CCN, Vertical Velocity and Microphysics Measurements in Stratus

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Marine Stratus/Stratocumulus Experiment (MASE)
July, 2005
DOE
G-1

Physics of Stratocumulus Tops (POST)
July-August, 2008
NSF
CIRPAS Twin Otter

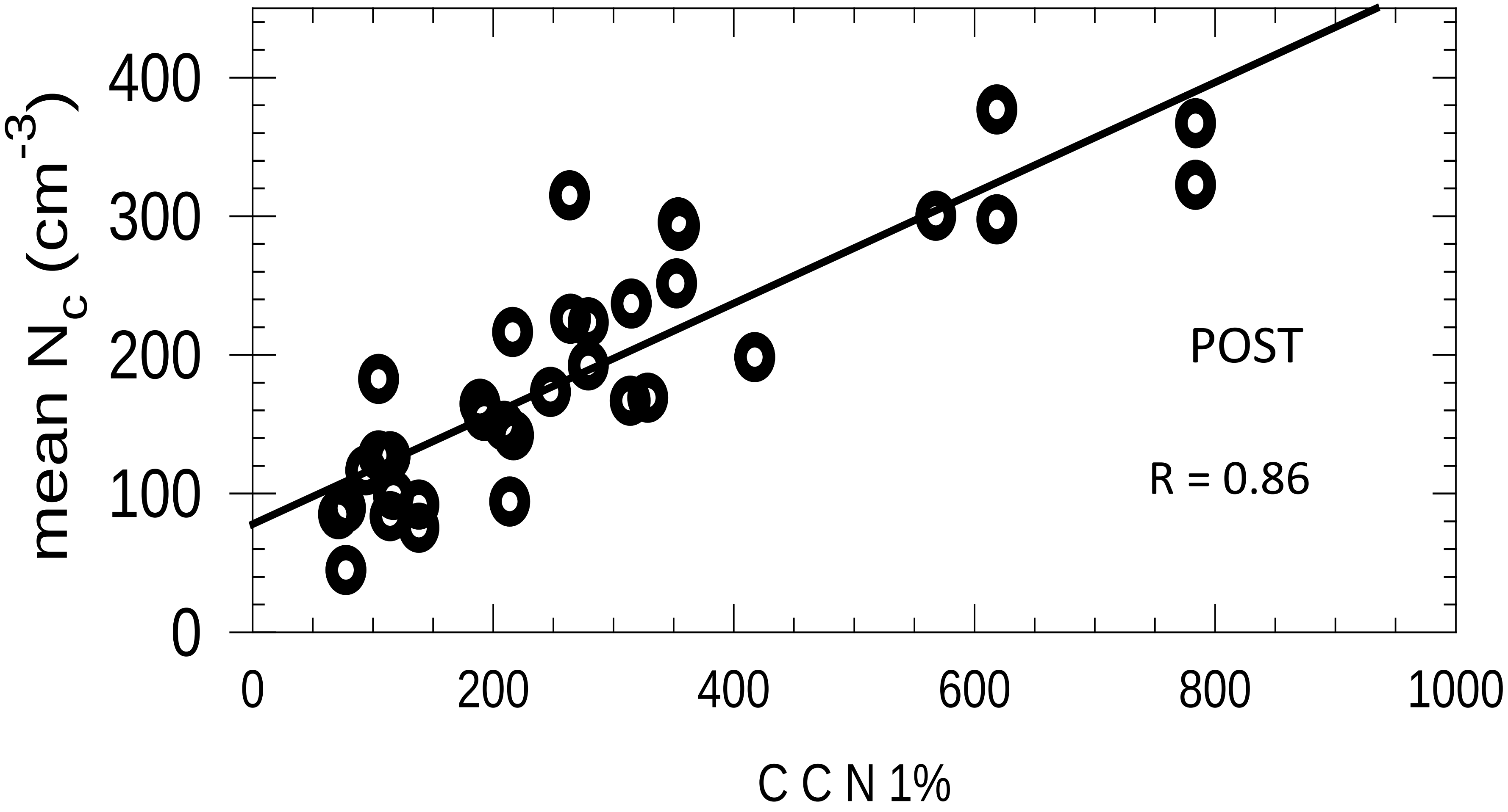
Same location off central California coast
off Monterey

MASE—always polluted
POST– clean to polluted and intermediate conditiions

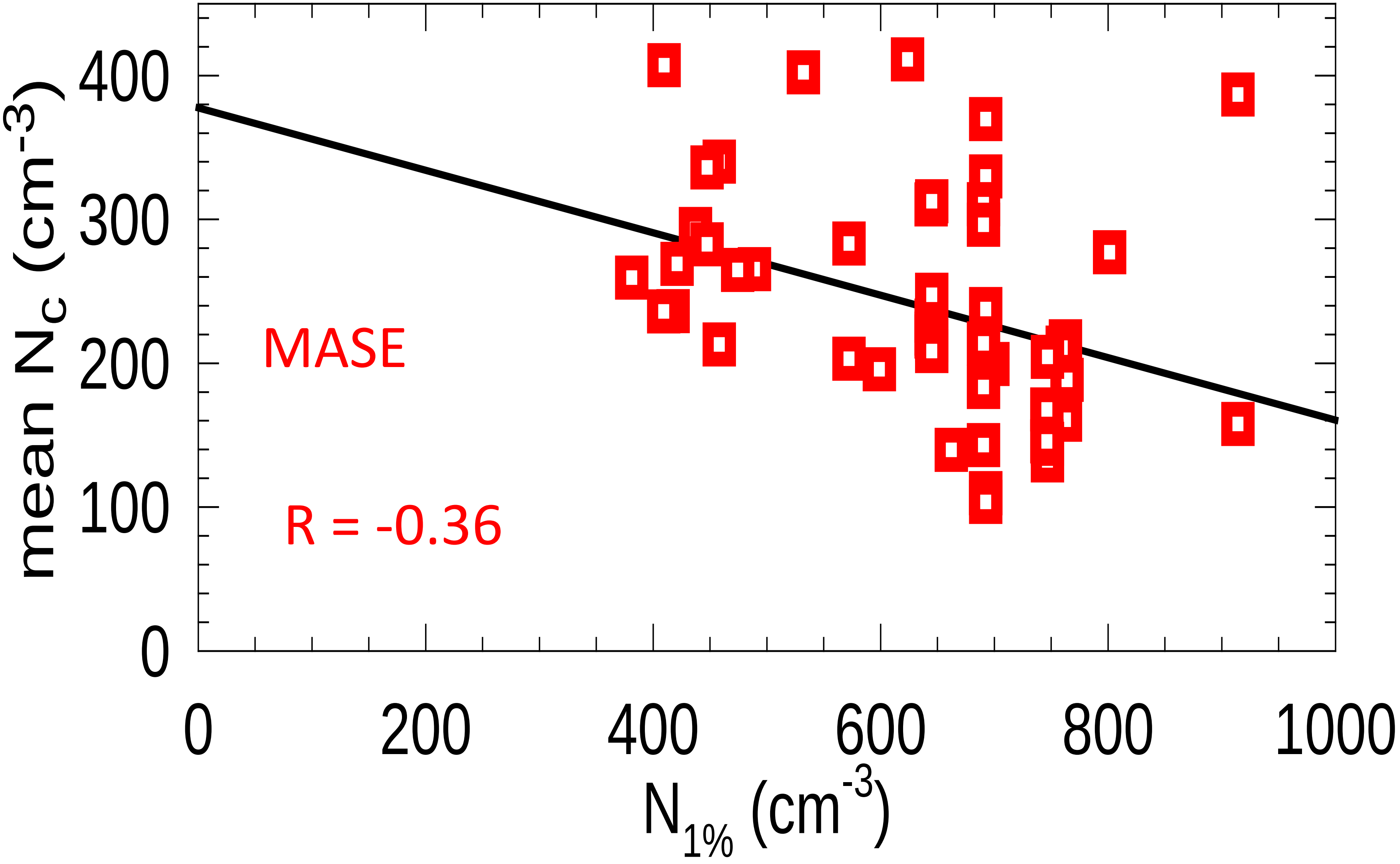
Measurements in two California stratus projects MASE and POST indicate that vertical velocity (W) or the variation of W (σ_w) becomes more important for determining droplet concentrations (N_c) at higher CCN concentrations (N_{CCN}) and higher N_c. In the polluted clouds of MASE σ_w completely dominates N_{CCN} in determining N_c and other cloud microphysical parameters. In POST there is a coupling between W and N_{CCN} that may be a result of differential latent heat exchange.

