What does weather-forecasting offer climate models?

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Outline

- Introduction
- Three Examples
- Conclusions
- Future Work

Clouds: An Enduring Problem

- A long-standing problem for climate models is the representation of clouds and precipitation
- Over many years, physical parameterizations have been improved but problems remain
- Diagnostic techniques have improved a lot
  - It's a lot more refined by than changing a parameter and running a climate simulation to see how the model's climate has changed
  - Single-column modeling has been extensively used by the GEWEX Cloud Systems Study group among others

Why Do ‘Weather Forecasts’?

- 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 Climate Change Prediction Program (CCPP) and Atmospheric Radiation Measurement (ARM) program
- CAPT is the “CCPP – ARM Parameterization Testbed”

CCPP + ARM = CAPT 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

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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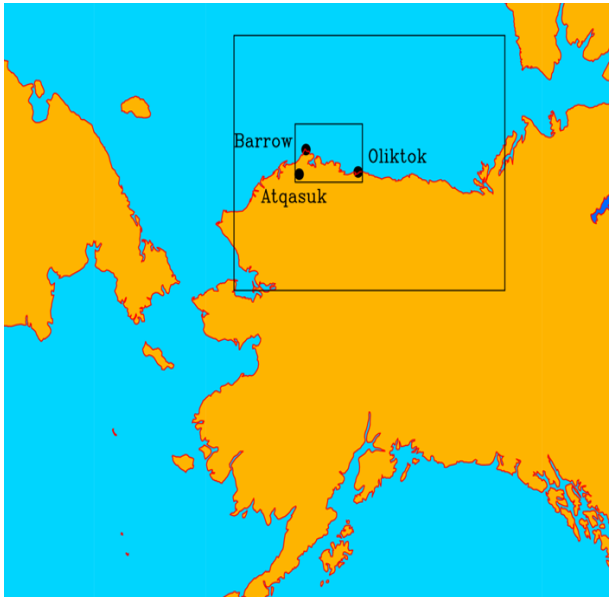
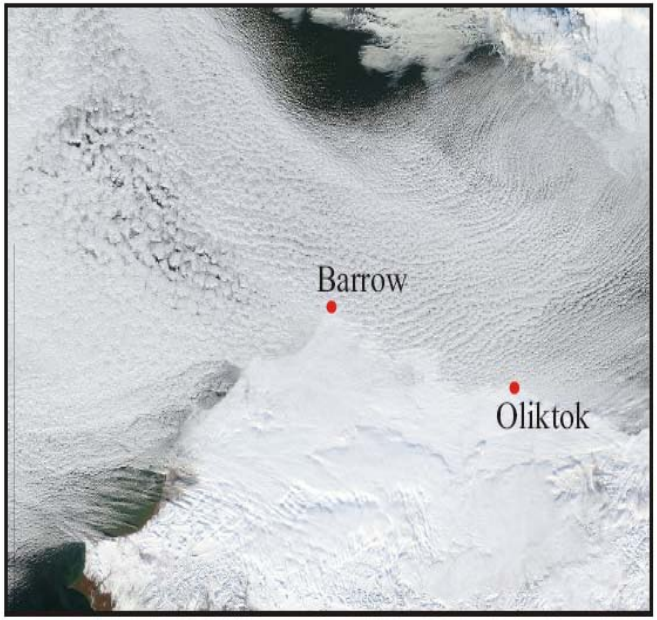
ARM M-PACE

