Numerical simulation of cumulus boundary layer: activation process of cloud condensation nuclei

ビン法雲微物理モデルを使った積雲境界層の再現実験：凝結核の活性化スキームと関連して

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RICO
RF-09
17 Dec 04
2004

Fields of trade wind congestus
typical cloud base 600 m
typical cloud top 2000-3000 m

Ⅰ. Objectives: To improve bulk parameterization scheme

Target : bulk scheme for warm rain (boundary layer clouds)

Boundary layer clouds are important for climate study.
Bulk parameterization schemes are used in large-scale models.
However, there are many ambiguous parameters in the schemes.
➡ To improve the bulk schemes, we will use the results of bin scheme models.

Model : CReSS with Kuba-Fujiyoshi bin model

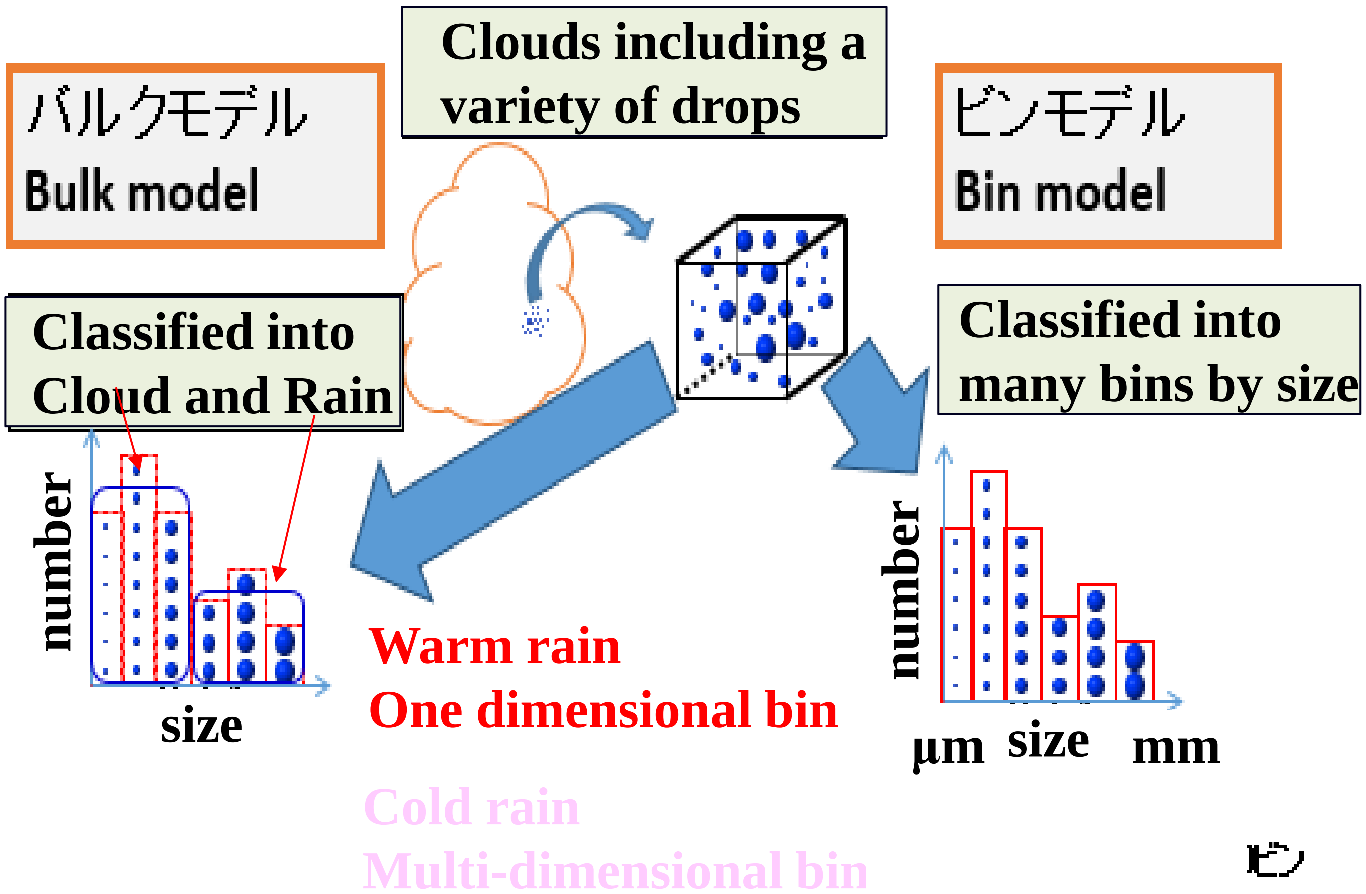
Case : RICO(Bermuda area, **trade wind cumulus**) model intercomparison case
↑GCSS(GEWEX cloud system study)

Results : layered structure (average potential temperature etc.), is well simulated, however, …

Problems and what to do :

There are many differences between the results of bin models.
Also in bin models, there are many ambiguities.
Improve the bin model by intercomparison experiments using KiD (**Kinematic Driver for microphysics intercomparison**) and comparison of the results with observations.

What occurs in clouds and what we are modeling



Processes included

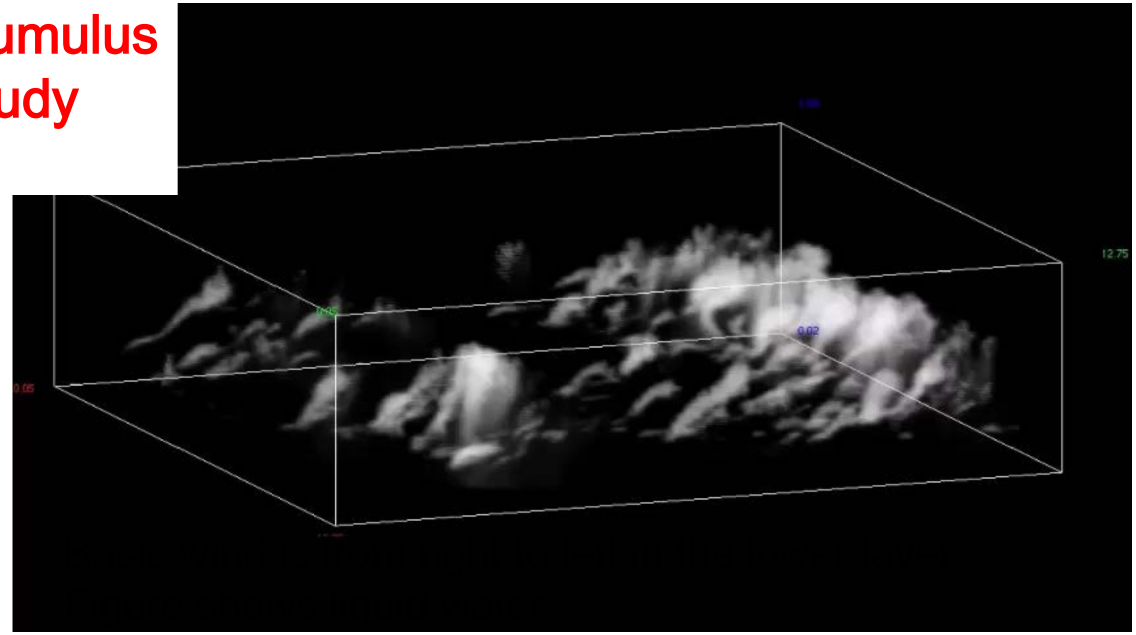
1. **Activation of aerosols**
   maximum value of super saturation determines the number of activated aerosols
2. **Deposition growth**
   the difference of the basic equations is whether the integration of time is used or not.
3. **Collision-coalescence**
   whether the kernel of the collision includes the effect of turbulence.

