What can climate modelers learn from a weather forecasting approach about errors in the parameterization of atmospheric moist processes?

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ARM Atmospheric Radiation Measurement

CCPP

WGNE Systematic Errors Workshop, February 12, 2007, San Francisco, California

NCAR

Outline

- Three reasons
- Methodology
- Four examples
- Final Remarks

Three Reasons

- Evaluate the simulation of moist processes against field observations taken on a particular day and location
- Evaluate the nature of moist processes parameterization errors before longer-time scale feedbacks develop
- Assess how soon climate biases develop

The Assumption

- The large-scale state of the atmosphere in the early periods of a forecast is realistic enough that errors may be ascribed to the parametric representation of moist processes
- An argument that supports this is that moist processes are often fast (~hours) and the large-scale state changes slowly (~days)

Methodology

- We initialize climate models with analysis values of pressure, winds, temperature, and humidity
- We use procedures that weather prediction centers use to initialize their models with analyses from other centers
- We do not do data assimilation

Methodology

- We work with two climate models – the NCAR CAM3 and GFDL AM2 – at the resolution that they are run for climate integrations (~2 latitude-longitude)
- We work with analysis data from multiple weather prediction centers including NCEP and ECMWF

Methodology

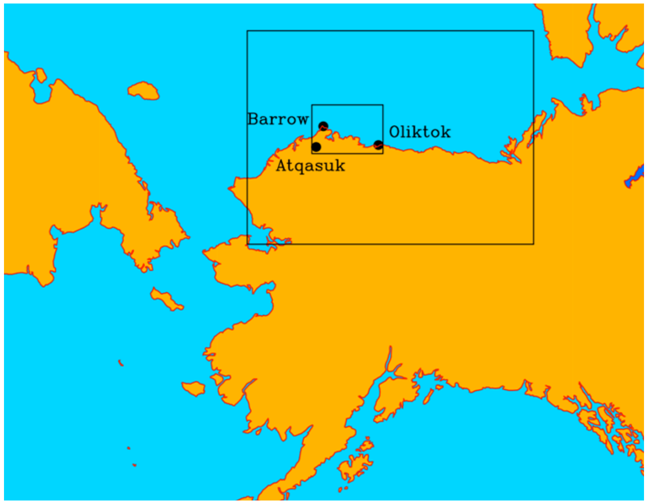
- We perform multiple forecasts and often form time series of model output by concatenating data at the same forecast range (e.g. hours 12 to 36 since start of the forecast) from integrations that start on successive days