- 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

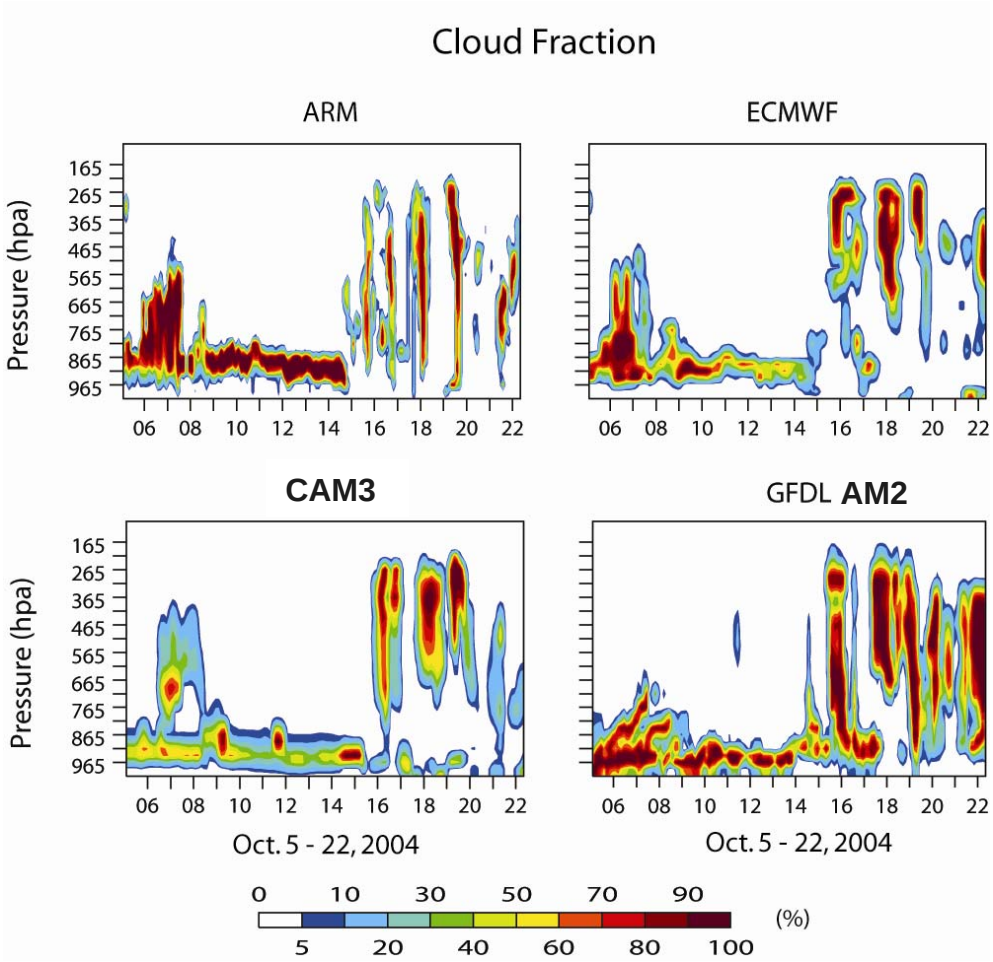




Composite Visible Satellite Image for October 9, 2004

Vertical Distribution Of Clouds

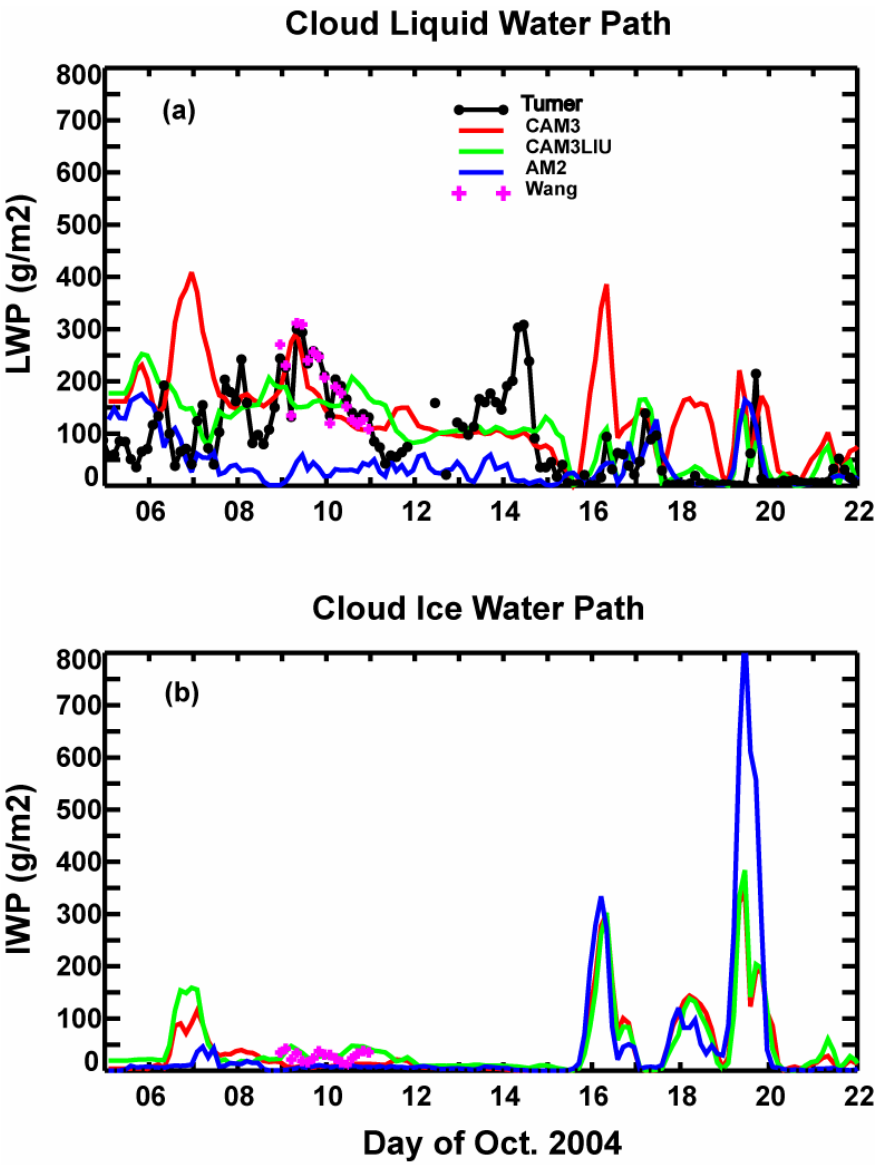
- From cloud radars and lidars, ARM deduces the vertical profile of clouds
- The weather-forecasting technique successfully provides a means for evaluating the parameterized clouds with field program data



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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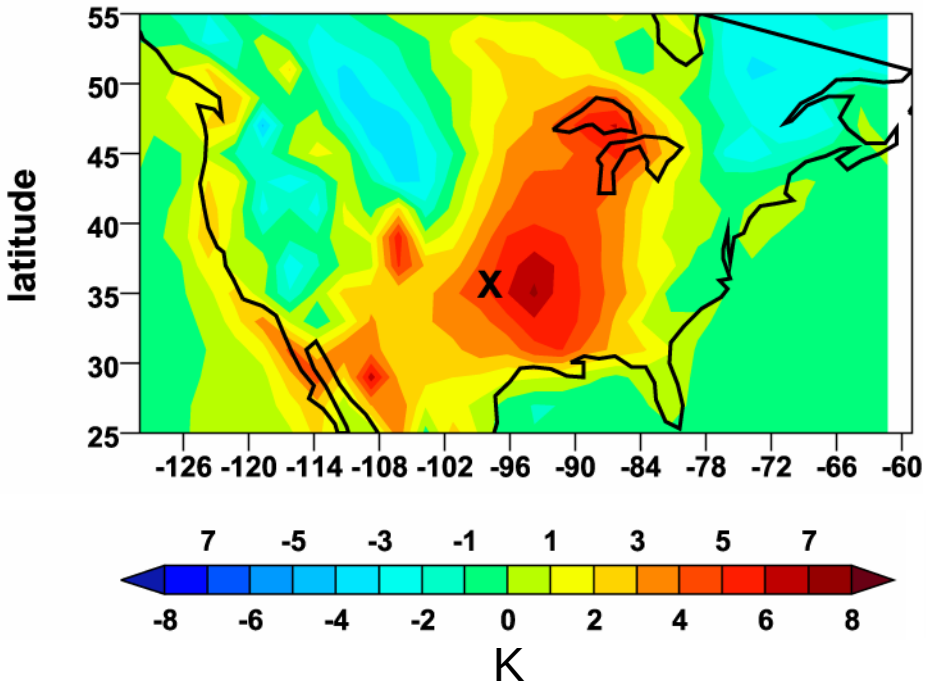
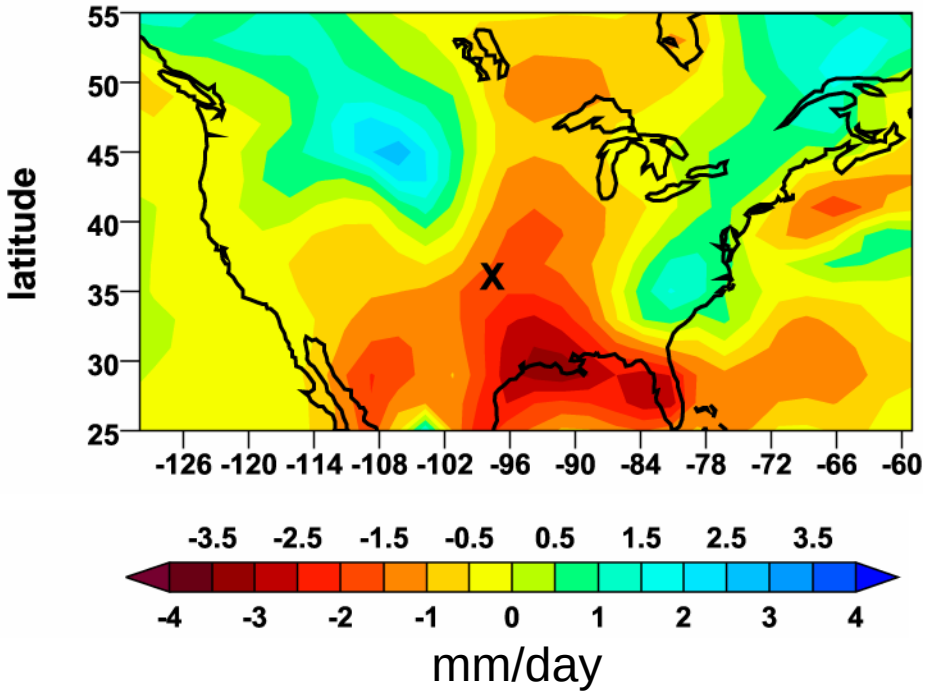
GFDL Summertime Bias