proj	flts	clouds	cb (m)	$N_{1\%}$ Mean (cm^{-3})	$N_{1\%}$ min (cm^{-3})	$N_{1\%}$ max (cm^{-3})	N_c Mean (cm^{-3})	N_c min (cm^{-3})	N_c max (cm^{-3})	$N_c/N_{1\%}$ active. ratio	k @ N_c
POST	15	34	209	268	72	784	190	45	377	0.79	0.52
MASE	9	50	< 100	597	356	914	240	104	411	0.41	0.82

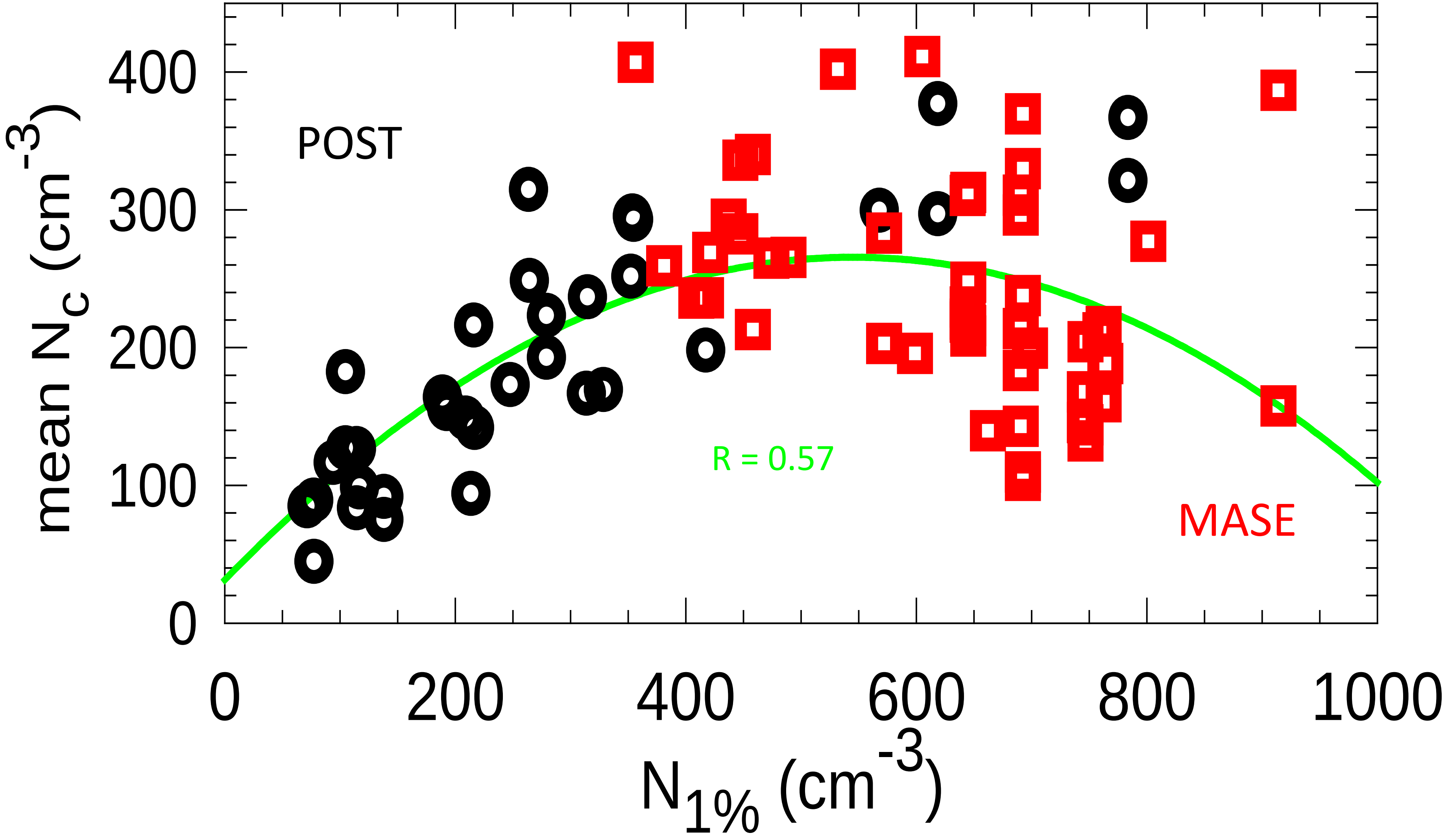
Table 1. Project, number of flights, number of clouds, mean CCN concentrations at 1% S ($N_{1\%}$), minimum $N_{1\%}$, maximum $N_{1\%}$, mean droplet concentrations (N_c), minimum N_c, maximum N_c, activation ratio, slope of CCN spectra at cloud effective supersaturation (S_{eff}).



