Evaluation of a New Mixed-Phase Cloud Microphysics Parameterization with a Single Column Model, CAPT Forecasts and M-PACE Observations

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AGU FALL MEETING

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Motivations

- ➢ Cloud microphysics in mixed-phase clouds has a significant impact on cloud optical depth, cloud radiative forcing, precipitation, 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 micriophysics in climate model is needed for accurate climate change prediction
- ➢ Single column models (SCM) and DOE CCPP-ARM Parameterization Testbed (CAPT) provide framework for testing cloud parameterizations

The ARM M-PACE: Oct. 5 – 22, 2004

The U.S. DOE ARM program conducted a campaign at its North Slope of Alaska (NSA) site to study the properties of mixed-phase clouds

Figure 1 Experimental layout. The two ARM sites are located at Barrow and Atqasuk; the two supplementalsites will be at Oliktok Point and the NSF Toolik Lake Field Station.

Cloud and Radiation Measurements

- ➢ Millimeter-wavelength cloud radar
- ➢ Micropulse Lidars
- ➢ Laser Ceilometers
- ➢ Aircrafts
- ➢ Surface Microwave Radiometers
- ➢ Surface Radiometric Instrument System
- ➢ Satellites

Data collected at Barrow were used in this study

Models

NCAR CAM3 FV 1.9x2.5 L26

- Run in single column mode (SCAM)
- Run in weather forecast: A series of 3-day forecasts were initialized with the NASA Data Assimilation Office (DAO) analysis every day at 00Z for M-PACE. 12-36 hour forecasts near the Barrow site are analyzed

Cloud Microphysical Schemes

- NCAR CAM3 (*Rasch and Kristjansson, 1998*)

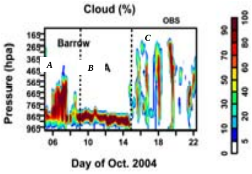
  Single-moment scheme to predict only mixing ratio of cloud condensate, liq/ice fraction determined by T. Assume that all ice when T < - 40C and all liq when T > -10C
- An improved scheme for CAM3 – CAM3LIU (*Liu et al., 2007a*)

  Double-moment to predict both mixing ratio and number density, ice nucleation mechanisms and liquid/ice fraction determined by the Bergeron process (Rotstayn et al. 2000).

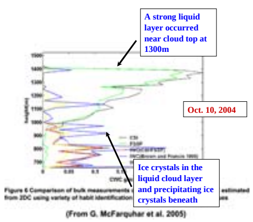
Observed Clouds

Barrow was covered with multilayered clouds in the mid-and low-levels in the early few days. For the period 9-14 October, persistent mixed-phase boundary layer clouds formed over ocean and advected into NSA. Scattered deep frontal clouds were seen after 15 October. The observed cloud systems were largely controlled by the synoptic-scale circulation affecting that area during M-PACE.

Radar Clouds

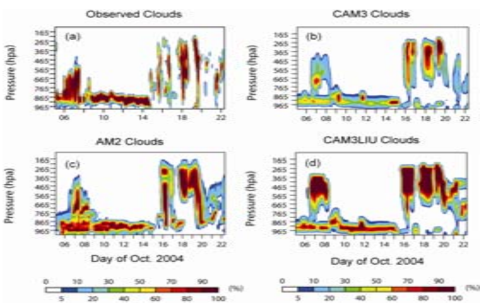


A: Multi-layer clouds
B: Persistent mixed-phase boundary layer clouds
C: Deep frontal clouds



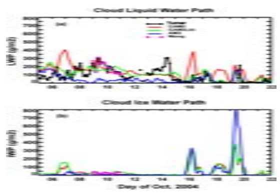
Aircraft measurements of cloud liquid and ice mixing ratio

CAPT Simulated Clouds (Xie et al., 2007)



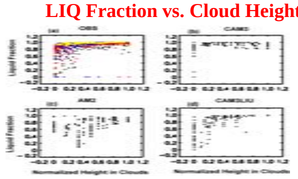
- *All models show skill in predicting various clouds observed during M-PACE*
- *CAM3 produces much less cloud fraction than the observations for the multi-layer and single-layer mixed-phase clouds, which are well simulated by CAM3LIU (and AM2)*
- *Both CAM3LIU (and AM2) largely overestimates the frontal clouds*

