Causes and Consequences of Bimodal CCN Spectra

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Cloud processing of CCN makes a second processed mode with lower critical supersaturation, S_c

Chemical—gas to particle conversion within droplets; SO_2 to sulfate or NO_x to nitrate.

Physical—coalescence or Brownian capture of interstitial CCN

All cloud processes decrease S_c.
--make better CCN

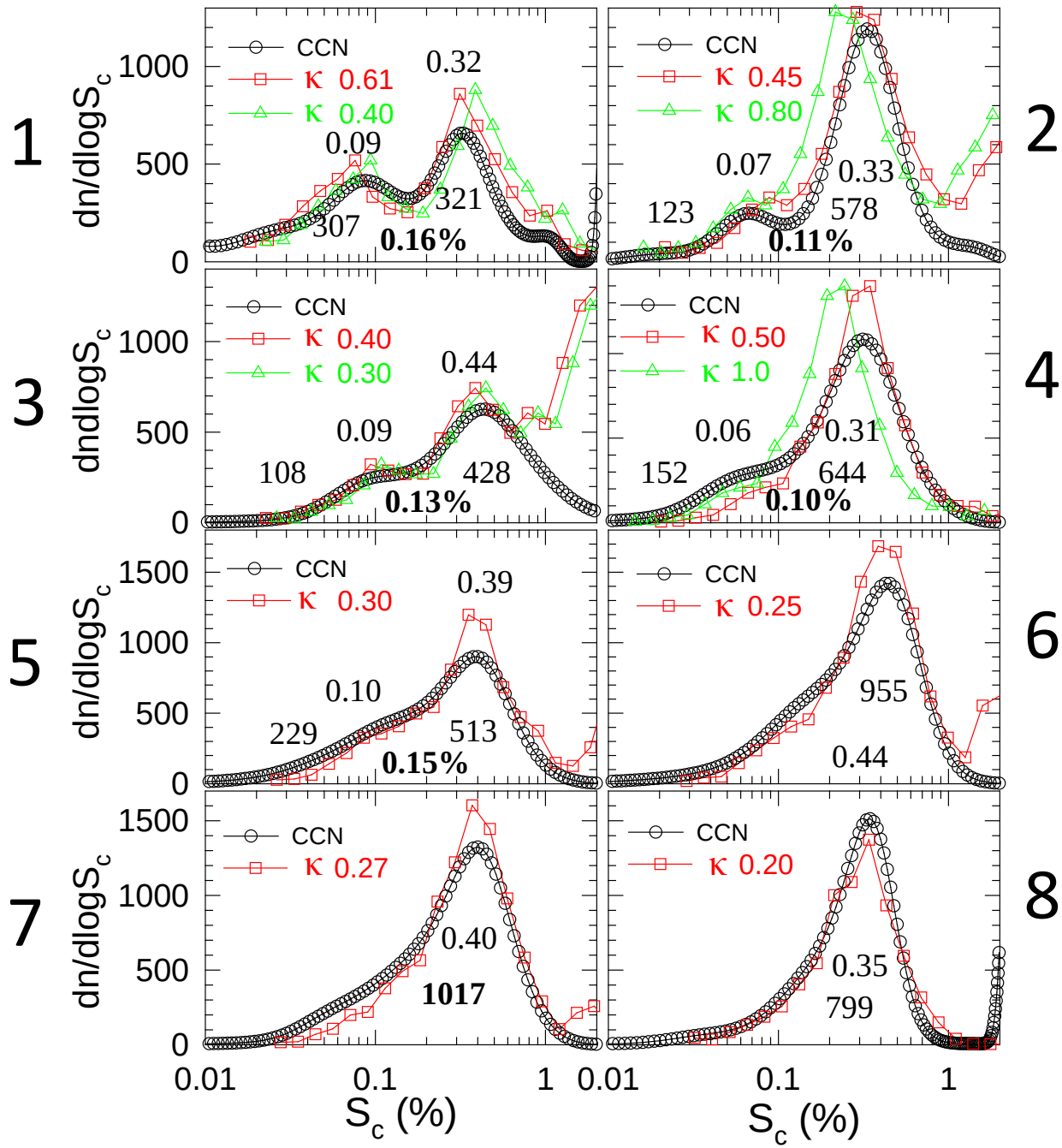
Only physical processes, reduce total CCN concentrations.

Hoppel minima (Hoppel et al., 1986;1994) in DMA size distributions have been used to deduce cloud supersaturations (Clarke et al., 1996, 1998, 1999, 2004, 2013), but they require assumptions or measurements of particle chemistry in order to provide hygroscopicity, κ, to convert size to S_c.

Now that CCN bimodality can be ascertained with the DRI CCN spectrometers composition is not needed to infer cloud S.

And with simultaneous DMA measurements κ, can also be estimated.

Fig. 1. MASE examples of detailed CCN and DMA (red and green) spectra for each of the 8 modal rating categories.
1--two well separated modes.
8--strictly monomodal.
2-7 intermediate-- modes not well separated or one mode a shoulder of another.
Concentrations (cm^{-3}) within each mode, modal S_c and $\mathbf{S_{eff}}$**Hoppel** for 1-5 are shown.
Hygroscopicity, κ, of each mode.
Unprocessed-higher S_c (right)
Processed-lower S_c (left)
From Hudson et al. (2014).



	flights	#	sec	κ_{pro}	κ_{unp}	mode	$S_{eff}H$	$S_{eff}S$
MASE California stratus	9	135	7509	0.50	0.40	4.80	0.15	0.23
ICE-T, Caribbean cumuli	8	50	1657	0.33	0.34	3.93	0.49	1.38

Table 1. Summary of detailed CCN spectral and DMA measurement means. Mode is a rating of the spectra from 1 to 8 with 1 being two well separated modes and 8 being strictly monomodal. Intermediate ratings have modes that are not so well separated or where one mode is a shoulder of another mode or where there are more than two modes. From Hudson et al. (2014).

