A Numerical Study on Impact of Hygroscopic Seeding on the Development of Warm Rain

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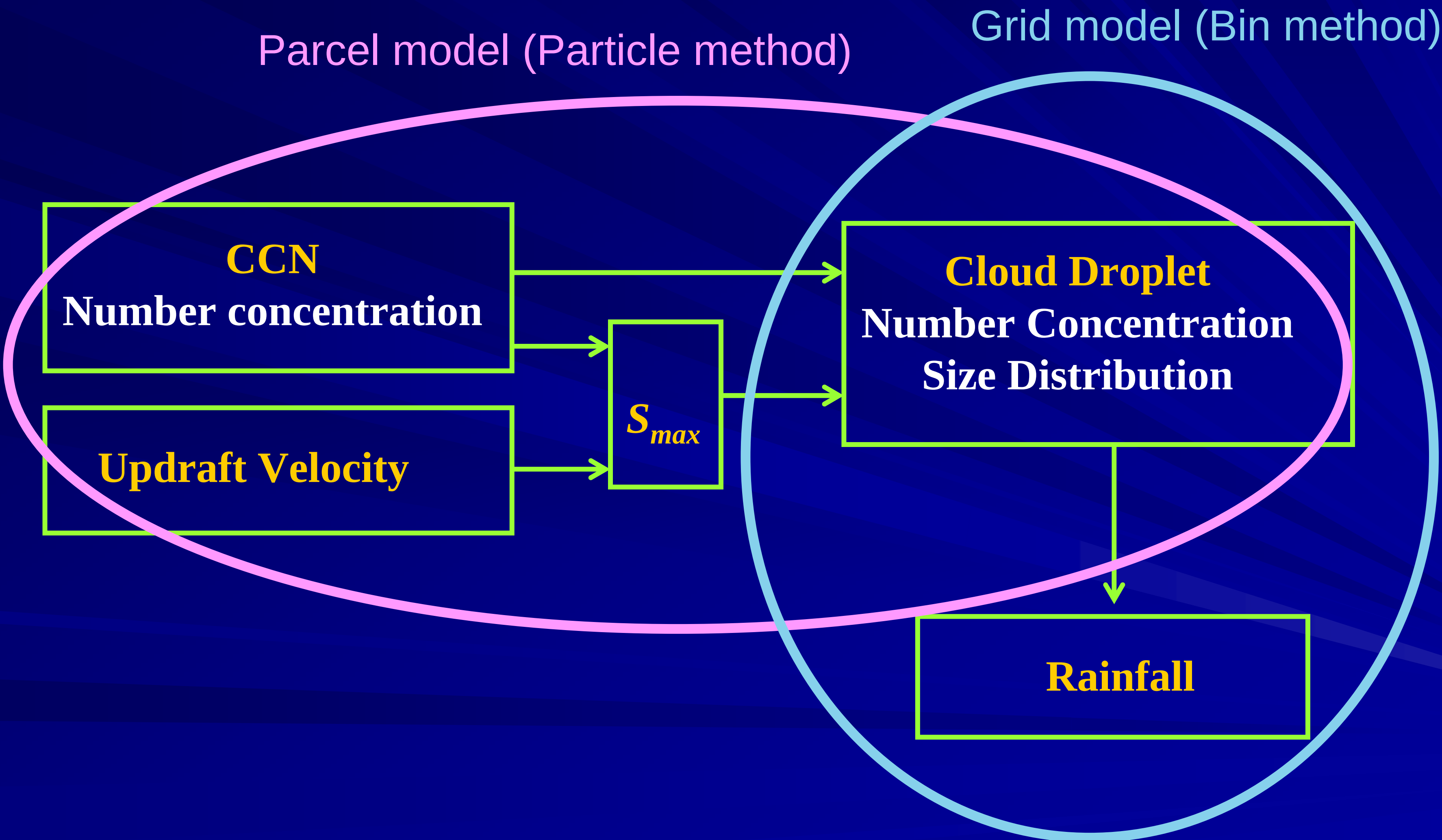
Hybrid Cloud-Microphysical Model



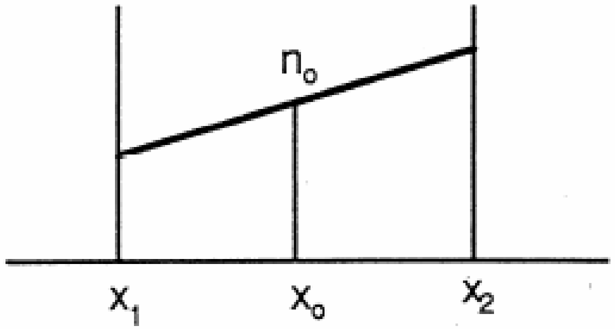
Two schemes for microphysics

	particle method (in the parcel)	bin method (on the grid)
Framework	Lagrangian	Semi-Lagrangian
Fixed values	n_j $(j = 1, 2, \ldots, 184)$ Number concentration of CCN included in each class	$r_i = r_1 2^{(i-1)/3k}$ $(i = 1, 2, \ldots, 73)$ Representative radius of droplets included in each bin.
Variable values	$r_j(t)$ Radius of droplets forming on CCN included in each class.	$n_i(t)$ Number concentration of droplets included in each bin.
Activation	Takeda and Kuba (1982)	not considered
Condensation	Takeda and Kuba (1982)	2 - moment bin method (Chen and Lamb, 1994)
Coalescence	not considered	2 - moment bin method (Chen and Lamb, 1994)
Δt	0.05 s	0.5 s

2 moment bin model (bin shift method : **Chen and Lamb, 1994**)