We used 71 bins whose ratio of mass between adjacent bins is $2^{1/2}$. However, for comparison, the results with 34 bins will be presented.

The details of the differences of the bin models will be omitted.

II. Intercomparison experiments (GCSS-RICO)

RICO：Bermuda area, trade wind cumulus
Case of GEWEX　Cloud System Study
http://www.knmi.nl/samenw/rico/



Grid
$\Delta x = \Delta y = 100$m, $\Delta z = 40$m

Domain Size 12.8km×12.8km× 4.0km
Number of Grids 128 x 128 x 100

Geostrophic Wind (cyclic lateral B.C.)
u：constant vertical shear 2x10^{-3} s^{-1}
v：uniform
pot. temp., water vapor

Bottom surface B.C.
SST: 299.8K　ΔT=0.6℃

Large scale forcings
Subsidence z> 2260m : w = -0.005[m/s
z<2260m : Constant Divergence
Horizontal advection (depending on z)

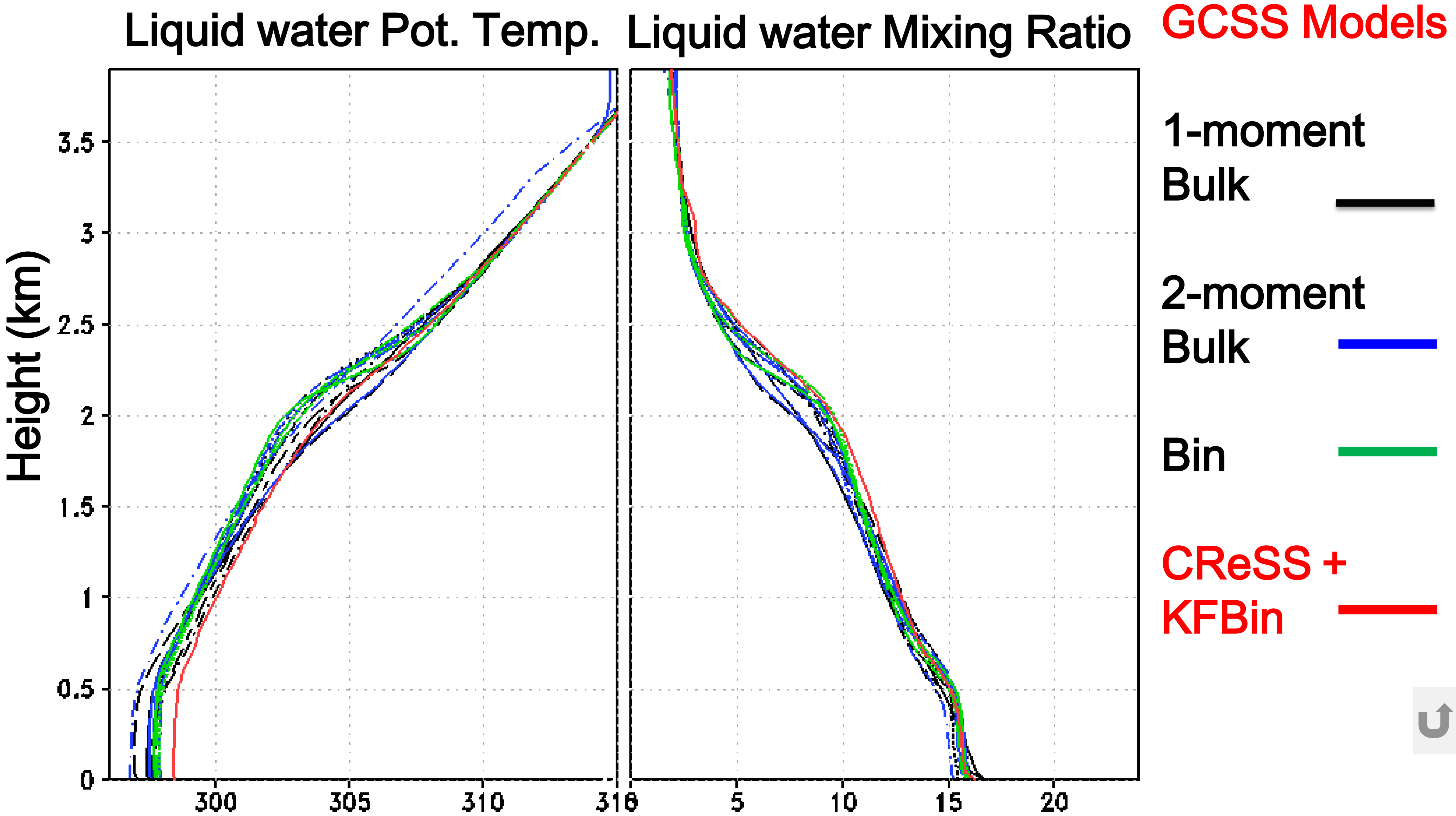
Duration : 24hours (last 4 hrs are analyzed)

Cloud microphysical models (15 models)

1 moment bulk	2 moment bulk	bin
MESO-NH	DALES	RAMS
SAM	UCLA	@NOAA
JAMSTEC	WVU	SAMEX
Utah	COAMPS	DHARMA
EULAG	UKMO	
2DSAM	RAMS	

