Cloud Properties Simulated by a Single-Column Model

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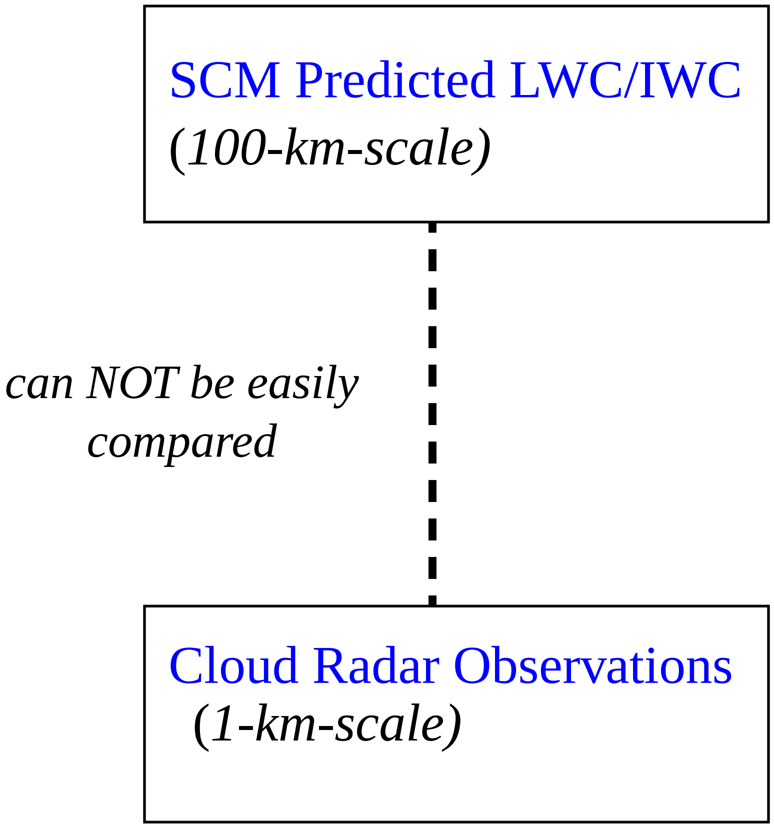
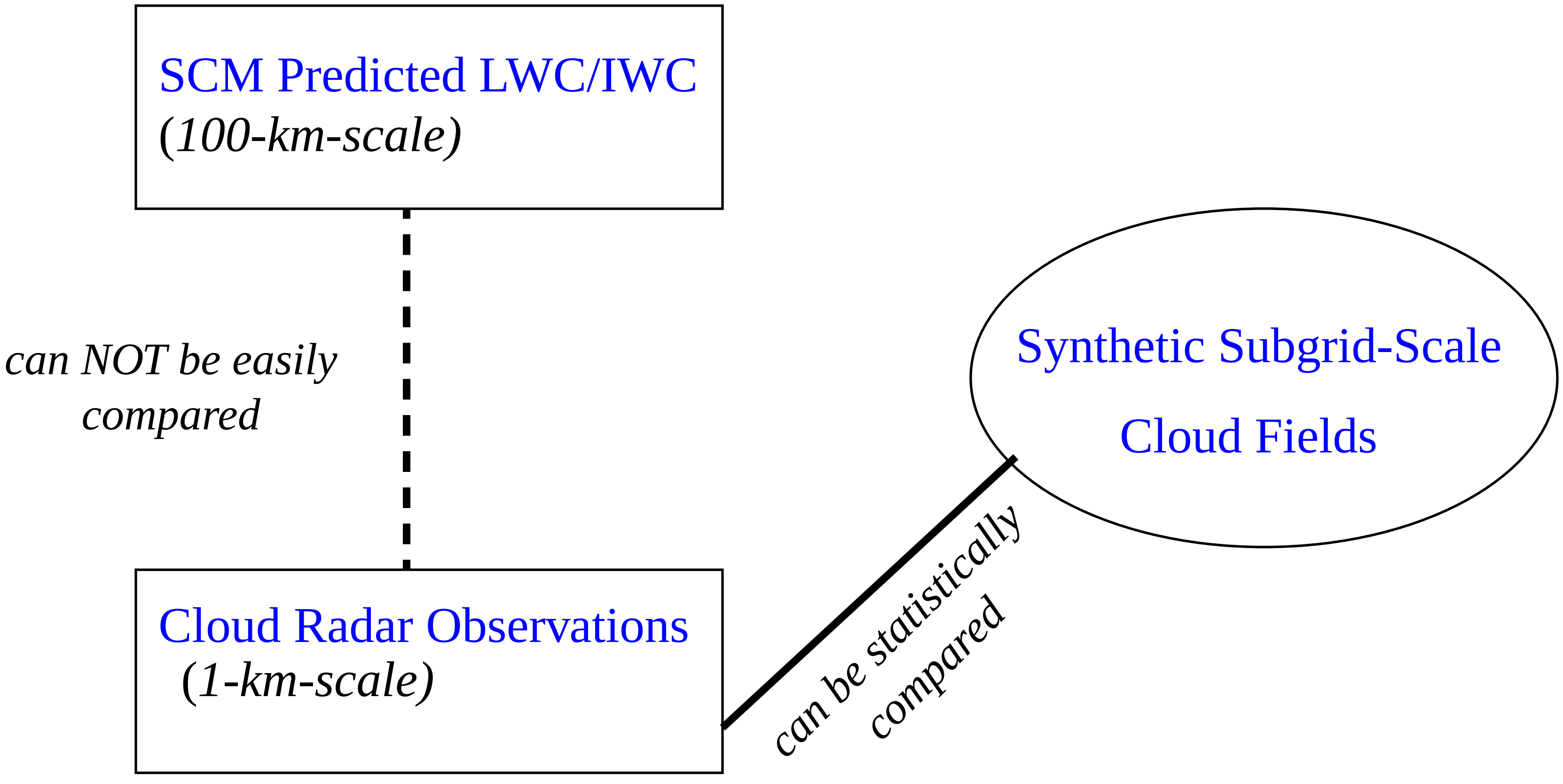
Part 1: Comparison with Cloud Radar Observations of Cirrus Clouds

Part 2: Evaluation of Detrainment and Microphysics using Results from a Cloud Resolving Model

NCEP Single Column Model

- Based on NCEP Global Forecast System.
- **Stratiform cloud LWC/IWC**: Prognostic equation (Zhao and Carr 1997; based on Sundqvist 1989).
- **Cloud fraction**: diagnosed from LWC/IWC and R.H. following Xu and Randall (1996). (Random overlap assumption used for radiation calculation)
- **Deep convection**: Simplified Arakawa-Schubert scheme with only one cloud type considered. Detrainment occurs at cloud top only. Includes a downdraft, which can detrain into the boundary layer, and precipitation evaporation (Pan and Wu 1995).


SCM Predicted LWC/IWC
(100-km-scale)
can NOT be easily compared
Cloud Radar Observations
(1-km-scale)


SCM Predicted LWC/IWC
(100-km-scale)
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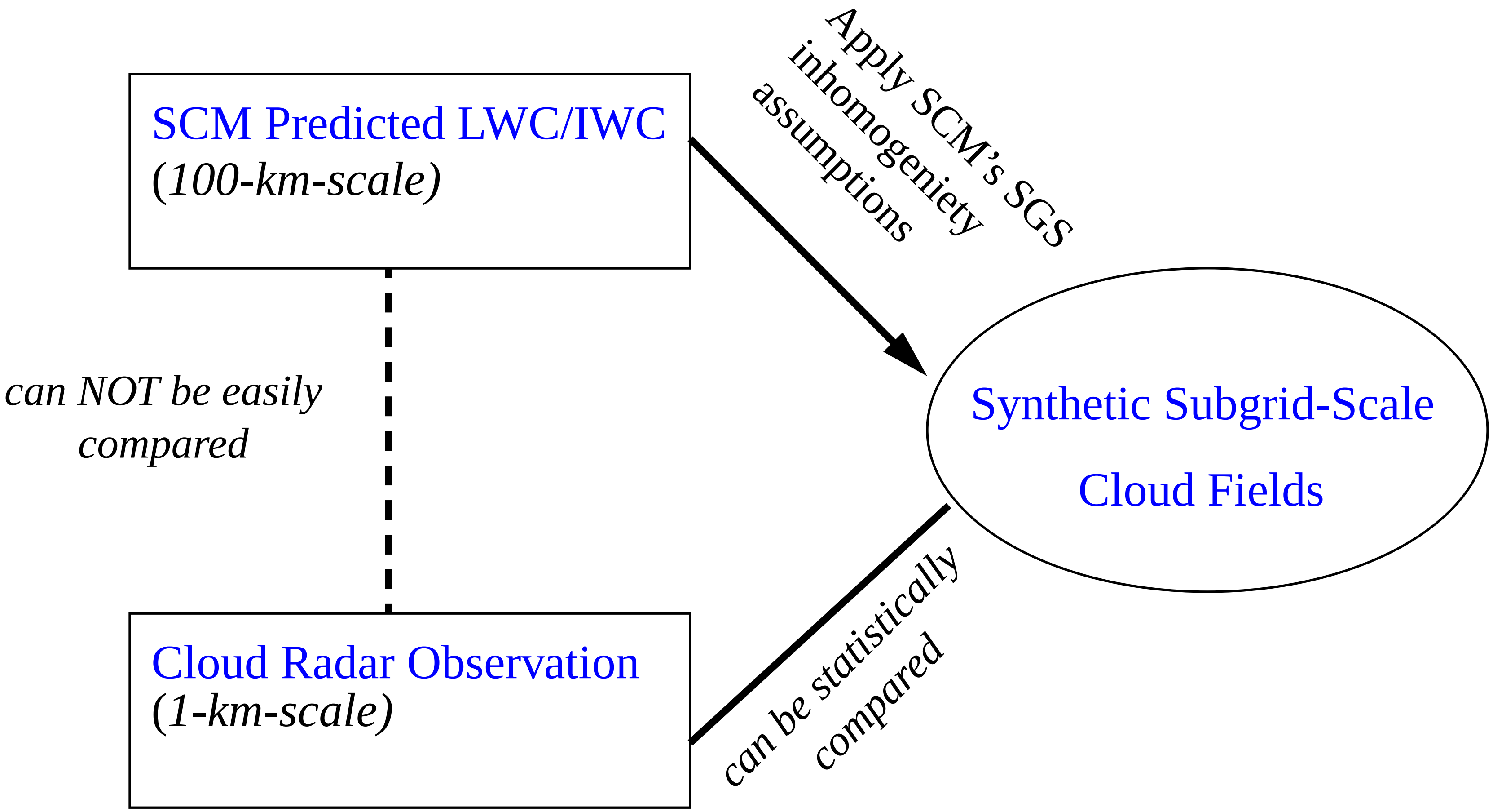
Cloud Radar Observations
(1-km-scale)
Synthetic Subgrid-Scale
Cloud Fields
can be statistically compared


SCM Predicted LWC/IWC
(100-km-scale)
Apply SCM's SGS inhomogeniety assumptions
can NOT be easily compared
Synthetic Subgrid-Scale Cloud Fields
Cloud Radar Observation
(1-km-scale)
can be statistically compared

IWC/LWC

+

Inhomogeniety Assumption

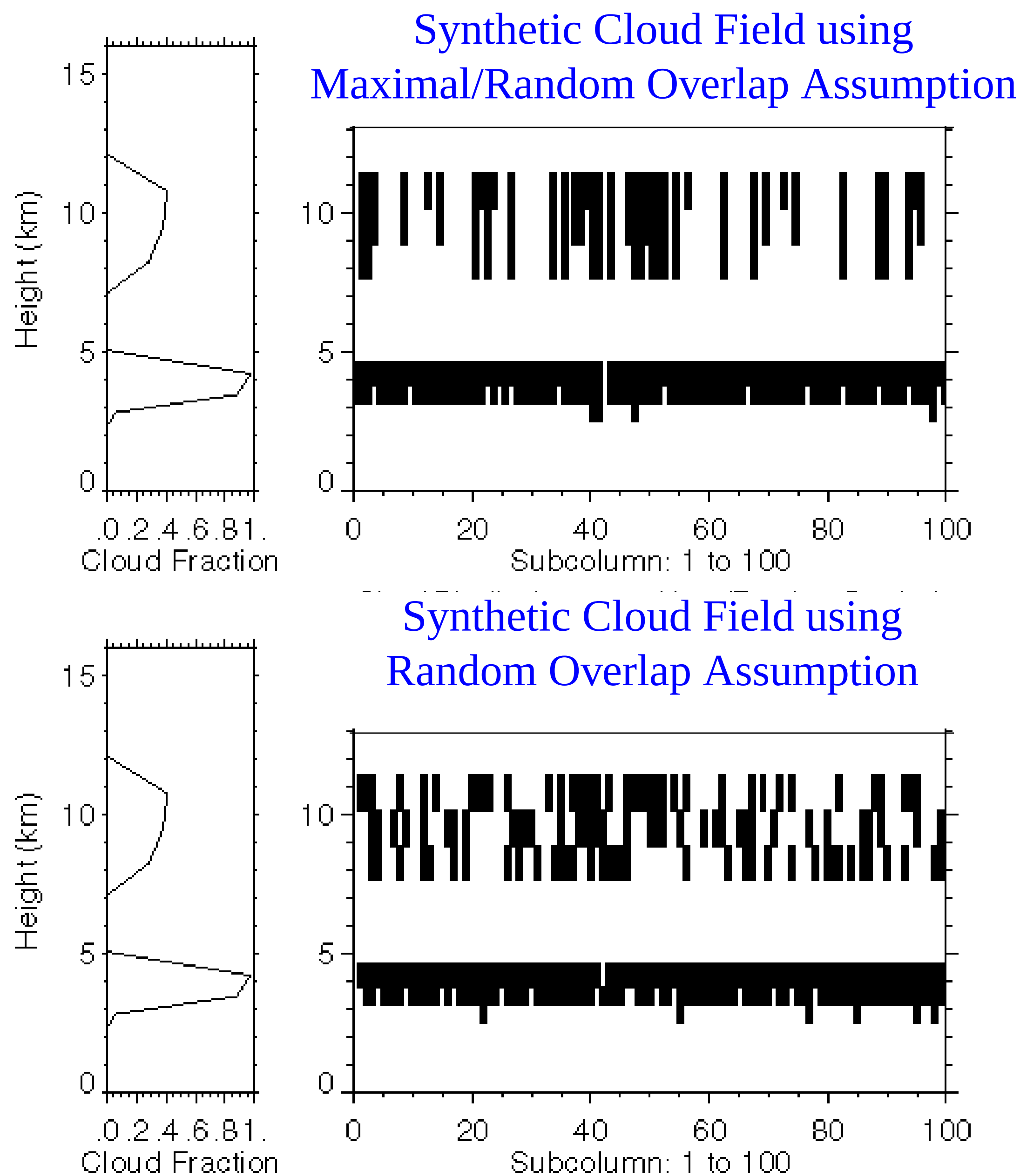
Cloud Fraction Profile

+

Overlap Assumption

Synthetic Cloud Field

(Klein and Jakob 1999)



SCM Analyses

NOSNOW rand: SCM cirrus clouds consist of cloud ice only, $dBZ = f(cldi, cldw)$, random overlap assumption.