Total number
Total mass

$$n(x) = n_o + k\,(x - x_o)$$



→ mass, solute, shape, size

$$N = \int_{x_1}^{x_2} n(x)\,dx, \tag{3.3}$$

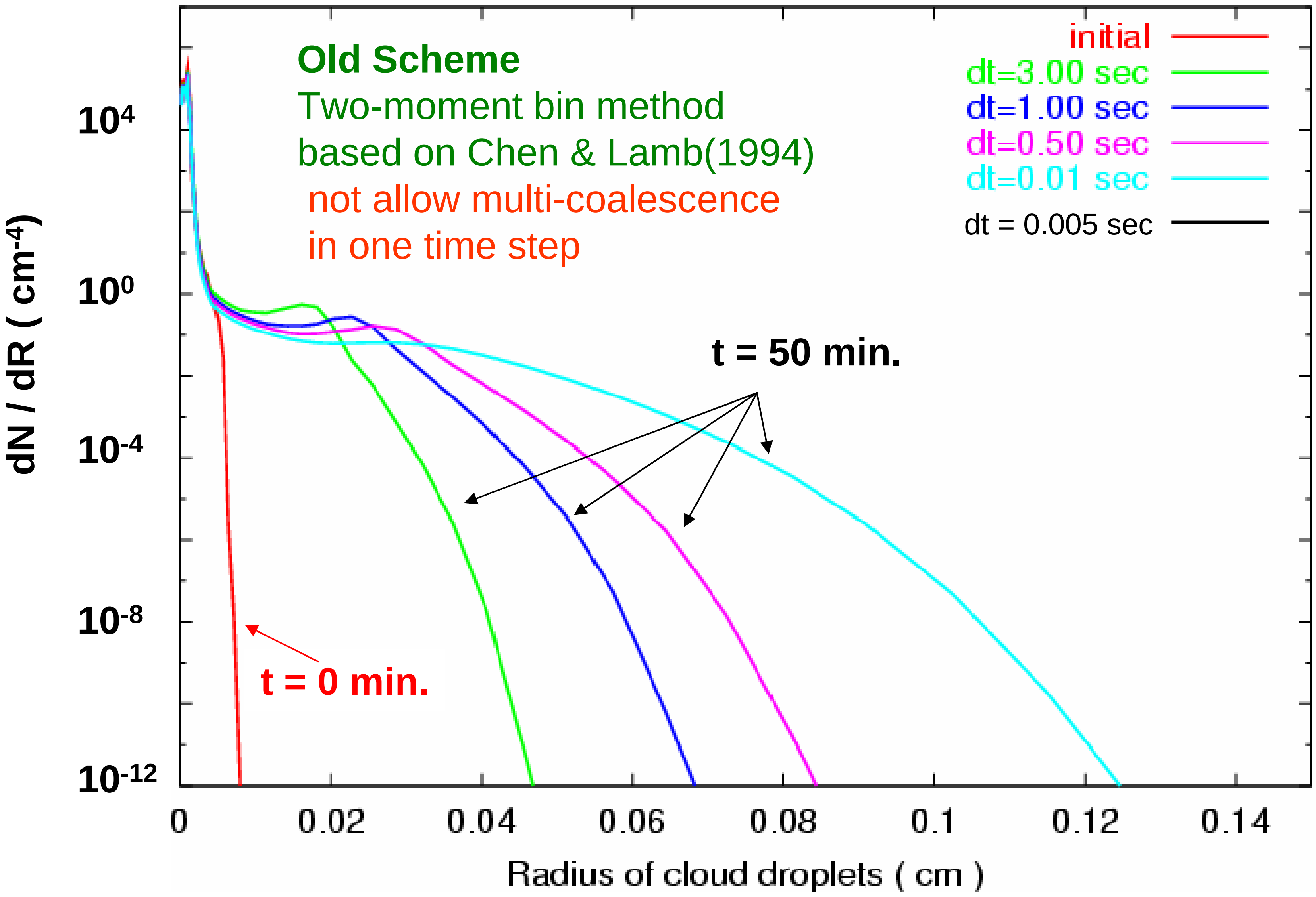
$$M = \int_{x_1}^{x_2} x\,n(x)\,dx, \tag{3.4}$$

$$n_o = \frac{N}{x_2 - x_1}, \text{ and } k = \frac{12(M - x_o N)}{(x_2 - x_1)^3}, \tag{3.5}$$

$$\text{where } x_o = \frac{x_1 + x_2}{2}.$$

Scheme of coalescence

Size Distribution of Cloud Droplet at t = 50 min. (coalescence only)



Multiple coalescences in one time step (following to Chen's doctoral thesis (1992))

$P(i, j)$: Probability (or number) of coalescence of a particle in i-th bin with particles in j-th bin for one time step (radius (i) > radius (j))

if $\sum_{j=1}^{i} P(i, j) \leq 1$ → **general stochastic coalescence**

if $\sum_{j=1}^{i} P(i, j) > 1$ and $\sum_{j=k}^{i} P(i, j) \leq 1$

→ i + k ~ i : **general stochastic coalescence**

rare and lucky

→ i + 1~ (k-1) : **continuous coalescence**

frequent (evenly shared)

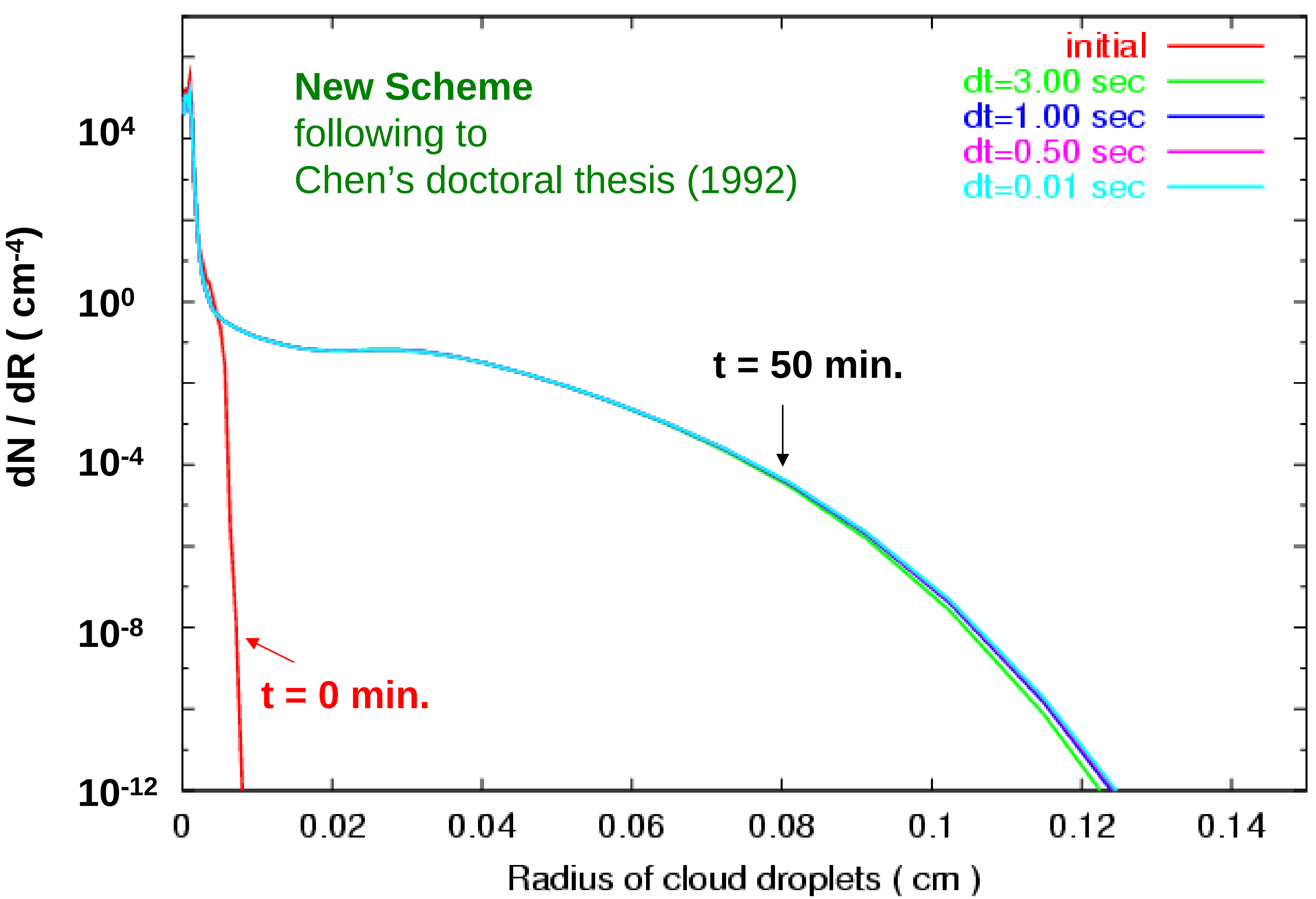
ex. when $P(i, j) = 2.8$

all particles in i-th bin coalesce 2.8 particles in j-th bin

collector (i)

collected particle (k ~ i ; 1~ (k-1))

Size Distribution of Cloud Droplet at t = 50 min. (coalescence only)



Coalescence Efficiency E_{coal}

Seifert, A., A. Khain, U. Blahak, and K. D. Beheng, 2005:
Possible effect of collisional breakup on mixed-phase deep convection simulated by a spectral (bin) cloud model. *J. Atmos. Sci.*, **62,** .1917-1931.

