Modeling of shallow convection with double-moment warm-rain microphysics

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Double-moment warm-rain microphysics of Morrison and Grabowski (2007, 2008):

- Prediction of concentrations and mass of cloud droplets and rain drops (4 variables);

- Prediction of in-cloud supersaturation and thus relating the concentration of activated cloud droplets to local value of the supersaturation; additional variable (concentration of activated CCN) needed;

- Allows various mixing scenarios for subgrid-scale mixing (from homogeneous to extremely inhomogeneous).

A Large Eddy Simulation Intercomparison Study of Shallow Cumulus Convection

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Peter G. Duynkerke,[f*] Hongli Jiang,[g] Marat Khairoutdinov,[h] David Lewellen,[i] Chin-Hoh Moeng,[j]
Enrique Sanchez,[k] Bjorn Stevens,[l] and David E. Stevens[m]

JAS
2003

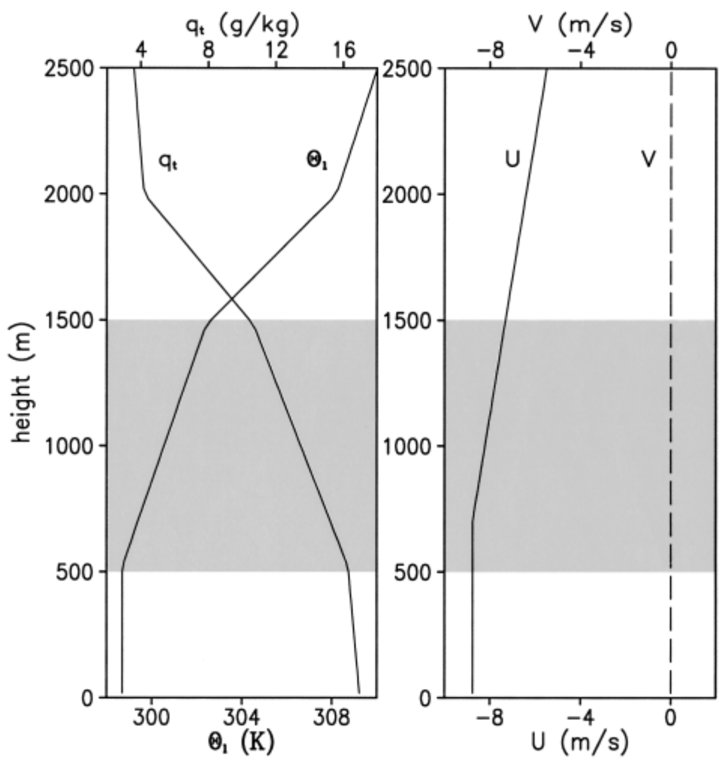
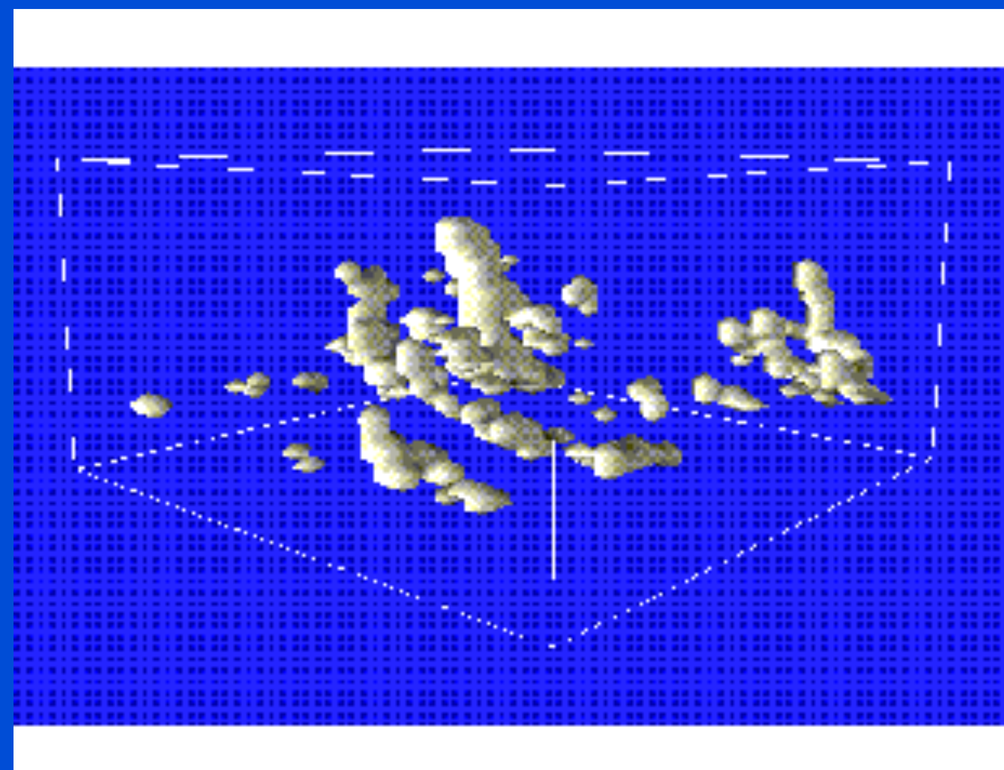


FIG. 1. Initial profiles of the total water specific humidity q_t, the liquid water potential temperature θ_ℓ, and the horizontal wind components u and v. The shaded area denotes the conditionally unstable cloud layer.



The Barbados Oceanographic and Meteorological Experiment (BOMEX) case (Holland and Rasmusson 1973)

Simulations reported here use higher spatial resolution and the same number of grid points in horizontal (thus smaller domain):

