Evaluation of cloud microphysical parameterizations with SCM, CAPT and M-PACE observations

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ARM Atmospheric Radiation Measurement Program

Goal: Improve Climate Model Parameterizations

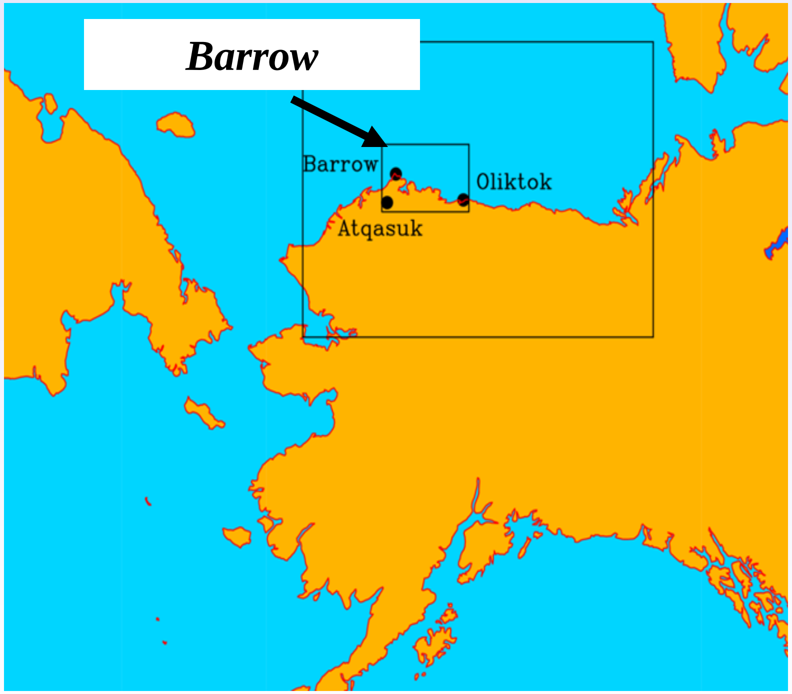
- **Tools: single column models (SCM) and DOE CCPP-ARM Parameterization Testbed (CAPT) (LLNL CAPT team)**

- **ARM measurements provide unique data for model evaluation and guidance for parameterization improvement**

Motivations

- **Cloud microphysics in mixed-phase clouds has a significant impact on cloud radiative forcing, precipitation formation, etc.**
- **The treatment of mixed-phase clouds in most current climate models is often oversimplified**
  - **Liquid/ice partitioning according to a temperature dependent function; Neglect ice nucleation and Bergeron-Findeisen process**
- **Improved representation of mixed-phase cloud microphysics in climate model is needed for accurate climate change prediction**

The ARM NSA Mixed-Phase Arctic Cloud Experiment (M-PACE)
October 5 to October 22, 2004



Measurements

Clouds and Cloud Microphysical Properties

- Millimeter-wavelength cloud radar
- Micropulse Lidars
- Laser Ceilometers
- Aircraft
- Microwave Radiometers