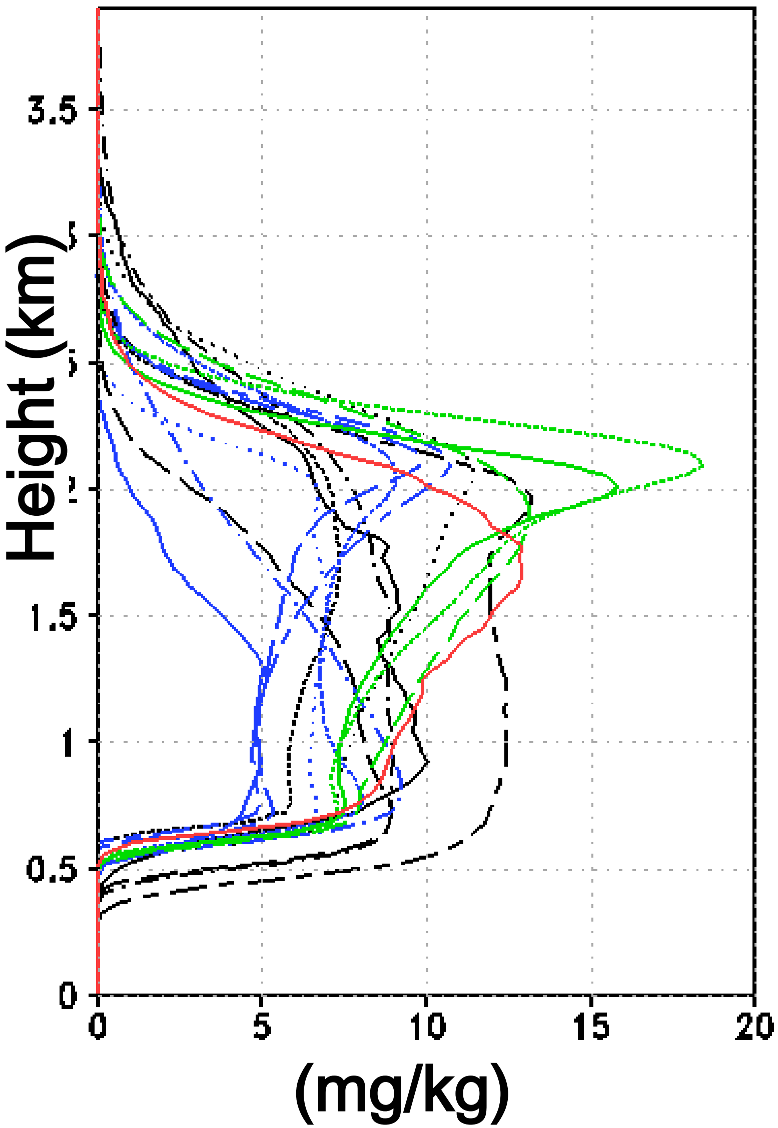
Our Model: CReSS (Tsuboki et al.) with Kuba-Fujiyoshi bin scheme

II-2. Averaged vertical profiles (20-24 hr)

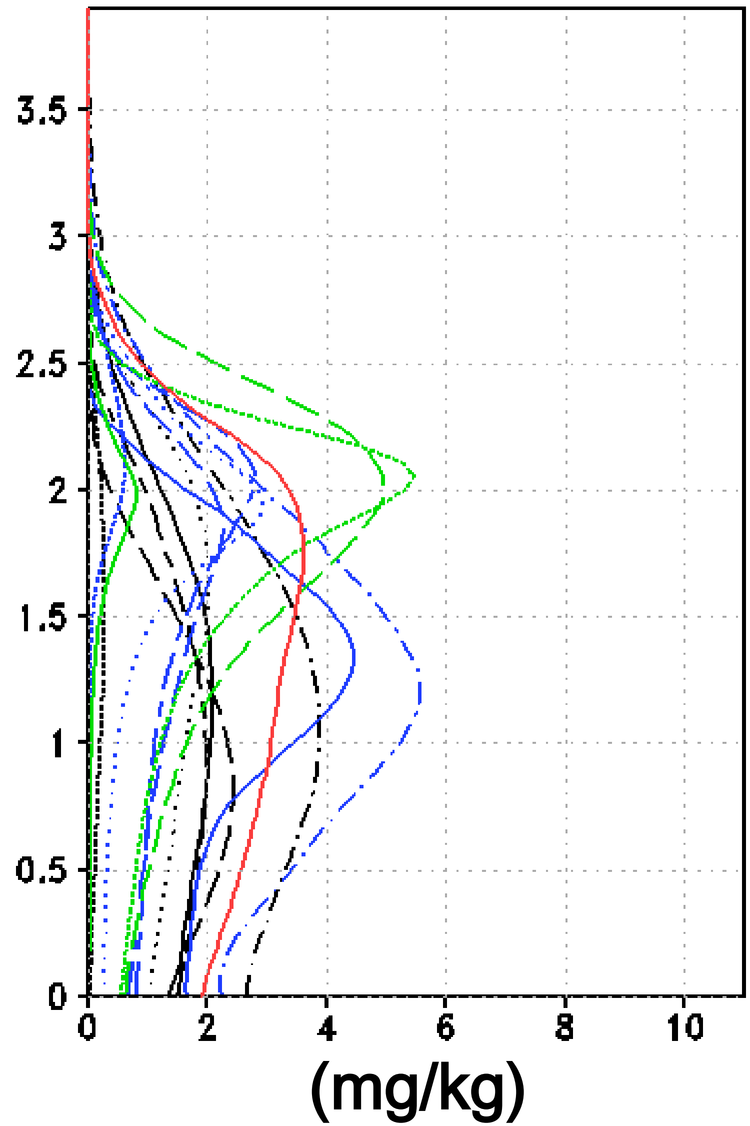


II-3. Averaged vertical profiles (20-24 hr)

Cloud water Mixing ratio



Rain water Mixing Ratio



GCSS Models

1-moment Bulk

2-moment Bulk

Bin

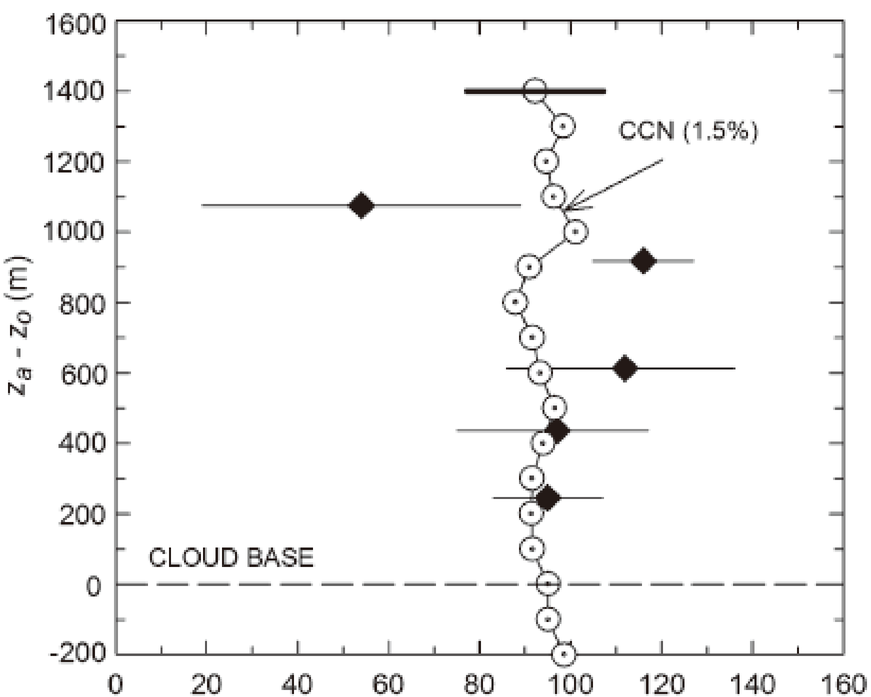
CReSS + KFBin

Cloud : r≦47.9μm

II-4. Averaged vertical profiles (20-24 hr)