domain: 6.4 x 6.4 x 4 km^3
grid: 128 x 128 x 200
gridlength: 50 x 50 x 20 m

Four simulations: 100.HM, 100.EI, 1000.HM, 1000.EI

aerosol *SGS mixing*

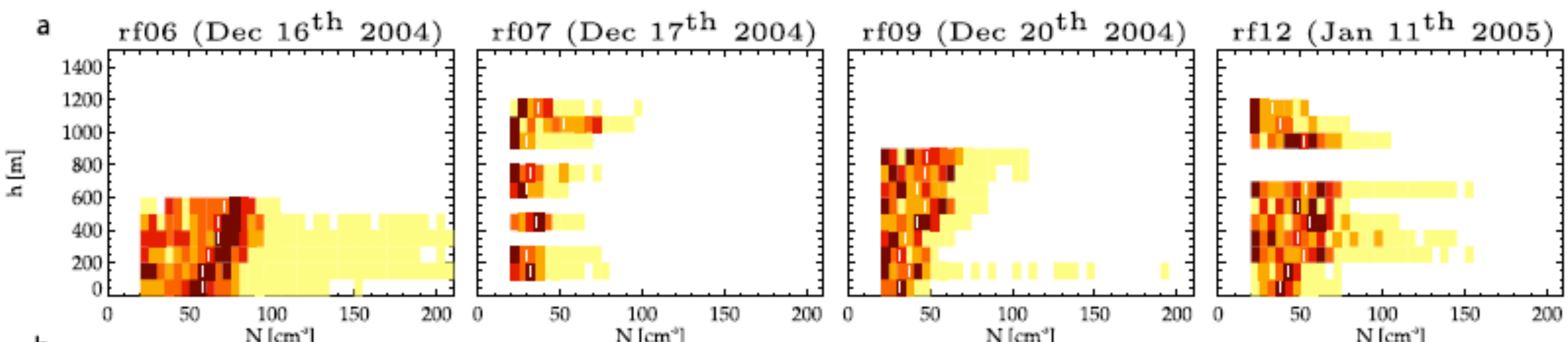
Gerber et al. *JMSJ* 2008

Table 3. Microphysics of the seven Cu at five different levels shown in Fig. 2, with mean values of LWC (liquid water content) and its sample standard deviation for three horizontal data resolutions, total droplet concentration N, and mean volume radius r_v. The latter two parameters correspond to 10-m resolution data. The subscript a indicates expected adiabatic values.

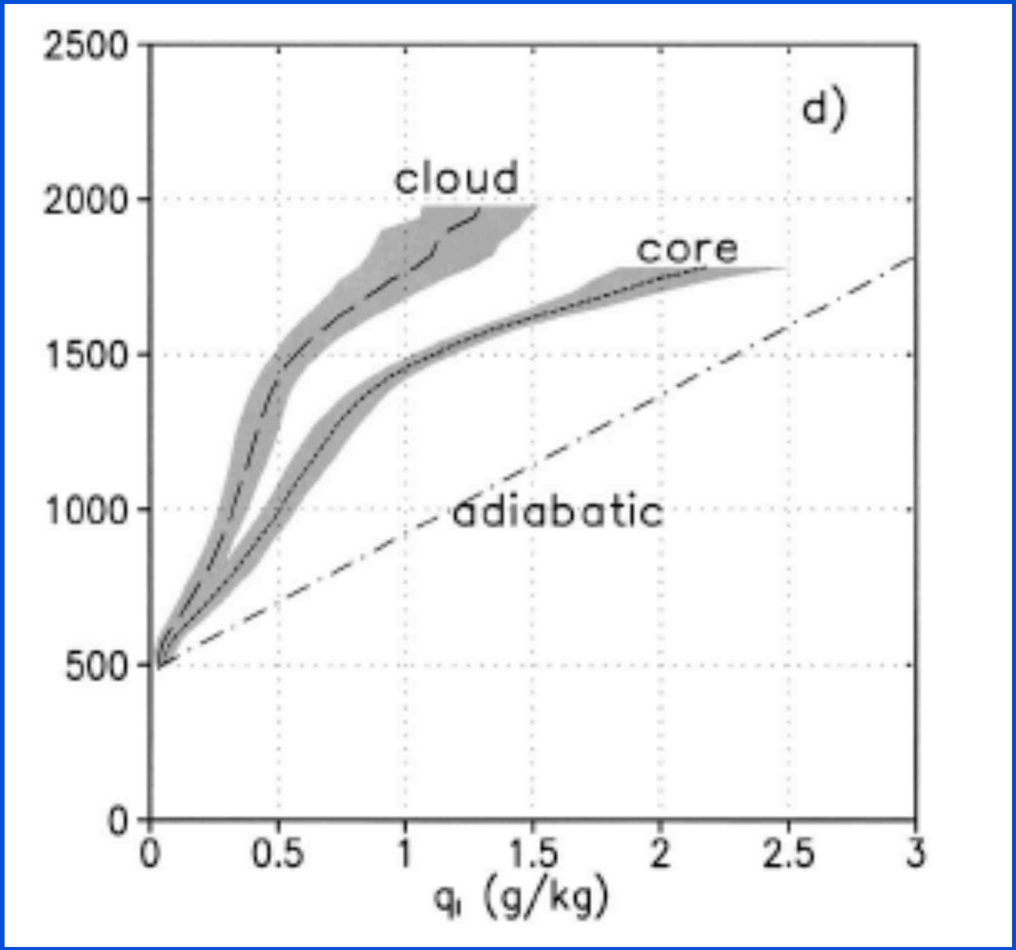
Level	LWC_a (g/m^3)	LWC (g/m^3)	s (10 cm) (g/m^3)	s (50 cm) (g/m^3)	s (1000 cm) (g/m^3)	N (No/cc)	s [N] (No/cc)	r_{va} (μm)	r_v (μm)	s (r_v) (μm)
1	.605	.284	.084	.078	.063	95	12	11.4	9.2	2.0
2	1.00	.427	.142	.136	.128	97	22	13.5	10.6	3.1
3	1.42	.520	.160	.153	.145	112	25	15.2	10.2	1.7
4	2.11	.536	.196	.184	.173	116	11	17.3	10.6	2.4
5	2.46	.331	.142	.135	.125	54	35	18.2	11.9	3.7