Surface Radiation

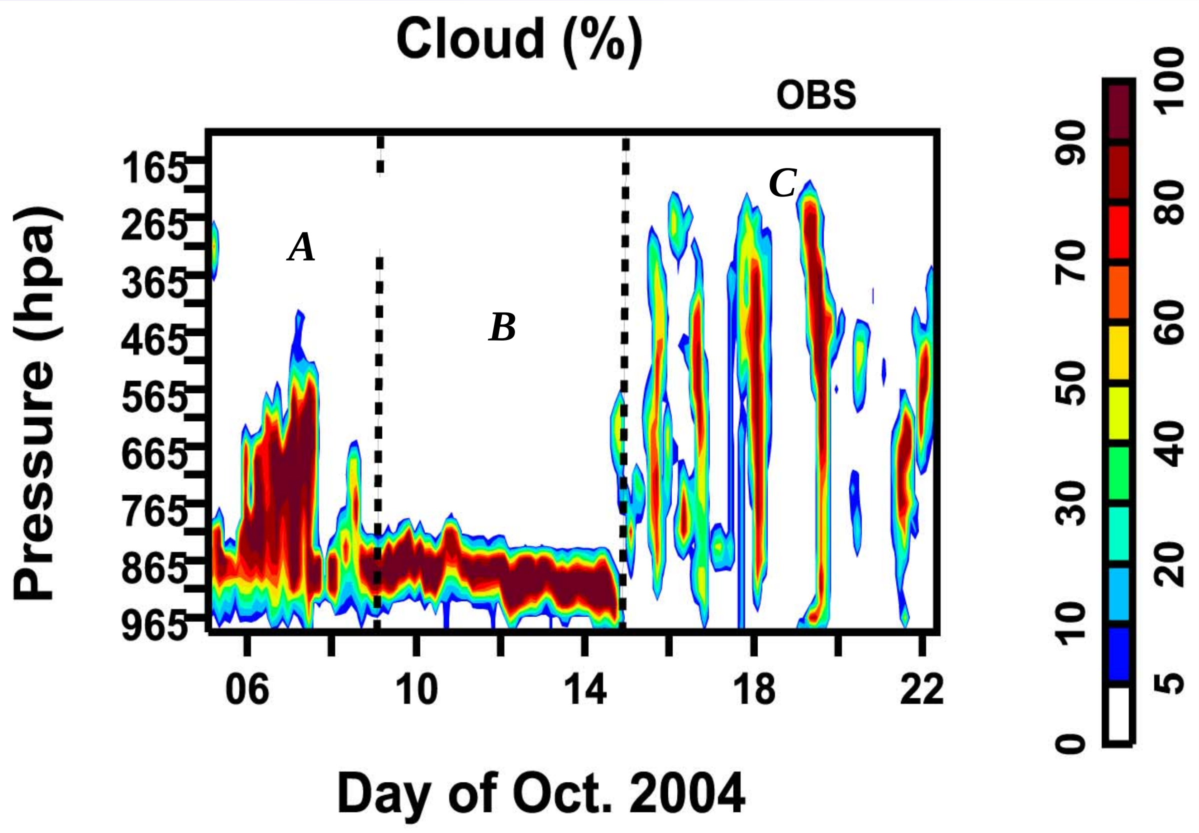
- Radiometric Instrument Systems

TOA Radiation

- NASA-Terra and NOAA-15, -16 Satellites

Data collected at Barrow were used in this study

Radar Clouds at Barrow



A: Multi-layer clouds

B: Persistent mixed-phase boundary layer clouds

C: Deep frontal clouds

Aircraft Measured Cloud Water Content

Oct. 10, 2004

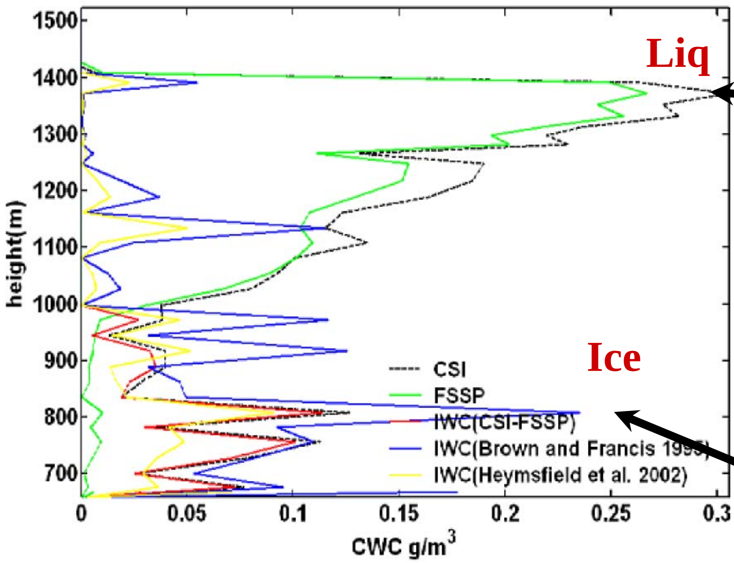


Figure 6 Comparison of bulk measurements of IWC (CSI-FSSP) against IWC estimated from 2DC using variety of habit identification and mass calculation techniques

(From G. McFarquhar et al. 2005)

A strong liquid layer occurred near cloud top at 1300m

Ice crystals in the liquid cloud layer and precipitating ice crystals beneath

For mixed-phase clouds, the range of cloud temp is from -5 C ~ -20 C

Model and Microphysical Schemes

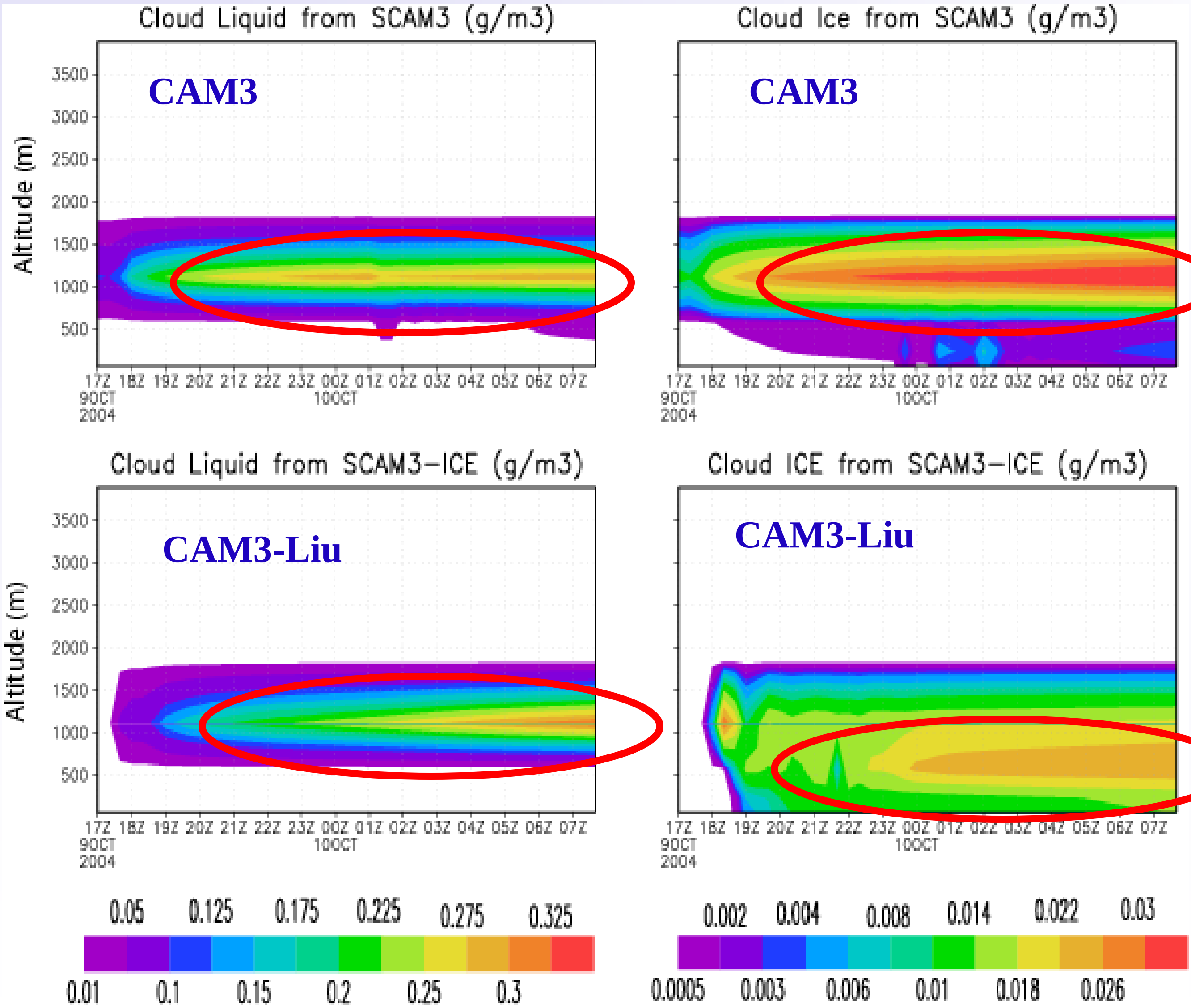
- **NCAR CAM3 FV 1.9x2.5 L26 initialized with GDAS Analysis at 00Z every day for M-PACE**
  - **Current scheme : Rasch & Kristjansson (1998)**
    - **single-moment, liq/ice partition determined by T**