Number Density of Cloud Droplets in Cloud

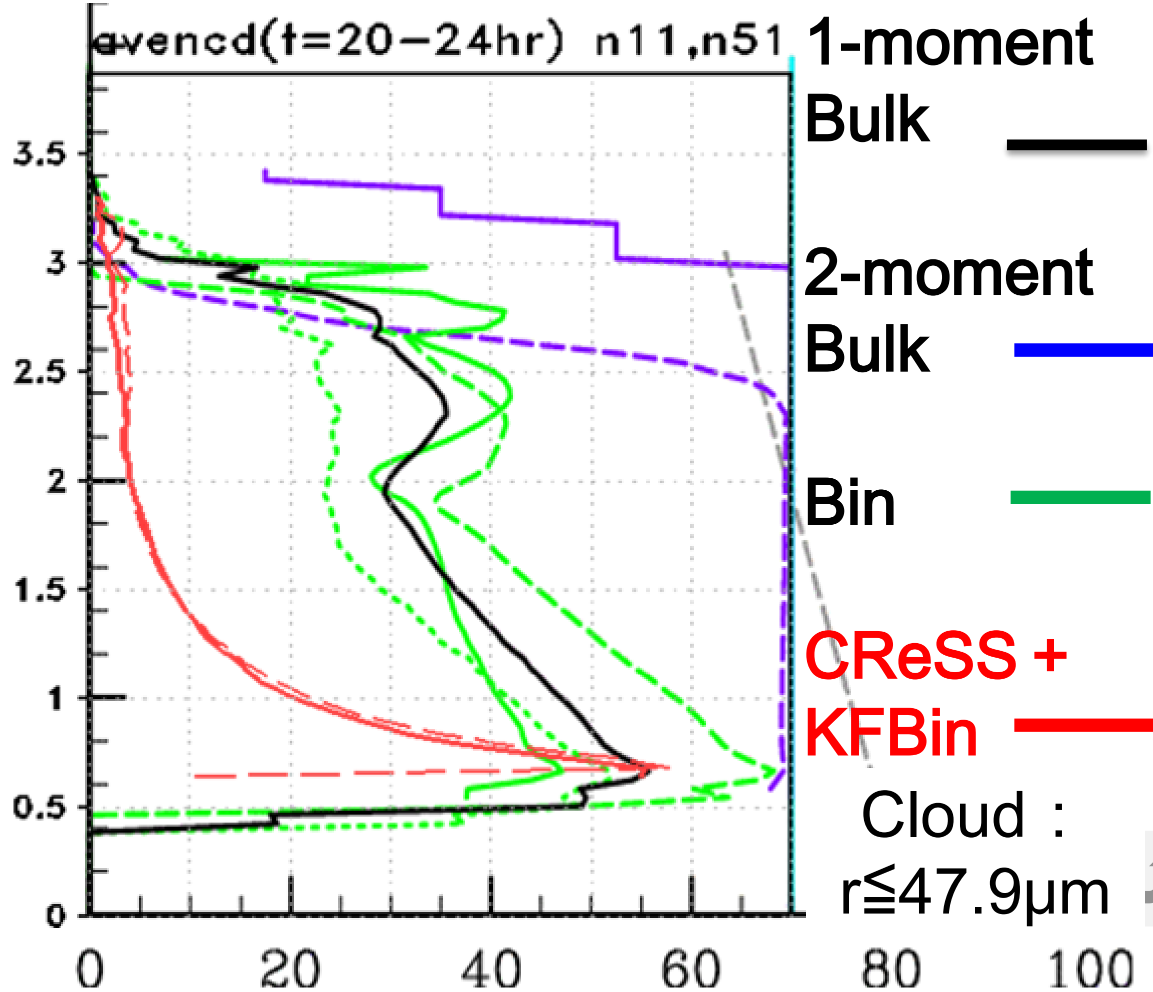
Airplane observation during RICO
- cloud droplets (solid diamonds)
- CCN(1.5% critical super sat., circles)



N and CCN [No. cm^{-3}]
Gerber JMSJ, 2008

F

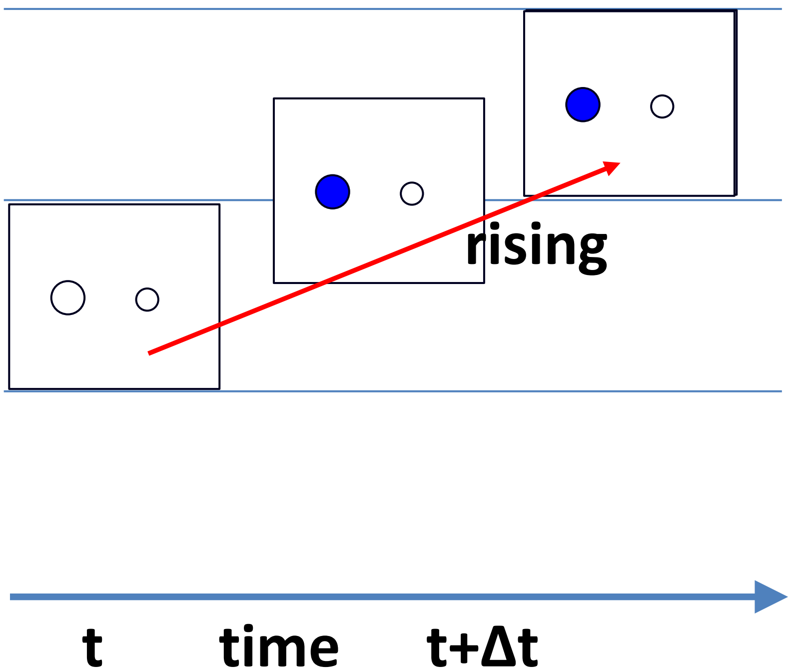
GCSS Models [3]



Number Density of Cloud Droplets[cm^{-3}]

III. activation process of aerosols in the KF model

activation process
in a parcel with
upward displacement



The number of activated CCN is important for the cloud growth.

The equation in terms of rh is often used.