Climate 2m Temperature Bias



Climate Precipitation Bias



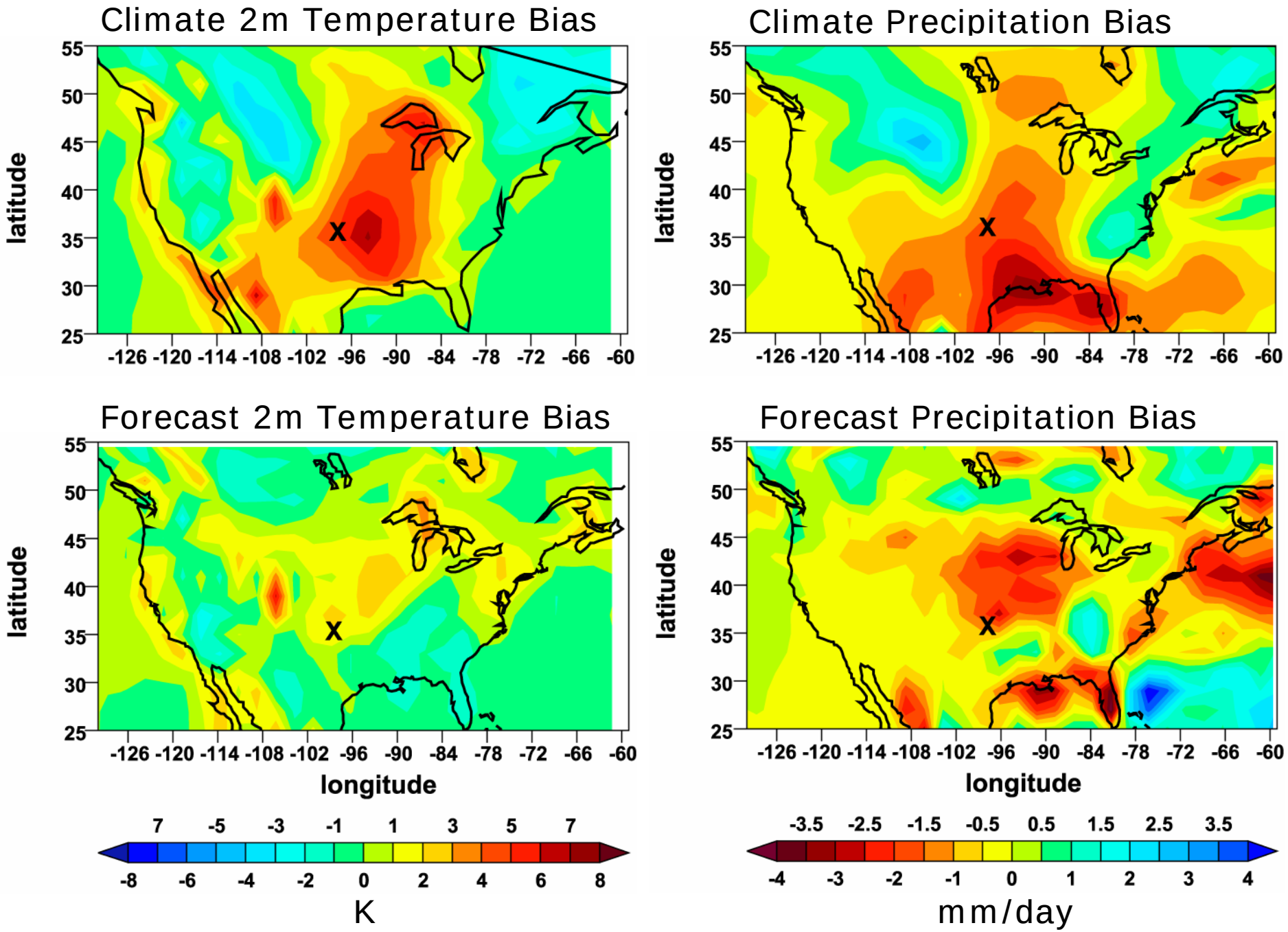
X *marks the location of the ARM Oklahoma site*

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)

