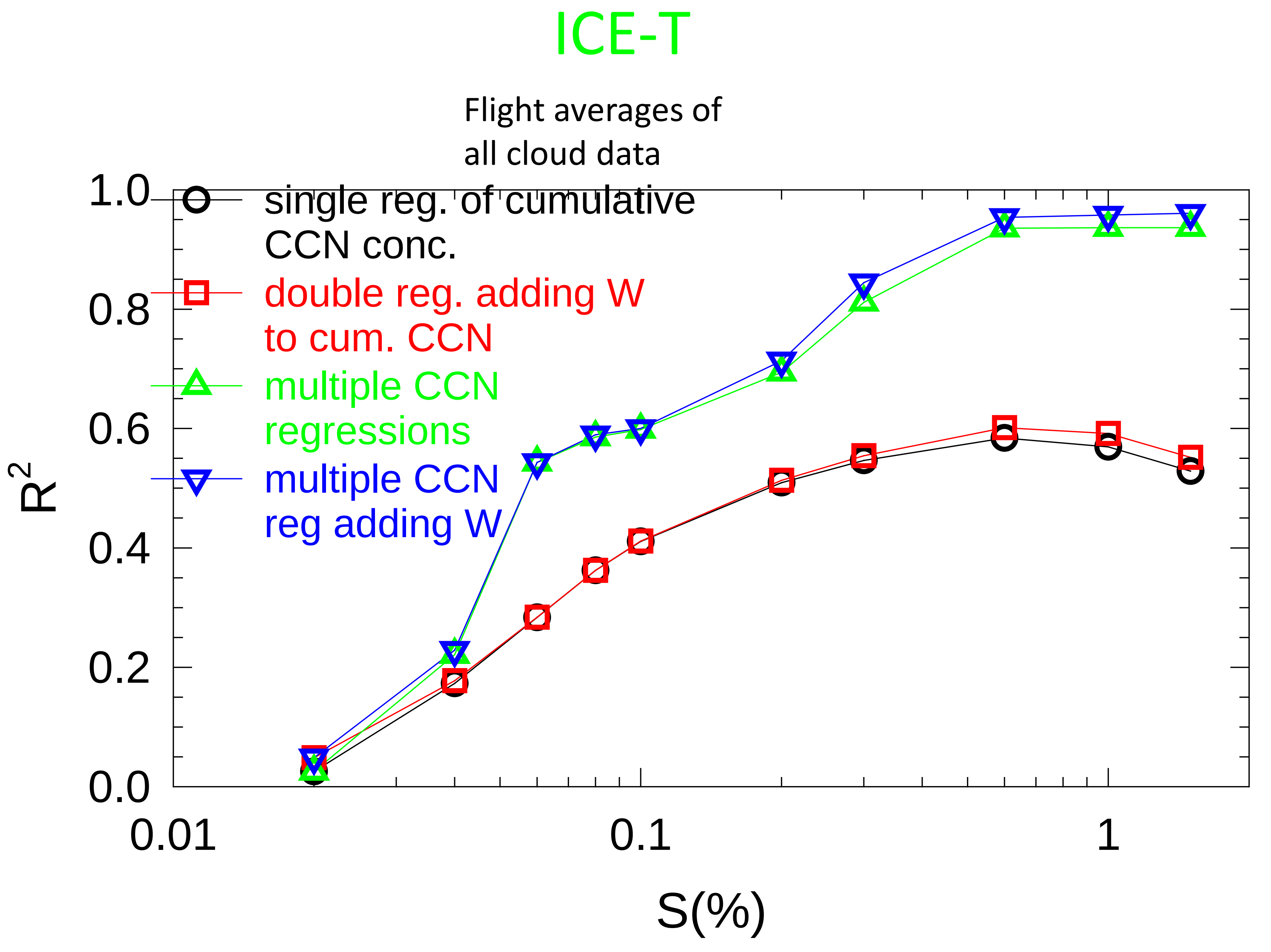




Regressions of flight-averaged droplet concentrations (N_c) against in-cloud vertical velocity (W) or standard deviation of W (σ_w).

