Evaluation and Improvement of the Cloud Resolving Model Component of the Multi-scale Modeling Framework

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Background

- Principal cause of differences in GCM climate sensitivity is atmospheric hydrology => clouds and water vapor
- Evaluation of GCM clouds and hydrology largely based on
  - Top-of-atmosphere radiation budget
  - ISCCP cloud fraction
  - ISCCP simulator: optical depth x pressure matrix
- The fundamental reason for the use of the MMF (or any model with cloud-scale dynamics) is to improve our treatment of clouds and their interaction with radiation and cloud-scale dynamics in climate models
- Lots more cloud data exist
  - NASA: MODIS, MISR, CERES, TRMM, etc.
  - DOE ARM
  - CloudSat, CALIPSO

Questions

- How do we use these new data to evaluate the MMF?
  - How do we use single point time series data?
  - How do we use high spatial resolution satellite data?
- How do we carry out a similar comparison for conventional climate models given the difference in spatial and temporal resolution?
- What are our criteria for climate model performance that will allow us to demonstrate improvement?

Evaluation Strategy

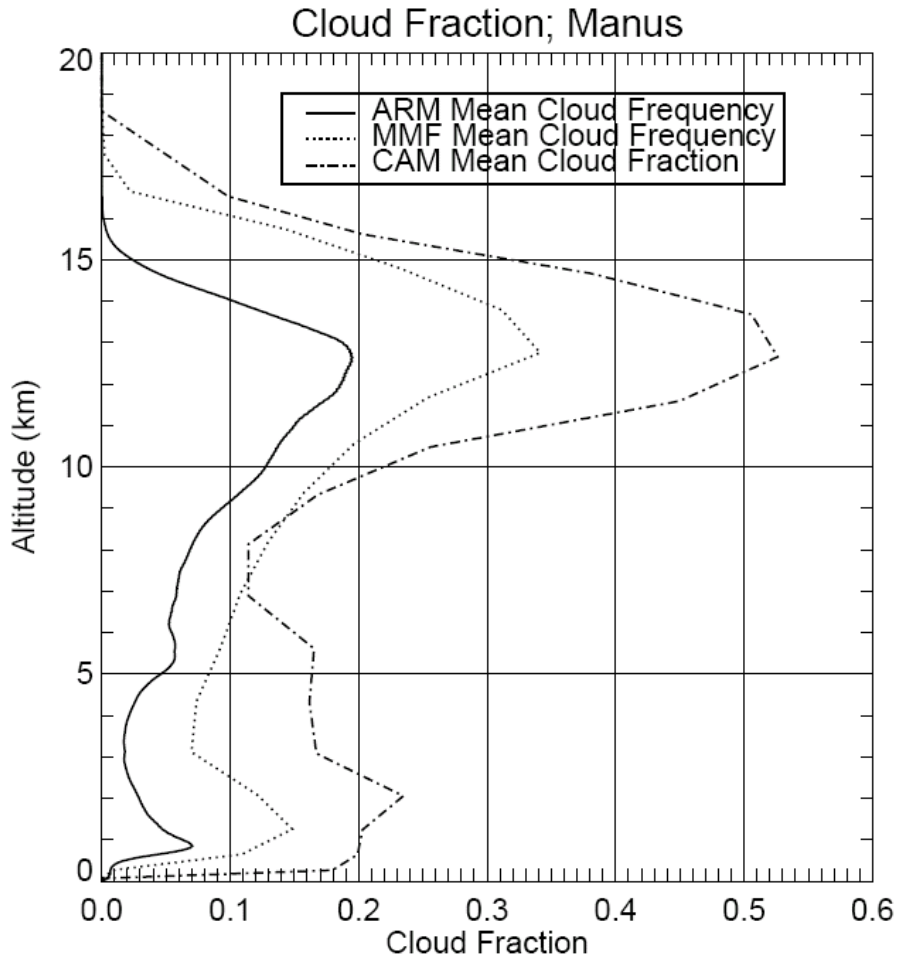
- Comparison of MMF and CAM (NCAR Community Atmosphere model) output with ARM observations and retrievals
  - Column radiative budget, cloud properties and profiles of heating rates
  - Satellite data, including a radar simulator for comparison with CloudSat
  - Analysis based on traditional time averaging & classification approaches
- Comparison of CRM (Cloud Resolving Model) run in "Forecast Mode" over the ARM site over several years
  - Probabilistic verification with "test scores"
- Examine diurnal cycles and the life-cycle of cloudiness
  - Diagnostics from existing runs
  - Possibly run in a "Global forecast" mode

