From LWP to COT: k coefficient

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Parameterization of Cloud Radiative Transfer in GCM

Cloud Module ⇒ LWP

Aerosol Module ⇒ N_{act}

⇒ **COT**

⇒ **Radiative transfer module**

Parameterization of Cloud Radiative Transfer in GCM

$$W = \frac{4}{3}\pi\rho_w \int_0^H N(h) r_3^3(h)\,dh = \frac{4}{3}\pi\rho_w \int_0^H M_3(h)\,dh$$

$$\tau = \int_0^H \pi Q_{ext}(\bar{x}) N(h) r_2^2(h)\,dh = \int_0^H \pi Q_{ext}(\bar{x}) M_2(h)\,dh$$

$$k = \left(\frac{r_2}{r_3}\right)^6 = \left(\frac{r_3}{r_e}\right)^3$$

Martin et al. 1994

$$\tau = A(kNH)^{1/3} W^{2/3}$$ **or** $$r_e = \left(\frac{3W}{4\pi\rho_w kNH}\right)^{1/3}$$

$$k = M_2^3 / N M_3^2$$

Martin et al. 1994, … and many others since

During the course of this work it was found that the most suitable parameterization for effective radius of droplets in layer clouds is

$$r_e\,[\mu\text{m}] = 10^3\left(\frac{3L\,[\text{g m}^{-3}]}{4\pi\rho_w k N_{TOT}\,[\text{cm}^{-3}]}\right)^{1/3}, \quad (14)$$

where the values of k and N_{TOT} are

(i) in maritime airmasses:

$$k = 0.80 \pm 0.07 \text{ (1 standard deviation)}$$

$$N_{TOT} = -1.15 \times 10^{-3} A^2 + 0.963 A + 5.30, \quad (15)$$

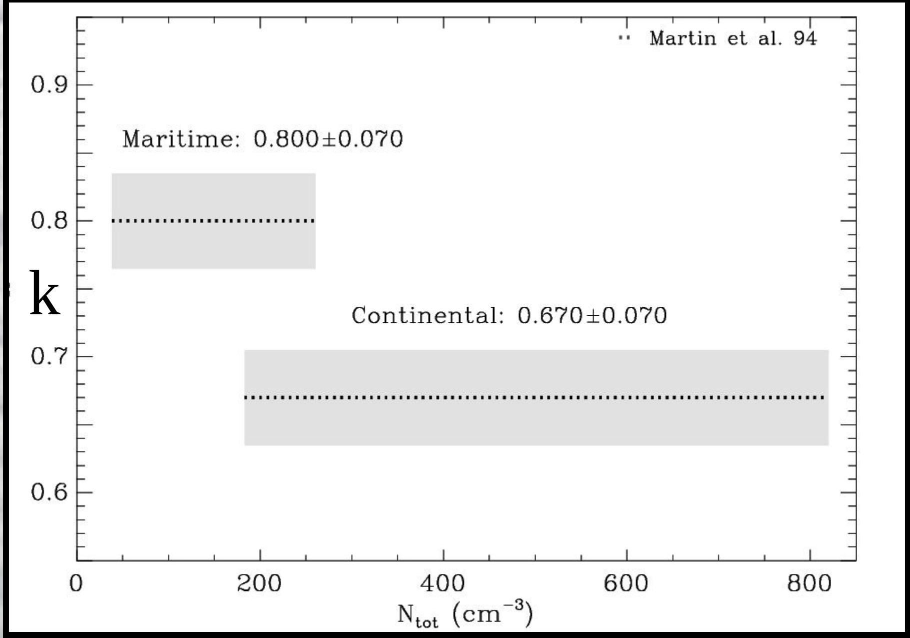
where A is the aerosol concentration in the range ($36 \leqslant A \leqslant 280$ cm^{-3}) and

(ii) in continental air masses:

$$k = 0.67 \pm 0.07 \text{ (1 standard deviation)}$$

$$N_{TOT} = -2.10 \times 10^{-4} A^2 + 0.568 A - 27.9 \quad (16)$$

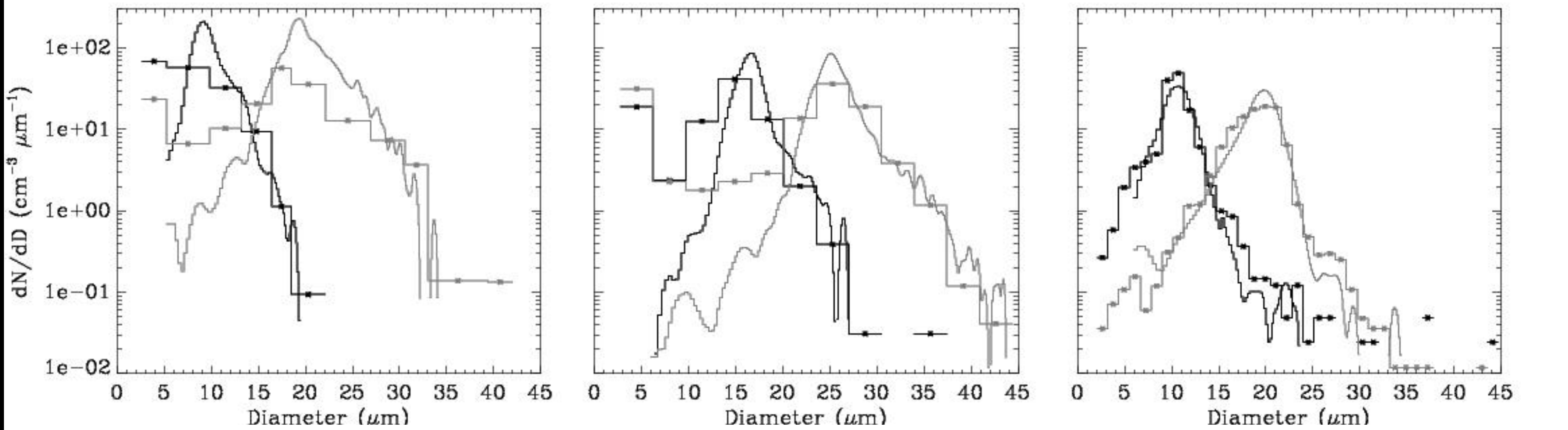
Chen et al. Global climate response to anthropogenic aerosol indirect effects: Present day and year 2100.
J. Geophys. Res.