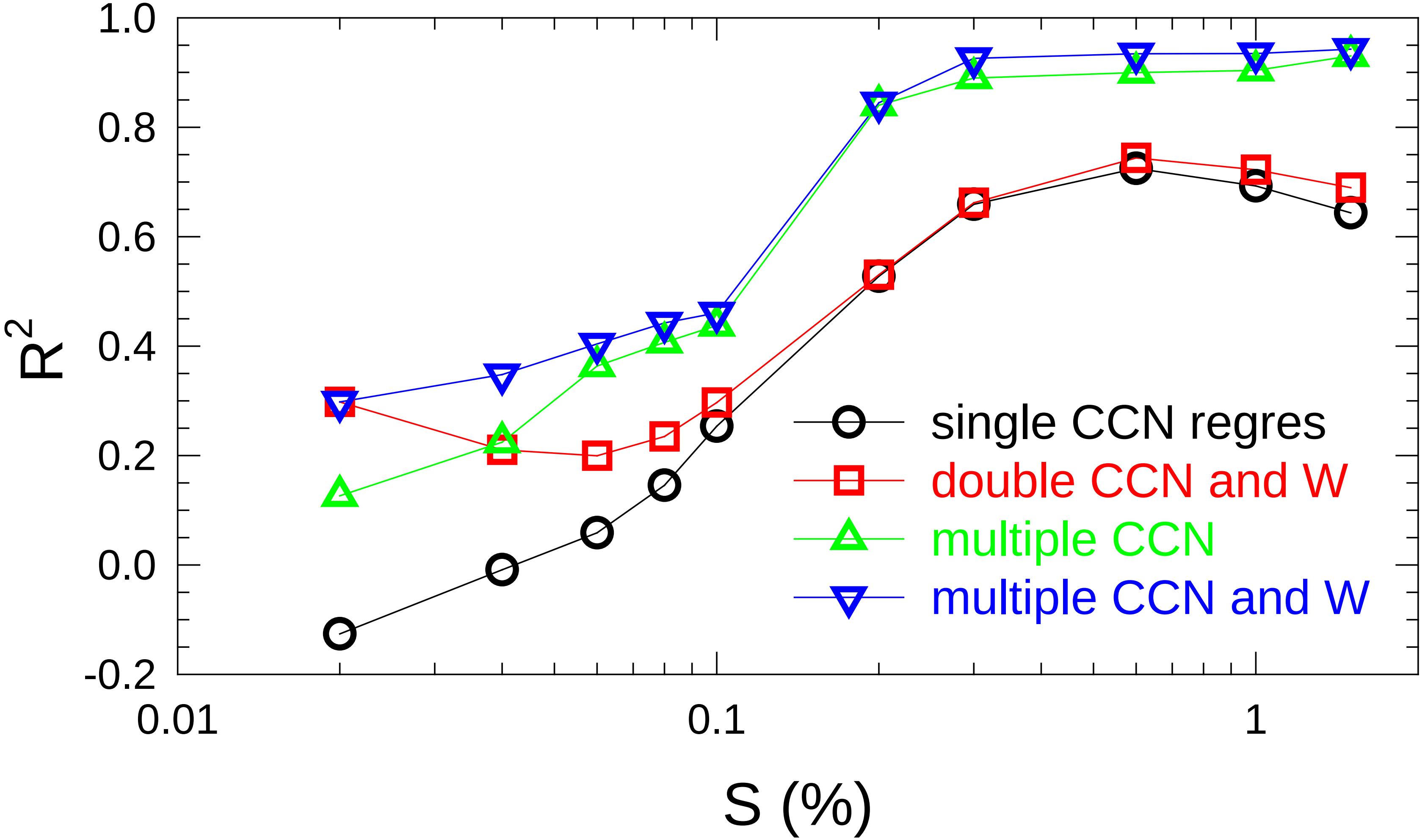
Double regressions of droplet concentrations (N_c) (cm^{-3}) from CCN at 1% S and W