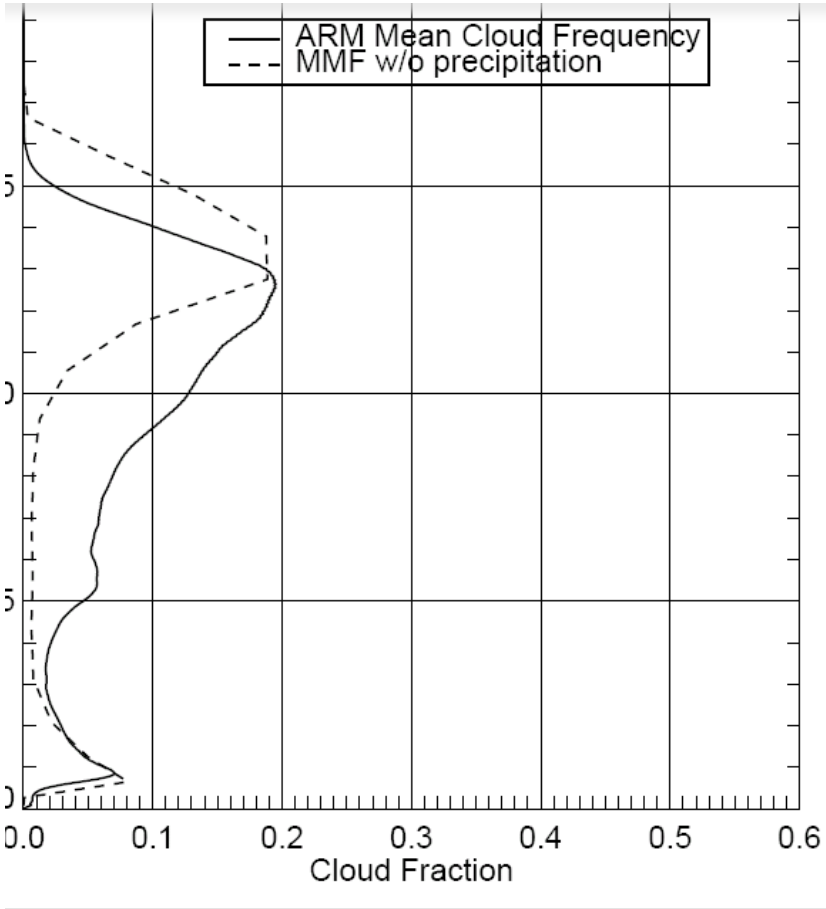
Initial Improvement Effort

- Focus on Boundary Layer Cloud Formation
  - Sensitivity tests
    - Run Current MMF at 1km rather than 4 km resolution (PNNL)
    - Other runs possible – enhanced vertical resolution
  - Implement 3rd order turbulence closer scheme
  - Variable Z Grid spacing & Layers

Tropical heating rate comparison

McFarlane, Mather, & Ackerman (PNNL)
manuscript in preparation


Cloud Fraction; Manus
ARM Mean Cloud Frequency
MMF Mean Cloud Frequency
CAM Mean Cloud Fraction
Altitude (km)
Cloud Fraction
0
5
10
15
20
0.0
0.1
0.2
0.3
0.4
0.5
0.6

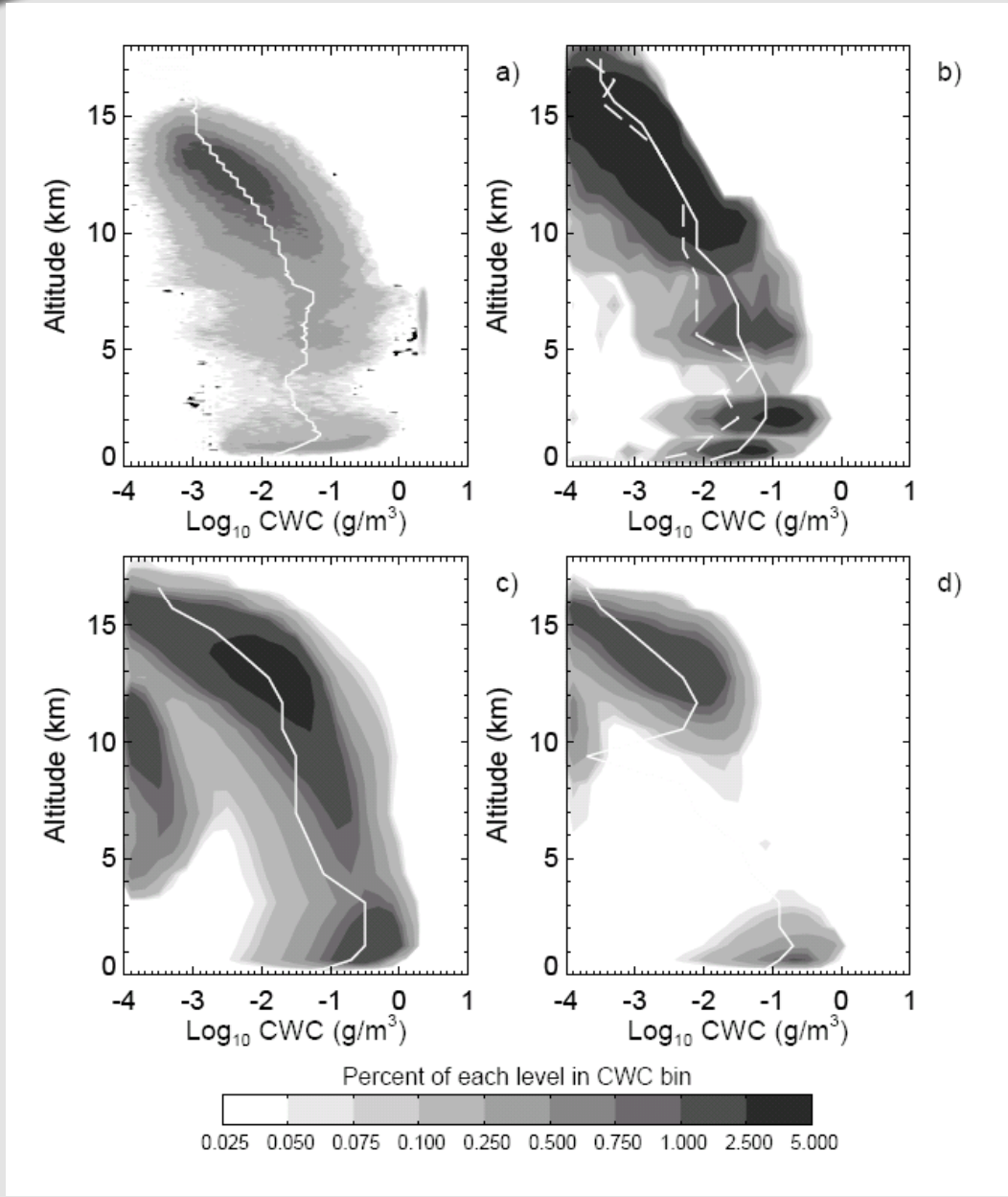

ARM Mean Cloud Frequency
MMF w/o precipitation
Cloud Fraction
0.0
0.1
0.2
0.3
0.4
0.5
0.6

