PCMDI Process Research

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PCMDI Review Meeting

August 27-28, 2007

Outline

- Introduction
- Research Highlights
- Future Directions
- Final Remarks

Goal

- The goal of PCMDI Process research is the improvement of climate models.
- Two foci of this work are:
  - Improved simulation of clouds and radiation with implications for the magnitude of long-term climate change
  - Improved simulation of precipitation with implications for hydrology, land biology, and climate impacts

The Nature Of Our Activity

- Our activity is diagnostic:
  - we are not building new climate models
  - we aim to facilitate the improvement of climate models
- We assess climate models - and modified versions of them - with observations
- Our goal is diagnose the causes of model errors

Why do the errors exist?

What can be done to improve the simulations?

Our Modus Operandi

- We integrate climate models in ‘weather-forecast mode’. Why?
  - better connection to field program data
  - better identification of the source of errors in a model’s climate
  - better identification of the effects of improved parameterizations

Programmatic Considerations

- This activity is termed CAPT
- CAPT is jointly funded by the DOE CCPP and DOE Atmospheric Radiation Measurement (ARM) program
- CAPT is the “CCPP – ARM Parameterization Testbed”
- CAPT employs the CAM and GFDL climate models
- CAPT involves scientists at LLNL and NCAR

CAPT Technique

- We integrate for several days the climate model using numerical weather prediction analyses as the initial condition
  - We do not do data assimilation
- We perform a set of integrations starting at different times within a period of interest and examine the results from the same forecast range
- We assume that the analysis is close enough to the true atmospheric state that differences between the forecasts and observations can be ascribed to model errors and the physical parameterizations in particular

CAPT Service

- We test developmental versions of the CAM and GFDL climate models and report the results to the model development teams
- We provide a unique platform for parameterization developers to assess the impacts of their modifications to the climate model
- We provide access to climate model simulations for observationalists within the ARM program

Research Highlights

1. *Using the observations from the ARM Mixed-Phase Arctic Cloud Experiment (M-PACE) to assess climate models*
2. *Understanding a bias in summertime climate over North America in the GFDL climate model*
3. *Understanding the role of parameterizations in the simulation of tropical precipitation*

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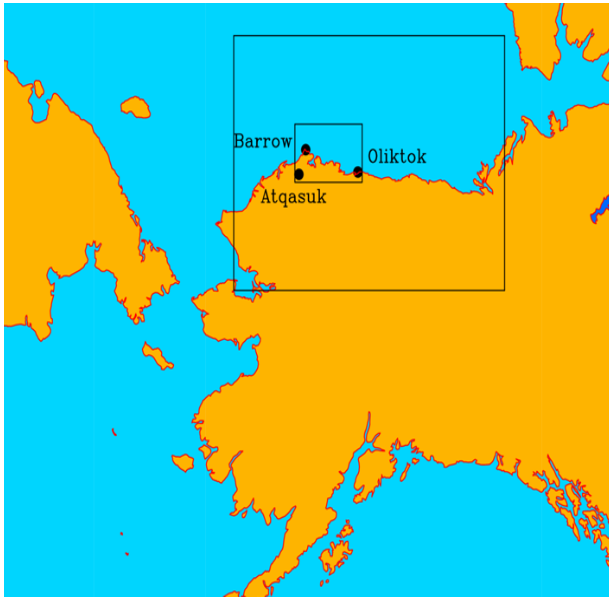
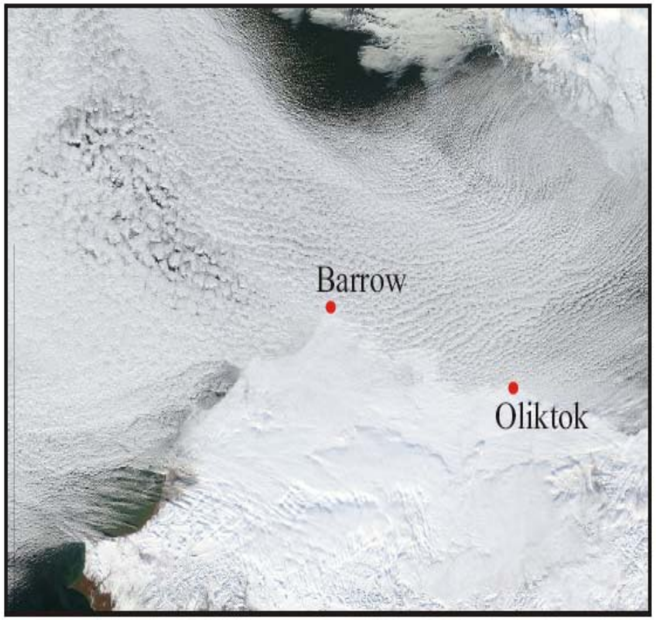
ARM M-PACE

- The ARM Mixed-Phase Arctic Cloud Experiment took place in Barrow, Alaska in October 2004.
- ARM took increased measurements (e.g. aircraft, radiosondes, stations) to observe the properties and physics of mixed-phase clouds