NOSNOW max/rand: SCM cirrus clouds consist of cloud ice only, $dBZ = f(cldi, cldw)$, maximal/random overlap assumption.

SNOW rand: SCM cirrus clouds consist of both cloud ice and snow, $dBZ = f(cldi, cldw, snow, rain)$, random overlap assumption.

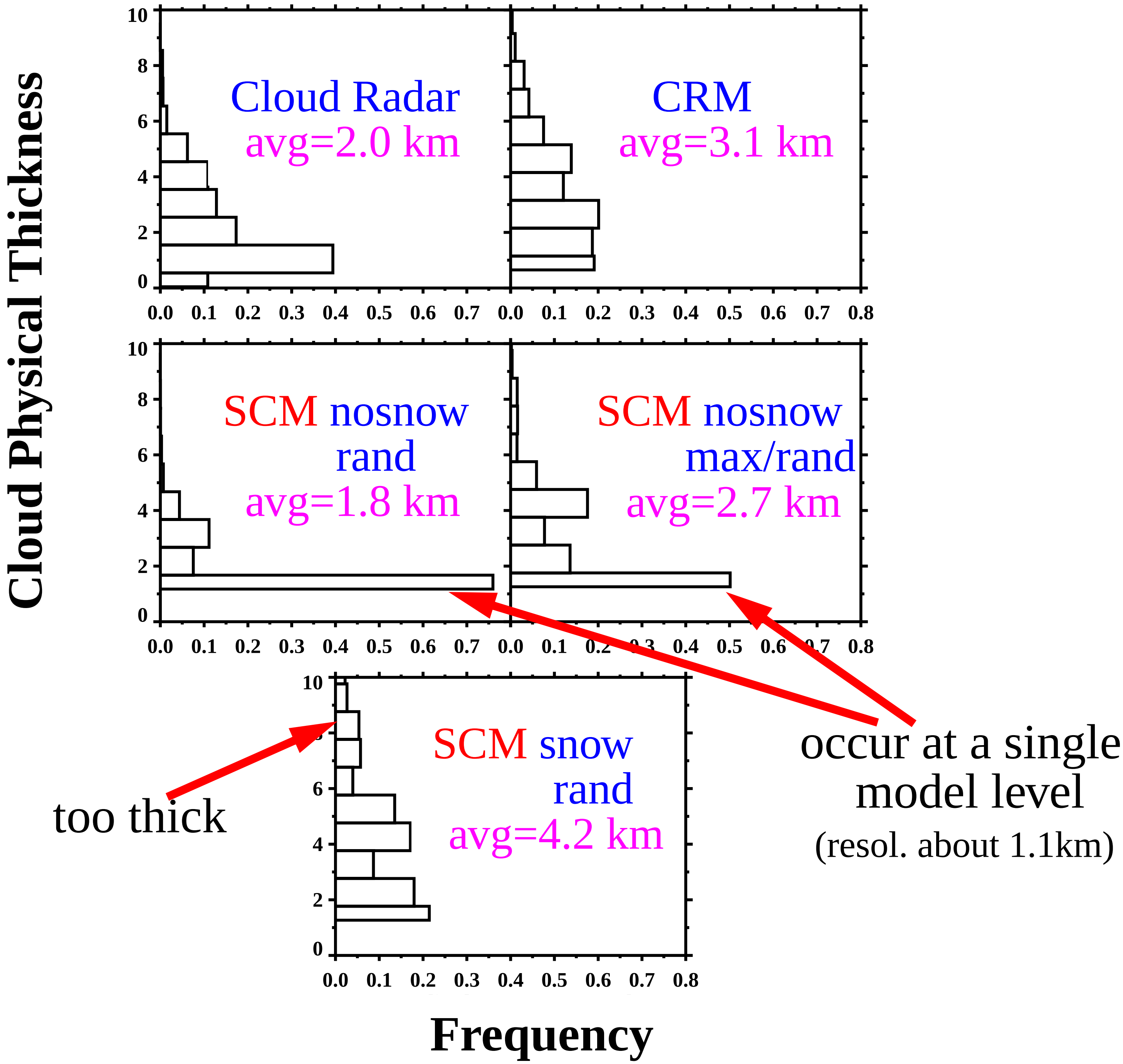
For each analysis, we sampled the SCM synthetic cloud fields at 100 sub-columns every hour over the entire simulation period (29 days) using definitions of “all cirrus” and “thin cirrus” analogous to MCA’s definitions.

The properties of the SCM “all cirrus” and “thin cirrus” were compared statistically to the observations.

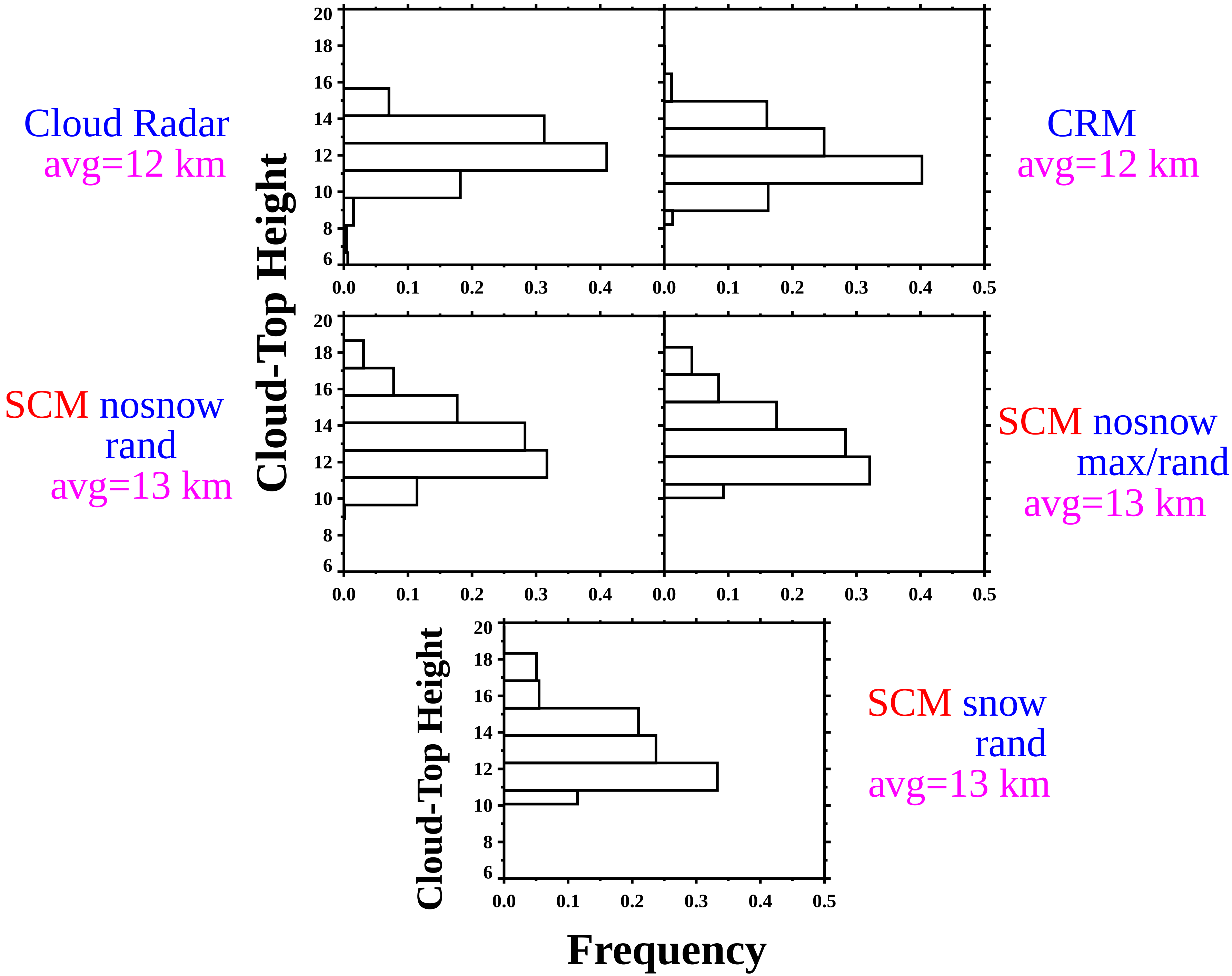
Cirrus Occurrence Frequency [correlation coefficient]

	Entire IOP	Subperiods A, B, C
SCM *nosnow max/rand*	**0.25 [0.44]**	**0.25 [0.54]**
SCM *nosnow rand*	**0.37 [0.47]**	**0.33 [0.68]**
SCM *snow rand*	**0.17 [0.09]**	**0.17 [0.22]**
CRM	**0.37 [0.30]**	**0.30 [0.70]**
Cloud Radar	**0.30 [0.63]**	**0.37 [0.63]**
GOES (ref. obs)	**0.27 [1.00]**	**0.34 [1.00]**

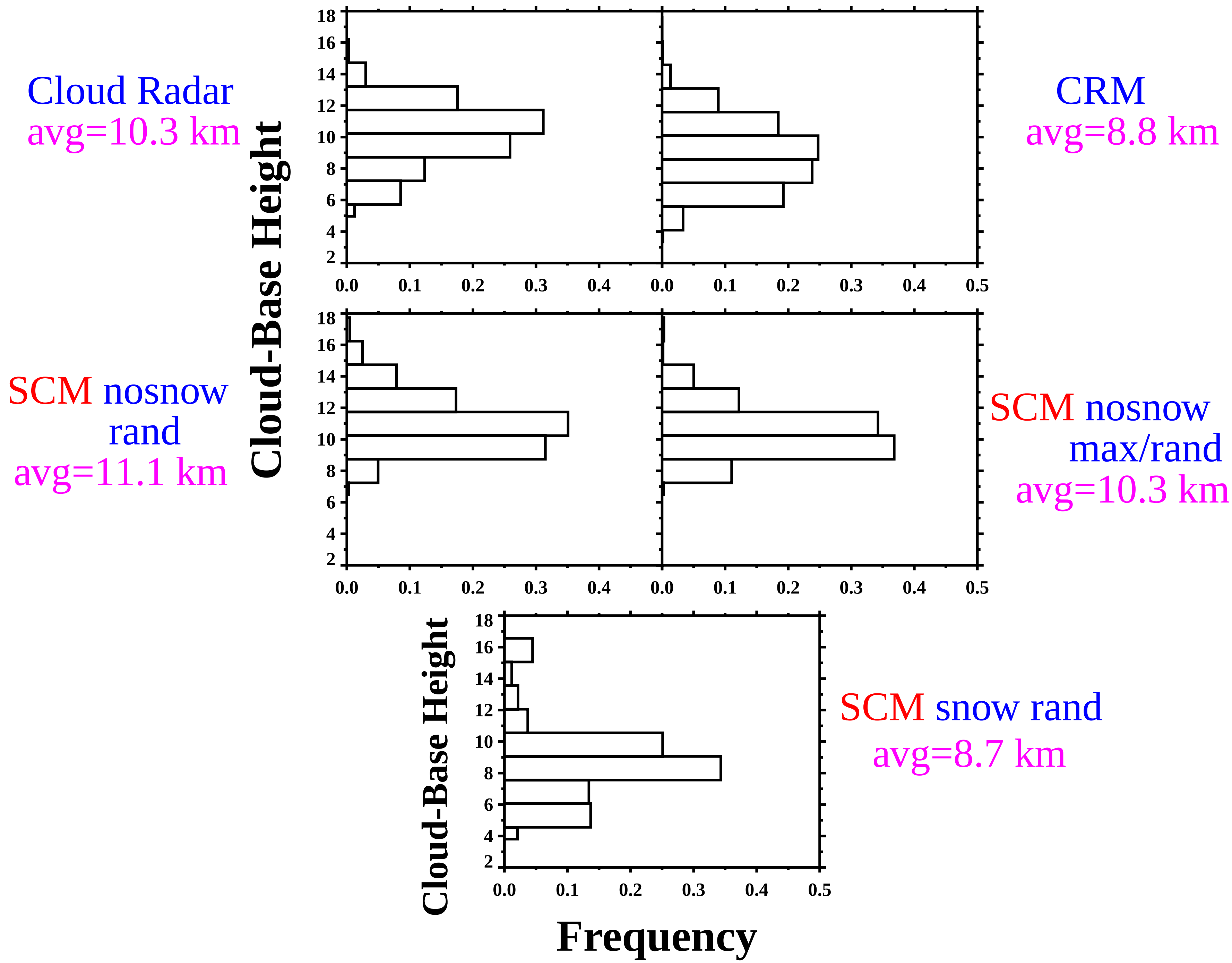
Frequency distributions of cirrus physical thickness