Data Base

Project	Location	Aircraft	Date	Flight	Cloud type	F-100 15 cl	F-100 40 cl	Fast-F
SCMS	Florida	C-130	22/07/95	RF04	Cu	x		x
SCMS	Florida	C-130	24/07/95	RF05	Cu	x		x
SCMS	Florida	M-IV	04/08/95	me05	Cu	x		x
SCMS	Florida	M-IV	05/08/95	me06	Cu	x		x
SCMS	Florida	M-IV	06/08/95	me07	Cu	x		x
SCMS	Florida	M-IV	07/08/95	me08	Cu	x		x
SCMS	Florida	M-IV	08/08/95	me09	Cu	x		x
SCMS	Florida	M-IV	09/08/95	me10	Cu	x		x
SCMS	Florida	M-IV	10/08/95	me11	Cu	x		x
SCMS	Florida	M-IV	11/08/95	me12	Cu	x		x
SCMS	Florida	M-IV	12/08/95	me13	Cu	x		x
ACE2	Canary islands	M-IV	25/06/97	me20	Sc			x
ACE2	Canary islands	M-IV	26/06/97	me21	Sc			x
ACE2	Canary islands	M-IV	08/07/97	me28	Sc			x
ACE2	Canary islands	M-IV	09/07/97	me30	Sc			x
ACE2	Canary islands	M-IV	16/07/97	me31	Sc			x
ACE2	Canary islands	M-IV	17/07/97	me33	Sc			x
ACE2	Canary islands	M-IV	18/07/97	me34	Sc			x
ACE2	Canary islands	M-IV	19/07/97	me35	Sc			x
DYCOMS-II	northeast Pacific	C-130	13/07/01	RF03	Sc		x	x
DYCOMS-II	northeast Pacific	C-130	24/07/01	RF07	Sc		x	x
DYCOMS-II	northeast Pacific	C-130	25/07/01	RF08	Sc		x	x
DYCOMS-II	northeast Pacific	C-130	27/07/01	RF09	Sc		x	x
RICO	Caribbean	C-130	16/12/04	RF06	Cu		x	x
RICO	Caribbean	C-130	17/12/04	RF07	Cu		x	x
RICO	Caribbean	C-130	19/12/04	RF08	Cu		x	x
RICO	Caribbean	C-130	20/12/04	RF09	Cu		x	x
RICO	Caribbean	C-130	07/01/05	RF10	Cu		x	x
RICO	Caribbean	C-130	11/01/05	RF11	Cu		x	x
EUCAARI	Netherlands	ATR-42	13/05/08	as49	Cu			x
EUCAARI	Netherlands	ATR-42	14/05/08	as50	Cu			x
EUCAARI	North Sea	ATR-42	15/05/08	as51	Sc			x
EUCAARI	North Sea	ATR-42	15/05/08	as52	Sc			x