Arabas et al. *GRL* 2009

ARABAS ET AL.: OBSERVATIONS OF CU MICROPHYSICS

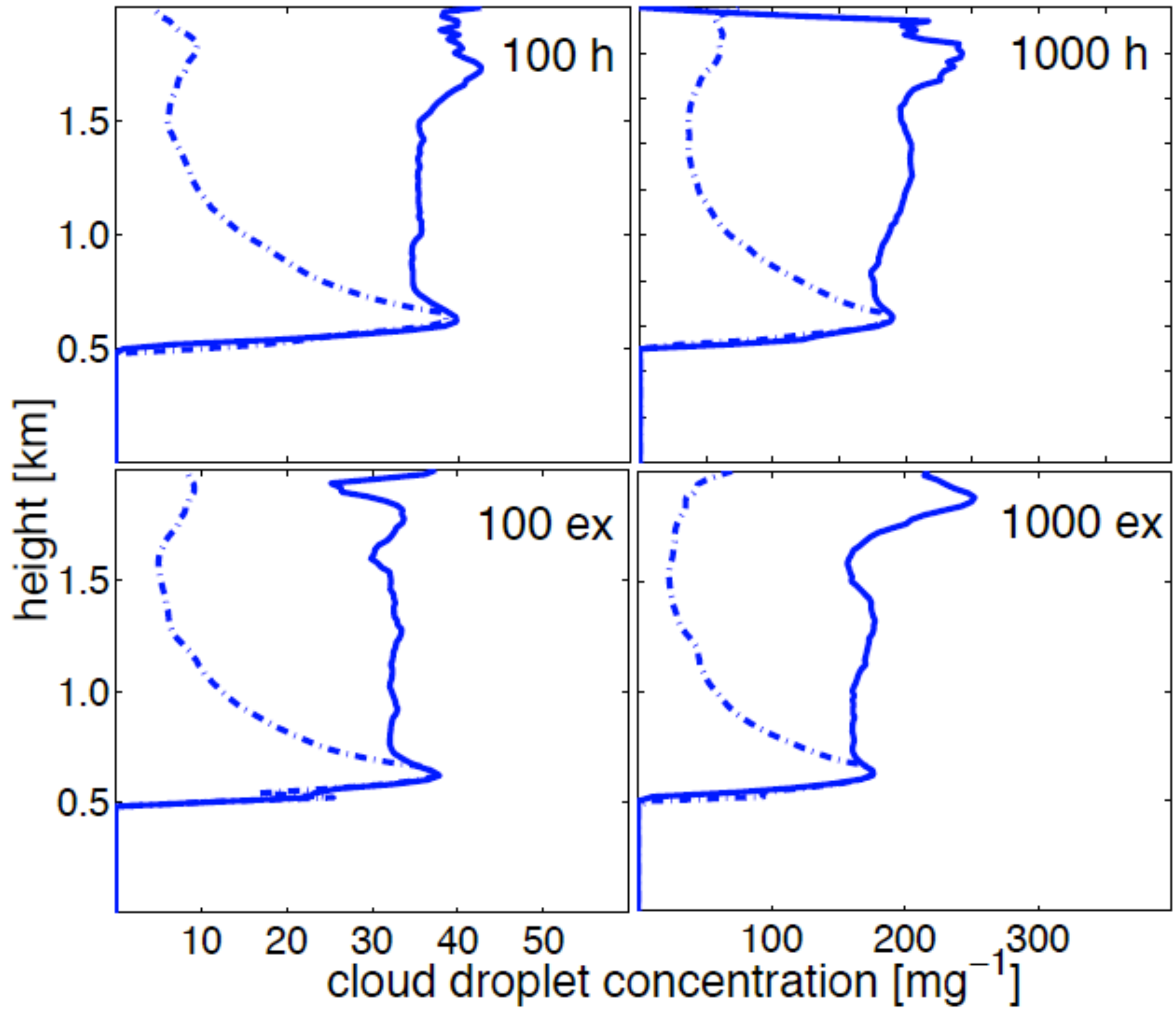


How is it possible that the dilution of the cloud water content is NOT accompanied by the dilution of the droplet concentration?

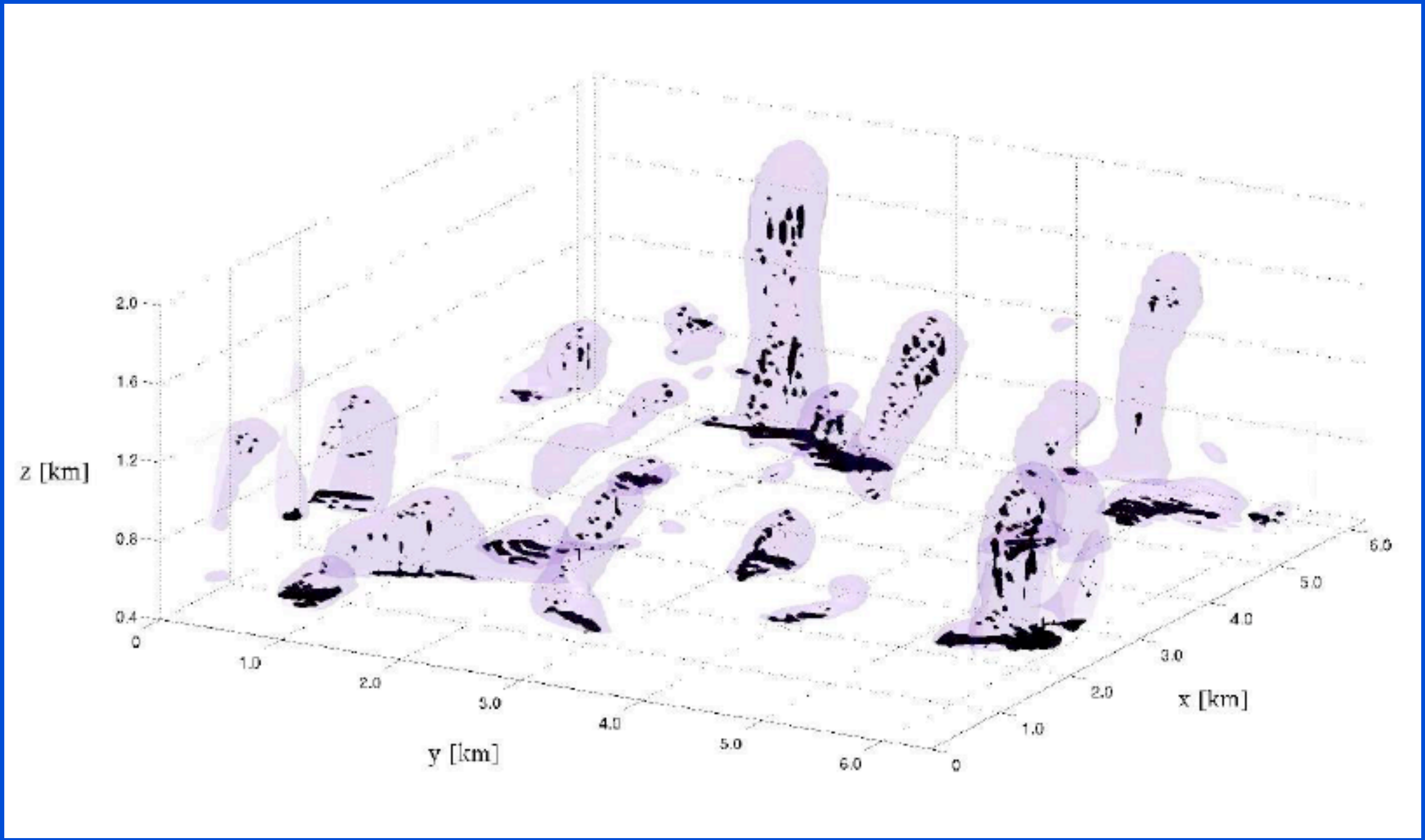


How is it possible that the dilution of the cloud water content is NOT accompanied by the dilution of the droplet concentration?

In-cloud activation (i.e., activation above the cloud base)!



100 h
1000 h
100 ex
1000 ex
height [km]
1.5
1.0
0.5
10
20
30
40
50
100
200
300
cloud droplet concentration [mg⁻¹]



Snapshot of 3D cloud water field (gray) and areas with significant activation of cloud droplets (black). BOMEX case. (Slawinska et al., in preparation).

