Using ARM observations from the Azores to better understand the biases of low cloud and its surface cloud radiative effect in CAM5

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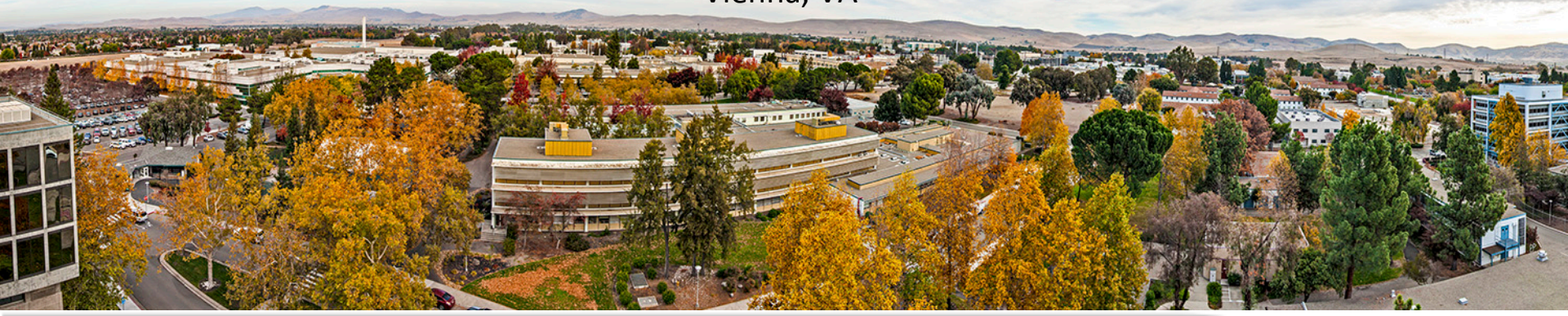
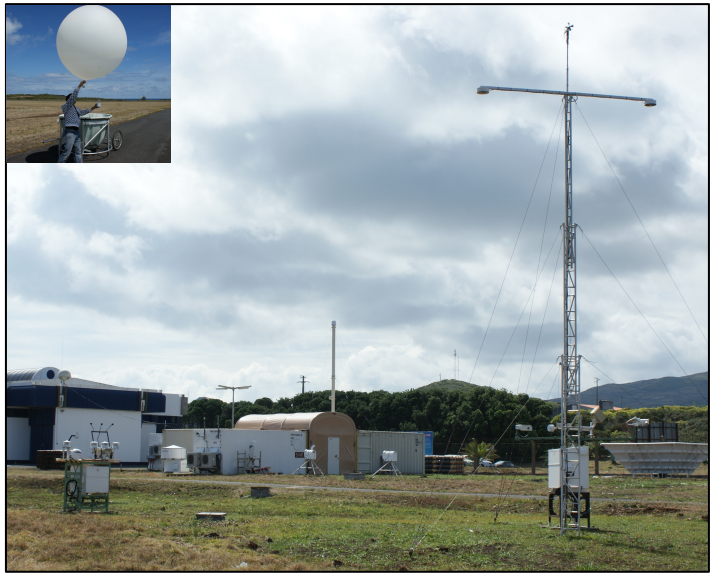
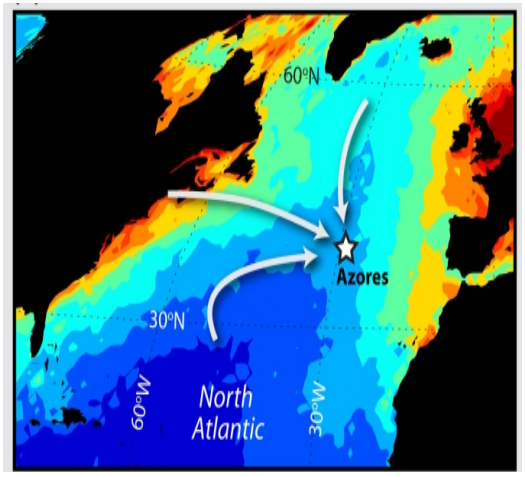


LLNL-PRES-690320
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Motivation

- The CAP-MBL ARM field campaign from Jun. 2009 to Dec. 2010

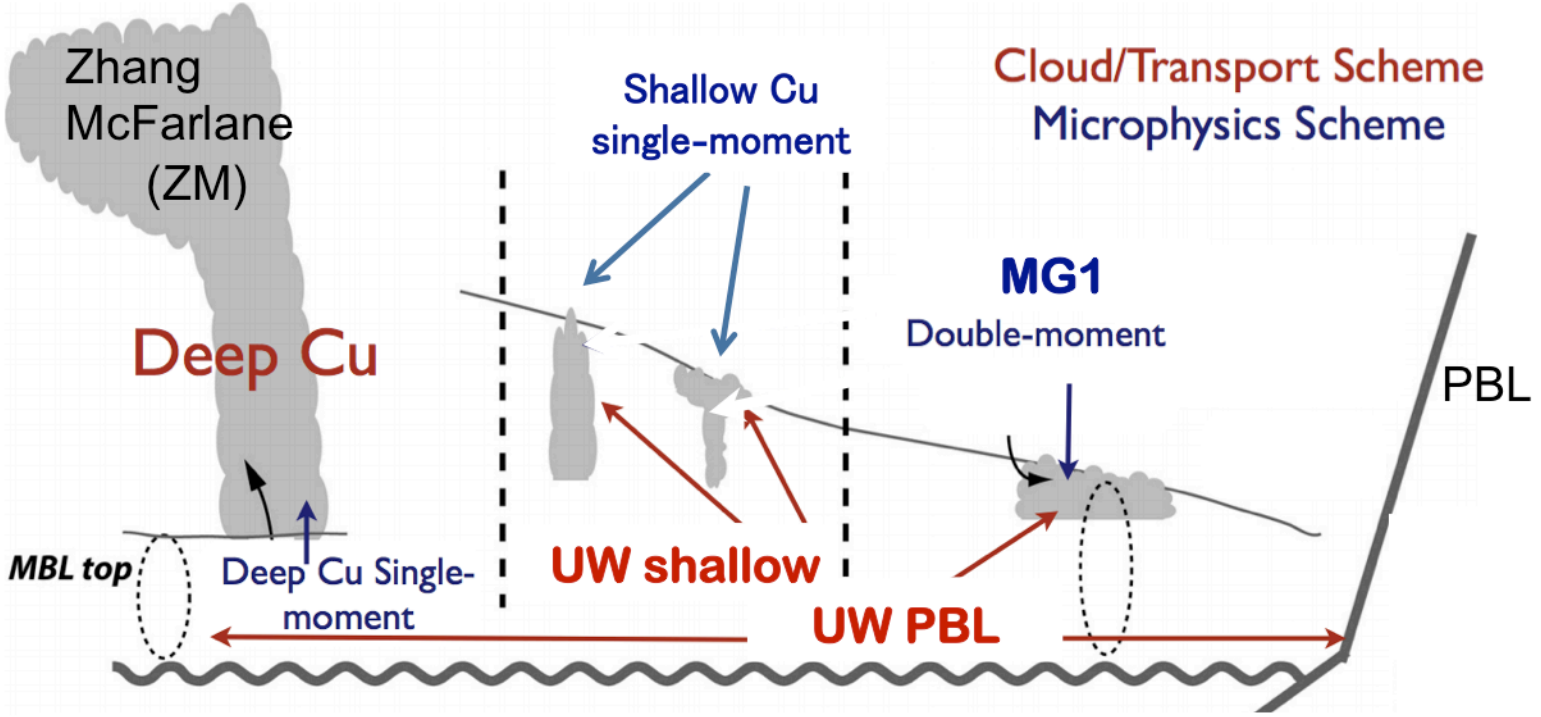




(Wood et al. 2014)

- Scientific Objective
  - To evaluate cloud parameterizations and identify deficiencies
  - Two versions of the Community Atmosphere Model (CAM)

CAM5.3 Physics Schemes



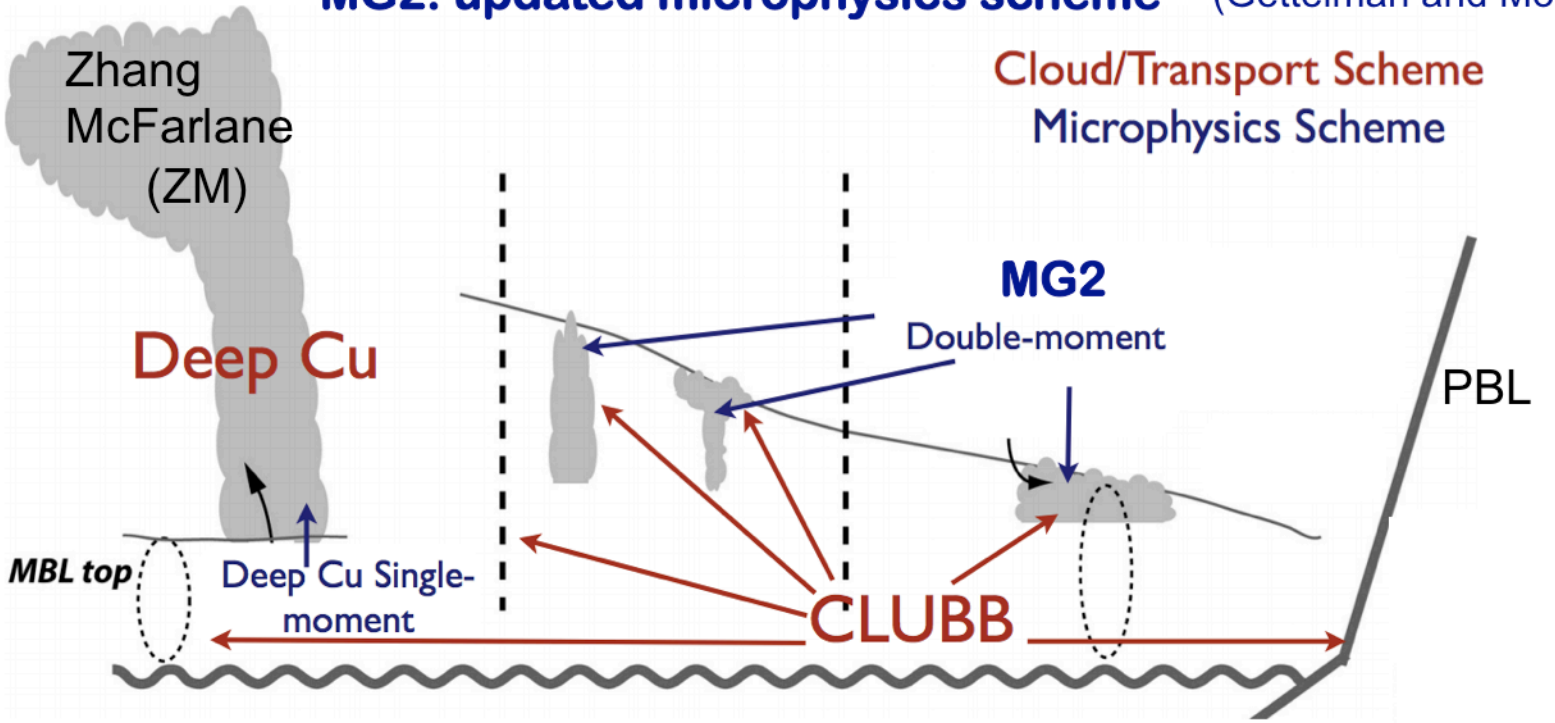
(Park & Bretherton 2009, Bretherton & Park 2009, Park et al. 2014, Morrison and Gettelman 2008)

Courtesy of R. Neal (NCAR)

CLUBB: Cloud Layers Unified By Binormals

Golaz 2002b, J. Atmos. Sci.