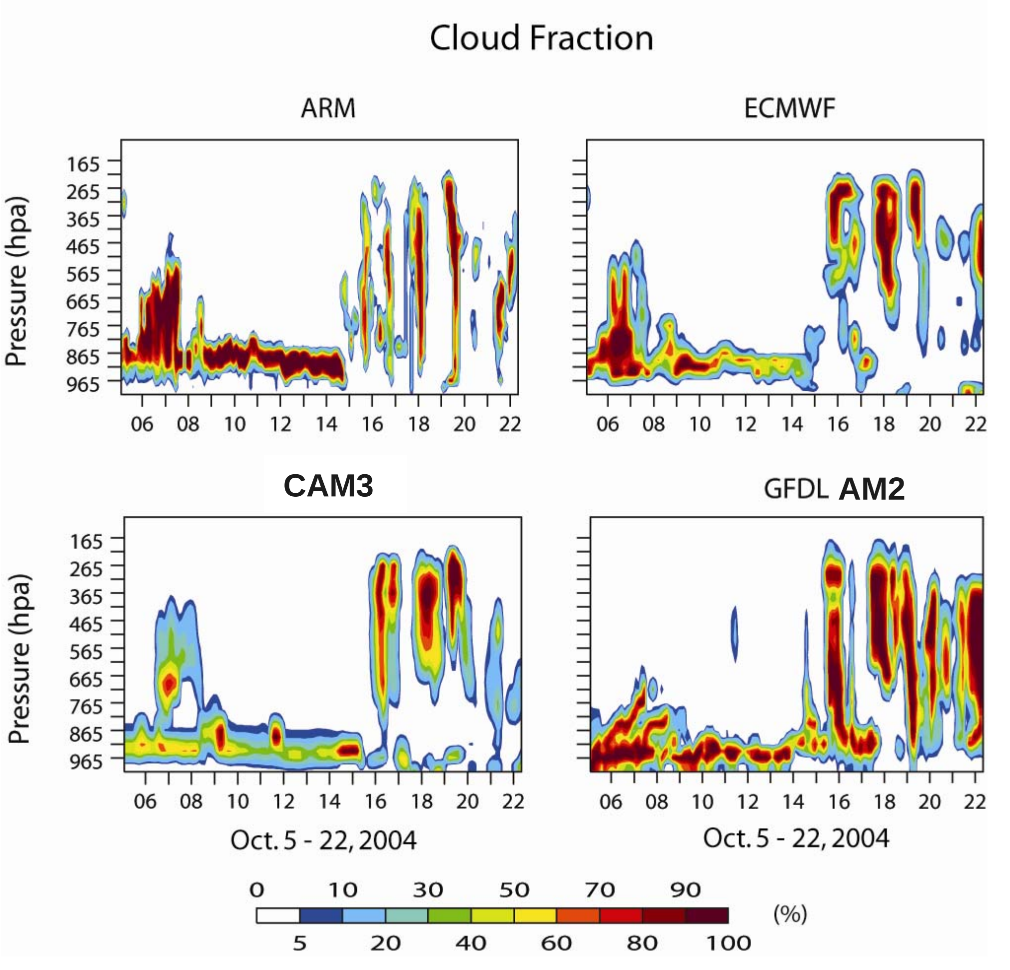




Composite Visible Satellite Image for October 9, 2004

Vertical Distribution Of Clouds

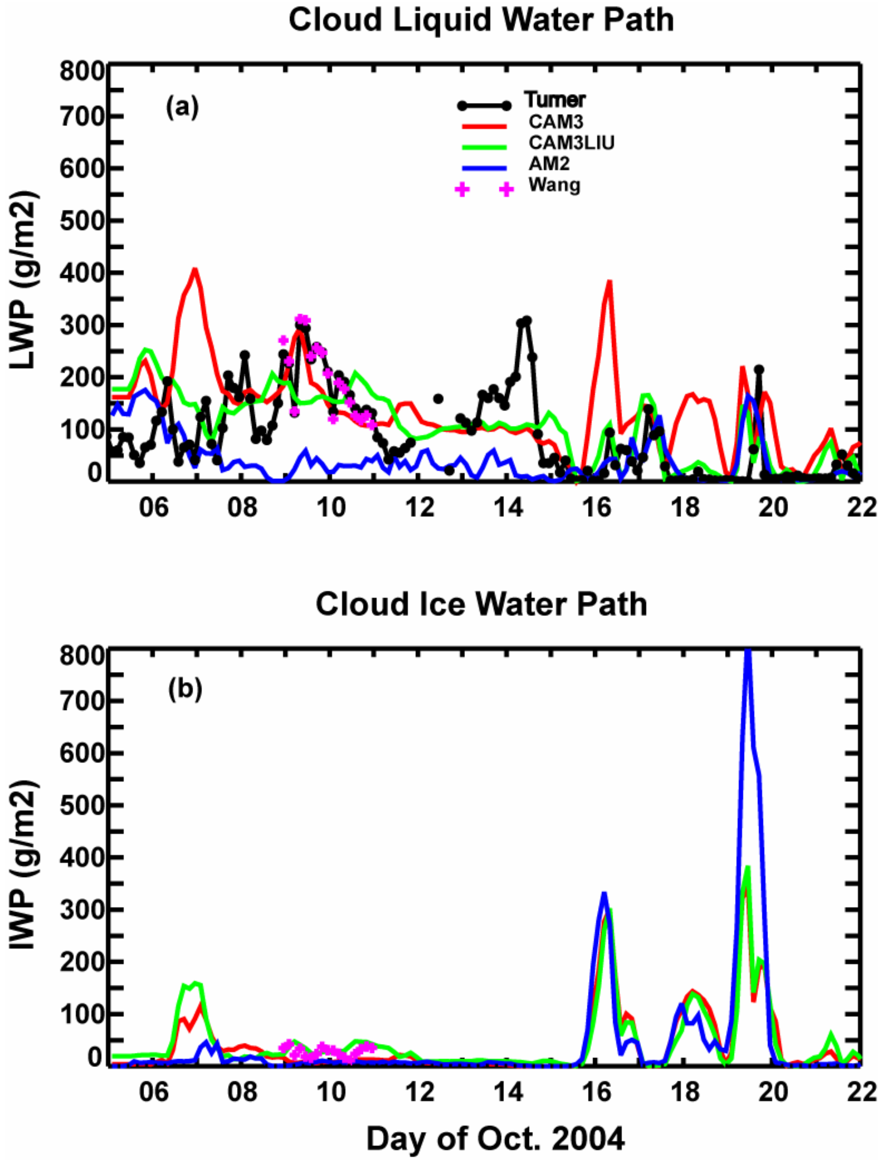
- From cloud radars and lidars, ARM deduces the vertical profile of clouds
- The weather-forecasting technique successfully provides a means for evaluating the parameterized clouds with field program data



The figures for the CAM3 and GFDL models display the forecasts for hours 12-36

Cloud Microphysics

- Cloud microphysics is a more difficult challenge
- A modified version of the CAM model ("CAM3Liu") which includes ice nucleation and predicts ice crystal number concentration reduces the incidence of excessive liquid water path during times of frontal clouds



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GFDL Summertime Bias

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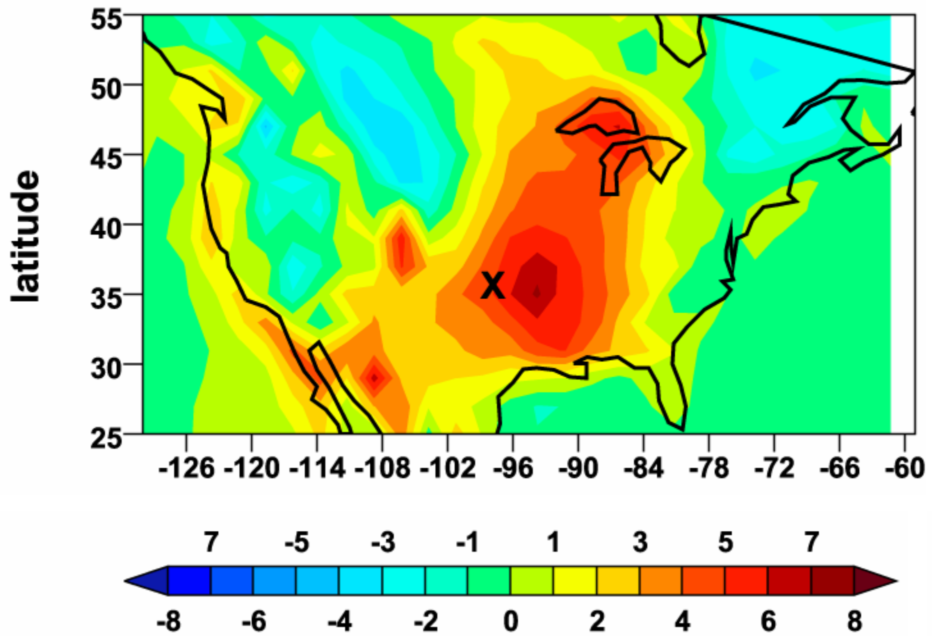
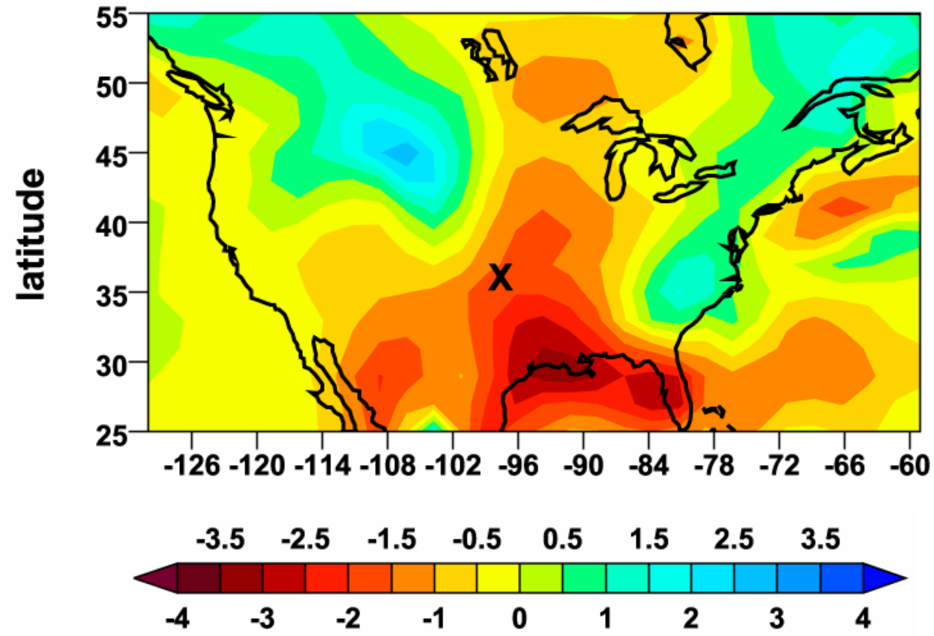
Climate 2m Temperature Bias



Climate Precipitation Bias



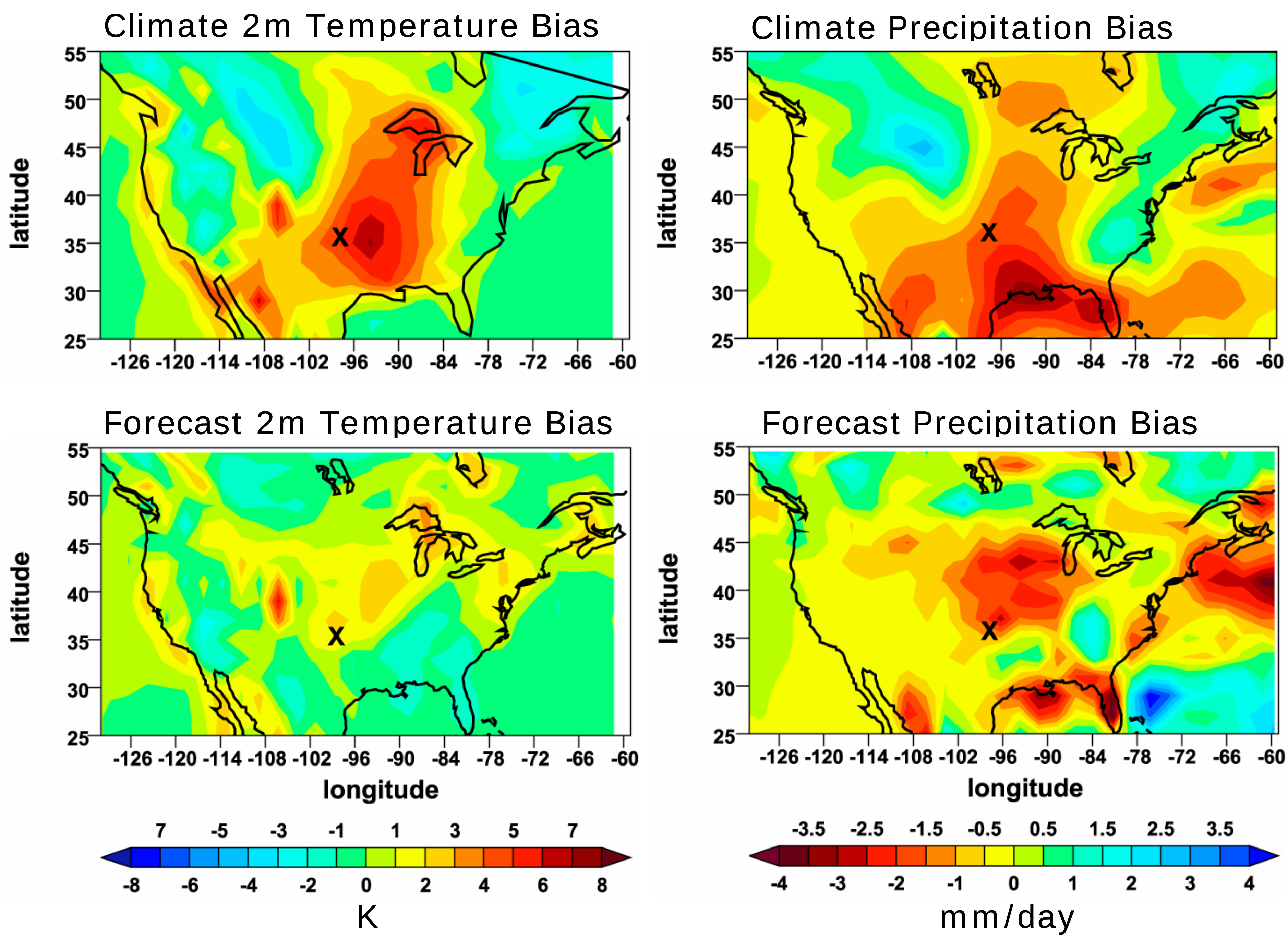
X *marks the location of the ARM Oklahoma site*