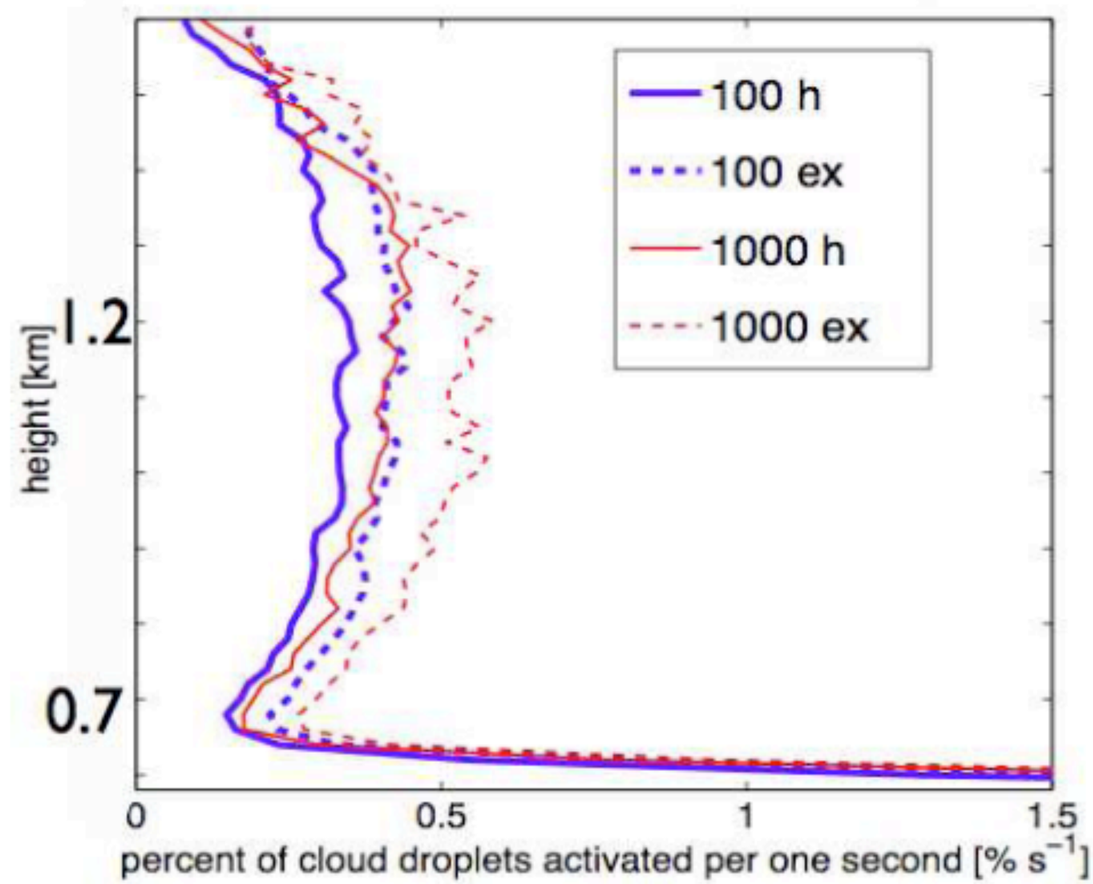
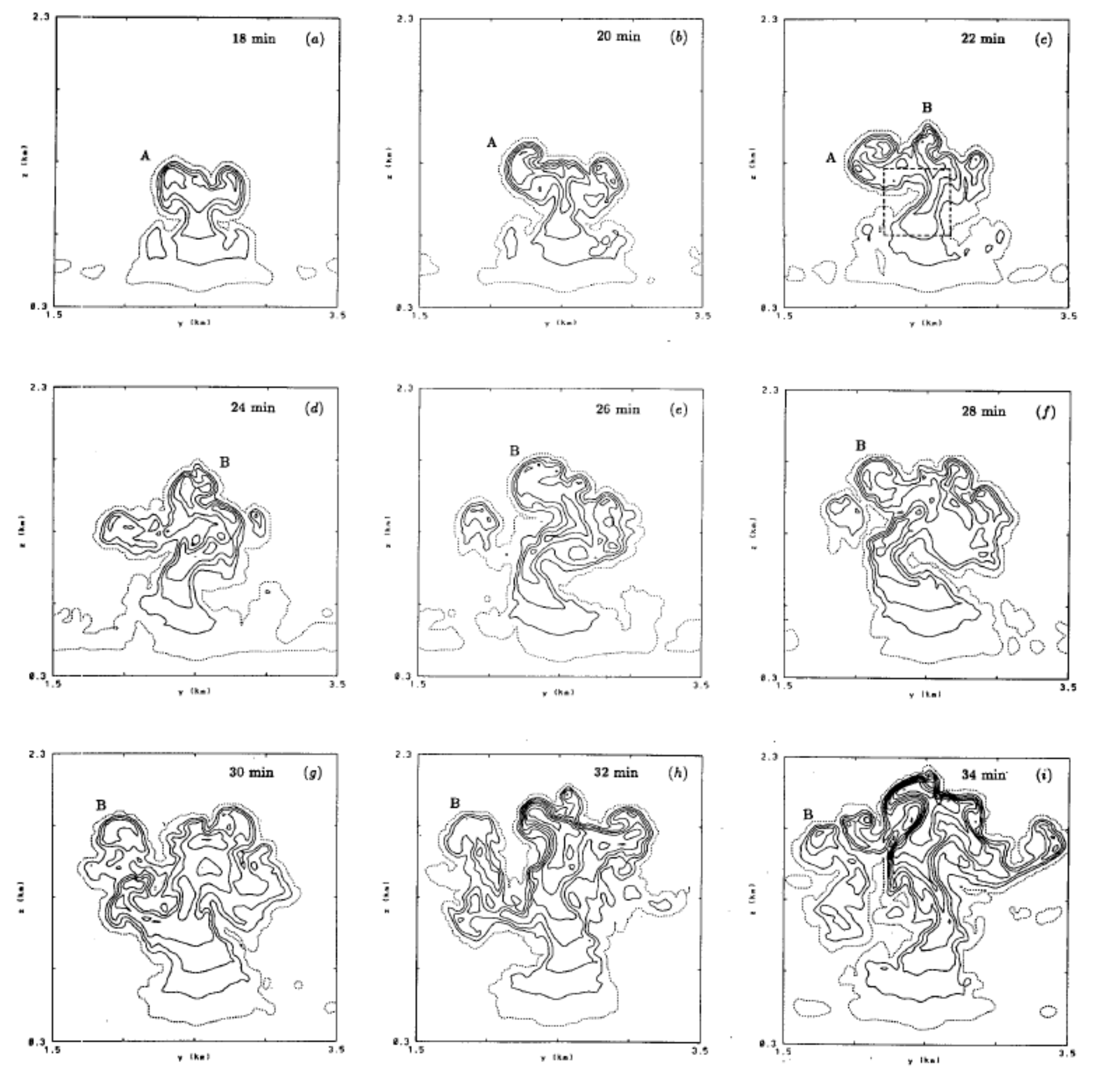
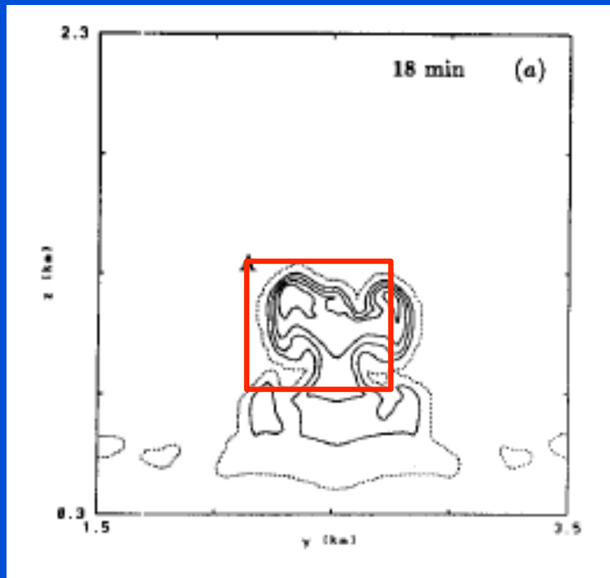
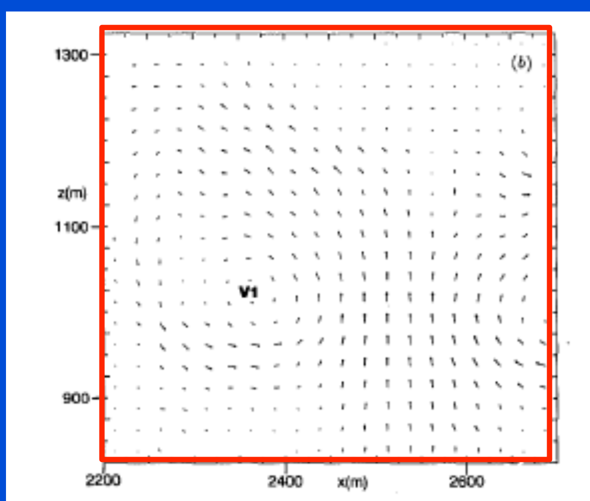