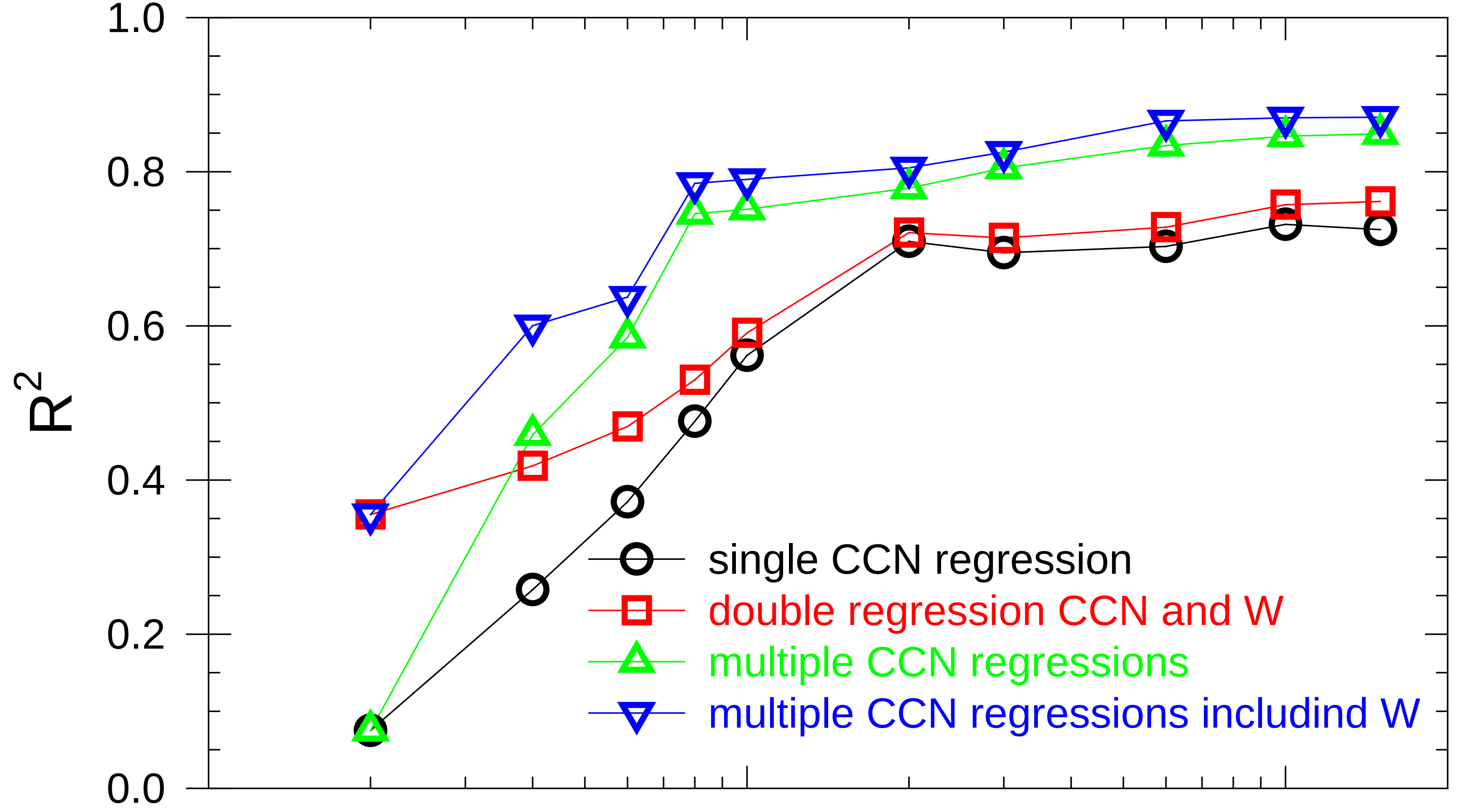

ICE-T
Flight averages of
all cloud data
single reg. of cumulative
CCN conc.
double reg. adding W
to cum. CCN
multiple CCN
regressions
multiple CCN
reg adding W
1.0
0.8
0.6
0.4
0.2
0.0
R^2
0.01
0.1
1
S(%)