MG2: updated microphysics scheme (Gettelman and Morrison 2015)



- Unifies moist and dry turbulence (except deep convection)
- Unifies microphysics
- High order closures (1 third order, 9 second order) $\overline{w'^3}$, $\overline{w'^2}$, $\overline{q_t'^2}$, $\overline{\theta_l'^2}$, $\overline{q_t'\theta_l'}$, $\overline{w'q_t'}$, $\overline{w'\theta_l'}$
- Use two Gaussians to described the sub-grid multivariate PDF: $P=P(w,q_t,\theta_L)$

Courtesy of R. Neal (NCAR)

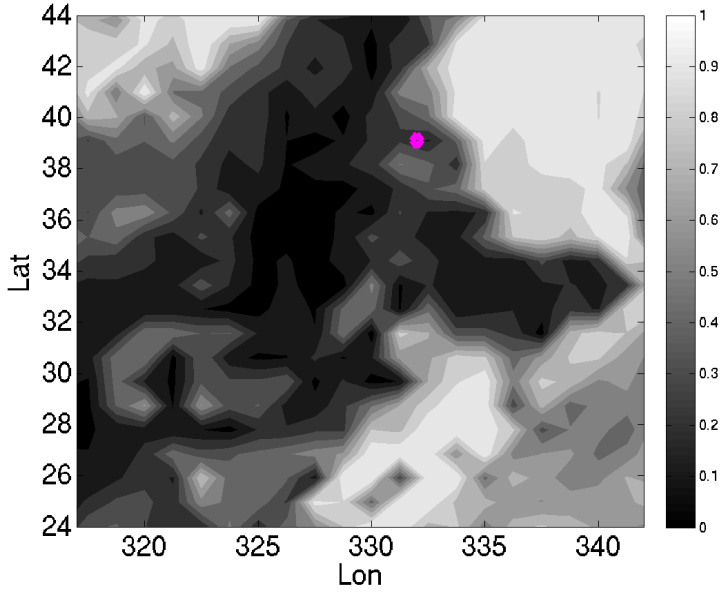
Cloud-Associated Parameterizations Testbed (CAPT) simulation experiments

- Short-term global hindcasts: CAM5.3 control vs. CLUBB-MG2

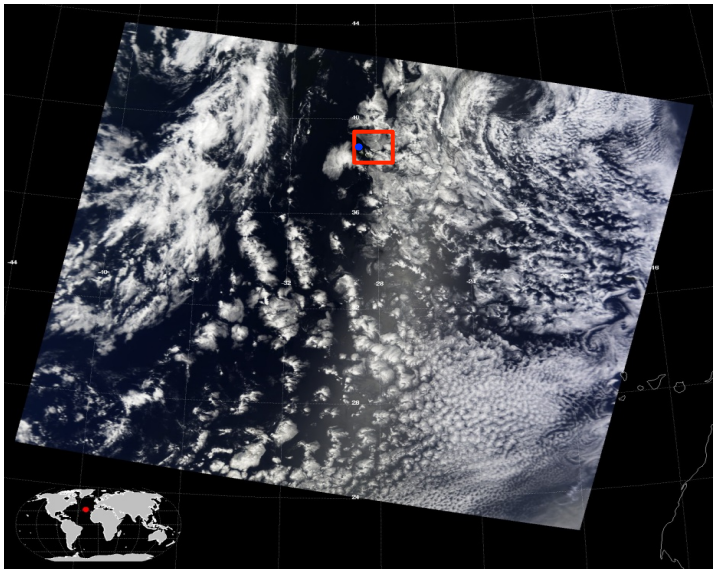
Horizontal resolution: ~1 degree

Model time step =1800 s

A snapshot of CAM5 low-cloud amount



MODIS Visible image



07/26/2010

Daily low-level-cloud cover variability

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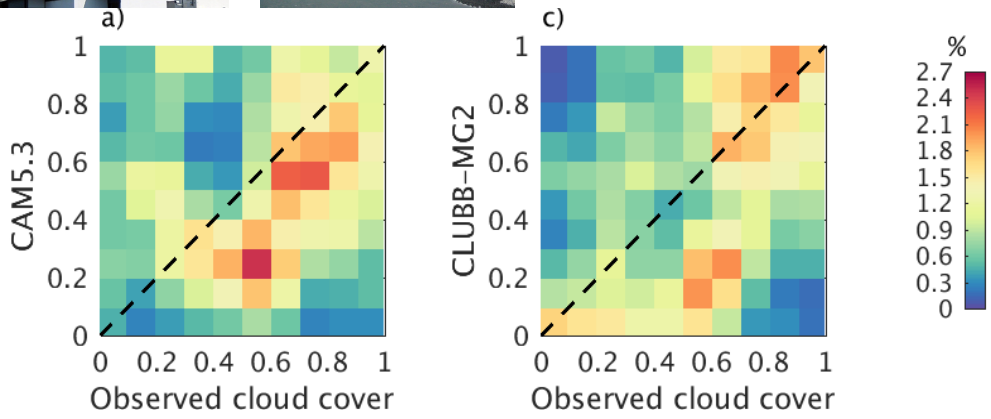
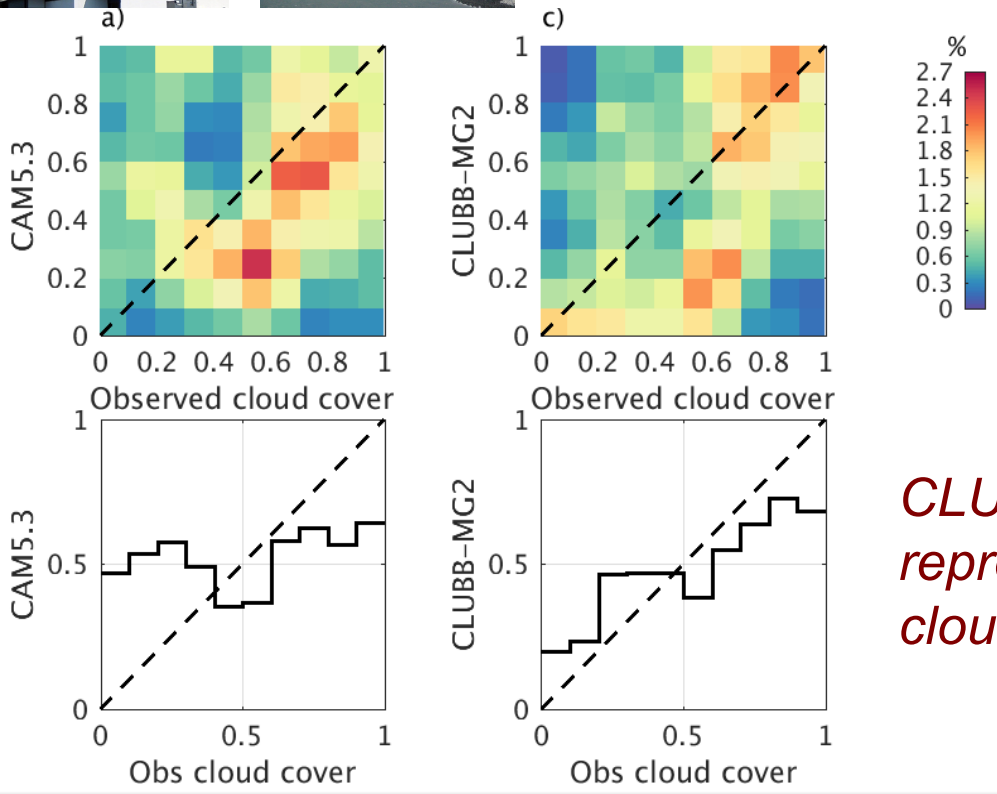
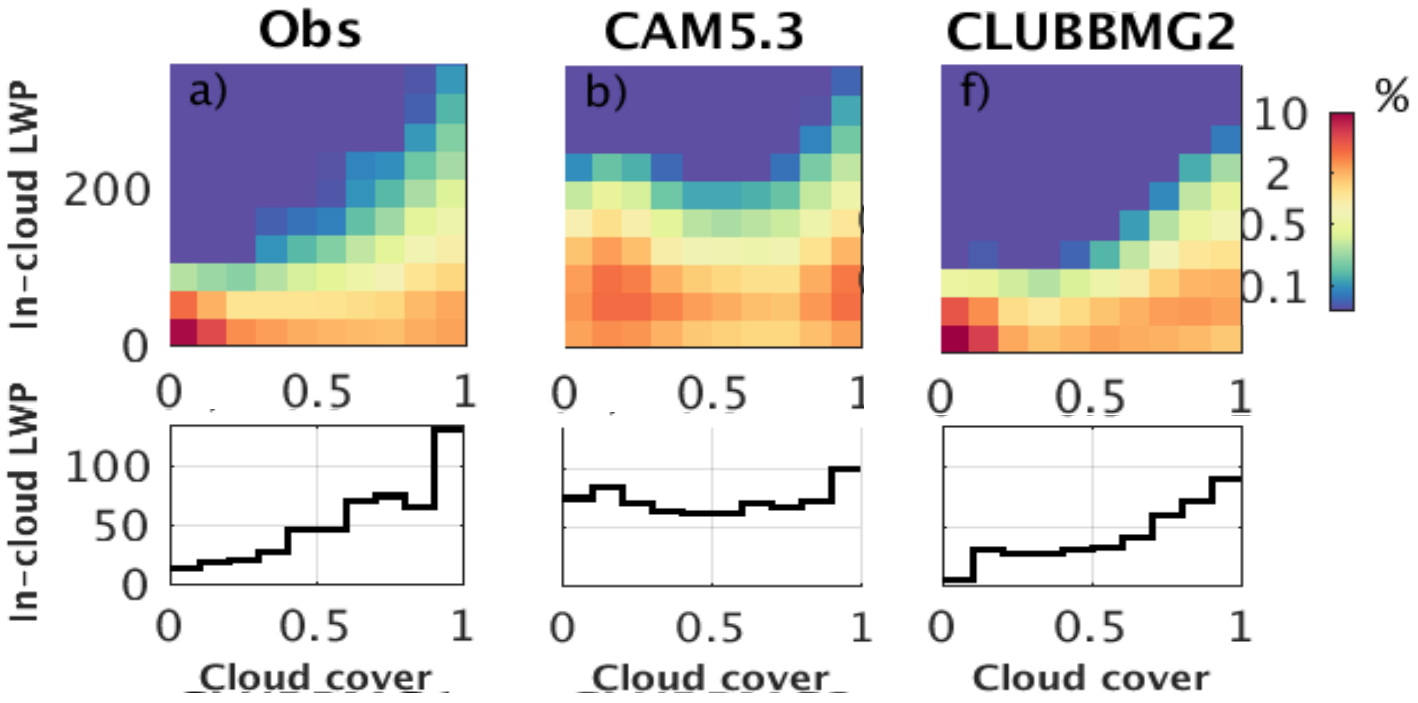


Daily low-level-cloud cover variability



CLUBB-MG2 better represents the daily cloud variation.