Instrumental Biases

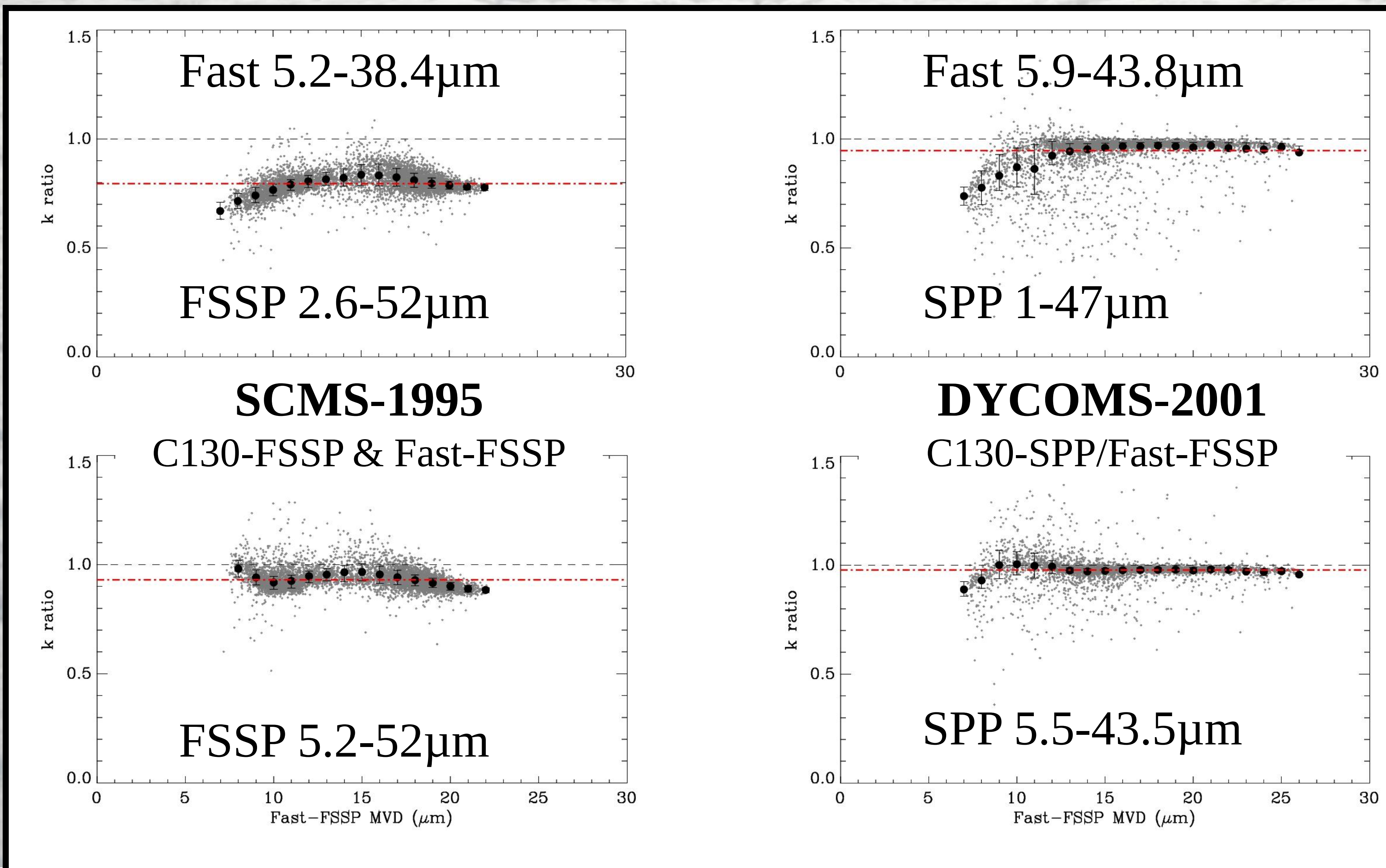


SCMS-1995 | **SCMS-1995** | **DYCOMS-2001**