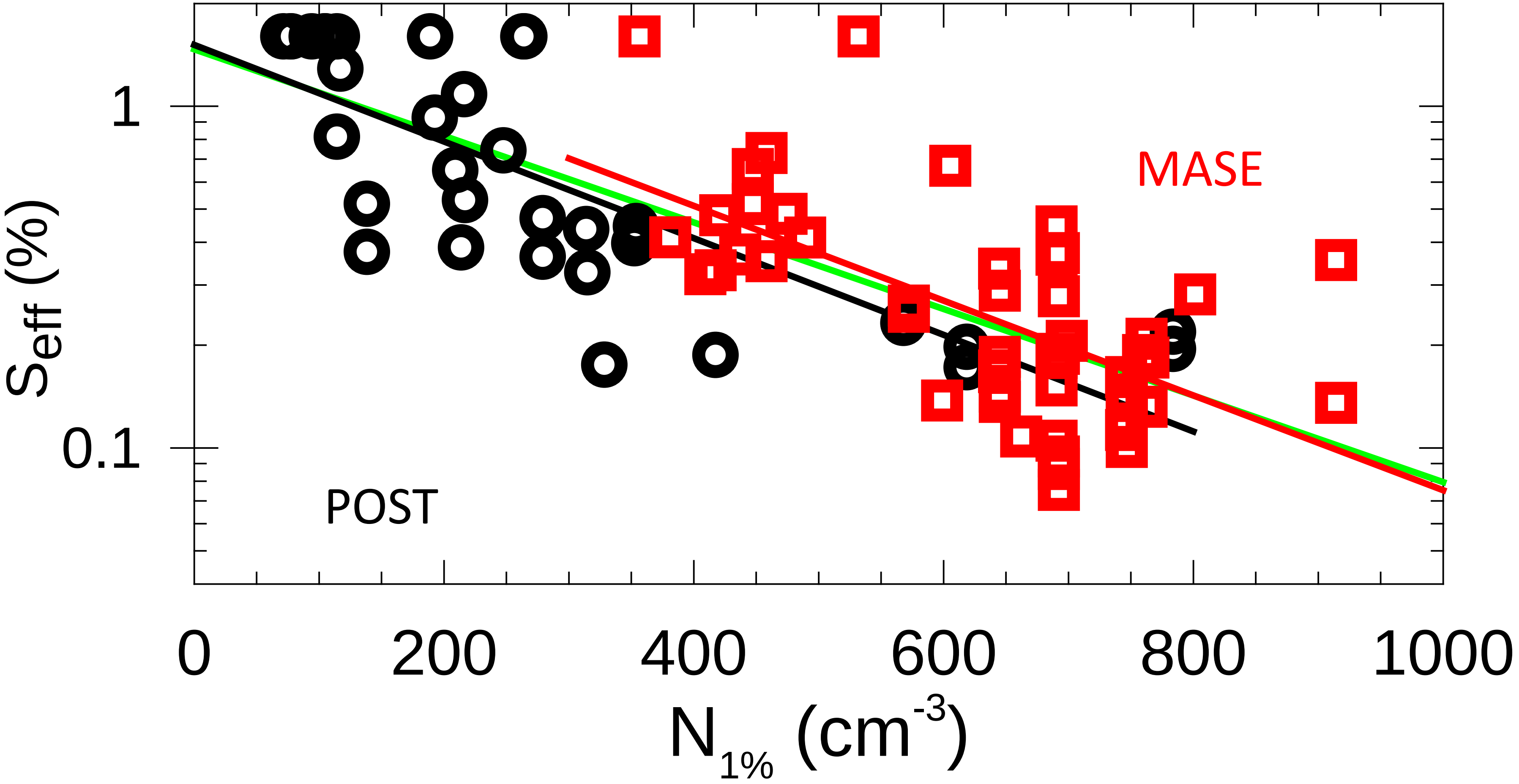
Expected positive relationship



Unexpected negative correlation



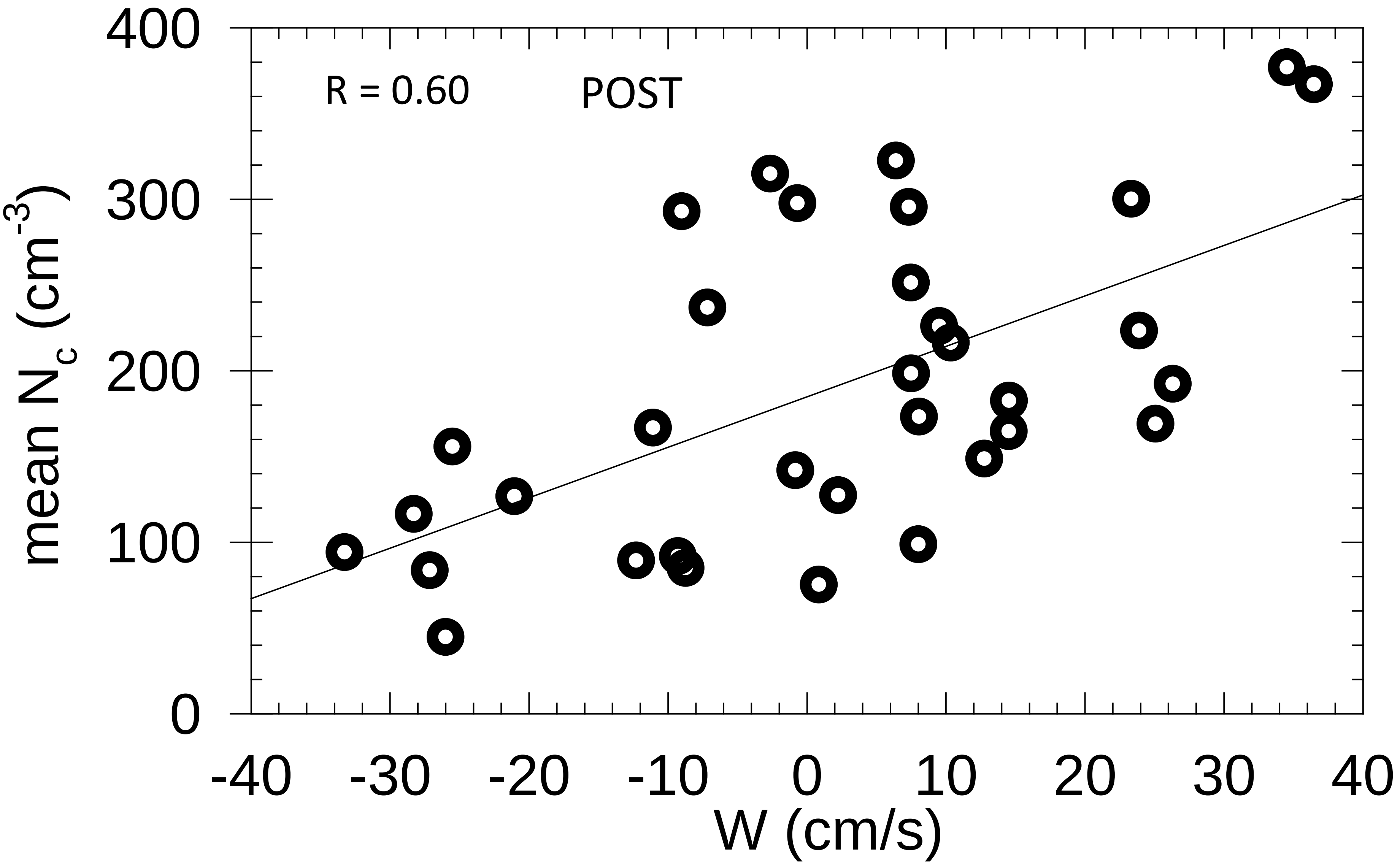
Extreme roll off



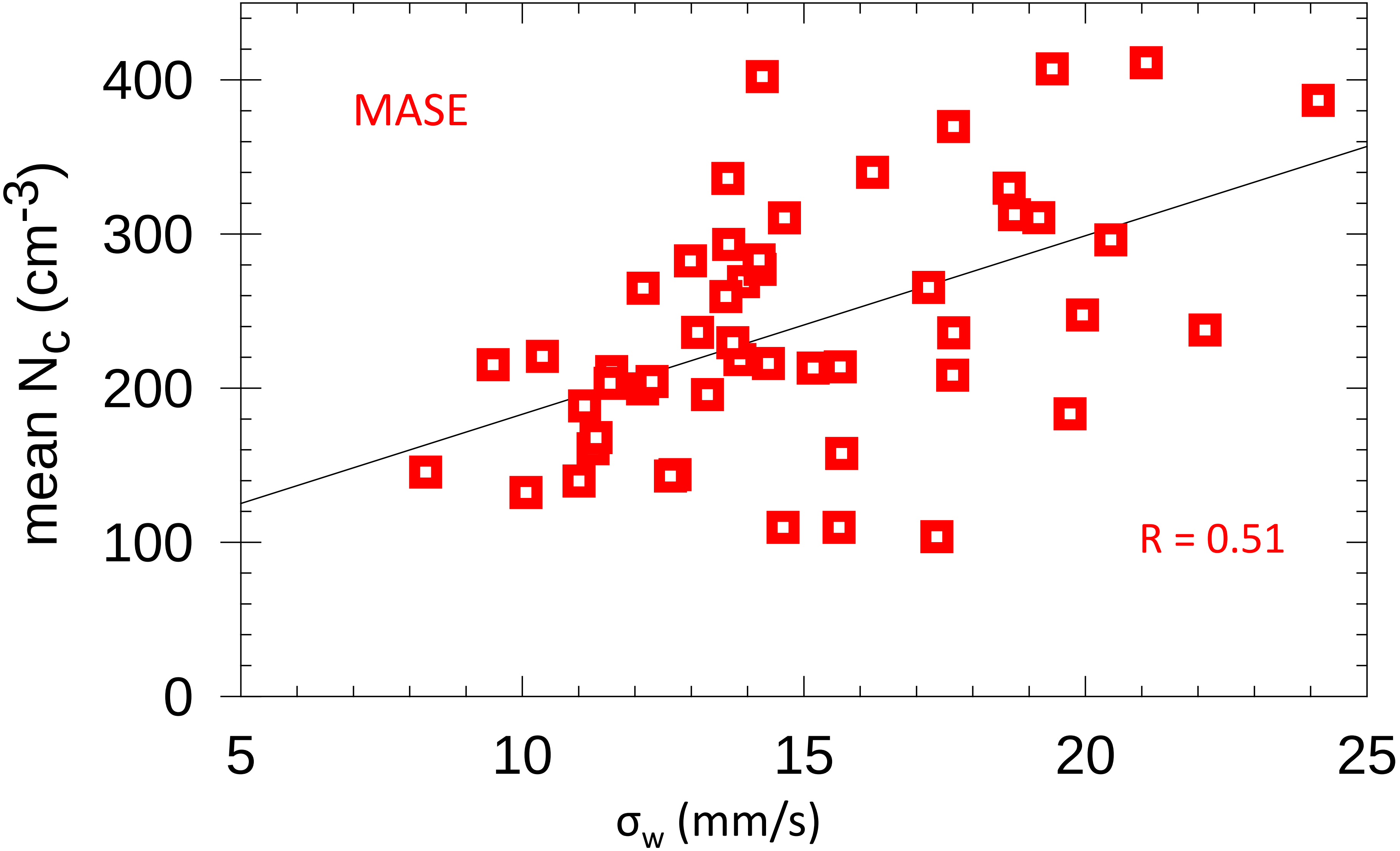
Suppression of cloud S by pollution

POST		MASE	
$N_{1\%}$ (cm^{-3})	S_{eff} (%)	$N_{1\%}$ (cm^{-3})	S_{eff} (%)
< 200	1.286		
200-400	0.641	< 500	0.429
> 400	0.200	500-700	0.178
		> 700	0.160

Table 2. Effective supersaturations (S_{eff}) within various $N_{1\%}$ bins for each project.