ARM

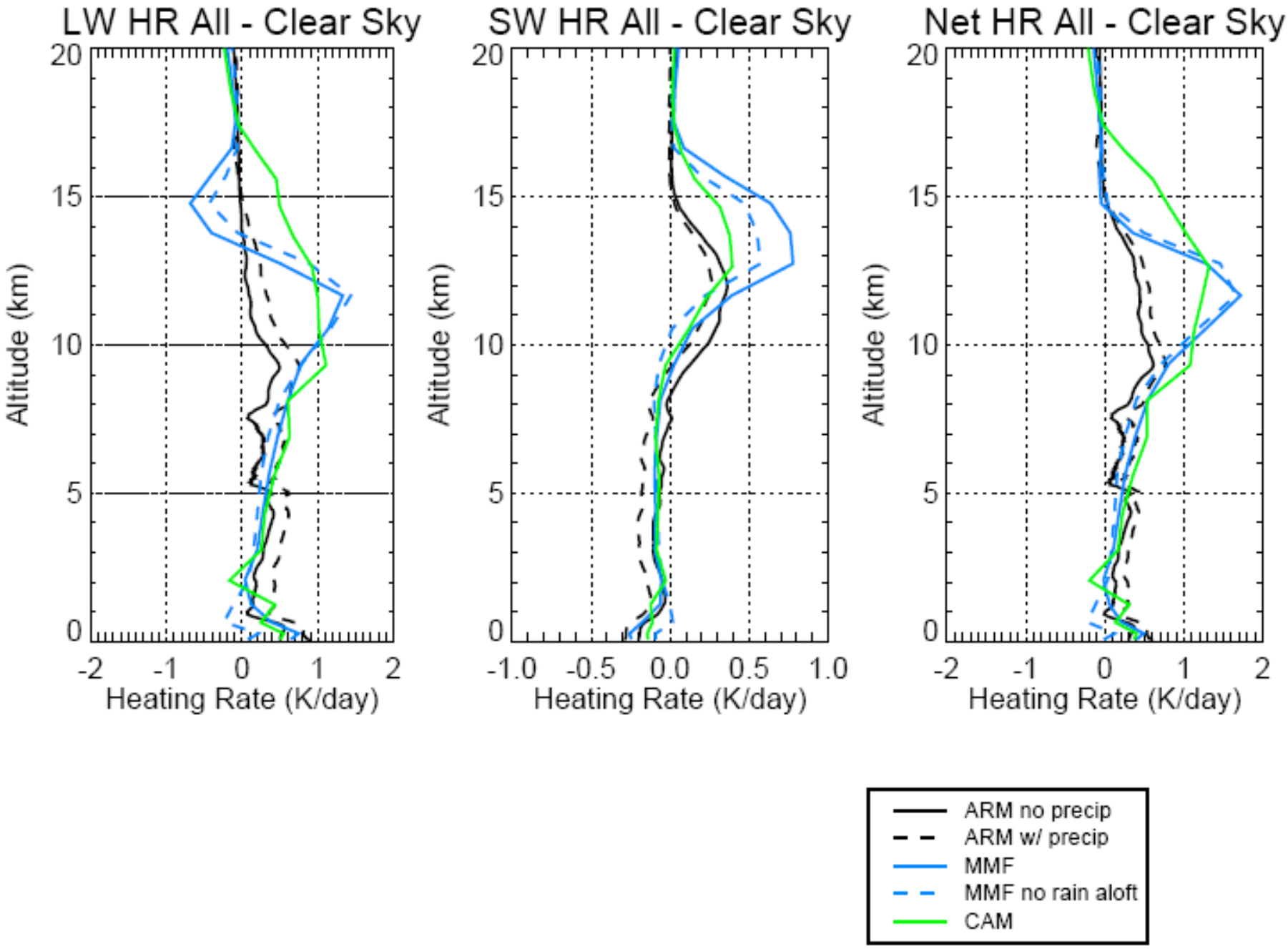
CAM

MMF

MMF – no precip



Condensed water content


LW HR All - Clear Sky
SW HR All - Clear Sky
Net HR All - Clear Sky
Altitude (km)
Heating Rate (K/day)
0
5
10
15
20
-2
-1
0
1
2
-1.0
-0.5
0.0
0.5
1.0
ARM no precip
ARM w/ precip
MMF
MMF no rain aloft
CAM