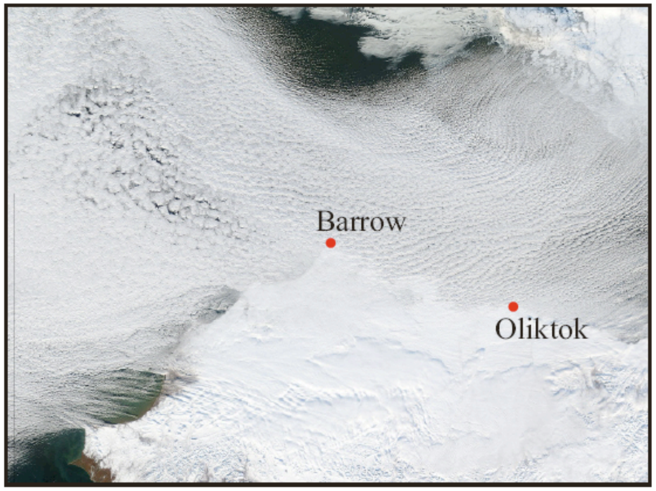
Example 1

Assessment of simulations of Arctic clouds with field campaign data

Arctic Cloud Simulations

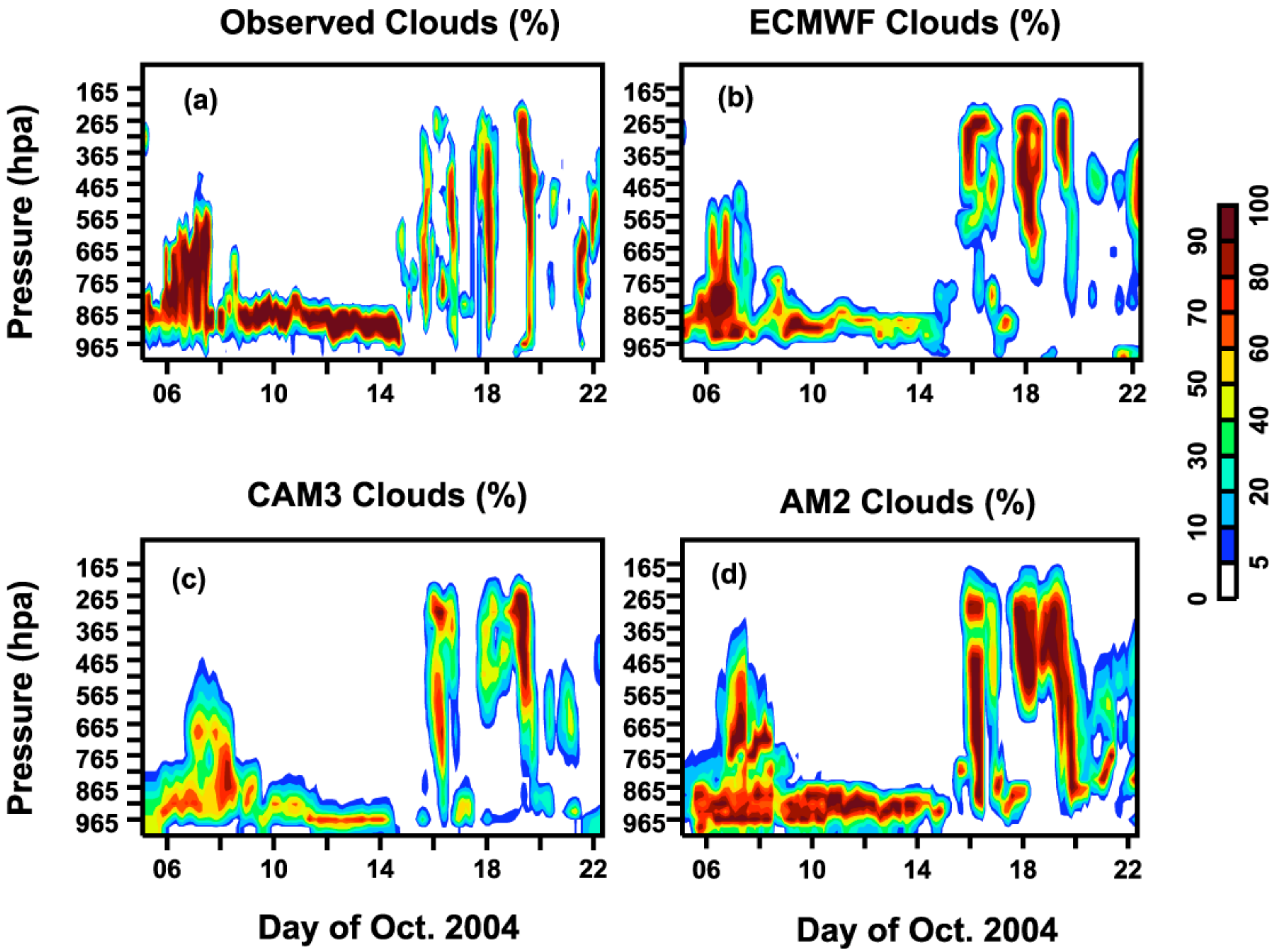
- The Department of Energy Atmospheric Radiation Measurement (ARM) program conducted a campaign at its North Slope of Alaska site to study the properties of mixed-phase clouds





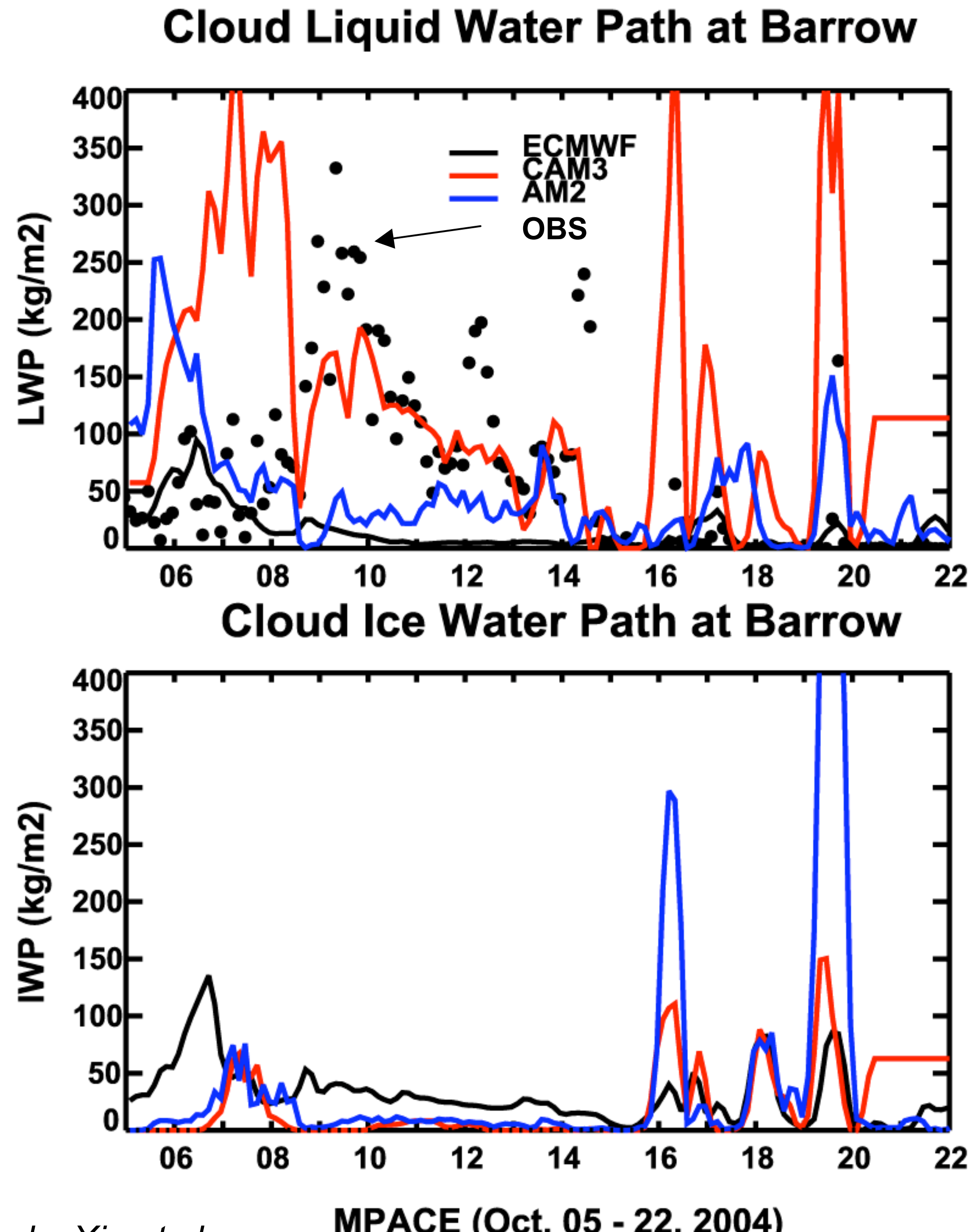
Composite Visible Satellite Image for October 9, 2004

