A New Method for Cloud Model Evaluation Using Satellite Data

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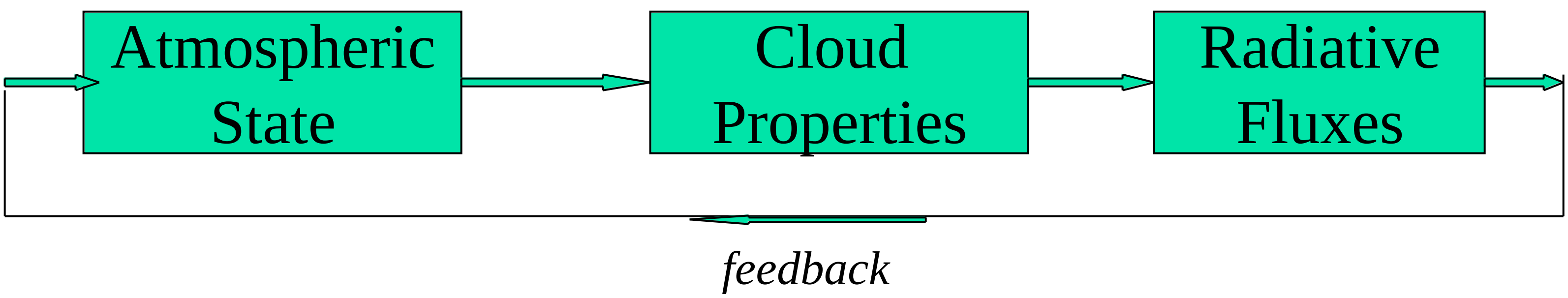
Outline

- Motivation
- New method of satellite data analysis
- Analysis of ECMWF predicted cloud fields
- Comparison of SSF with ECMWF
- Cloud-resolving model simulations
- Possible improvements of CRM simulations
- Future plans

Motivations

- Importance of radiative feedback of clouds in the climate syste
- Uncertainties in modeling cloud-radiation interactions in globa climate models (GCMs)



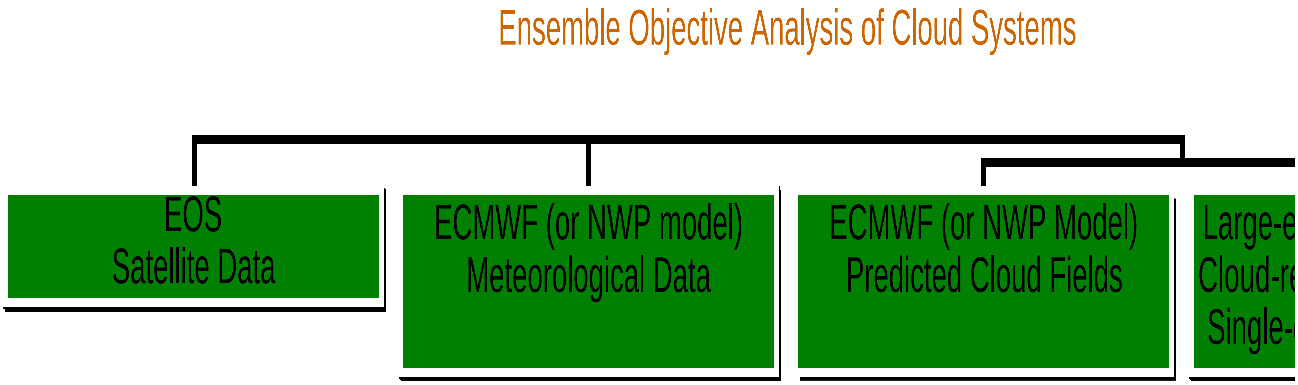
- Nonlinearity of cloud processes requiring observations on all relevant modeling scales (in space and in time)
- Existing methods of cloud model evaluation are inadequate

Existing methods for cloud model evaluatio

- **Regional field experiments (DOE ARM, TOGA-COARE, ASTEX, GATE, etc.)**
  - Detailed measurements of cloud properties and atmospheric states
  - Limited cases at selected locations for a short period
  - Extrapolate limited cases to global conditions
  - Cloud models may perform well for certain cloud-system types, but not all major types

- **Global and regional mont mean data (CERES, ISSCI ERBE, etc.)**
  - Large regions and many different cloud-system types
  - Measure only a few variables
  - Impossible to unscramble th nonlinear cloud feedback processes, due to spatial anc temporal averaging
  - Cloud models may perform v for the wrong reasons, due t cancellations of errors in GCI

A new method of satellite data analysis for cloud model evaluation

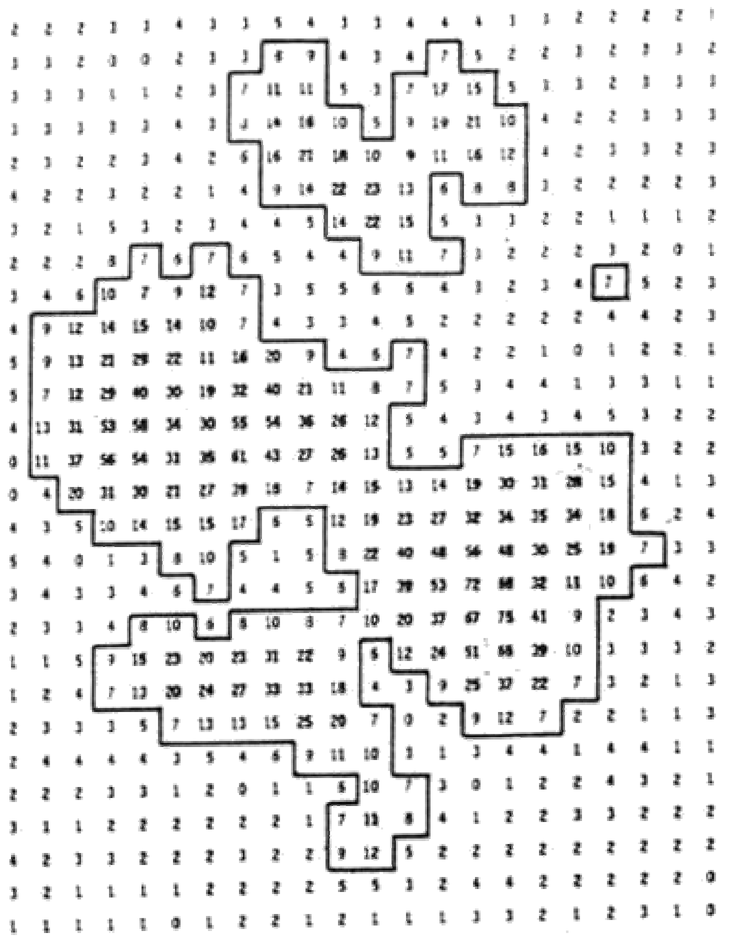


- Analyze the statistics of subgrid characteristics of cloud systems, *not* the mea
- Matching the CERES SSF (Single Scanner Footprint …) cloud and radiative data with ECMWF meteorological data (T, q, u, v and advective tendencies)
- Perform cloud model simulations driven by ECMWF advective tendencies
- Also evaluate the ECMWF parameterizations using predicted cloud fields

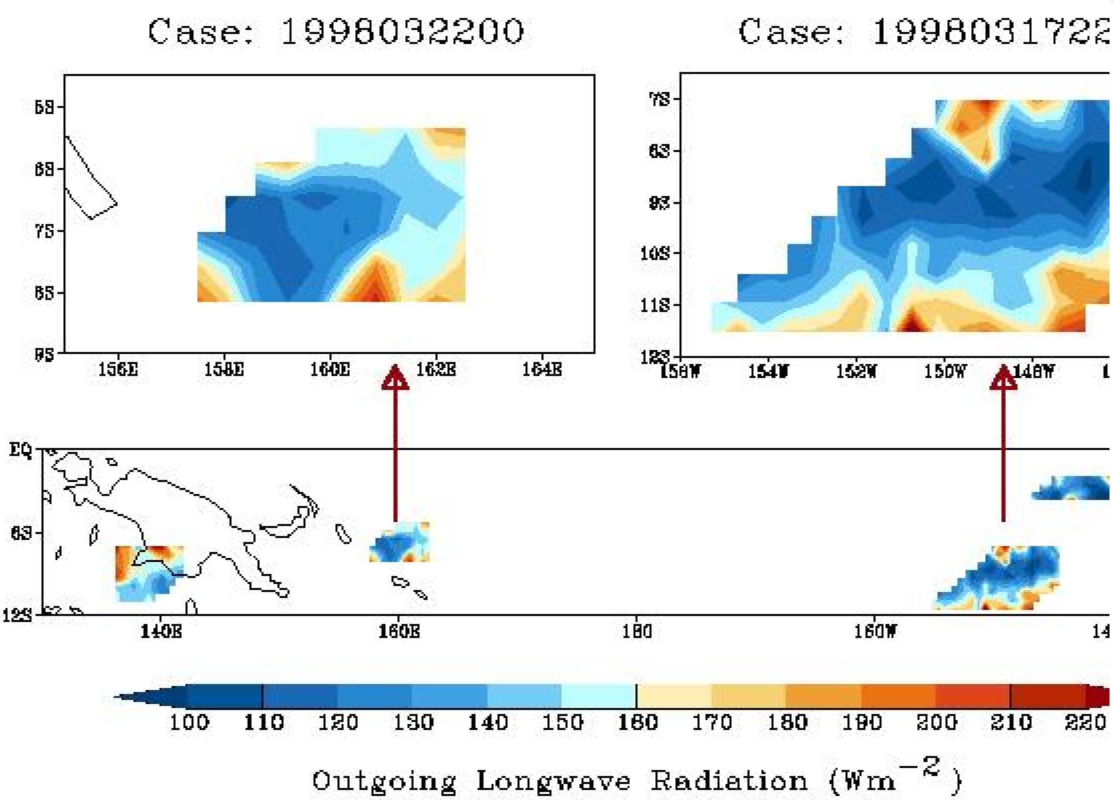
Objective Analysis of EOS satellite dat

Define a cloud system as a contiguous region of the Earth with a **single dominant** cloud type (e.g. stratocumulus, stratus, and deep convection)

Determine the shapes and sizes of the cloud systems by the satellite data and by the cloud property selection criteria (Wielicki and Welch 1986)