Hourly cloud cover vs. in-cloud LWP



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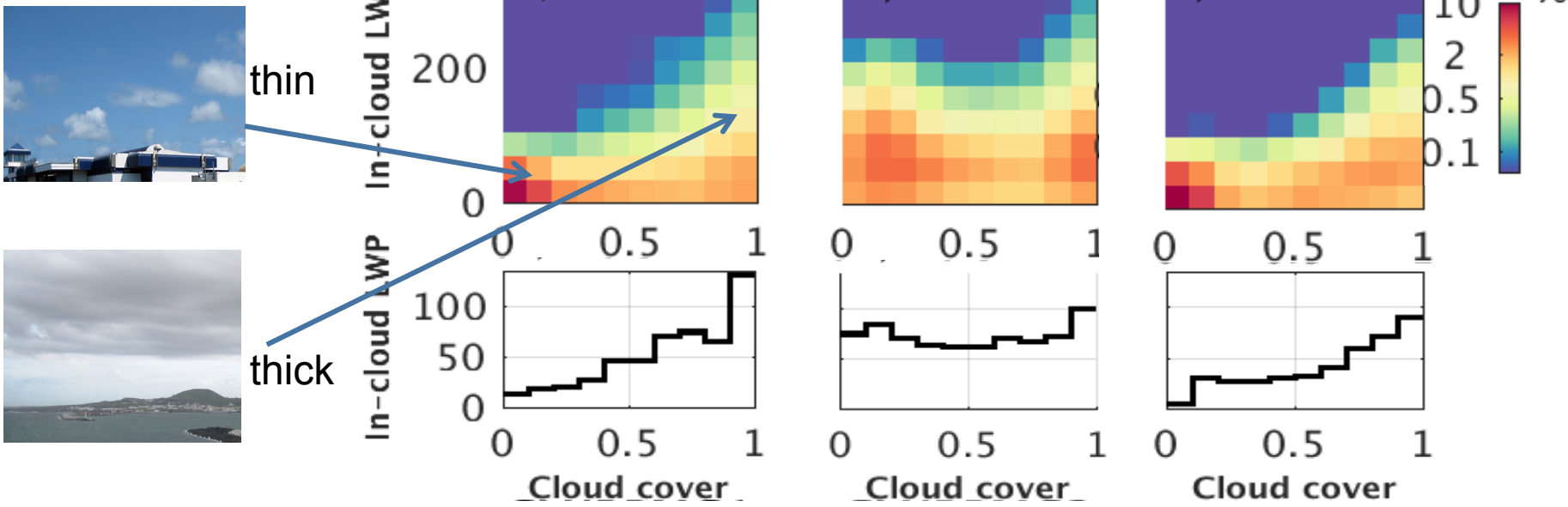

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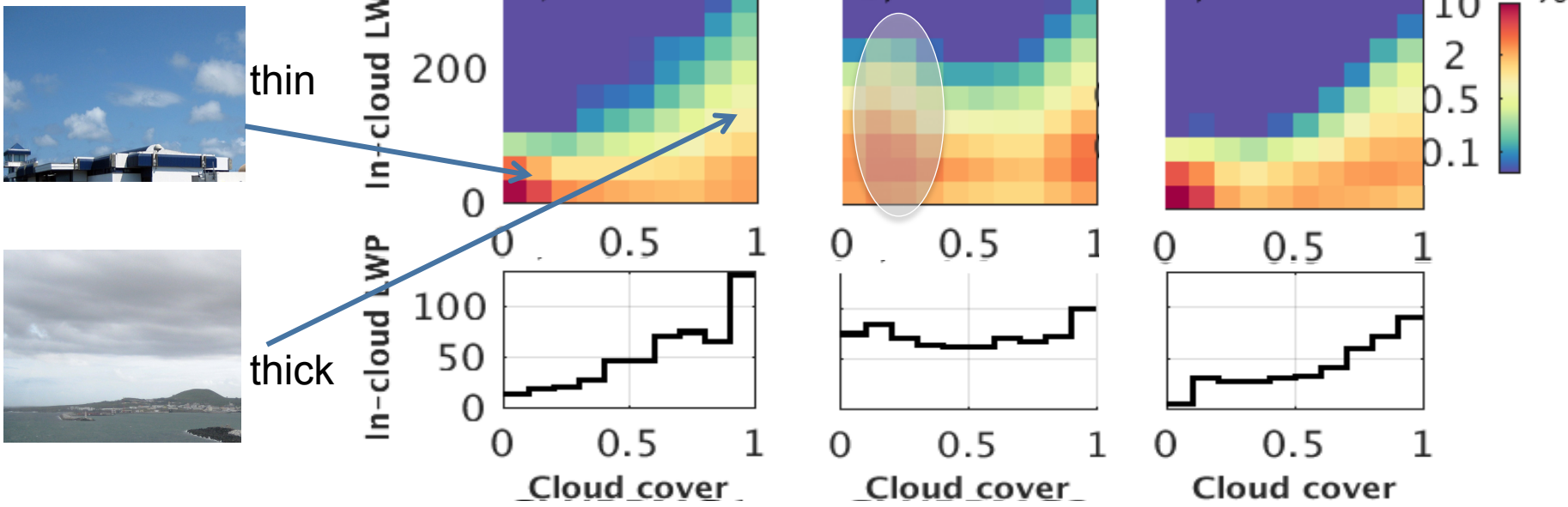
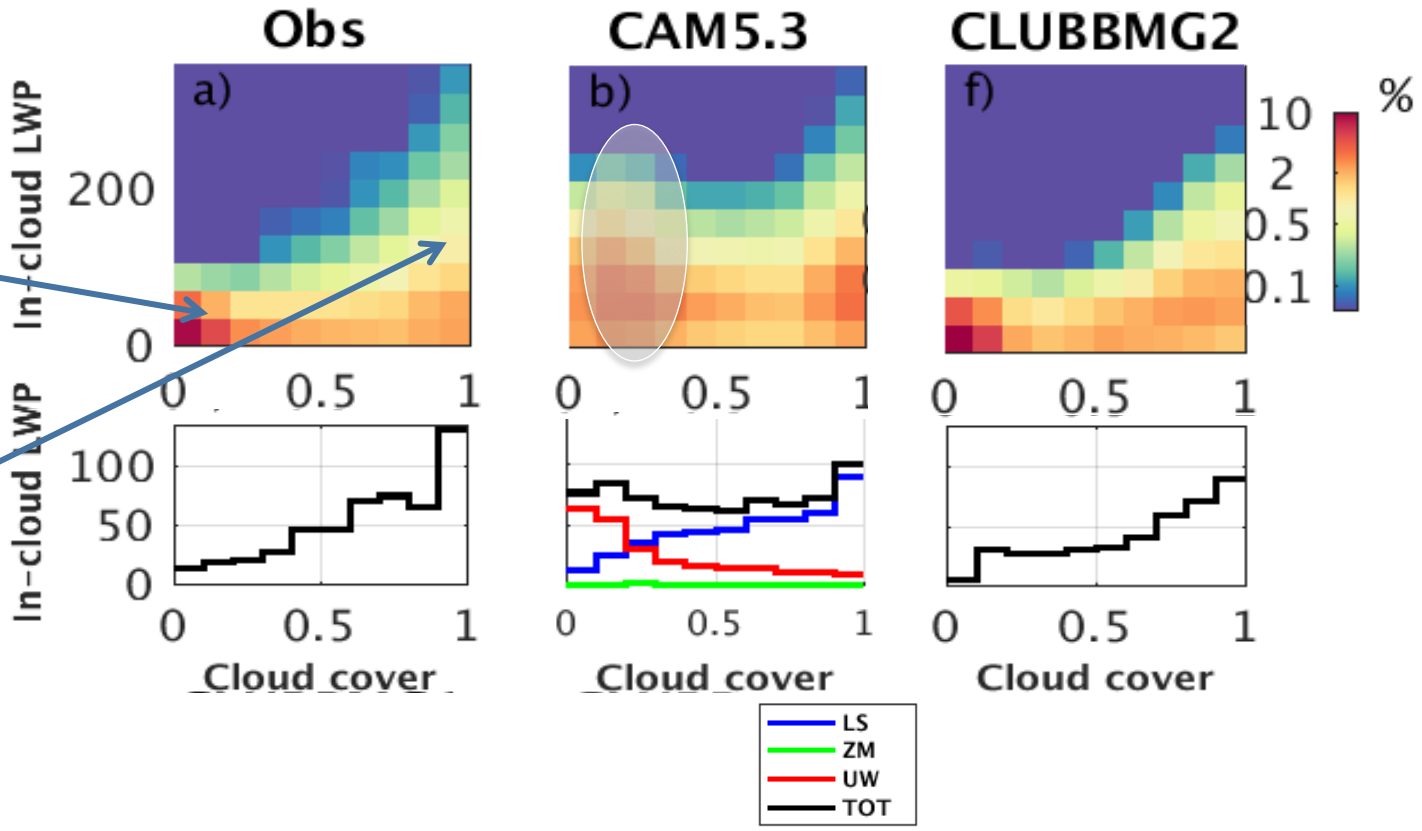