Evaluation of MMF Cloud properties using satellite data

Zonally-averaged cloud fraction

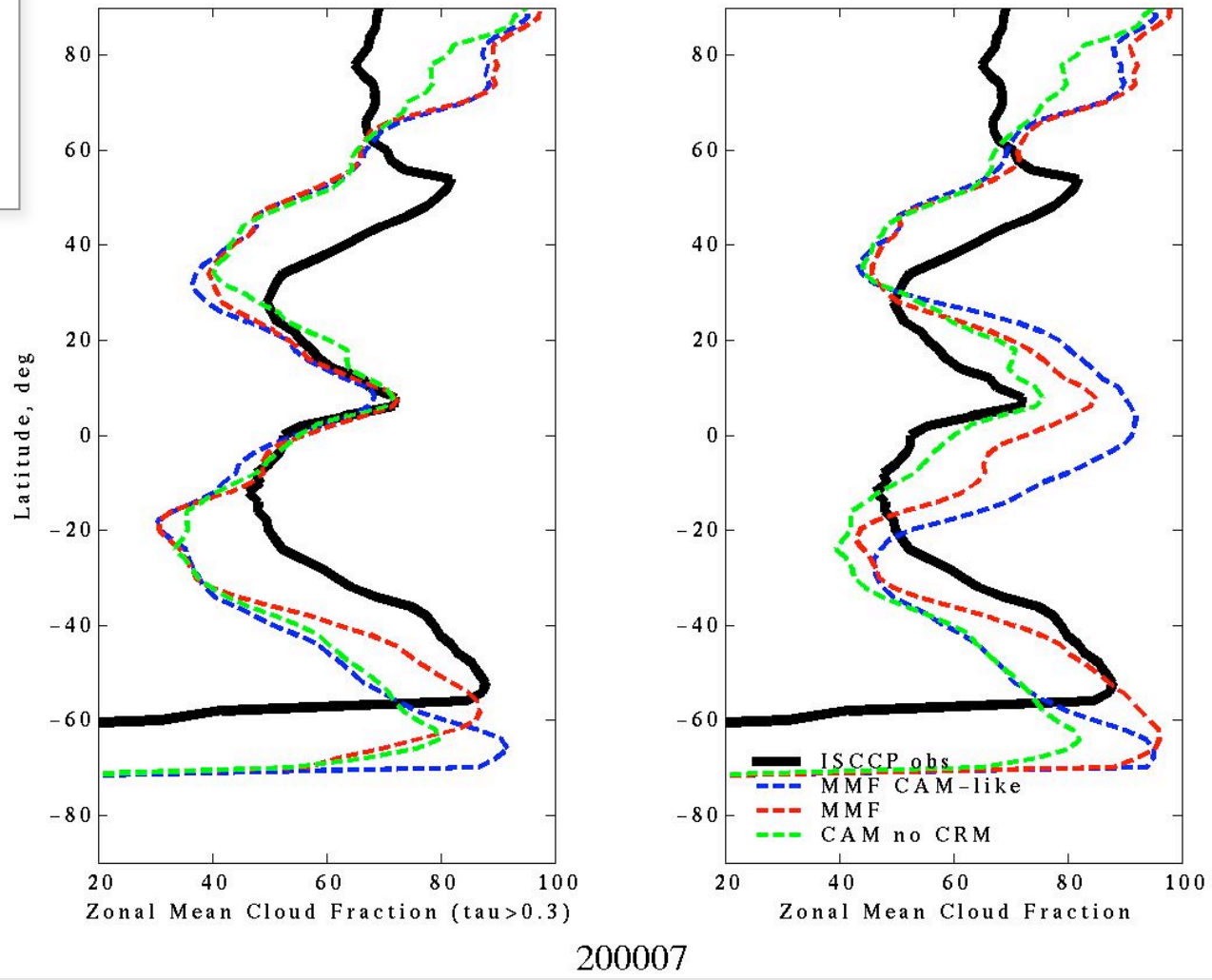
Left panel assumes ISCCP optical depth detection threshold of 0.3

Tropics

- Good agreement if threshold is used
- MMF has too much high thin cloud (upper layers too moist)

Extra-tropics

- Underestimate cloud amount in mid-lat
- Overestimate in polar latitudes



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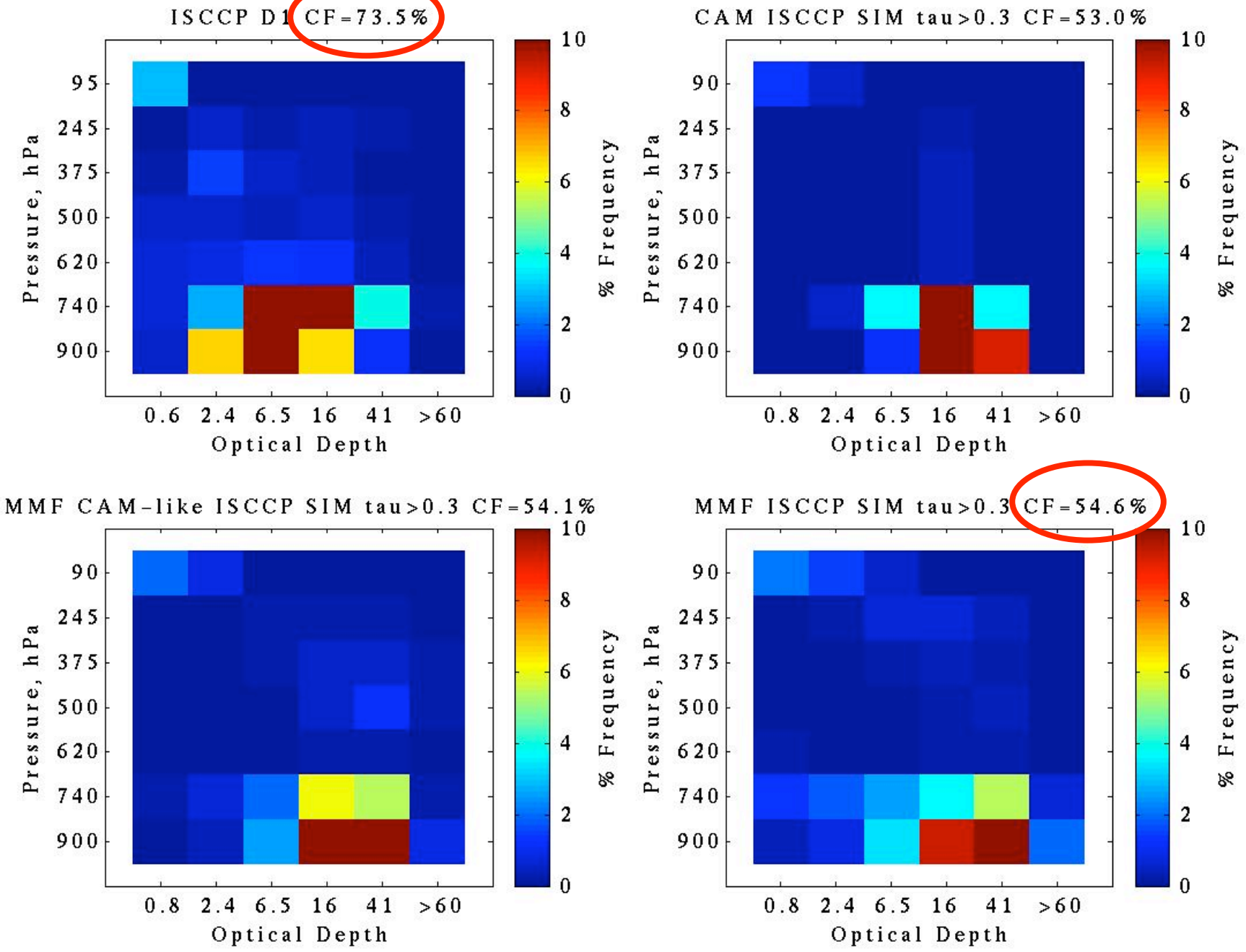
CTH-OD Histograms : California Stratus