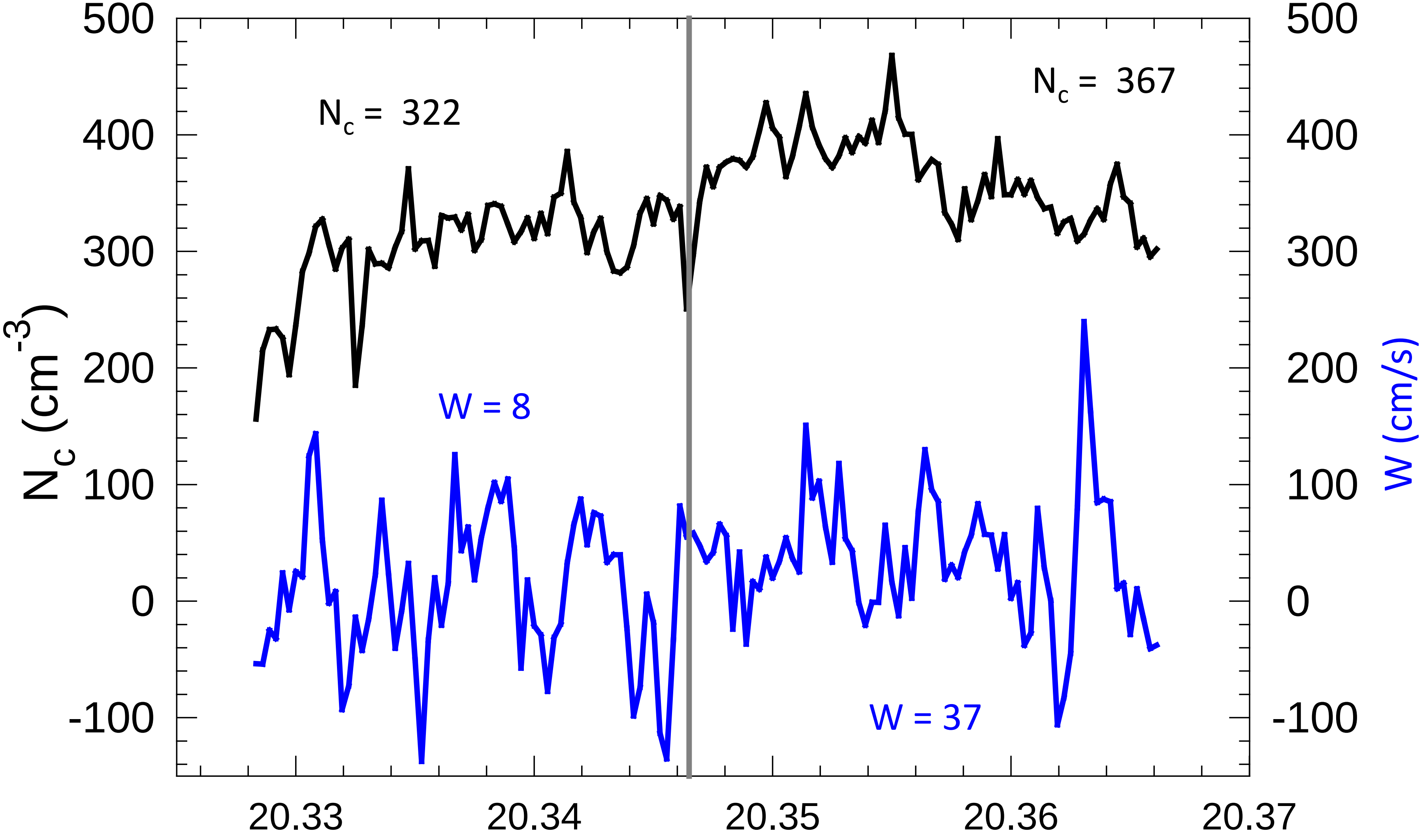


Positive but weaker vertical velocity influence

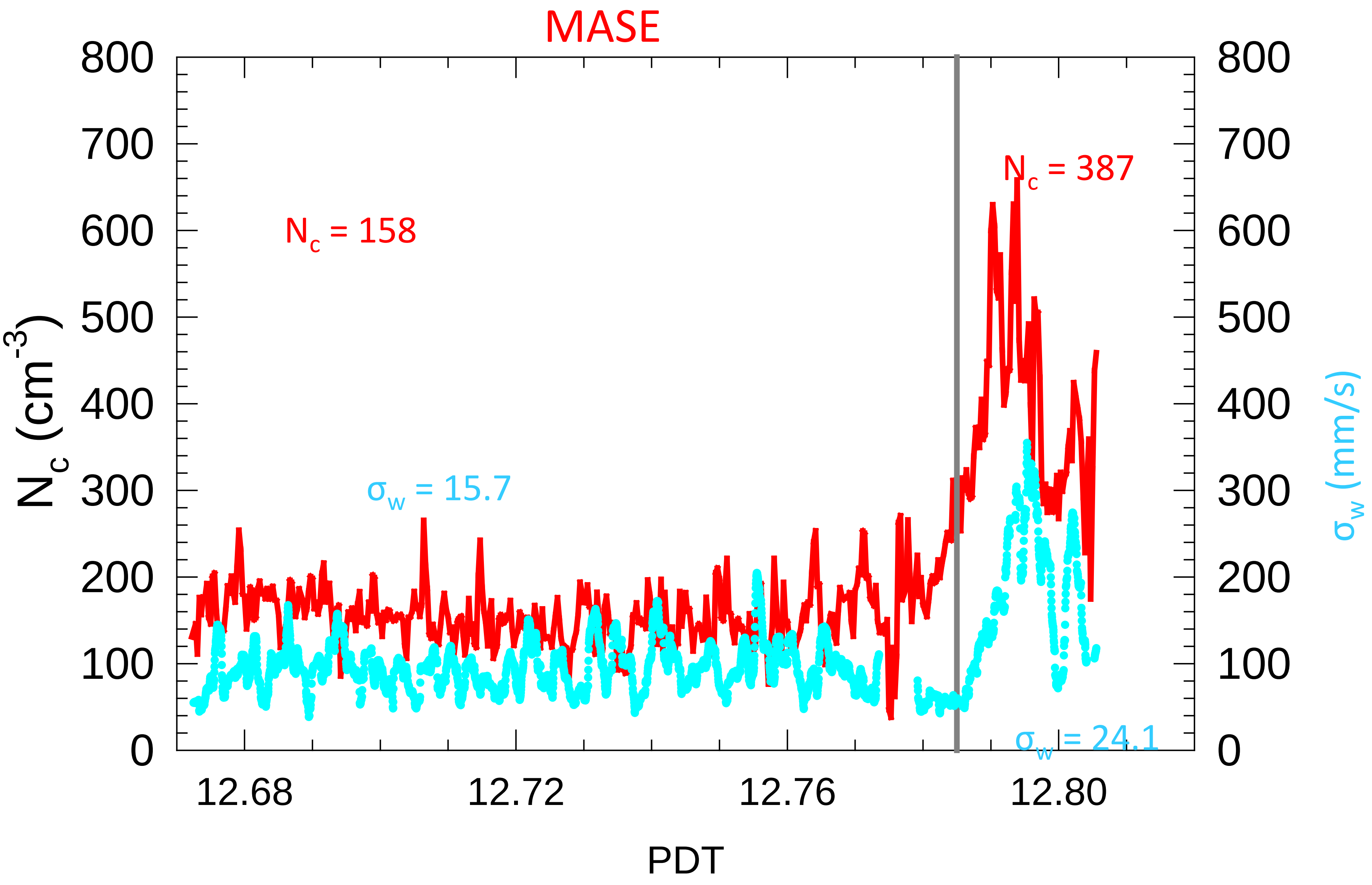


Positive vertical velocity influence

POST



Same aerosol different W, split cloud pass



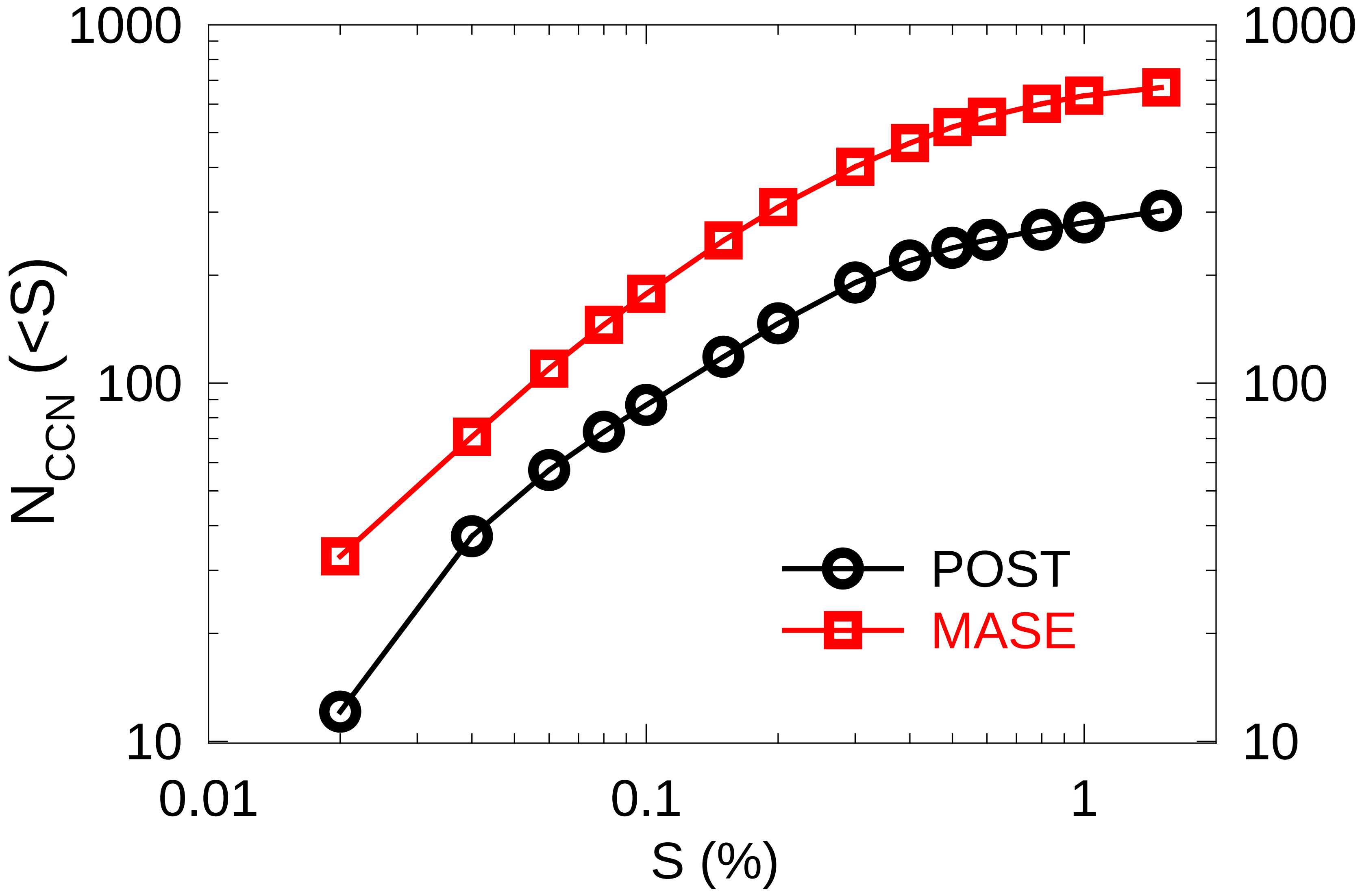
Same aerosol different W, split cloud pass

Date	HW (cm/s)	LW (cm/s)	N_{cd}H-L) (cm^{-3})
18 July	34.5	-0.7	420-343
18 July	36.5	6.4	407-352
28 July	26.3	23.9	240-223
1 Aug	0.8	-9.3	85-103
8 Aug	-21.1	-27.2	192-109
12 Aug	14.54	2.2	217-147
Mean	15.26	-0.78	260-213
Mean-x1A	18.15	0.92	295-235