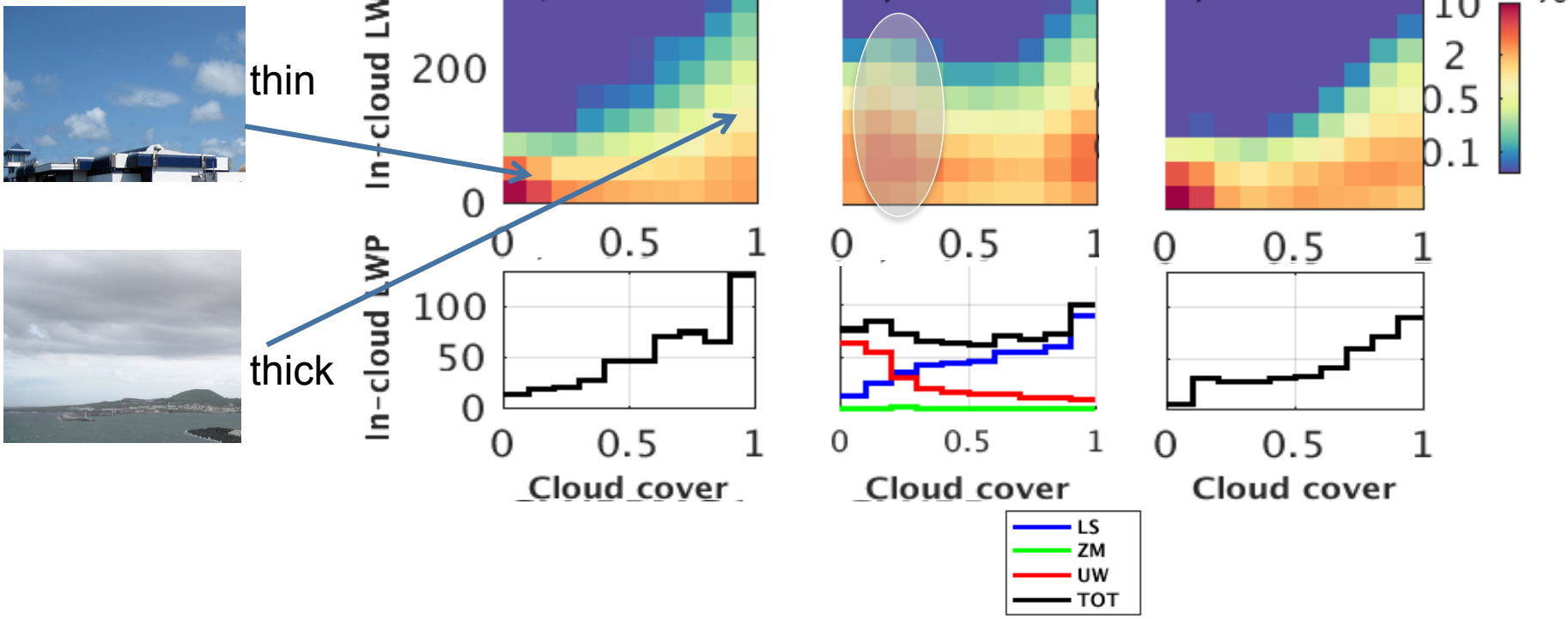
Hourly cloud cover vs. in-cloud LWP

thin

thick

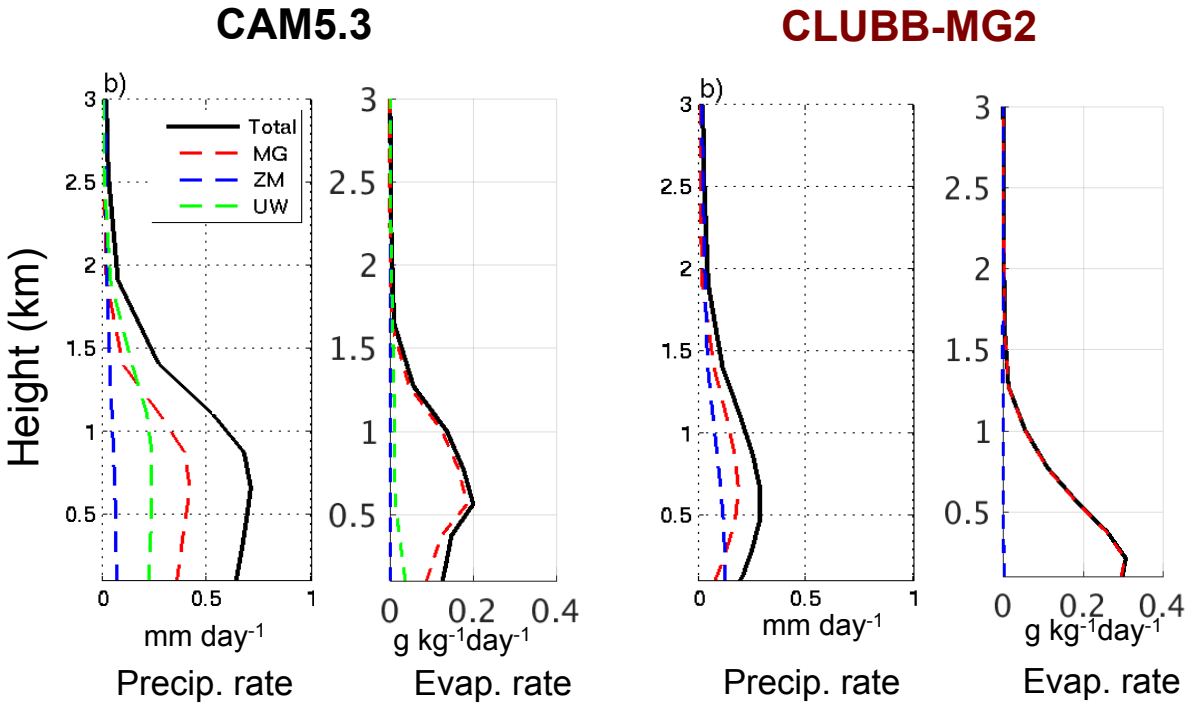


Hourly cloud cover vs. in-cloud LWP



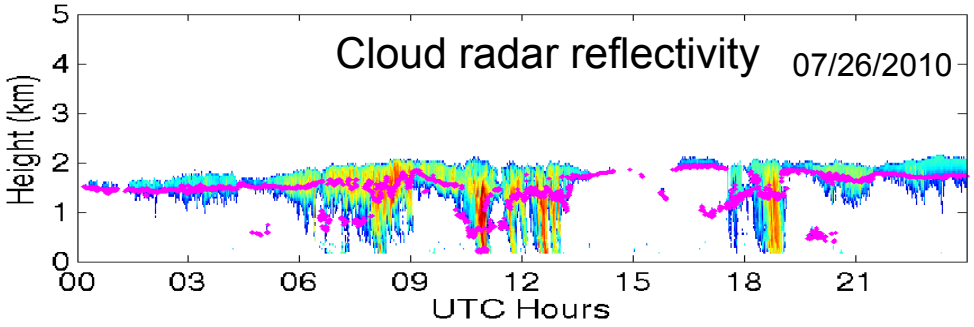
CLUBB scheme also better simulates the relationship of cloud fraction to LWP
➔ the consistent treatment through the PDF approach.

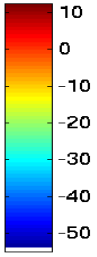
Precipitation and evaporation



- Precipitation flux decreases in CLUBB-MG2 compared with CAM5.3.
- Deep convection scheme is active during 34 days in CAM5.3, and 55 days in CLUBB-MG2.
- Sub-cloud precipitation evaporation is largely enhanced in CLUBB-MG2.

Precipitation and sub-cloud evaporation





dBZ

(Rémillard et al. 2012)

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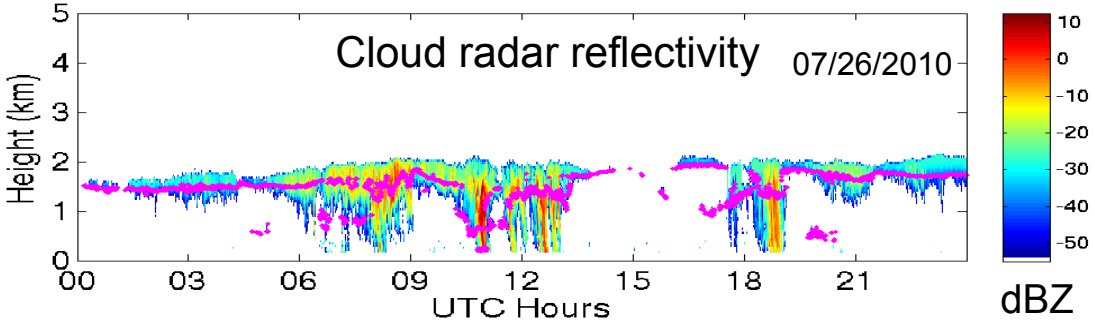

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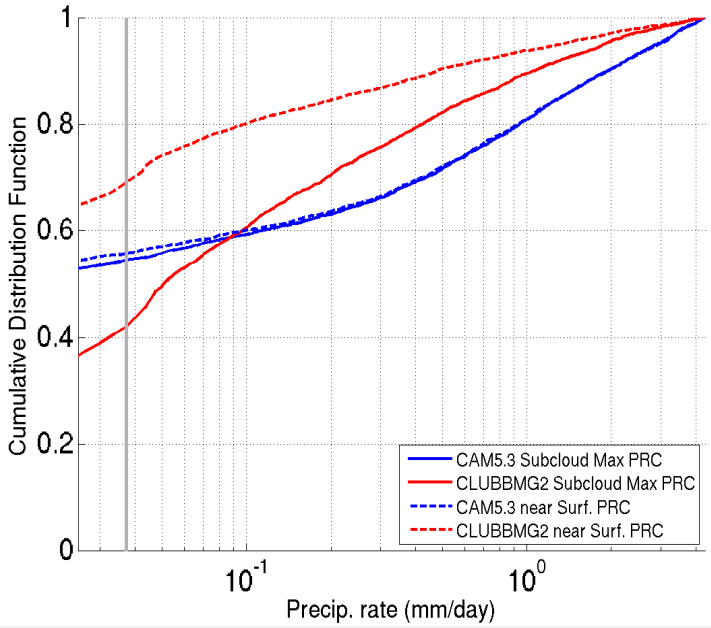

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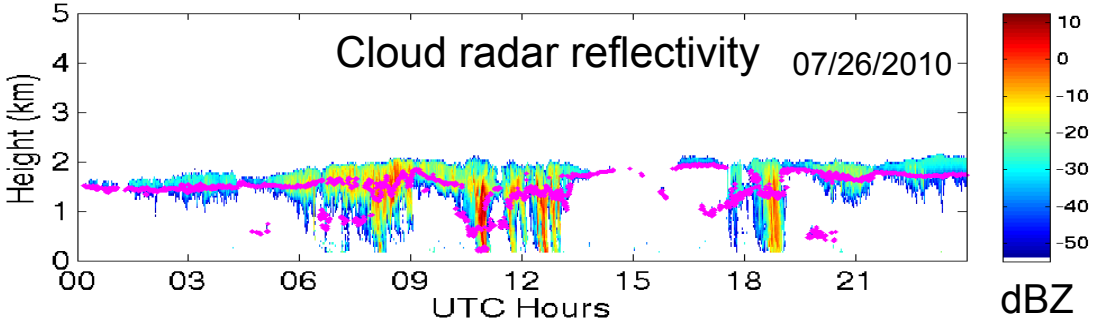

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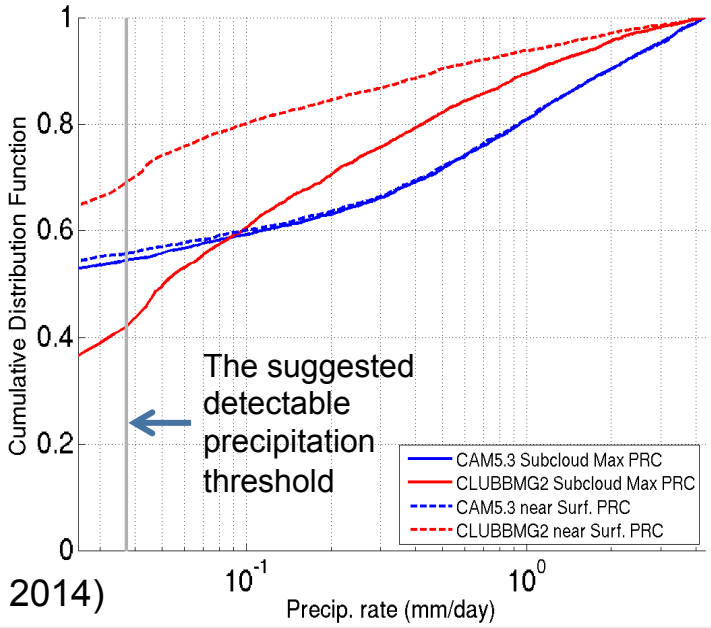
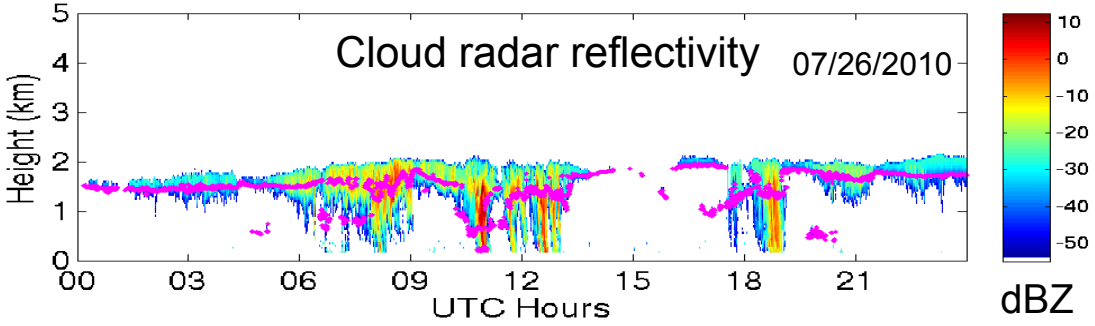