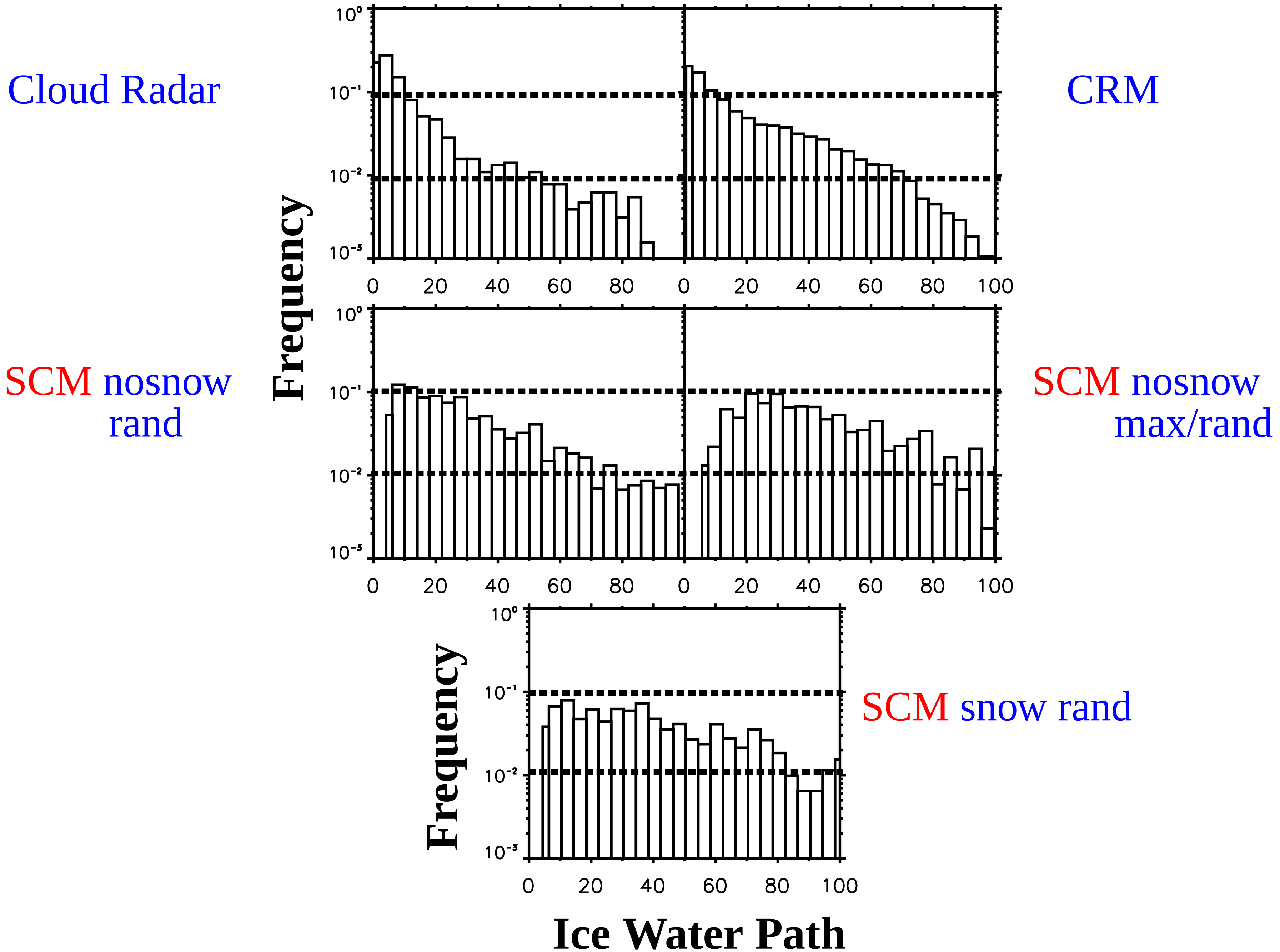
Frequency distributions of cirrus cloud-top height



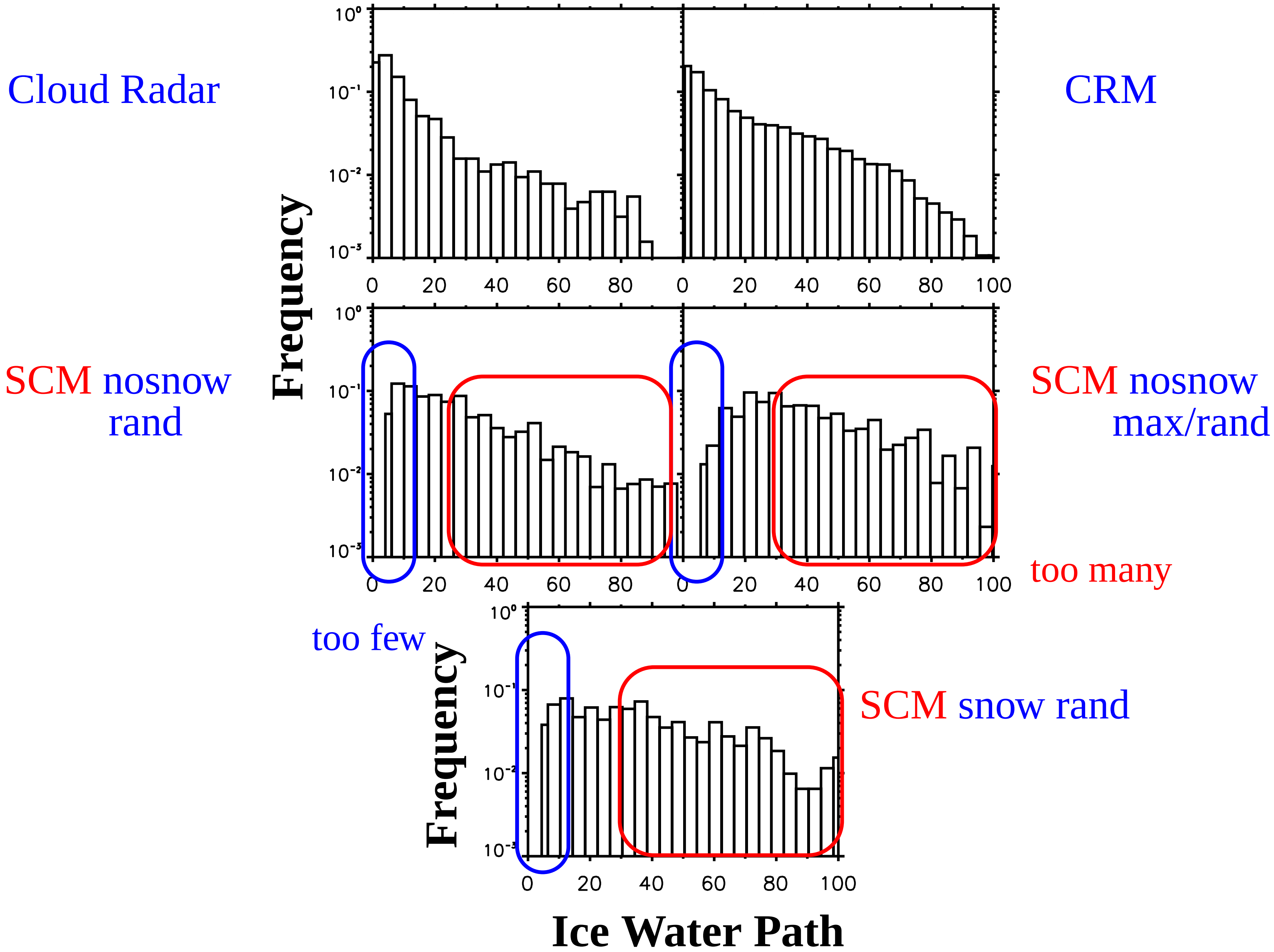
Frequency distributions of cirrus cloud-base height



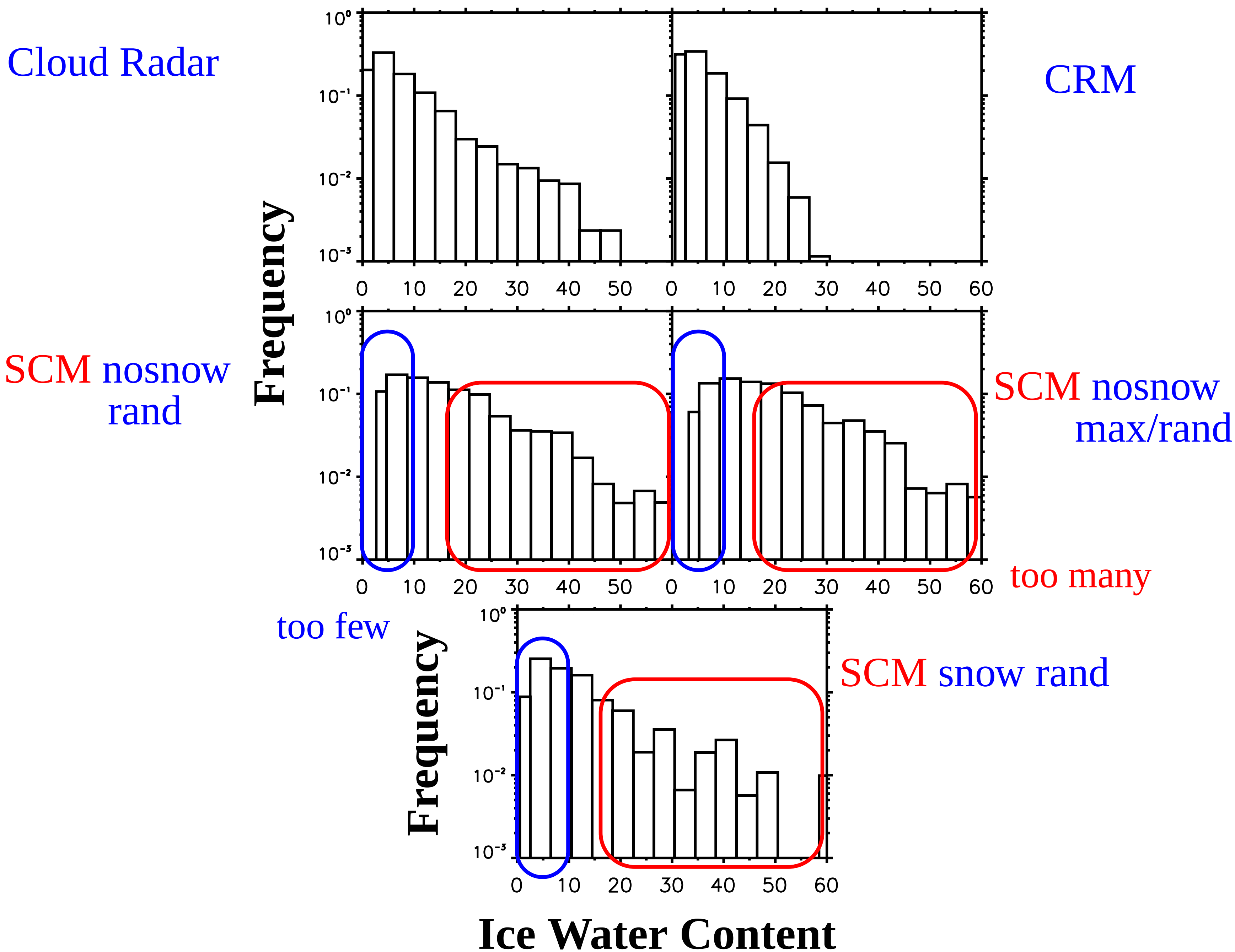
Frequency distributions of thin cirrus IWP



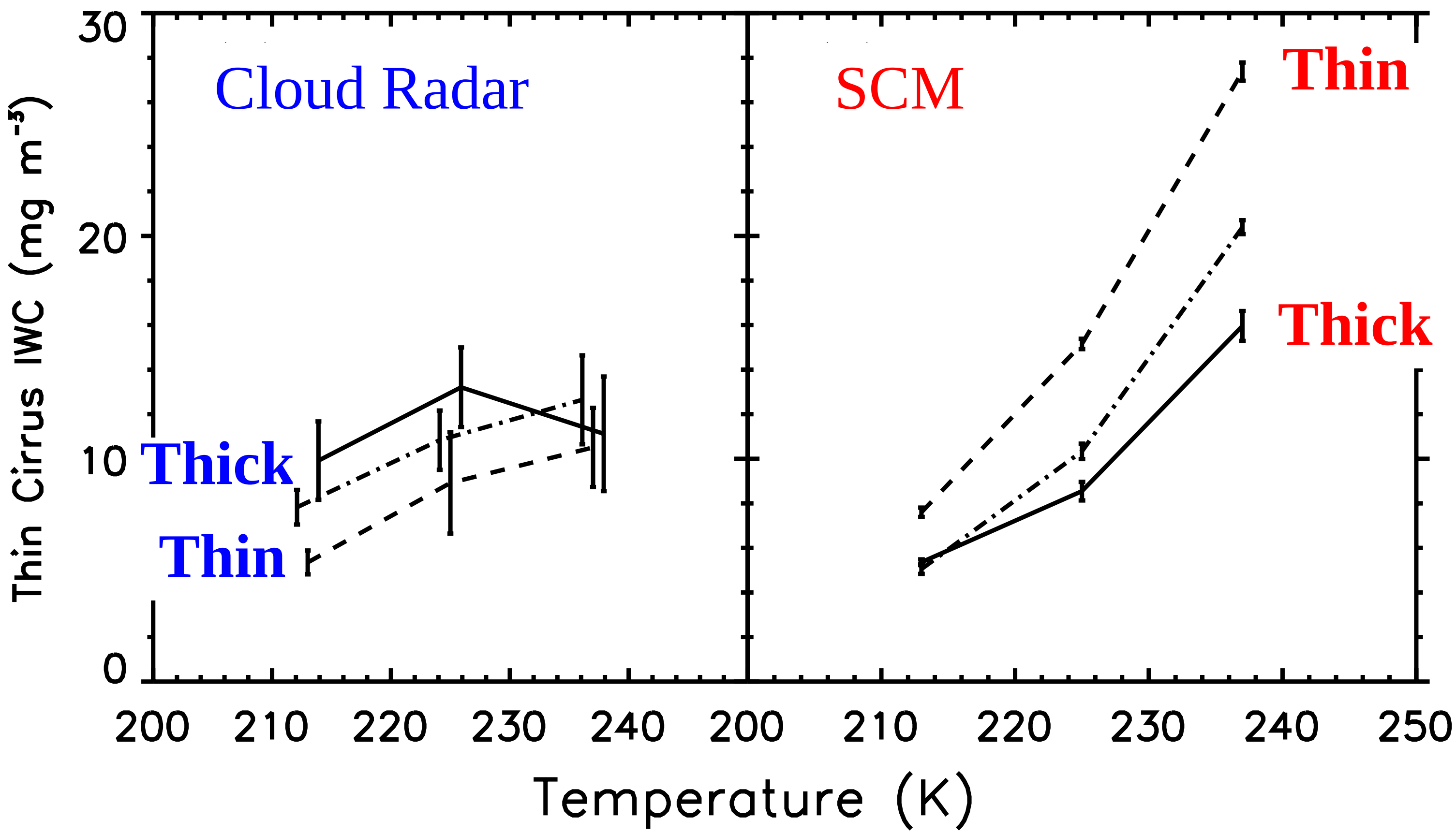
Frequency distributions of thin cirrus IWP