RICO

Flight averages of
all cloud data

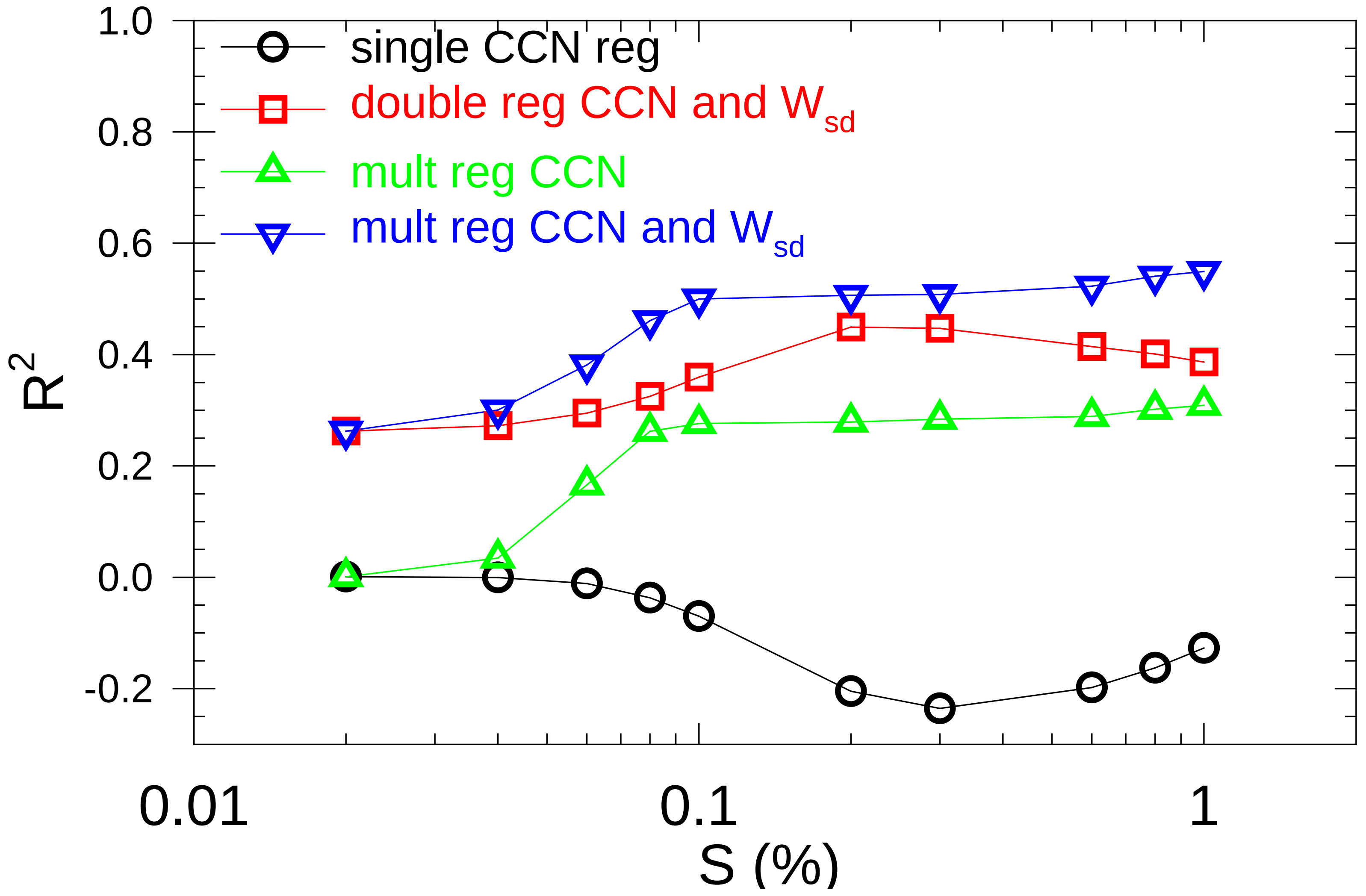


POST



1.0
0.8
0.6
0.4
0.2
0.0
R^2
single CCN regression
double regression CCN and W
multiple CCN regressions
multiple CCN regressions includind W

MASE



single CCN reg
double reg CCN and W_{sd}
mult reg CCN
mult reg CCN and W_{sd}
R^2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0.01
0.1
1
S (%)

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

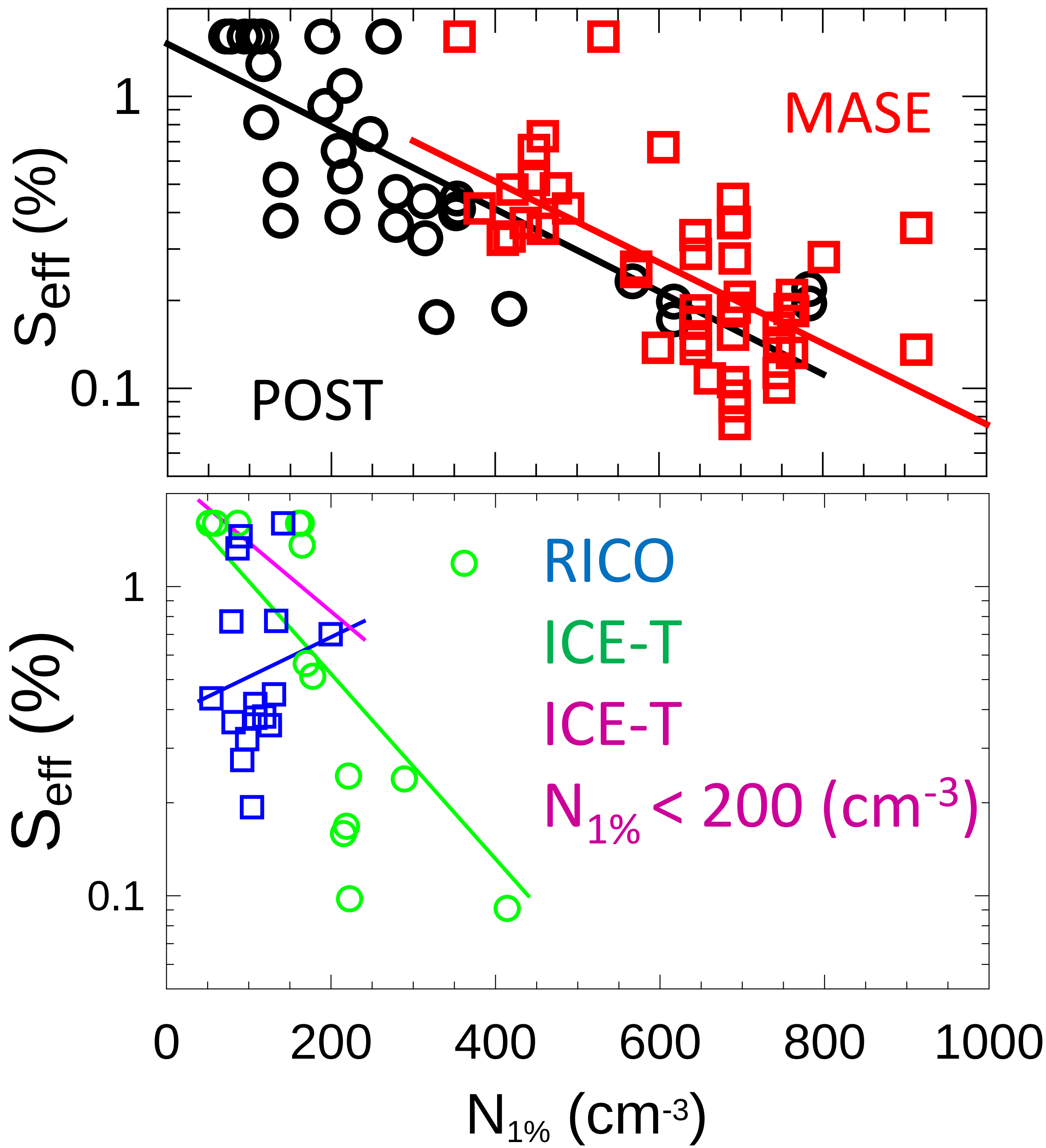
$$R^2_{adj} = 1 - (1-R^2)(n-1)/(n-p-1)$$