Samples of Cloud Objects in March



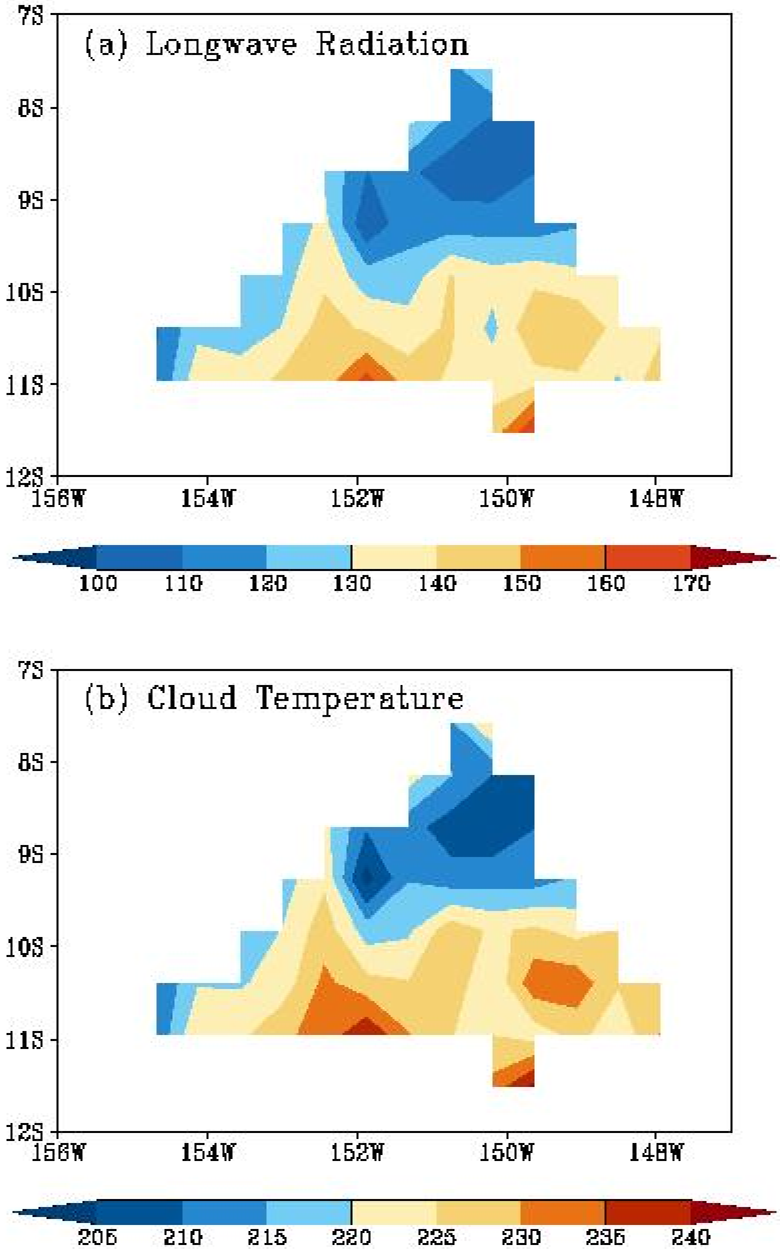
Analysis of the SSF data set

- March 1998 CERES/TRMM and March 2000 Terra data (> 190 GB/month)
- 29 cases of tropical convective systems with diameters greater than 300 km for March 1998
- Parameters analyzed from CERES SSF data product:

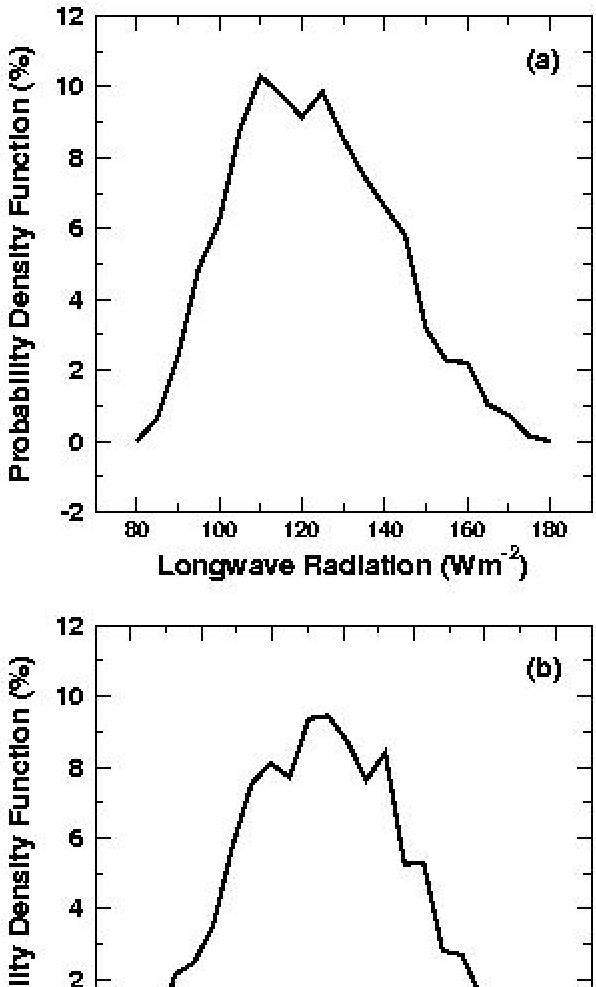
Cloud optical depth	Cloud top height
Ice water path	Cloud top pressure
Ice diameter	Cloud top temperature
TOA SW	Liquid water path
TOA albedo	Water droplet radius
OLR, Emissivity	Cloud amount

Cloud system selection criteri
for tropical deep convective systems

- Cloud top height > 10 km
- Cloud optical depth > 10
- Overcast pixels
- Latitudes between 25 °S and 25 °N



(a) Longwave Radiation
7S
8S
9S
10S
11S
12S
156W
154W
152W
150W
148W
100 110 120 130 140 150 160 170
(b) Cloud Temperature
7S
8S
9S
10S
11S
12S
156W
154W
152W
150W
148W
205 210 215 220 225 230 235 240



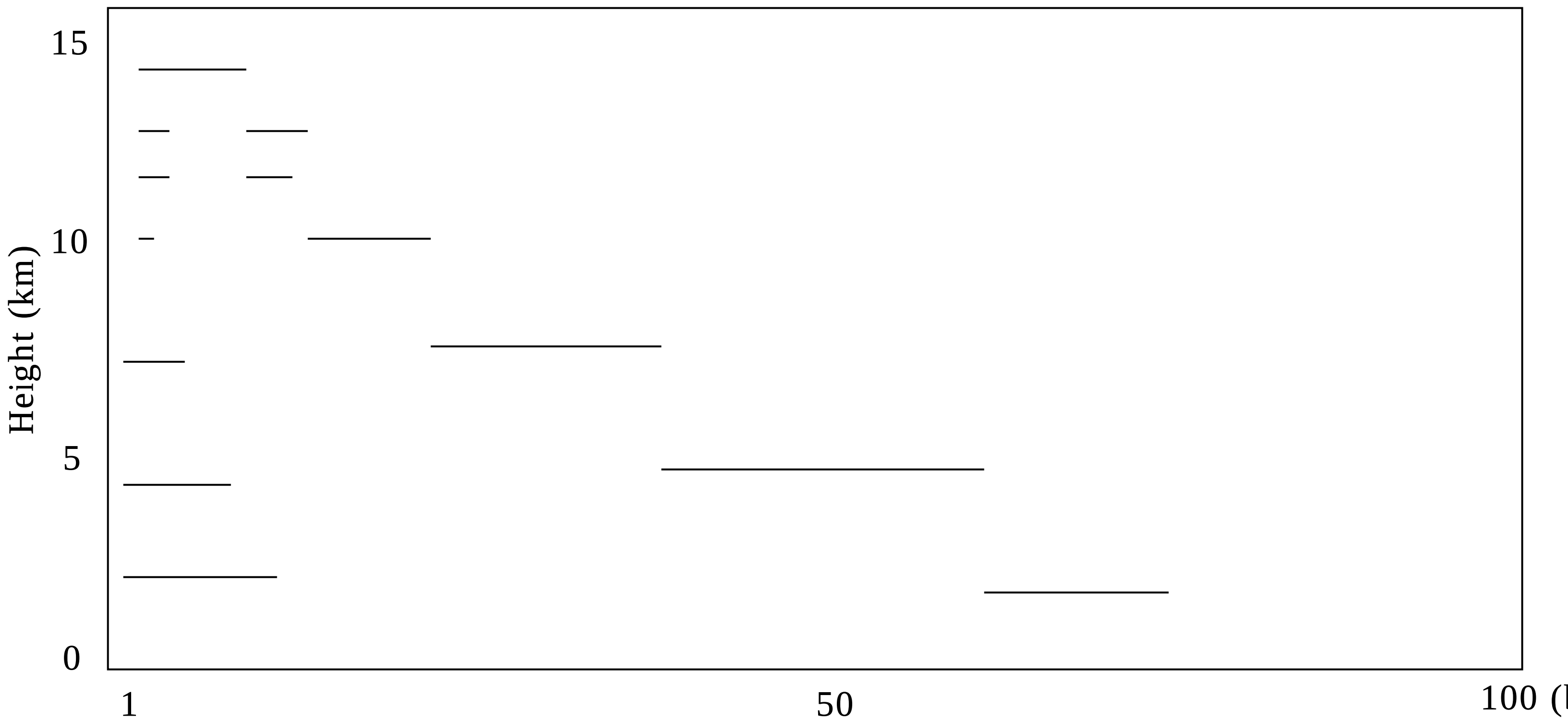
(a)
Probability Density Function (%)
Longwave Radiation (Wm^{-2})
(b)
Probability Density Function (%)
Cloud Effective Temperature (K)

Analysis of ECMWF predicted cloud fields

- ECMWF meteorological data
  - 1/2° x 1/2° gridded, six hourly analysis from data assimilatio
  - temperature, specific humidity, horizontal wind components
- ECMWF predicted cloud fields (prognostic parameterization)
  - 1/2° x 1/2° gridded, six-hour predictions
  - cloud liquid water content
  - cloud ice water content
  - cloud cover
- ECMWF grids are much bigger than some SSF pixels (range from 10 x 10 km^2 to 100 x 100 km^2)
- ECMWF does not provide cloud optical properties; we need to use the Fu-Liou radiation code, but it does not treat partially cloudy columns

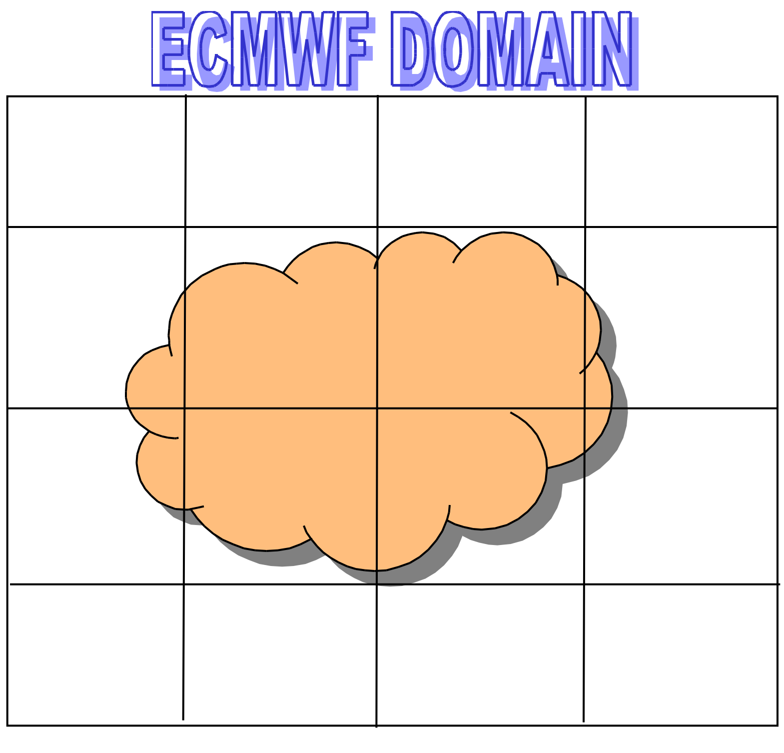
Analysis of ECMWF predicted cloud fields (cont.)