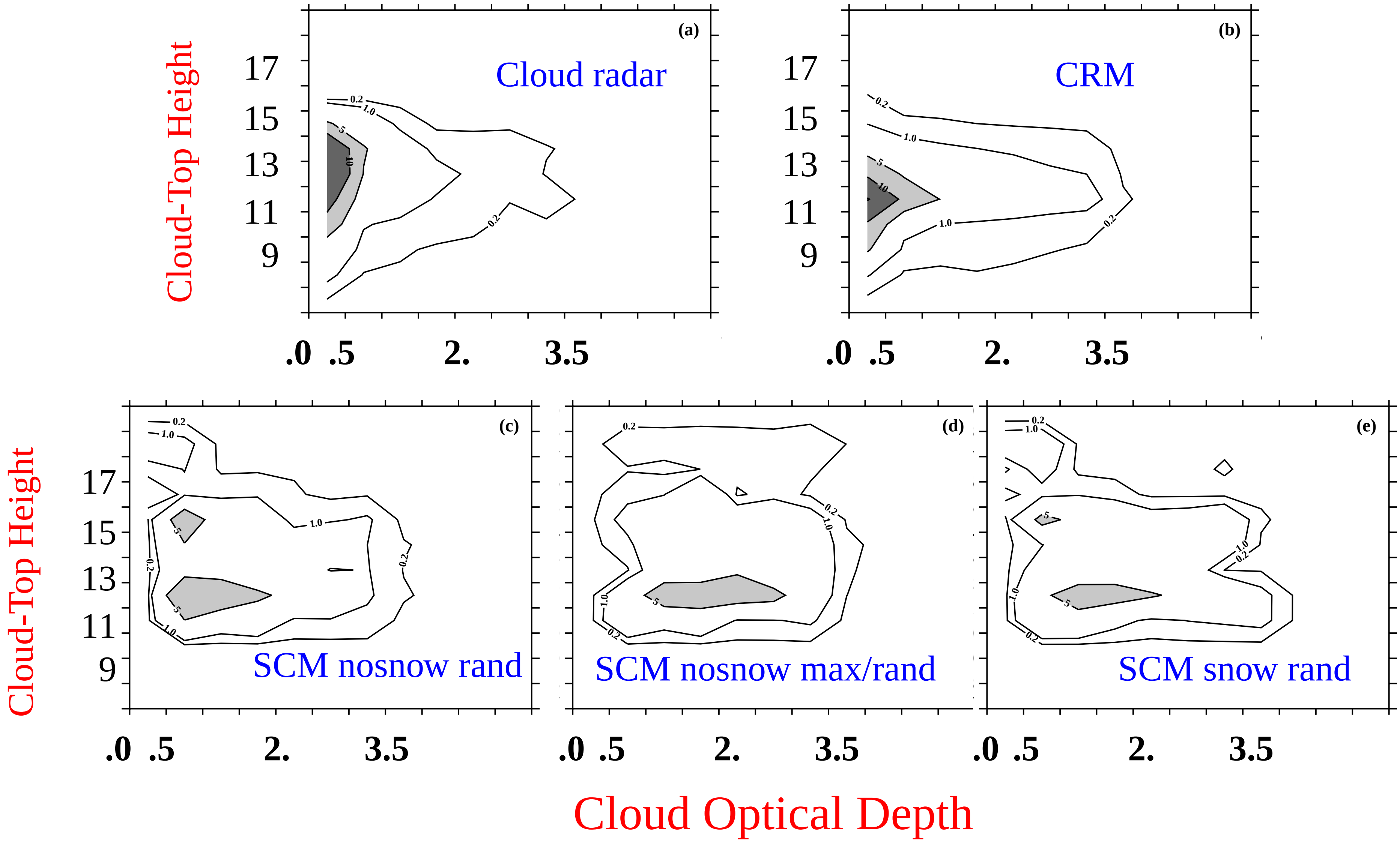
Frequency distributions of thin cirrus IWC



Thin Cirrus IWC vs cloud physical thickness and temperature

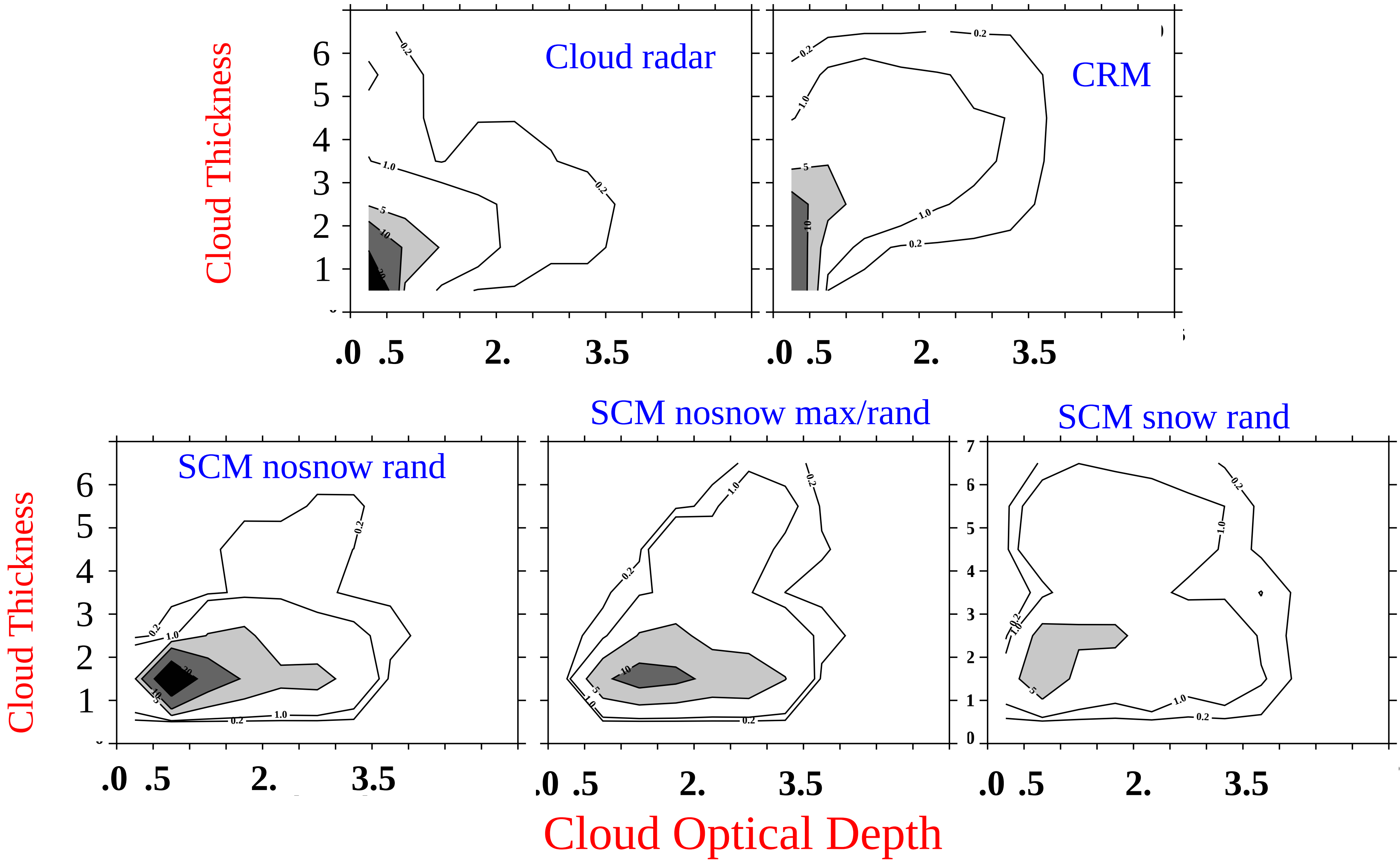


Joint frequency distributions of thin cirrus in various cloud optical depth and cloud-top height intervals



The SCM thin cirrus clouds: have distributions depend little on the assumptions of cloud overlap and snow, have relatively too few low τ and too many high τ.

Joint frequency distributions of thin cirrus in various cloud optical depth and cloud physical thickness intervals



The SCM thin cirrus clouds have distributions depend on the assumptions of cloud overlap and snow; too many SCM *nosnow* thin cirrus clouds occur at a single model layer; the SCM *snow* thin cirrus clouds are optically too thick.

Conclusions for Part 1

1) By applying an overlap assumption to the SCM profiles of cloud fraction and cloud water/ice mixing ratio, SCM cirrus properties can be analyzed and compared directly to the cirrus observations and retrievals from the cloud radar.

2) The SCM cirrus cloud-base height and physical thickness depend on the assumption about cloud overlap and more significantly on whether snow/rain is considered as cloud/hydrometeor.

3) Both the SCM and CRM cirrus cloud amounts temporally correlate better with the observations when little large-scale horizontal advection of hydrometeor occurred.

4) Regardless of the overlap assumption used and no matter if snow is included or not, the SCM thin cirrus:

-- IWP/IWC distribution is skewed to large values;
-- IWP and IWC increase with temperature too rapidly;
-- IWCs decrease with cloud physical depth instead of increasing as observed.

5) Too many SCM *nosnow* cirrus clouds occur at a single model level.

Part 2: Evaluation of Detrainment and Microphysics using Results from a Cloud Resolving Model

The reasons for the differences of cirrus properties between the SCM and the observations are closely related to **detrainment** and **microphysical processes** in the model.

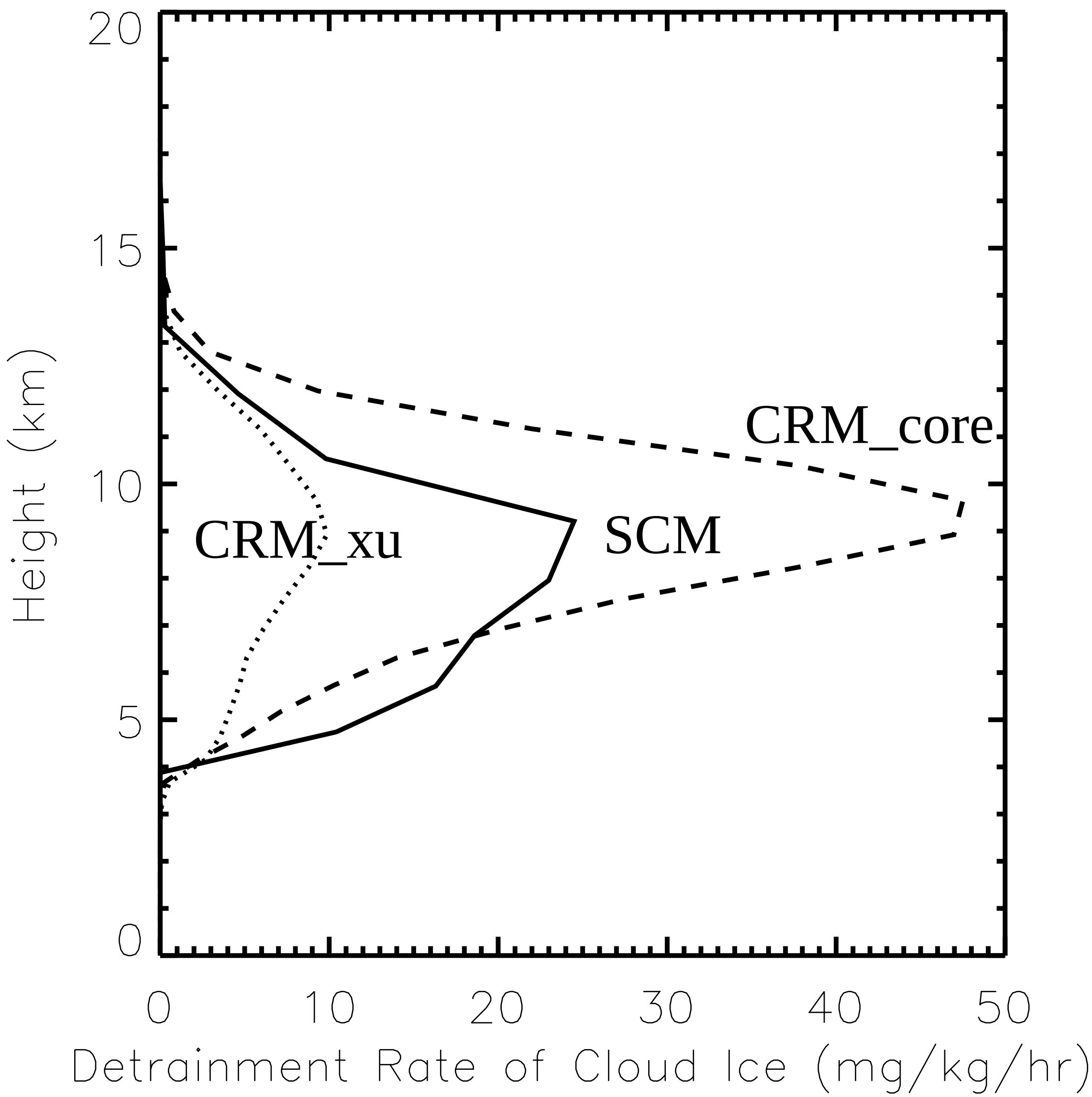
Since no observational data of detrainment and microphysical processes was available, we compared the SCM with the CRM.