Cloud Fraction at Barrow



Cloud Condensate

- Models differ dramatically in the amount of condensate and the partitioning between liquid and ice
- These differences are most likely due to their parameterization of cloud microphysical properties and these observations can be used to assess new parameterizations



For more details, see the poster by Xie et al.

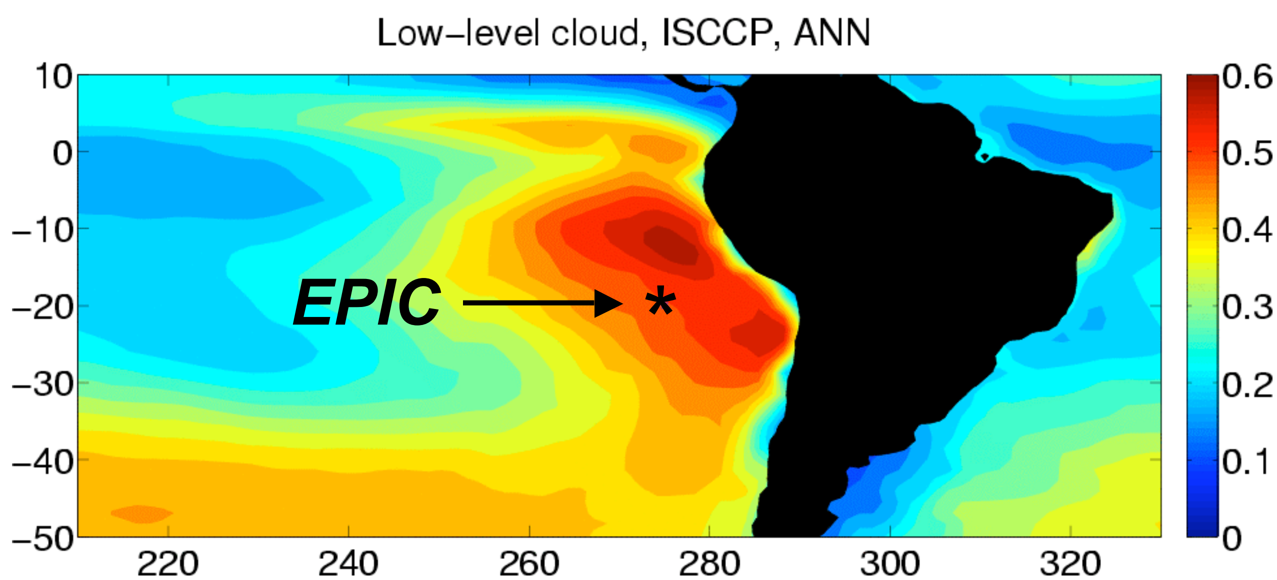
Anton Beljaars is acknowledged for contributions to this work

Example 2

Assessment of simulations of marine stratocumulus with field campaign data

Subtropical Stratocumulus

- The Eastern Pacific Investigation of Climate (EPIC) campaign positioned a ship in the Southeast Pacific stratocumulus region for several days in October 2001

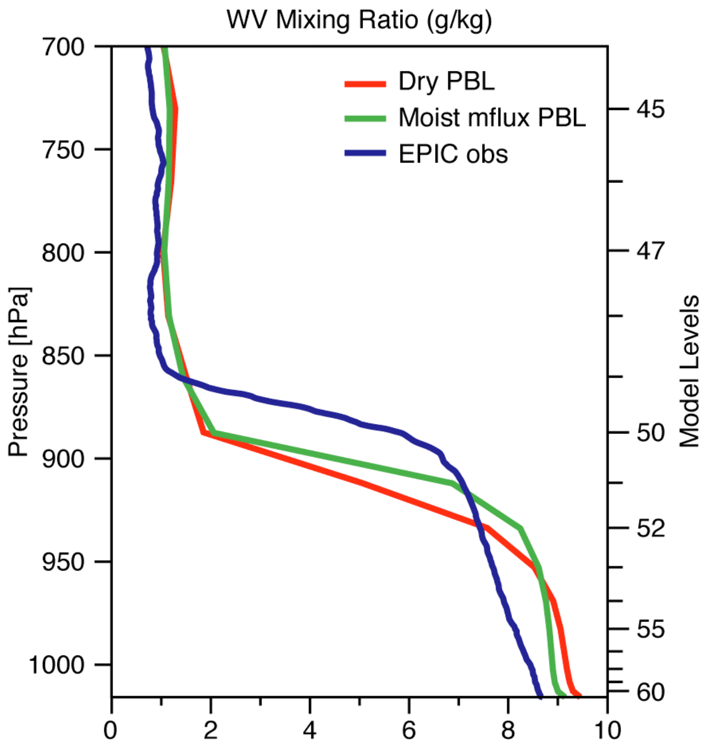


This work is described more fully in the poster by Hannay et al.