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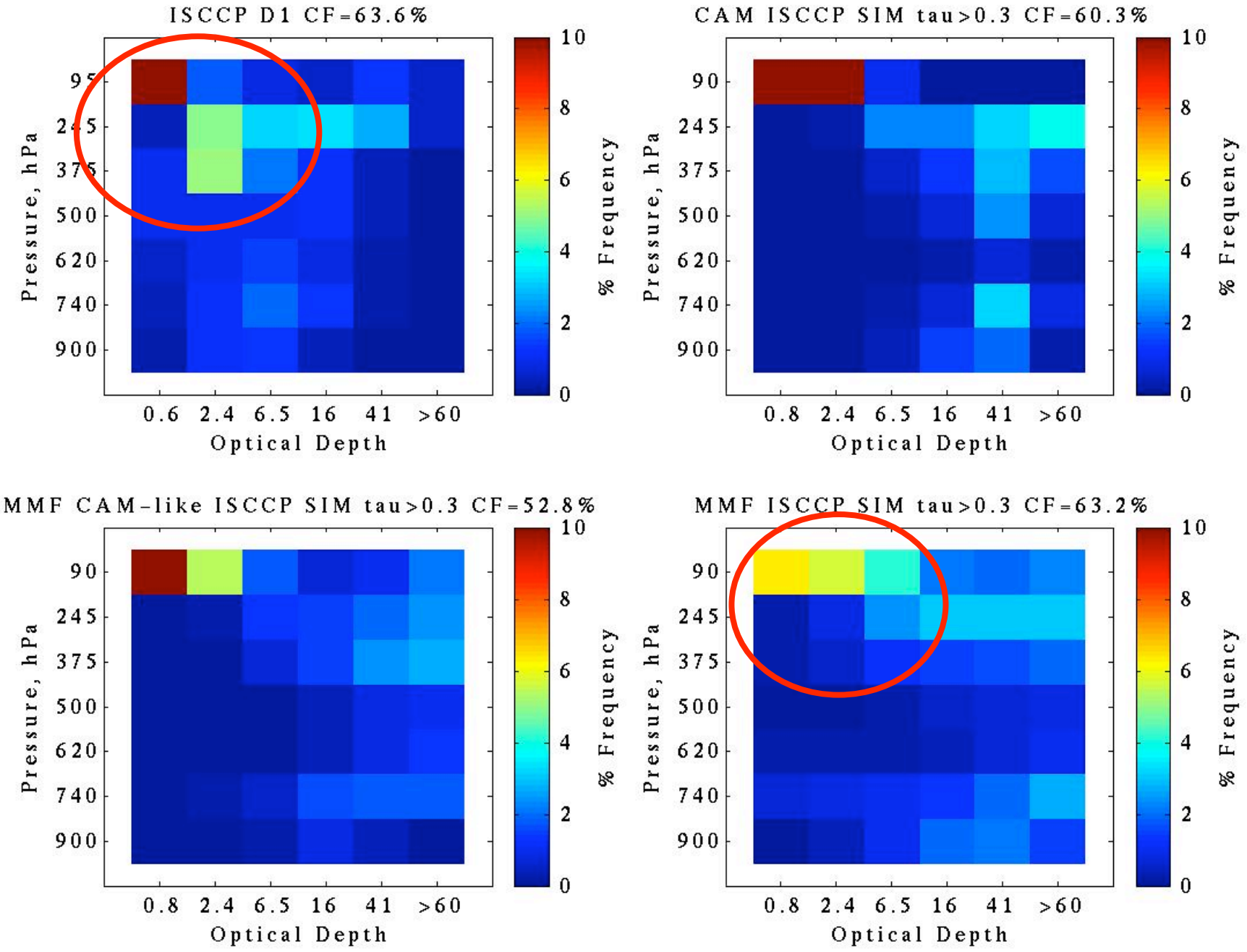
CTH-OD Histograms : Tropical Western Pacific