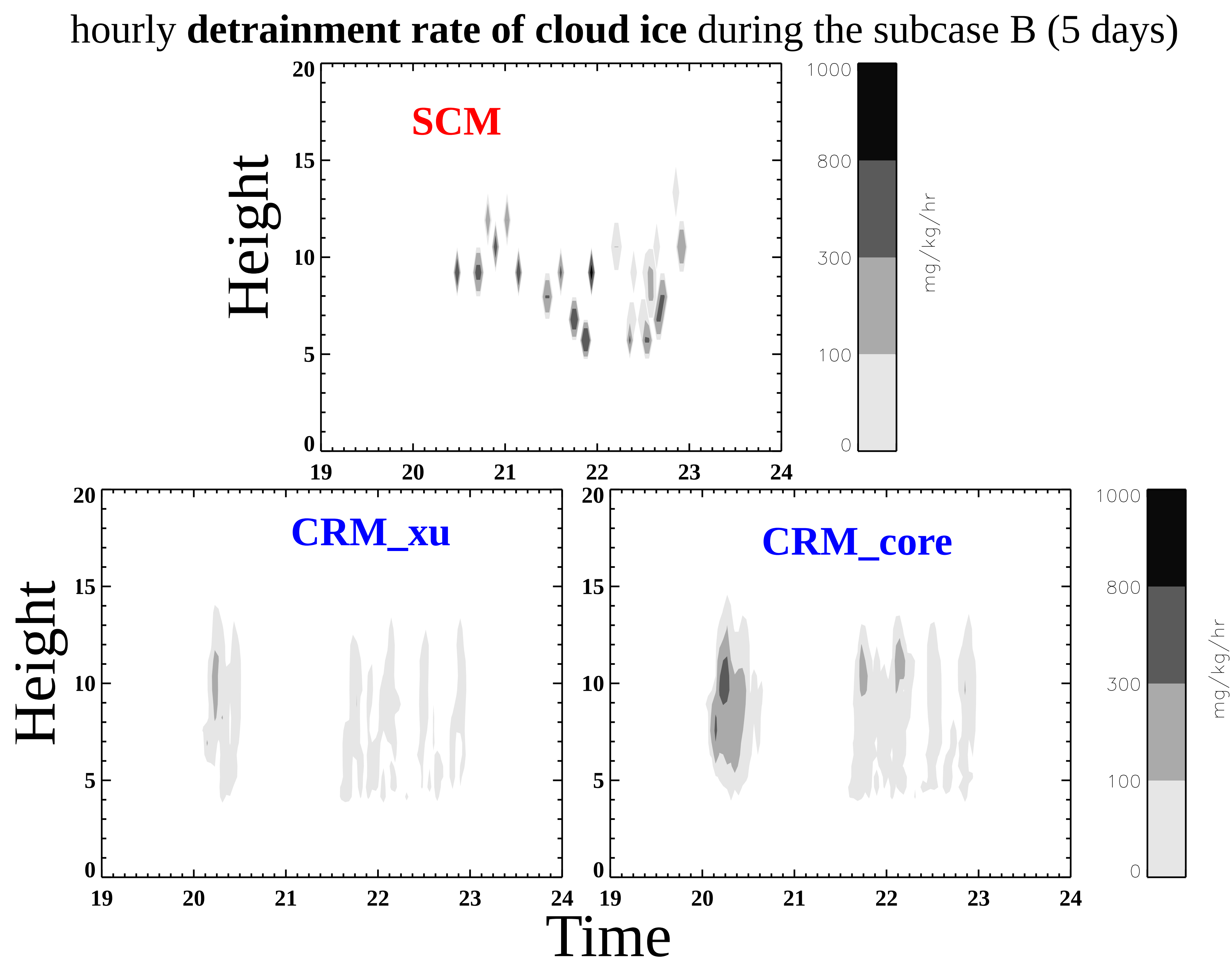
Detrainment and Microphysics Evaluation

Using results from the simulations performed by the SCM and the CRM for the summer 1997 IOP.

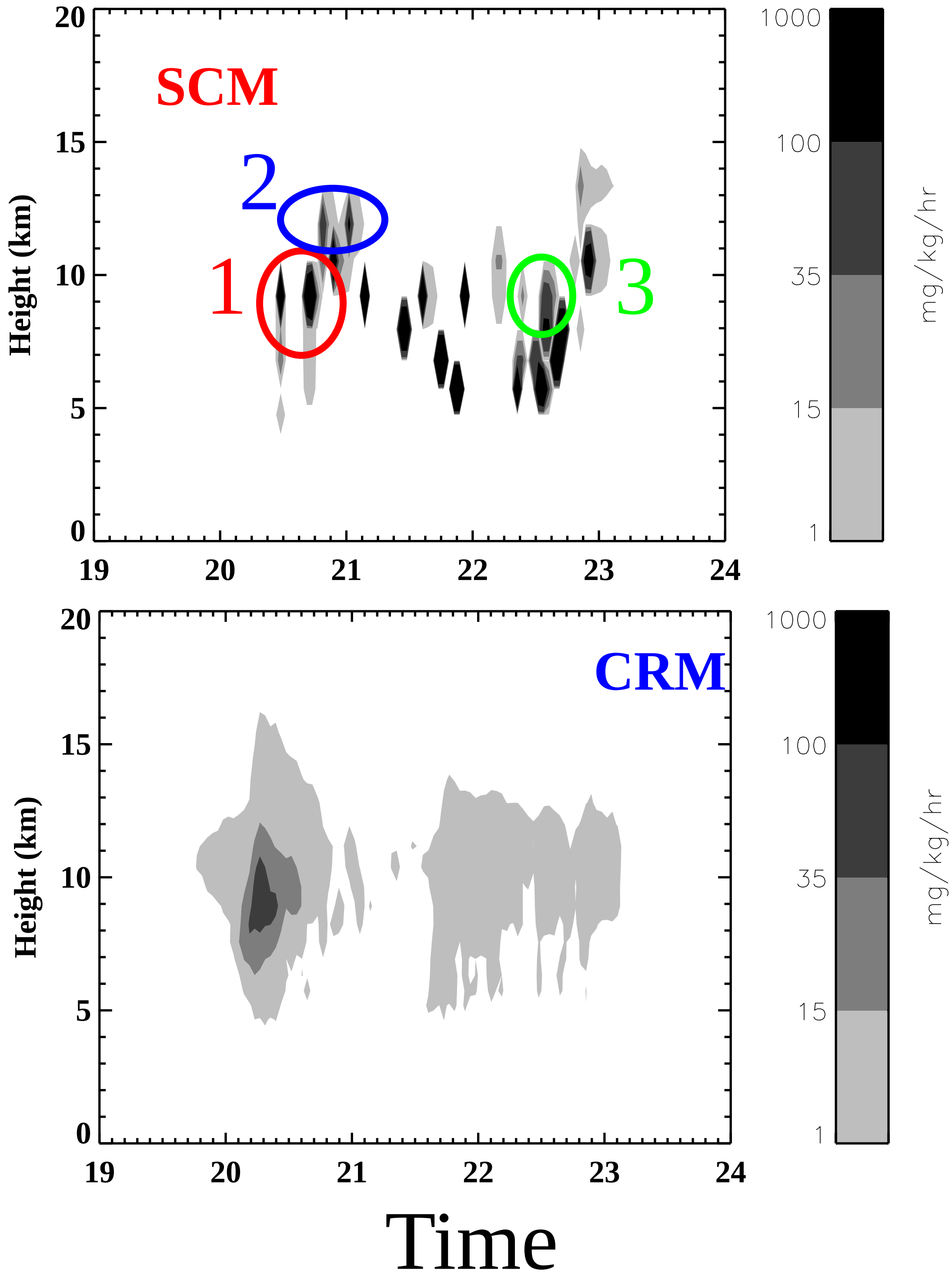
Two methods were used to find the **CRM convective regions**. One includes both active and relatively in-active convective region (CRM_xu). The other includes only the most active convective region (CRM_core).

Time-averaged **detrainment rate of cloud ice** over the entire IOP

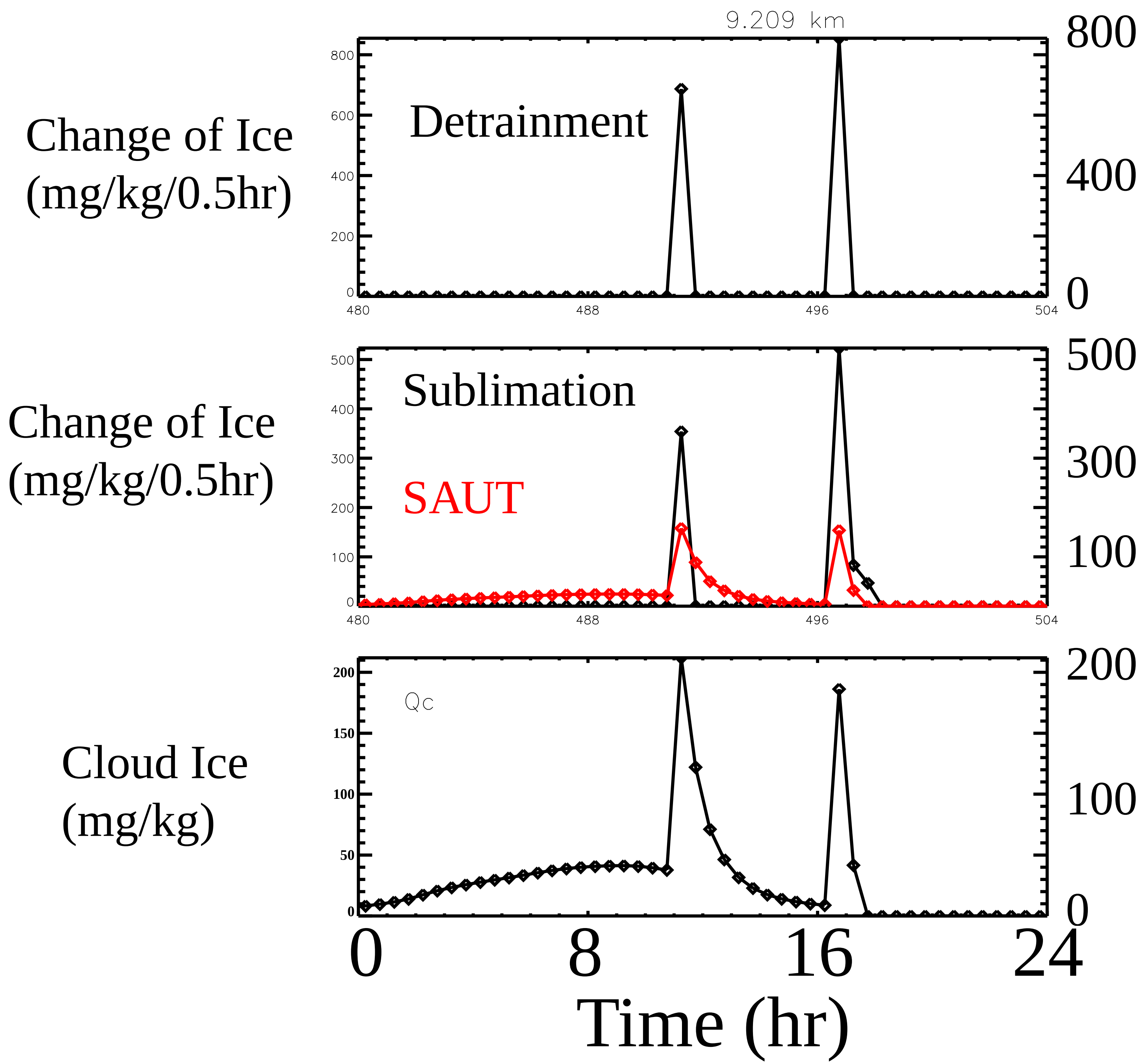



hourly **detrainment rate of cloud ice** during the subcase B (5 days)
SCM
CRM_xu
CRM_core
Height
Time
mg/kg/hr
0
100
300
800
1000
19
20
21
22
23
24
0
5
10
15
20

hourly **L.S. sublimation rate of cloud ice** during the subcase B

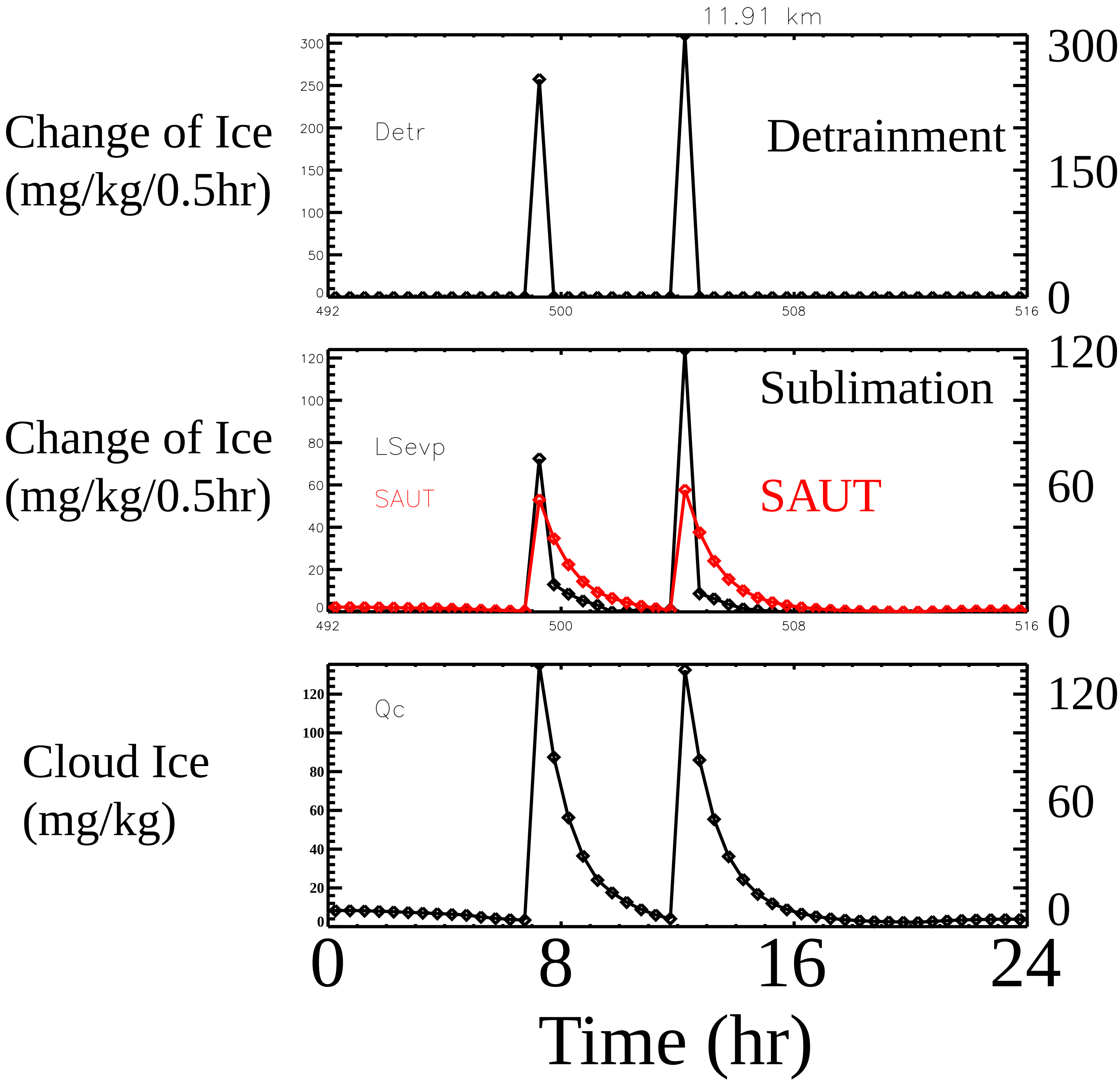


Example 1:



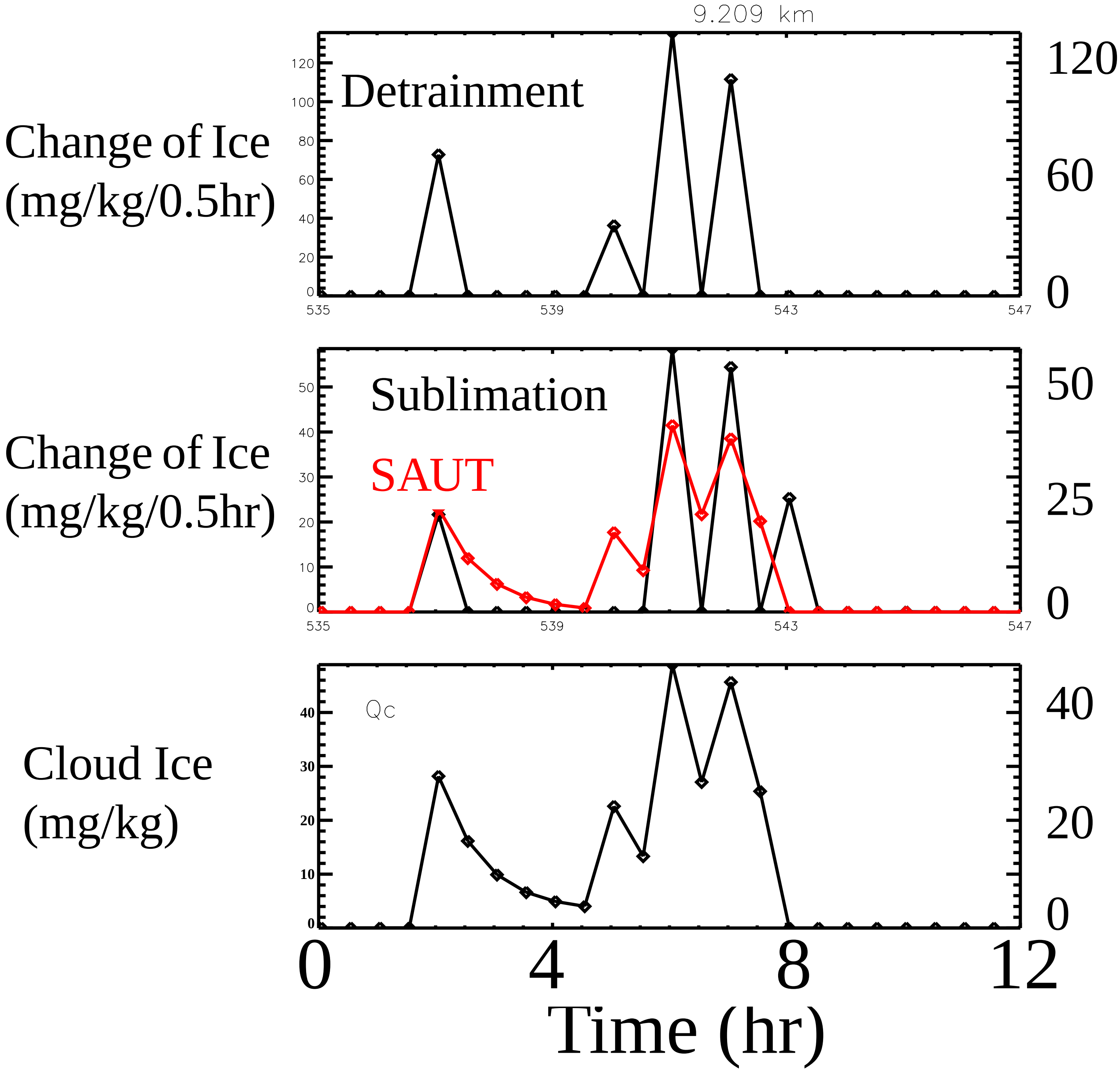
9.209 km
Change of Ice (mg/kg/0.5hr)
Detrainment
800
400
0
Change of Ice (mg/kg/0.5hr)
Sublimation
SAUT
500
300
100
Cloud Ice (mg/kg)
Qc
200
100
0
0
8
16
24
Time (hr)

Example 2:



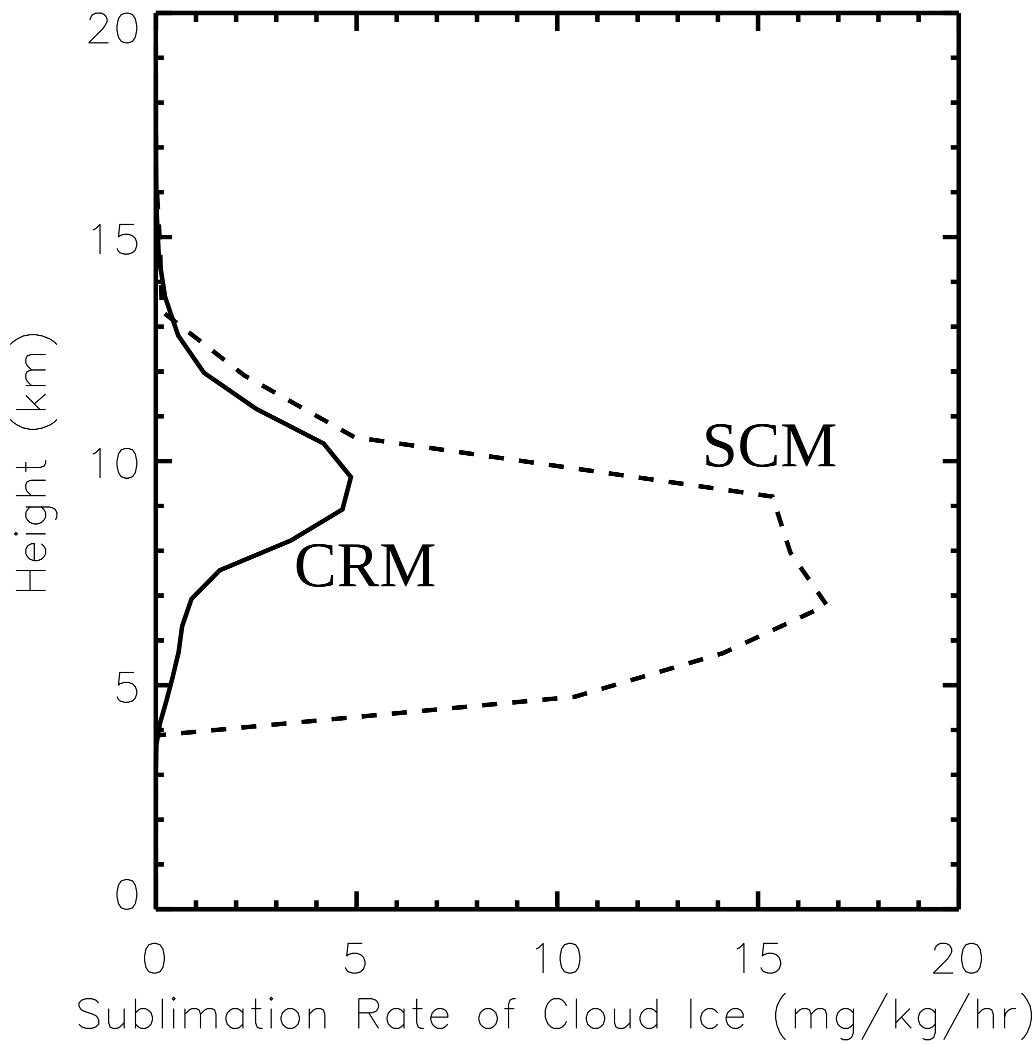
11.91 km
Change of Ice (mg/kg/0.5hr)
Detr
Detrainment
300
150
0
Change of Ice (mg/kg/0.5hr)
LSevp
SAUT
Sublimation
SAUT
120
60
0
Cloud Ice (mg/kg)
Qc
120
60
0
0
8
16
24
Time (hr)

Example 3:

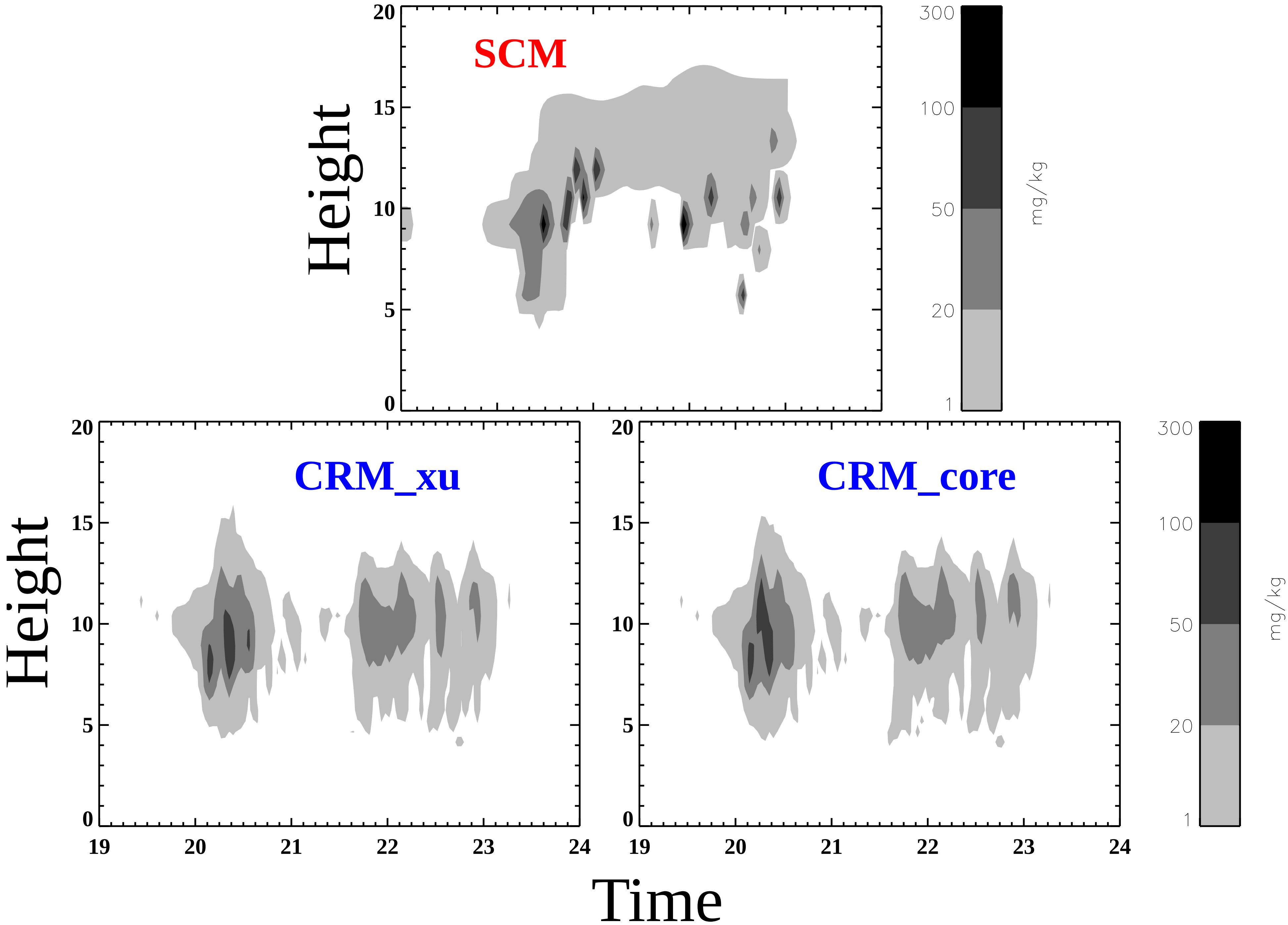


9.209 km
Change of Ice (mg/kg/0.5hr)
Detrainment
120
100
80
60
40
20
0
535
539
543
547
120
60
0
Change of Ice (mg/kg/0.5hr)
Sublimation
SAUT
50
40
30
20
10
0
535
539
543
547
50
25
0
Cloud Ice (mg/kg)
Qc
40
30
20
10
0
40
20
0
0
4
8
12
Time (hr)