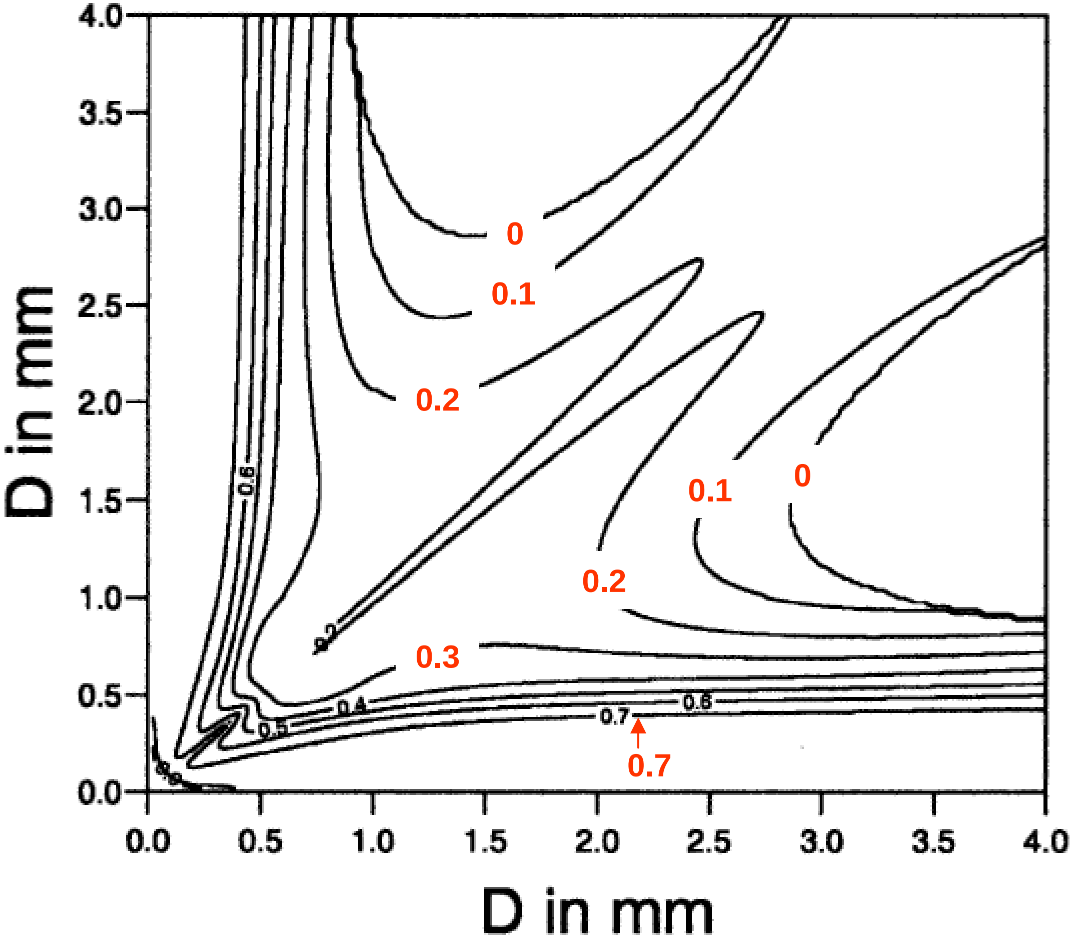


FIG. 3. Same as Fig. 1, but according to Eq. (5), after Beard and Ochs (1995) and Low and List (1982b).

Parcel model is triggered

Bin on the grid point

When relative humidity at the grid point reaches 100% for the first time

→ Initial cloud droplets size distribution

When relative humidity at the grid point is larger than 100% and cloud water on the windward side of the point does not exist

→ Influx of droplets from the windward

WMO 5th Cloud Modeling Workshop

2000, Aug, 7-11
Glenwood Springs, Colorado, U.S.A.

Case1-Warm Rain Development

Provided by Szumowski et al. (1998)