What Is The Cause Of This Bias?

- Deciphering the cause of this bias is difficult because there are strong land-atmosphere feedbacks in the summer season
- Is precipitation low because the soil is dry? Or is the soil dry because precipitation is low?
- The warm bias is a manifestation of the dry soil
- The GFDL model is known to have very strong land-atmosphere feedbacks (Dirmeyer et al. 2006)

Forecasting Methodology

- We can partially sort this out by prescribing the land-model initial conditions from a ‘stand-alone’ integration of the land-model driven with observations including those for precipitation
- The initial land model state will not have biases that are a function of the inability of the model atmosphere to produce precipitation
- Forecasts were performed for everyday in the period June-July 1997 when ARM had an intensive observing period at its Oklahoma site


Climate 2m Temperature Bias
Climate Precipitation Bias
Forecast 2m Temperature Bias
Forecast Precipitation Bias
latitude
longitude
55
50
45
40
35
30
25
-126 -120 -114 -108 -102 -96 -90 -84 -78 -72 -66 -60
X
7 -5 -3 -1 1 3 5 7
-8 -6 -4 -2 0 2 4 6 8
K
-3.5 -2.5 -1.5 -0.5 0.5 1.5 2.5 3.5
-4 -3 -2 -1 0 1 2 3 4
mm/day

Results At The ARM Site

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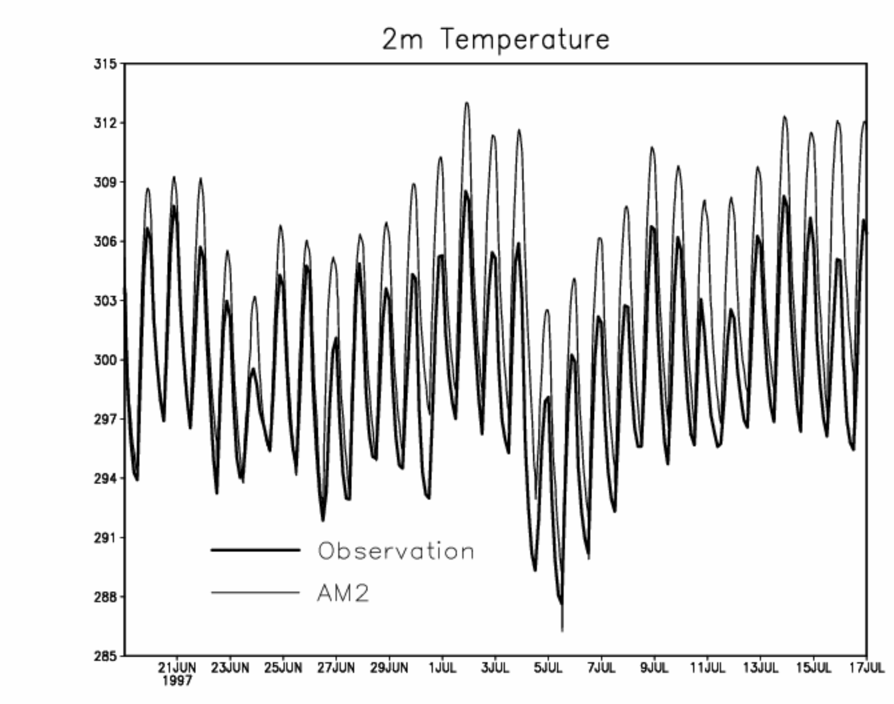
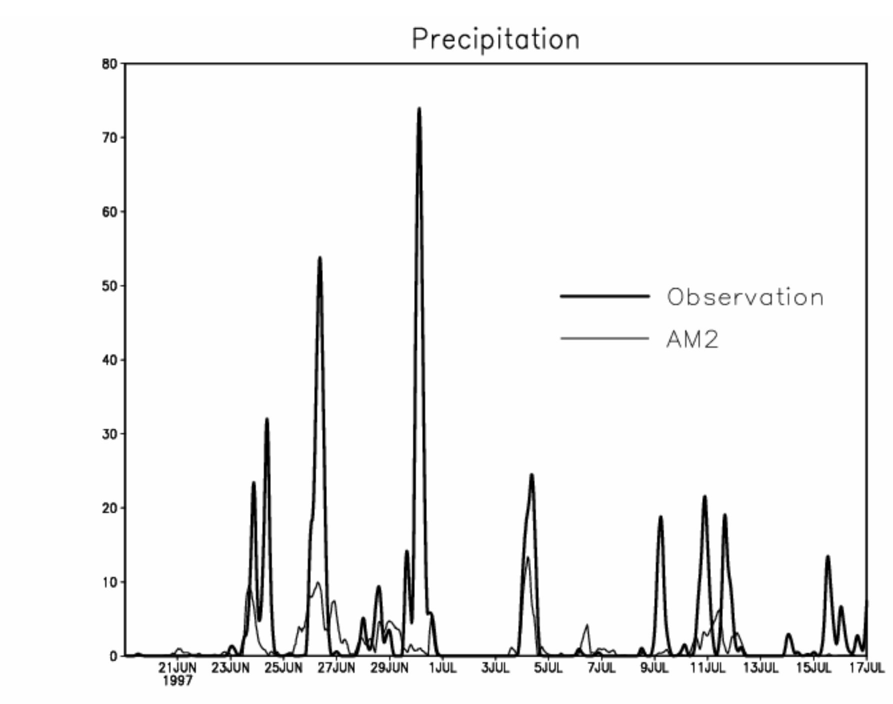
- The 12-36 hour forecast has a warm and dry bias – but the magnitude of the warm bias is only 50% of the climate bias





What Insight Is Gained?

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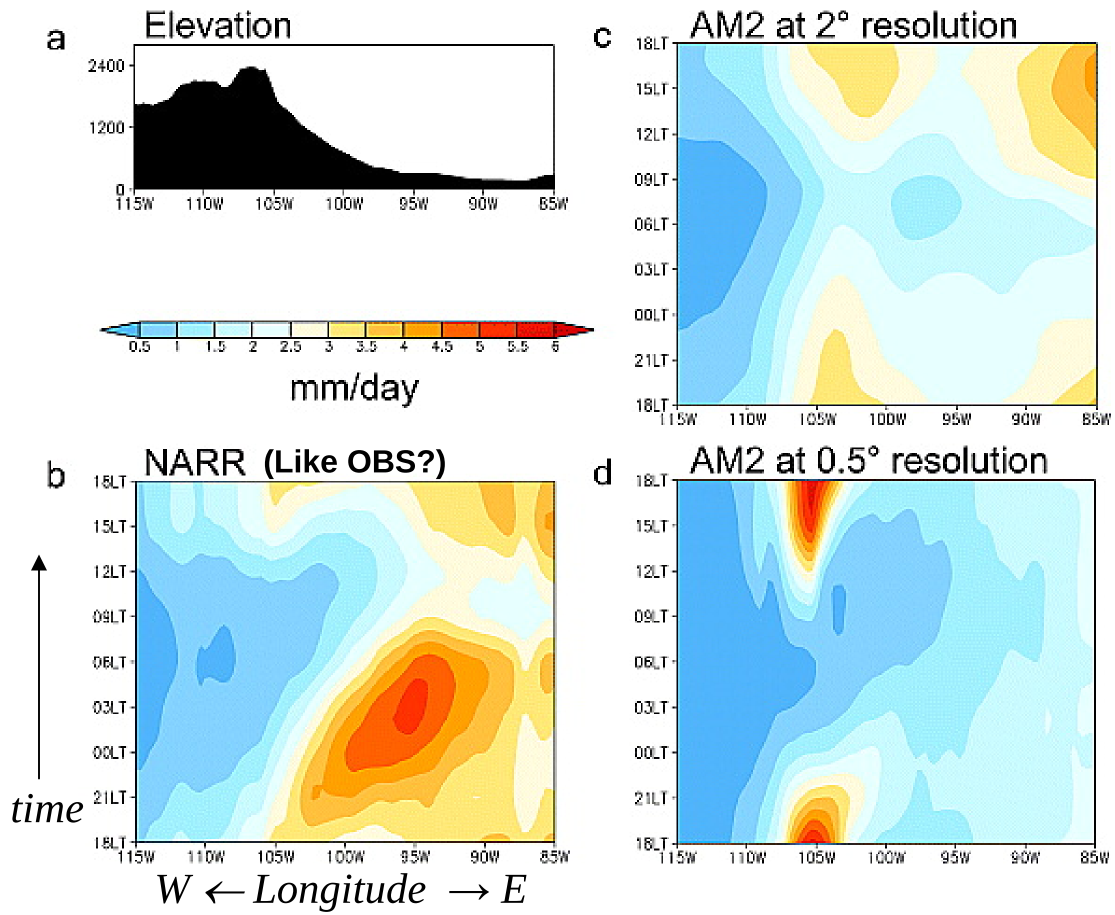
- At the ARM site, the model fails to simulate enough precipitation: 1.3 vs. 4.0 mm day^{-1}
- The model does simulate a reasonable amount of evaporation: 3.5 vs. 4.0 mm day^{-1}
- As a result, the soil dries out with longer forecast times (e.g. due to the several week time scale of soil moisture) which leads to lower evaporation, warmer temperatures, and even less precipitation
- *Thus the precipitation underestimate is largely present even when there is enough soil moisture*