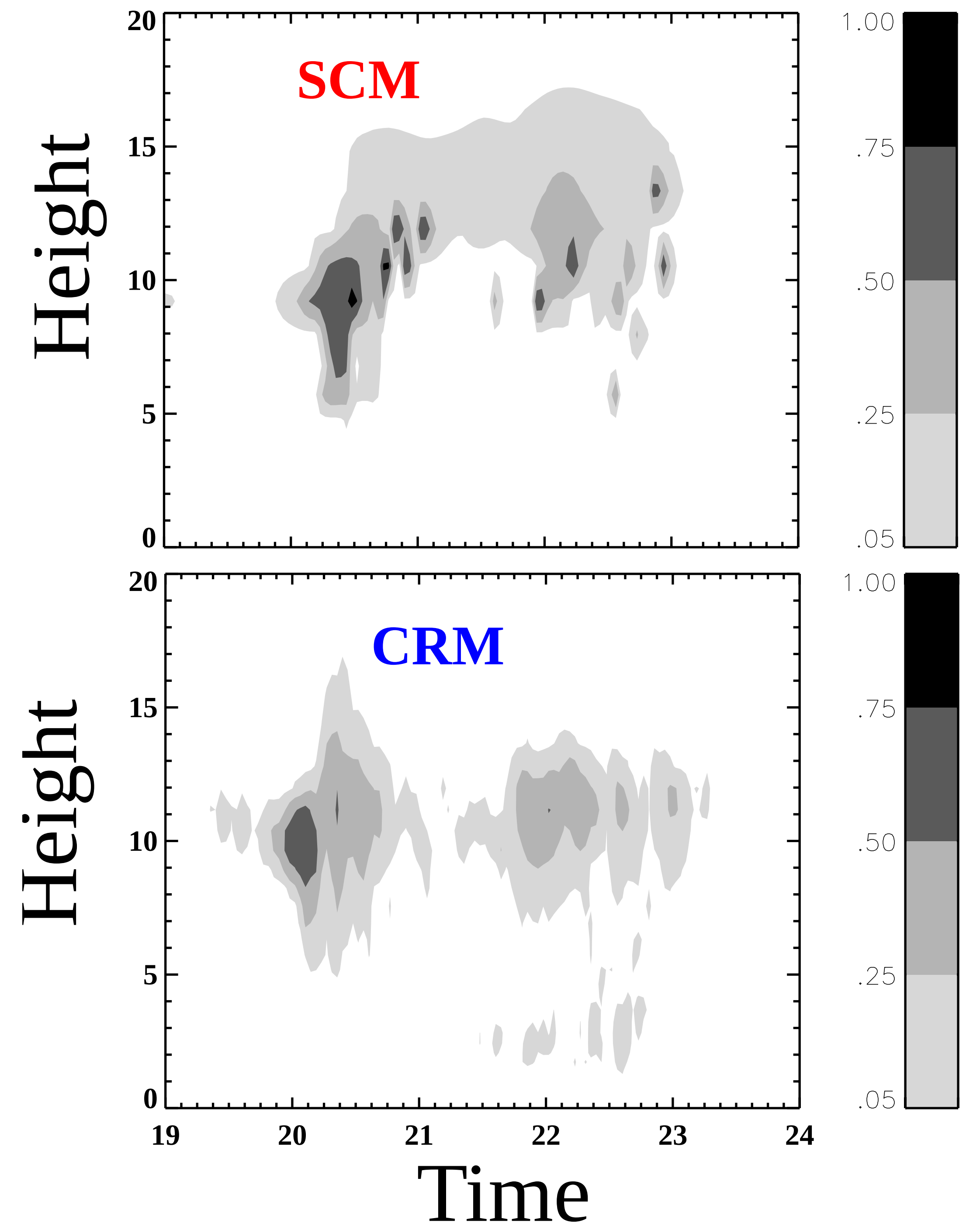
Time-averaged **L.S. sublimation rate of cloud ice** over the entire IOP



hourly **cloud ice mixing ratio** in non-convective region (including non-cloud regions) during the subcase B (5 days)



hourly **Cloud Fraction** during the subcase B (5 days)



Microphysics Evaluation

Using results from the simulations performed by a 1-D cirrus model using the same microphysics as the SCM (Dscm) and the CRM (Dcrm) use.

Initially, cloud ice (500 mg/kg) was put at a single saturated layer (pressure = 370 mb) to represent the detrained cloud ice.

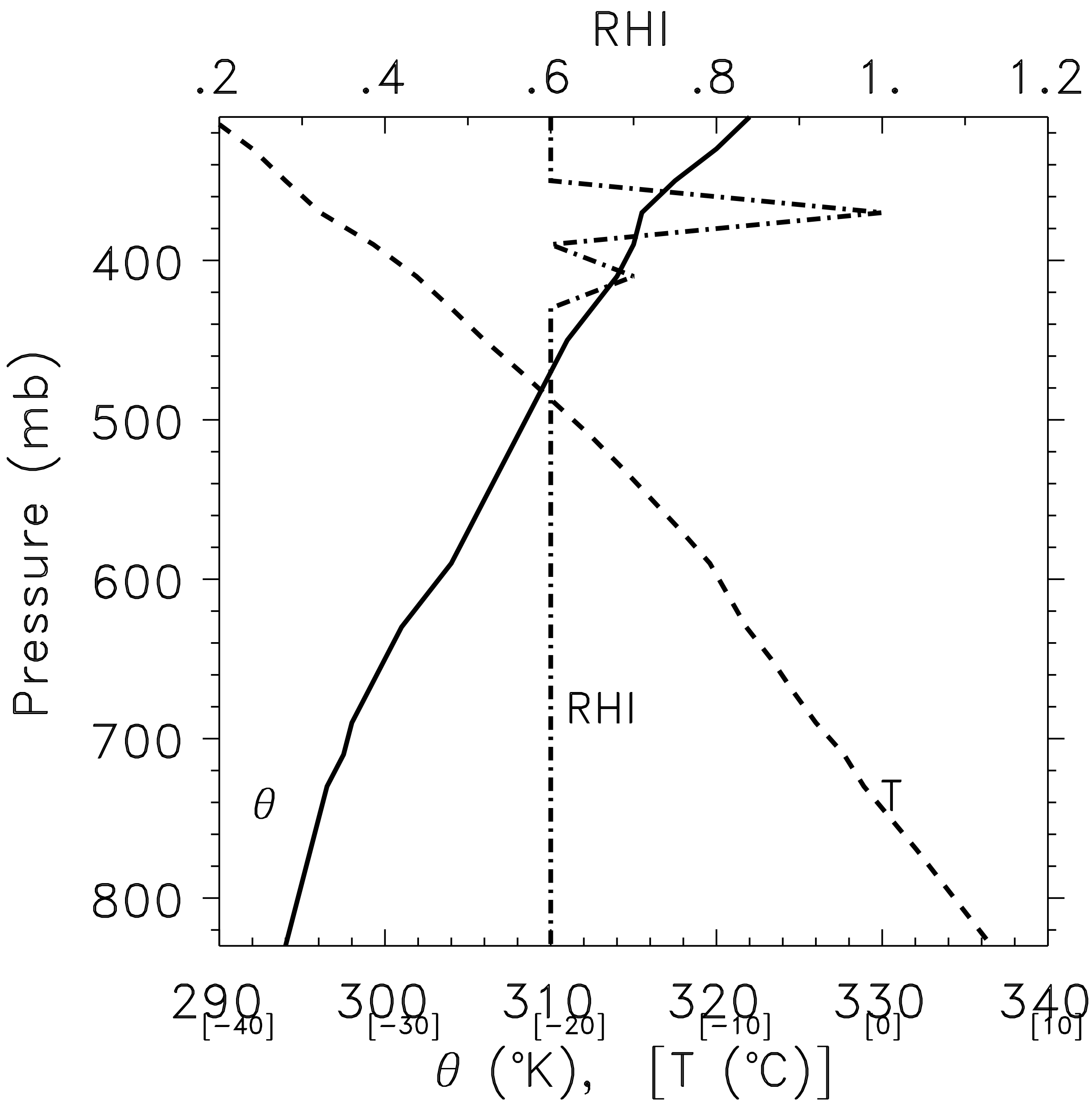
Model top: 300 mb   Model bottom: 820 mb   dP = 20 mb

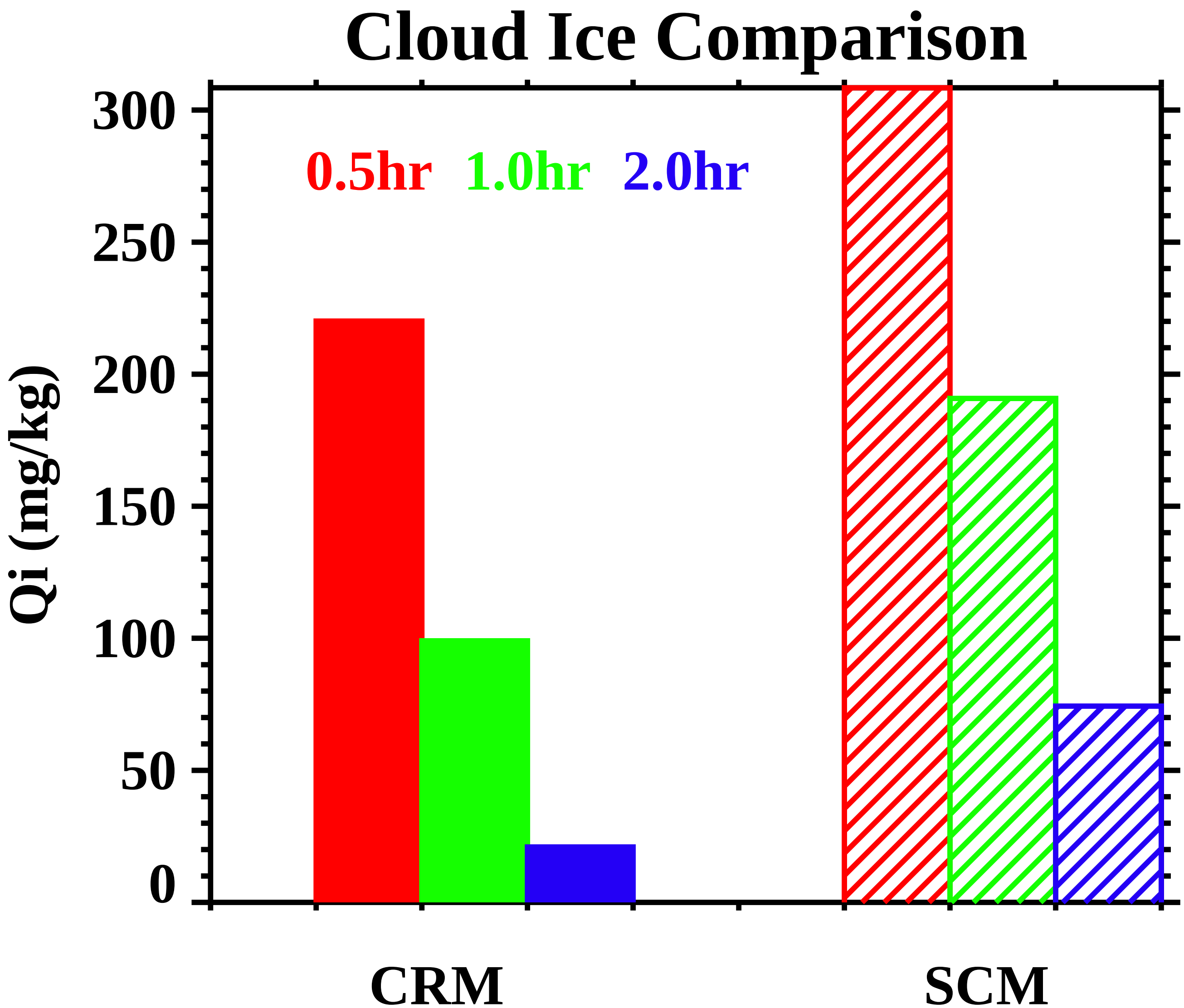
No L.S. vertical velocity.

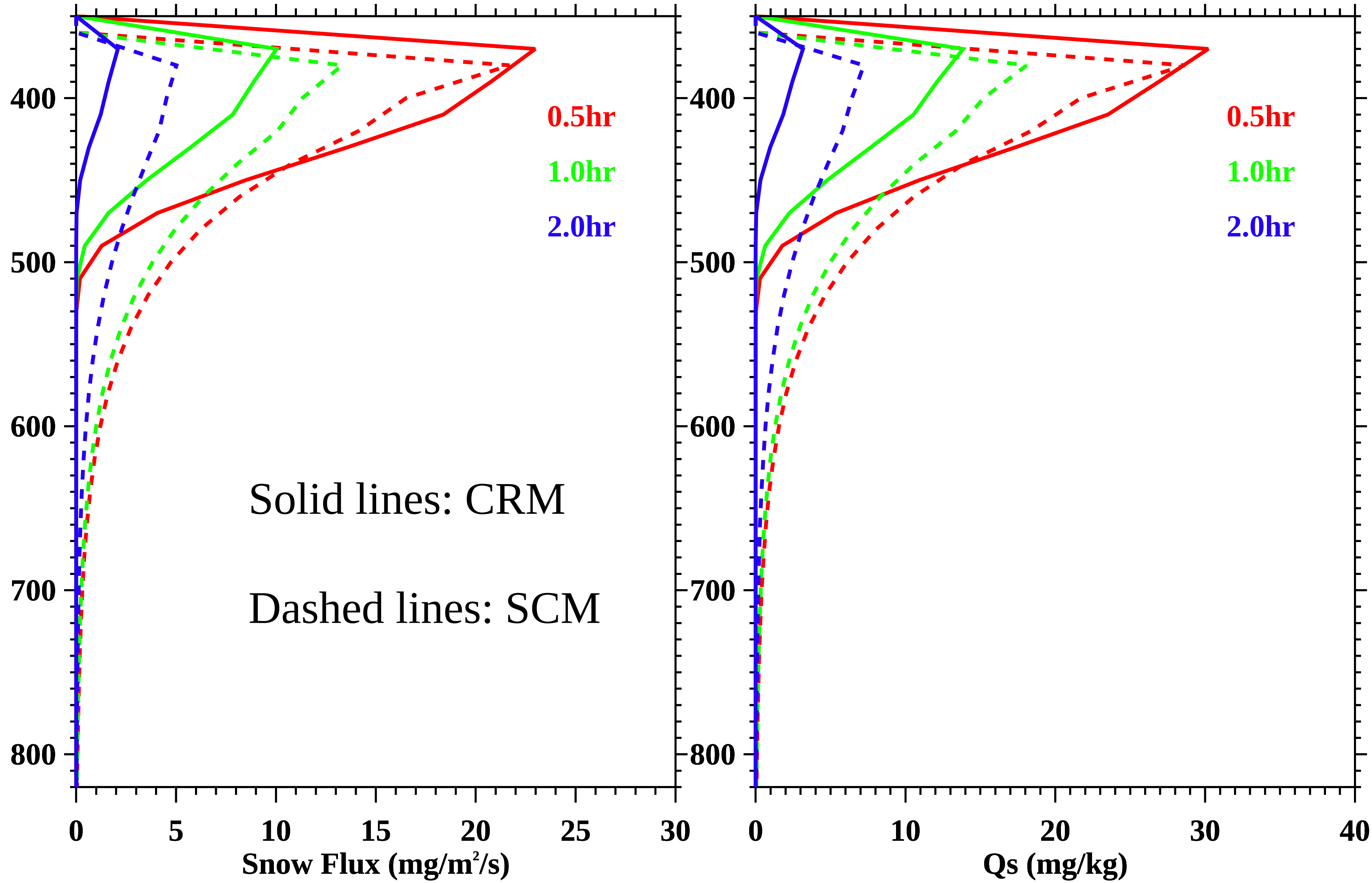
Time step for Dscm is 1800 s (.5 hour), for Dcrm is 20 s.