      All ice when T < - 40C, all liq when T > -10C
  - **New scheme 1 : Morrison & Gettelman (2008)**
    - **Double-moment, liq/ice partition determined by microphysical processes (Bergeron, heterogeneous nucleation)**
  - **New scheme 2 : Liu et al (2007)**
    - **Double-moment, liq/ice partitiion determined by microphysical processes (Bergeron, Rotstayns et al., 2000)**

SCM Simulations of Mixed-Phase Boundary layer Clouds (Oct. 9-10)

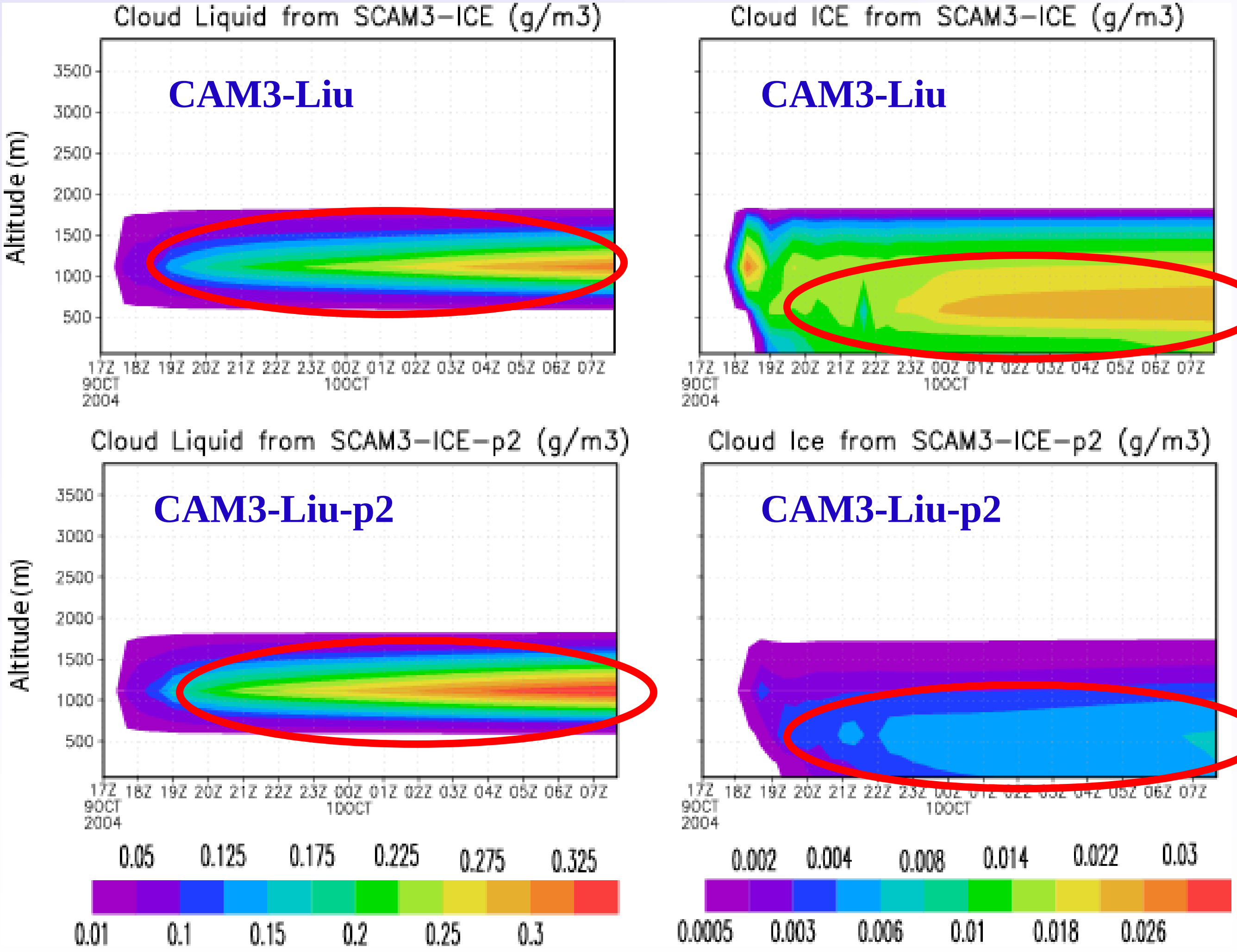
(Liu et al. 2007)

LWC and IWC in Boundary Layer Mixed-phase Clouds



- *CAM3: LWC and IWC profiles overlap with each other in clouds*
- *CAM3LIU: effectively separates the LWC and IWC maximum with the clouds in the bottom portion purely ice phase with ice precipitating beneath*
- *Ni ~ 2 /L*
- *Snow component is added to the total cloud condensate to be consistent with aircraft data*