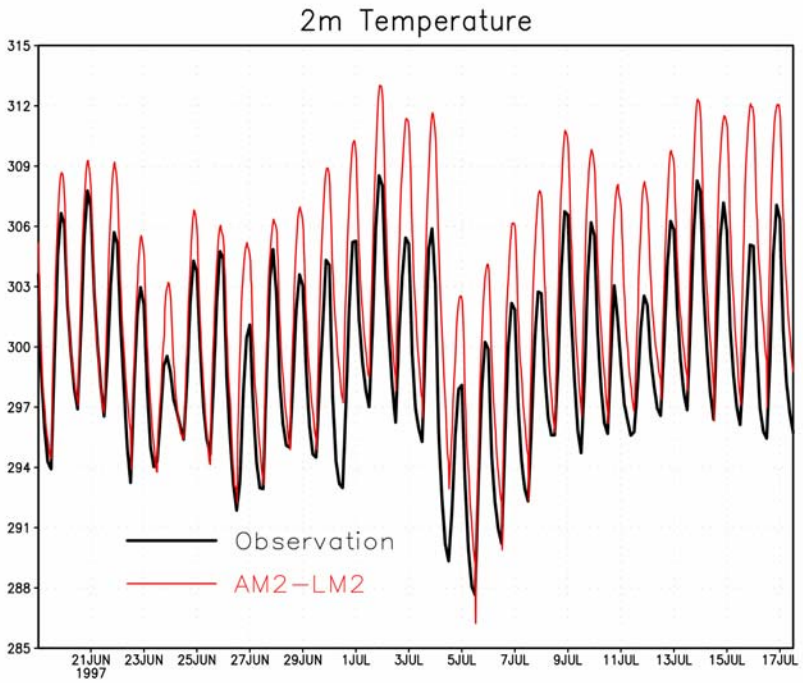
Forecasting Methodology

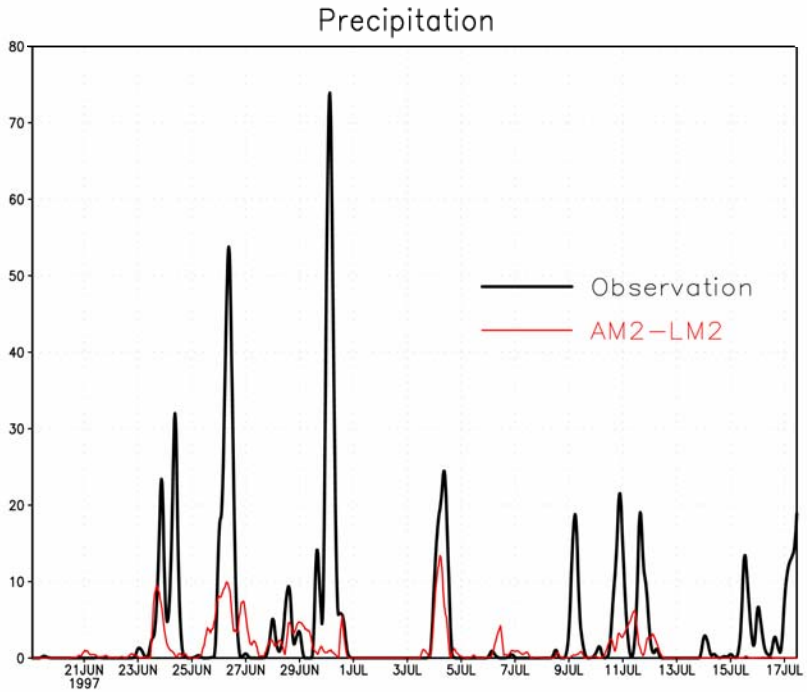
- We can partially sort this out by prescribing the land-model initial conditions from a ‘stand-alone’ integration of the land-model driven with observations including those for precipitation
- The initial land model state will not have biases that are a function of the inability of the model atmosphere 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

- 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?

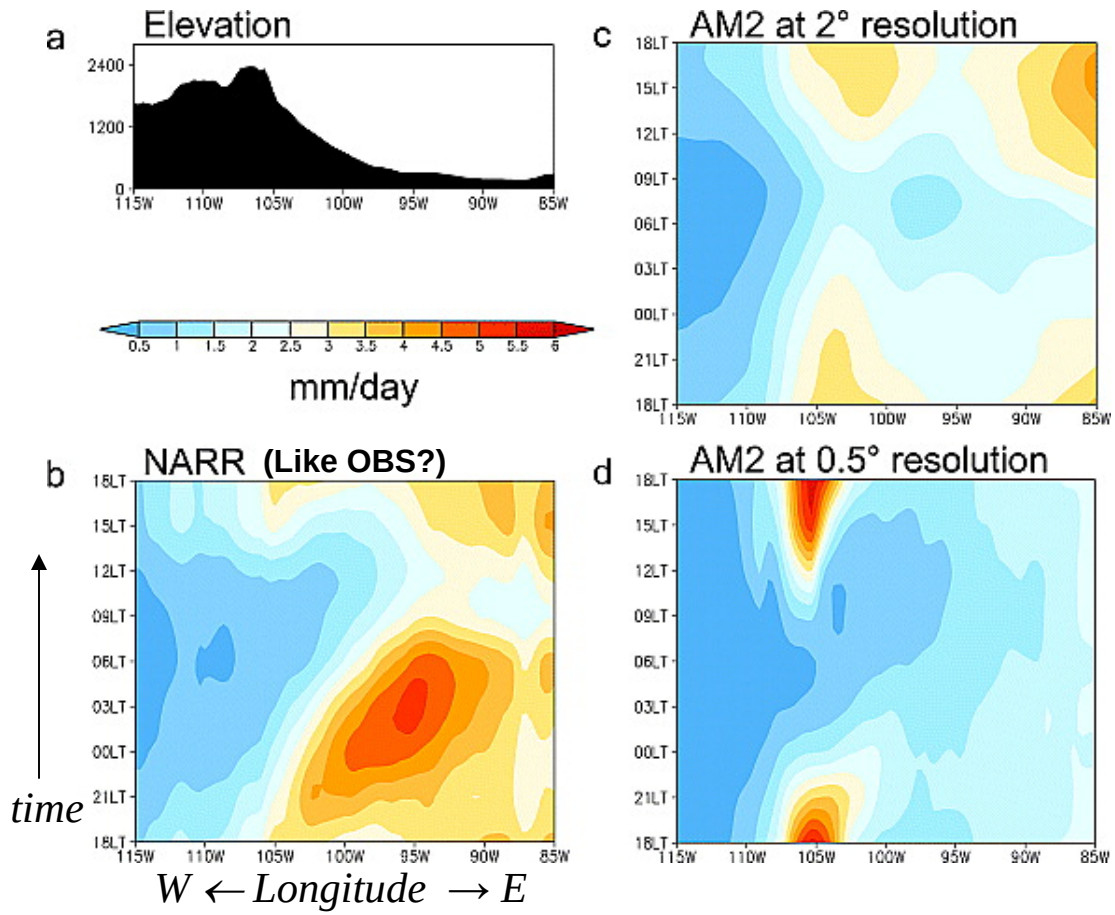
- At the ARM site, the model fails to simulate enough precipitation: 1.3 vs. 4.0 mm day^{-1}
- The model does simulate a reasonable amount of evaporation: 3.5 vs. 4.0 mm day^{-1}
- As a result, the soil dries out with longer forecast times (e.g. due to the several week time scale of soil moisture) which 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