Simulation period: 4 hours.

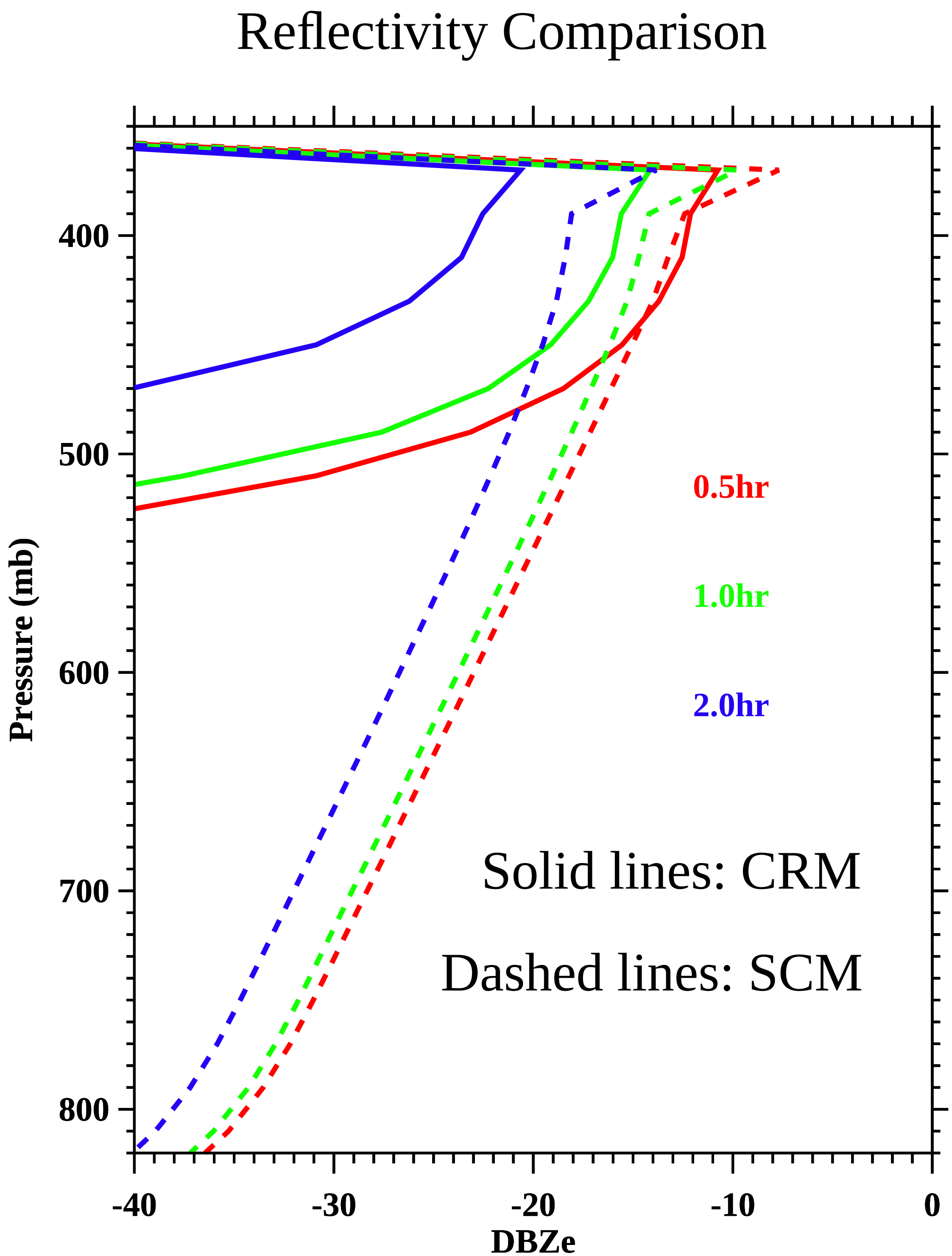
Initial Atmospheric State



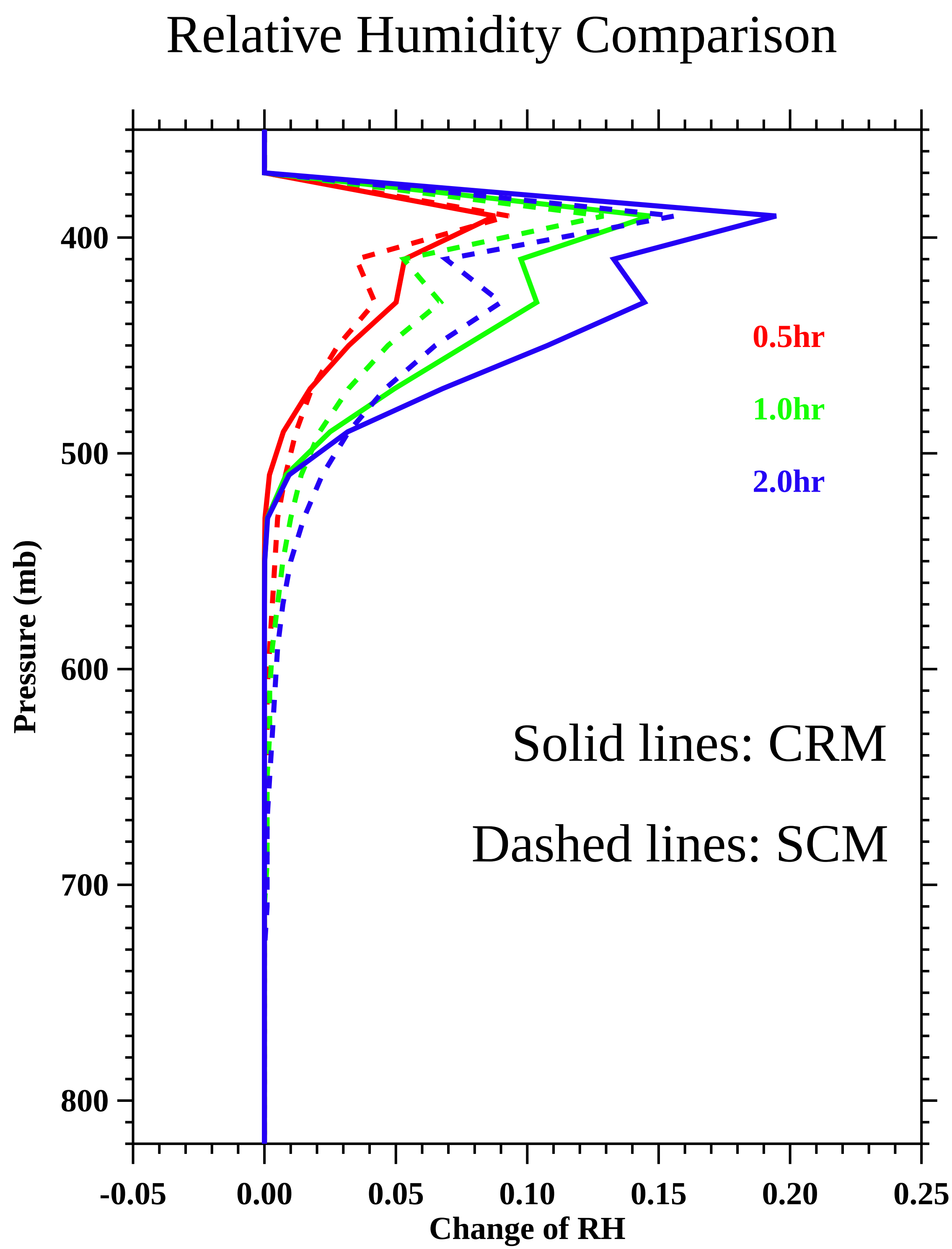

Cloud Ice Comparison
0.5hr
1.0hr
2.0hr
Qi (mg/kg)
300
250
200
150
100
50
0
CRM
SCM



400
500
600
700
800
0.5hr
1.0hr
2.0hr
Solid lines: CRM
Dashed lines: SCM
0
5
10
15
20
25
30
Snow Flux (mg/m²/s)
400
500
600
700
800
0.5hr
1.0hr
2.0hr
0
10
20
30
40
Qs (mg/kg)

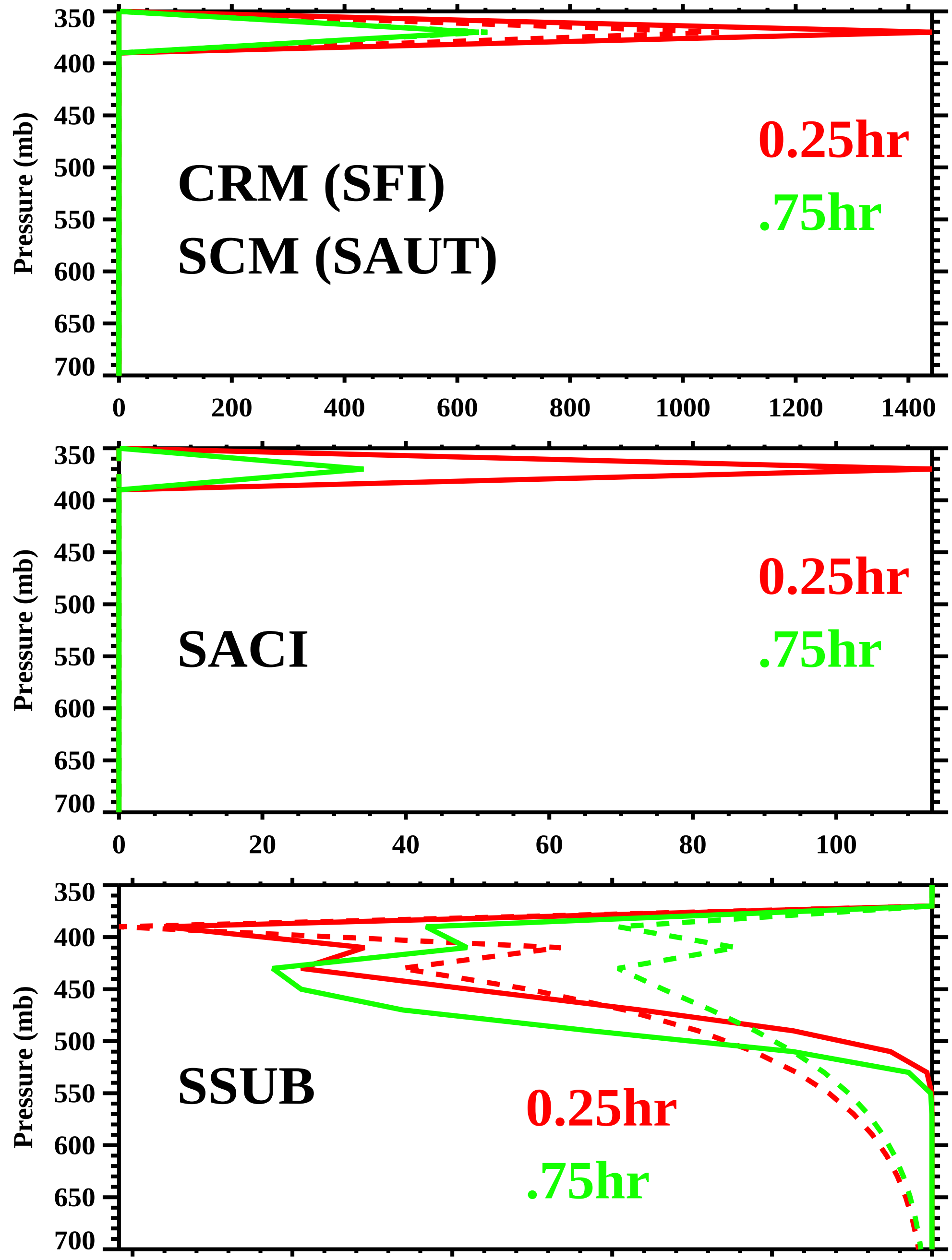


Reflectivity Comparison
Pressure (mb)
400
500
600
700
800
-40
-30
-20
-10
0
DBZe
0.5hr
1.0hr
2.0hr
Solid lines: CRM
Dashed lines: SCM



Relative Humidity Comparison
400
500
600
700
800
Pressure (mb)
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
Change of RH
0.5hr
1.0hr
2.0hr
Solid lines: CRM
Dashed lines: SCM

Half-hourly averaged Microphysical Rates (mg/kg/10^4s)



Conclusions for Part 2

1) With a correct time-averaged detrainment rate of cloud ice, but infrequent events combined with the assumption of no horizontal inhomogeniety of cloud ice, the SCM will not in general produce the correct *cloud-scale* statistics of cloud ice.

2) The SCM cloud ice sublimates immediately after detrained at too large rates.

3) The SCM diagnoses snow flux assuming that the net generation by microphysics is balanced by snow fall out in one time step.

This results in snow extending too low, and hence a downward “transport” of water vapor through snow sublimation.

4) Under overcast situation, the dominant mechanism for cloud ice decrease is transformation of cloud ice to snow via the aggregation of ice crystals in the SCM, and via the growth of Bergeron-process embryos in the CRM.