What Insight Is Gained?

- Unless you increase the precipitation, there is not much hope for realistically eliminating the temperature bias in the model
- However, a model with a weaker land-atmosphere feedback strength might have a smaller warm bias
- What is the nature of summertime precipitation in the Central U. S.?
- Much of the precipitation is nocturnal occurring in events of propagating mesoscale convection that are initiated near sunset in the Rockies

Precipitation Diurnal Cycle

- The GFDL model can initiate convection at sunset in the Rockies but it does not propagate even at 0.5º resolution



NARR is the North American Regional Reanalysis

Research Highlights

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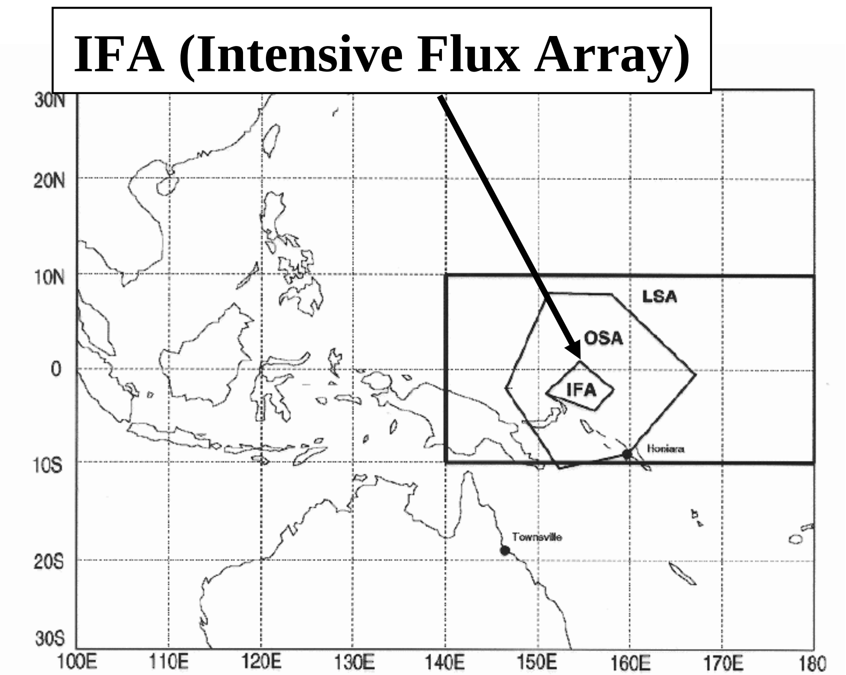
Tropical Precipitation Is A Problem

- Tropical variability is poorly simulated in atmospheric models (Lin et al. 2006)
- The Madden-Julian Oscillation (MJO) in model simulations is generally weak and propagates too fast
- How can a weather forecasting approach be helpful?
- If you initialize a climate model with analysis data in different phases of the MJO, how does the modeled precipitation behave?
- We have performed forecasts for the period of the TOGA-COARE field experiment

TOGA-COARE

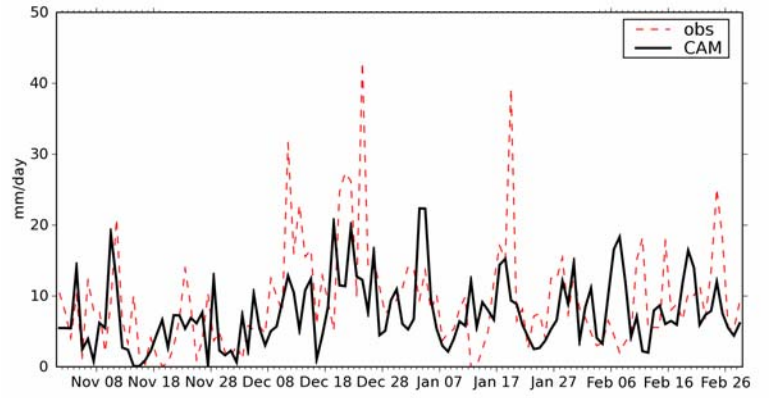
- The Tropical Ocean Global Atmosphere – Coupled Ocean Atmosphere Response Experiment was a large field campaign performed in the tropical western Pacific between November 1992 and February 1993



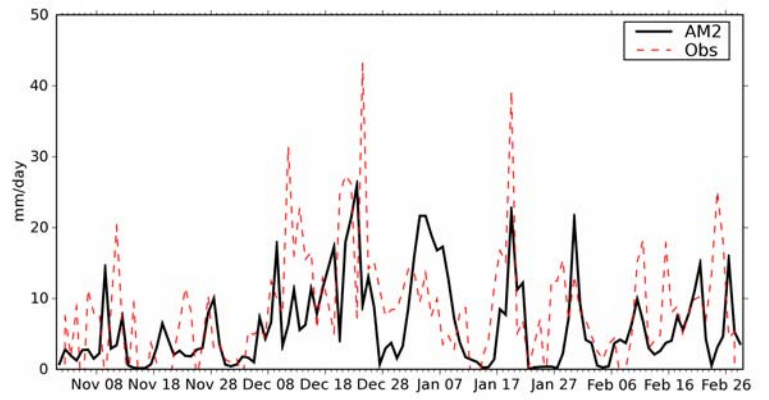
IFA Precipitation

- Daily mean precipitation is from forecast day 3
- The modification by Guang Zhang (UCSD) replaces the CAPE closure with a closure tied to the rate at which the large-scale circulation destabilizes the free troposphere. The modification also adds a trigger using relative humidity in the boundary layer