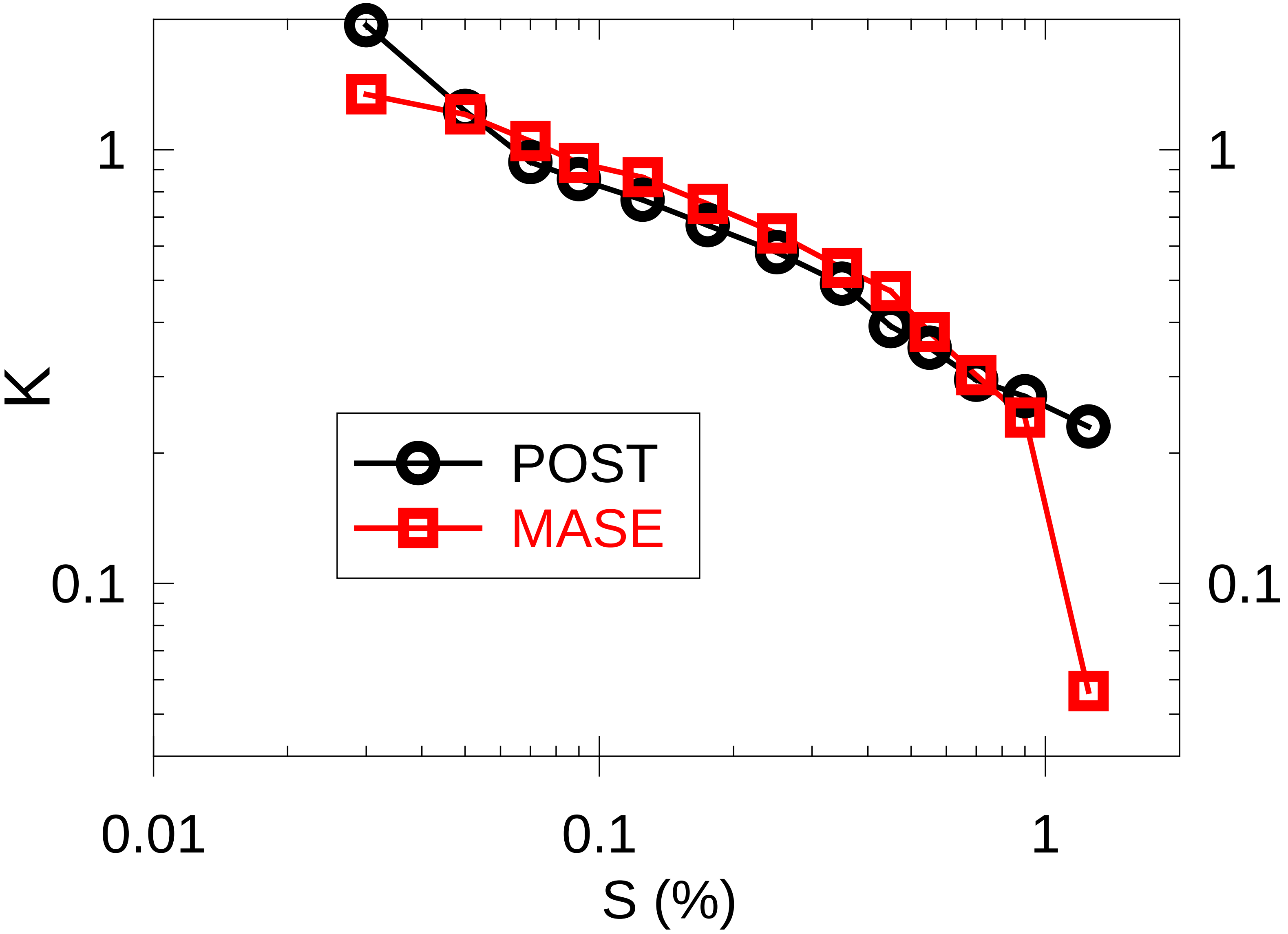
Table 3. Six pairs of POST adjacent divided cloud passes based on abrupt differences in W and N_c (Fig. 9a is an example). Column 2 is mean W of the higher W cloud portion, column 3 is W of the lower W cloud portion, column 4 is the mean N_c of the higher and lower W cloud portions.

Date	Hσ_w (cm/s)	Lσ_w (cm/s)	N_c(H-L) (cm^{-3})
15 July	16.2	15.2	414-269
18 July	24.1	15.7	573-226
19 July	17.7	14.6	596-175
19 July	18.6	15.6	524-205
19 July	22.1	17.4	413-222
19 July	12.3	10.1	388-192
19 July	11.3	8.3	294-200
20 July	15.6	12.6	268-212
20 July	14.7	13.9	388-282
20 July	18.7	17.6	382-281
22 July	13.6	13.0	400-342
22 July	14.2	11.6	344-333
Mean	16.6	13.8	415-245

Table 4. Twelve pairs of MASE adjacent divided cloud passes based on abrupt differences in σ_w and N_c (Fig. 9b is an example). Column 2 is σ_w of the higher σ_w cloud portion, column 3 is σ_w of the lower σ_w cloud portion, column 4 is the mean N_c of the higher and lower σ_w cloud portions.



Mean CCN spectra



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

$$N_c \propto N_{1\%}^{[1-(k/k+2)]}\, W^{[3k/2(k+2)]}$$

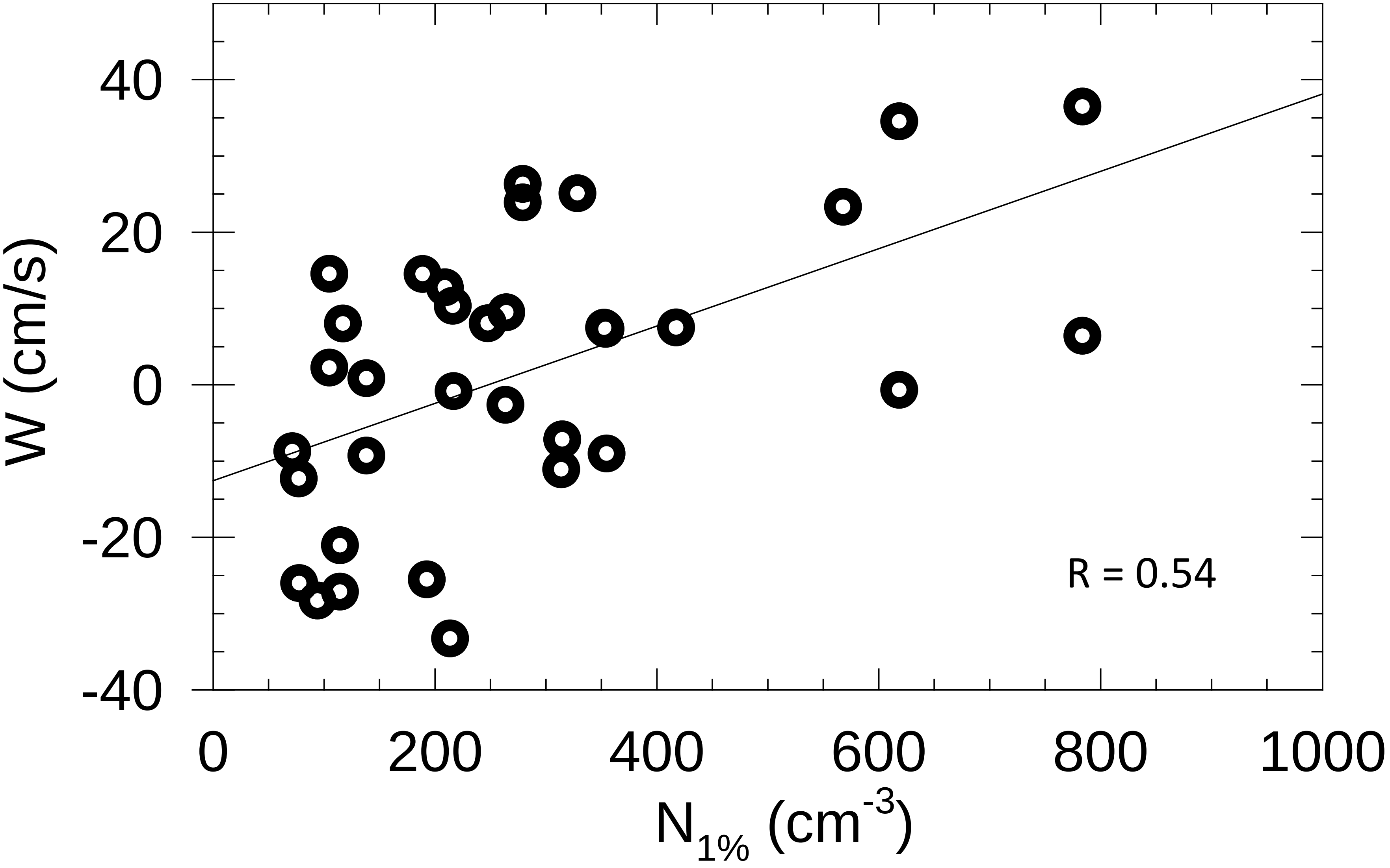
k	$N_{1\%}$	W
0.20	0.90	0.14
0.42	0.82	0.26
0.50	0.80	0.30
0.52	0.79	0.31
0.75	0.72	0.40
0.82	0.71	0.44
1.00	0.67	0.50
2.00	0.50	0.75
3.00	0.40	0.90
4.00	0.33	1.00