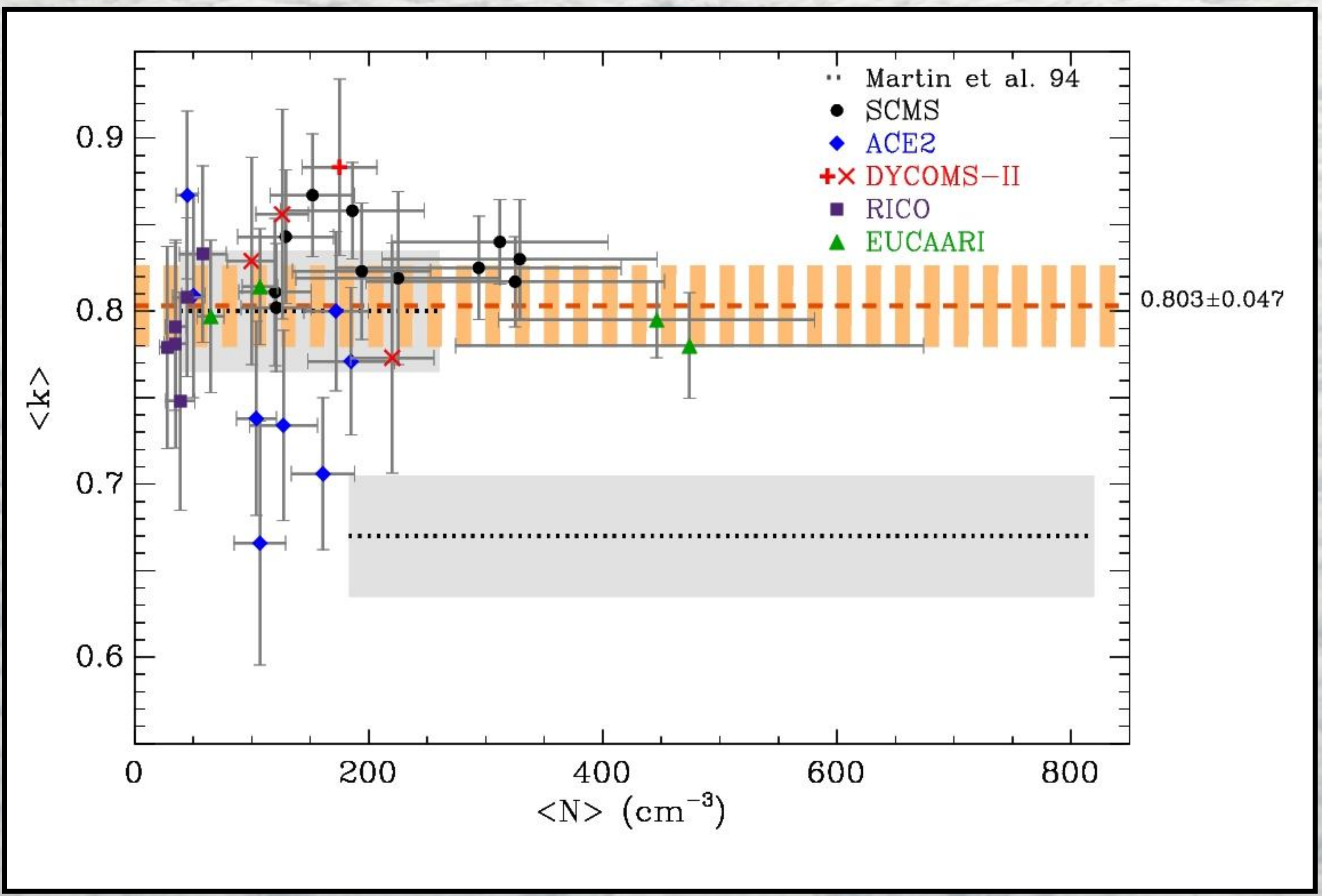
C130-FSSP & Fast-FSSP | ME-FSSP/Fast-FSSP | C130-SPP/Fast-FSSP