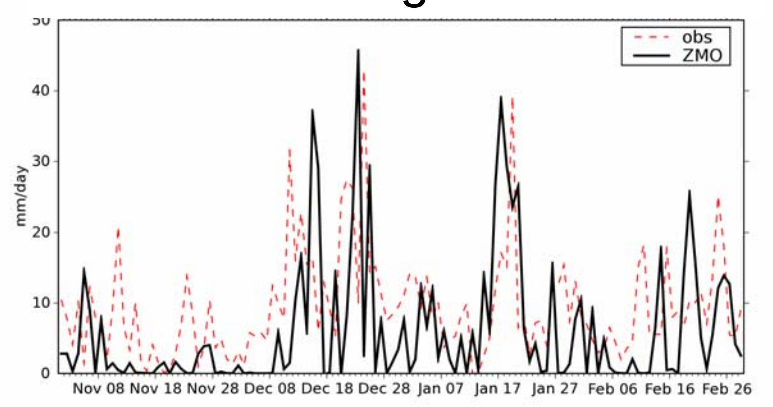
CAM3



GFDL AM2

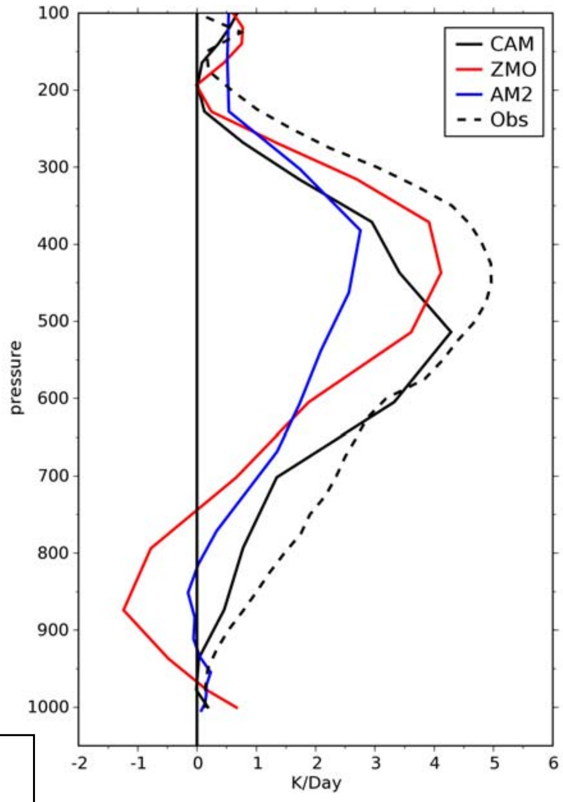


CAM3 w/Zhang Modification

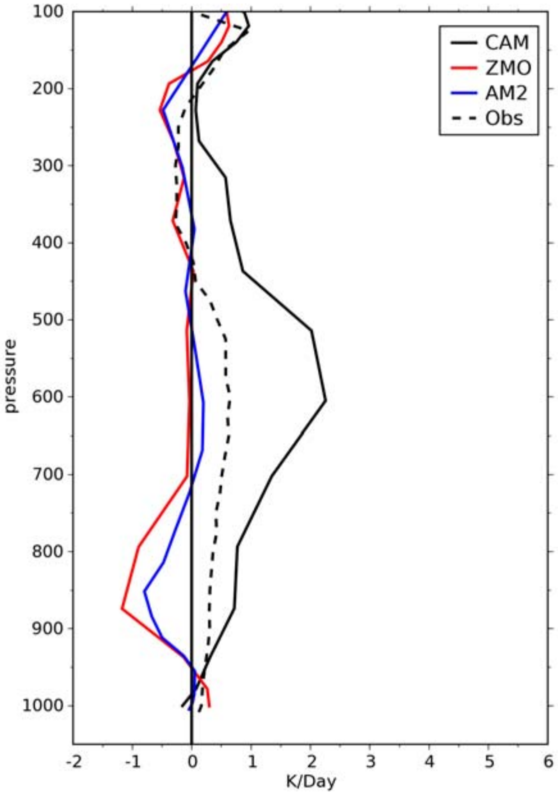


Do Models Respond Correctly?

Q1 on days observed to have precipitation



Q1 on days observed to have no precipitation



Q1 = diabatic heating

ZMO = Zhang MOdification

Precipitation Beyond The IFA

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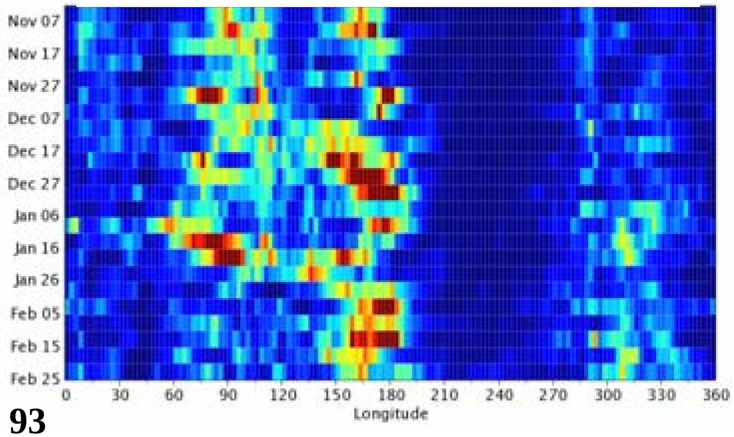
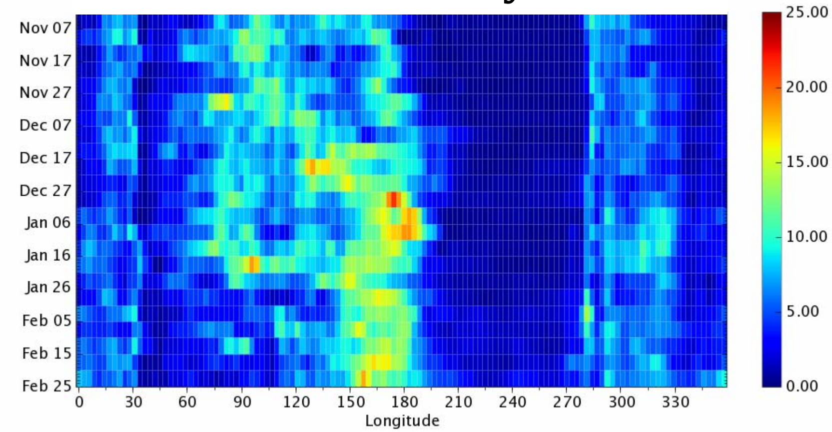
Nov. 92

Satellite observations

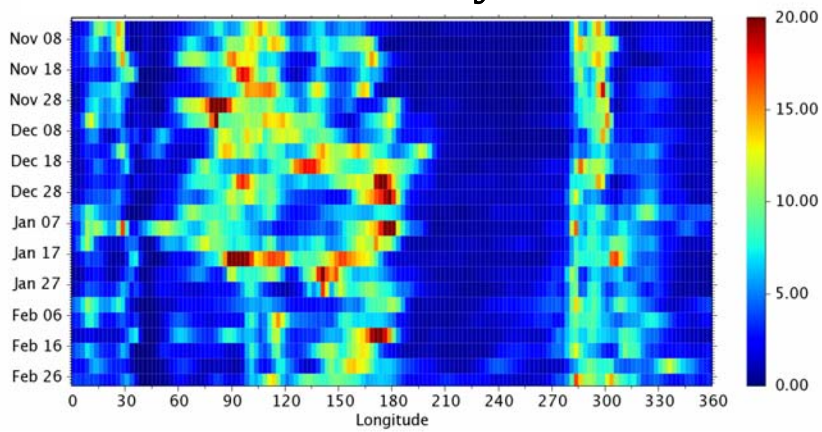


Feb. 93

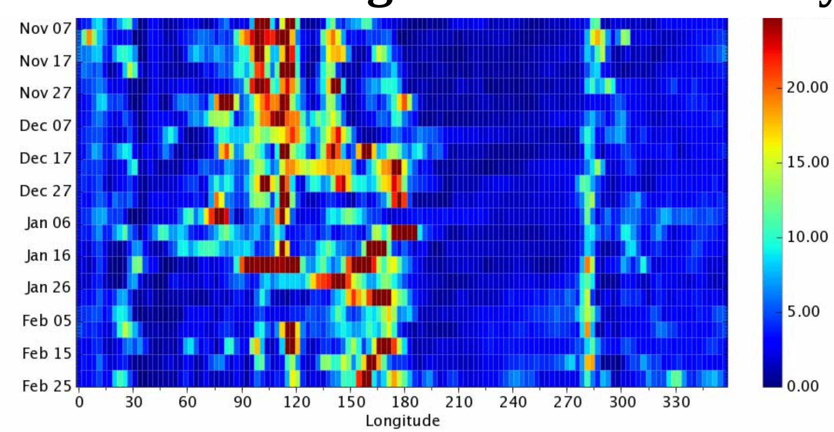
CAM3 – Day 3



AM2 – Day 3



CAM3 with Zhang Modification – Day 3



Precipitation averaged over 5-day intervals and averaged from 5N to 5S

What Does This Tell You?

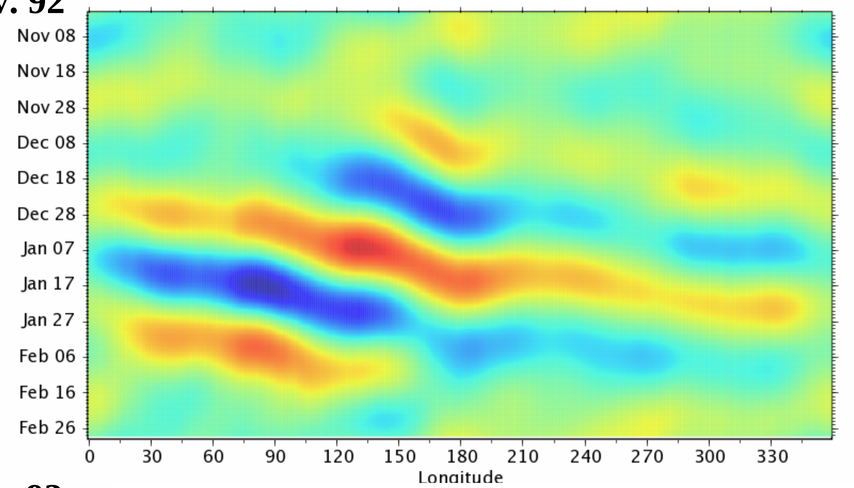
- If a model fails to respond correctly to the observed atmospheric state, why should we expect a good simulation of tropical variability in a free running climate integration?
- The relative amount of tropical variability (e.g. intraseasonal activity) in climate integrations of the three models can be predicted from this ensemble of 3 day forecasts