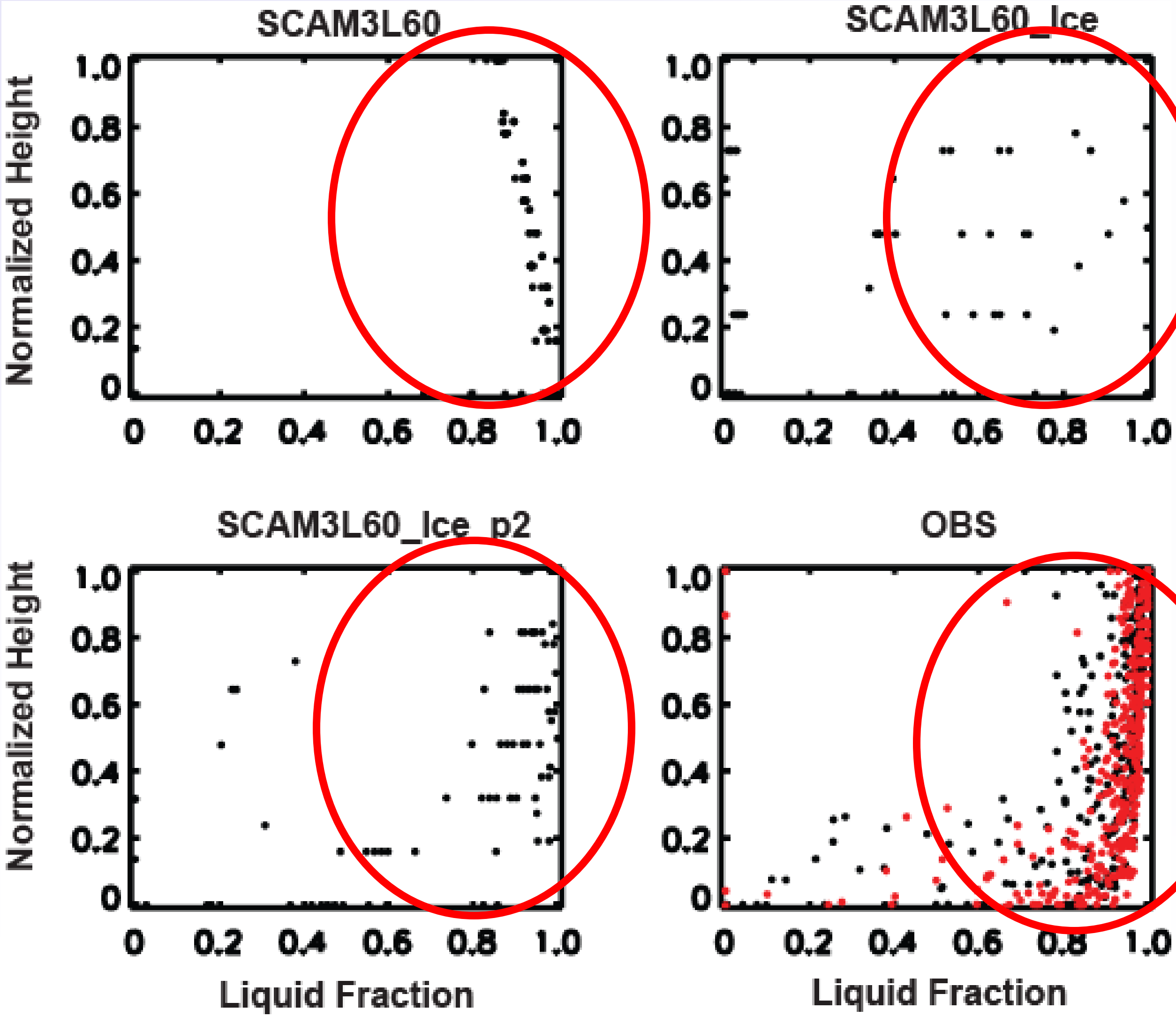
LWC and IWC in Boundary Layer Mixed-phase Clouds



- ***CAM3LIU-p2 (a sensitivity test with CFDC ice nuclei number ~ 0.2 /L):***

- ***ice number concentration plays an important role in the simulated mixed-phase clouds***

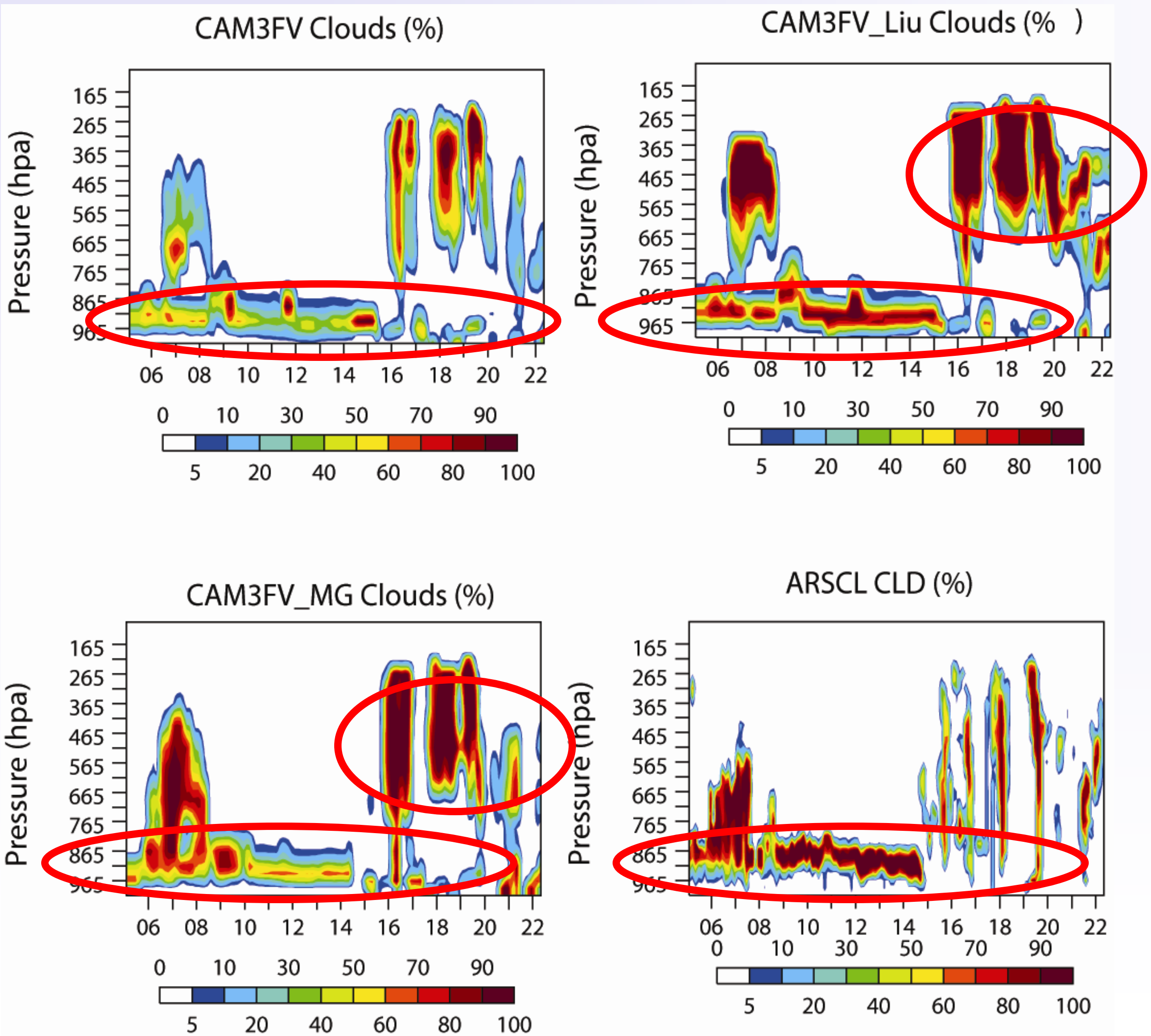
Boundary Layer Mixed-Phase clouds
Model vs. Aircraft Data