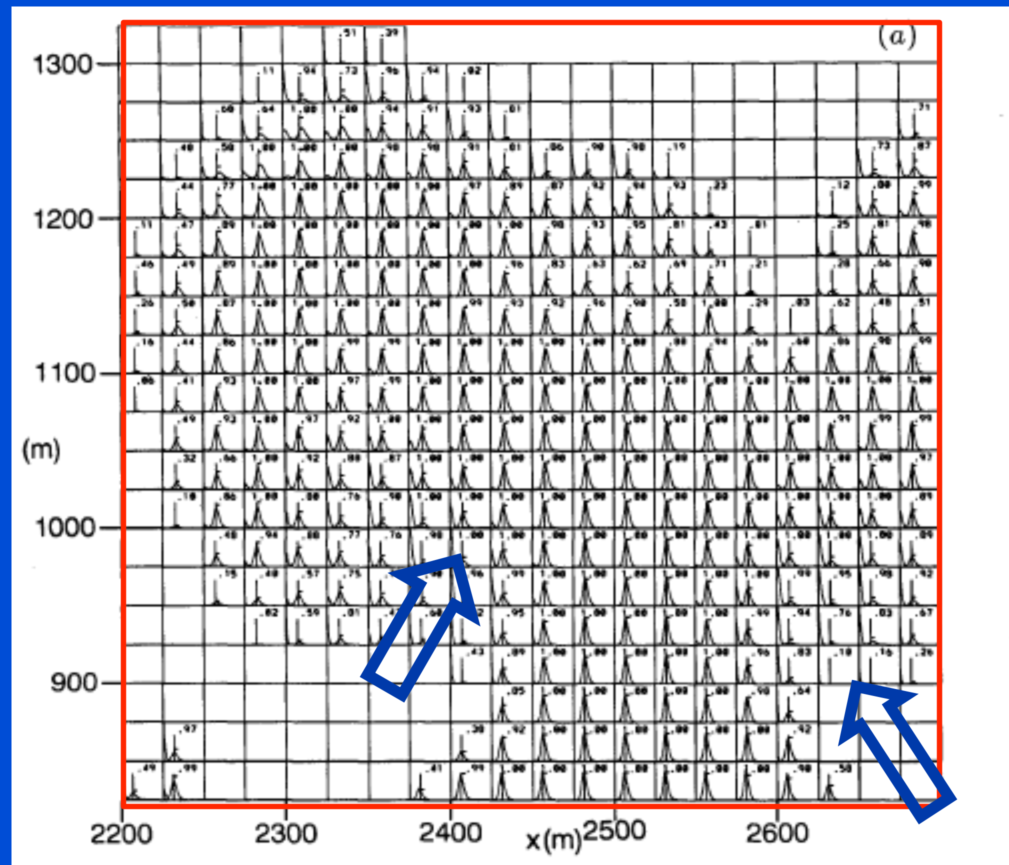
Figure 15: Vertical profiles of the ratio of the sum (over time and points from a given level) of total activation tendency and cloud droplet concentration for pristine (blue line) and polluted (red line) with prescribed either homogeneous (solid line) or extremely inhomogeneous (dashed line) mixing scenario.



Brenguier and Grabowski (JAS 1993)