$n_{acti} \propto \exp(a*(rh-100))$

↑grid value should not be used

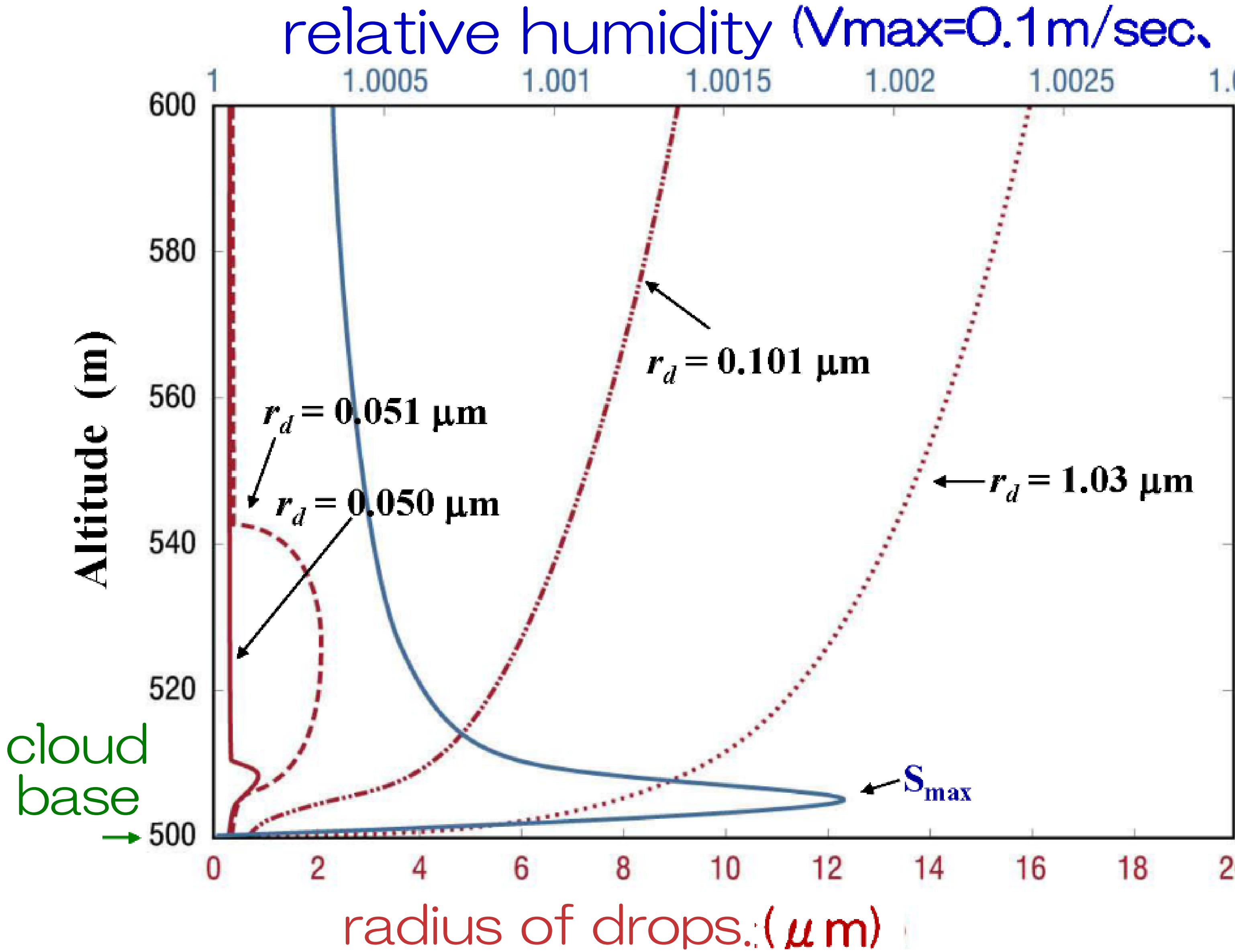
The number of activated CCN should be considered with very small time and space intervals.

When large aerosols are activated, supersaturations is decreased.

➡ small aerosols are not activated.

➡ In KF model, the number is parameterized in terms of w.

vertical change of rel. hum. and radius of droplets



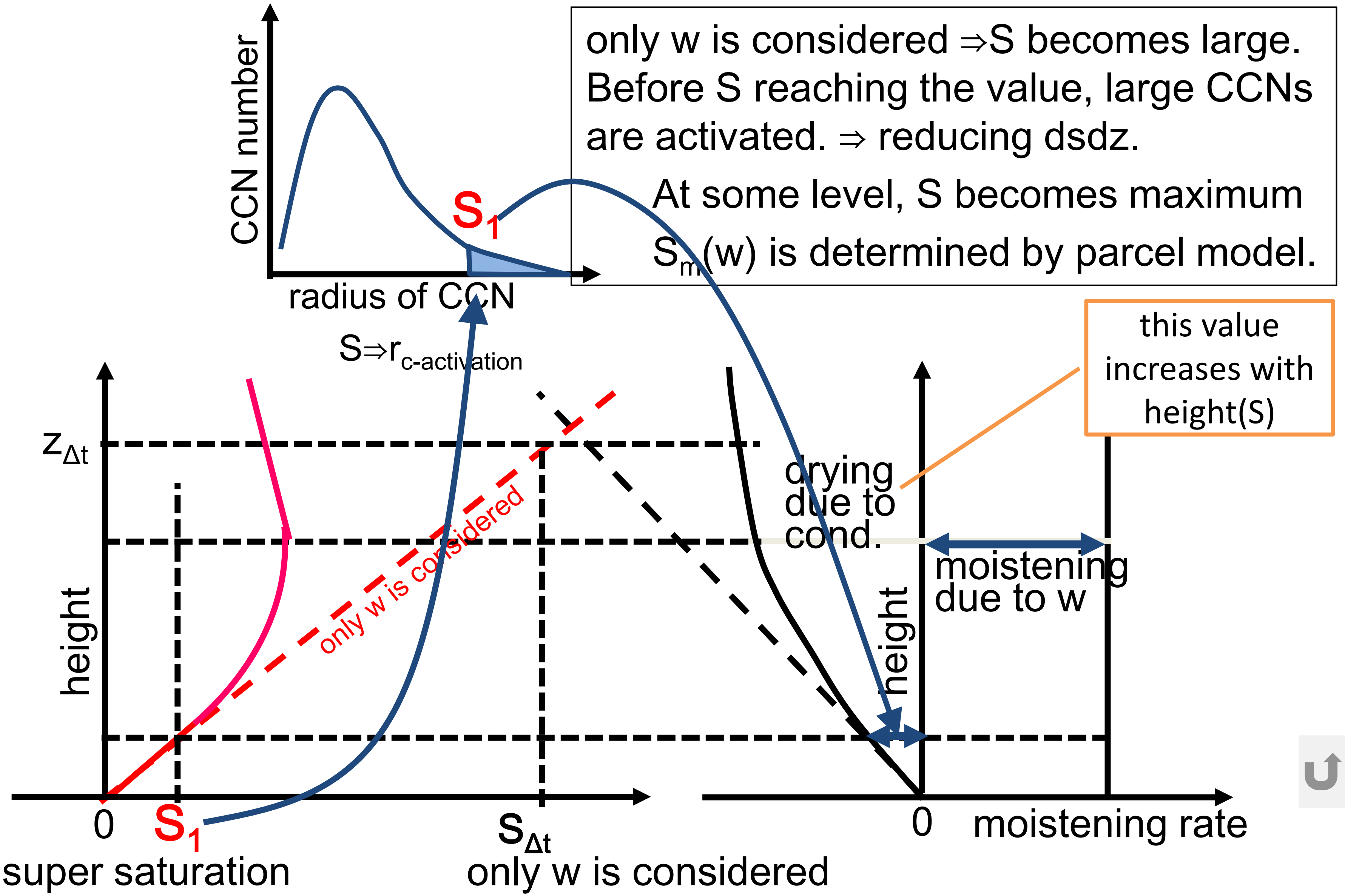
Larger drops begin to grow earlier.

Rel. hum. decreases by condensation.

What is important is the maximum value of r.h..

S=r.h.-1.0, super saturation.