- Divide an ECMWF grid box into 100 subgrid boxes (~30 km^2)
- Use the maximum/random overlap assumption (Klein & Jacob 1999)
- Use the Fu-Liou radiation codes to obtain cloud optical properties and radiative fluxes for each subgrid box

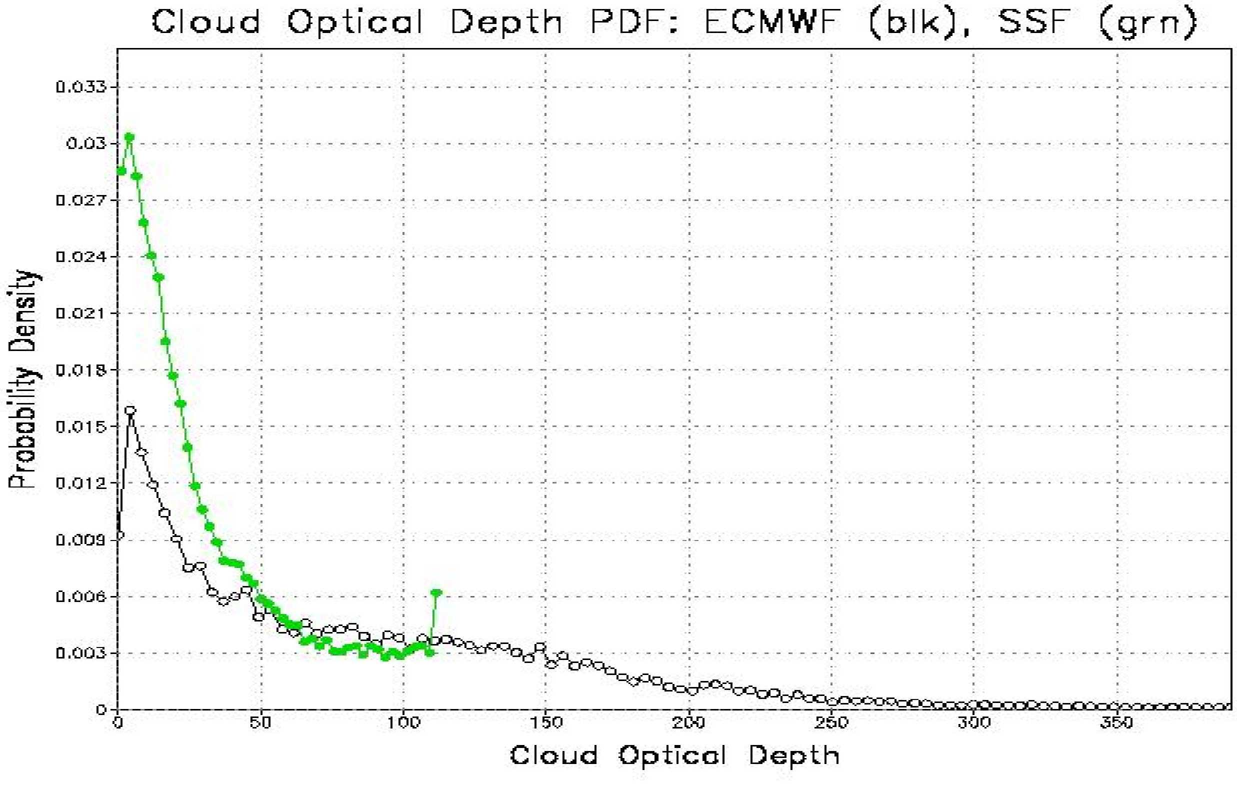


Comparison of SSF with ECMWF

- Only subgrid boxes with cloud top height > 10 and cloud optical depth > 10 are selected for statistical analysis
- Cloud top is defined for thick anvil with optical depth > 2
- Clouds within the vicinity of the observed cloud systems are also included

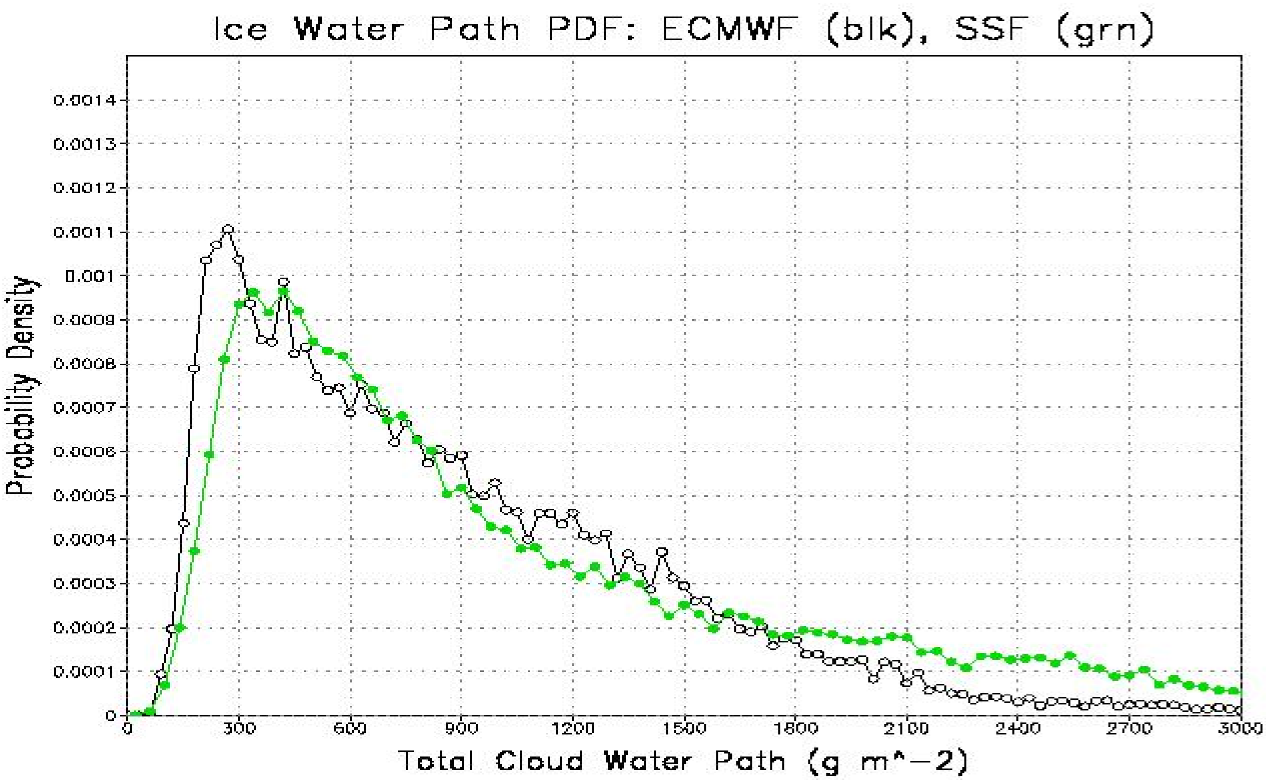


Comparison of SSF with ECMWF
Cloud optical depth (29 cases combined)