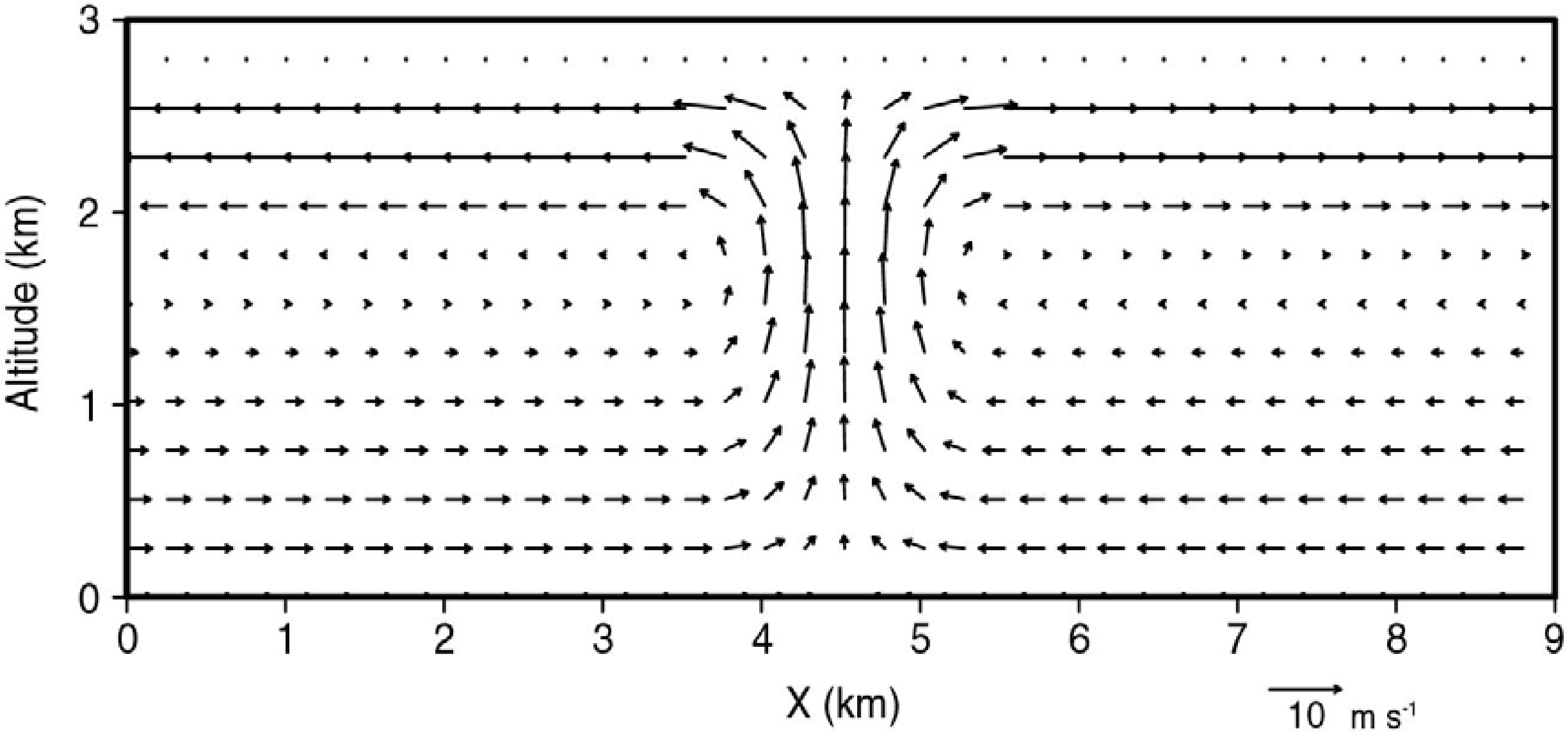
Dynamical flame

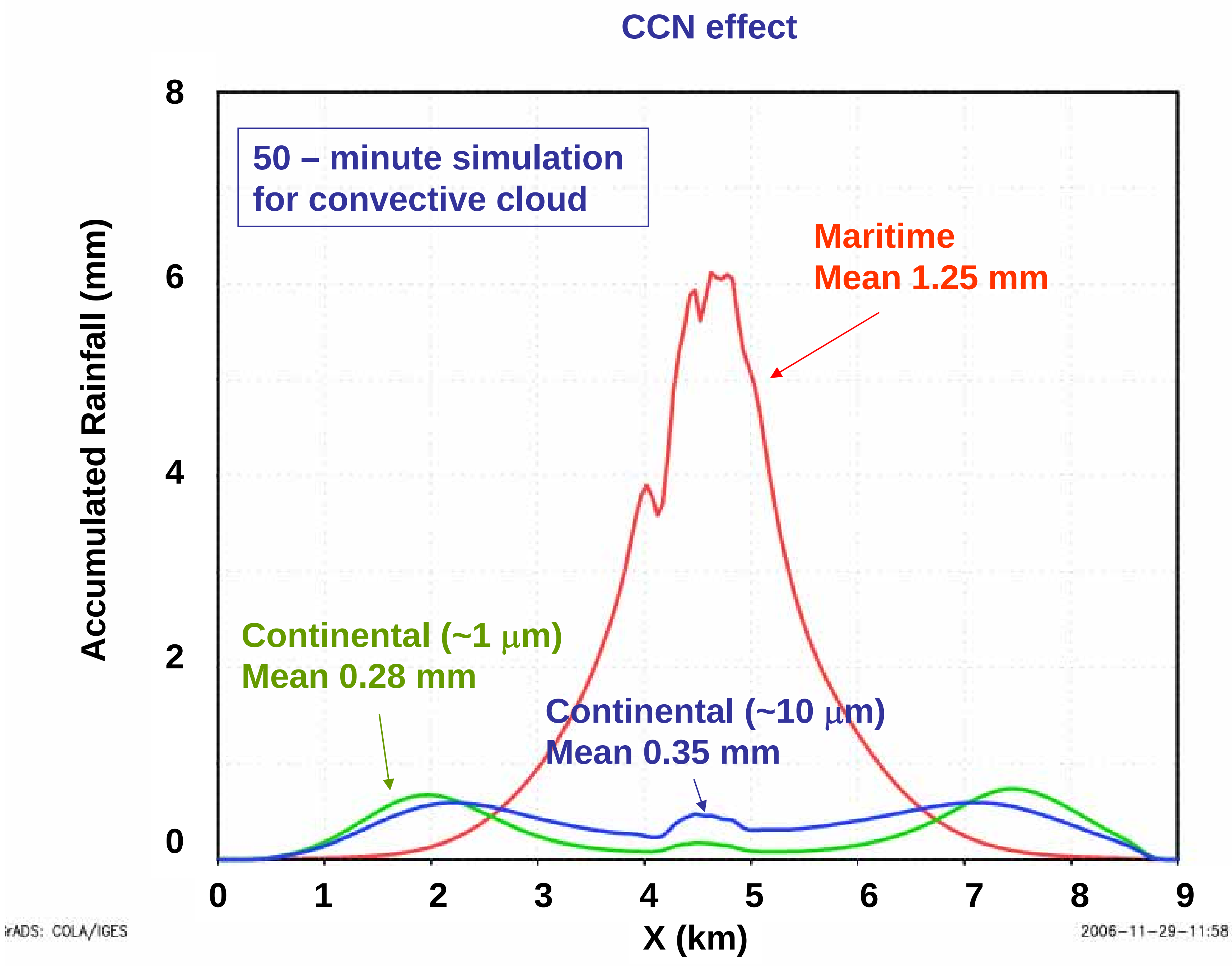
flow field : 2D shallow convection (time dependent flow function)
domain : 9 km wide x 3 km deep
Δx, Δz : **50 m**
Δt : **3 sec**
advection scheme: modified Smolarkiewicz (1984)

CCN spectrum $N_{CCN} = \mathrm{fn}(S)$ *etc.*

Wind Field (25 min)