III-2. maximum value of supersaturation at cloud base



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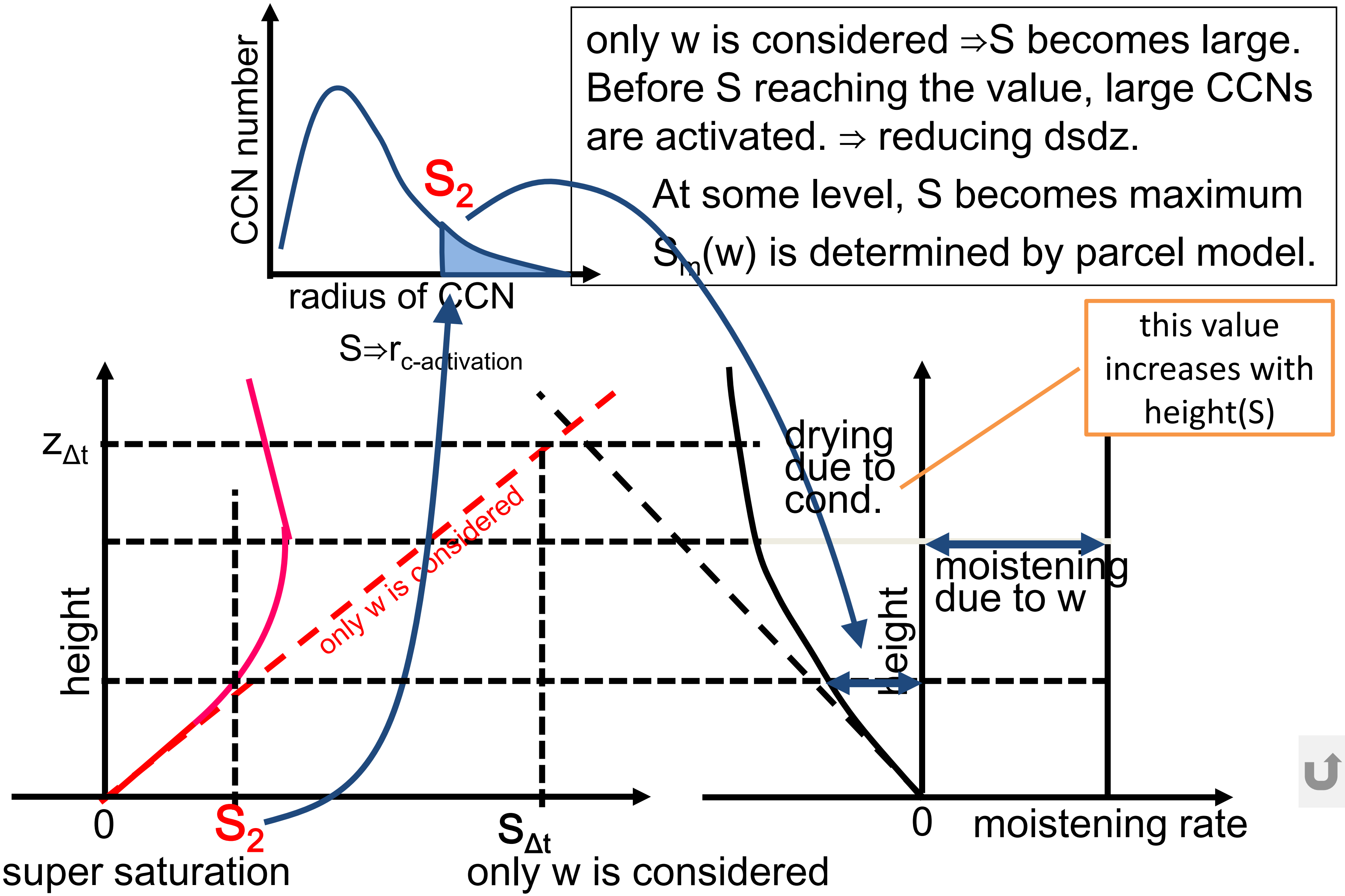