(Ahlgrimm & Forbes 2014)

Precipitation and sub-cloud evaporation



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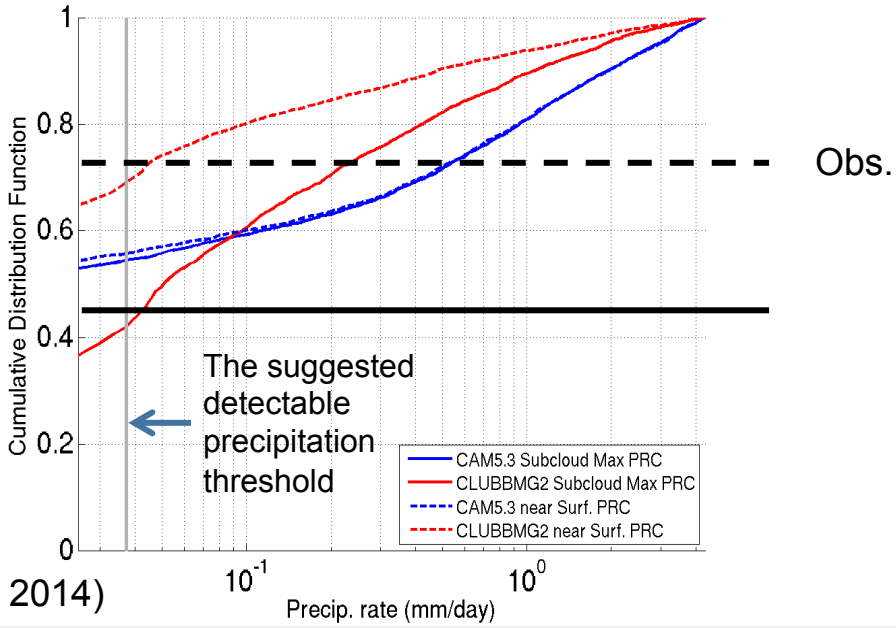

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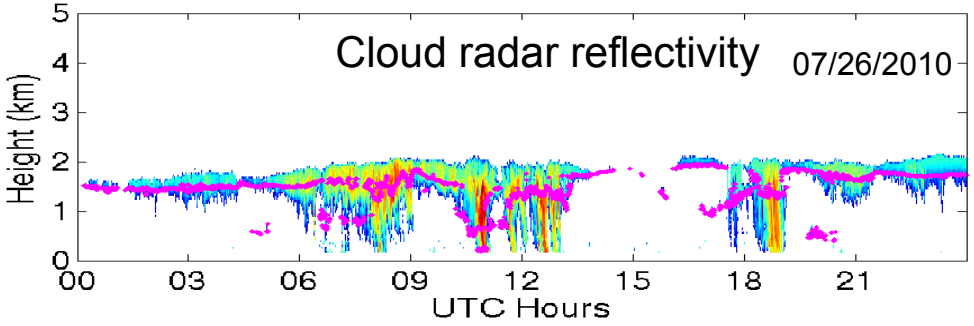

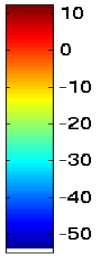

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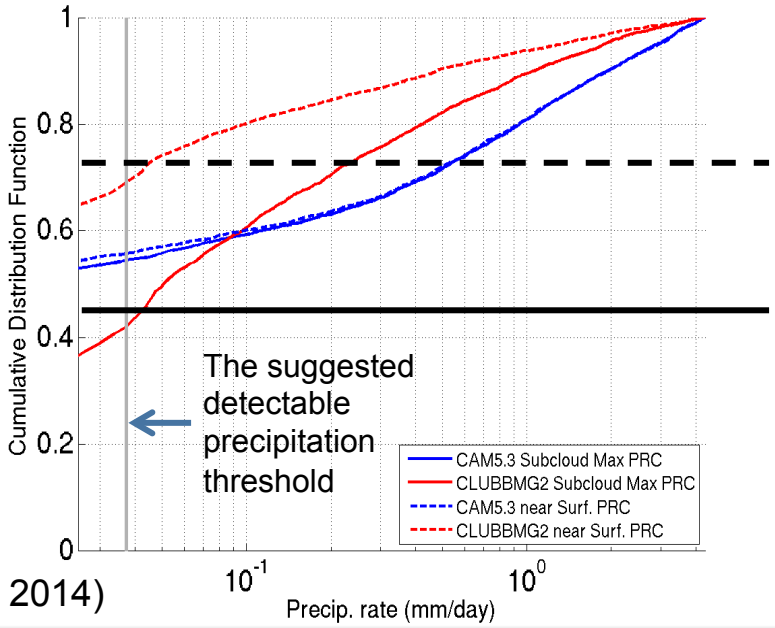


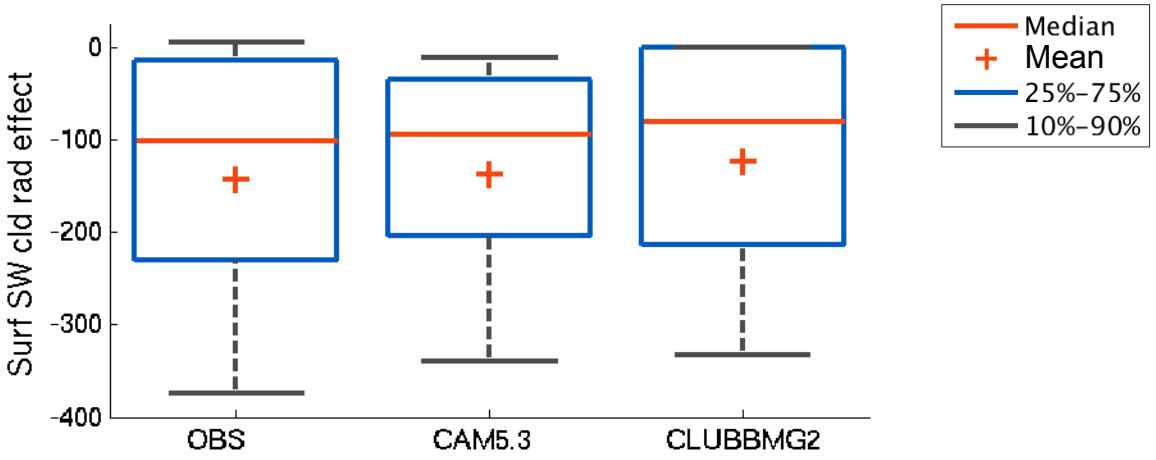
Obs.

(Ahlgrimm & Forbes 2014)

CLUBB-MG2: about half of the time sub-cloud precipitation evaporated out before reaching the surface → much more realistic

Surface SW cloud radiative effect (CRE)

$$CRE = SW^{\downarrow} - SW^{\downarrow}_{Clear}$$



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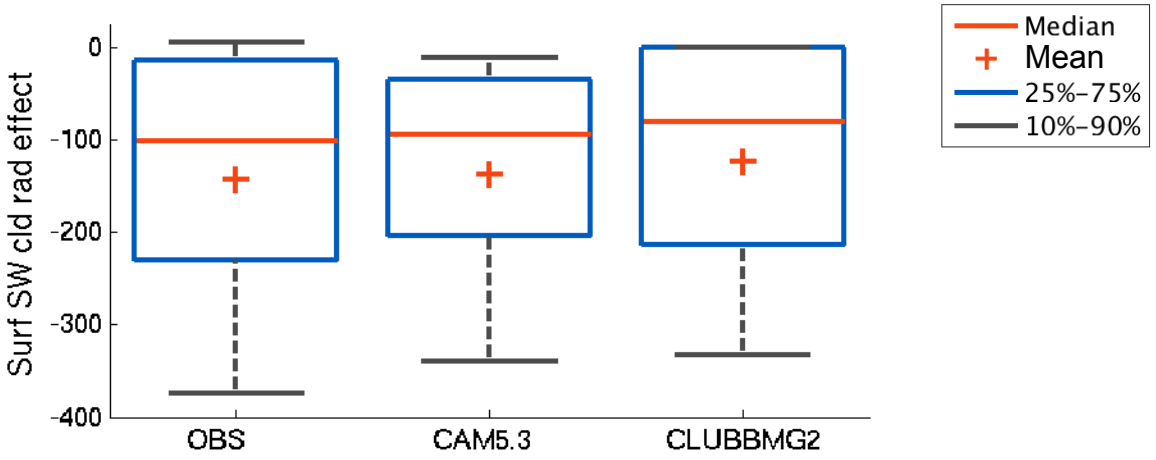

- SW CRE is mainly controlled by **cloud cover** and cloud optical thickness which is proportional to **log(cloud LWP)** and effective radius.