Jiang et al. (2006)

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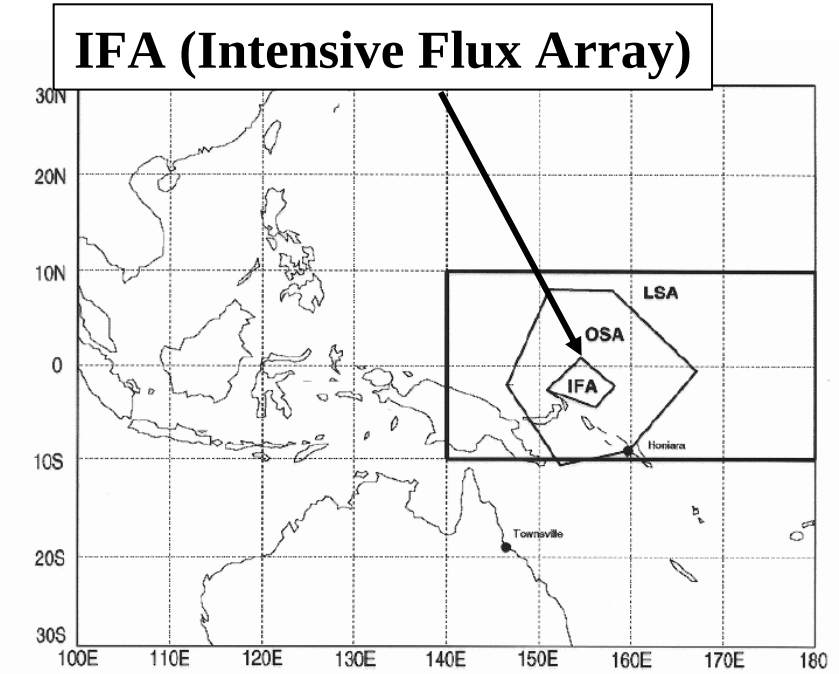
Tropical Precipitation Is A Problem

- 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

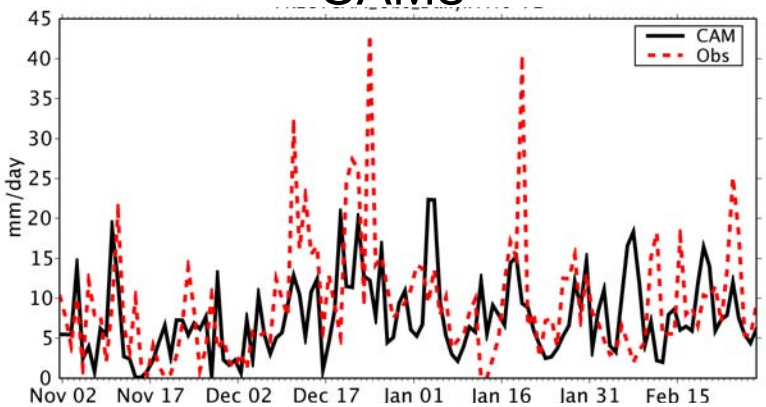
- The Tropical Ocean Global Atmosphere – Coupled Ocean Atmosphere Response Experiment was a large field campaign performed in the tropical western Pacific between November 1992 and February 1993