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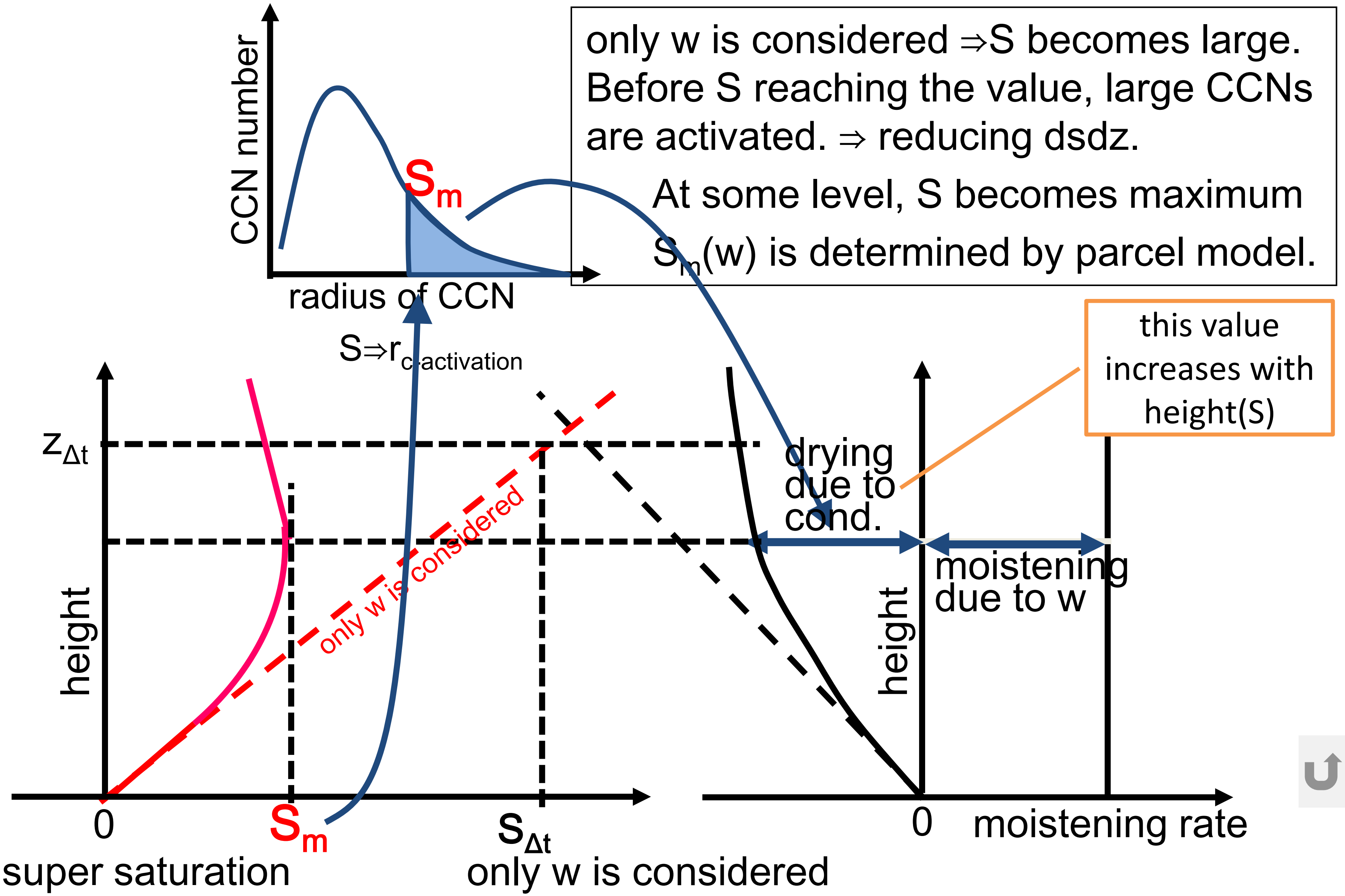
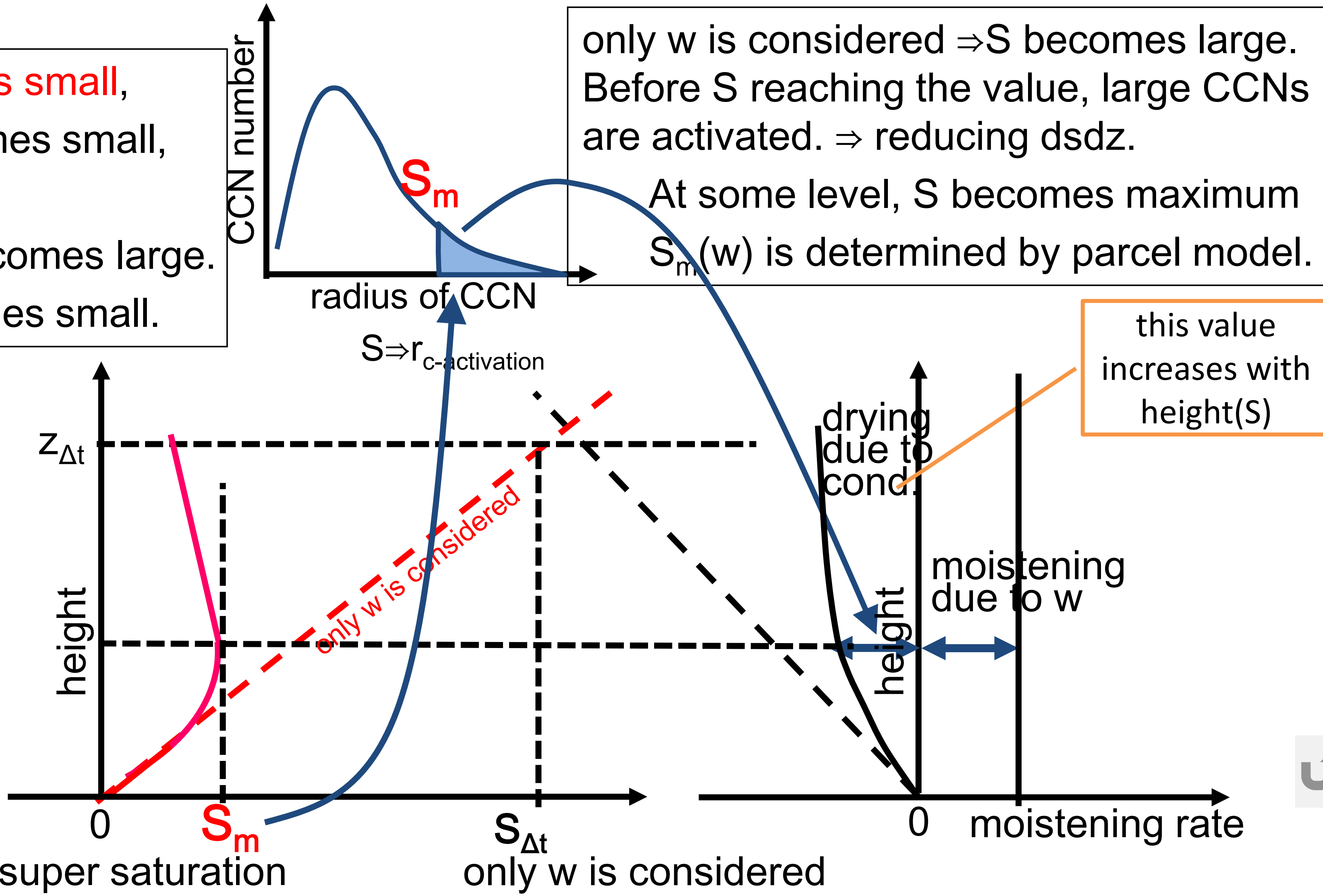


III-2. maximum value of supersaturation at cloud base

When w is small,
S_m becomes small,
and
$r_c(S_m)$ becomes large.
N_c becomes small.

only w is considered ⇒S becomes large.
Before S reaching the value, large CCNs are activated. ⇒ reducing dsdz.

At some level, S becomes maximum
$S_m(w)$ is determined by parcel model.