CAPT Forecasts

(Xie et al., 2008)

Simulated Clouds



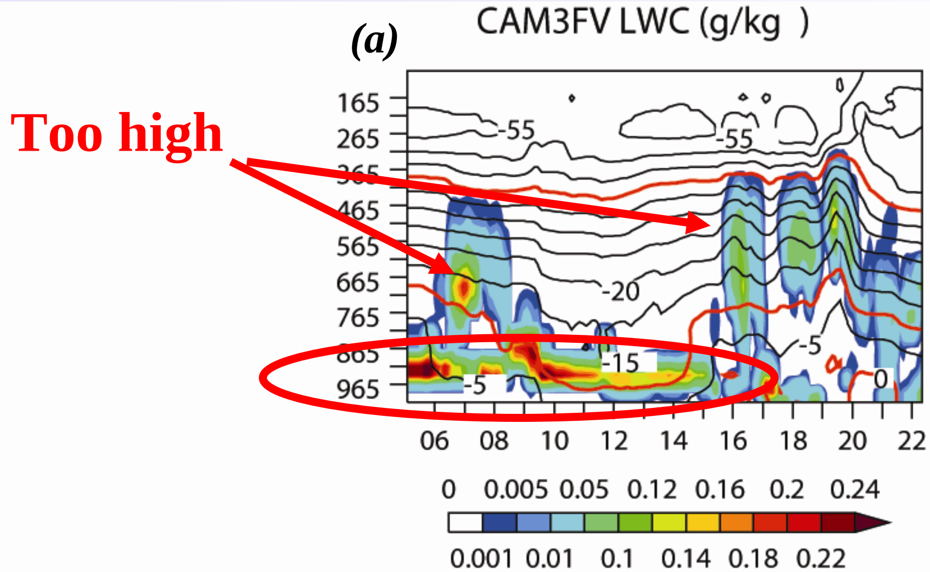
- **CAM3FV: Default model**
- **MG: Morrison's scheme**
- **Liu: Liu's scheme**

- **CAM3FV significantly underestimates the multi-layer and BL clouds**
- **Both MG and Liu schemes reduce the problem**

For MG and Liu:

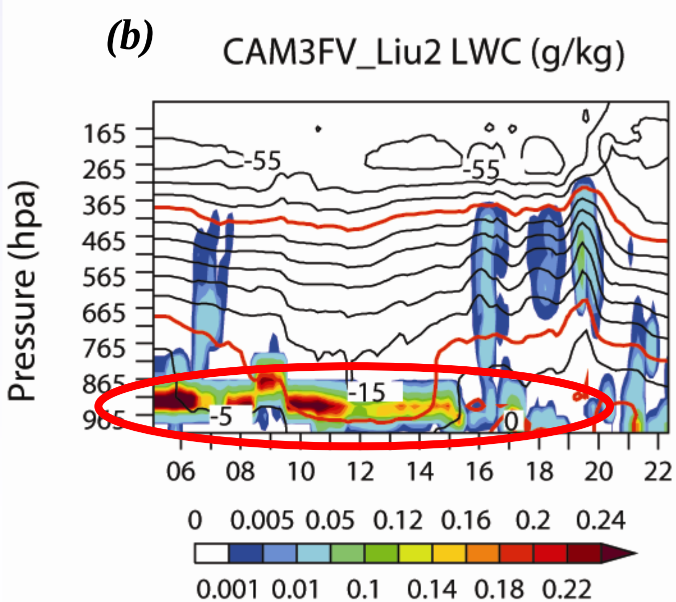
- **Mid- and high clouds are over-predicted and last longer than the Observed**
- **Boundary-layer clouds are still underestimated, especially in MG**