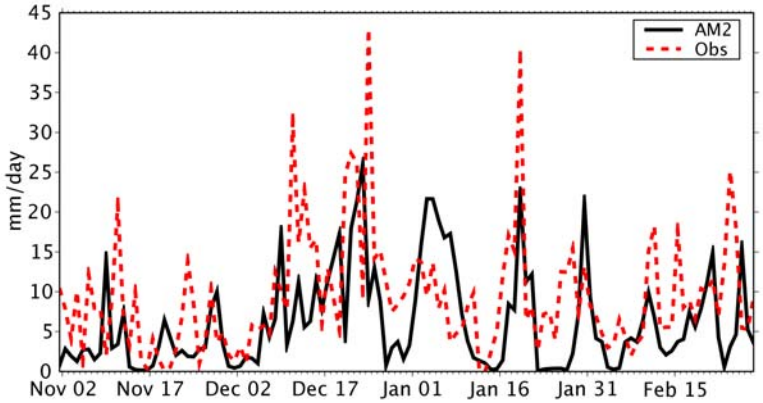
IFA Precipitation

- 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

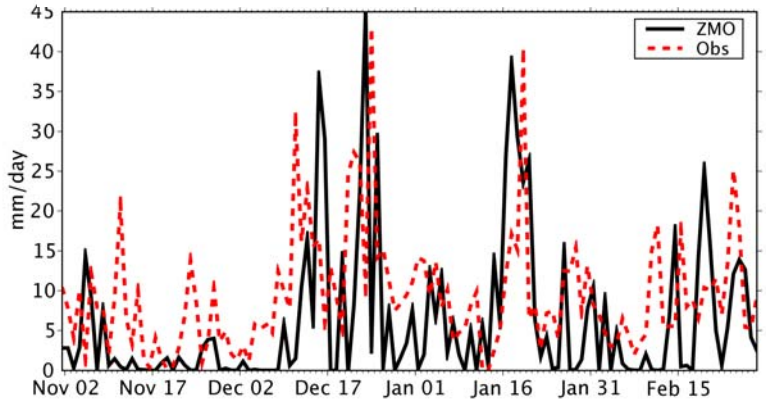
CAM3



GFDL AM2

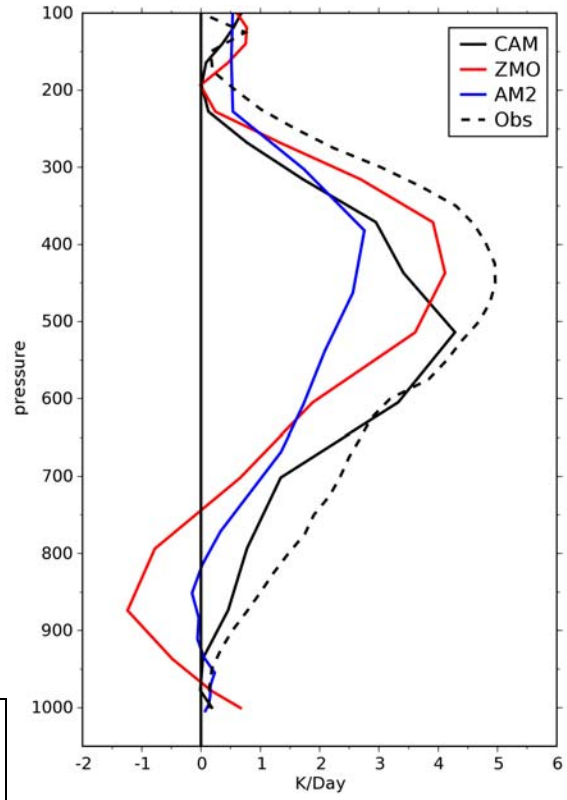


CAM3 w/Zhang Modification

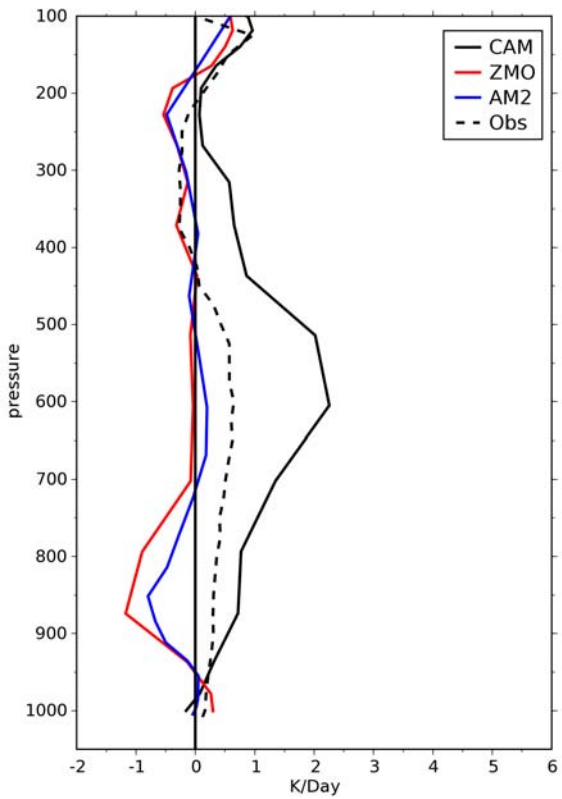


Do Models Respond Correctly?