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. This is especially true when the input parameters are uncorrelated with each other as would be the case for junk data. Input parameters that are correlated with each other provide less improvement to R^2.

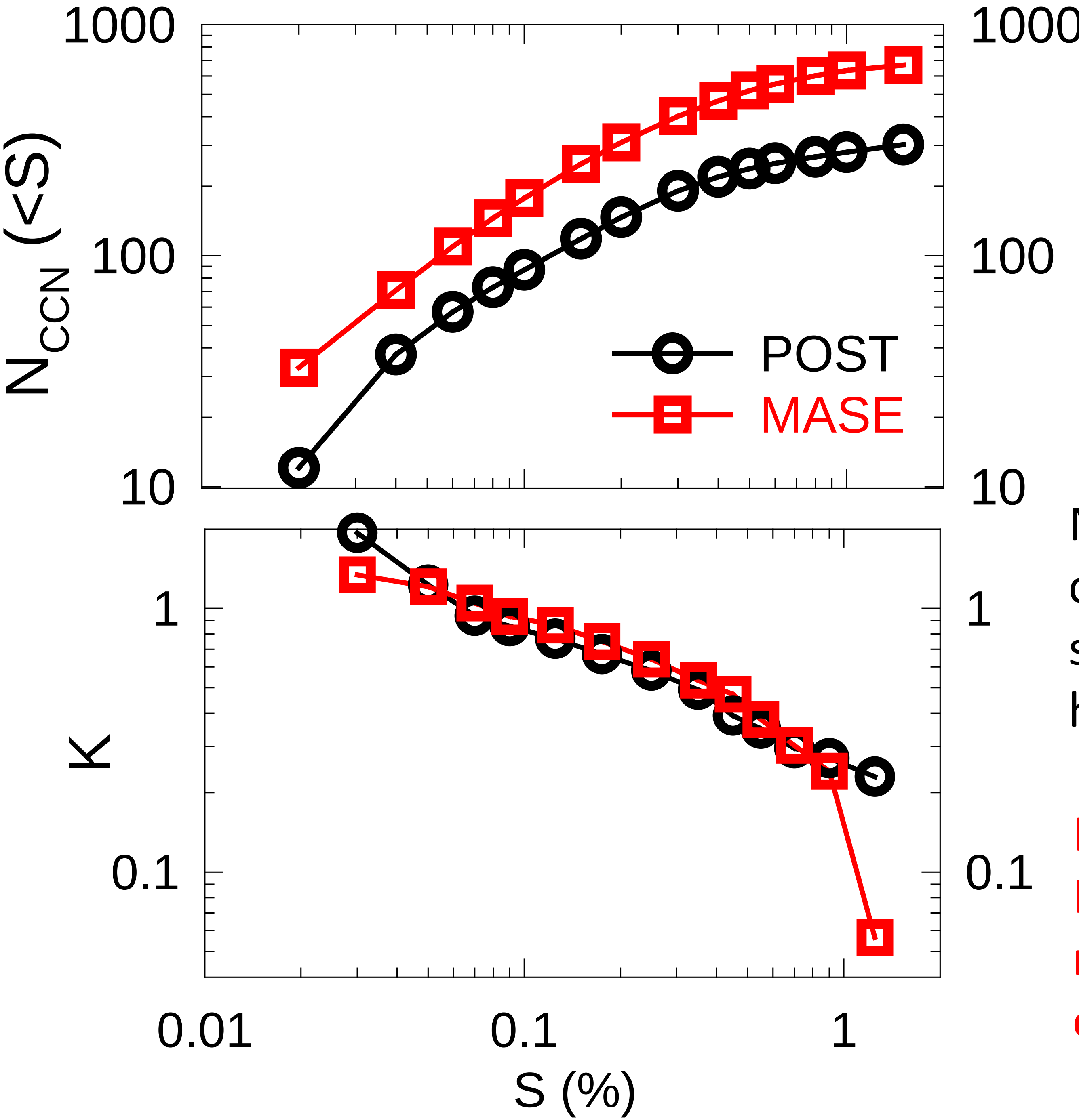
Flight averages of all cloud parcels

proj	R $N_{1\%}$-N_c	R_{adj} $N_{1\%}$-N_c	R W-N_c	R_{adj} W-N_c	R_{adj} W-$N_{1\%}$	R [$N_{1\%}$,W]-N_c	R_{adj} [$N_{1\%}$,W]-N_c	R N_{CCN}(S)-N_c	R_{adj} N_{CCN}(S)-N_c	R [N_{CCN}(S),W]-N_c	R_{adj} N_{CCN}(S),W]-N_c
POST	0.86	0.85	0.60	0.58	0.52	0.87	0.86	0.92	0.89	0.93	0.91
MASE	-0.36	-0.33	0.51	0.49	0	0.62	0.60	0.55	0.38	0.74	0.65
RICO	0.83	0.82	0.44	0.37	0.22	0.85	0.82	0.94	0.89	0.96	0.92
ICE-T	0.75	0.73	-0.01	-	-0.04	0.77	0.75	0.97	0.91	0.97	0.92



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)



Mean
cumulative
CCN spectra

