Cloud Properties Simulated by a Single-Column Model

Yali Luo and Steven Krueger
University of Utah
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 Randal (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) can NOT be easily compared

Cloud Radar Observations (1-km-scale) can be statistically compared

Synthetic Subgrid-Scale Cloud Fields
can NOT be easily compared

SCM Predicted LWC/IWC
(100-km-scale)

Apply SCM’s SGS inhomogeneity assumptions

can be statistically compared

Cloud Radar Observation
(1-km-scale)

Synthetic Subgrid-Scale Cloud Fields
IWC/LWC
+ Inhomogeneity 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.
<table>
<thead>
<tr>
<th></th>
<th>Entire IOP</th>
<th>Subperiods A, B, C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SCM nosnow max/rand</strong></td>
<td>0.25 [0.44]</td>
<td>0.25 [0.54]</td>
</tr>
<tr>
<td><strong>SCM nosnow rand</strong></td>
<td>0.37 [0.47]</td>
<td>0.33 [0.68]</td>
</tr>
<tr>
<td><strong>SCM snow rand</strong></td>
<td>0.17 [0.09]</td>
<td>0.17 [0.22]</td>
</tr>
<tr>
<td><strong>CRM</strong></td>
<td>0.37 [0.30]</td>
<td>0.30 [0.70]</td>
</tr>
<tr>
<td><strong>Cloud Radar</strong></td>
<td>0.30 [0.63]</td>
<td>0.37 [0.63]</td>
</tr>
<tr>
<td><strong>GOES (ref. obs)</strong></td>
<td>0.27 [1.00]</td>
<td>0.34 [1.00]</td>
</tr>
</tbody>
</table>
**Frequency distributions of cirrus physical thickness**

- **Cloud Radar**: avg = 2.0 km
- **CRM**: avg = 3.1 km
- **SCM nosnow rand**: avg = 1.8 km
- **SCM nosnow max/rand**: avg = 2.7 km
- **SCM snow rand**: avg = 4.2 km

Too thick cloud thicknesses occur at a single model level (resol. about 1.1 km).
Frequency distributions of cirrus cloud-top height

Cloud Radar
avg=12 km

CRM
avg=12 km

SCM nosnow rand
avg=13 km

SCM nosnow max/rand
avg=13 km

SCM snow rand
avg=13 km
Frequency distributions of cirrus cloud-base height

Cloud Radar
avg=10.3 km

CRM
avg=8.8 km

SCM nosnow
rand
avg=11.1 km

SCM nosnow
max/rand
avg=10.3 km

SCM snow rand
avg=8.7 km
Frequency distributions of thin cirrus IWP

Cloud Radar

CRM

SCM nosnow rand

SCM nosnow max/rand

SCM snow rand

Ice Water Path
Frequency distributions of thin cirrus IWP

Cloud Radar

SCM nosnow rand

SCM nosnow max/rand

too few

too many

SCM snow rand

CRM
Frequency distributions of thin cirrus IWC

Cloud Radar

CRM

SCM nosnow

rand

too few

too many

SCM nosnow

max/rand

too few

SCM snow rand

Ice Water Content
Thin Cirrus IWC vs cloud physical thickness and temperature
The SCM thin cirrus clouds: have distributions depend little on the assumptions of cloud overlap and snow, have relatively too few low $\tau$ and too many high $\tau$. 
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)
hourly L.S. sublimation rate of cloud ice during the subcase B
Example 1:

- **Change of Ice (mg/kg/0.5hr)**
- **Detrainment**
  - 9.209 km

- **Change of Ice (mg/kg/0.5hr)**
  - **Sublimation**
  - **SAUT**

- **Cloud Ice (mg/kg)**
  - **Q_c**

Time (hr): 0 8 16 24
Example 2:

Change of Ice (mg/kg/0.5hr)

Change of Ice (mg/kg/0.5hr)

Cloud Ice (mg/kg)
Example 3:

- Change of Ice (mg/kg/0.5hr)
- Detrainment
- Sublimation
- Cloud Ice (mg/kg)
- Time (hr): 0, 4, 8, 12
- Distance: 9.209 km
- SAUT
- QC
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.
Snow Flux (mg/m$^2$/s)

Solid lines: CRM
Dashed lines: SCM

Qs (mg/kg)
Reflectivity Comparison

Solid lines: CRM
Dashed lines: SCM
Relative Humidity Comparison

Solid lines: CRM
Dashed lines: SCM

Change of RH vs Pressure (mb)
Half-hourly averaged Microphysical Rates (mg/kg/10^4 s)
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 sublimes 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.