$\kappa_{pro} > \kappa_{unp}$ implies chemical processing for MASE not ICE-T

mode ICE-T < mode MASE implies more bimodality in cumuli

S_{eff} ICE-T > S_{eff} MASE shows higher cumuli S

S_{eff}Hoppel <S_{eff} by comparing CCN spectra with droplet concentrations, especially for ICE-T

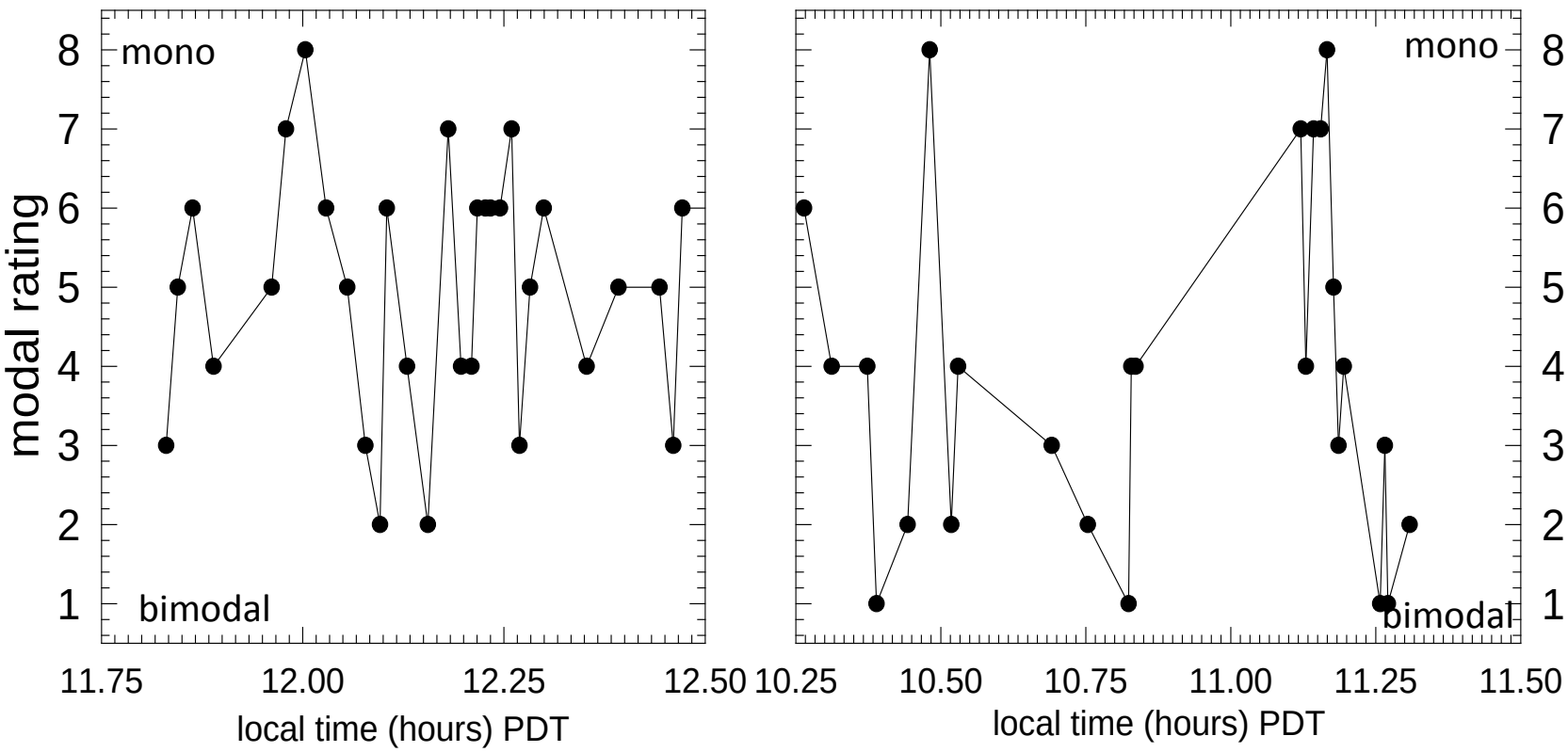


Figure 2. Time plots of CCN spectral modality under MASE stratus; (a) 18 July, (b) 23 July.

Bimodal and monomodal are intermingled under solid status.