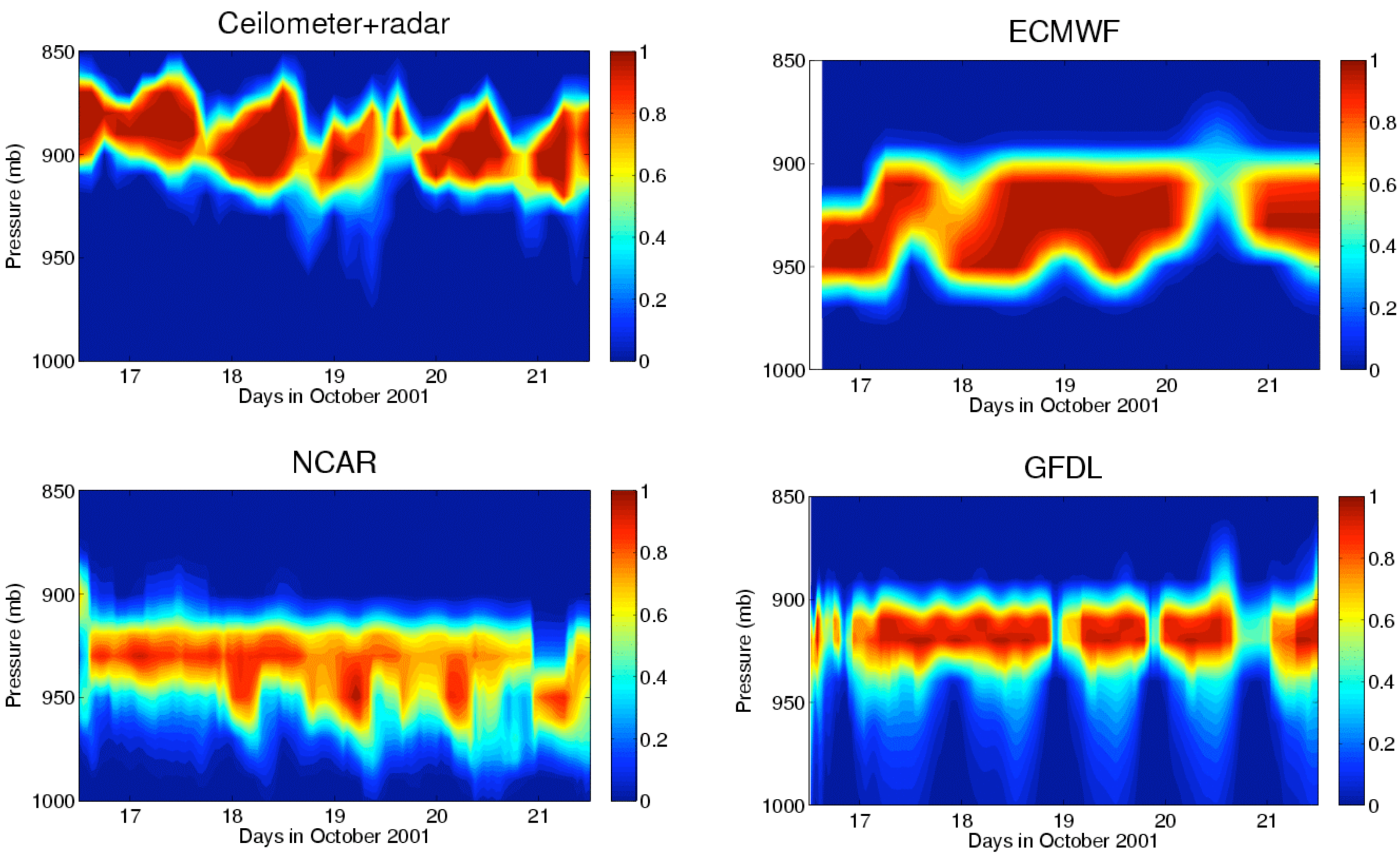
Chris Bretherton, Jim Hack, Jeff Kiehl, and Martin Koehler are acknowledged for contributions to this work

Analysis Quality

- The ECMWF analysis has an underestimate of boundary layer depth
- The model version with better low clouds has a deep boundary layer