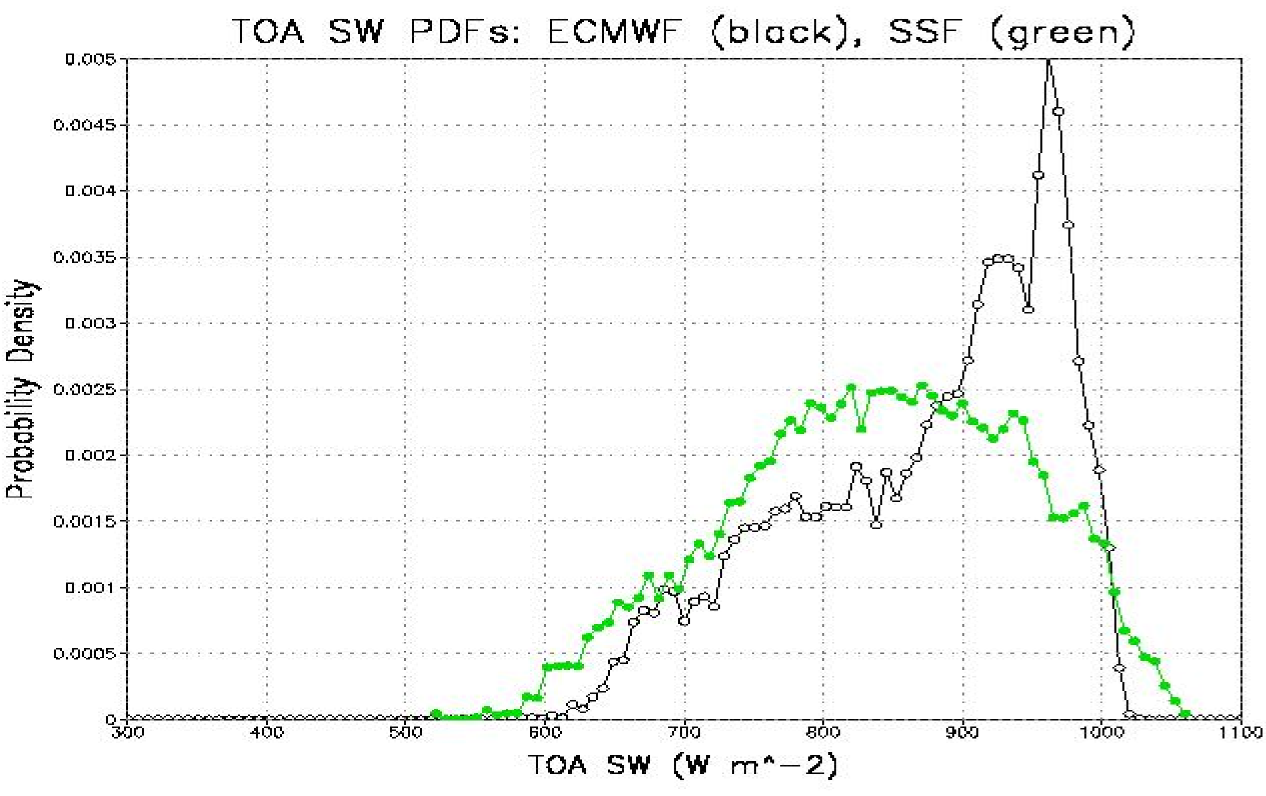


Comparison of SSF with ECMWF

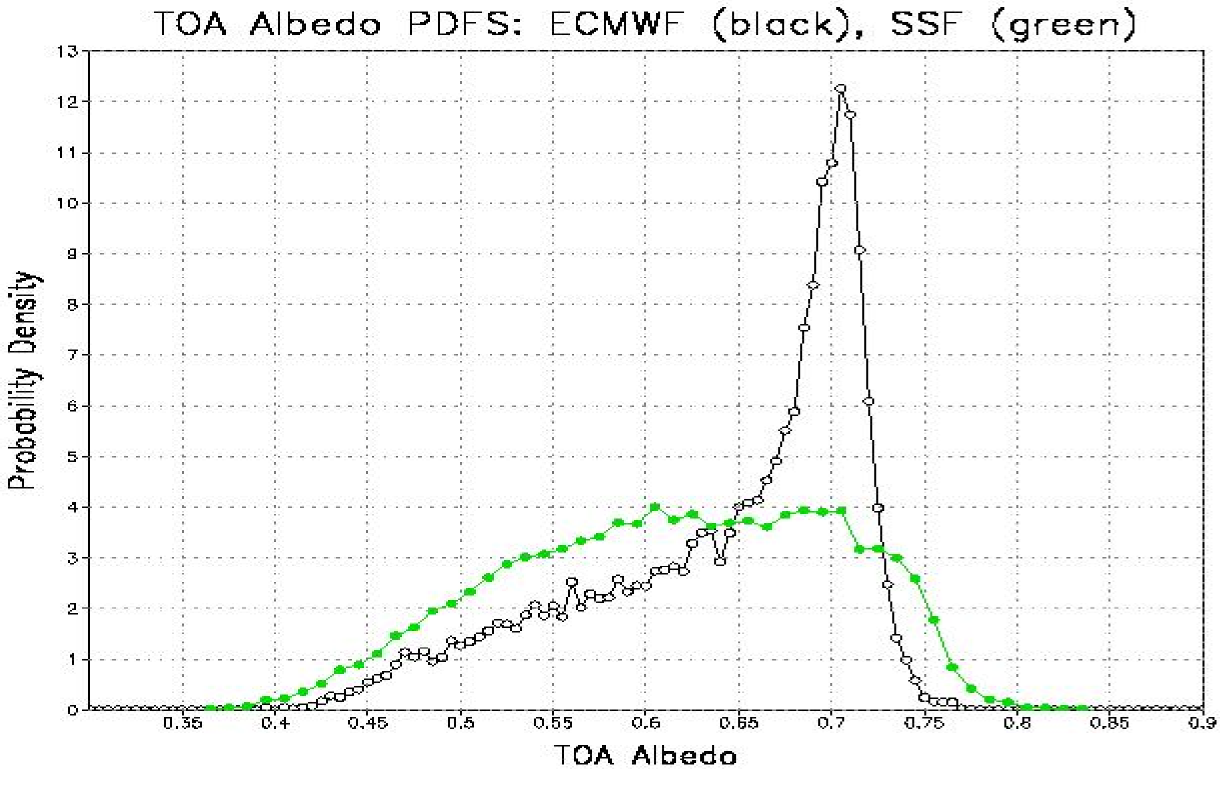
Ice (total, for ECMWF) water path



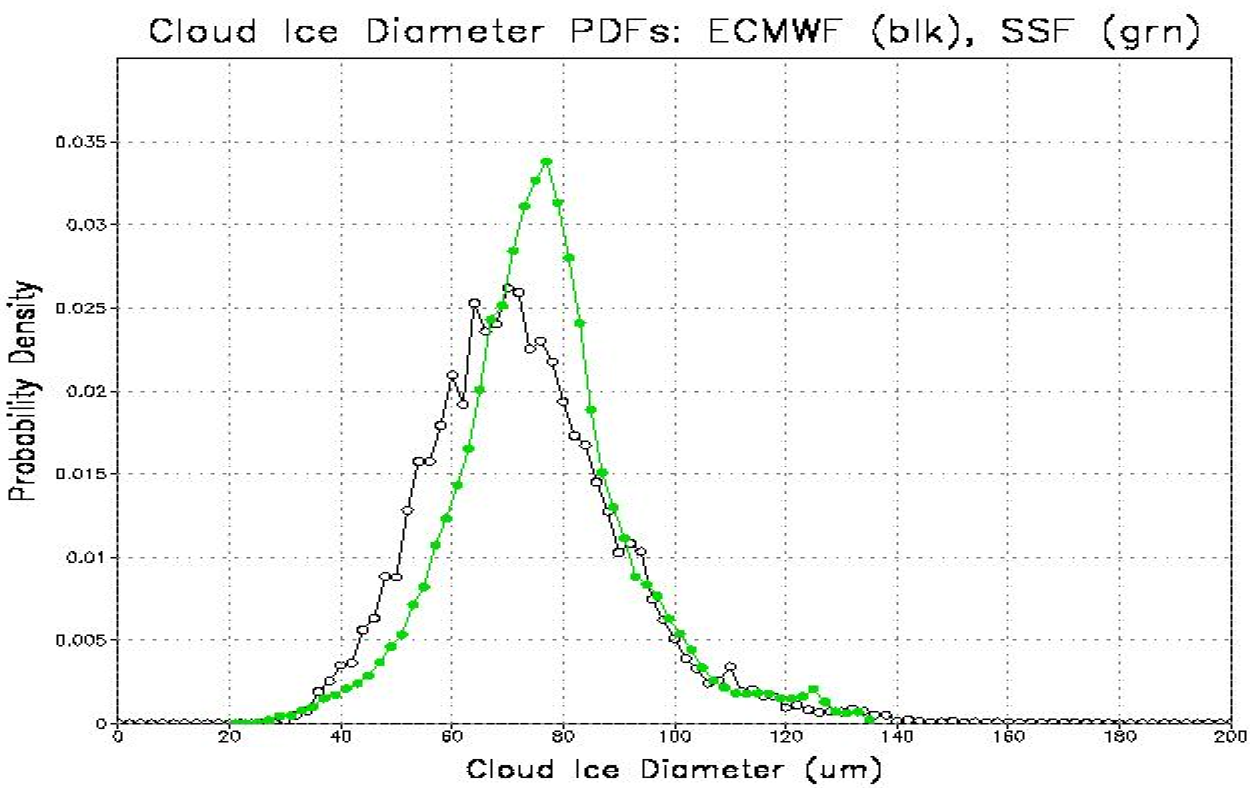
Comparison of SSF with ECMWF
TOA solar radiation