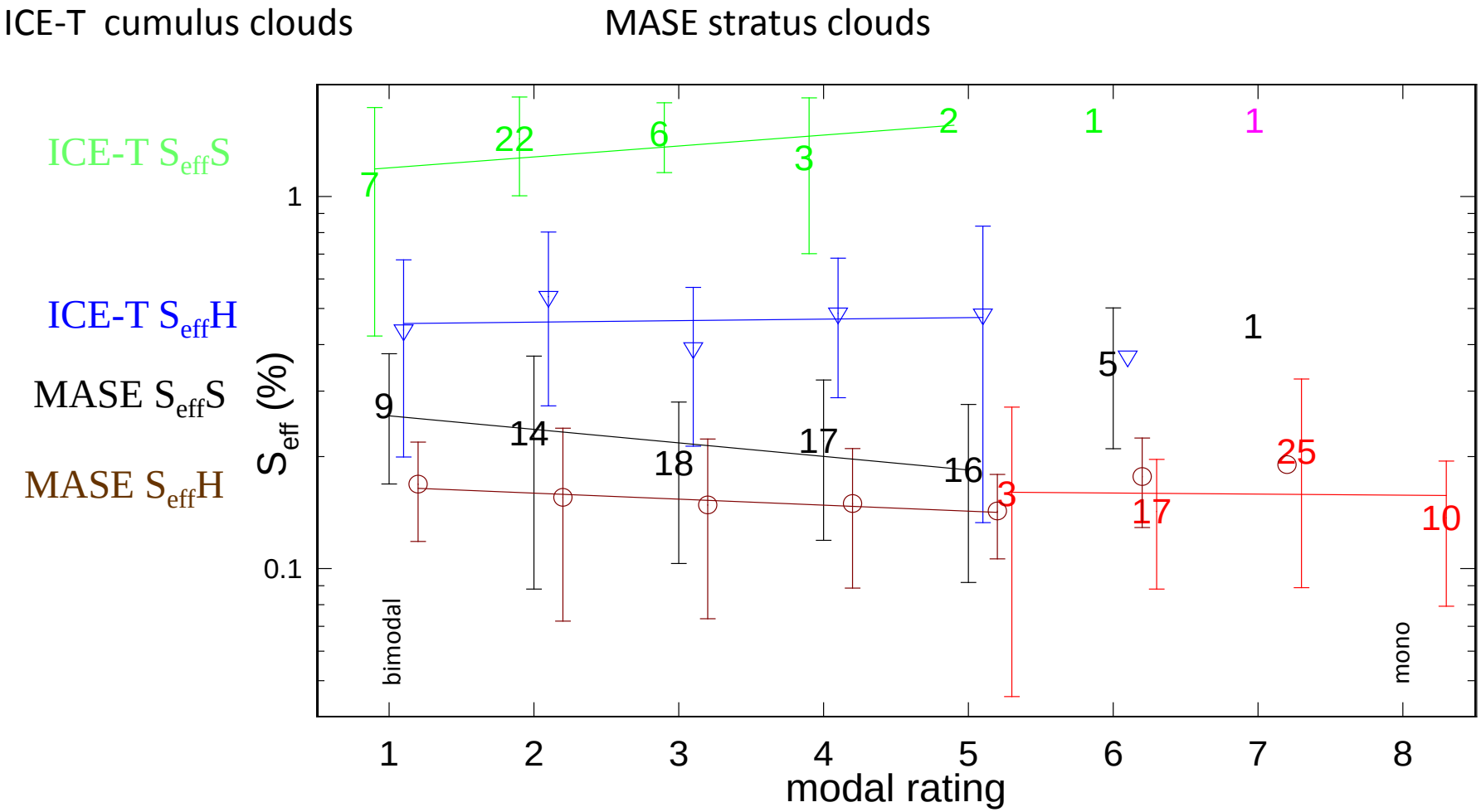


Figure 3. Mean effective supersaturations (S_{eff}) for each modal rating category.
Green ICE-T CCN spectral comparisons with droplet concentrations, $S_{eff}S$,. Blue ICE-T Hoppel minima, $S_{eff}H$.
Pink ICE-T $S_{eff}S$ for monodisperse CCN spectra.
Black MASE $S_{eff}S$. Brown MASE $S_{eff}H$. Red MASE $S_{eff}S$ for monodisperse CCN spectra.
For $S_{eff}S$, the data points are number of cases in each category; same for corresponding $S_{eff}H$.
Error bars are standard deviations (sd) of cases in each modal category.

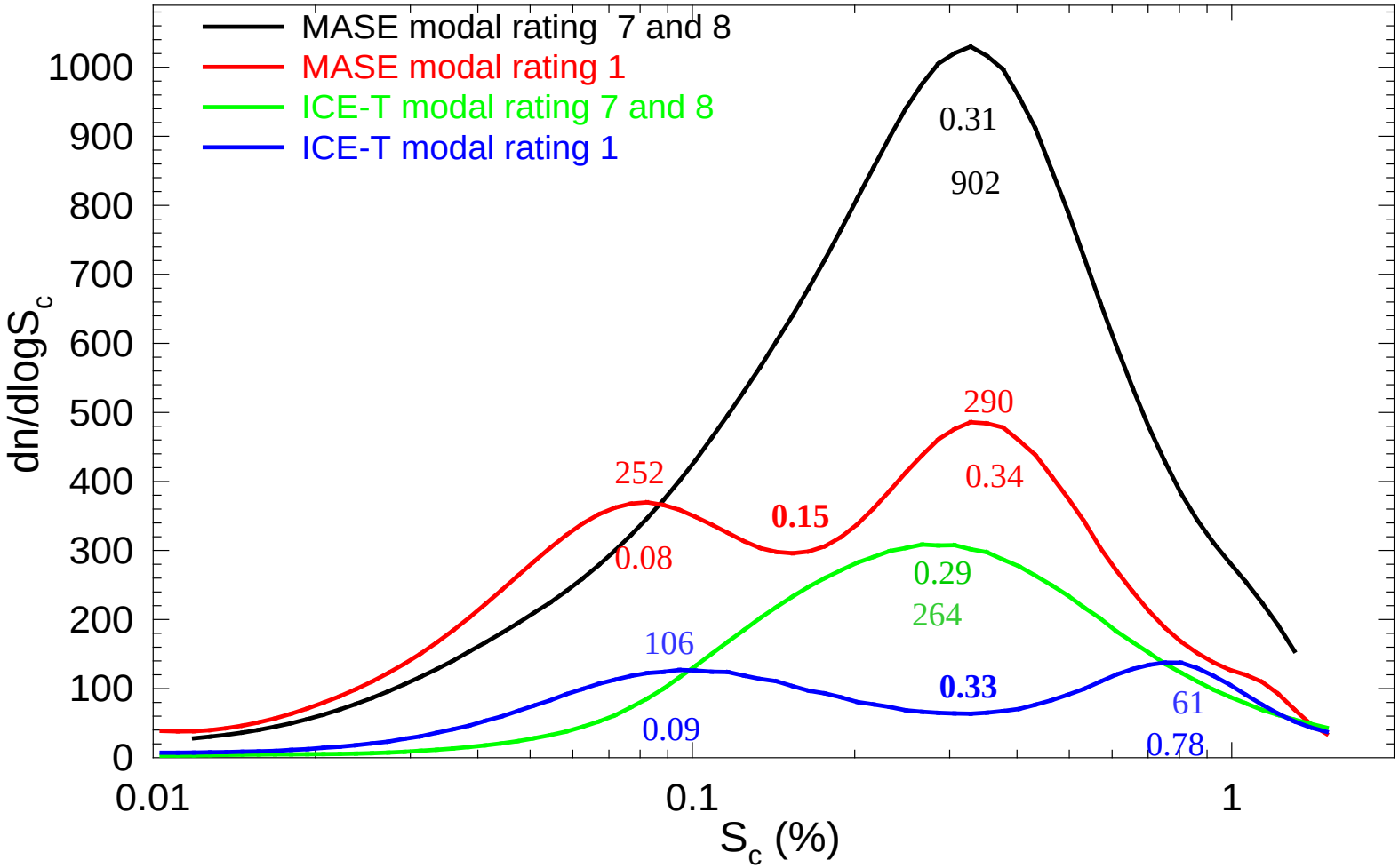


Figure 4. As Fig. 1 but composites of the MASE and ICE-T monomodal (rating 7 and 8) and most bimodal (rating 1) spectra. Modes S, S_{eff}H (%) and mean of N_{CCN}M, N_{CCN}U and N_{CCN}P are shown (cm^{-3}).