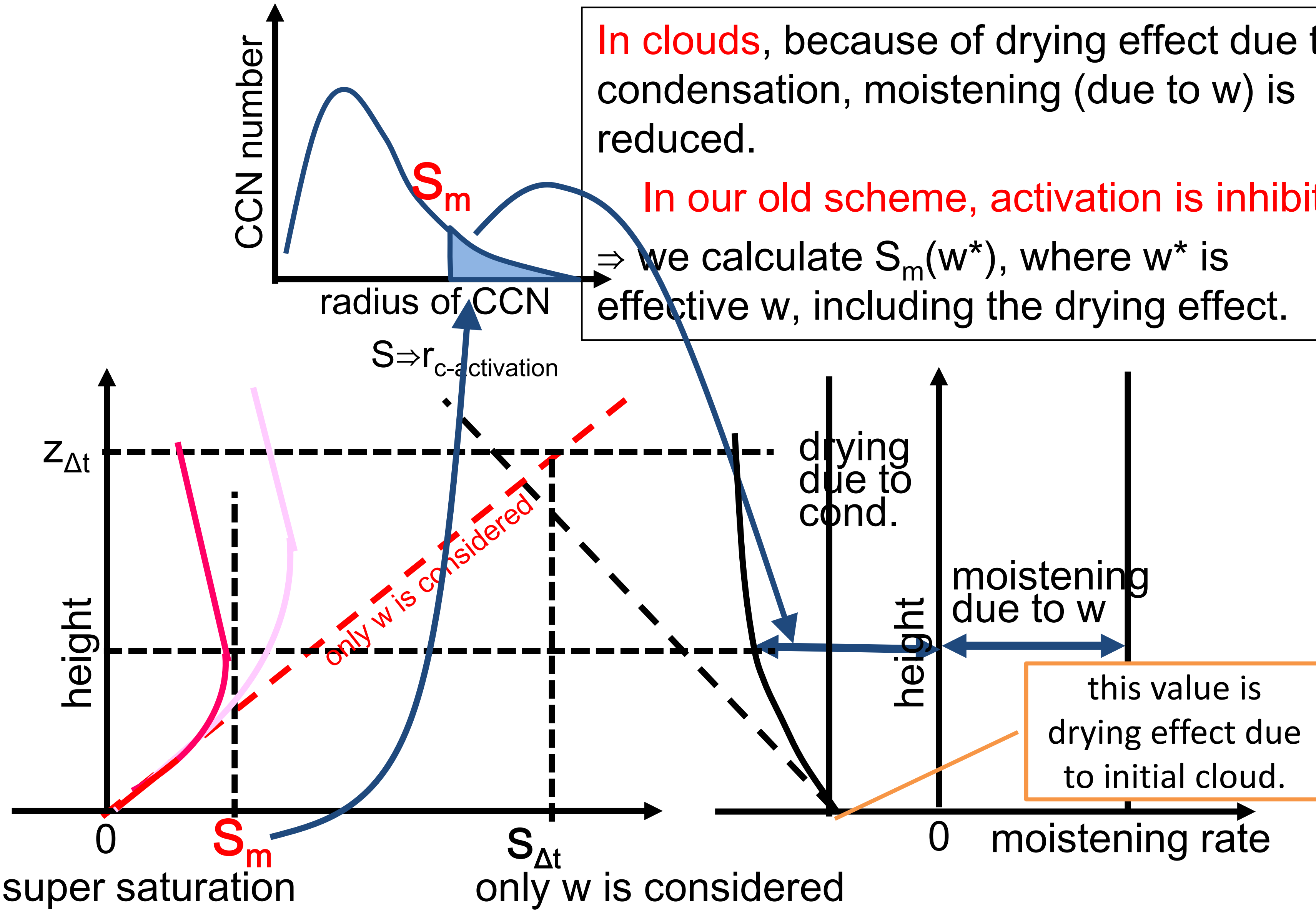


III-3.maximum value of supersaturation in cloud

In clouds, because of drying effect due to condensation, moistening (due to w) is reduced.

In our old scheme, activation is inhibited.

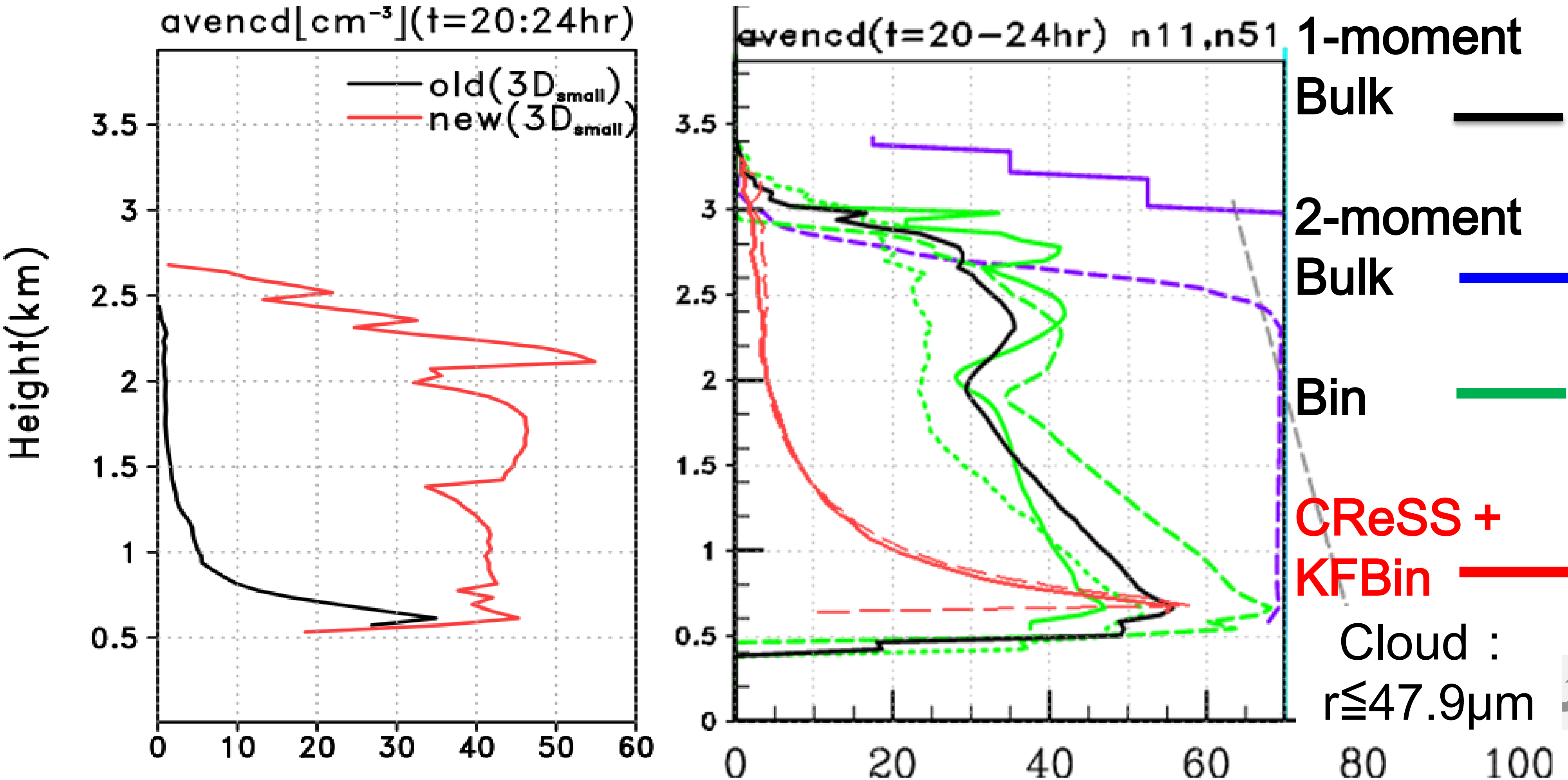
⇒ we calculate $S_m(w^*)$, where w* is effective w, including the drying effect.



III-4. Averaged vertical profiles (new-scheme)

Number Density of Cloud Droplets in Cloud

GCSS Models [3]



Number Density of Cloud Droplets[cm^{-3}]

Summary - 1

- A numerical experiment of cumulus convection observed during RICO was performed using a bin microphysical model developed by Kuba and Fujiyoshi.
- 久芳ー藤吉が開発したビン法雲微物理モデルを使い、RICOで観測された積雲の数値実験を行った。
- In this model, the number of activated aerosols is determined by a parameterization scheme in terms of w.
- このモデルでは、活性化するエアロゾルの個数をwによって決めるパラメタリゼーションを使っている。
- The results of the simulation indicates that the vertical profiles of the averaged values of temperature, humidity, liquid water mixing ratios are similar to observation and other model results.
- 再現実験の結果、水平平均の温度、湿度、雲水量などの結果は、観測や他のモデルと同じような結果が得られた。

Summary - 2

- However, the vertical profile of the number density of cloud droplets in clouds (n_c)indicates very rapid decrease with height. The reason of this result is that the model does not include the aerosol activation process in clouds.
- しかし、雲内雲粒数密度が高さ方向に急減する結果が得られた。この原因は、雲内でのエアロゾルの活性化が入っていないためであると考えられた。
- When we include the aerosol activation process in clouds in the model, the very rapid decrease of n_c is removed, and the results becomes similar to other results.
- 雲内でもwによって決まるエアロゾルの活性化を入れた結果、雲内雲粒数密度が高さ方向に急激に減る問題は解消し、他のモデルや観測と似た結果が得られるようになった。
- We would like to compare the results with some observation, and …
- 今後、観測結果（粒径分布、凝結水量と降水量の関係など）とも比較して、よりよいものにし、バルク法の改良を進めていきたい。