Table 4. Exponents of the two main factors that determine N_c by the equation of Twomey (1959).

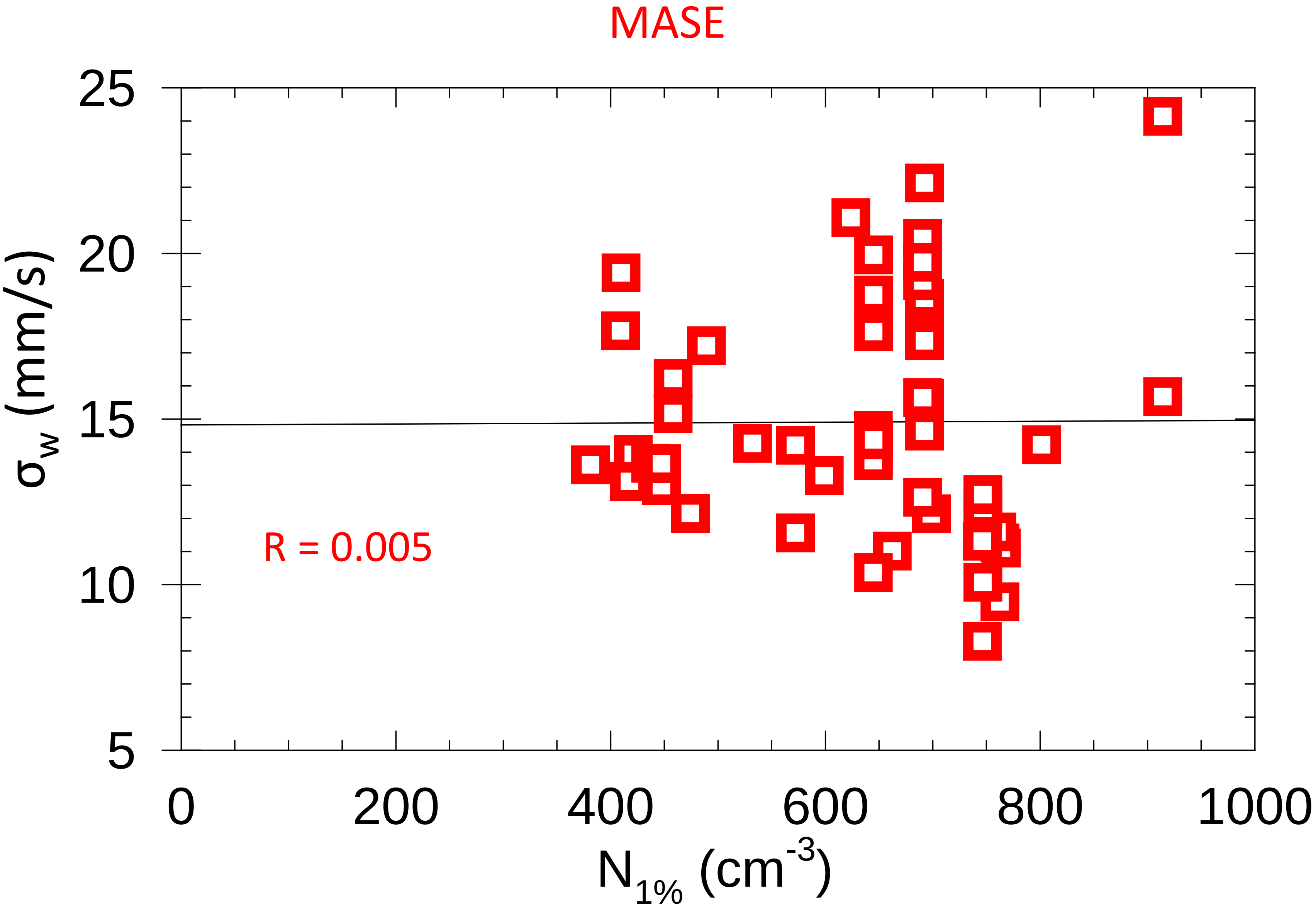
N_{CCN} influence decreases with k
W influence increases with k
Higher k, steeper slope,
N_{CCN} changes more for
same S differences, so W
variations cause more N_c
variations

Changeover from N_{CCN} to W influence happens at lower k than Twomey showed.