252+290 = 542 < 902 and 106+61 = 167 < 264 **is evidence of coalescence**

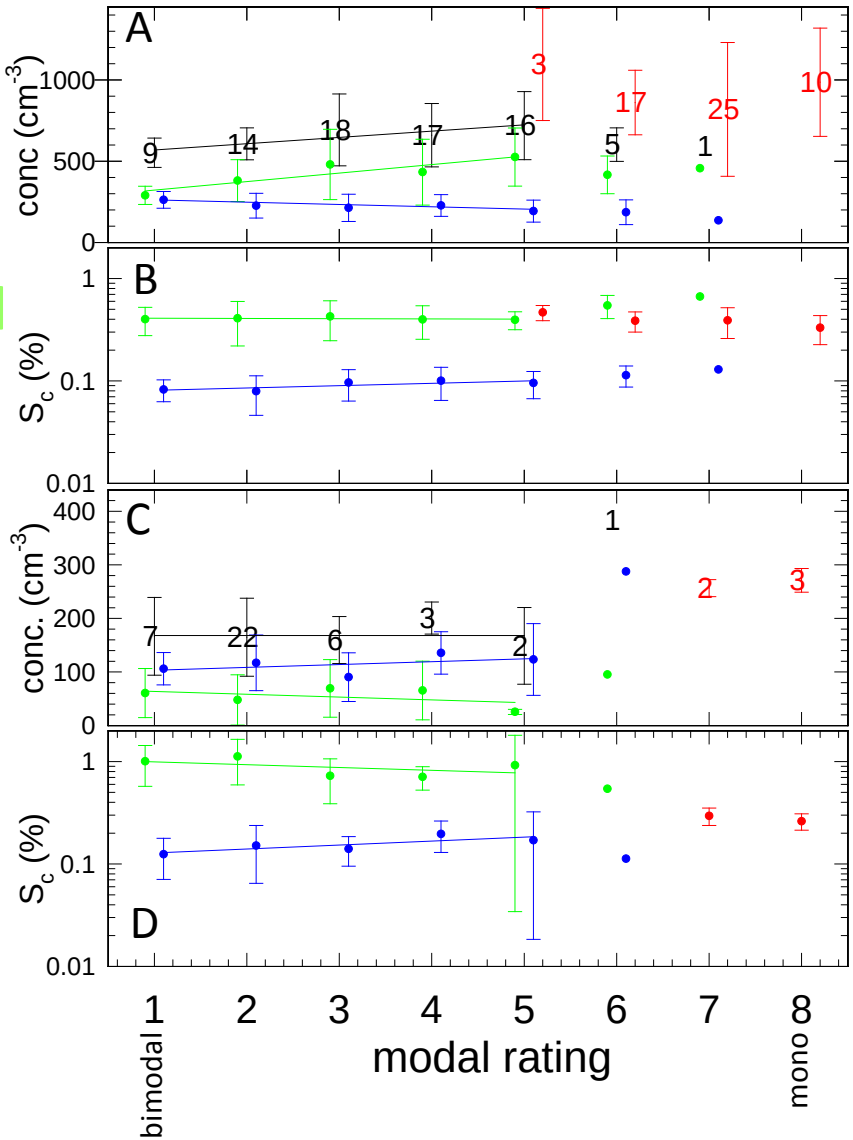
Difference between black and red to the right is evidence of chemistry or more likely Brownian capture in MASE that does not happen in ICE-T (blue and green are close on the right).