The FSSP-100 provides accurate measurements of the mean droplet diameter, but it significantly overestimates the width of the spectrum, hence underestimates the k coefficient. This is especially true when droplets are smaller, i.e. in high concentration clouds

Instrumental Biases



Results



Martin et al. 94
SCMS
ACE2
DYCOMS−II
RICO
EUCAARI
0.803±0.047
0.9
0.8
0.7
0.6
<k>
0
200
400
600
800
<N> (cm−3)

Martin et al. 1994, … and many others since

During the course of this work it was found that the most suitable parameterization for effective radius of droplets in layer clouds is

$$r_e\,[\mu\text{m}] = 10^3\left(\frac{3L\,[\text{g m}^{-3}]}{4\pi\rho_w k N_{TOT}\,[\text{cm}^{-3}]}\right)^{1/3}, \quad (14)$$

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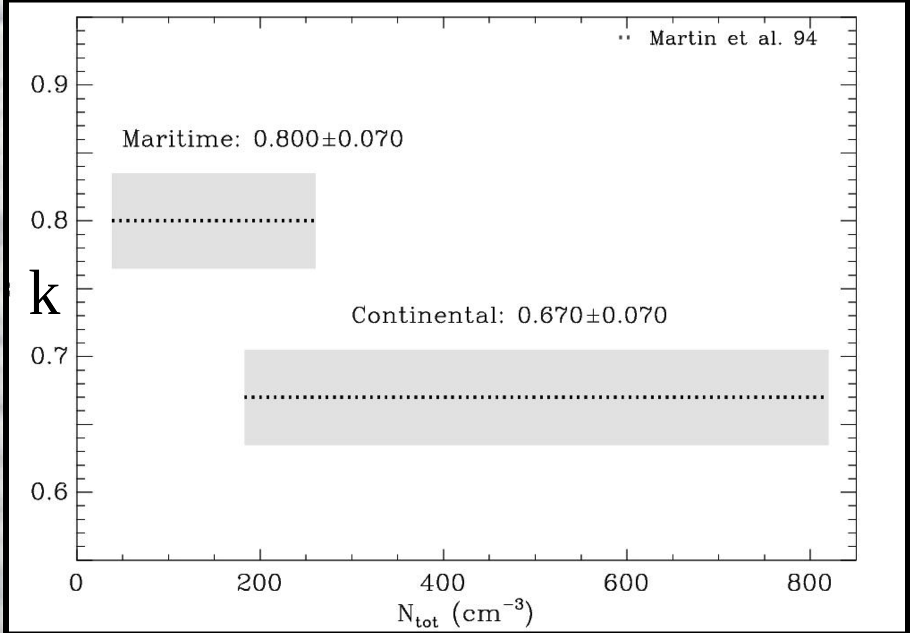
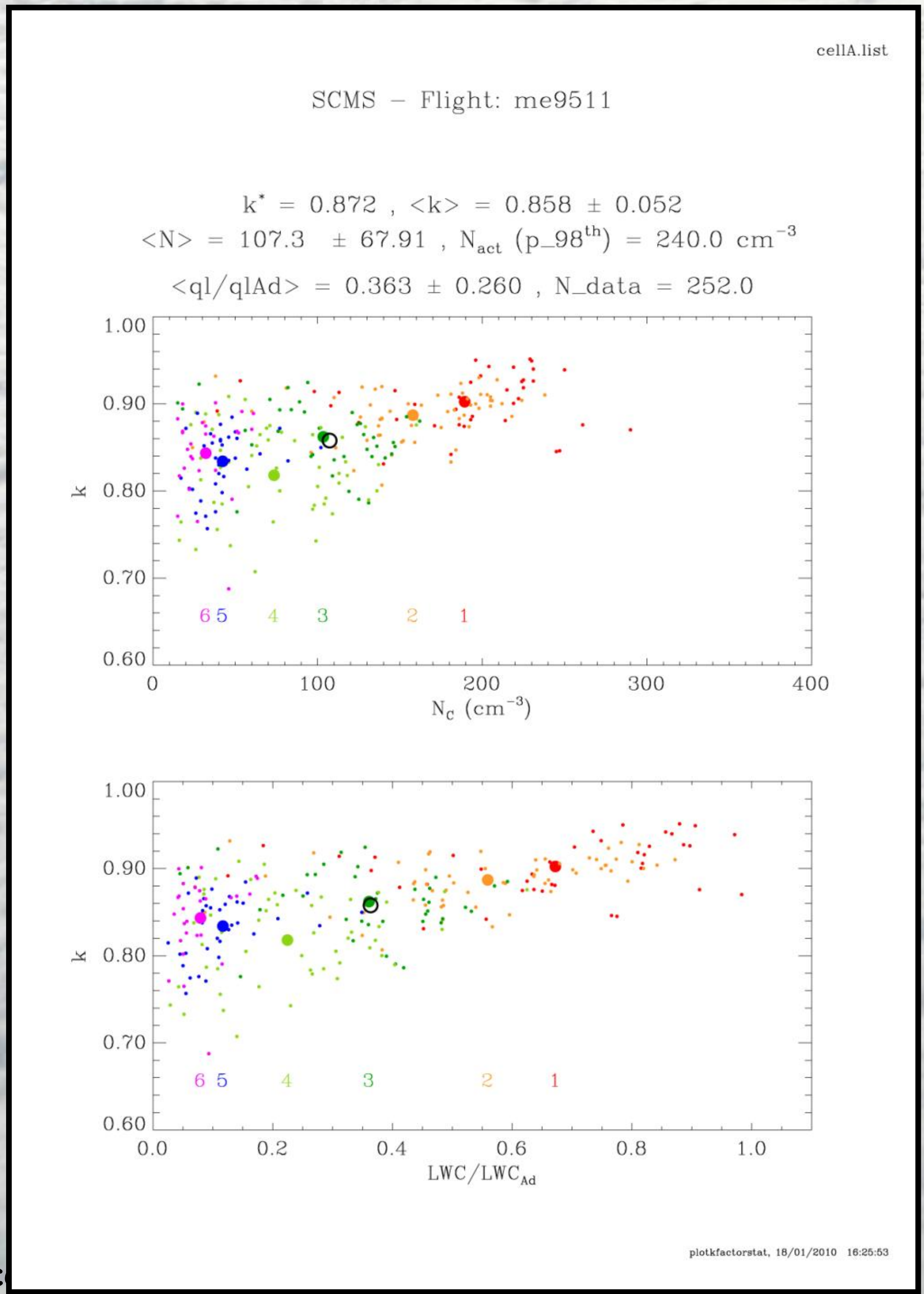