POST



Unexpected positive correlation



uncorrelated

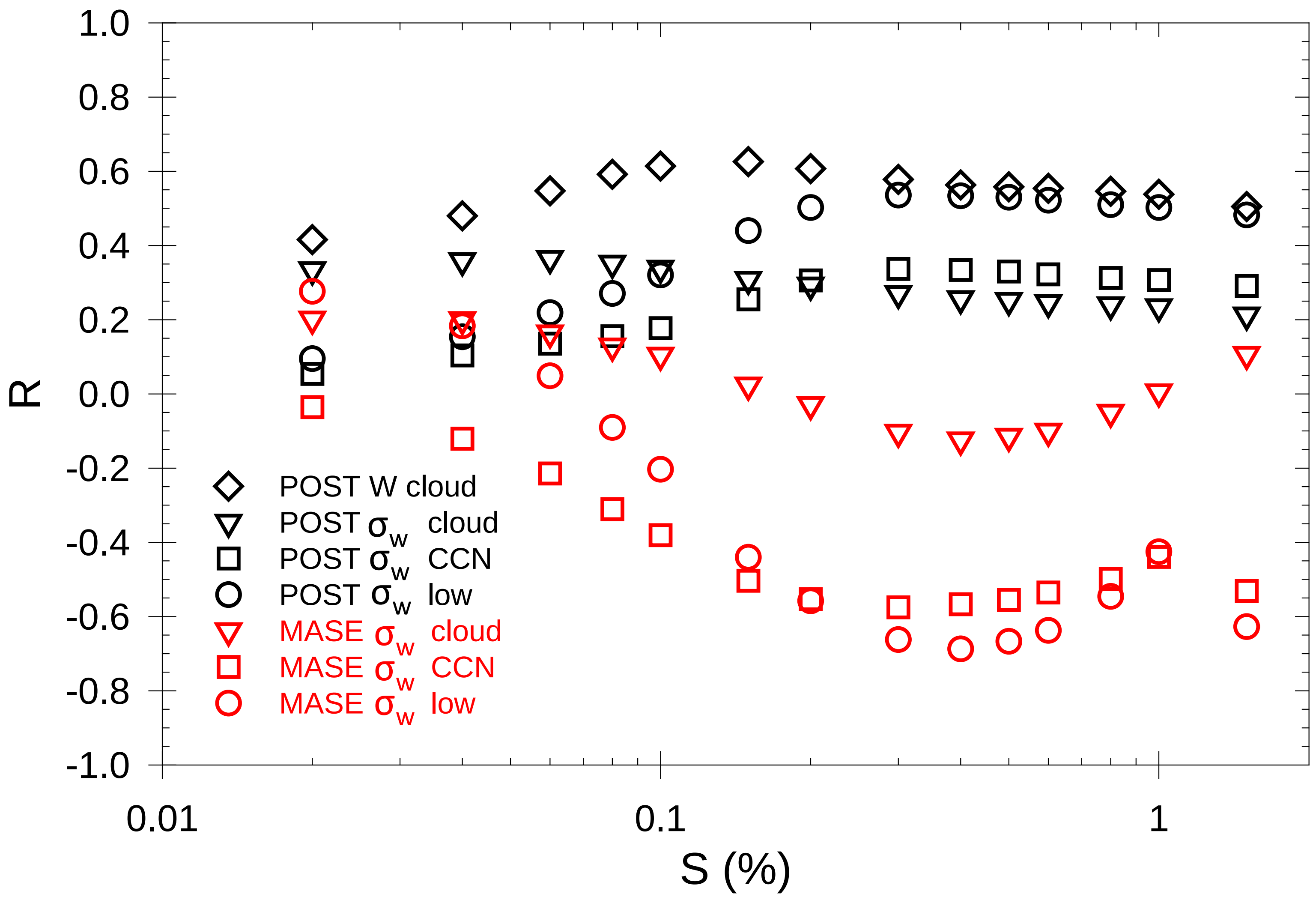


Fig. 17. R for W-N_{CCN} in POST and σ_w-N_{CCN} for POST and MASE. POST W cloud (black diamonds) is same as gray diamonds in Fig. 7, MASE cloud (red triangles) is same as dark pink diamonds in Fig. 7. CCN refers to σ_w measurements at the same subcloud locations as the CCN measurements, low refers to σ_w measured over longer below cloud distances.

Correlated at all S in POST, uncorrelated at all S in MASE.

Two theories may explain the N_{CCN}-σ_w relationship
both involve differential latent heat exchange,
which stirs the air

Anti IAE—smaller droplets of polluted clouds evaporate more easily
(less cloudiness with IAE)
more latent cooling
more air motions
more entrainment
more evaporation
more latent cooling
etc.

Drizzle suppression by more CCN
below cloud drizzle evaporation stabilizes boundary layer
thus suppression of drizzle destabilizes, stirring the air

Both processes increase turbulence in more polluted air.
Do not see in MASE—too polluted, effect is “saturated out.”

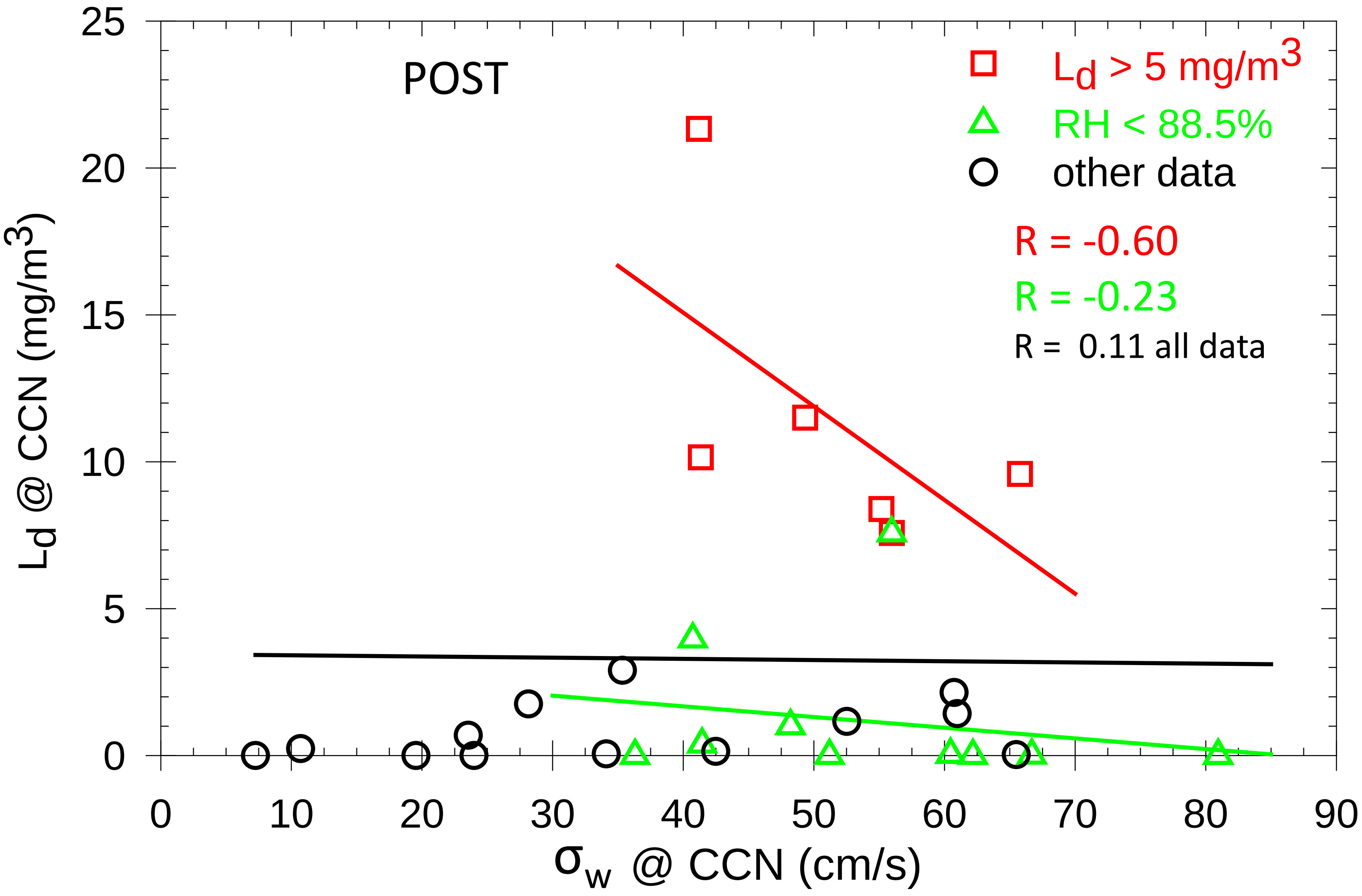


Fig. 16. Drizzle drop LWC (L_d) measured below cloud where CCN were measured against σ_w at the same location.

Summary/conclusions

Pollution suppresses cloud S thus making relevant only CCN at low S

where k is higher, favors W or σ_w variations compared to N_{CCN}

variations, limits IAE.

Pollution increases turbulence

aerosol affects dynamics

greater turbulence may then reenhance IAE

vis-a-vie anti IAE ?