total

unprocessed

processed

monomodal

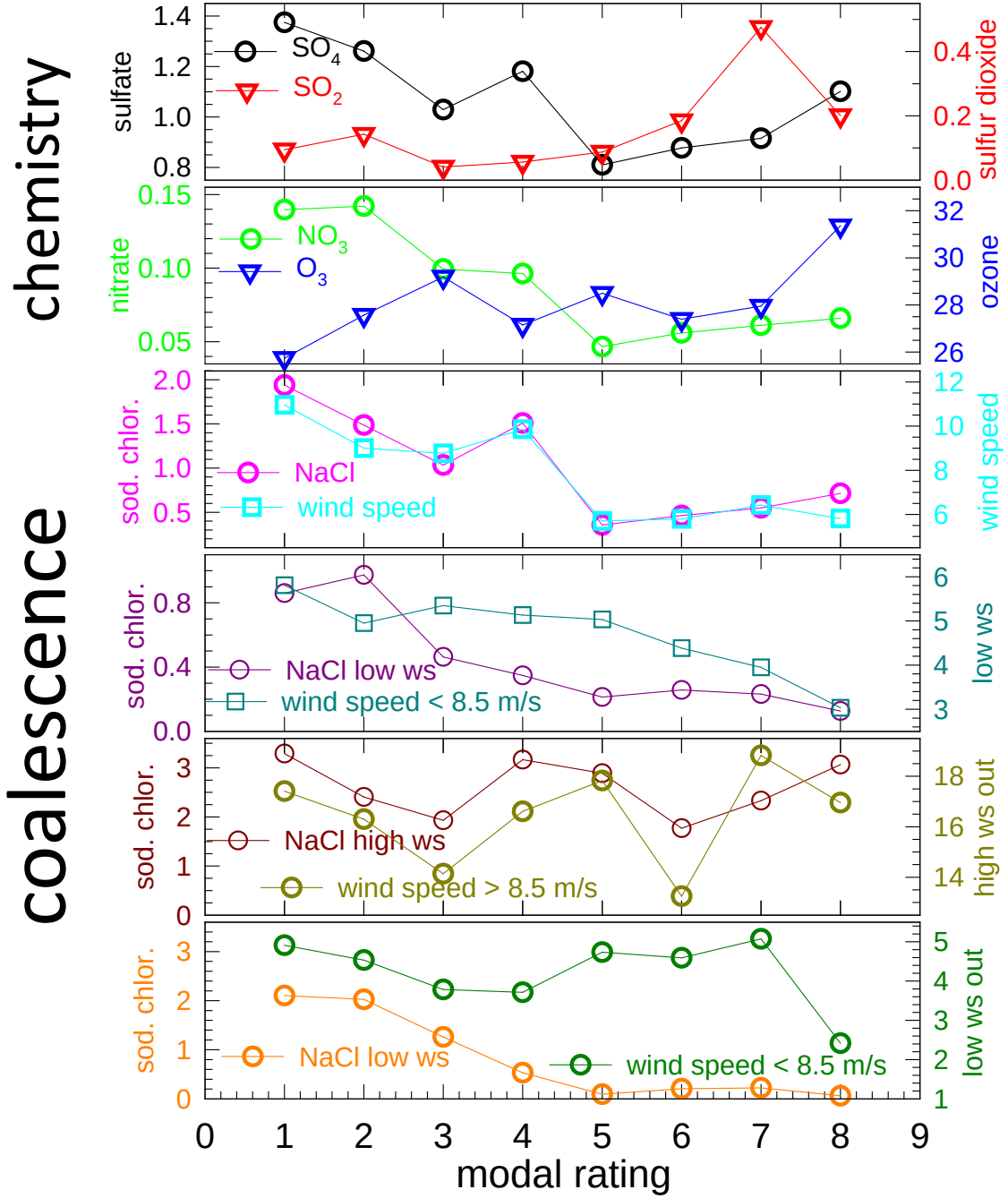


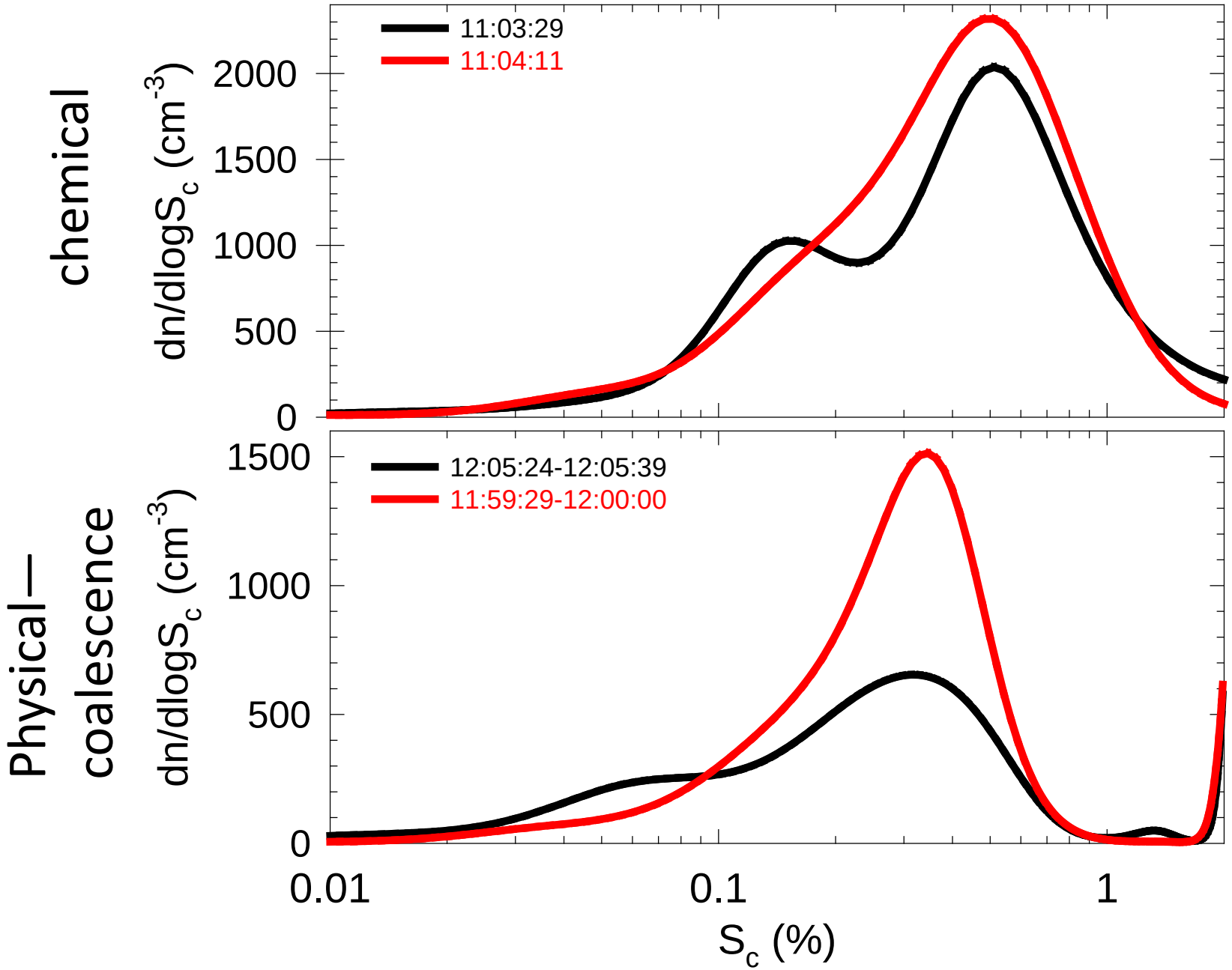
MASE stratus clouds

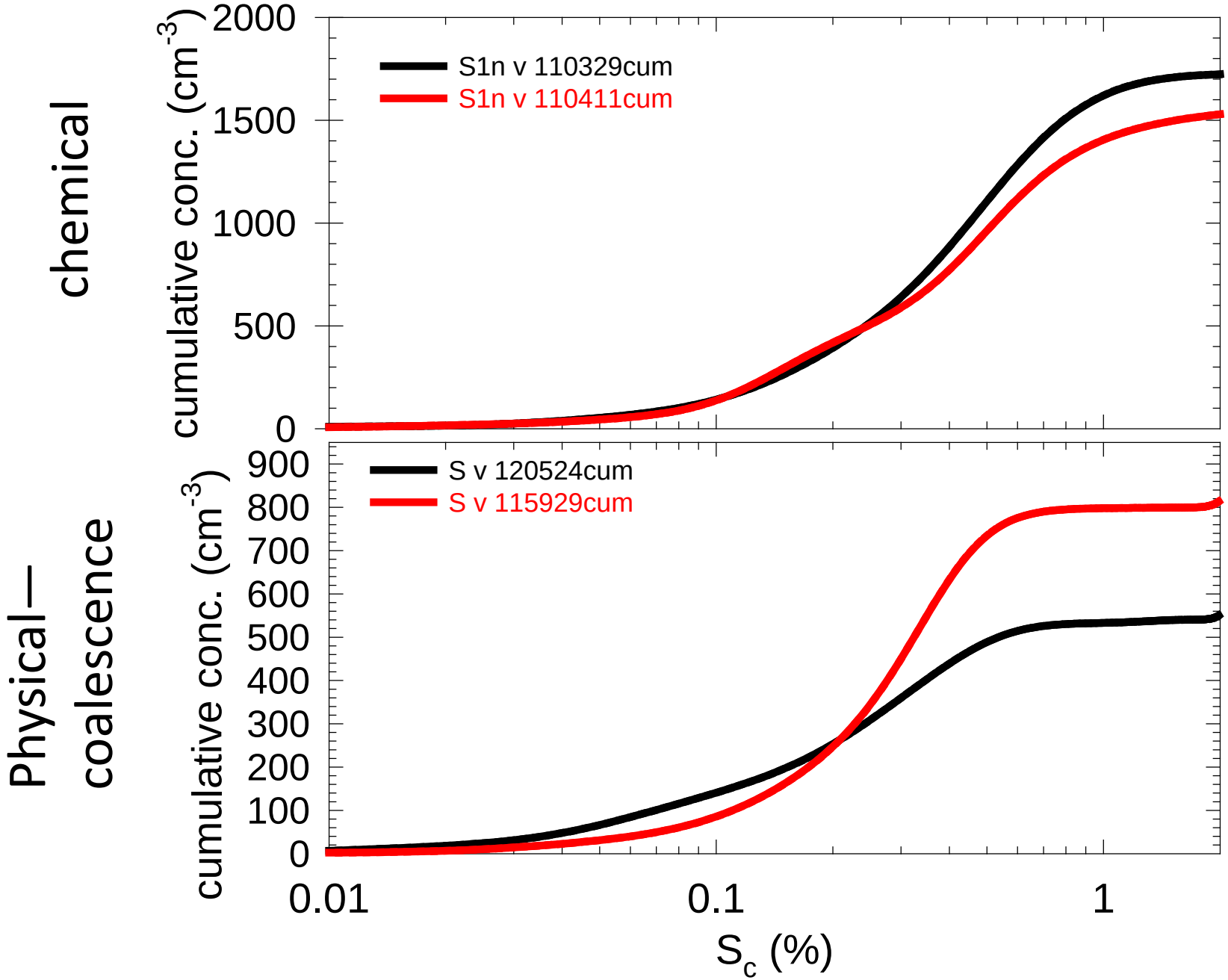