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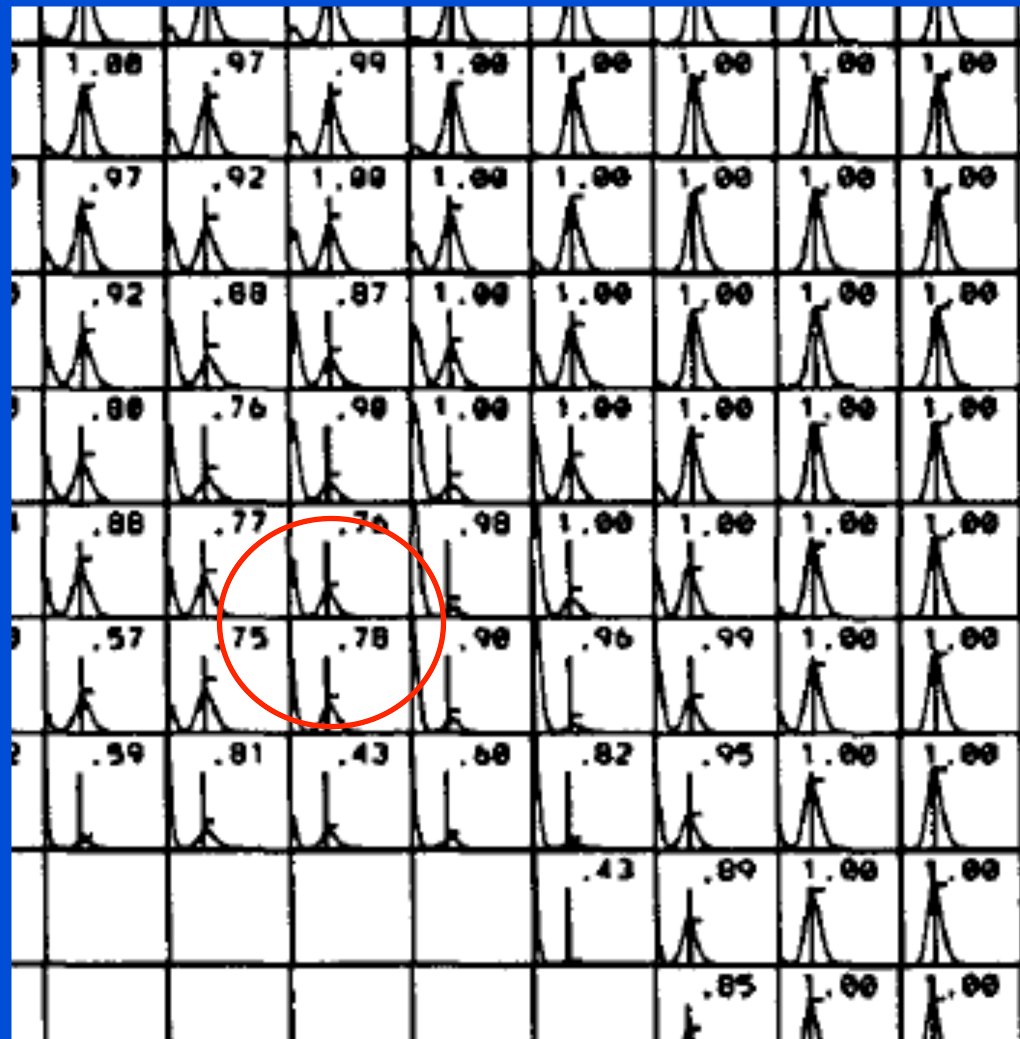
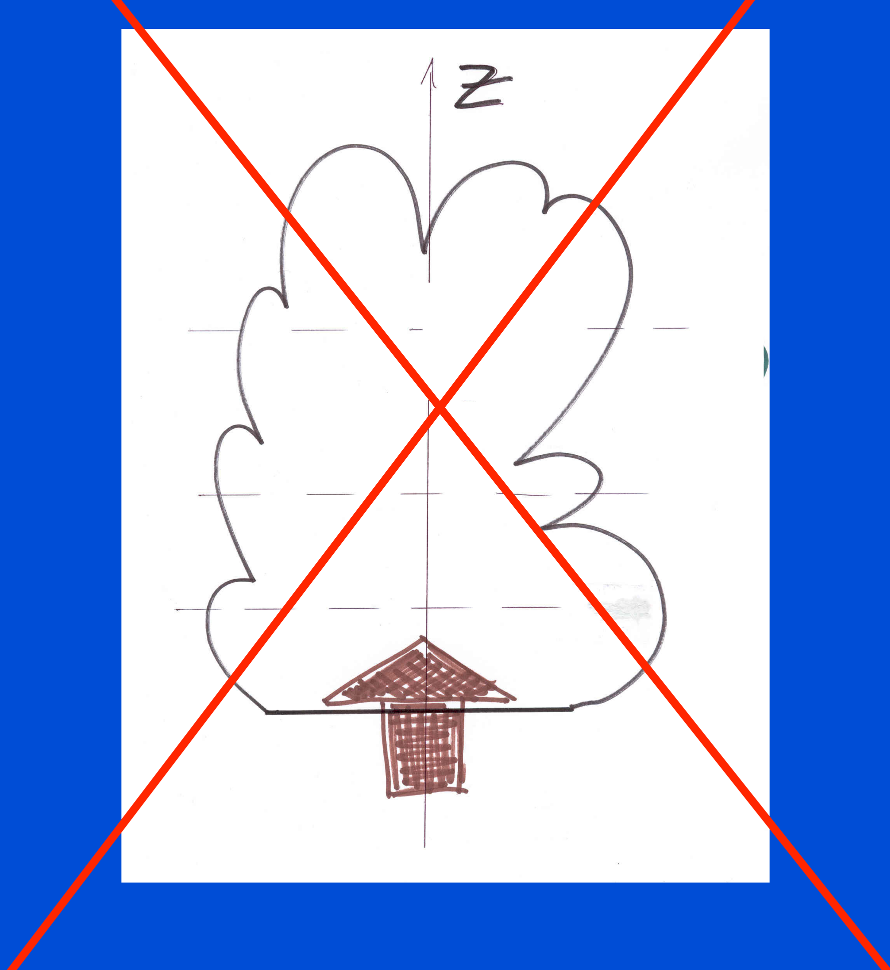
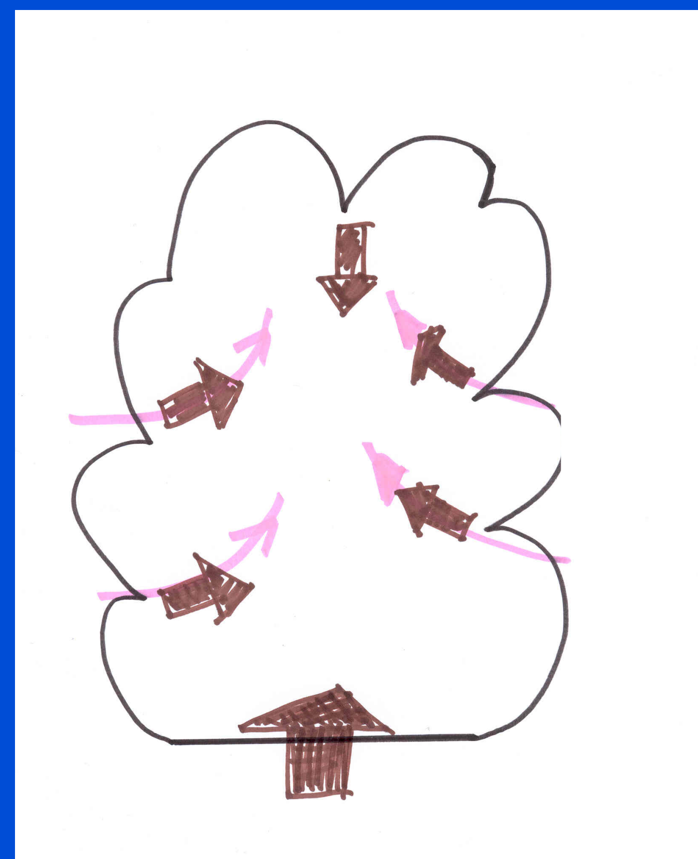