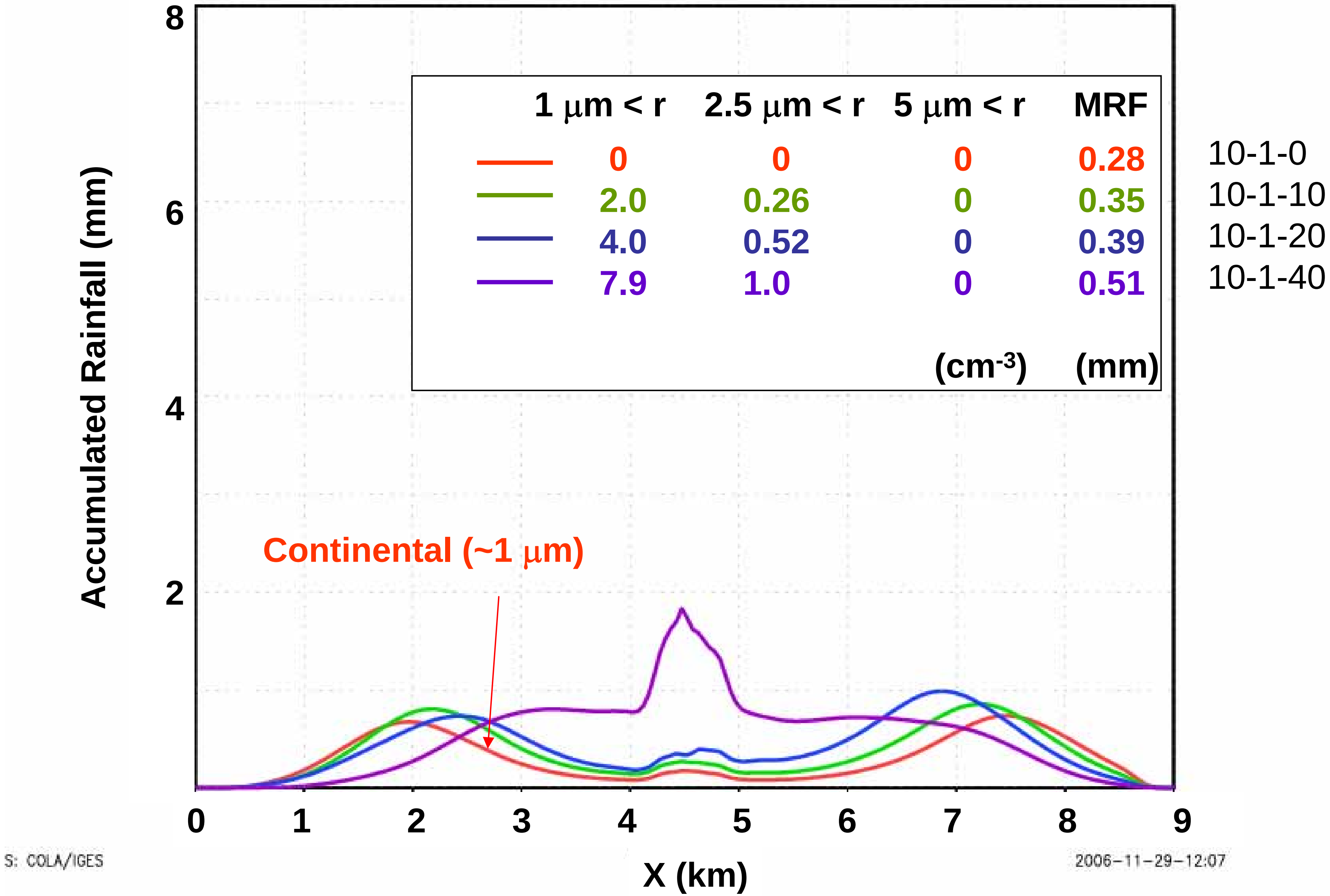
Shallow cumulus cloud



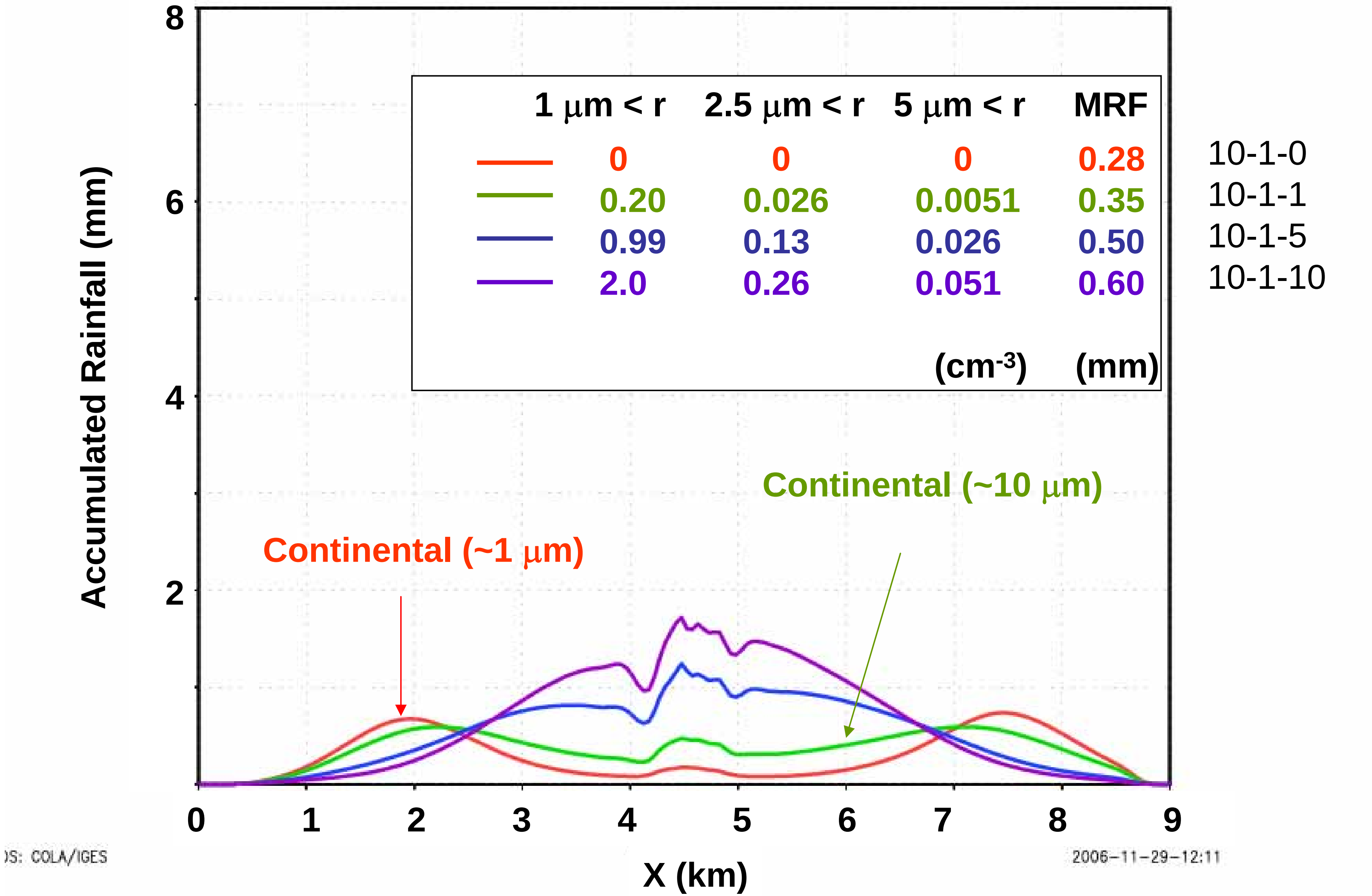


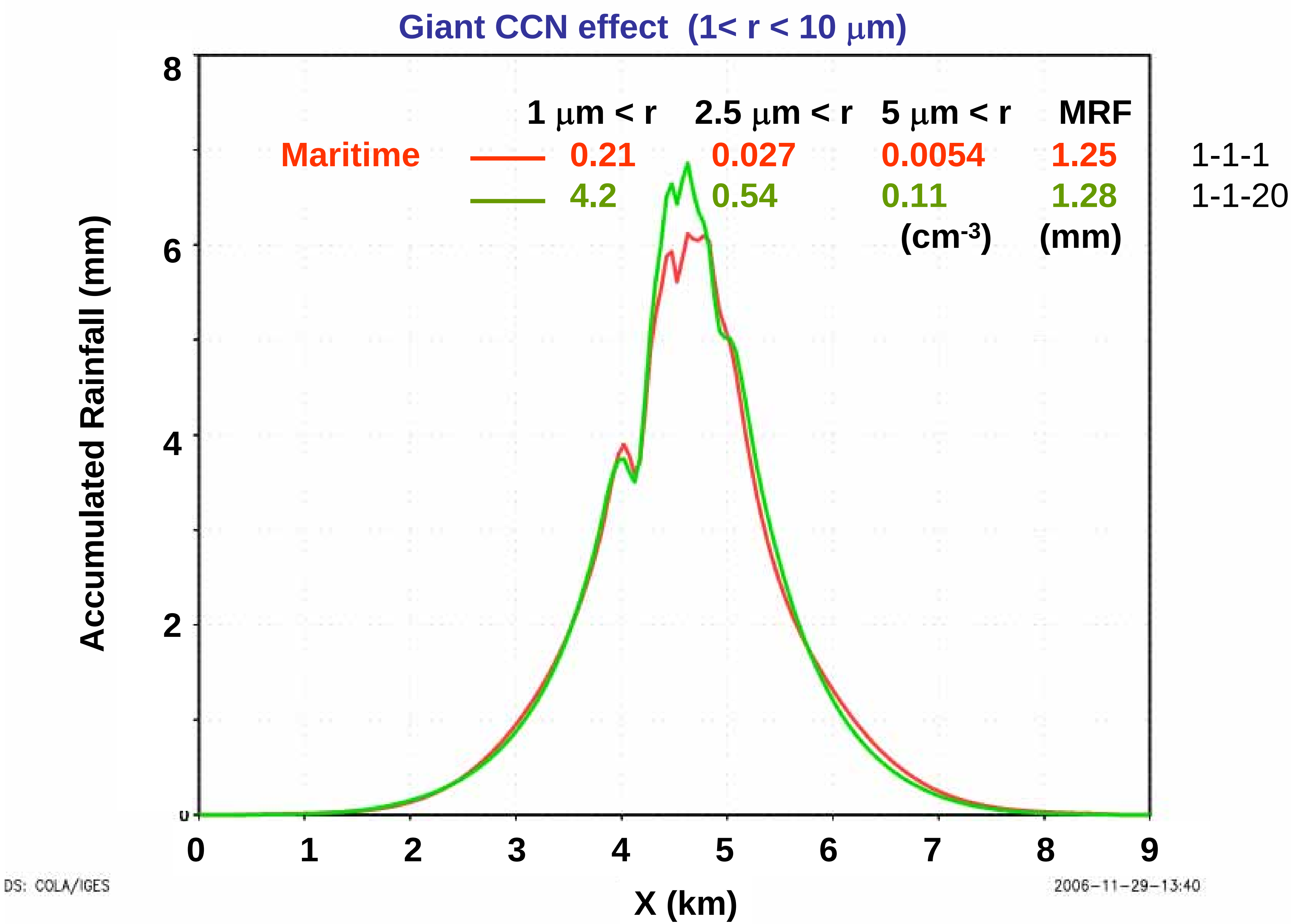
CCN effect
50 – minute simulation
for convective cloud
Maritime
Mean 1.25 mm
Continental (~1 μm)
Mean 0.28 mm
Continental (~10 μm)
Mean 0.35 mm
Accumulated Rainfall (mm)
0
2
4
6
8
0
1
2
3
4
5
6
7
8
9
X (km)
GrADS: COLA/IGES
2006-11-29-11:58