ICE-T cumulus clouds

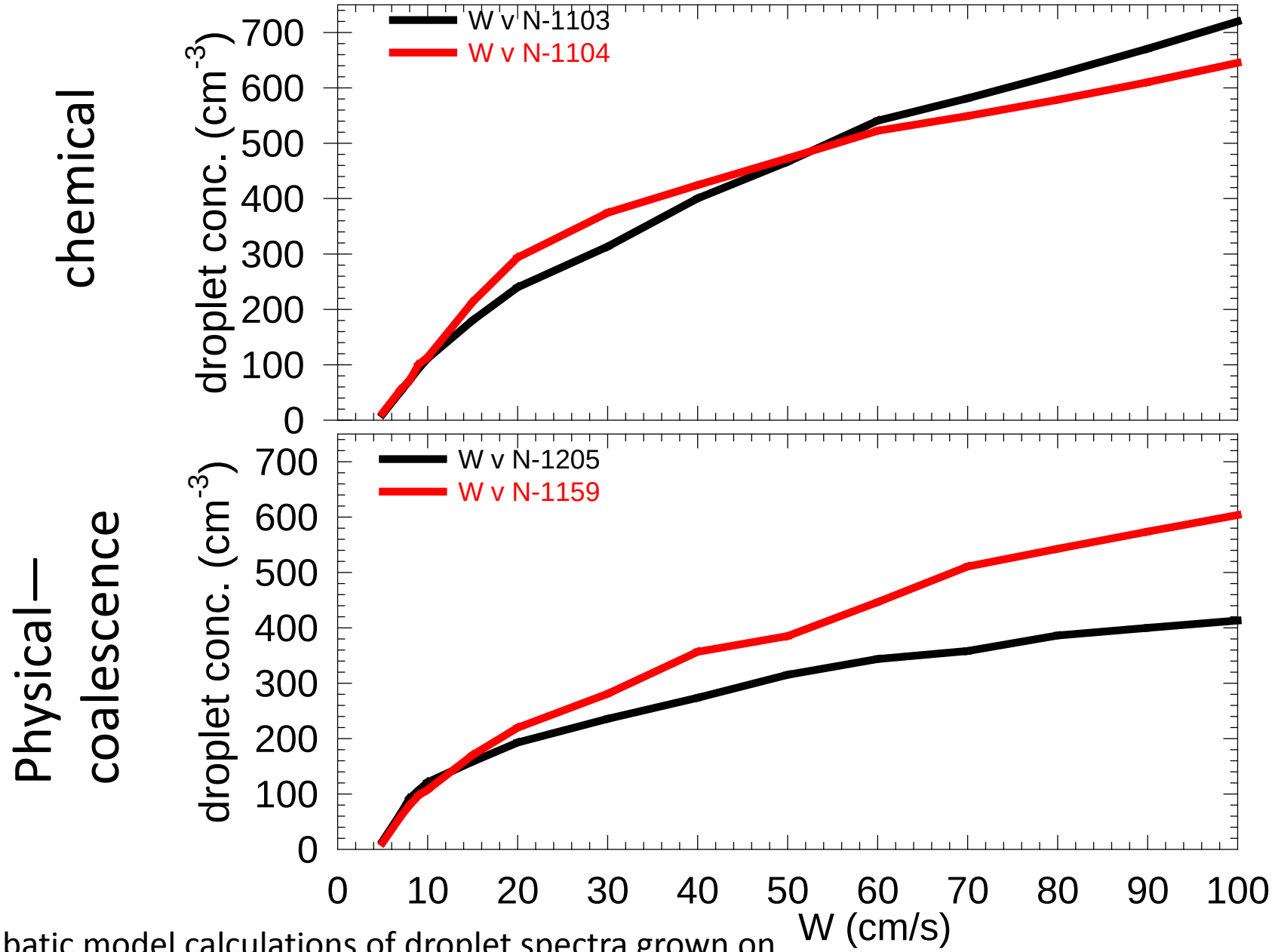
Lower total bimodal (black) than monomodal (red) concentrations (A and C) are evidence of coalescence and autoconversion.