Circulation Anomalies

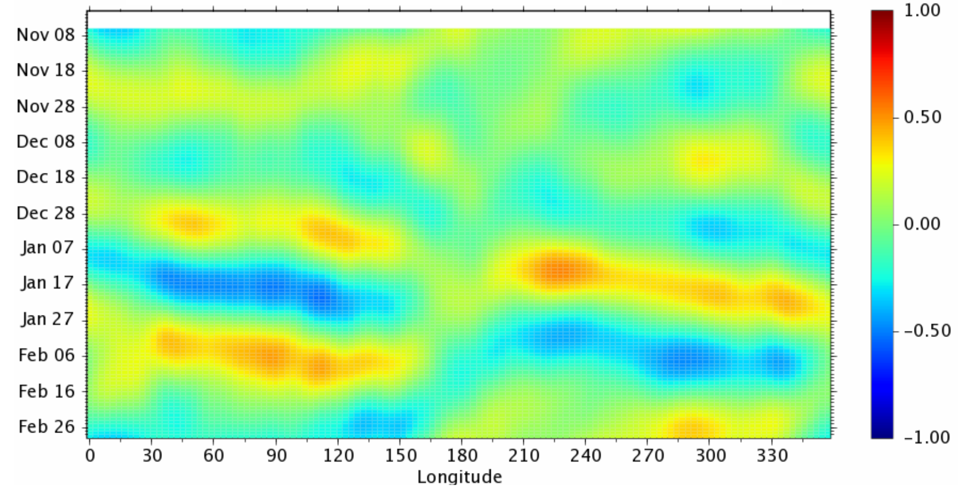
Nov. 92

Feb. 93

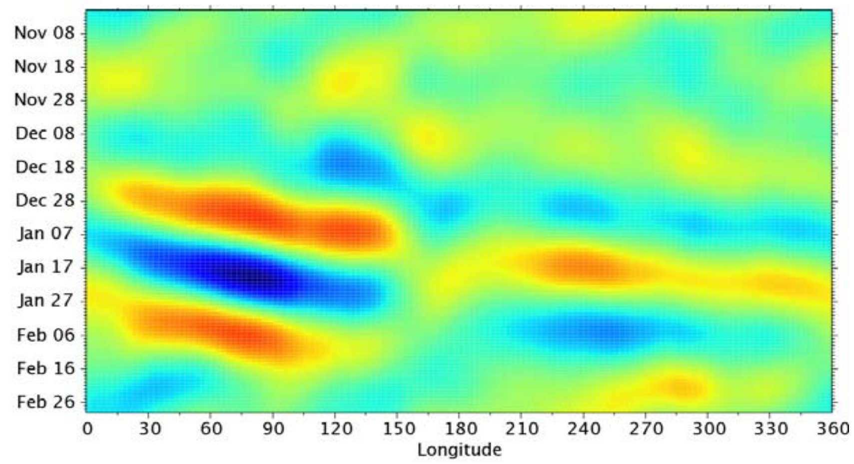
ERA 40



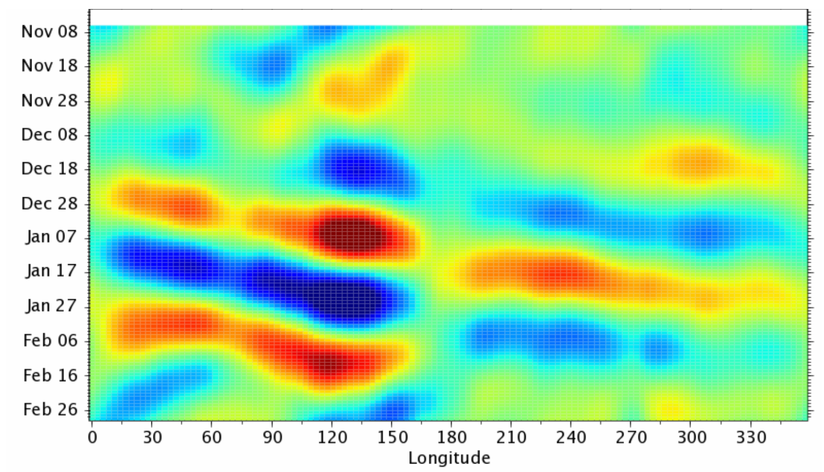
CAM3 – Day 6



AM2 – Day 6



CAM3 with Zhang Modification – Day 6



200 hPa Velocity Potential averaged from 5N to 5S and band-passed filter to 30-70 days

Climate Versus Forecast Errors

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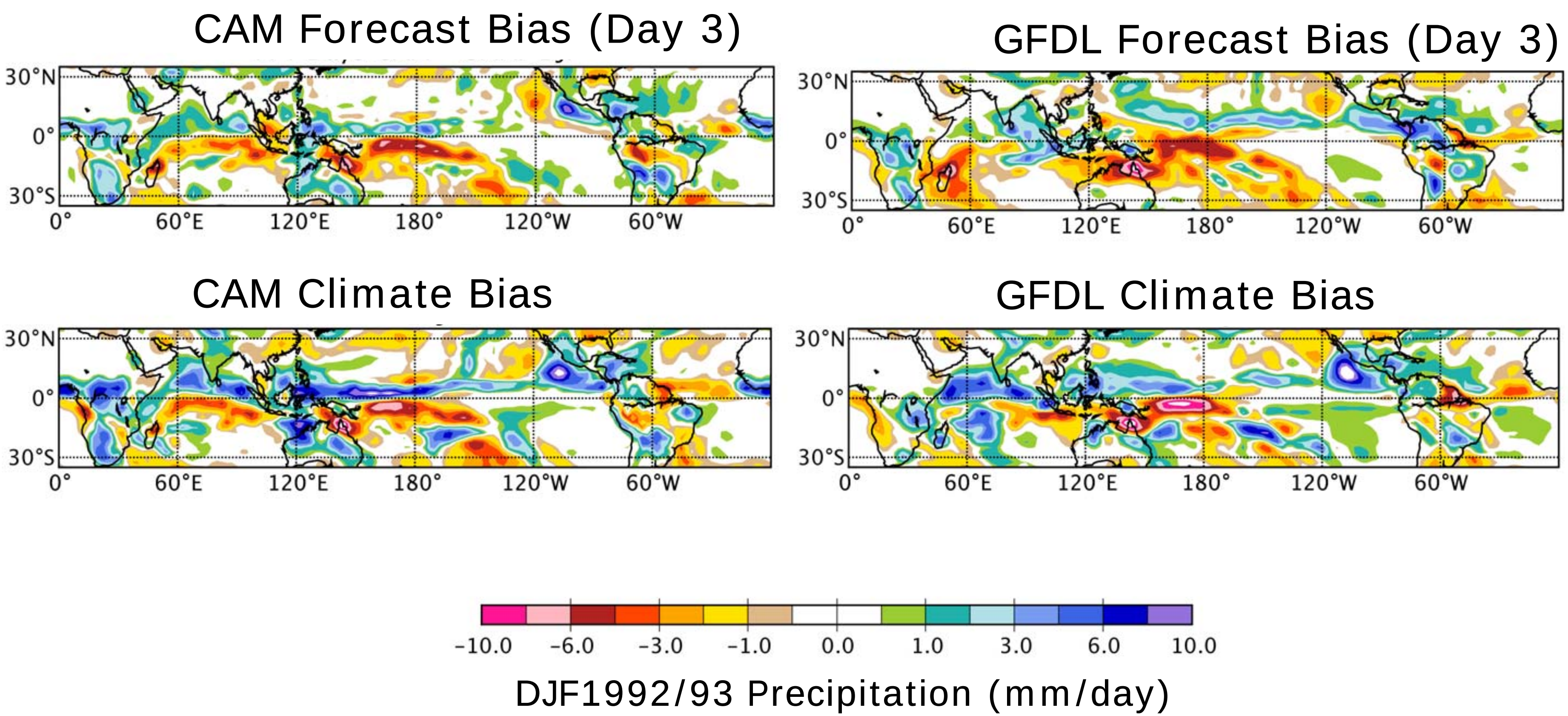


Future Directions

- Continuity
- Explorations
- Using CloudSat and Calipso
- Using Models That Resolve Clouds

Continuity

- We will continue to simulate ARM field campaigns with a focus on the simulation of clouds and precipitation
- We will continue to test new parameterizations developed by others

Explorations

- We will explore the sensitivity of simulations to model resolution (more routinely)
- We will explore the value of ensemble forecasting
- We will explore the utility of the weather forecast mode to assess aerosol indirect effects

CloudSat and Calipso

Program for Climate Model Diagnosis and Intercomparison

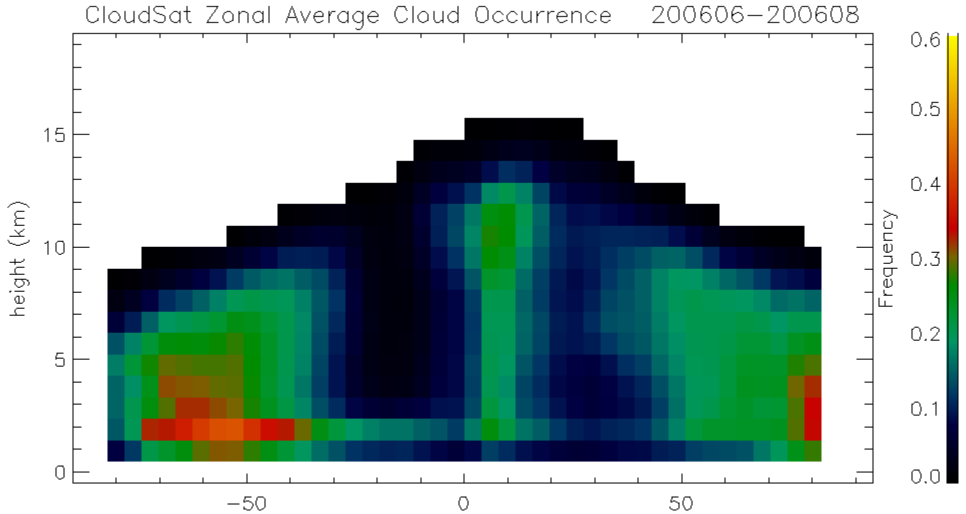
- The launching in 2006 of the NASA satellites CloudSat and Calipso provided the first global view of the vertical structure of clouds and precipitation
- Through NASA funding, we have hired a post-doctoral student, Yuying Zhang, to help us analyze the new observations and compare to climate models