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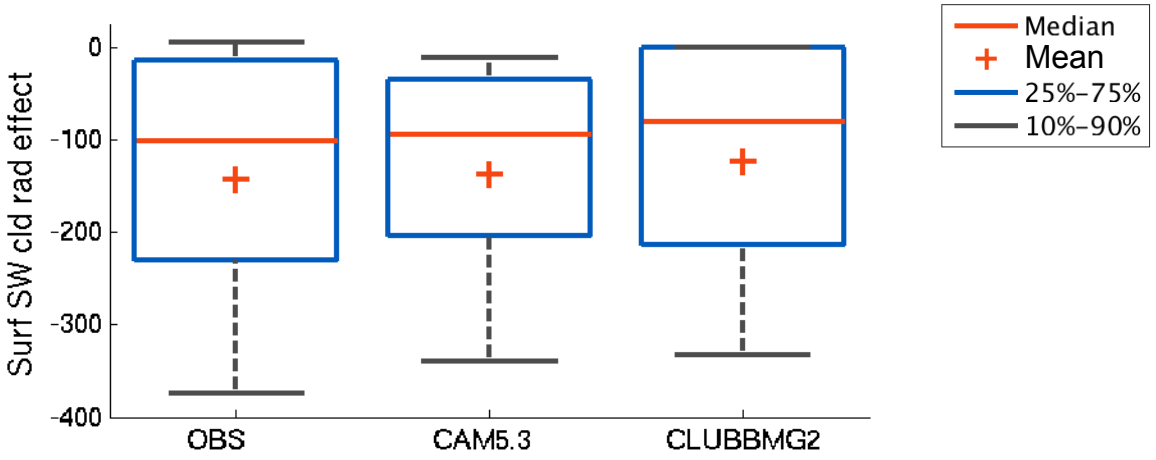
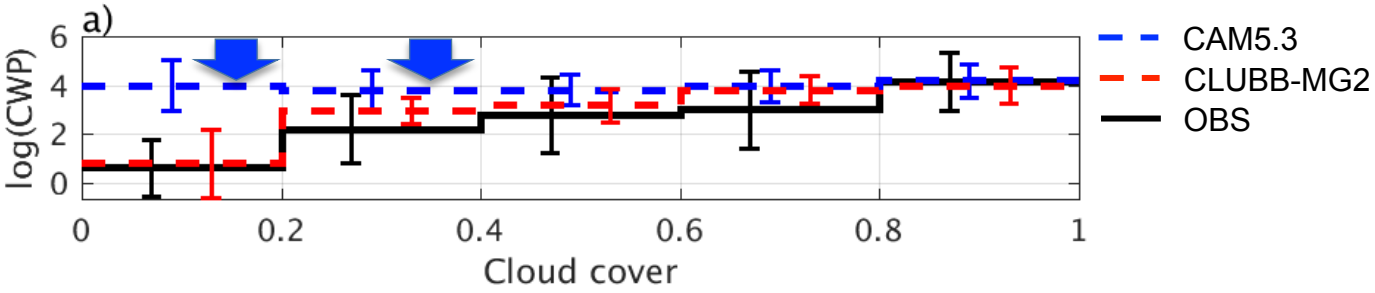


- SW CRE is mainly controlled by **cloud cover** and cloud optical thickness which is proportional to **log(cloud LWP)** and effective radius.
- Can ARM observations help identify where the SW CRE biases come from?

Surface SW CRE vs. in-cloud LWP and cloud cover

Surface SW CRE vs. in-cloud LWP and cloud cover



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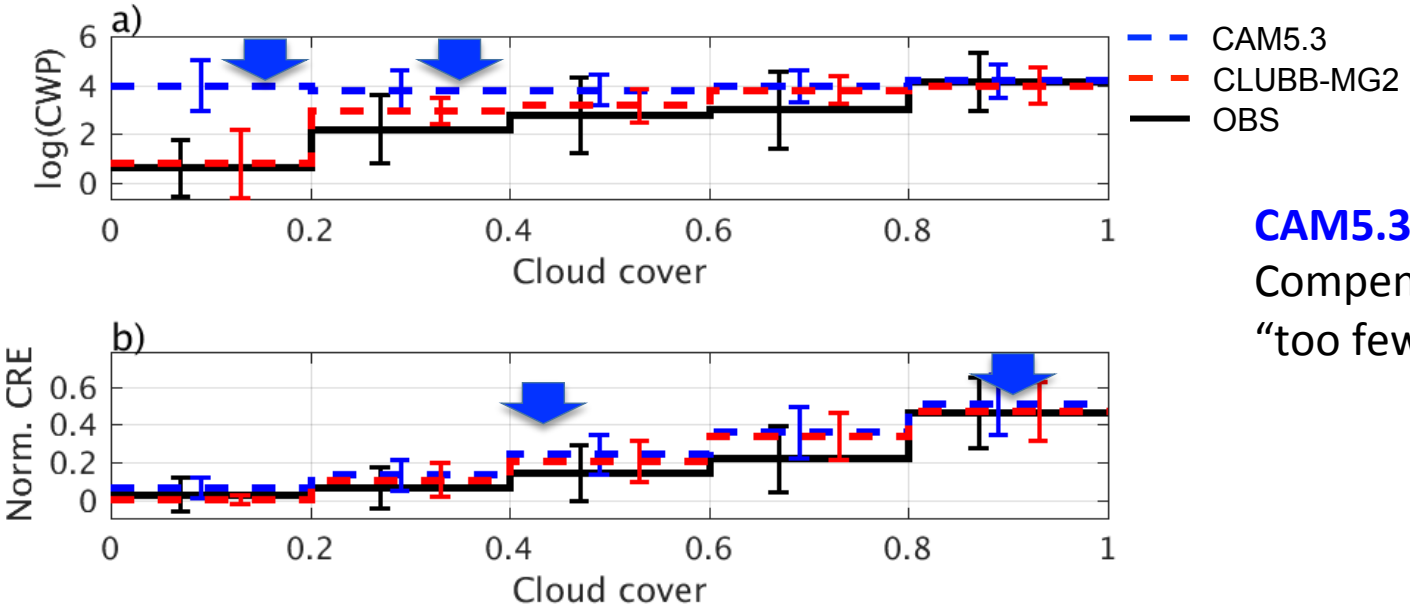
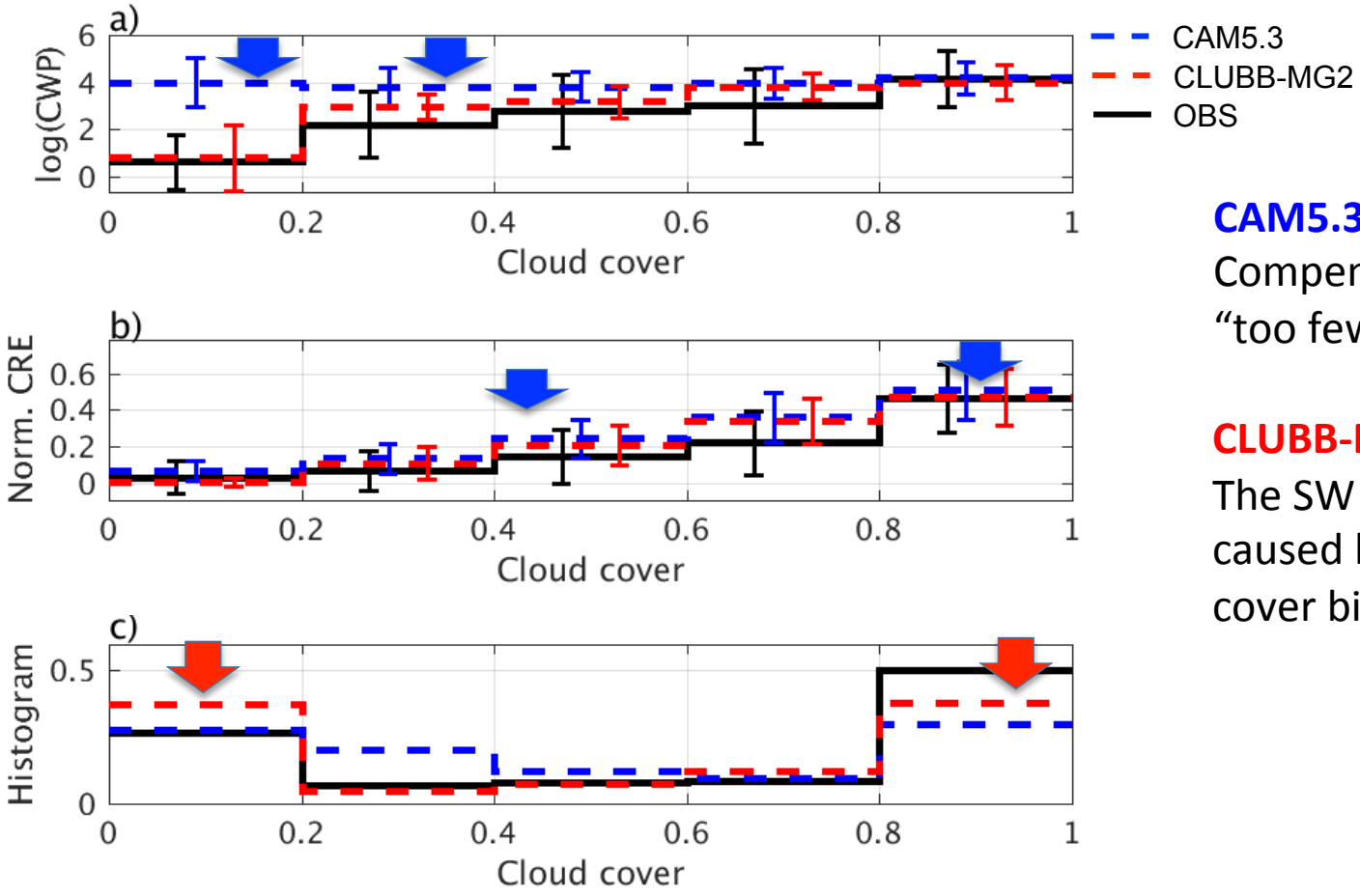


CAM5.3

Compensating errors

"too few, too bright"

Surface SW CRE vs. in-cloud LWP and cloud cover



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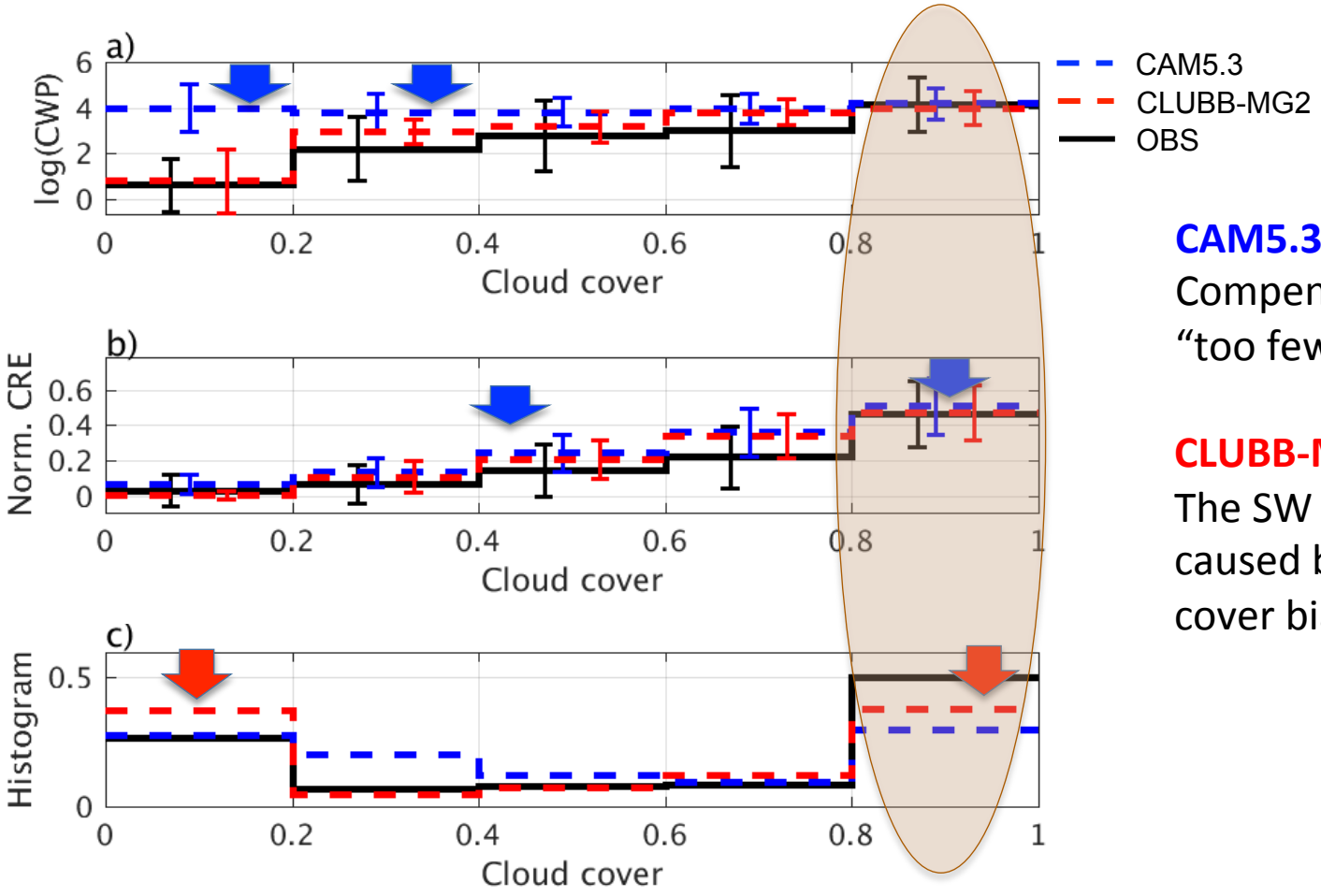
CLUBB-MG2