Giant CCN effect (1< r < 2.8 μm)



Giant CCN effect (1< r < 10 μm)





Giant CCN effect (1< r < 10 μm)
1 μm < r
2.5 μm < r
5 μm < r
MRF
Maritime
0.21
0.027
0.0054
1.25
1-1-1
4.2
0.54
0.11
1.28
1-1-20
(cm-3)
(mm)
Accumulated Rainfall (mm)
X (km)
DS: COLA/IGES
2006-11-29-13:40

Conditions for Hygroscopic Seeding

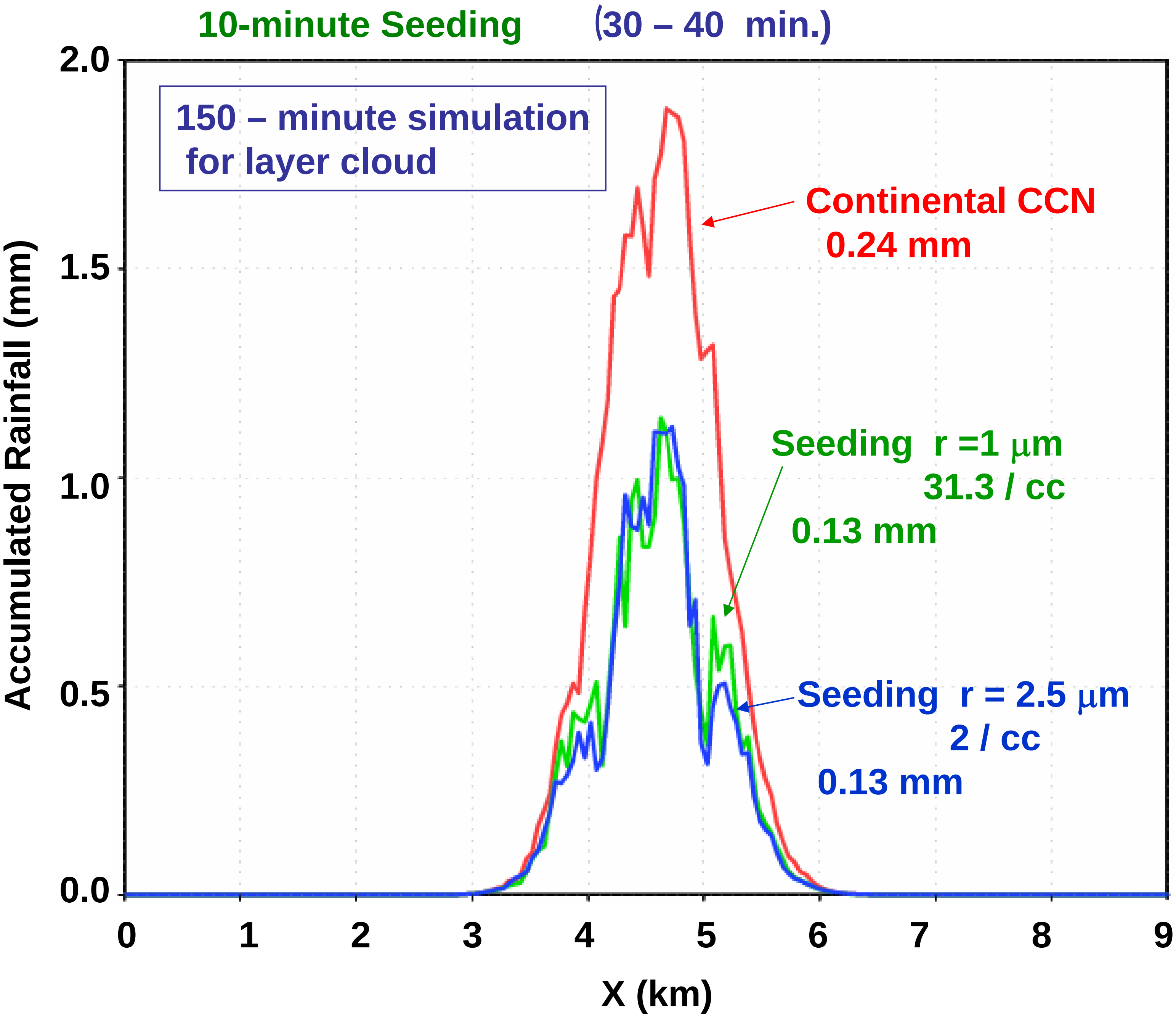
Airplane:

duration of seeding   10 minutes
area of seeding   under the cloud base

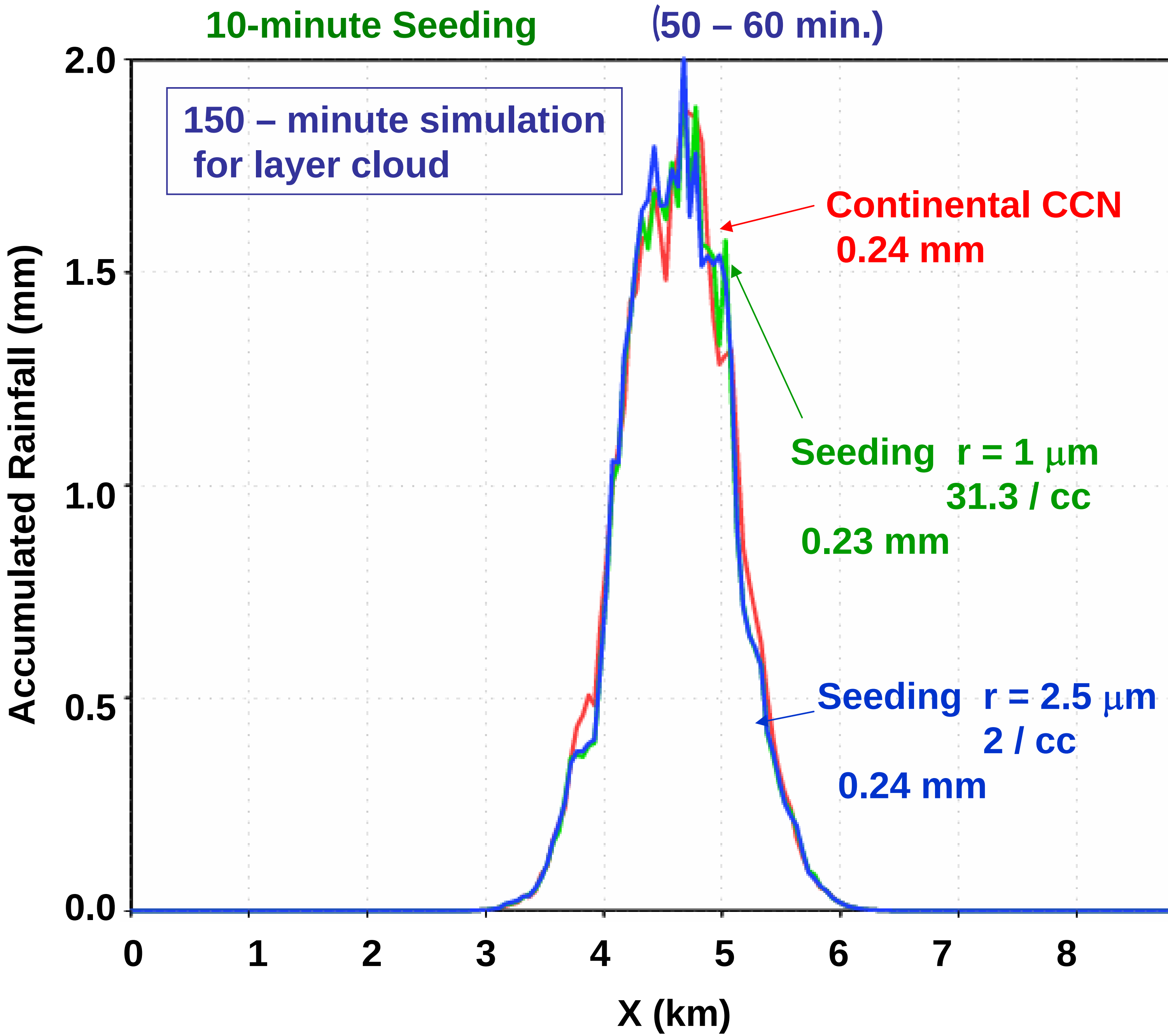
Seeding material: monodisperse (1 or 2.5 μm in radius)
NaCl
constant total mass

Cloud: 150-minute simulation

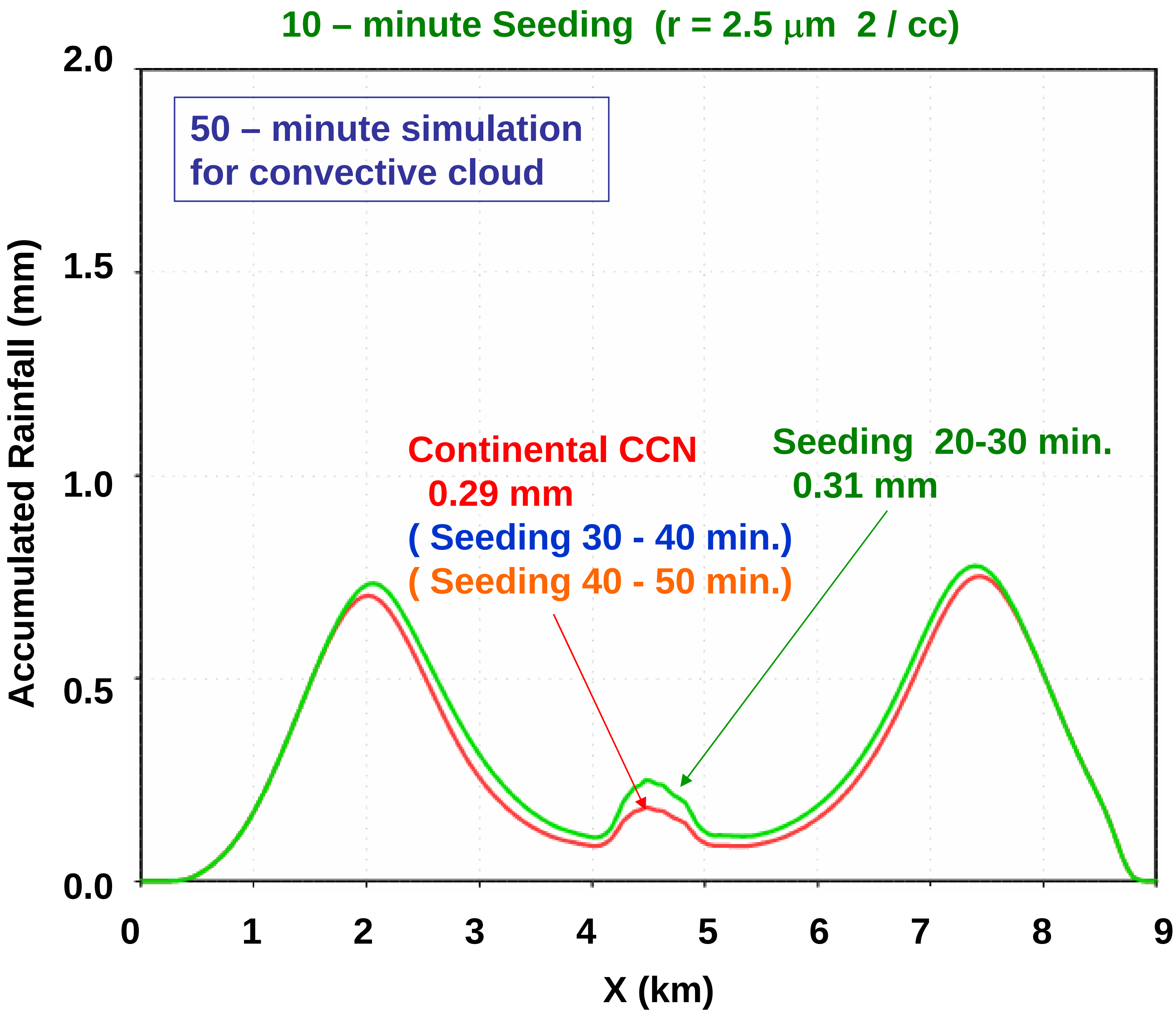
Uniform layer cloud (weak updraft   0.1 ~ 0.8 m / sec)



10-minute Seeding (30 – 40 min.)
150 – minute simulation
for layer cloud
Continental CCN
0.24 mm
Seeding r =1 μm
31.3 / cc
0.13 mm
Seeding r = 2.5 μm
2 / cc
0.13 mm
Accumulated Rainfall (mm)
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
8
9
X (km)



10-minute Seeding
(50 – 60 min.)
150 – minute simulation
for layer cloud
Continental CCN
0.24 mm
Seeding r = 1 μm
31.3 / cc
0.23 mm
Seeding r = 2.5 μm
2 / cc
0.24 mm
Accumulated Rainfall (mm)
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
8
9
X (km)



10 – minute Seeding (r = 2.5 μm 2 / cc)
50 – minute simulation
for convective cloud
Continental CCN
0.29 mm
(Seeding 30 - 40 min.)
(Seeding 40 - 50 min.)
Seeding 20-30 min.
0.31 mm
Accumulated Rainfall (mm)
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
5
6
7
8
9
X (km)