CAPT Simulated Cloud LWP and IWP (Xie et al., 2007)



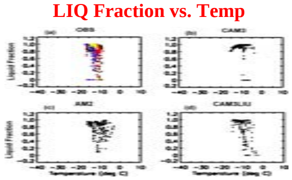
- *CAM3 overestimates LWP for mid- and high level clouds. This problem is largely reduced in CAM3LIU.*

LIQ Fraction vs. Cloud Height



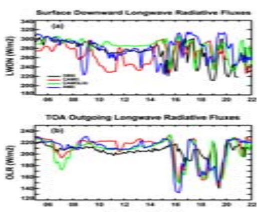
- *Snow component is added to the total cloud condensate to be consistent with aircraft data*
- *Cloud height is normalized*
- *Aircraft data: liquid dominates, liquid fraction (fliq) increases with height, a strong liquid layer near cloud top, and ice seen in the lower half of clouds*
- *CAM3: fliq decreases with height due to its temperature dependent cloud phase partitioning*
- *CAM3LIU: reasonably captures the observed variation*

LIQ Fraction vs. Temp



- *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*
- *CAM3LIU: reasonably captures the observed variation with temperature of fliq by including the Bergeron process*

Downwelling Surface LW and TOA OLR



Period Oct. 5-14: multi-layer and single-layer mixed-phase clouds

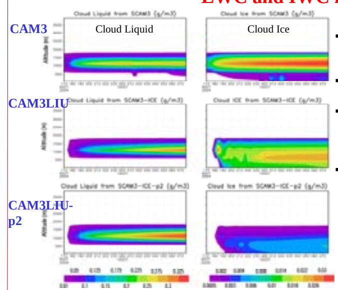
- *CAM3 significantly underestimates the observed surface downward LW and overestimates OLR. This problem is largely reduced in CAM3LIU (and AM2) because of the improved cloud simulations in these models*

Period Oct. 15-22: deep frontal clouds

- *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*

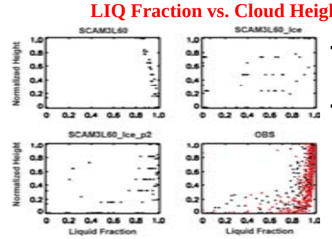
SCM Simulated Mixed-phase Boundary Layer Clouds (Oct. 9-10) (Liu et al., 2007b)

LWC and IWC in Clouds



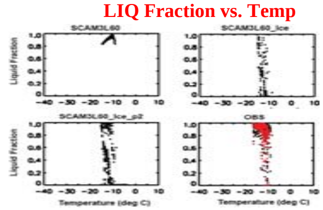
- *Snow component is added to the total cloud condensate to be consistent with aircraft data*
- *CAM3: LWC and IWC profiles overlap with each other in clouds*
- *CAM3LIU: effectively separates the LWC and IWC maximum with the clouds in the bottom portion purely ice phase with ice precipitating beneath*
- *CAM3LIU-p2 (a sensitivity test with lower CFDC ice nuclei number): ice number concentration plays an important role in the simulated mixed-phase cloud microphysics*

LIQ Fraction vs. Cloud Height



- *CAM: using a prescribed fliq increasing with temperature produces an opposite trend of fliq with altitudes*
- *CAM3LIU: reasonably captures the observed variation of fliq*

LIQ Fraction vs. Temp



- *The standard SCAM gives a fliq decreasing with lower temperature, an opposite trend compared with the observation (another branch of fliq decreasing with higher temperature is caused from snow around cloud base).*
- *CAM3LIU: reasonably captures the observed variation*

Summary

- CAM3 significantly underestimates the observed boundary layer mixed-phase cloud fraction and cannot realistically simulate the variations with temperature and cloud height of liquid water fraction due to its oversimplified cloud microphysical scheme.
- The simulation of the boundary layer mixed-phase clouds and their microphysical properties is considerably improved in CAM3 when a new physically based cloud microphysical scheme is used (CAM-LIU). The new scheme also leads to an improved simulation of the surface and top of the atmosphere longwave radiative fluxes. This study has shown that the Bergeron process, i.e., the ice crystal growth by vapor deposition at the expense of coexisting liquid water, is important for the models to correctly simulate the characteristic of the observed microphysical properties in mixed-phase clouds.

References

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