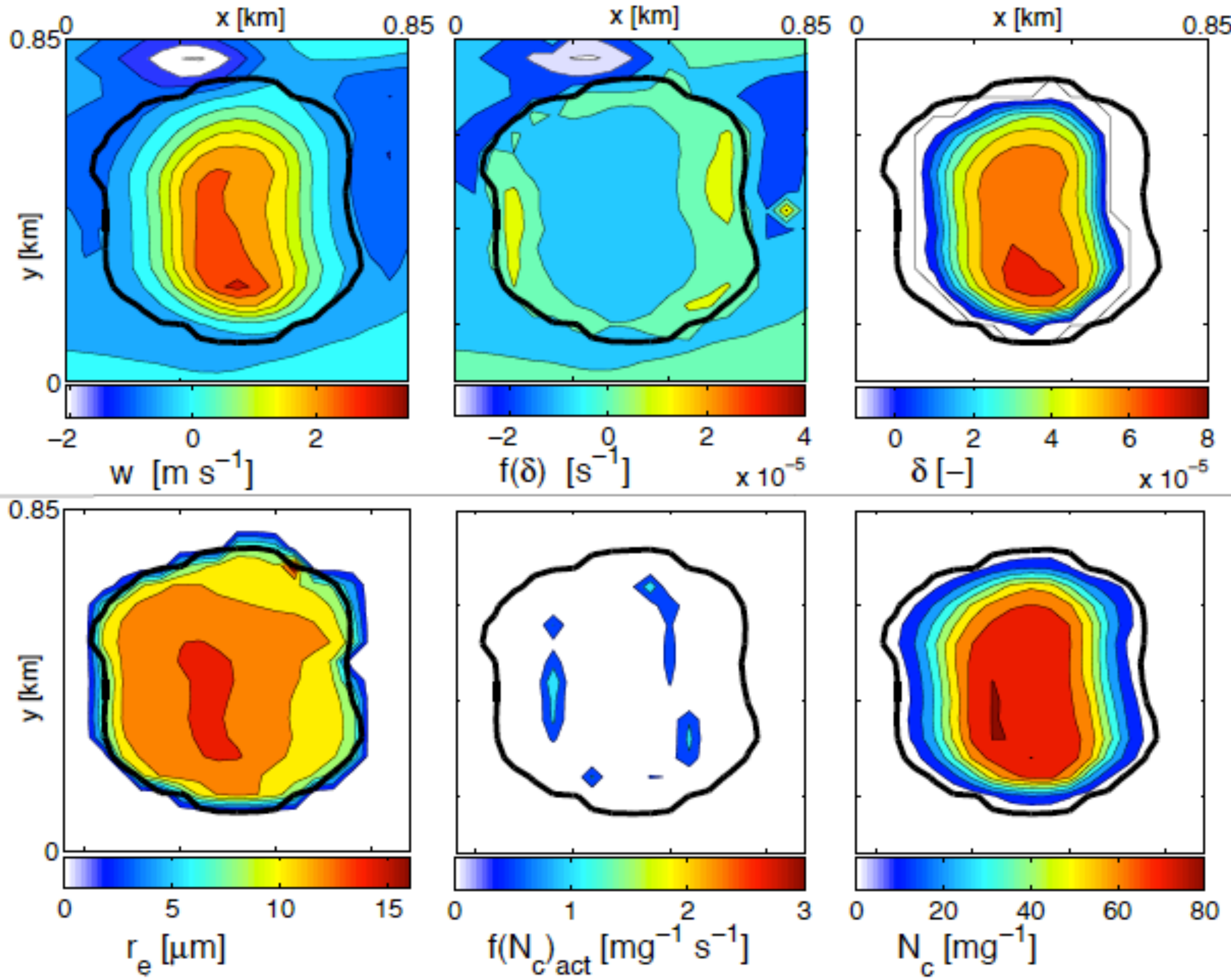
Brenguier and Grabowski (JAS 1993)