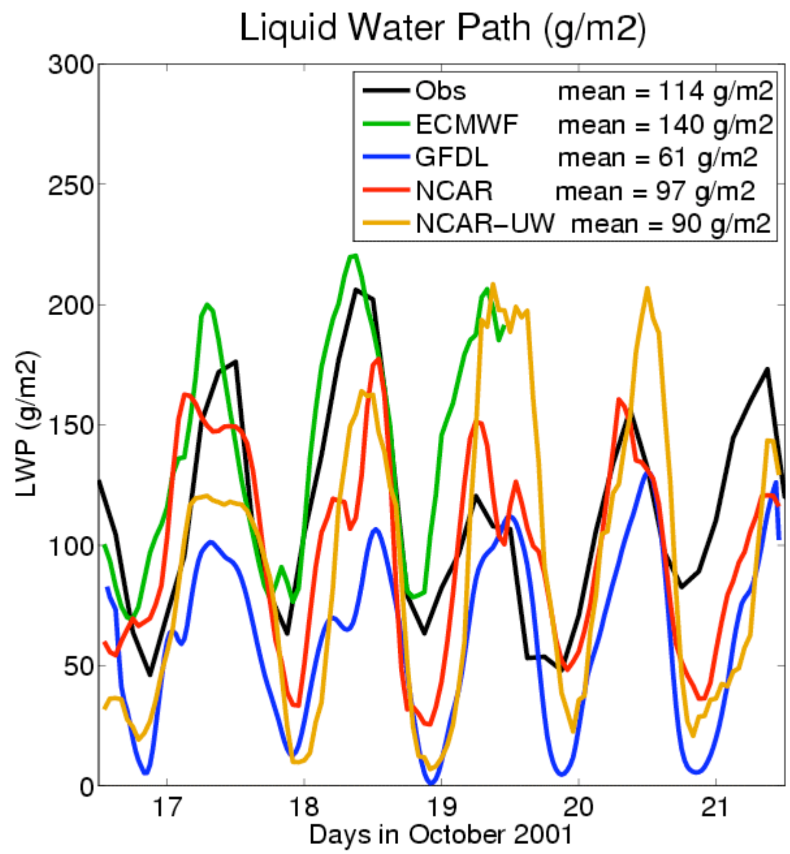


Cloud Fraction at EPIC



Cloud Condensate

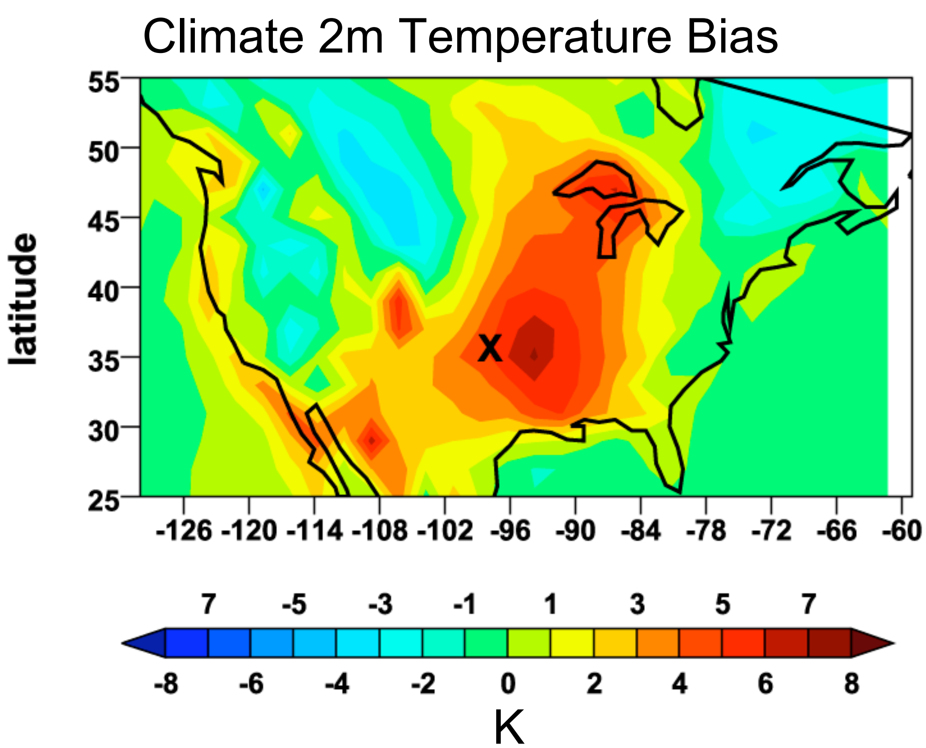
- All models have a diurnal cycle in integrated liquid
- As the minimum value occurs during when the sun is up, the strong underestimates in the minimum value cause significant solar radiation biases