Comparison of SSF with ECMWF
TOA Albedo

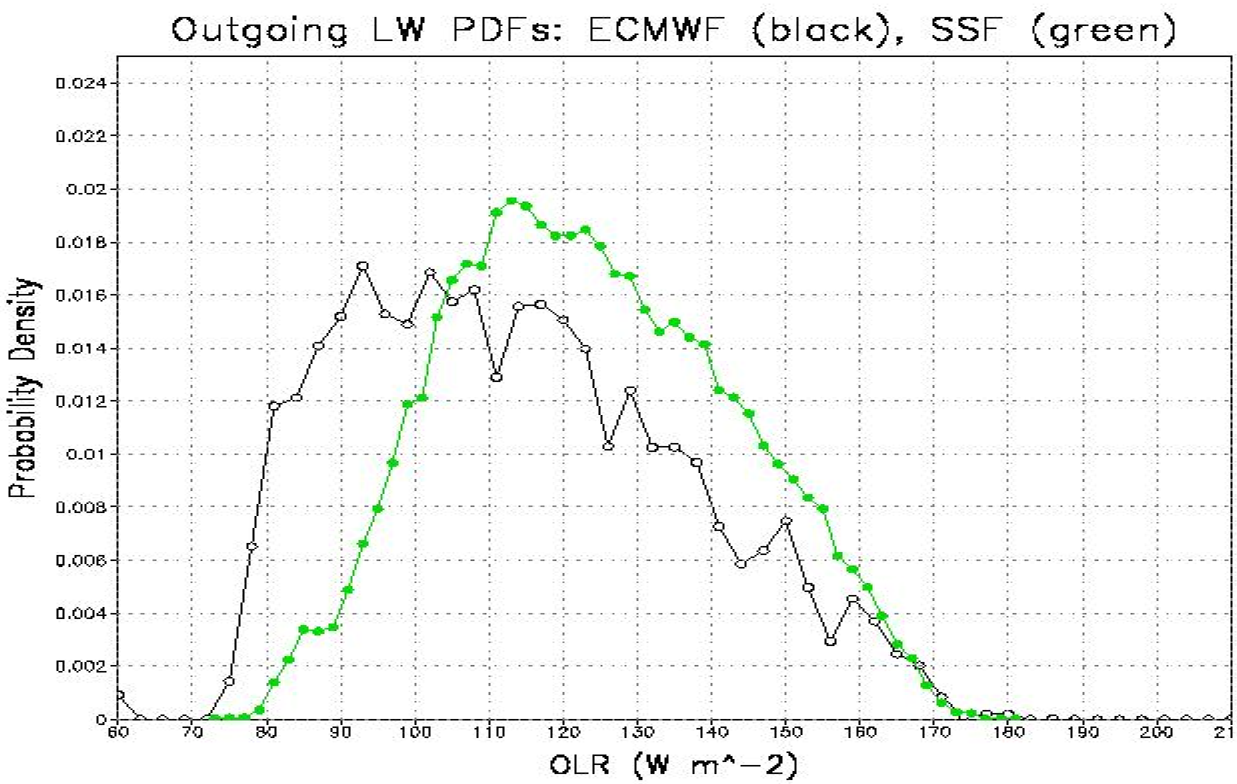


Comparison of SSF with ECMWF
Cloud ice diameter

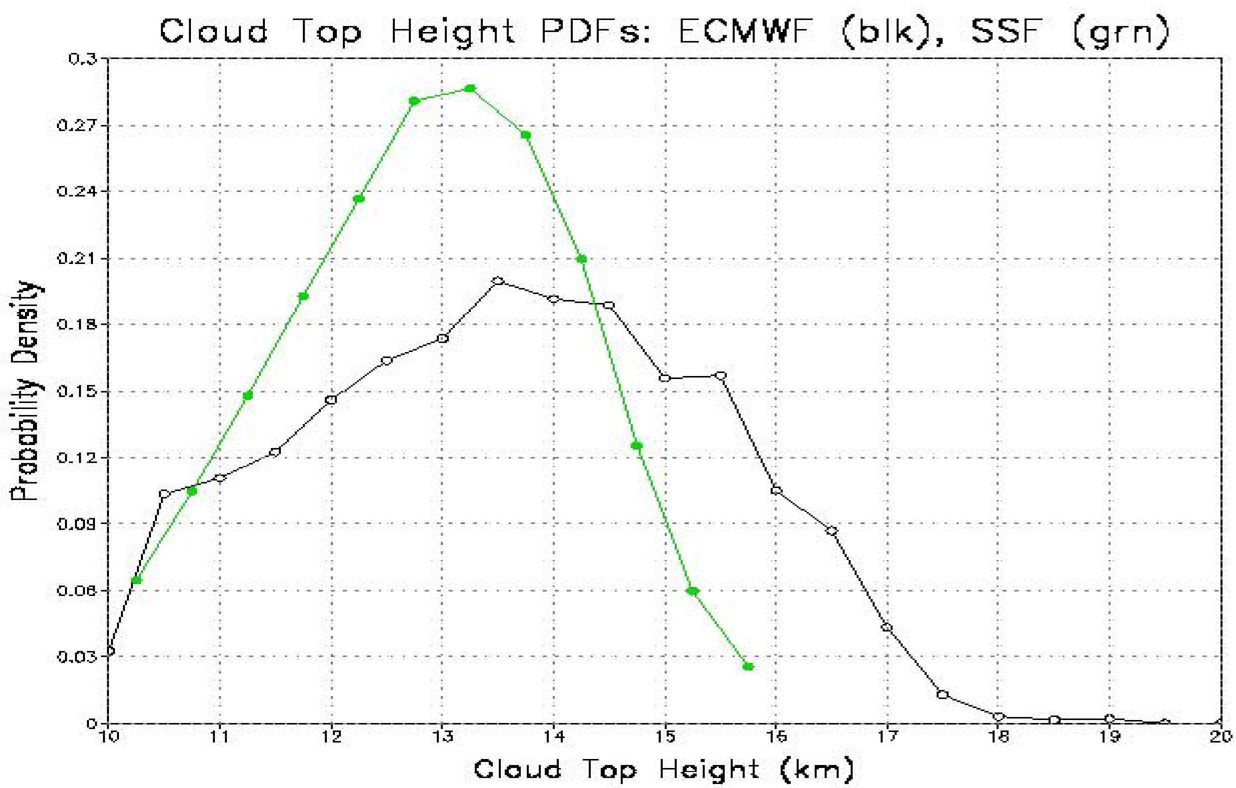


Comparison of SSF with ECMWF

Outgoing longwave radiation



Comparison of SSF with ECMWF
Cloud top height



Comparison of SSF with ECMWF
Summary

- The probability density functions (PDFs) of ECMWF predicted cloud fields basically agree with satellite observations
- The PDFs of most parameters are close to the Gaussian distribution, except for optical depth and total (ice) water path, which are exponentially distributed
- The ECMWF predicted clouds tend to be deeper an colder than those observed with the SSF

Cloud resolving model simulation
What is a cloud-resolving model (CRM)?

- Sufficient spatial and temporal resolution to resolve individual cloud elements (~ 1 km)
- Sufficient large domain and long time scale for statistical analyses of cloud systems
- Explicitly resolve cloud-scale and mesoscale dynamical processes
- Need to parameterize turbulence, cloud microphysics and radiative transfer
- Often used as a tool for cloud parameterization development for GCMs
- Will probably be used as a "super parameterization" in future GCMs

Cloud-resolving model simulatio
Description of the models

LaRC2d CRM (UCLA/CSU; Krueger 1988; Xu and Randall 1995)

- Two-dimensional, anelastic dynamics (no sound waves)
- Third-moment turbulence closures (35 prognostic equations a one diagnostic equation)
- Three-phase cloud microphysics parameterization (Lin et al. 1983; Krueger et al. 1995)
- Harshvardhan et al. (1987) radiative transfer parameterizatio
- LaRC3d CRM (Advanced Regional Prediction System; Xue et a 2000)
- 2-D or 3-D fully compressible dynamics
- Prognostic turbulent kinetic energy (TKE) closure
- Three-phase cloud microphysics parameterization (Lin et al. 1983)
- Chou (1990, 1992) and Chou and Suarez (1994) radiative transfer parameterization

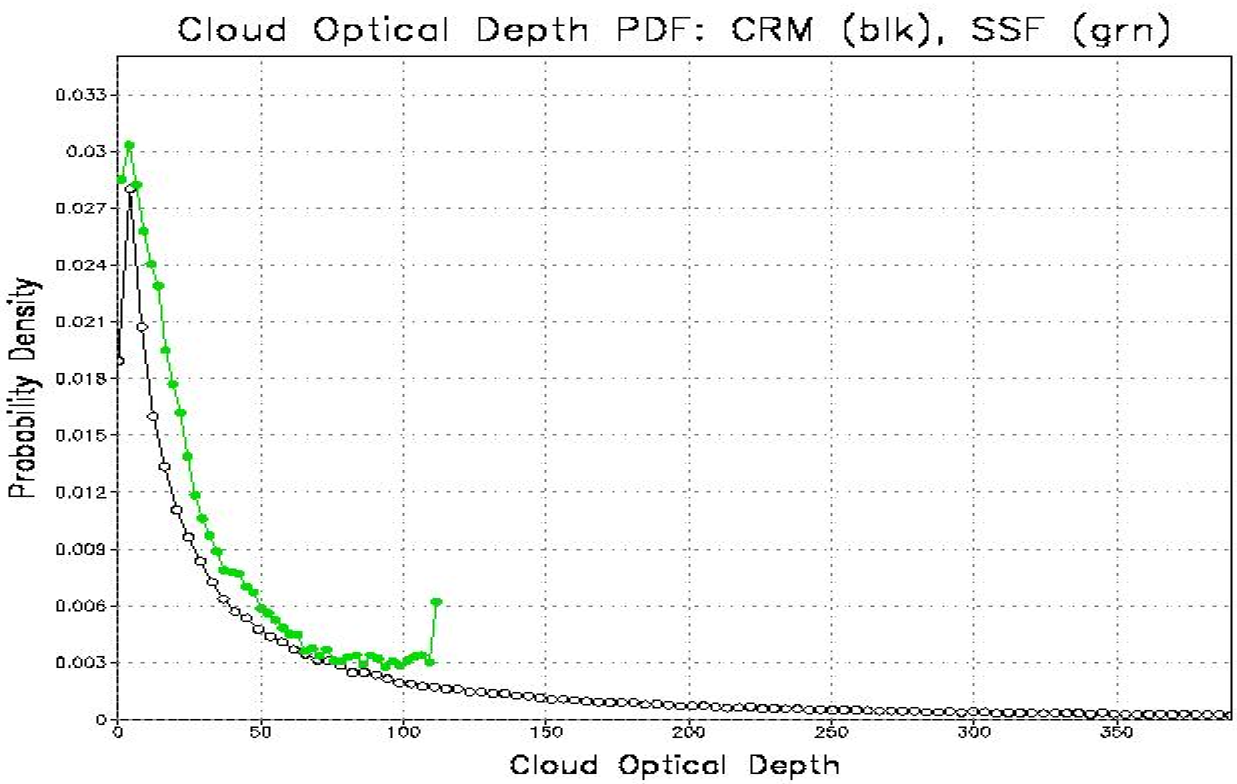
Cloud resolving model simulatio

Design of simulation

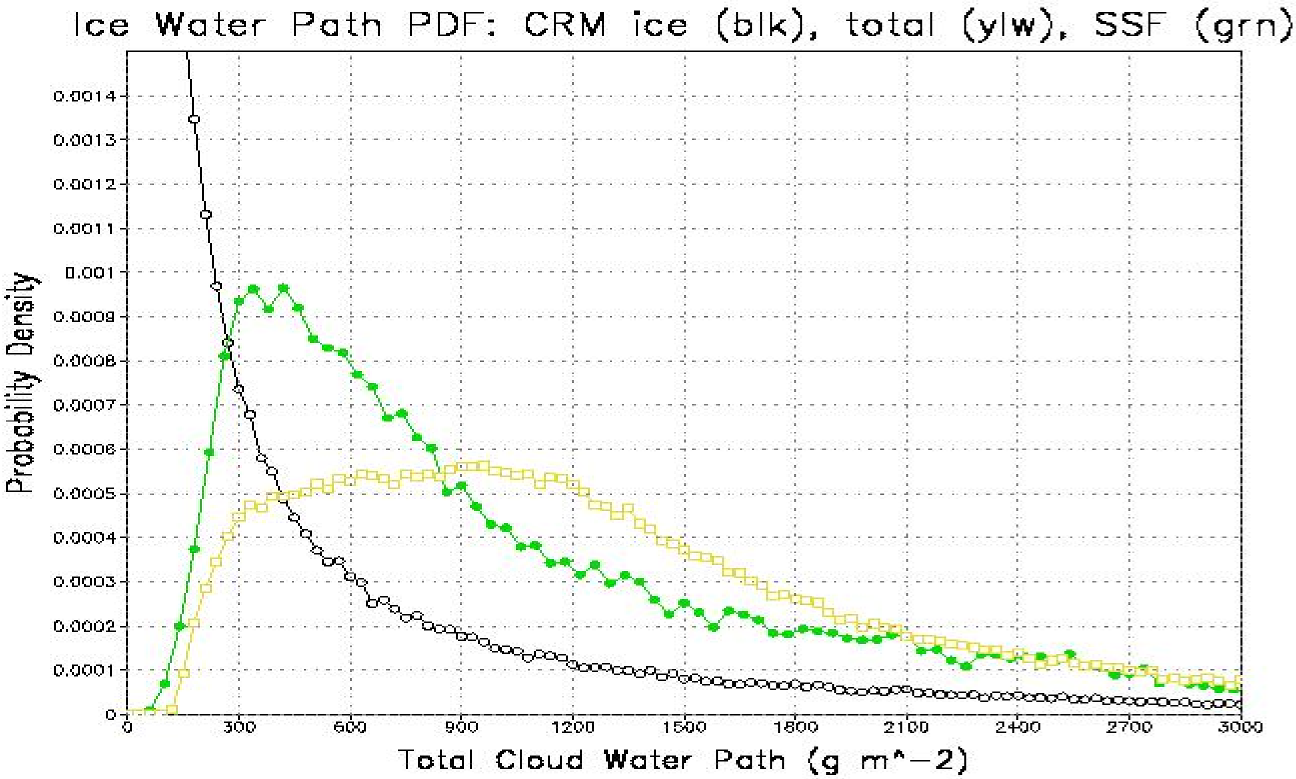
- 2-D (x-z), horizontal grid size is 2 km
- Prescribe large-scale advective tendencies that are calculated from ECMWF data and averaged over an square area three times a great as the satellite observed cloud system
- The advective tendencies are assumed to b quasi-steady
- Simulation lasts for 24 h
- Only the last 12 h is analyzed