The SW CRE bias is mainly caused by negative cloud cover bias

Surface SW CRE vs. in-cloud LWP and cloud cover



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The SW CRE bias is mainly caused by negative cloud cover bias

Hourly cloud optical depth and effective radius (preliminary)

For overcast scenes (cloud cover > 0.8):

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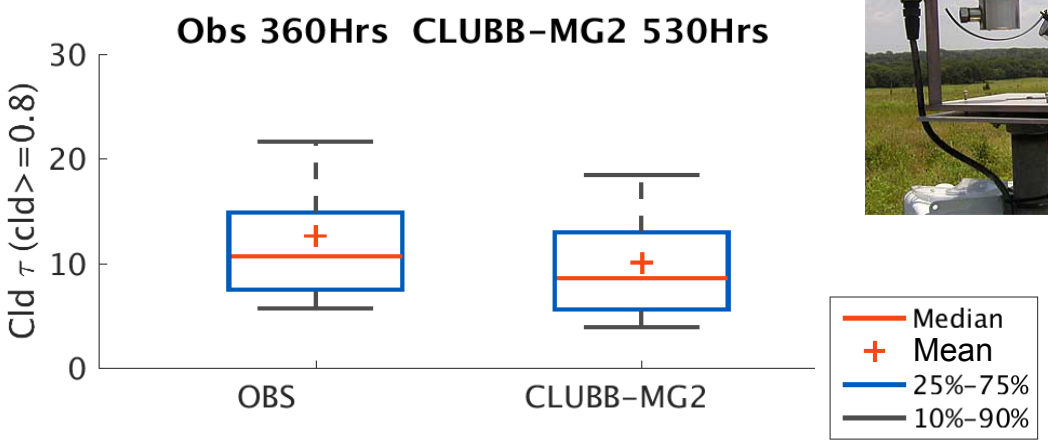
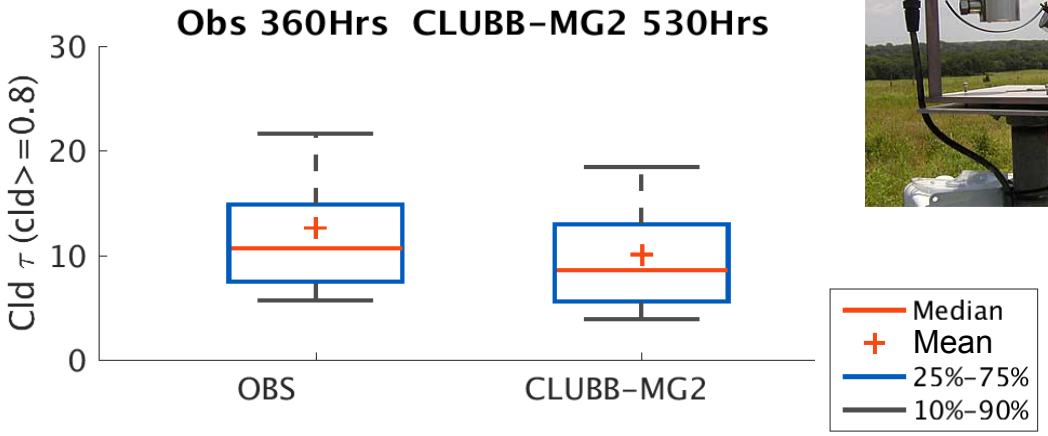
- The mean hourly CLUBB-MG2 cloud optical depth is smaller than the mean observed cloud optical depth by ~ 2.6.

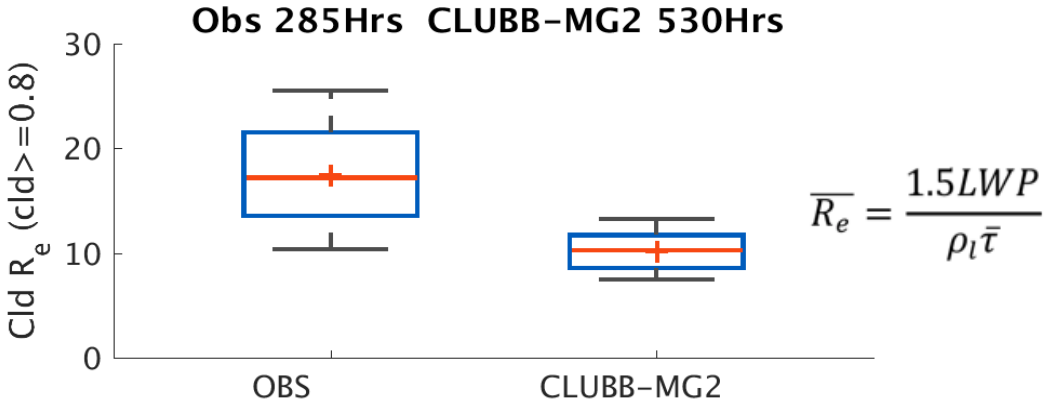


Hourly cloud optical depth and effective radius (preliminary)

For overcast scenes (cloud cover > 0.8):

- The mean hourly CLUBB-MG2 cloud optical depth is smaller than the mean observed cloud optical depth by ~ 2.6.
- The mean hourly CLUBB-MG2 cloud Re is smaller than the mean observed cloud Re by 7.3 micron.





$$\overline{R_e} = \frac{1.5LWP}{\rho_l \bar{\tau}}$$

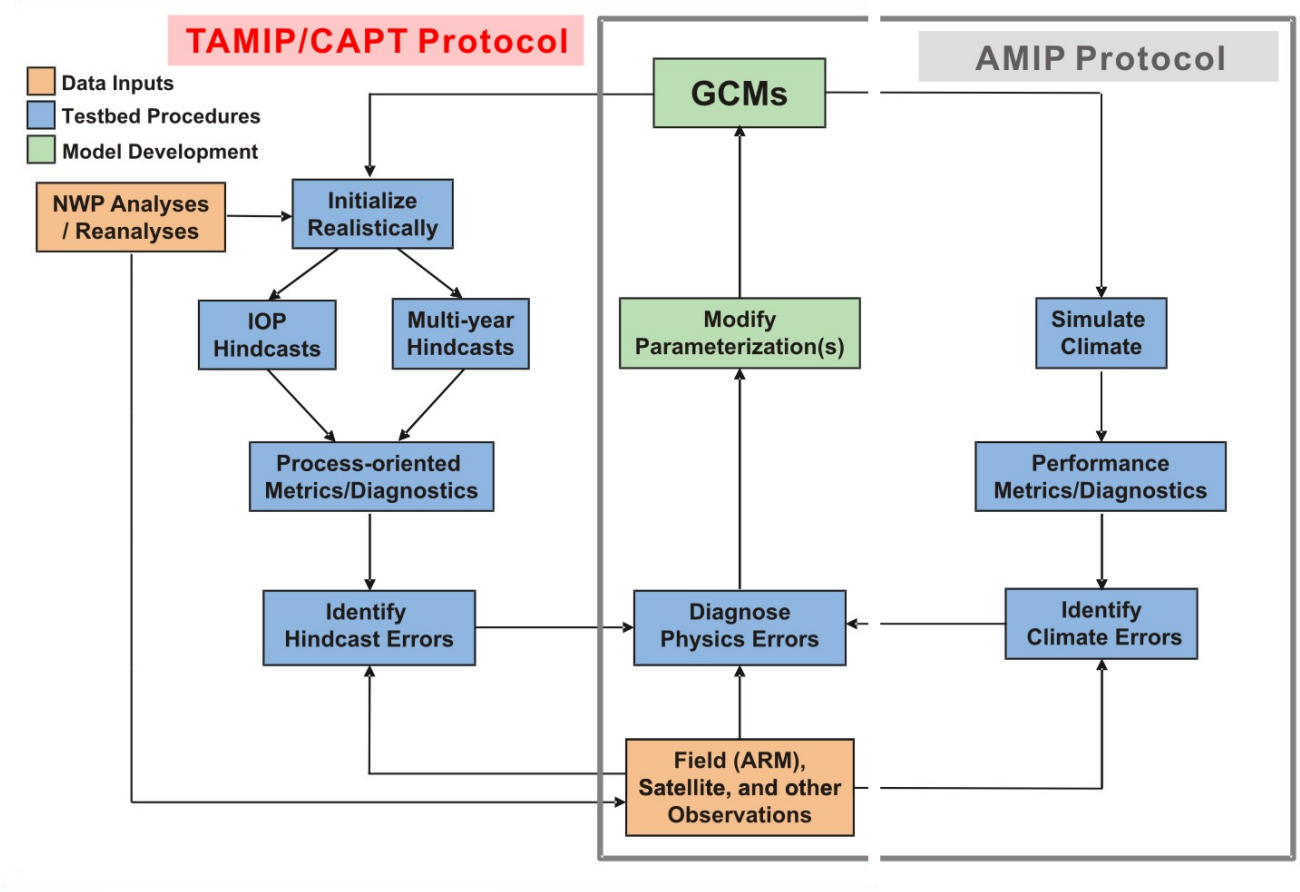
Summary

- **ARM field observations with CAPT approach** can help assess climate model improvement and biases.
- The ARM cloud and LWP observations combing with radiation measurement help identify what part of the cloud biases causes the surface radiative cloud effect biases in model simulations
- We need new precipitation observations to evaluate the precipitation related processes in model simulations.
- We need cloud optical measurements for broken clouds.

Thanks!