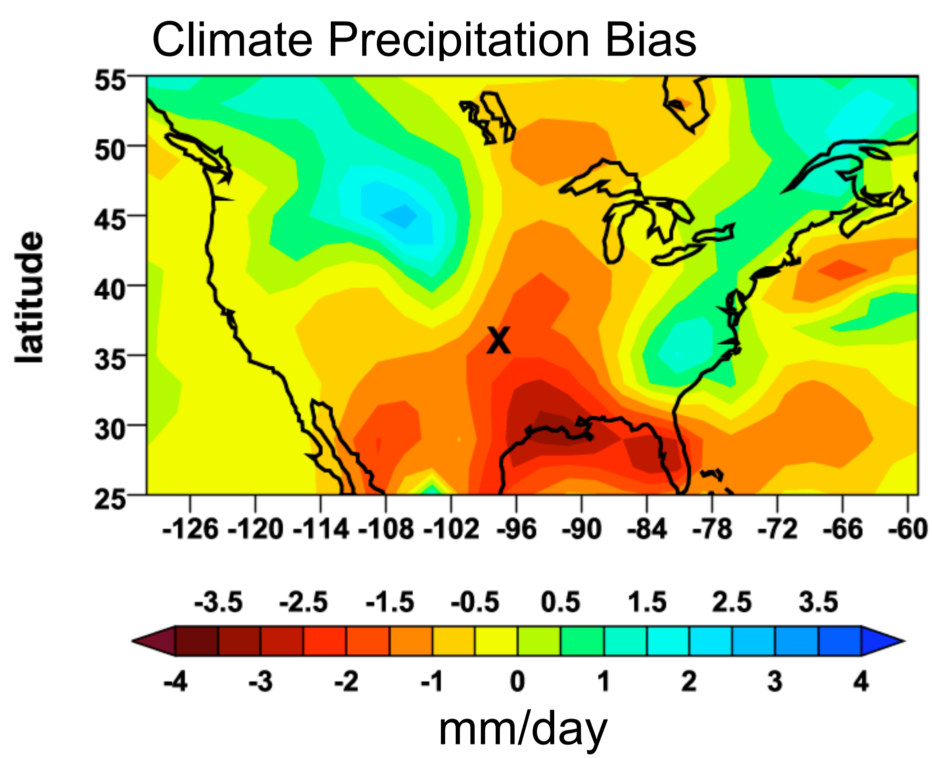


Example 3

Diagnosis of a regional climate bias

GFDL Summertime Bias Over North America





X marks the location of the ARM Oklahoma site

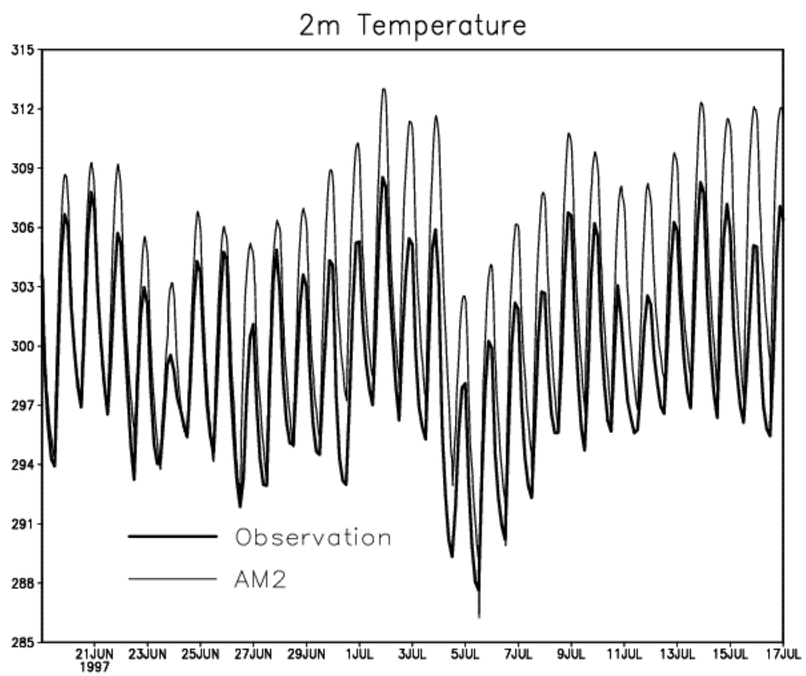
What is the cause of this bias?

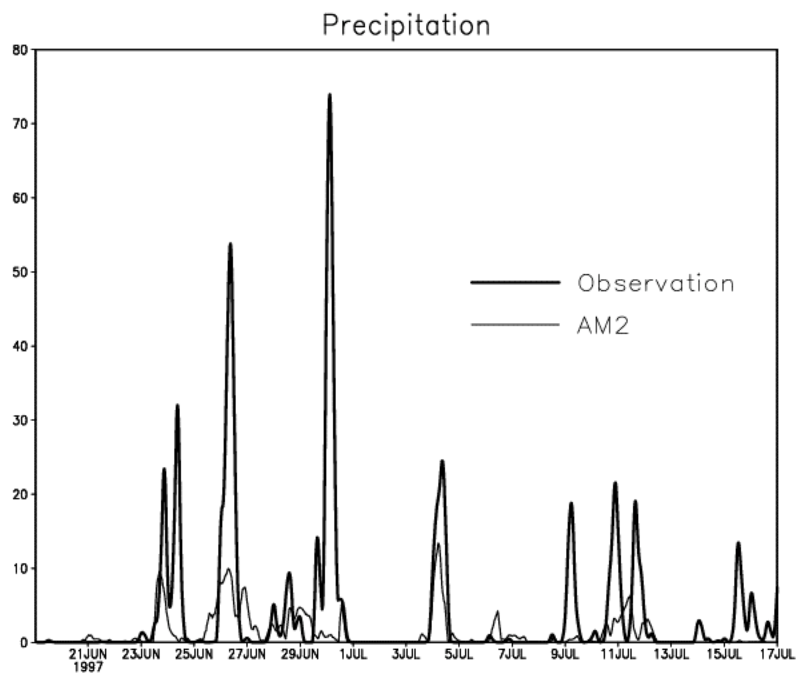
- In summer, there are strong land-atmosphere feedbacks
- Is precipitation low because the soil is dry? Or is the soil dry because precipitation is low?
- The warm bias is a manifestation of the dry soil
- The GFDL model is known to have very strong land-atmosphere feedbacks (Dirmeyer et al. 2006)

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

Forecast 2-meter Temperature and Precipitation at the ARM Oklahoma Site (June-July 1997)





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

How does this help?

- 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. soil moisture has a several week time scale) which leads to warmer temperatures, lower evaporation and less precipitation
- Thus the precipitation underestimate is present even when there is enough moisture in the soil

How does this help?

- Unless you increase the precipitation – much of which is nocturnal and occurring in events of propagating convection that are initiated near sunset in the lee of the Rockies, there is not much hope for realistically eliminating the bias in this model
- However, a model with a weaker land-atmosphere feedback strength might have a smaller warm bias

Xianan Jiang, and Sergey Malyshev are acknowledged for contributions to this work