Comparison of CRMs with SSF

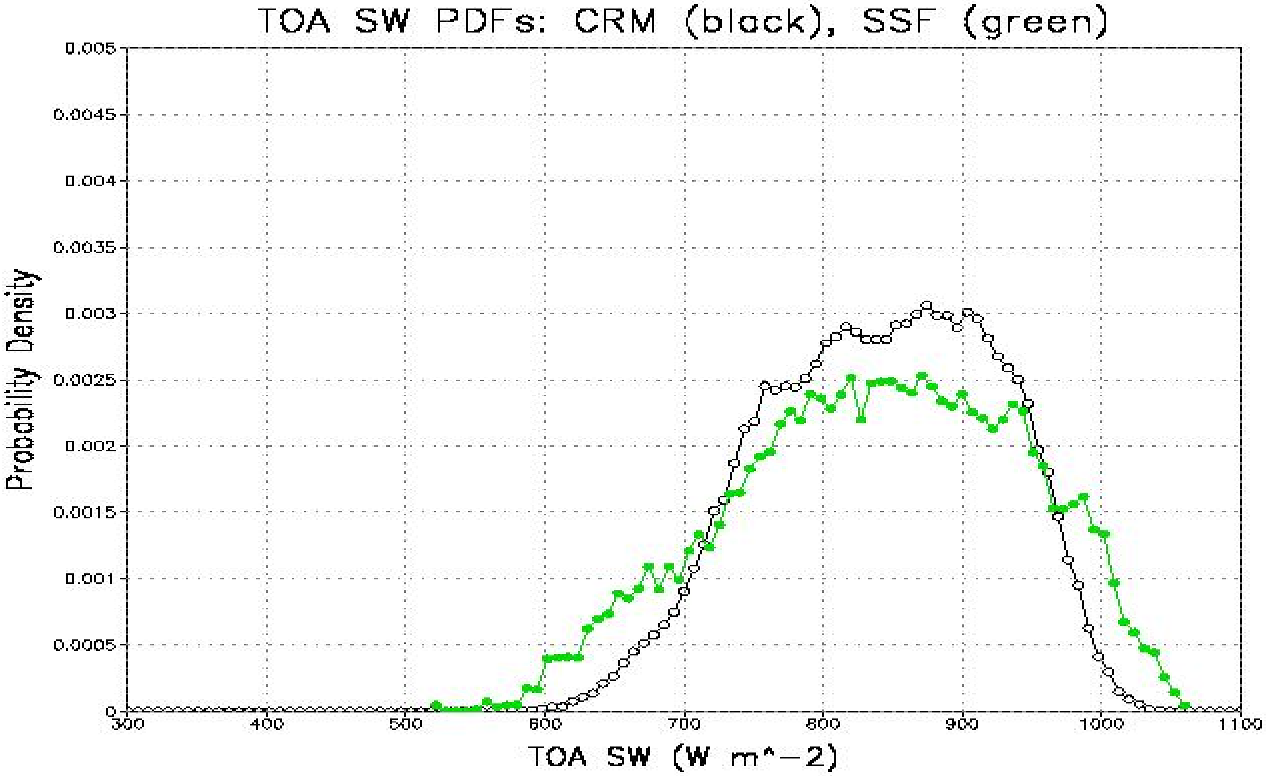
Cloud optical depth – LaRC2d



Comparison of CRMs with SSF
Ice water path – LaRC2d

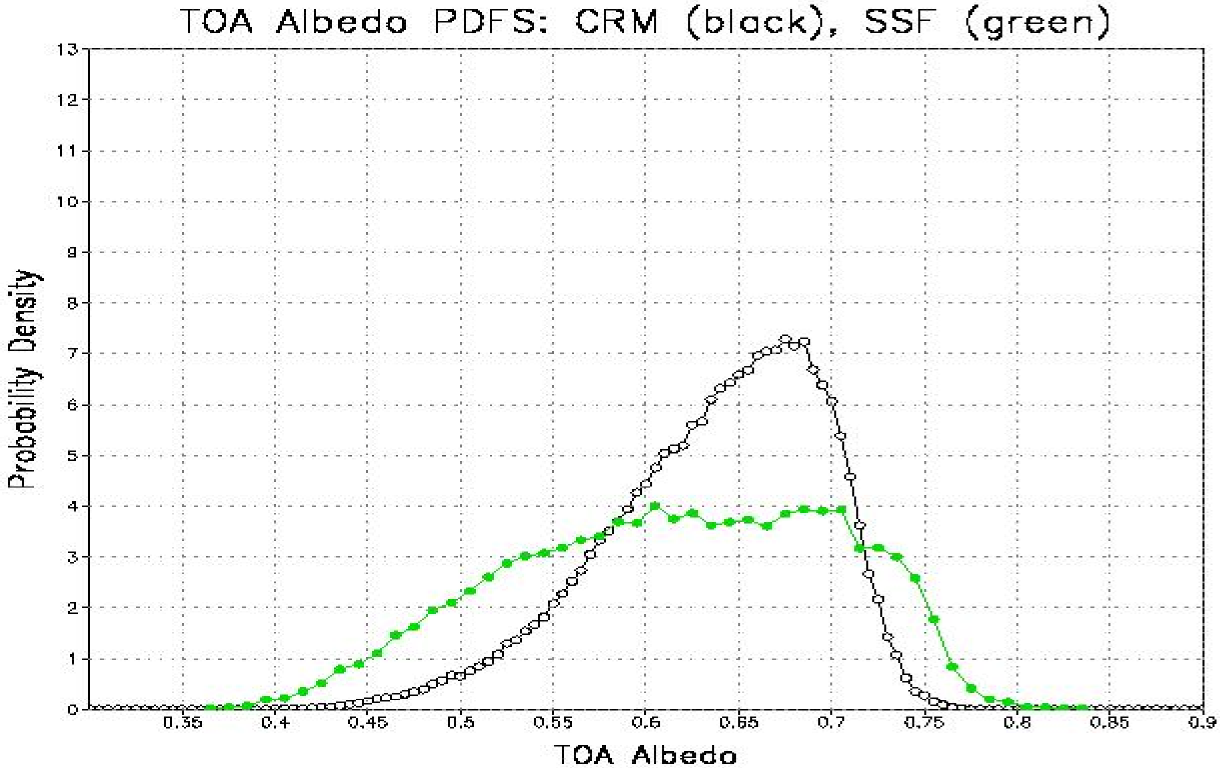


Comparison of CRMs with SSF
TOA SW – LaRC2d



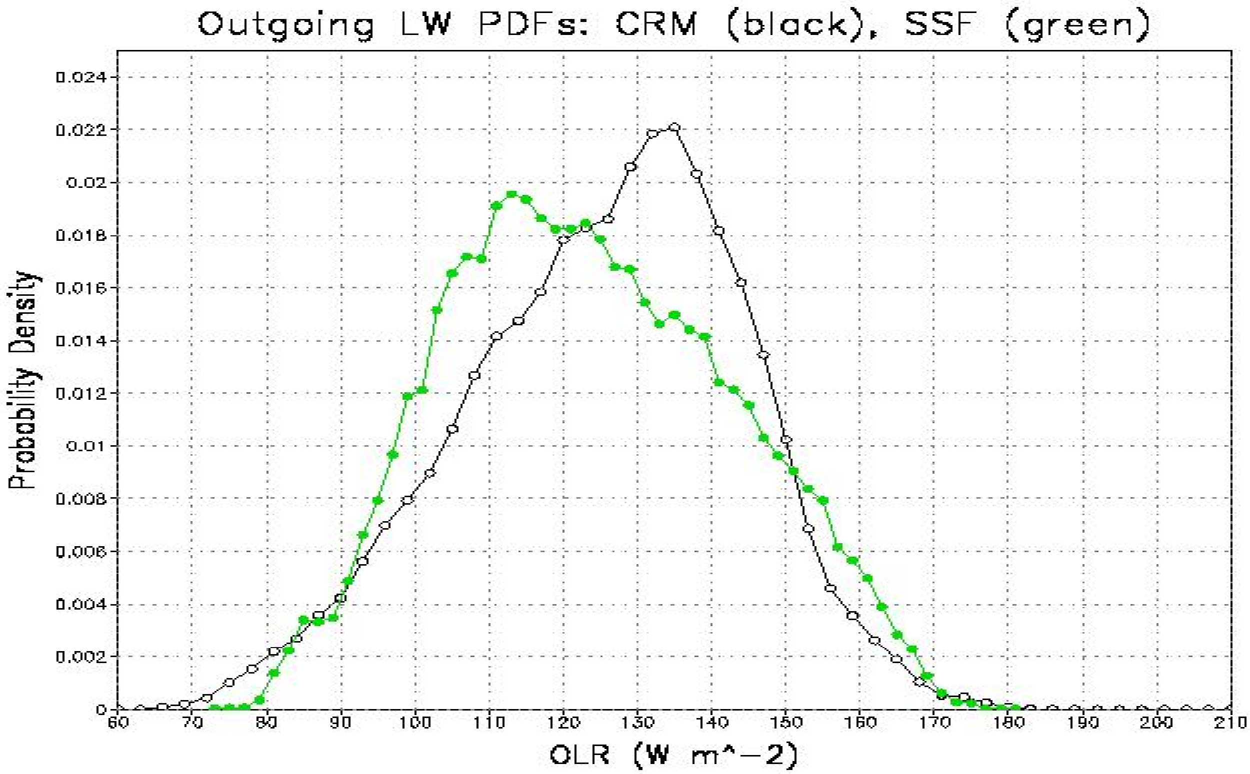
Comparison of CRMs with SSF

TOA albedo – LaRC2d



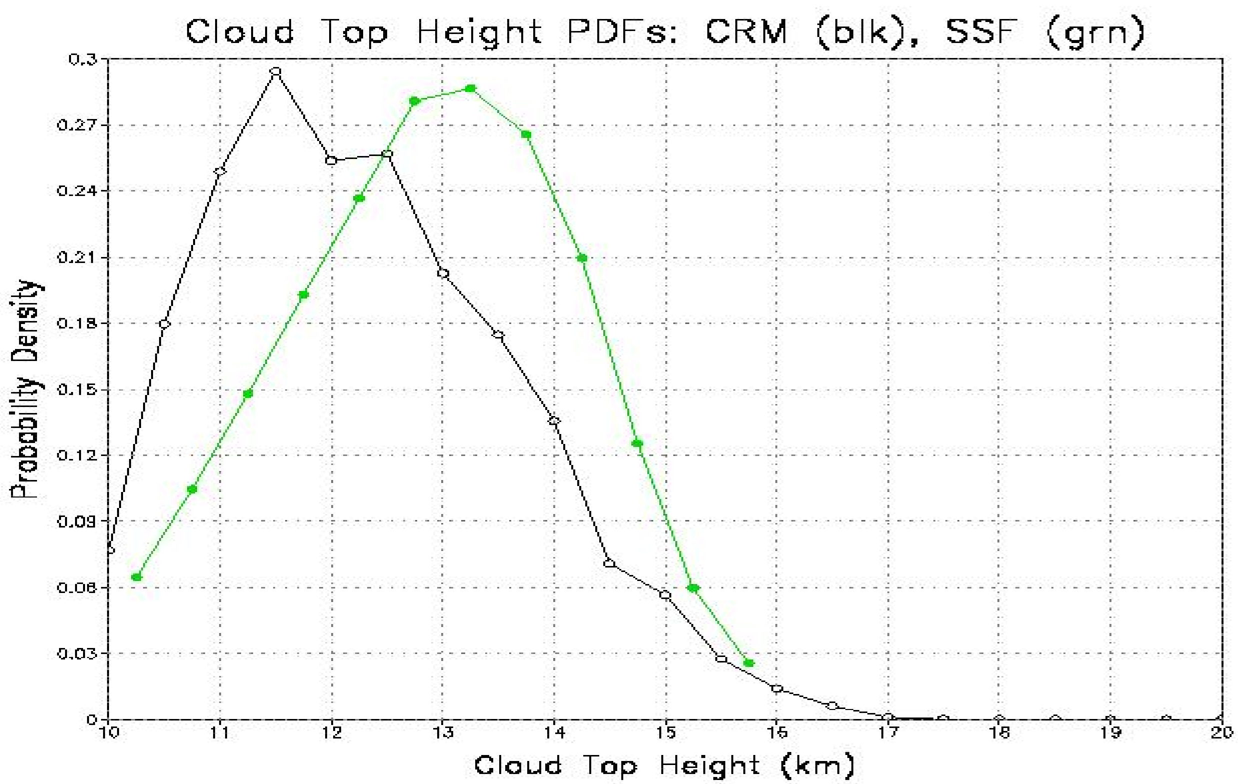
Comparison of CRMs with SSF