When entrainment effects become important, the relationship between r_e and r_v breaks down and such data have been ignored in the analysis.

K coefficient and sub-adiabaticity



Vertical Integration

$$W = \frac{4}{3}\pi\rho_w \int_0^H N(h) r_3^3(h)\,dh = \frac{4}{3}\pi\rho_w \int_0^H M_3(h)\,dh$$

$$\tau = \int_0^H \pi Q_{ext}(\bar{x}) N(h) r_2^2(h)\,dh = \int_0^H \pi Q_{ext}(\bar{x}) M_2(h)\,dh$$

$$\tau = A(kNH)^{1/3} W^{2/3}$$ with $$k = M_2^3 / N M_3^2$$

Is true only in vertically uniform clouds !

Vertical Integration

In convective clouds, that are vertically stratified, with LWC increasing from cloud base to top : $q_c = C_w h$

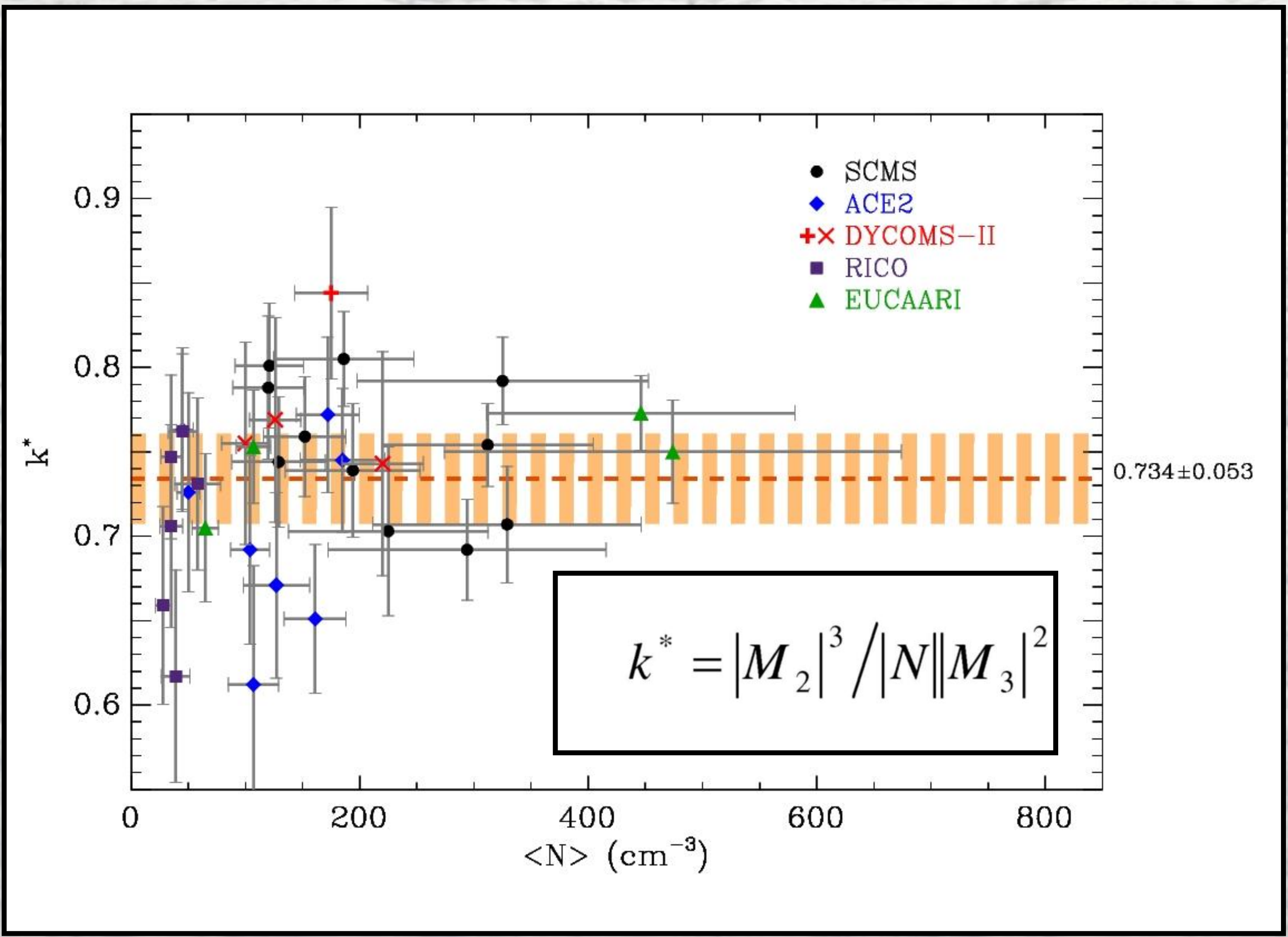
$$k^* = |M_2|^3 / |N||M_3|^2, \qquad \text{where } |x| = \int_0^H x(h)dh .$$

Assuming k is constant throughout the cloud, $r_2^2 = k^{1/3} \alpha^{2/3} h^{2/3}$, where $\alpha = C_w/(4/3\pi\rho_w)$.

It follows that $|M_2| = 3/5\, k^{1/3} \alpha^{2/3} N H^{5/3}$, and $|M_3| = 1/2\, \alpha N H^2$, and finally:

$$\mathbf{k^* = (3/5)^3 (1/2)^{-2} k = 0.864\, k}$$

Results


SCMS
ACE2
DYCOMS−II
RICO
EUCAARI
0.9
0.8
0.7
0.6
k*
0
200
400
600
800
<N> (cm-3)
0.734±0.053
$k^* = |M_2|^3 / |N||M_3|^2$