traditional view

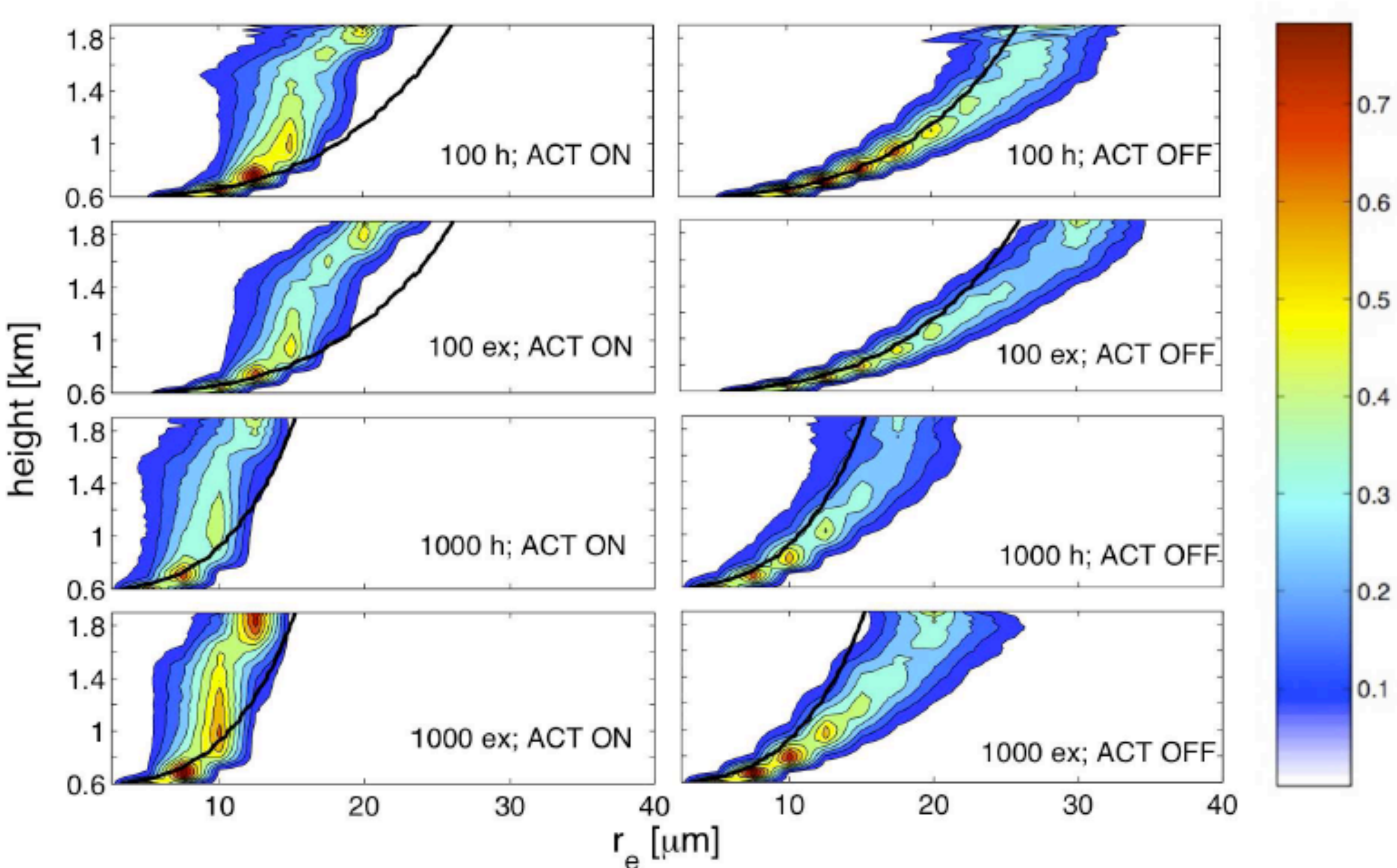


view suggested by model simulations





x [km]
0
0.85
y [km]
w [m s−1]
−2
0
2
f(δ) [s−1]
x 10−5
−2
0
2
4
δ [−]
x 10−5
0
2
4
6
8
r_e [µm]
0
5
10
15
f(N_c)_act [mg−1 s−1]
0
1
2
3
N_c [mg−1]
0
20
40
60
80



100 h; ACT ON
100 h; ACT OFF
100 ex; ACT ON
100 ex; ACT OFF
1000 h; ACT ON
1000 h; ACT OFF
1000 ex; ACT ON
1000 ex; ACT OFF
height [km]
r_e [μm]
1.8
1.4
1
0.6
10
20
30
40
0.1
0.2
0.3
0.4
0.5
0.6
0.7

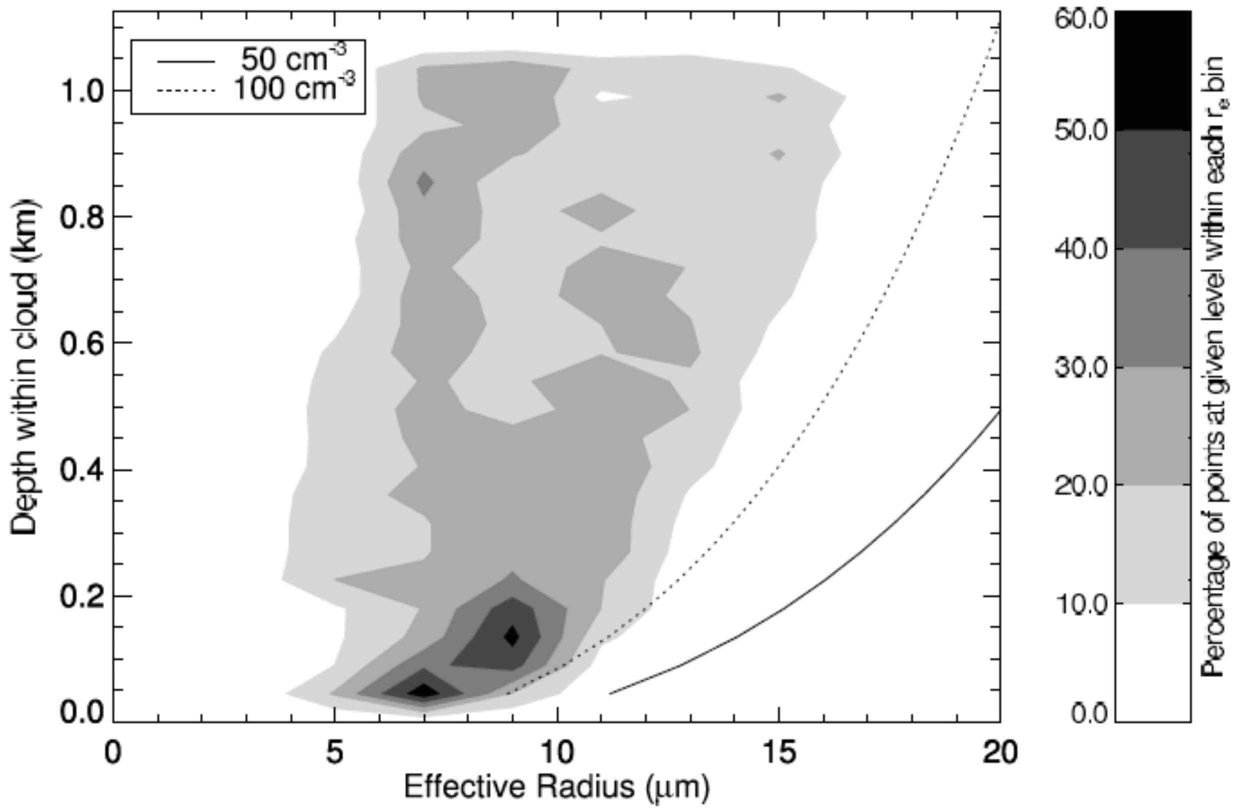


Figure 5: CFAD of the effective radius using 2 μm wide bins for the entire data set analyzed in the study of McFarlane and Grabowski (2007). Effective radius for adiabatic clouds with droplet concentrations of 50 and 100 cm^{-3} are shown by solid and dashed lines, respectively. Taken from McFarlane and Grabowski (2007).

Table 2: Optical thickness (τ), mean effective radius ($\overline{r}_e$), mean TOA albedo (A_{cloudy}) and cloud droplet lifetime (τ_d) for pristine (100) or polluted (1000) cases with homogeneous (h) or extremely inhomogeneous (ex) mixing scenario, with in-cloud activation turned on (ACT ON) or off (ACT OFF). See text for details.

	τ	$\overline{r}_e$ [μm]	A_{cloudy}	τ_d [min]
100 h; ACT ON	6.28	18.37	0.270	4.00
100 ex; ACT ON	5.64	18.77	0.265	3.20
1000 h; ACT ON	9.68	11.37	0.347	3.48
1000 ex; ACT ON	8.52	11.71	0.338	2.91
100 h; ACT OFF	5.14	24.62	0.238	4.20
100 ex; ACT OFF	5.48	27.43	0.233	3.48
1000 h; ACT OFF	7.37	15.61	0.308	4.53
1000 ex; ACT OFF	6.93	17.71	0.289	3.71

Conclusions:

Activation of cloud droplets above the cloud base is essential for realistic simulation of cloud microphysics. In simulations reported here, about 40% of cloud droplets is activated above the cloud base. Only with in-cloud activation, key features of observed shallow cumuli can be simulated (e.g., constant mean concentration of cloud droplets with height)

Activation seems to mimic entrainment-related activation observed in higher-resolution cloud simulation.