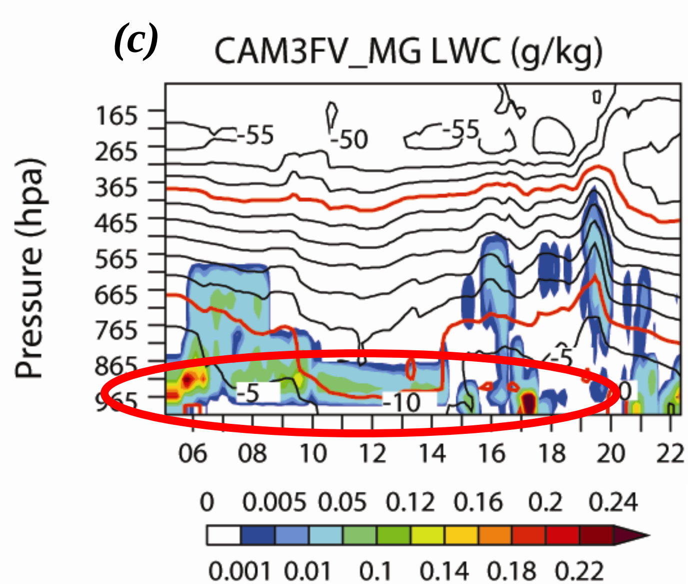
Simulated Liquid Water Content



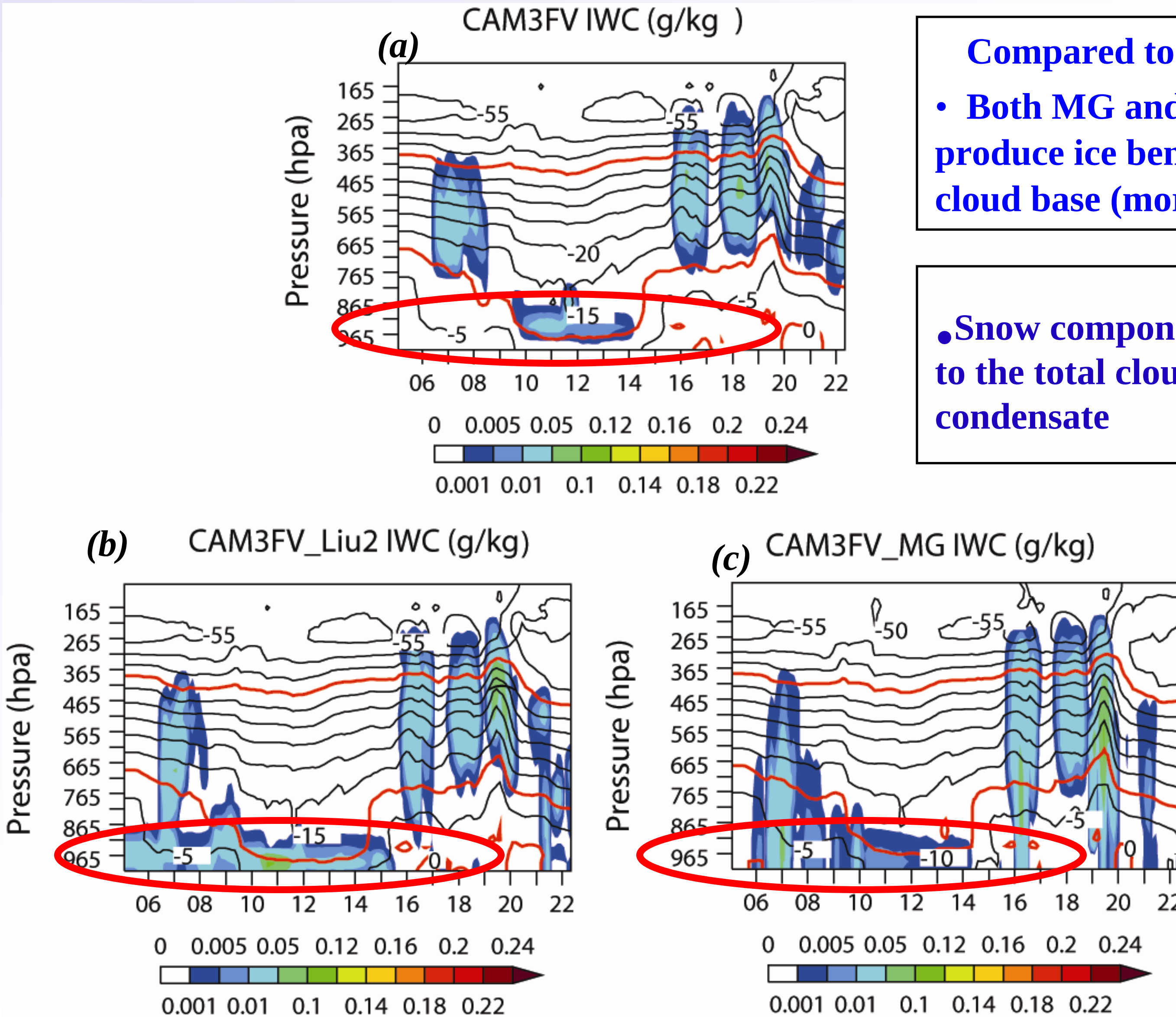
Compared to CAM3FV:

- **MG : less LWC for all types of clouds**
- **Liu : less LWC for mid- and high level clouds while comparable for BL clouds**