Q1 on days observed to have precipitation



Q1 on days observed to have no precipitation



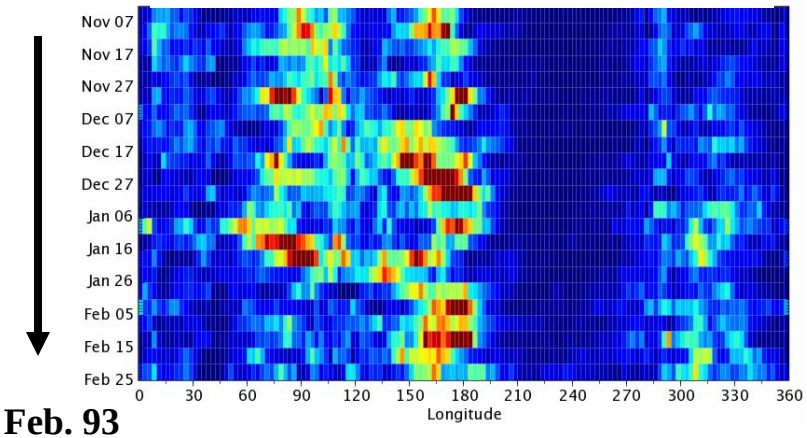
Q1 = diabatic heating

ZMO = Zhang MOdification

Precipitation Beyond The IFA

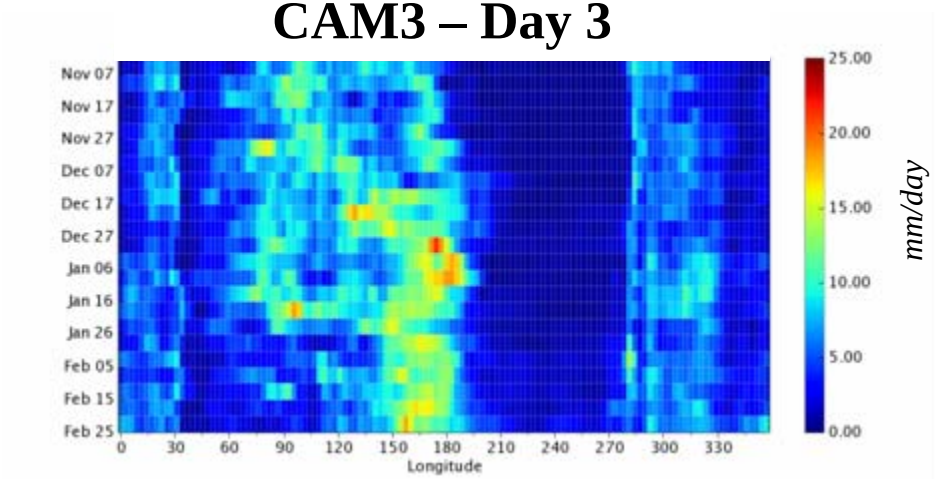
Nov. 92

Satellite observations

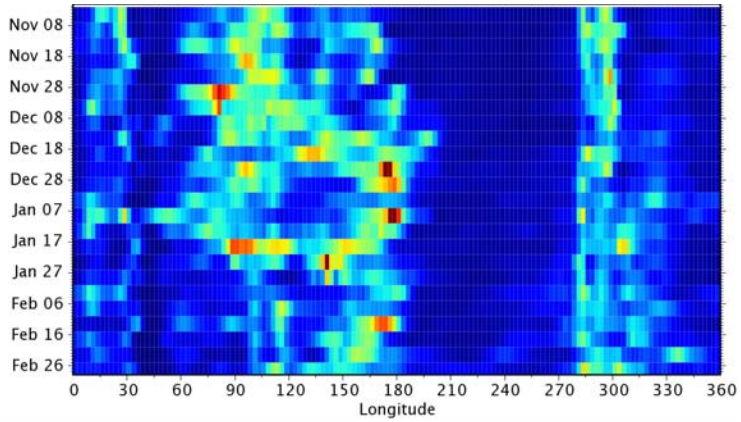


Feb. 93

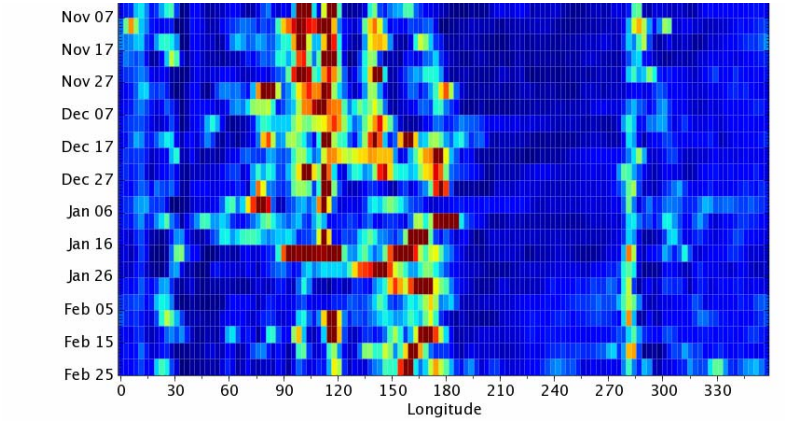
CAM3 – Day 3



AM2 – Day 3



CAM3 with Zhang Modification – Day 3



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

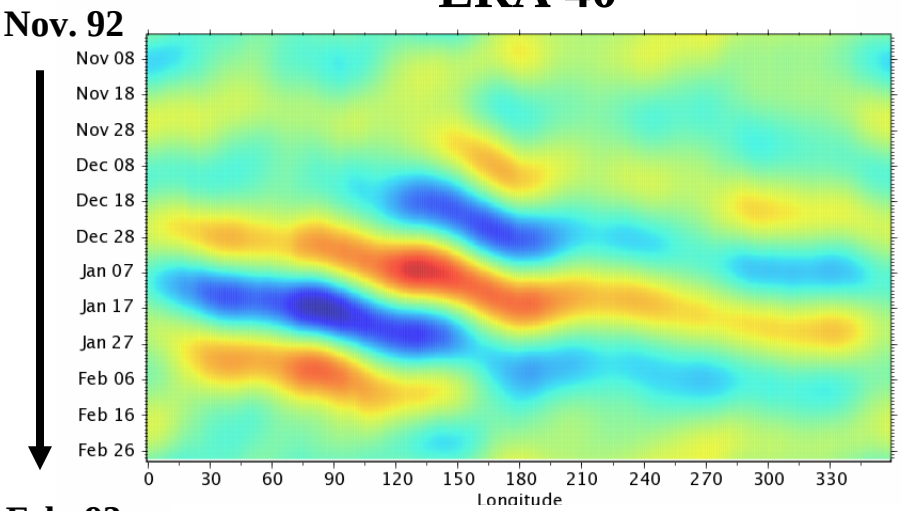
What Does This Tell You?