Example 4

Assessment of simulations of tropical convection

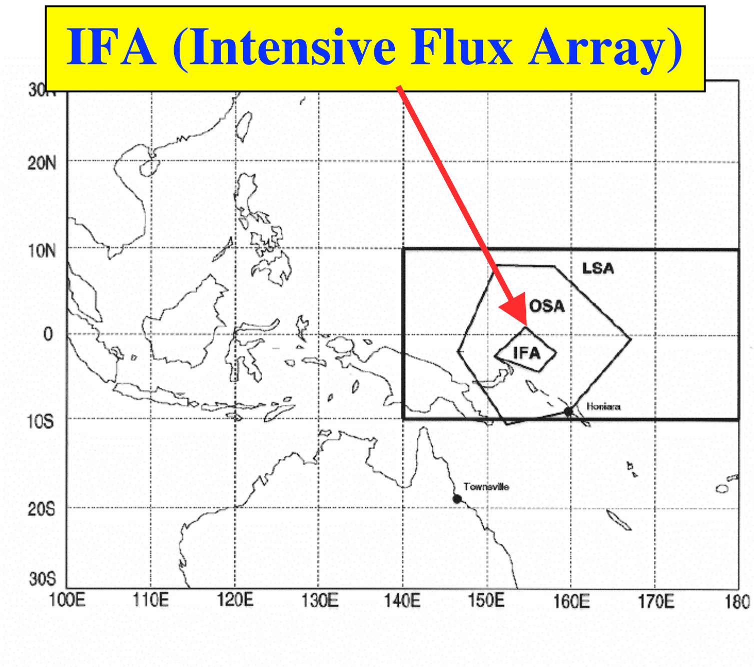
Simulations of Tropical Variability Remain Problematic

- Variability of many types 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?

Weather Forecasting Approach

- If you initialize a large-scale model in different phases of the observed MJO, does the model simulated convection behave well?
- Are analyses good enough to give you the large-scale structures of the MJO?

TOGA-COARE



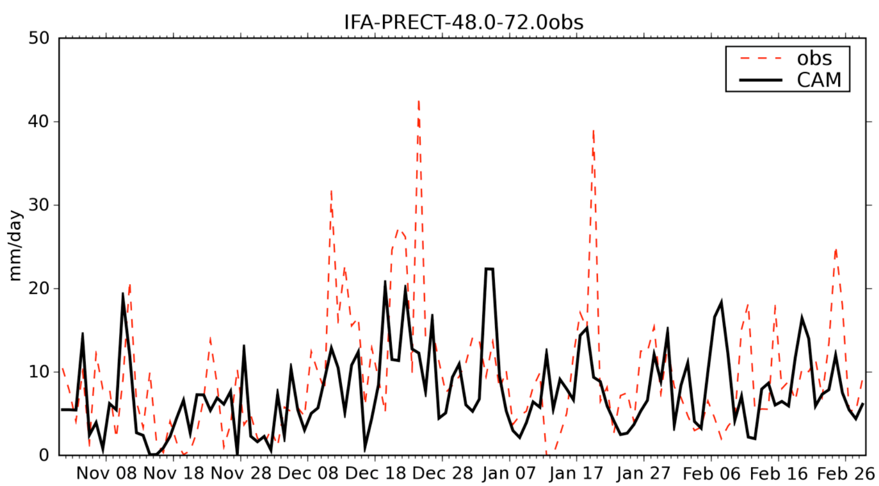
- We perform forecasts of the NCAR and GFDL models initialized with ERA-40 every day in the period November 1992-February 1993

For more details, see the poster by Potter et al.

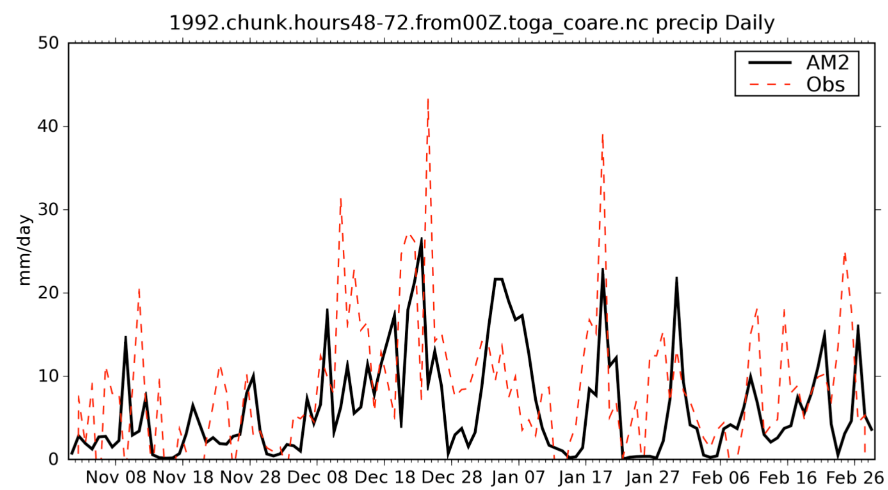
Robert Pincus, Xu Wei and Guangjun Zhang are acknowledged for contributions to this work