Simulated Ice Water Content

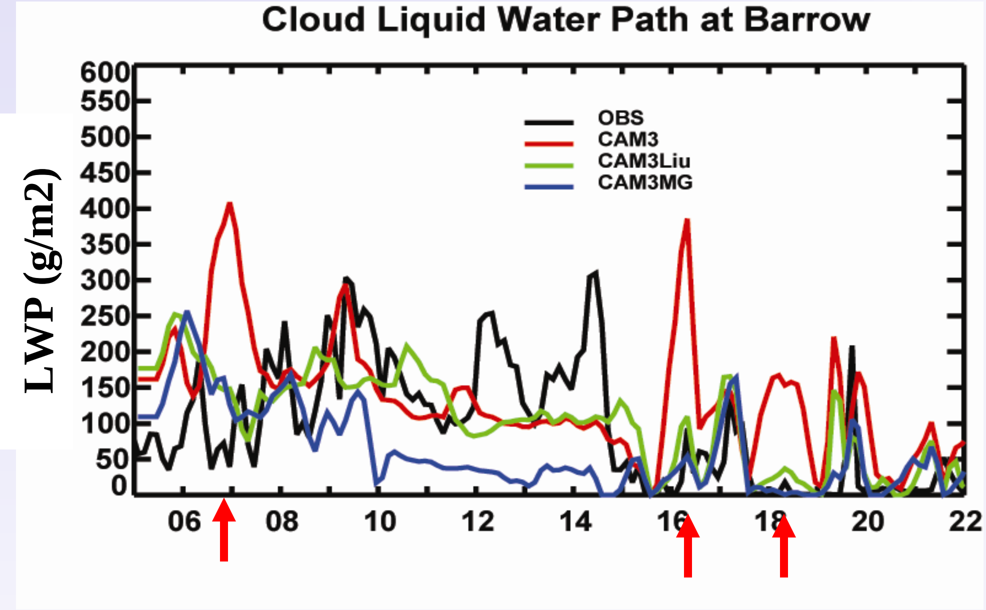


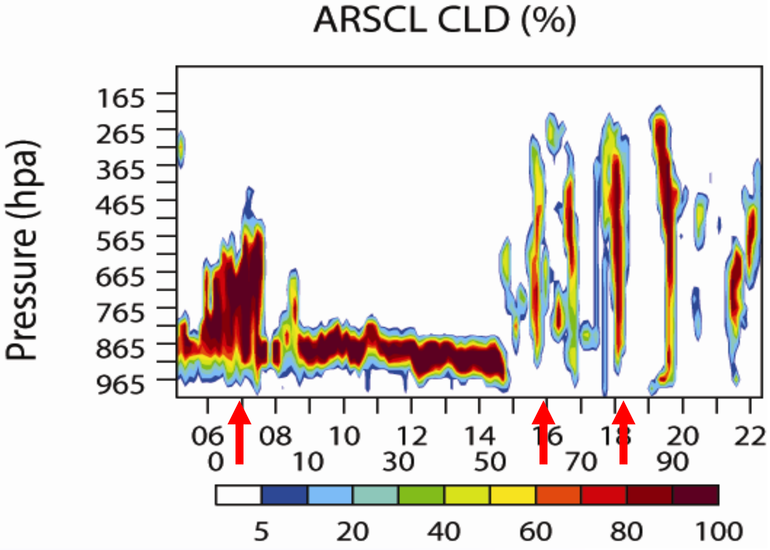
Compared to CAM3FV:

- **Both MG and Liu produce ice beneath the cloud base (more realistic)**

- **Snow component is added to the total cloud condensate**

Liquid Water Path



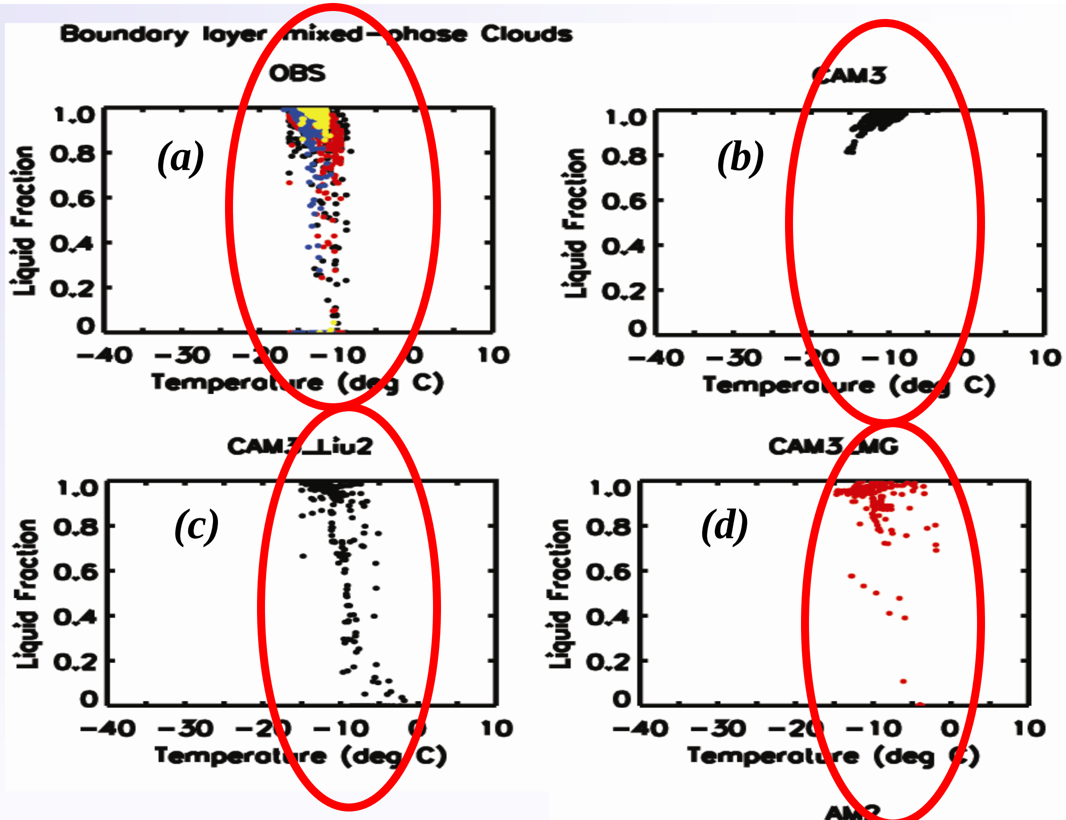


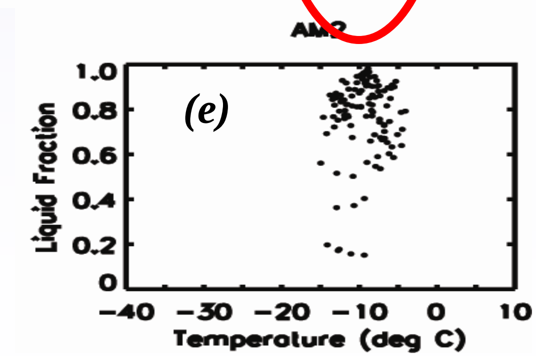
CAM3FV: too much liquid in the mid- and high clouds. This problem is significantly reduced with the new schemes