Mean slope of cumulative CCN spectra, typically higher k at low S.

Lower S_{eff} of MASE makes relevant higher k of CCN spectra

N_{CCN} influence decreases with k

W influence increases with k

Higher k, steeper CCN slope,

N_c changes more for

same S differences, so W variations cause more N_c variations than N_{CCN} variations.

Low S_{eff} of MASE makes higher k more relevant.

Twomey (1959)

Summary/conclusions

In ICE-T, RICO and POST vertical velocity (W) seemed to play a minor role compared to N_{CCN} for determining N_c.

But in MASE W, actually W_{sd} (σ_w), dominated N_{CCN} for determining N_c.

Pollution suppresses cloud S thus making relevant only CCN at low S where k is higher.

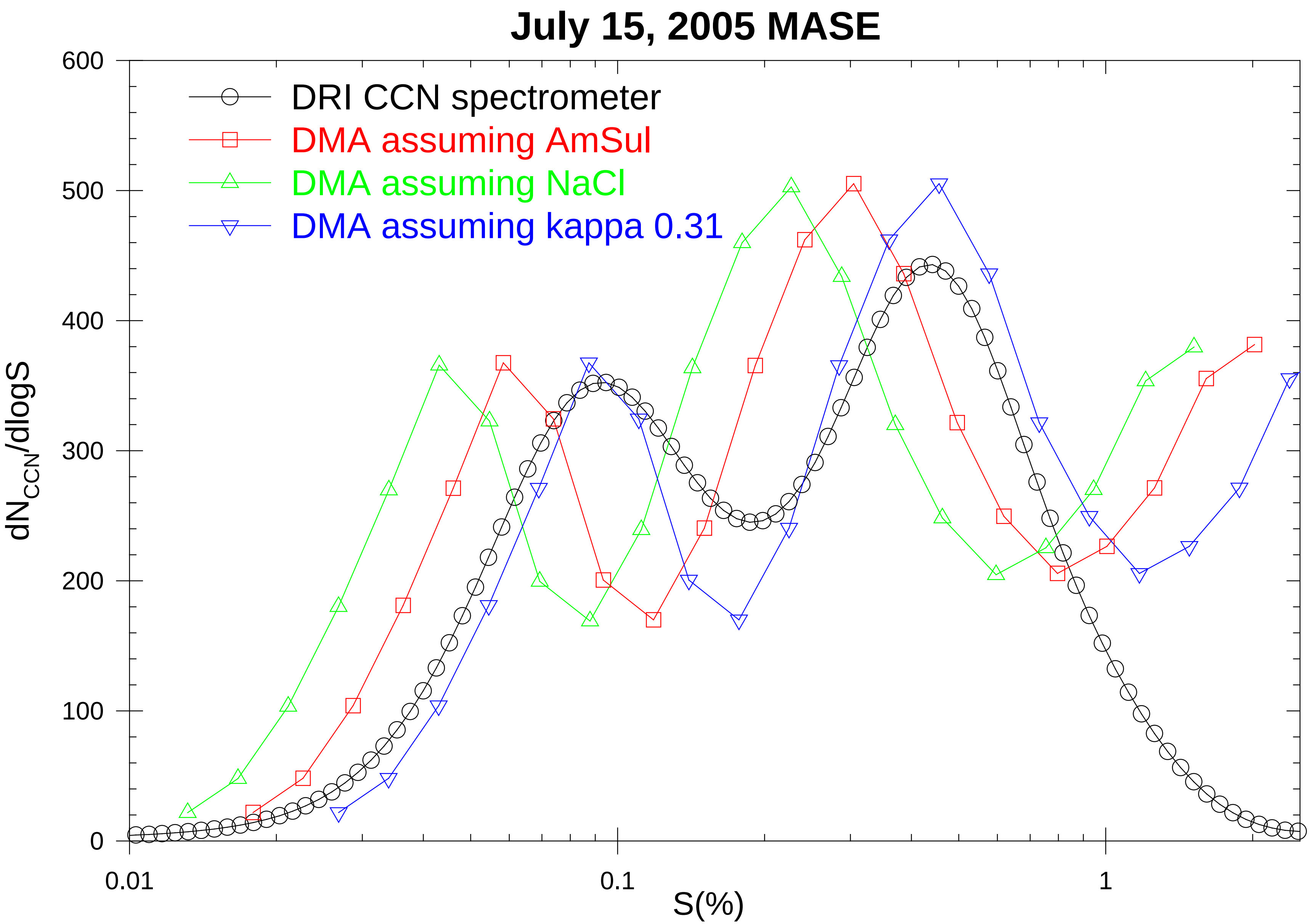
This favors W or σ_w variations over N_{CCN} variations for determining N_c. Thus, the negative or noncorrelation of N_c with N_{CCN} in MASE is resolved. This limits IAE.