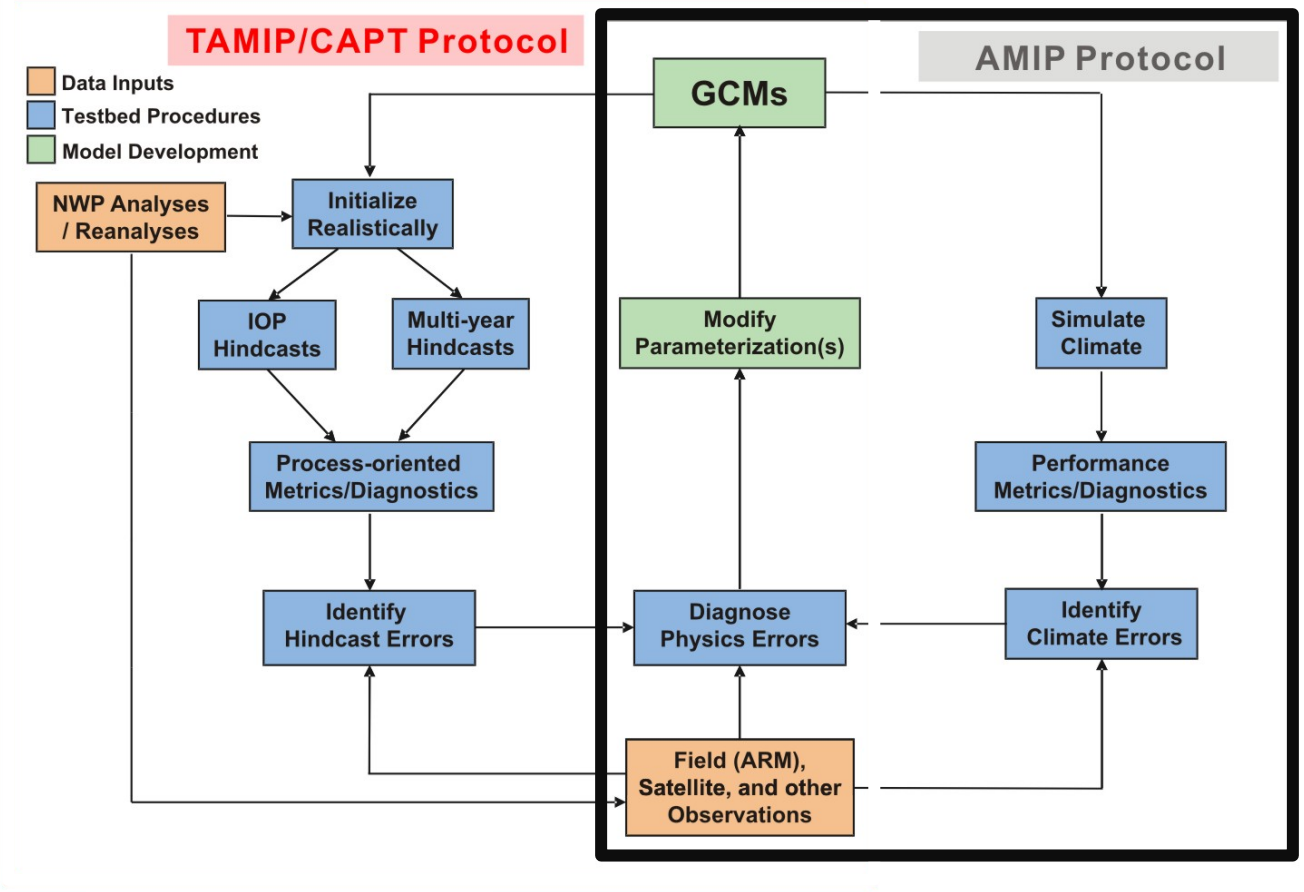
Extra slides

Climate model evaluation and development



Courtesy of H.-Y. Ma

Climate model evaluation and development



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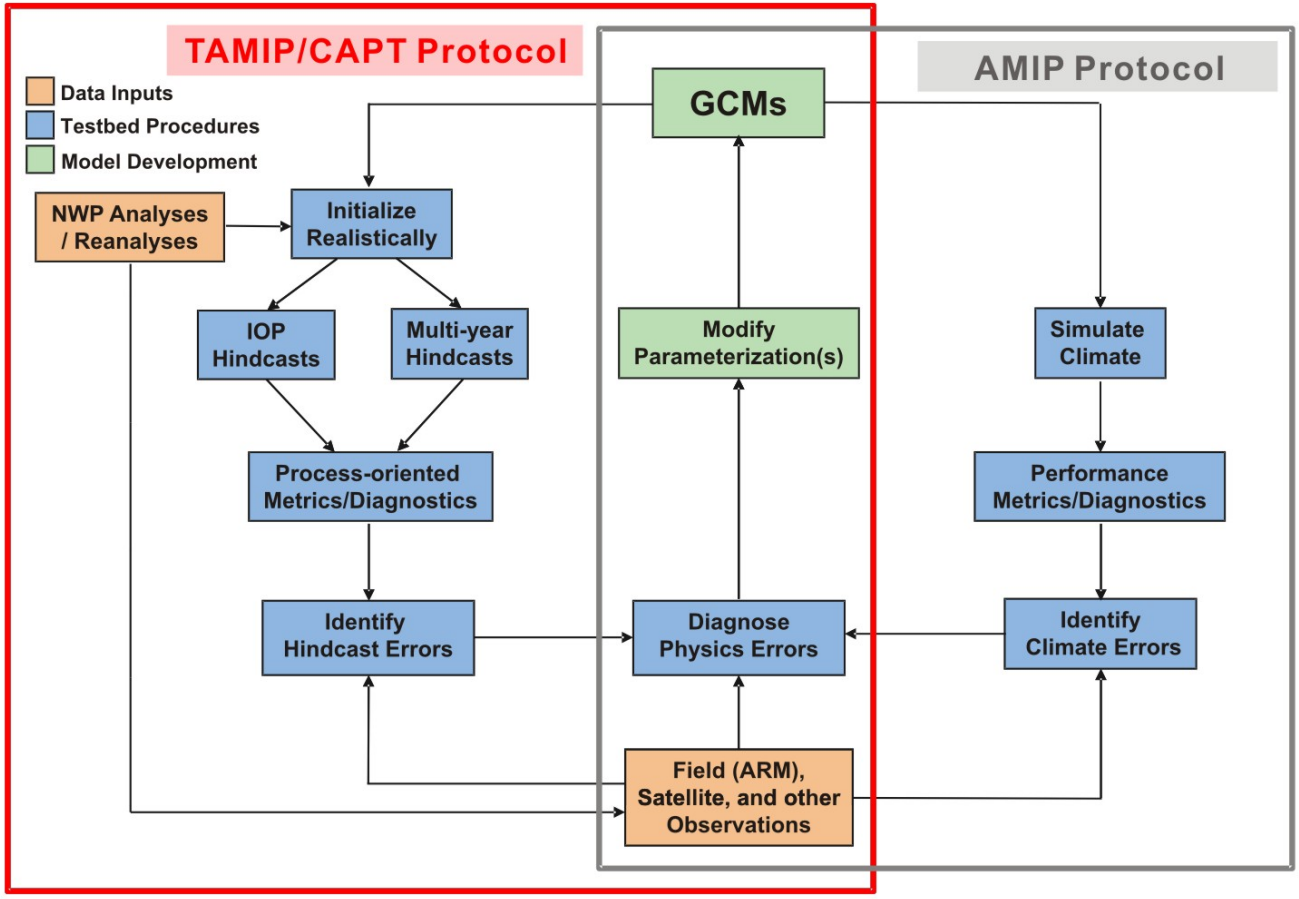


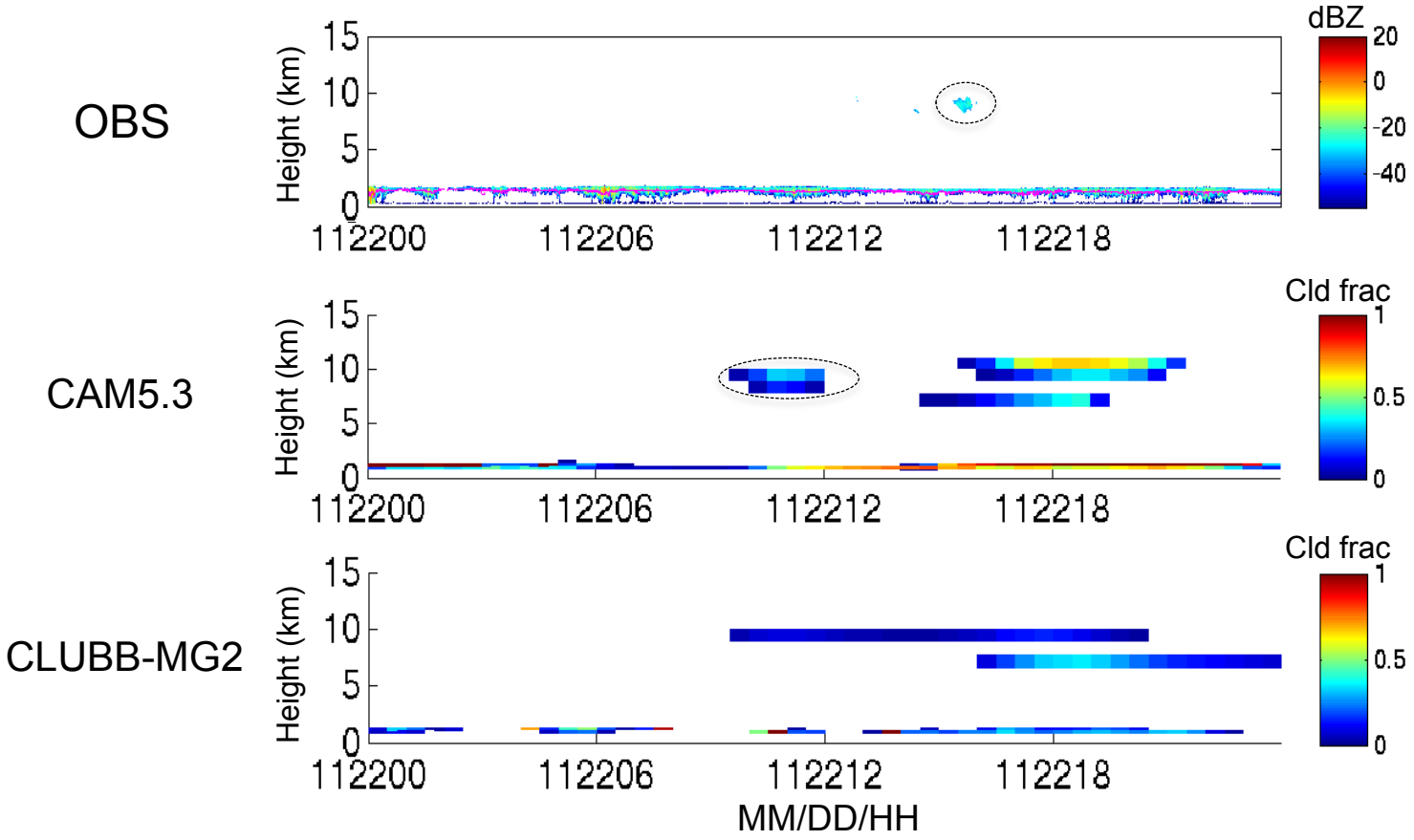
Courtesy of H.-Y. Ma

Advantages of CAPT:

1) can minimize the general circulation bias

2) can be directly compared with detailed processes observations (Phillips et al. 2004)

Hours without cloud above 3 km height



More than 1200 daytime hours without cloud above 3 km from the observations, CAM5.3 and CLUBB-MG2