MG: significantly underestimates the liquid in BL clouds

LIU: shows the best overall performance in LWP

Boundary Layer Mixed-Phase clouds
Model vs. Aircraft Data

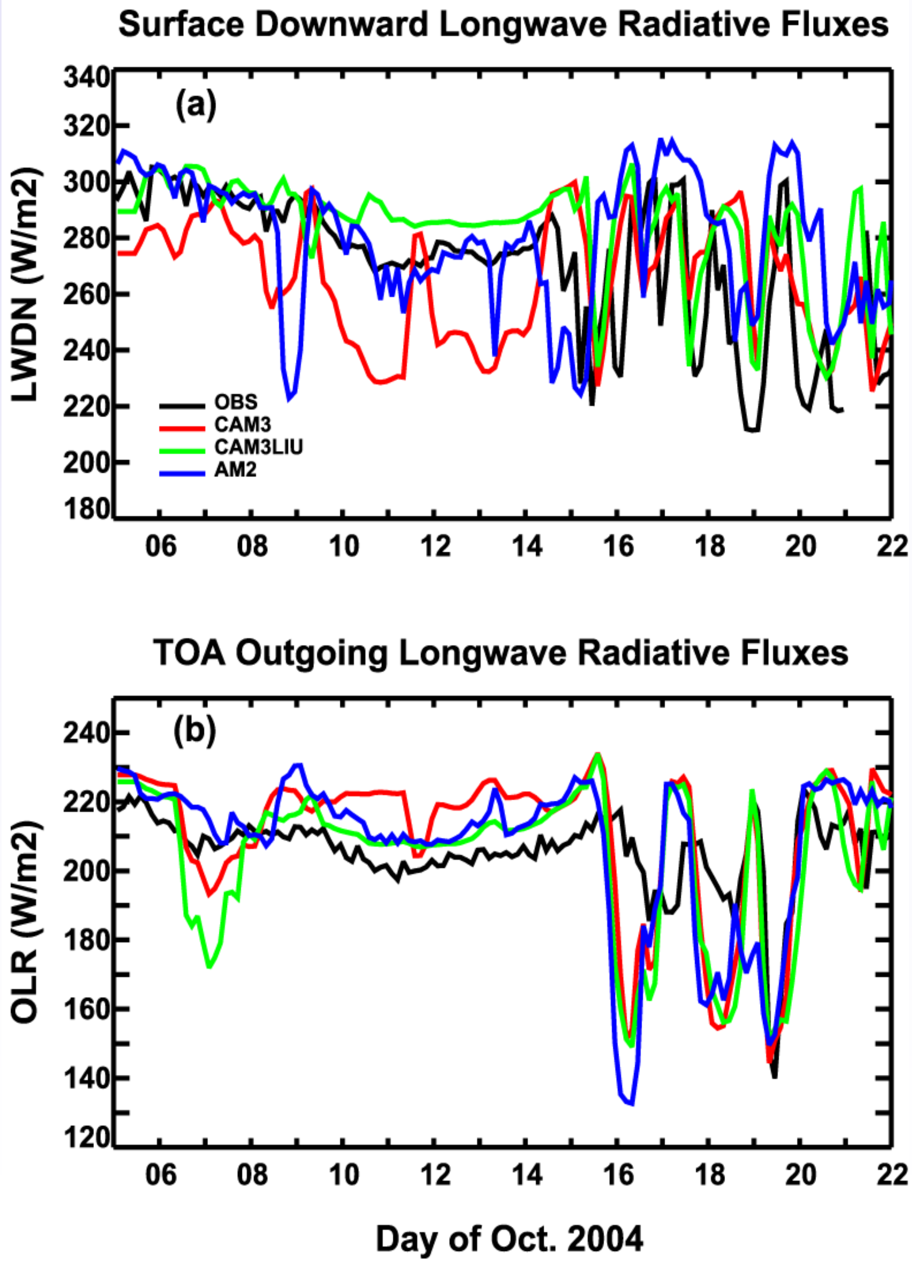




- **Aircraft data: no clear relationship between fliq and temperature; liquid and ice coexist within the temperature range of -16c to -9c**
- **CAM3: fails to reproduce the observed features**
- **MG & CAM3LIU: reasonably captures the observed variation with temperature of fliq by including the Bergeron process**

Impact on LW radiation

CAM3 significantly underestimates the observed surface downward LW and overestimates OLR. This problem is largely reduced in CAM3LIU (and AM2) because of the improved cloud simulations in these models



Downward LR

All the models generally overestimate the observed surface downward LW and underestimate OLR, consistent with the higher frontal cloud fraction produced by the these models

Outgoing LR

Summary

- New schemes show a lot of promising features in the simulated Arctic clouds and cloud microphysical properties
  - Improved simulations for multi-layer stratus and BL mixed-phase clouds
  - Improved LWP for mid- and high level clouds
  - Improved ice prediction and liquid/ice partitioning
  - Improved simulation of radiation

However…

- New schemes overestimate mid- and high-level clouds
- LWP for the BL mixed-phase clouds largely underestimated by Morrison’s scheme

Future Work

- **Understand heterogeneous ice nucleation mechanisms in mixed-phase clouds through laboratory and field campaign studies (e.g., ARM ISDAC)**

- **Developing ice nucleation parameterizations for large scale models**

Work in Progress

- **Working to implement Liu et al. (2007) ice microphysics in the CAM MG microphysics scheme**
  - **Ice nucleation related to aerosol (Liu & Penner, 2005)**
  - **Allow ice supersaturation**
  - **Liquid & ice cloud fraction (cloud fraction for ice cloud consistent with ice microphysics)**
  - **Using CAPT & SCM to further test microphysics**