For multiple CCN regressions, addition of W made little difference.

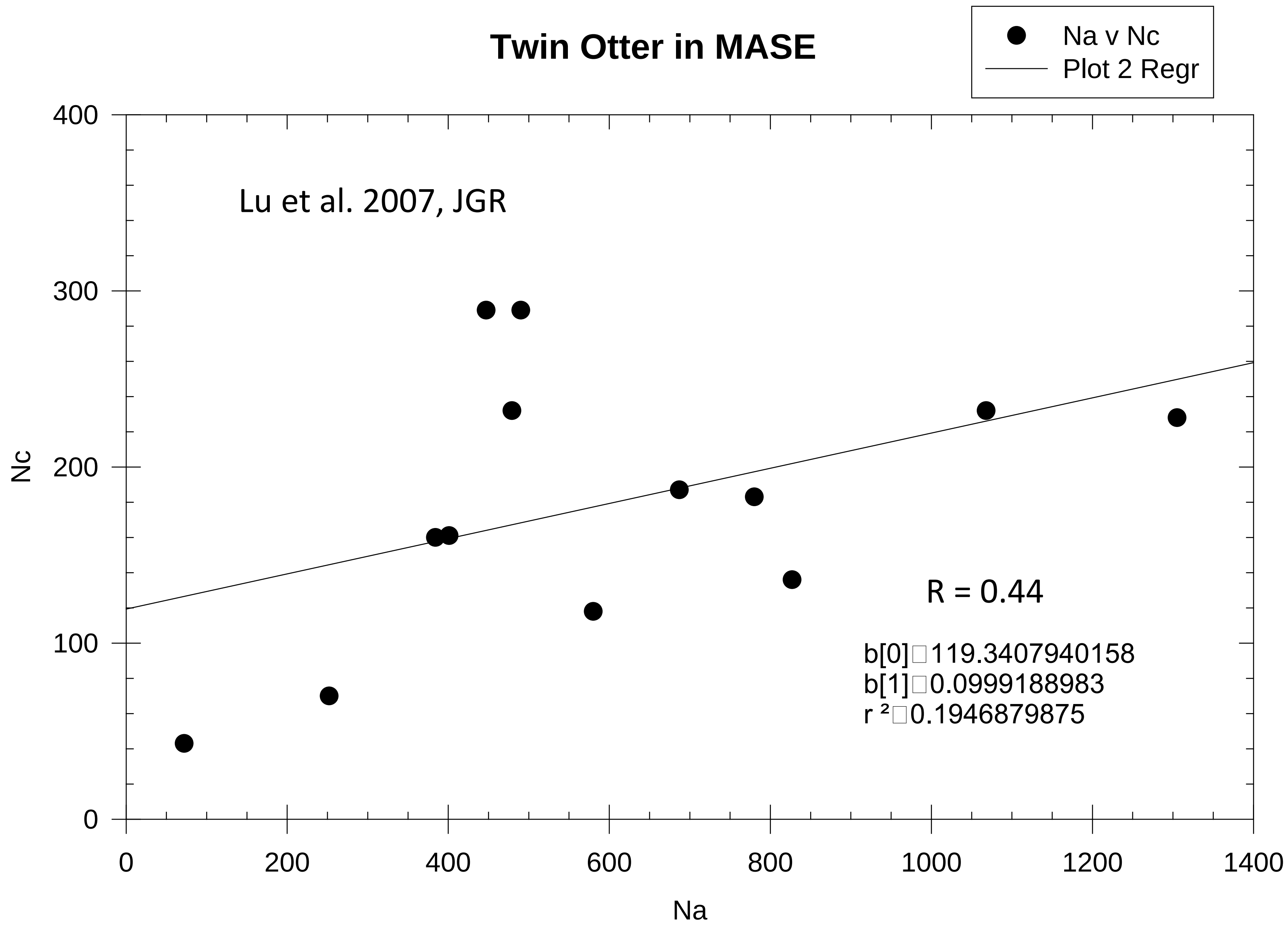
Multiple regressions using entire CCN spectra showed superior regressions even when adjusted.