- 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

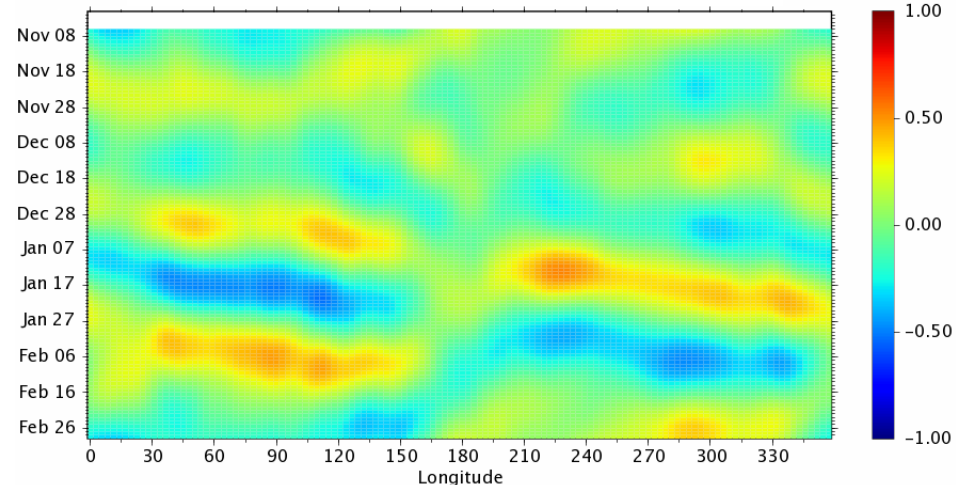
Circulation Anomalies

Program for Climate Model Diagnosis and Intercomparison

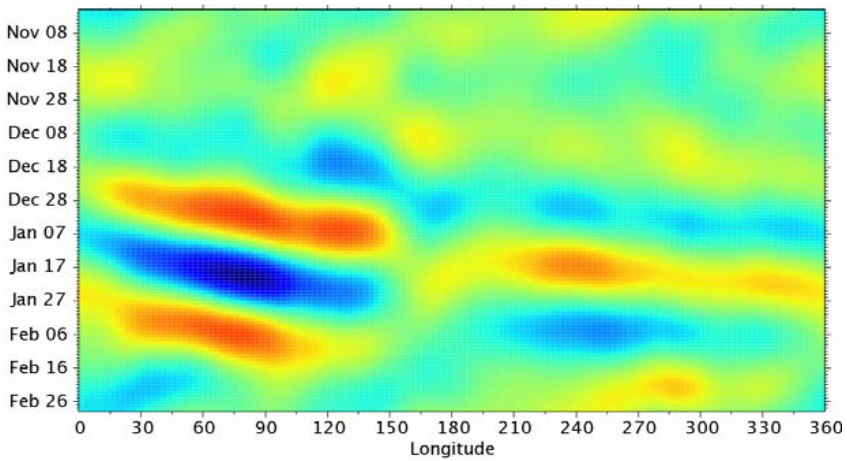
ERA 40



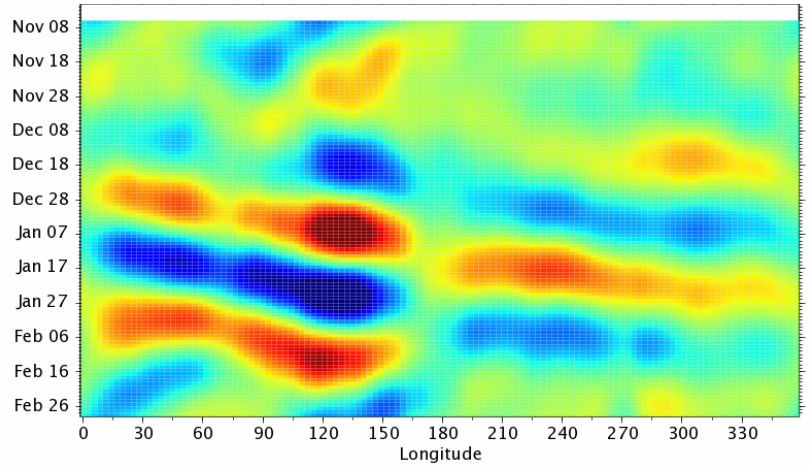
CAM3 – Day 6



AM2 – Day 6

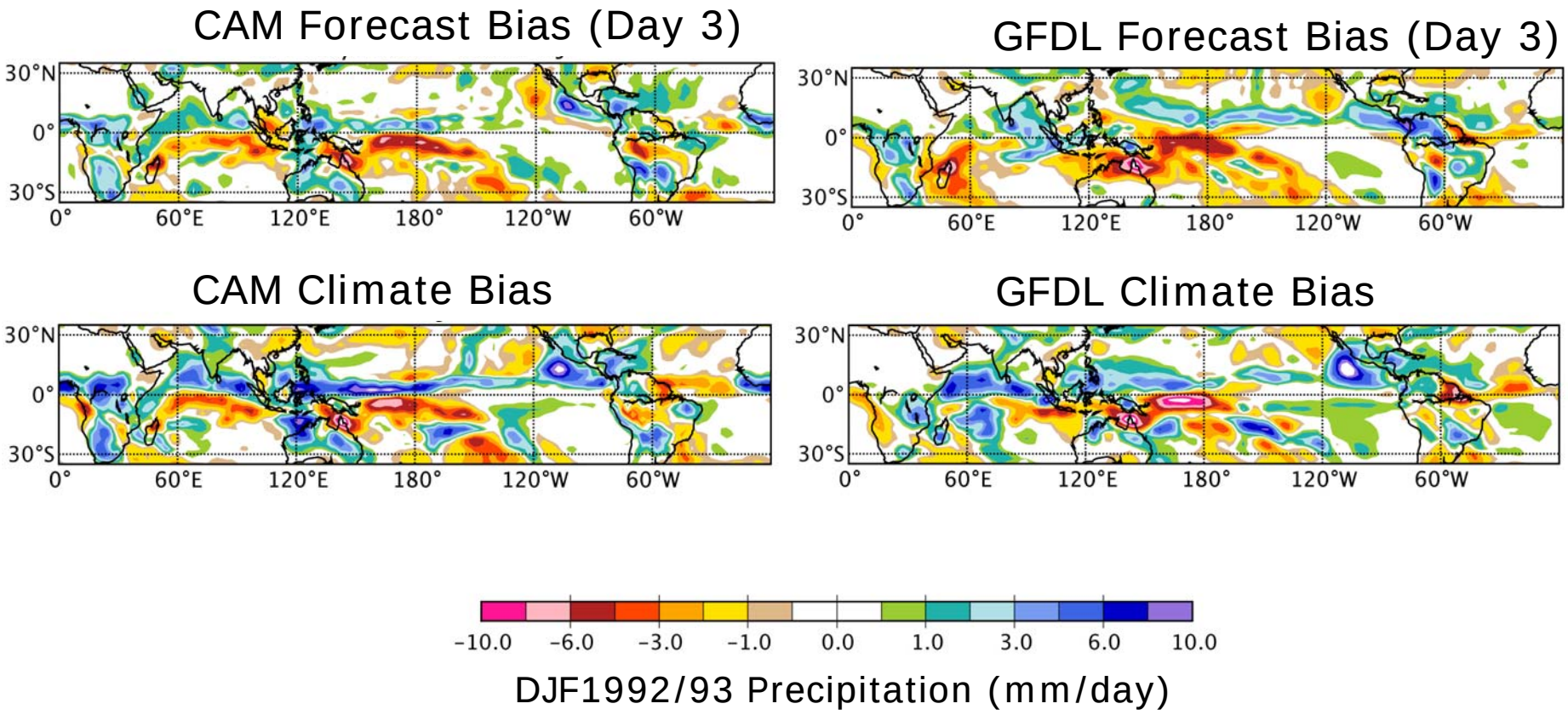


CAM3 with Zhang Modification – Day 6



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

Climate Versus Forecast Errors



Conclusions

- 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
- However, weather forecasting does not replace the need to do climate integrations nor the need to be creative in devising improvements to model parameterizations

Future Work

- Ensemble forecasting
- Aerosols in forecast mode to address aerosol-cloud interactions
- Multi-scale modeling framework (or ‘super-parameterization’) in forecast mode

Questions?

For Further Reading See:

- Phillips, T. J. and Coauthors, 2004: Evaluating parameterizations in general circulation models: climate simulation meets weather prediction. *Bull. Amer. Met. Soc.,* **85**, 1903–1915.
- Xie, S. and Coauthors, 2004: Impact of a revised convective triggering mechanism on Community Atmosphere Model, Version 2, simulations: Results from short-range weather forecasts. *J. Geophys. Res.*, **109**, D14102, doi:10.1029/2004JD004692.
- Boyle, J. S. and Coauthors, 2005: Diagnosis of Community Atmospheric Model 2 (CAM2) in numerical weather forecast configuration at Atmospheric Radiation Measurement (ARM) sites. *J. Geophys. Res.,* **110**, D15S15, doi:10.1029/2004JD005042.
- Williamson, D. L. and Coauthors, 2005: Moisture and temperature balances at the Atmospheric Radiation Measurement Southern Great Plains Site in forecasts with the Community Atmosphere Model (CAM2), *J. Geophys. Res.*, **110**, D15S16, doi:10.1029/2004JD005109.

For Further Reading See:

- Klein, S. A. and Coauthors, 2006: Diagnosis of the summertime warm and dry bias over the U. S. Southern Great Plains in the GFDL climate model using a weather forecasting approach. *Geophys. Res. Lett.*, **33**, L18805, doi:10.1029/2006GL027567.
- Boyle, J. S. and Coauthors, 2007: Climate model forecast experiments for TOGA-COARE. *Mon. Wea. Rev.,* in press.
- Xie, S. and Coauthors, 2007: Simulations of Arctic Mixed-Phase Clouds in Forecasts with CAM3 and AM2 for M-PACE. *J. Geophys. Res.*, submitted.
- Williamson, D. L. and J. G. Olson, 2007: A comparison of forecast errors in CAM2 and CAM3 at the ARM Southern Great Plains Site. *J. Clim.*, in press.
- Hannay, C. and Coauthors, 2007: Forecasts of Southeast Pacific stratocumulus with the NCAR, GFDL and ECMWF models. *Mon. Wea. Rev.*, to be submitted.