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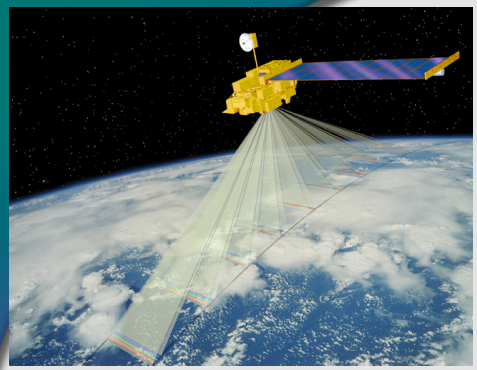
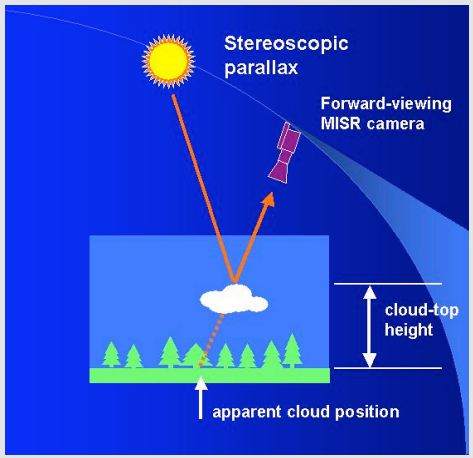
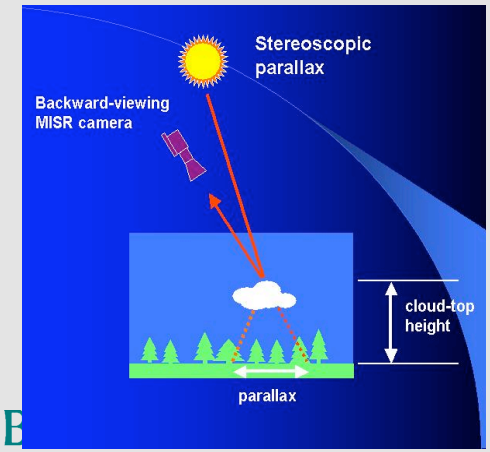
Development of new tools

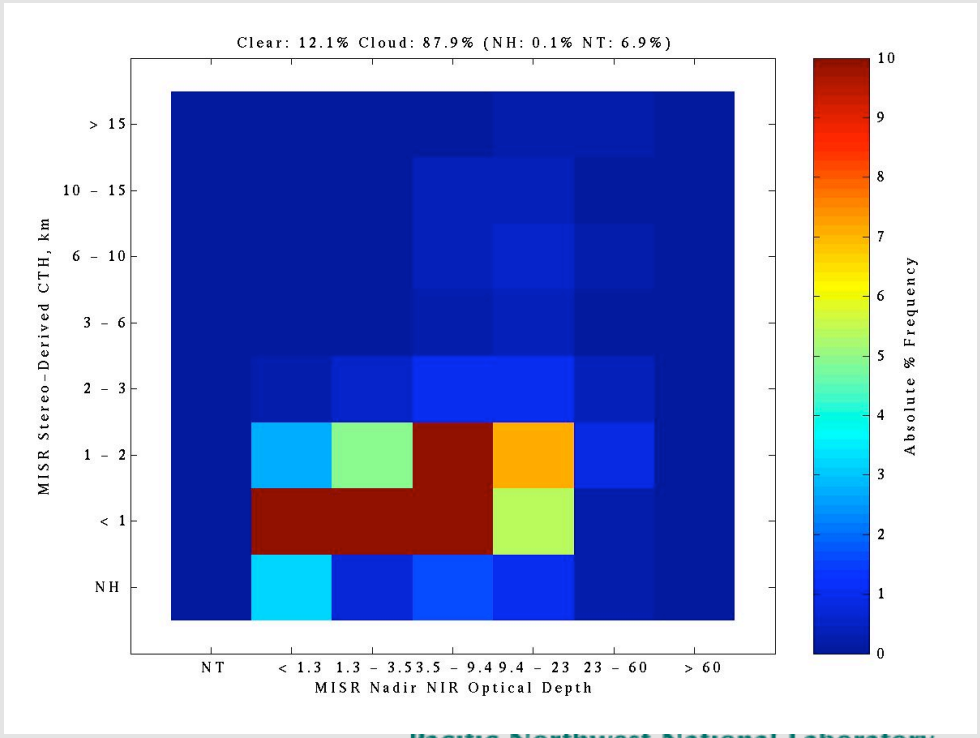
MISR CTH-OD



- MISR multi-angle imagery obtains retrievals of Cloud Top Height using geometric stereo-imaging
- Currently generating CTH-OD histograms similar to those created by ISCCP, but using MISR stereo-imaging
- Will use the multiple cameras to minimize the effects of sun glint on the optical depth retrieval.