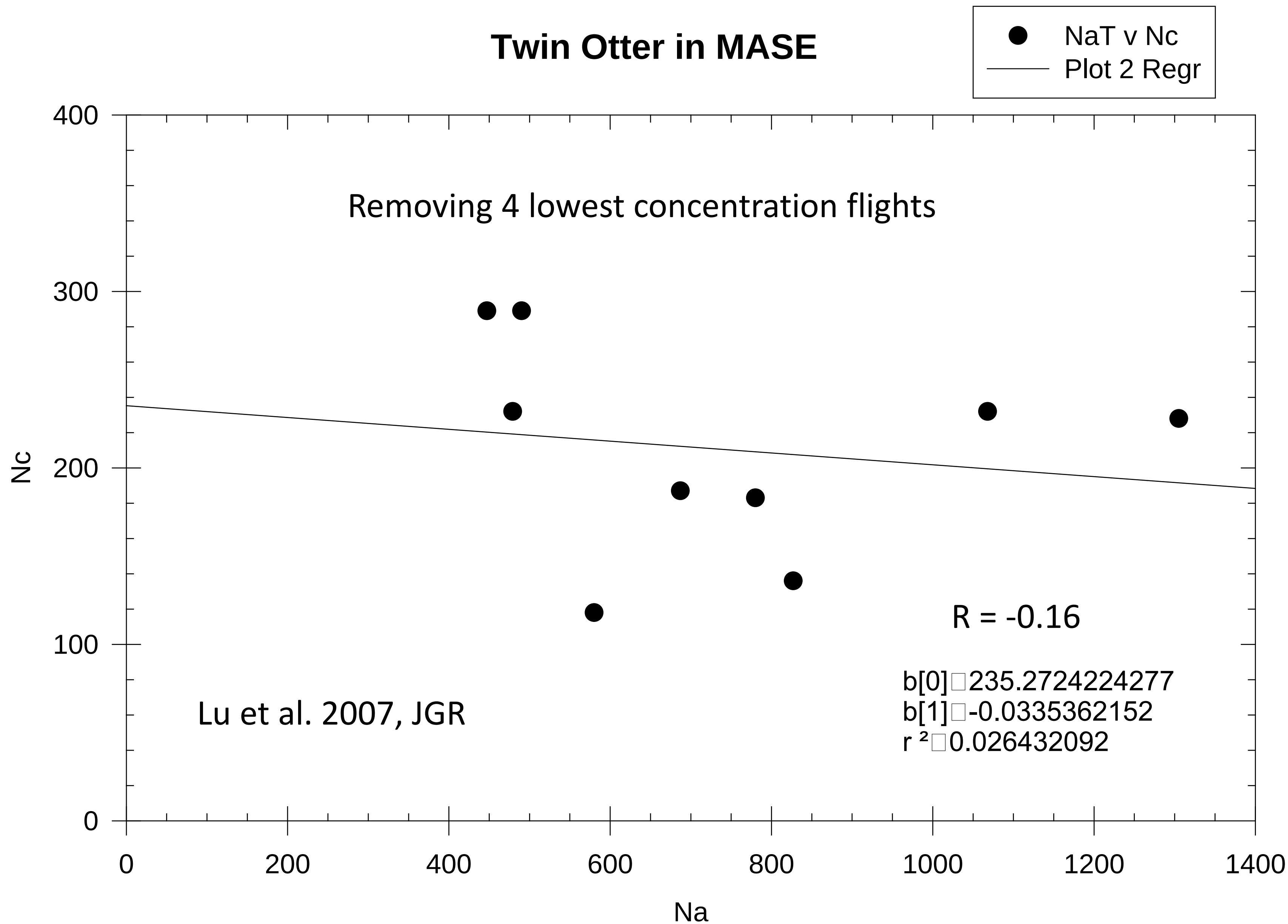
Hudson and Noble, 2013: CCN and vertical velocity influences on droplet concentrations and supersaturations in clean and polluted stratus clouds. JAS, in press.

Hudson and Noble, 2013: Low Altitude Summer/Winter Microphysics, Dynamics and CCN Spectra of Northeastern Caribbean Small Cumuli; and Comparisons with Stratus. Submitted to JGR in October.



July 15, 2005 MASE
DRI CCN spectrometer
DMA assuming AmSul
DMA assuming NaCl
DMA assuming kappa 0.31
dN_CCN/dlogS
S(%)
0
100
200
300
400
500
600
0.01
0.1
1


Twin Otter in MASE
Na v Nc
Plot 2 Regr
Lu et al. 2007, JGR
R = 0.44
b[0]□119.3407940158
b[1]□0.0999188983
r ²□0.1946879875
Nc
Na
0
100
200
300
400
0
200
400
600
800
1000
1200
1400



Twin Otter in MASE
NaT v Nc
Plot 2 Regr
Removing 4 lowest concentration flights
R = -0.16
b[0]□235.2724224277
b[1]□-0.0335362152
r ²□0.026432092
Lu et al. 2007, JGR
Nc
Na
400
300
200
100
0
0
200
400
600
800
1000
1200
1400