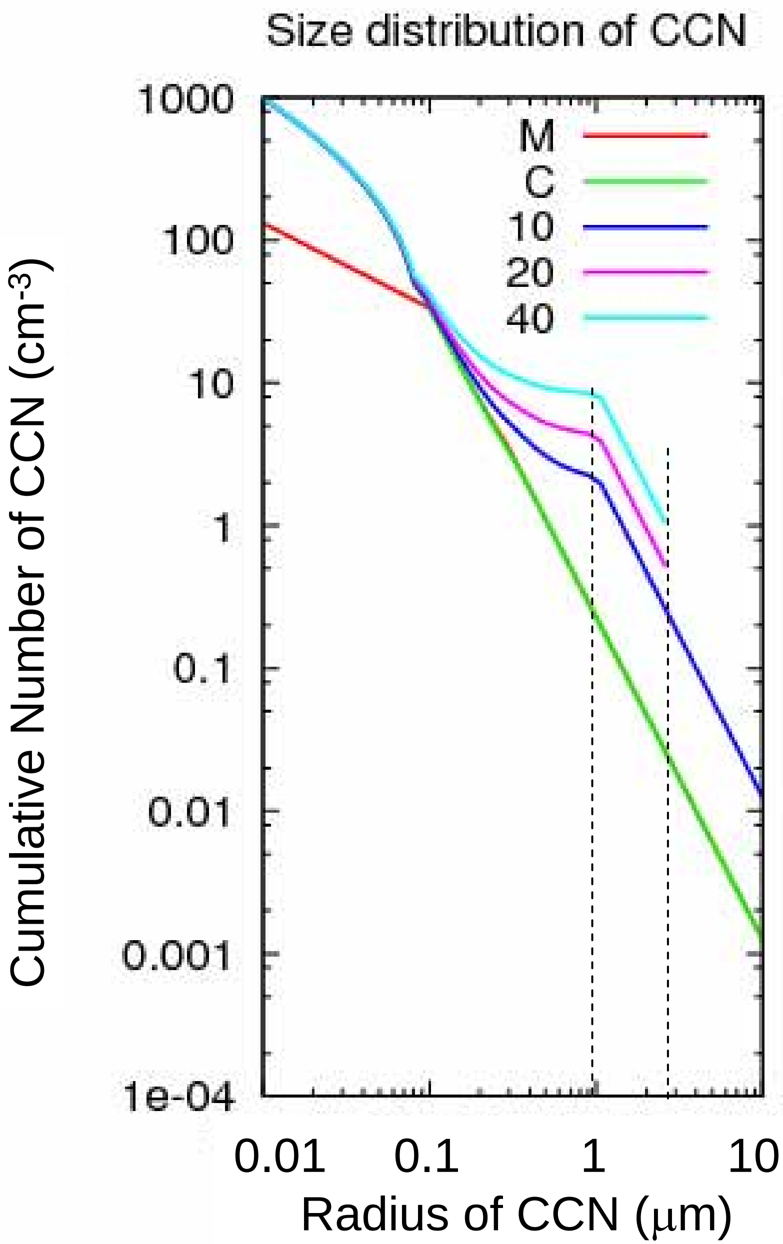
Summaries

Hybrid cloud-microphysical model is developed to estimate the effect of CCN on precipitation.

10-minnute seeding of 1 or 2.5 μm NaCl particles for small-updraft cloud is not effective in increasing rainfall.

More research (larger particles, larger updraft cloud, timing of seeding) should be tried.

Probably giant particle CCN are effective in increasing rainfall in only case with many small CCN and large updraft.



Size distribution of CCN
Cumulative Number of CCN (cm-3)
Radius of CCN (μm)
1000
100
10
1
0.1
0.01
0.001
1e-04
0.01
0.1
1
10
M
C
10
20
40

Effect of giant particle CCN on warm rain

	0.01μm < r	1 μm < r	2.5 μm < r	5 μm < r	MRF(mm)	Ratio
Continental	~1000	0	0	0	0.28	1.00
Seeding S10		2.0	0.26	0	0.35	1.25
S20		4.0	0.52	0	0.39	1.39
S40		7.9	1.0	0	0.51	1.82
Seeding L01		0.20	0.026	0.0051	0.35	1.25
L05		0.99	0.13	0.026	0.50	1.79
L10		2.0	0.26	0.051	0.60	2.14
Maritime	~100	0.21	0.027	0.0054	1.25	1.00
Seeding L20		4.2	0.54	0.11	1.28	1.02

Coalescence Efficiency E_{coal}

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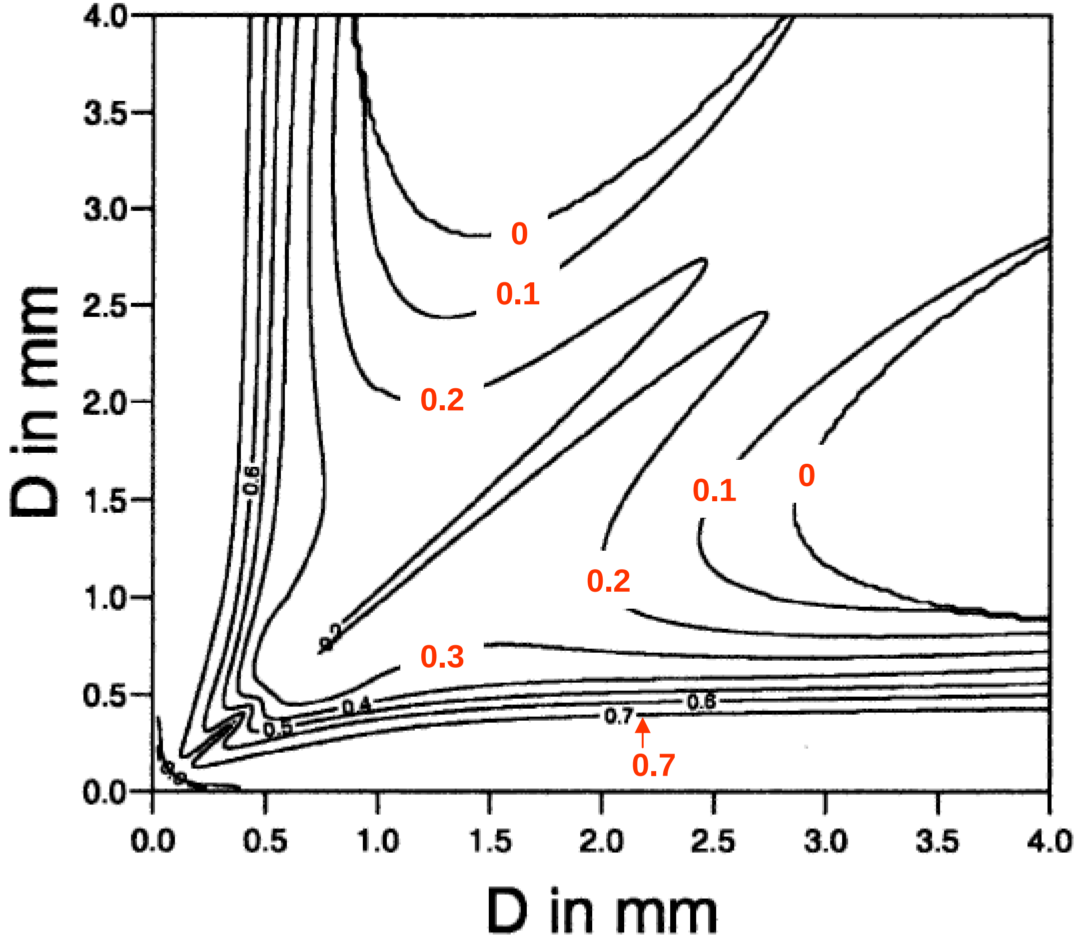

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