Outgoing LW – LaRC2d



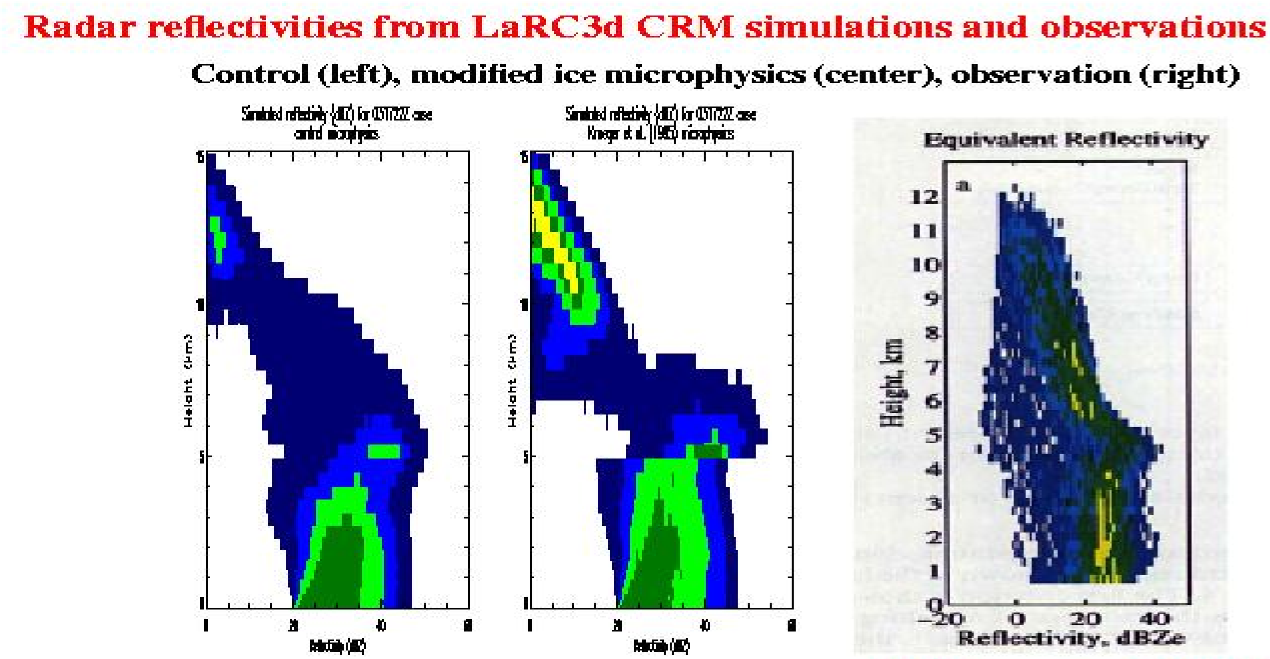
Comparison of CRMs with SSF

Cloud top height – LaRC2d



Simulations with LaRC3d CRM

Sensitivity to ice microphysics

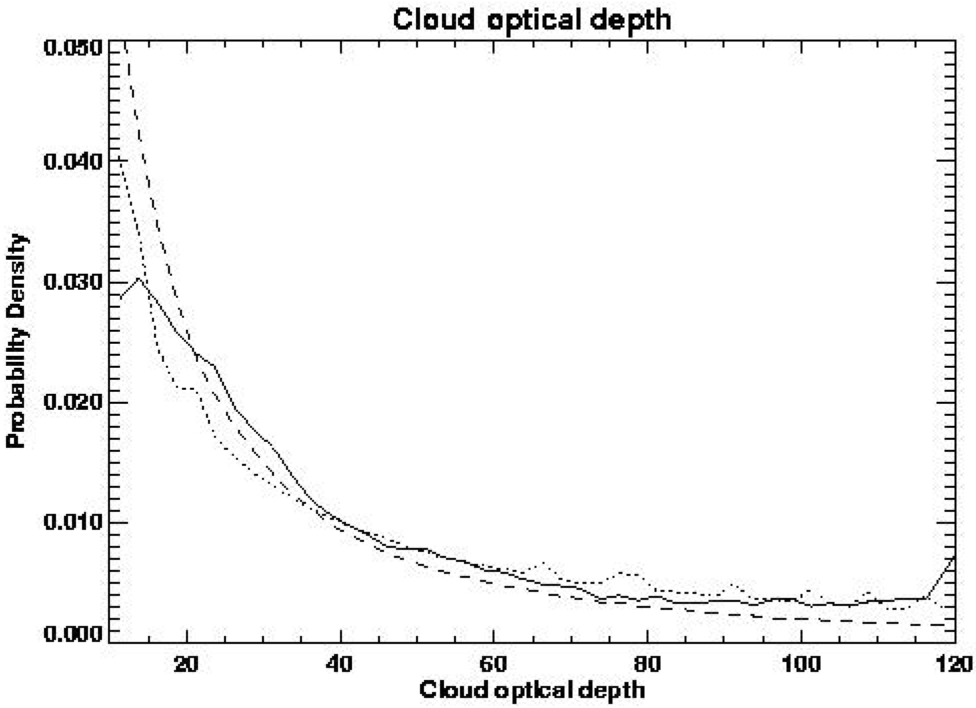


Williams et al. (1995)

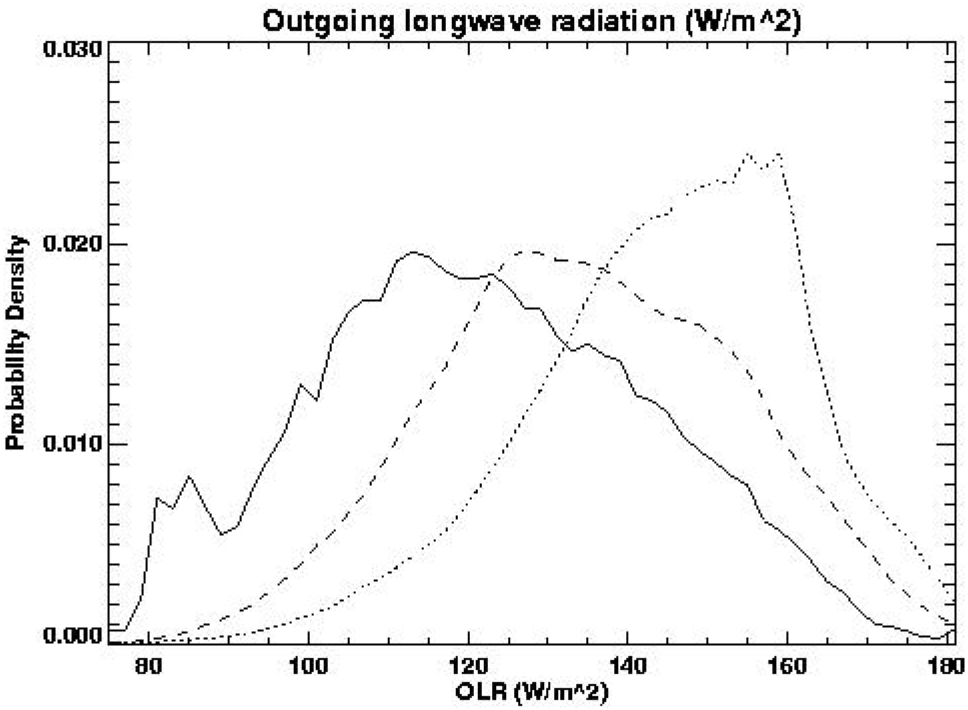
Comparison of CRMs with SSF

Cloud optical depth – LaRC3d

SSF (solid), control (dotted), modified microphysics (dashed)