Parameterization of Cloud Radiative Transfer in GCM

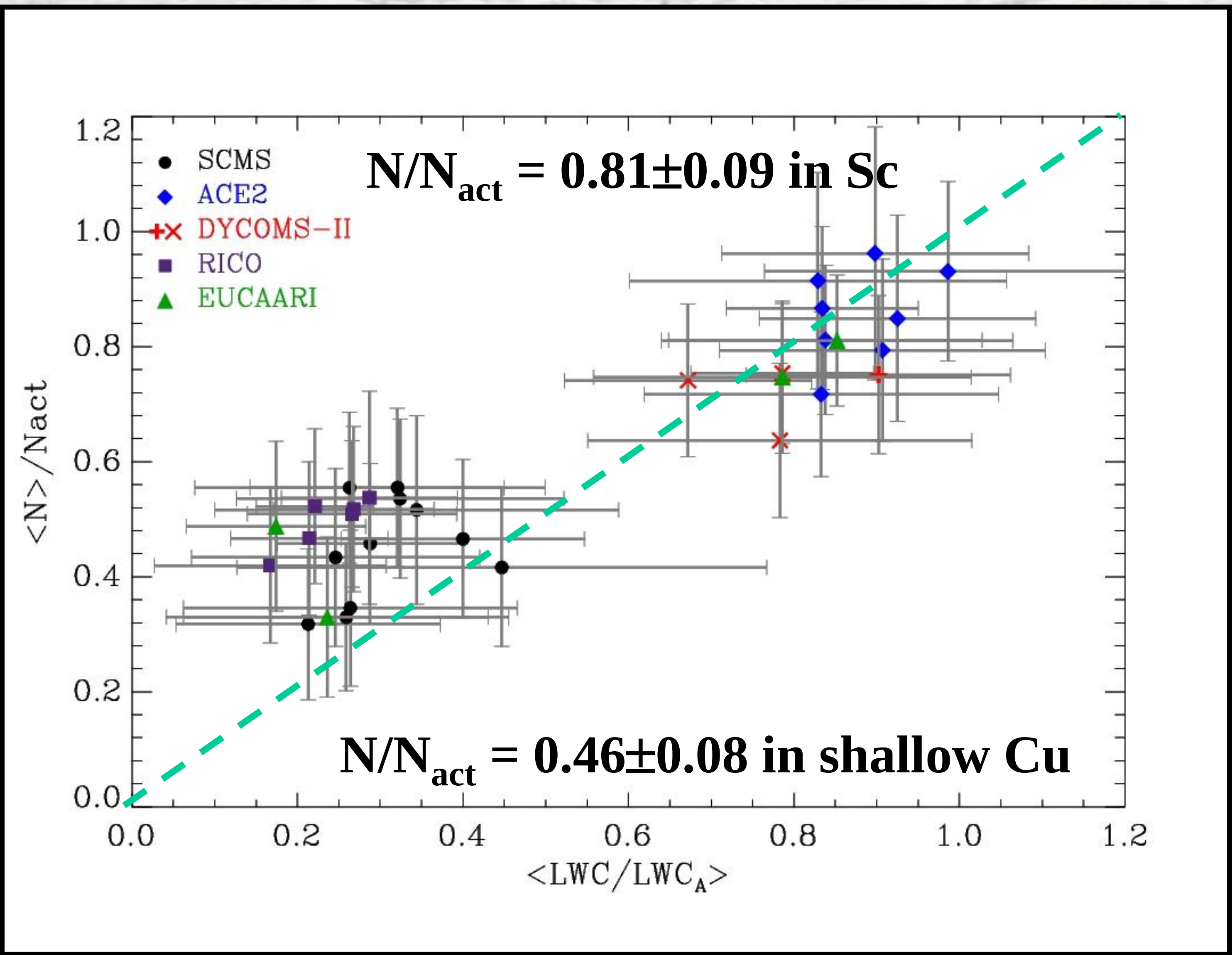
Cloud Module ⇒ LWP
Aerosol Module ⇒ N_{act}

⇒ **COT**

⇒ **Radiative transfer module**
COT & N

But $N \neq N_{act}$
because of entrainment-mixing

Results



SCMS
ACE2
DYCOMS−II
RICO
EUCAARI
N/N_{act} = 0.81±0.09 in Sc
N/N_{act} = 0.46±0.08 in shallow Cu
<N>/Nact
<LWC/LWC$_A$>
0.0
0.2
0.4
0.6
0.8
1.0
1.2

Entrainment and mixing : Conceptual Model

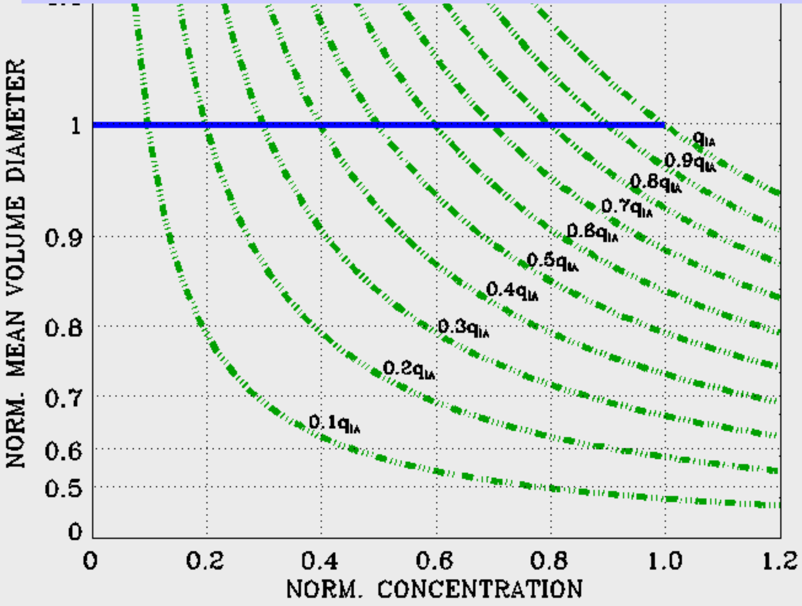
Inhomogeneous | **Homogeneous**

Key Parameters (Baker et al., 1979)

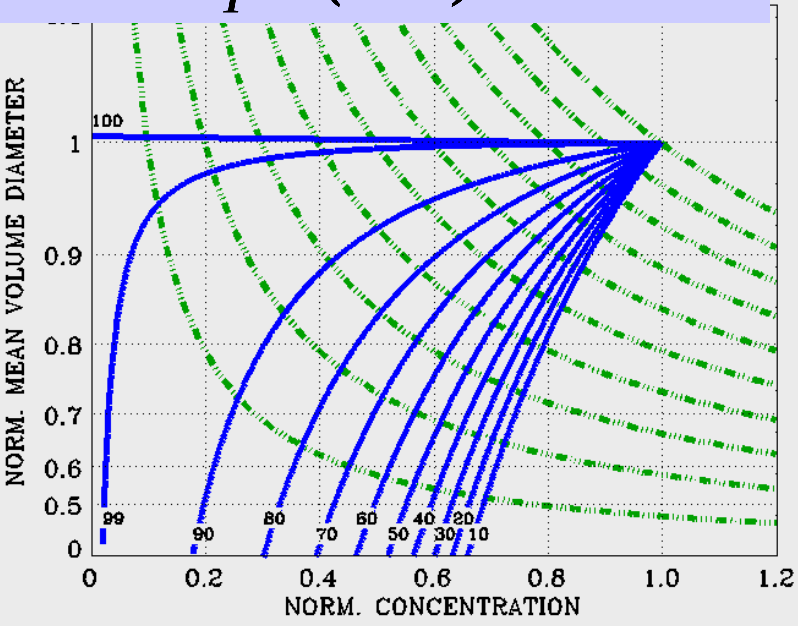
droplet life time >> **turbulent homogeneisation**