CloudSat and Calipso

- She has analyzed the different modes of tropical cloud variability as they are contained in CloudSat data (Zhang et al. 2007). She has identified the prominent modes of tropical cloudiness including thick low cloud, thin low cloud and cirrus, anvil cirrus, deep convection, and cumulus congestus.
- Through international collaborations, she is constructing simulators for CloudSat and Calipso, which in the spirit of the ISCCP simulator, will facilitate the use of this new data by the climate modeling community

Cloud Fraction: CloudSat vs. GFDL

Altitude

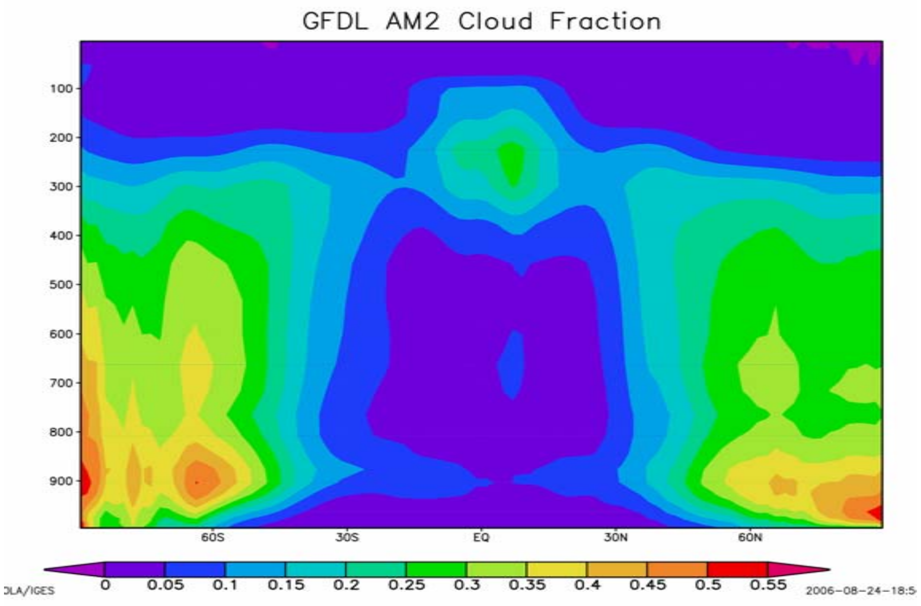


Latitude

CloudSat Only (June-August 2006)

figure courtesy of Jay Mace

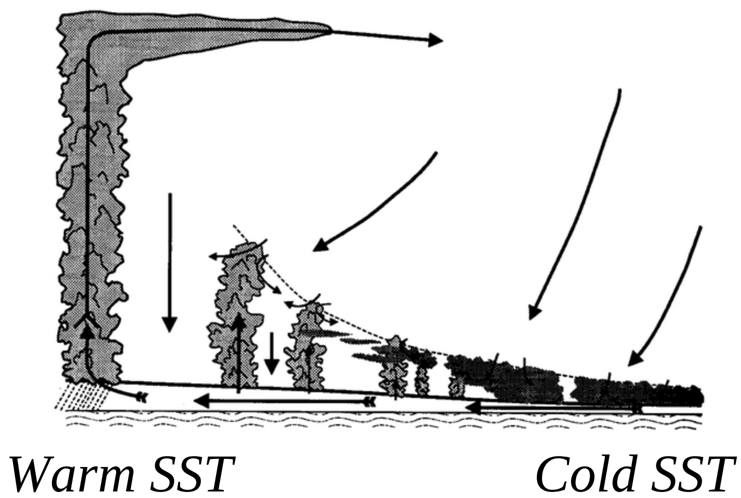
Pressure



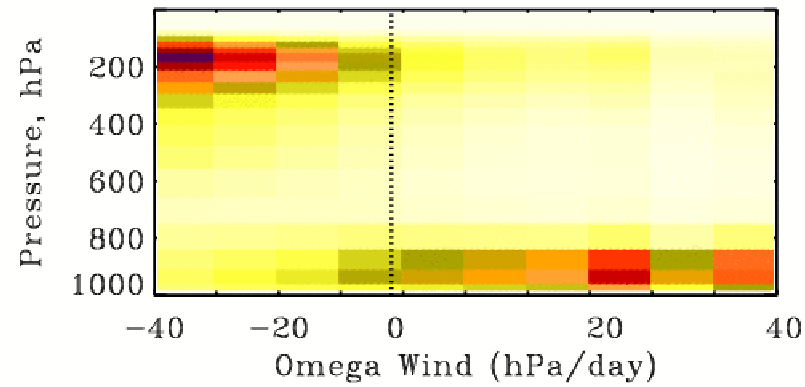
GFDL AM2 (June-August Climatology)

Stephen A.

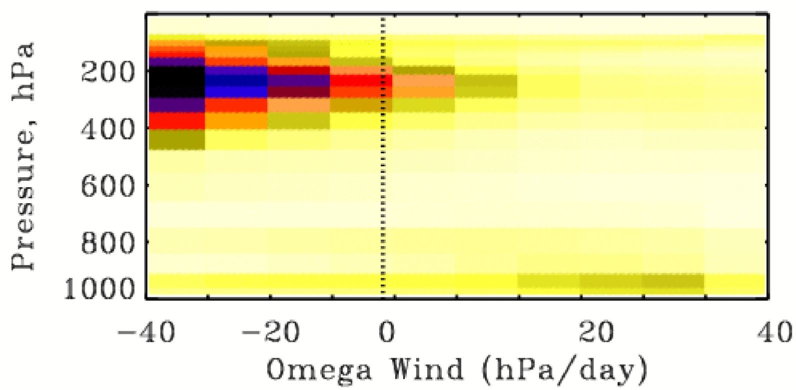
Bony Diagrams



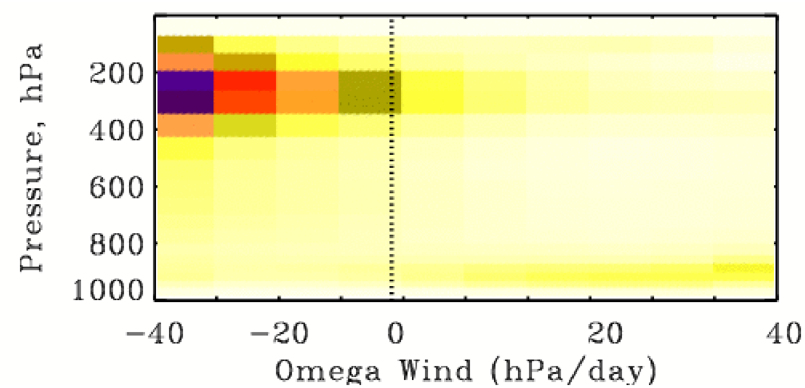
CloudSat + Calipso



CAM2



GFDL



Using Models That Resolve Clouds

- Climate model resolution is generally increasing, but for the foreseeable future resolutions will not be finer than 50 km
- However, two global models have recently been created which “resolve” clouds
  - Global cloud resolving model of the Earth Simulator (~4 km)
  - Multi-scaling Model Framework (MMF or “Super-parameterization”, Randall et al. 2003) which embeds a cloud resolving model into each grid-box of a global circulation model

Using Models That Resolve Clouds

- While these models may be prototypes for future generations, they will have a limited impact in the near term on the climate change community
- We view these models as a potential source of information that may influence the future development of parameterizations in the lower-resolution climate models

Strengths Of MMF

- The MMF has been ‘trumpeted’ as more successful than conventional climate models in simulating
  - The diurnal cycle of precipitation over land
  - The Madden-Julian Oscillation

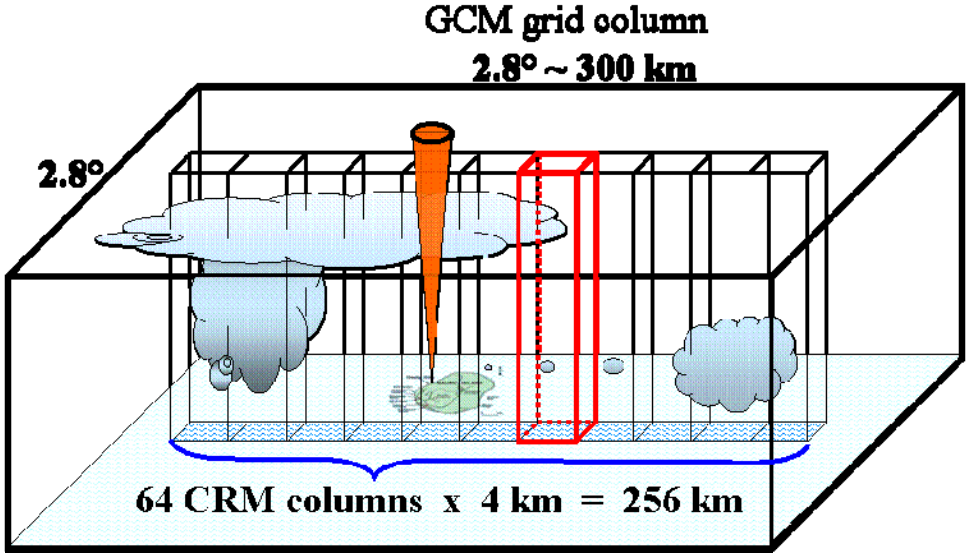


Illustration of a single grid box in the MMF model. Each grid box contains a two dimensional cloud resolving model with 64 columns of 4 km horizontal resolution. The cloud resolving model calculates the processes that are represented by parameterizations in a conventional climate model.