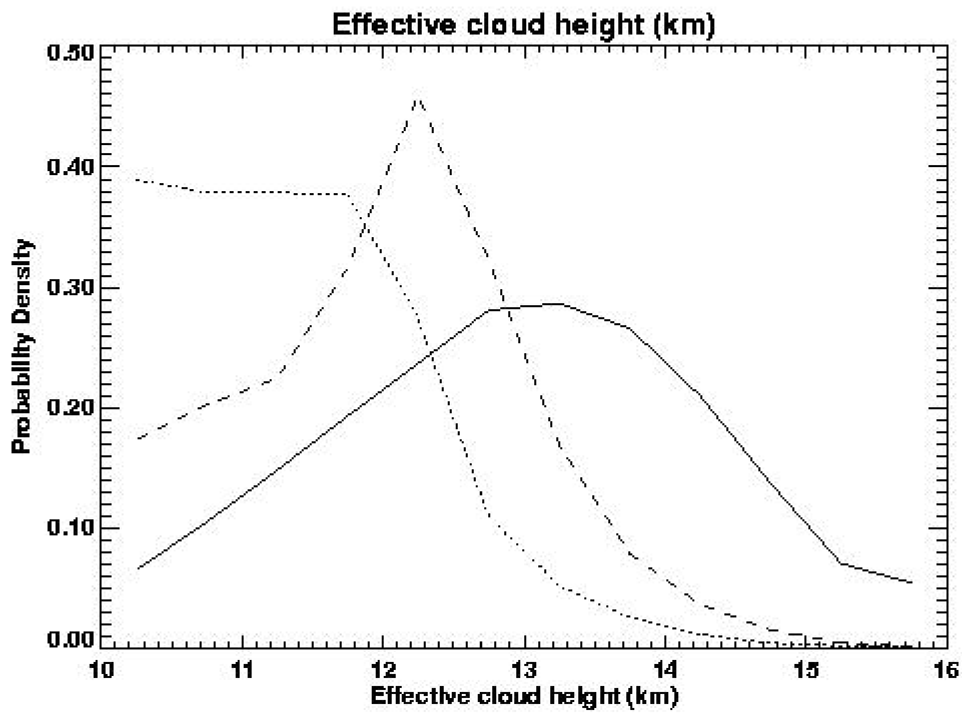
Comparison of CRMs with SSF
Outgoing LW – LaRC3d
SSF (solid), control (dotted), modified microphysics (dashed)



Comparison of CRMs with SSI

Cloud top height – LaRC3d

SSF (solid), control (dotted), modified microphysics (dashed)



Comparison of CRMs with SSF
Summary

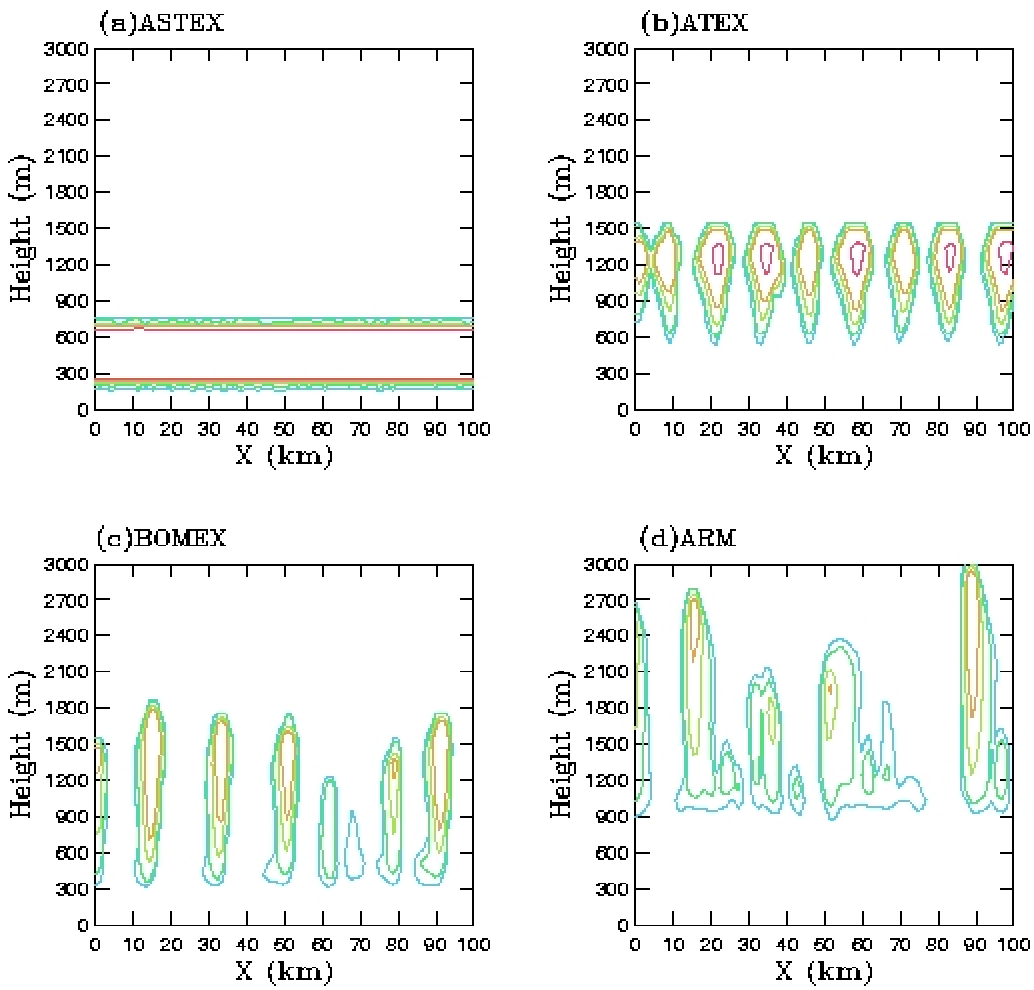
- Most of our CRM results agree with satellite observations well
- The CRM clouds tend to be shallower and warmer than those observed with the SSF for both LaRC2d and LaRC3d models, unlike those predicted by the ECMWF model
- Inadequate ice-phase microphysics and the forcing method (single profile) are two possible causes for the CRM results

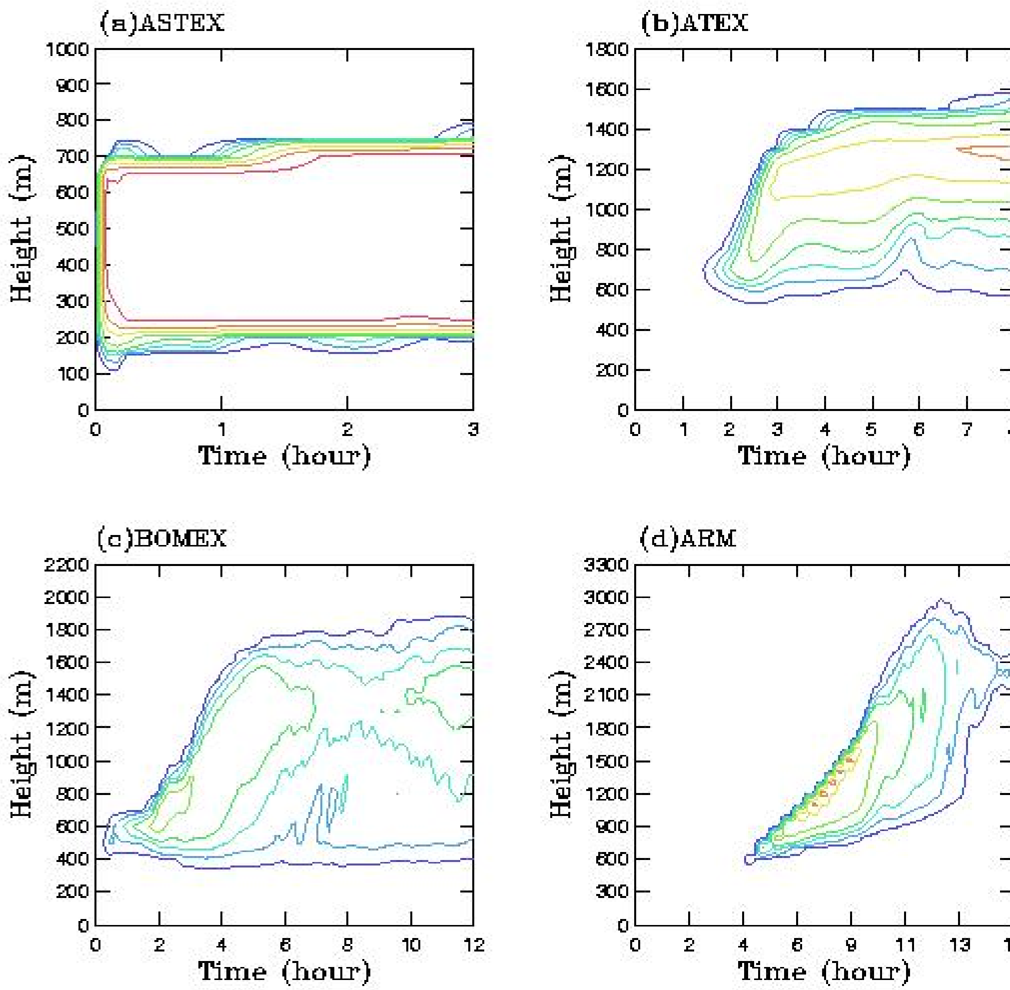
Possible improvements of CRM simulations

- Sensitivity tests to the advective forcings, eliminating those cases with inconsistent advective forcings
- Two-column advective forcings, instead of single-column ones
- Improvements to model physics [ice microphysics, radiation and turbulenc closure (LaRC3d CRM)]

Future plan

- Statistical analysis of all cloud systems identified by SSF data for the March 1998 a March 2000 periods
- CRM simulations of these two periods
- Analysis of SSF data for other major cloud types such as stratus and stratocumulus
- CRM simulations of these shallow cloud typ
- Comparison of CRM simulations with single-column model (SCM) simulations


(a)ASTEX
(b)ATEX
(c)BOMEX
(d)ARM
Height (m)
X (km)
0
300
600
900
1200
1500
1800
2100
2400
2700
3000
0 10 20 30 40 50 60 70 80 90 100



(a)ASTEX
1000
900
800
700
600
500
400
300
200
100
0
Height (m)
0
1
2
3
Time (hour)
(b)ATEX
1800
1600
1400
1200
1000
800
600
400
200
0
Height (m)
0
1
2
3
4
5
6
7
8
Time (hour)
(c)BOMEX
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Height (m)
0
2
4
6
8
10
12
Time (hour)
(d)ARM
3300
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
Height (m)
0
2
4
6
9
11
13
15
Time (hour)