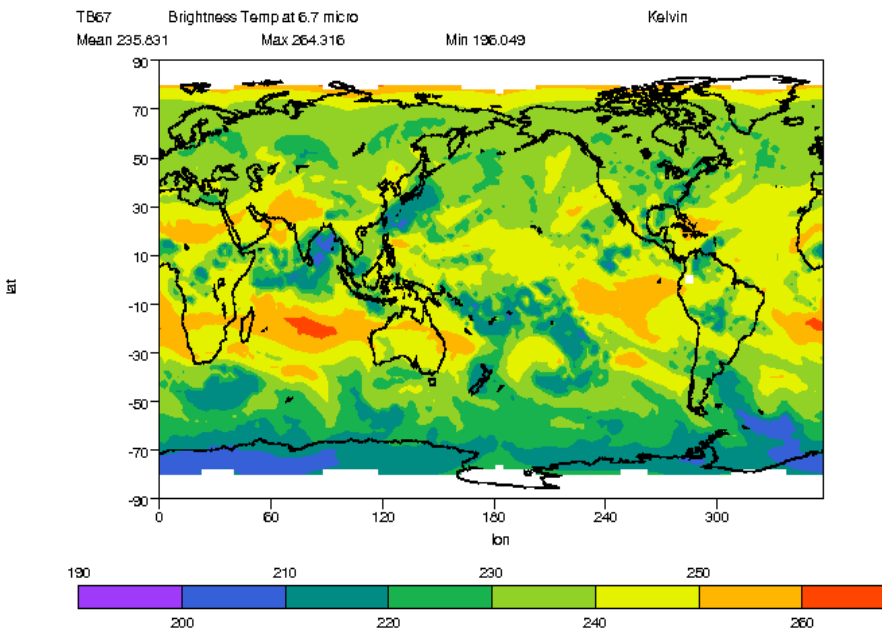






Marchand & Ackerman, PNNL

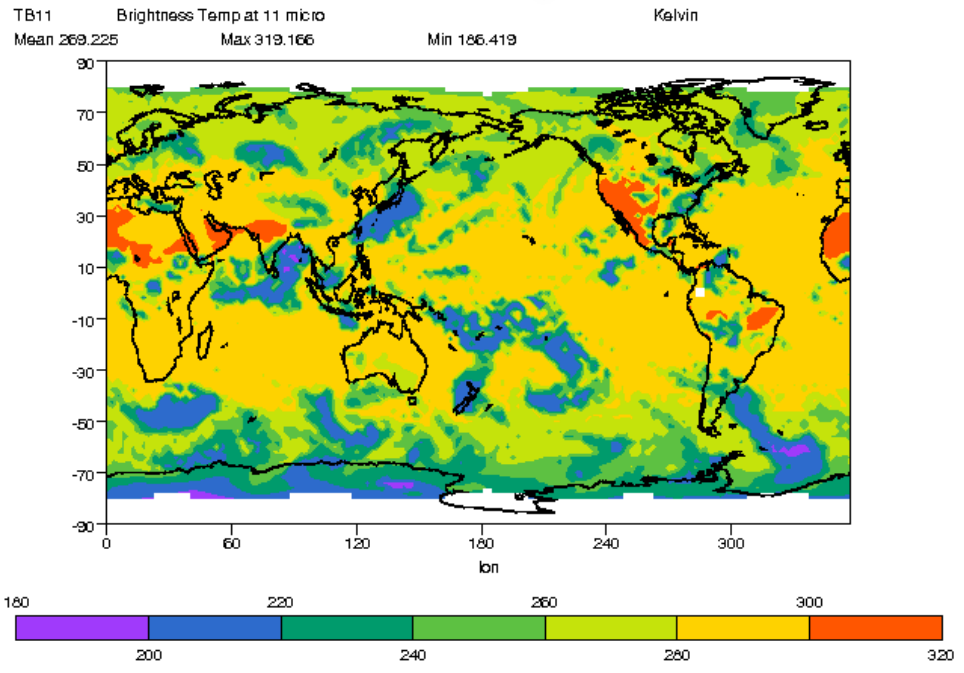
Simulated Satellite IR imagery



TOA brightness temperature at

6.7 μm

11 μm



Courtesy: S. Klein, LLNL

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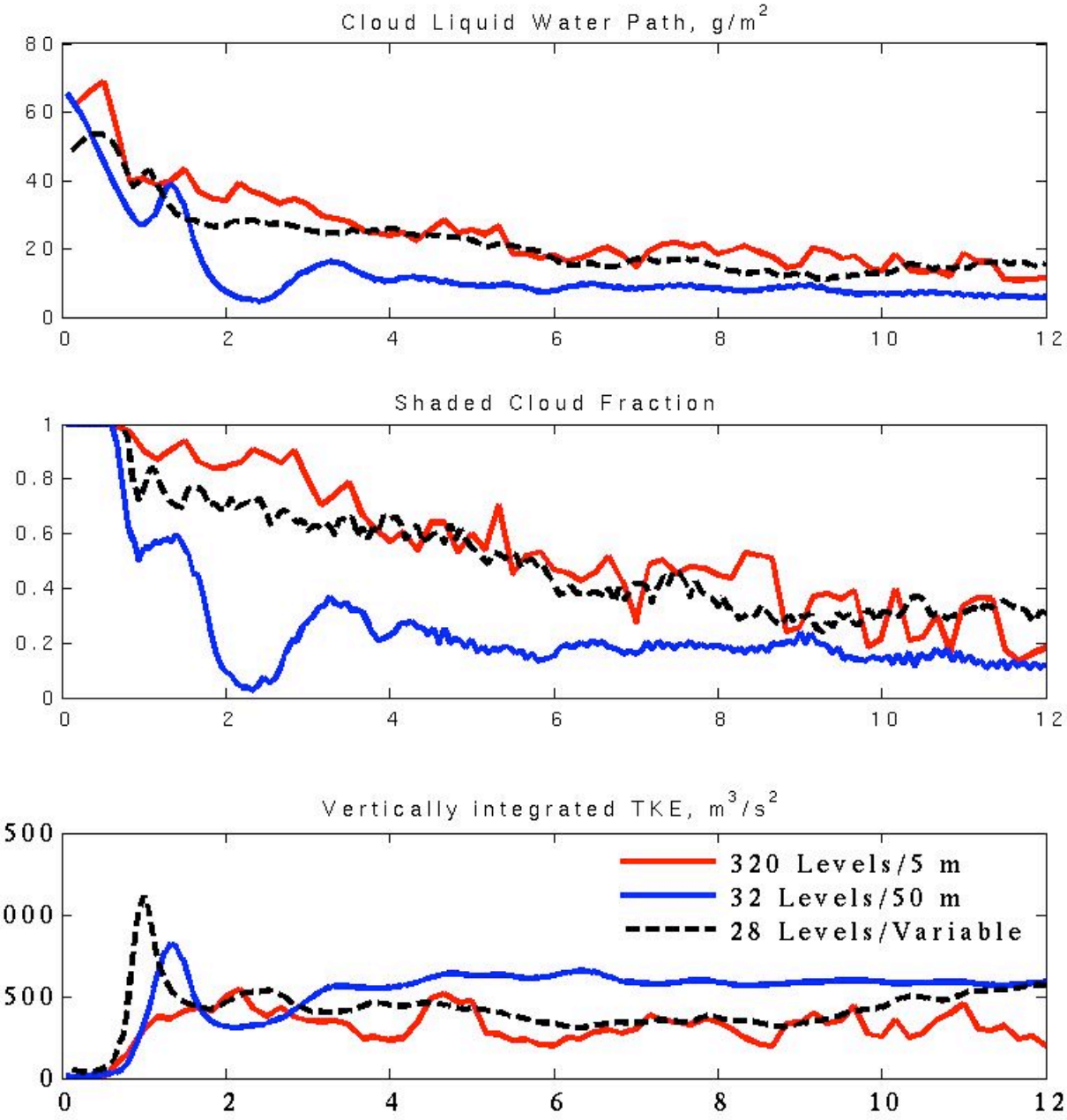
Testing and improving the CRM representation of boundary layer clouds