MASE stratus

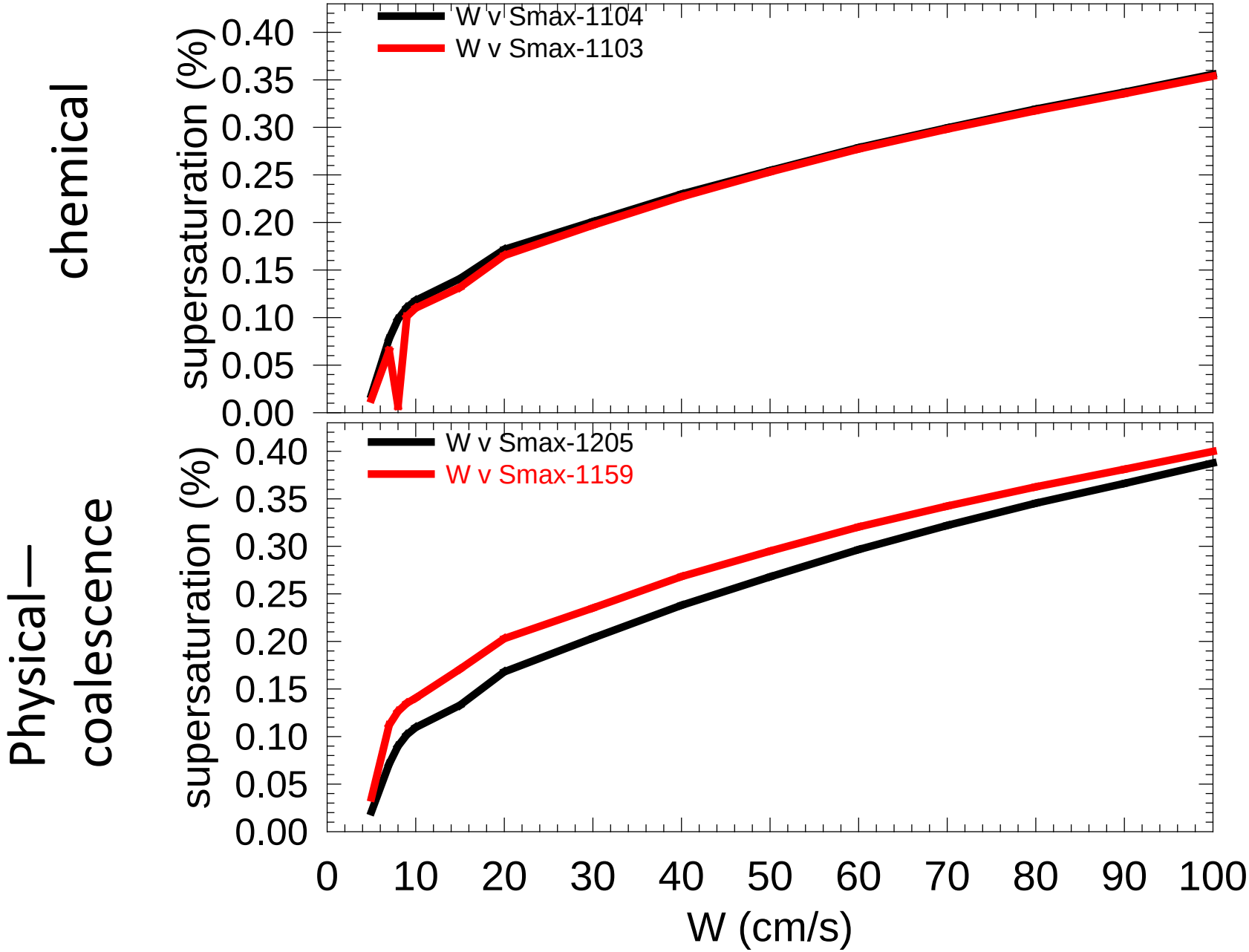


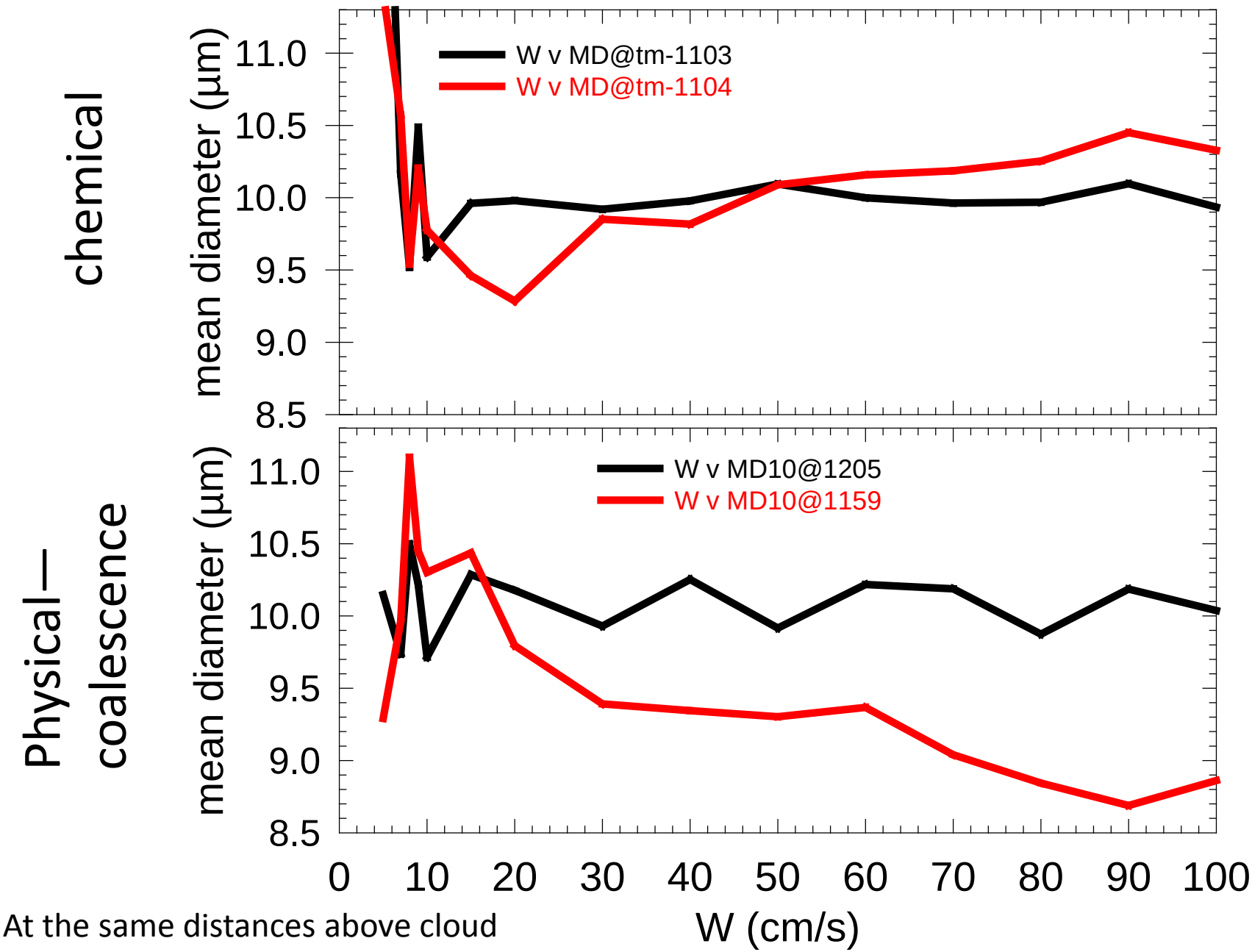

chemical
11:03:29
11:04:11
dn/dlogS$_c$ (cm^{-3})
2000
1500
1000
500
0
Physical—coalescence
12:05:24-12:05:39
11:59:29-12:00:00
dn/dlogS$_c$ (cm^{-3})
1500
1000
500
0
0.01
0.1
1
S$_c$ (%)


chemical
Physical—
coalescence
cumulative conc. (cm-3)
2000
1500
1000
500
0
S1n v 110329cum
S1n v 110411cum
900
800
700
600
500
400
300
200
100
0
S v 120524cum
S v 115929cum
0.01
0.1
1
Sc (%)

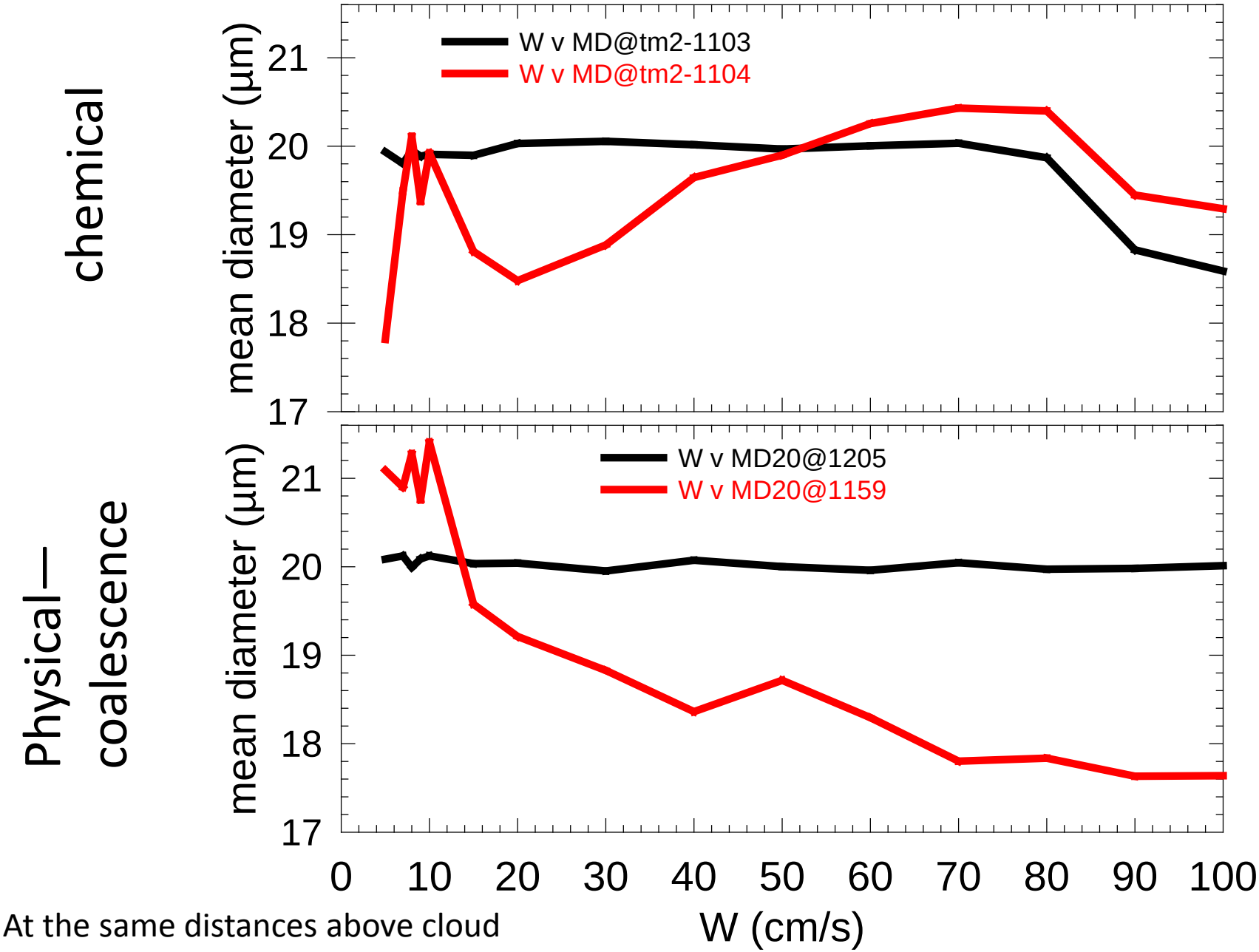


Adiabatic model calculations of droplet spectra grown on these CCN spectra for various vertical wind speeds, W.


chemical
Physical—
coalescence
supersaturation (%)
supersaturation (%)
W v Smax-1104
W v Smax-1103
W v Smax-1205
W v Smax-1159
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0
10
20
30
40
50
60
70
80
90
100
W (cm/s)



At the same distances above cloud base for the two spectra.



At the same distances above cloud base for the two spectra.

Cloud processing is enhancing

and/or

reducing (buffering)

the indirect aerosol effect.ck

Detailed CCN spectra can be examined from 33 aircraft projects and several surface measurement projects.