$\tau_d = - (d^2 / AS)$ >> $\tau_T = (X^2/\varepsilon)^{1/3}$

$\frac{d_V^3}{d_{VO}^3}$

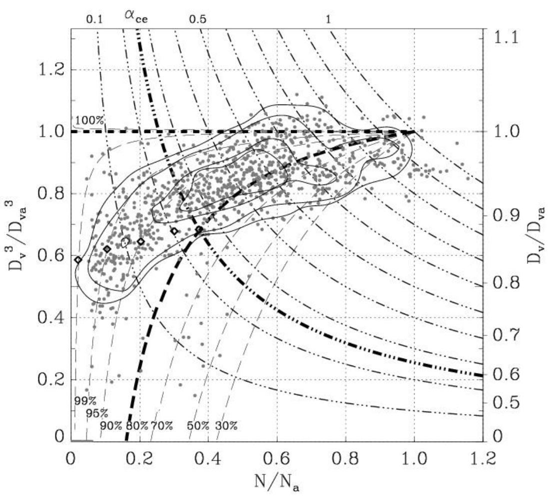


N / No



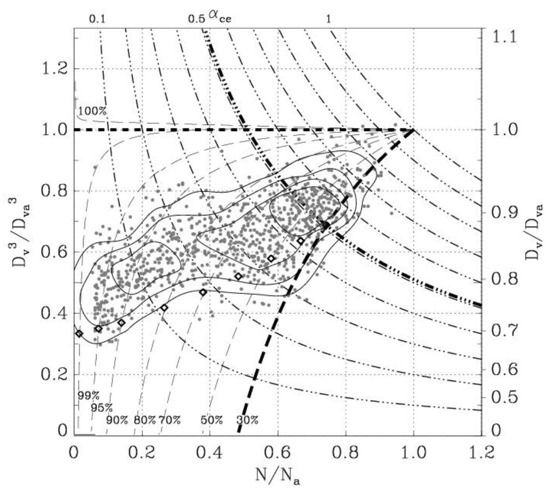
N / No

Entrainment and mixing : Case Studies



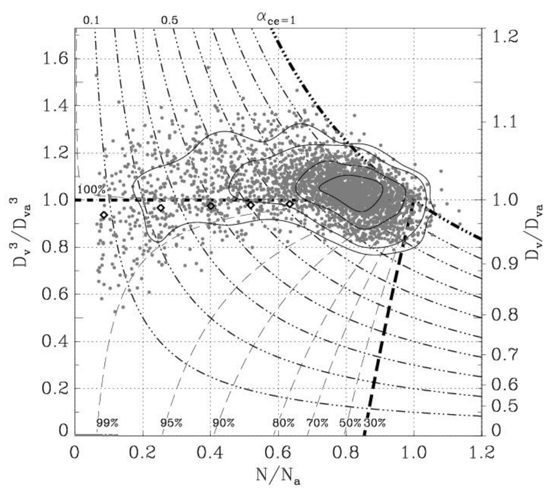
SCMS Cu

τ_d / τ_T = 6.6



SCMS Cu

τ_d / τ_T = 1.9



DYCOMS-II Sc

τ_d / τ_T = 0.05

Burnet & Brenguier, JAS 2006

Conclusion

$$\tau = A(k^*_{act} N_{act} H)^{1/3} W^{2/3}$$ **where** $$k^*_{act} = k^* N / N_{act}$$

N/N_{act} = 0.81±0.09 in stratocumulus clouds
N/N_{act} = 0.46±0.08 in shallow cumuli

$$k^*_{act} = 0.73 \times 0.81 = 0.59$$ **in stratocumulus clouds**

$$k^*_{act} = 0.73 \times 0.46 = 0.34$$ **in shallow cumuli**

Thank you

for your attention

Entrainment and mixing : Case Studies

Key Parameters:

droplet life time $\gg$ **turbulent homogeneisation**

$$\tau_d = -(d^2 / AS) \quad \gg \quad \tau_T = (X^2/\varepsilon)^{1/3}$$

	DYCOMS-RF03	SCMS-me9506
S	- 0.7	- 0.7
d	15 µm	30 µm
τ_d	0.8 s	3.2 s
w	0.5 m/s	5 m/s
T_c	12.3 C	14.1 C
q_{lc}	0.7 g/kg	3.4 g/kg
T_e	16.2 C	20.0 C
q_{ve}	5 g/kg	4 g/kg
N	350 cm^{-3}	250 cm^{-3}
P	950 hPa	750 hPa