DYCOMS case

Simulation performed with SAM (CRM in the MMF)

Conclusion: **Can match the high vertical resolution results with fewer levels if we pick their location carefully**

(Marchand, PNNL)

LBA SHALLOW-to-DEEP CONVECTION TRANSITION, GCSS WG4 CASE 4 (Grabowski et al. 2006)

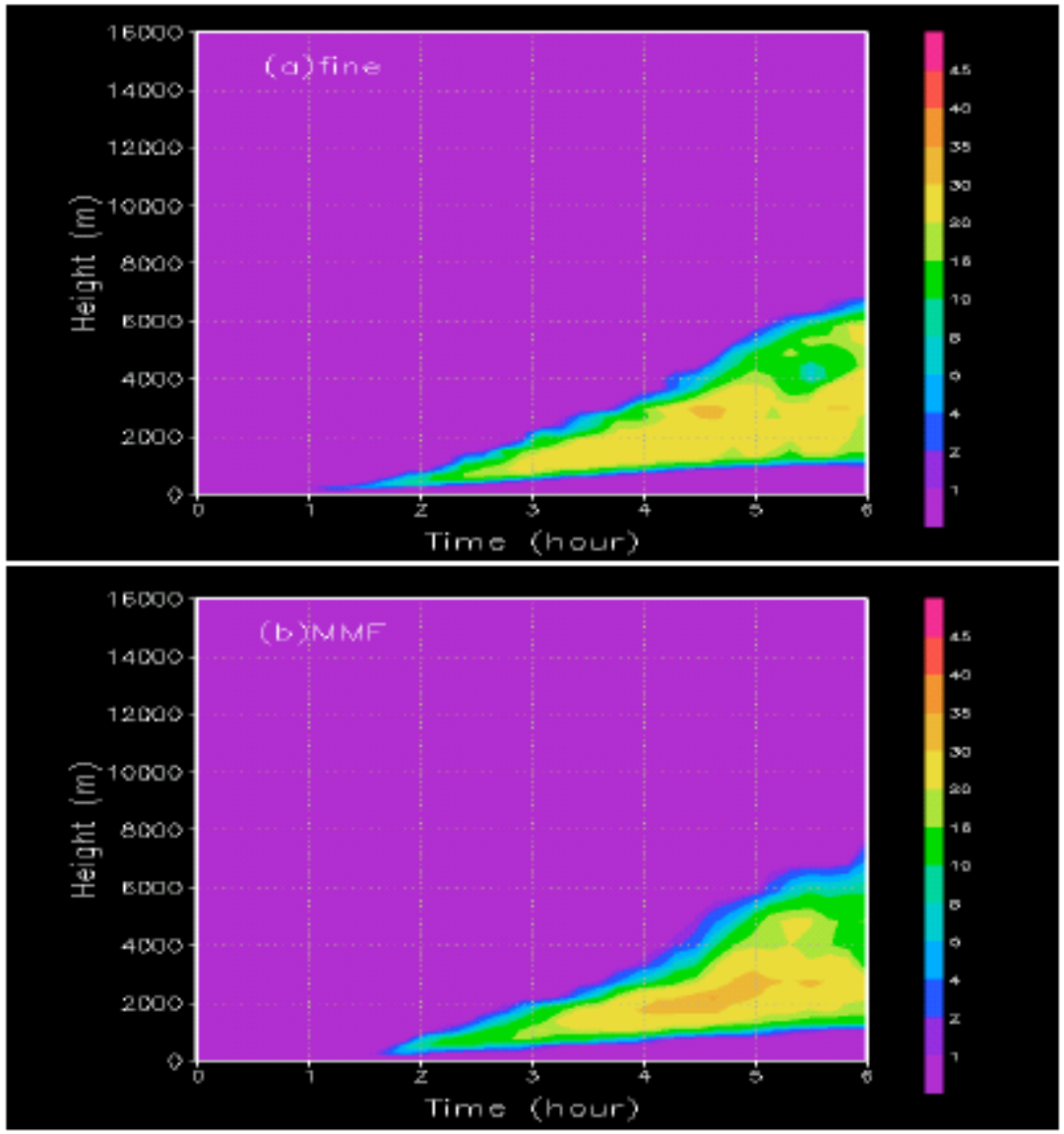


Fig. 5: Time series of cloud fraction for the LBA case of GCSS WG 4: (a) with twice the vertical resolution of the MMF, and (b) with the MMF resolution.

CRM uses third order turbulence closure

Runs are in 2D for 64 columns at 4 km resolution

Comparison of

- CRM run at MMF resolution

- CRM run at twice that resolution

(Cheng and Xu, LARC)

In conclusion …

- Evaluation projects are underway with DOE and PNNL support – in varying degrees of readiness
- Tool development is proceeding but takes time
- Model development just beginning – looking for more support from DOE
- Evaluation strategy and data sets will be applicable to any higher resolution global model (MMF, Quasi-3D, GCRM)
- Eager to collaborate with MMAP developments

Thanks for your attention!