Initial Analysis Of MMF

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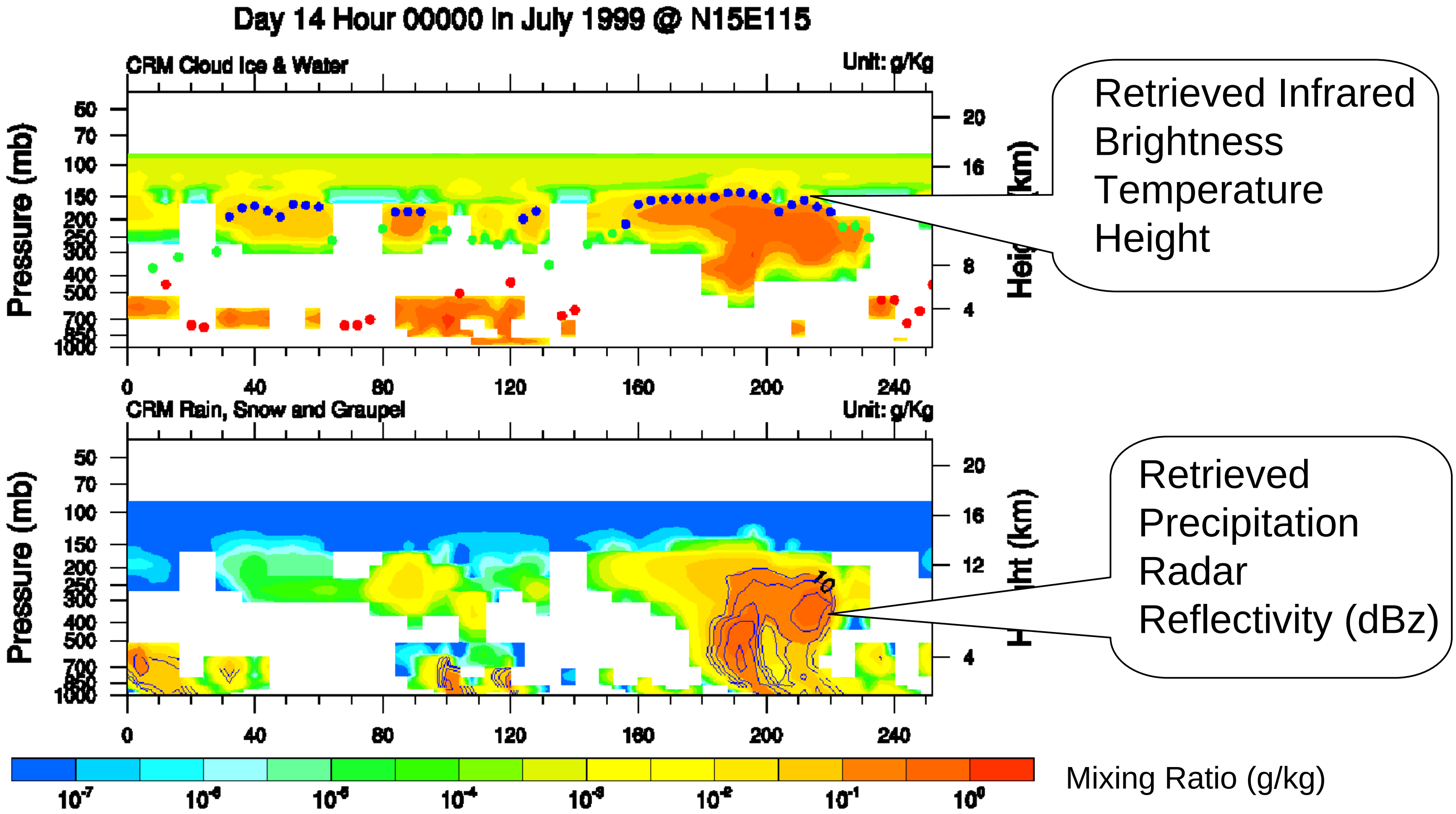
- Through ARM funding, we have hired a post-doctoral student, Yunyan Zhang, to examine the diurnal cycle of precipitation in MMF
- The diurnal cycle has been studied with global satellite data through infrared brightness temperatures (Tian et al. 2004) and precipitation radar reflectivity (TRMM, Nesbitt and Zipser 2003)
- She has applied simulators for the infrared brightness temperature and the TRMM precipitation radar reflectivity to the cloud model data to compare with the satellite data

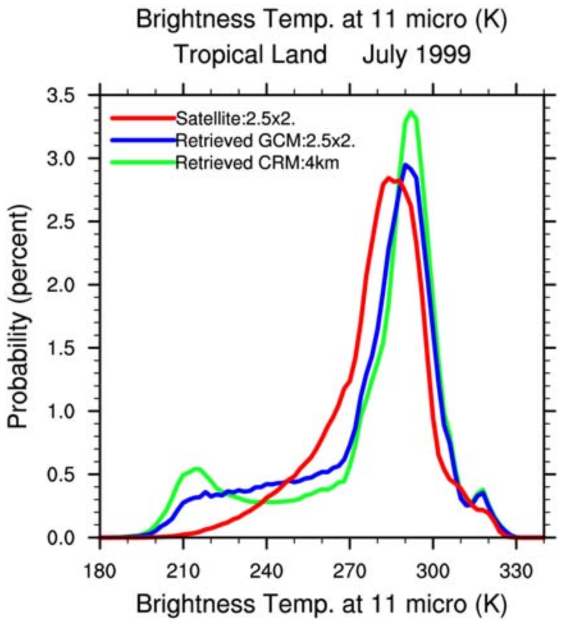
Simulator Illustration

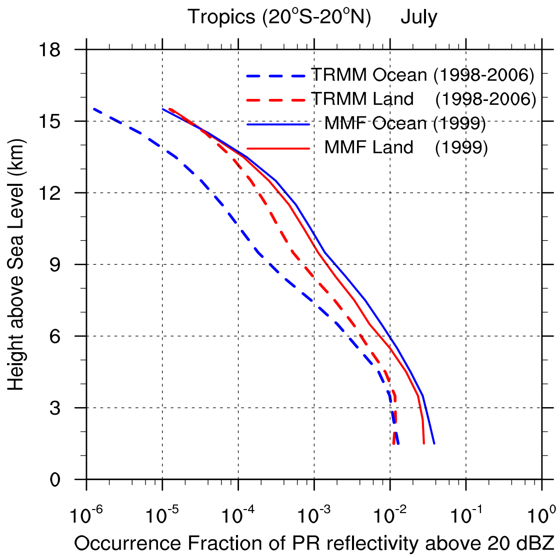


The figure illustrates a 'snapshot' of the cloud (upper panel) and precipitation (lower panel) condensate fields (color shading) from a single embedded cloud resolving model. Also shown are the height of the simulated infrared brightness temperature (dots) and radar reflectivity (contours).

Initial Results Indicate Problems

- MMF has too many high clouds and too few midlevel clouds
- MMF has precipitation too often with no contrast between land and ocean
- Corresponding diurnal cycles based on these simulated measures show poor agreement with observations





Further MJO Research

- How may MMF be useful for understanding the necessary ingredients for a good MJO?
- We will explore integrating MMF in ‘weather-forecast’ mode
  - Marat Khairoutdinov has shown credible simulations with nudging
  - We have set up the MMF at LLNL
- We will run side-by-side experiments with the MMF and the CAM/AM
- We will apply MJO CLIVAR forecast diagnostics to the simulations

Final Remarks

- We have a robust diagnostic activity at PCMDI oriented to improving the simulation of clouds and precipitation in climate models
- Weather forecasting:
  - facilitates the use of field campaign data
  - indicates the manner in which errors develop
  - demonstrates the impact of the parameterization improvements more cleanly
- Our activity is an essential piece of the model development/improvement process. However, the diagnostics are generally not prescriptive

Questions?

For Further Reading See:

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For Further Reading See:

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