Precipitation at the IFA

NCAR



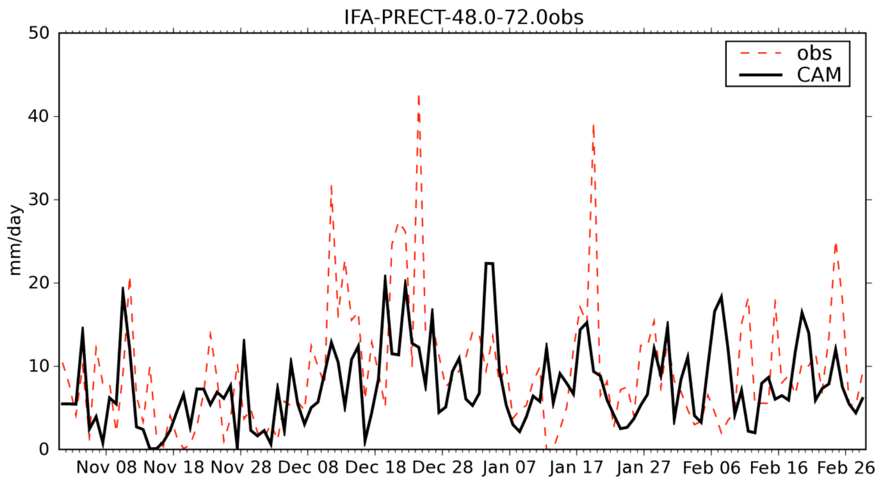
GFDL



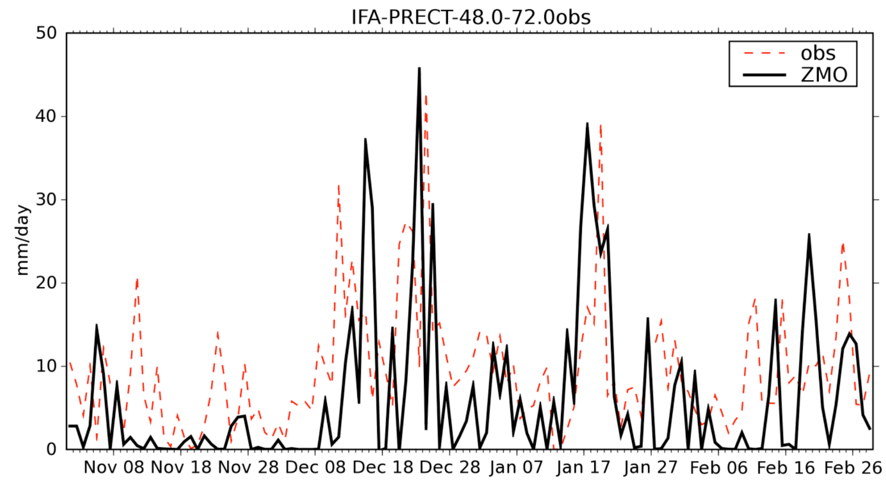
- We examine day 3 precipitation because during the first two days there is a precipitation spin-down and rebound

Sensitivity to Parameterization Choices

CAM3 Original



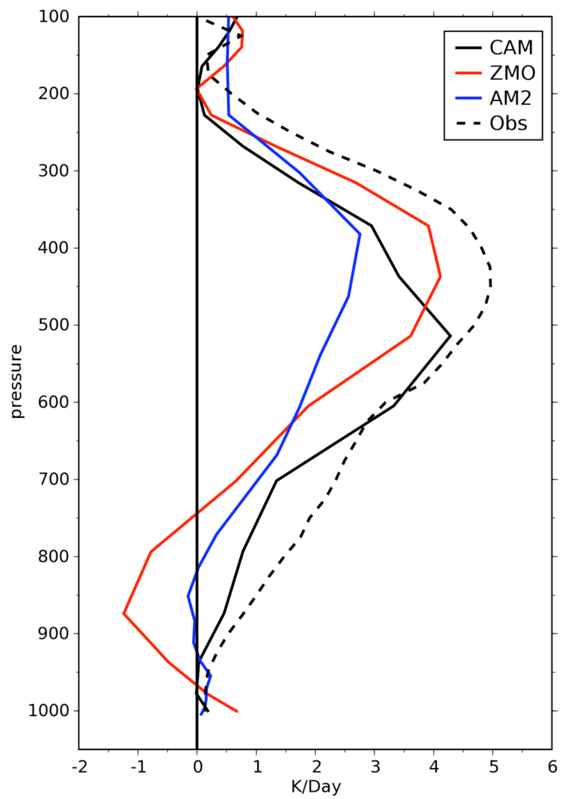
CAM3 Modified



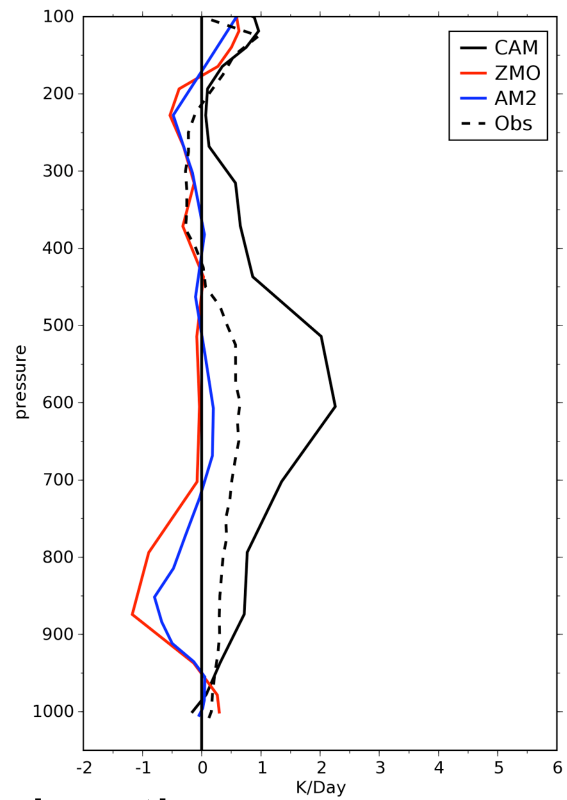
- The modification by Guangjun Zhang (UCSD) adds a boundary layer relative humidity trigger and replaces the CAPE closure with a closure tied to the rate at which the large-scale circulation destabilizes the free troposphere

Do the simulations convect when they should?

Q1 on days observed to have precipitation



Q1 on days without precipitation



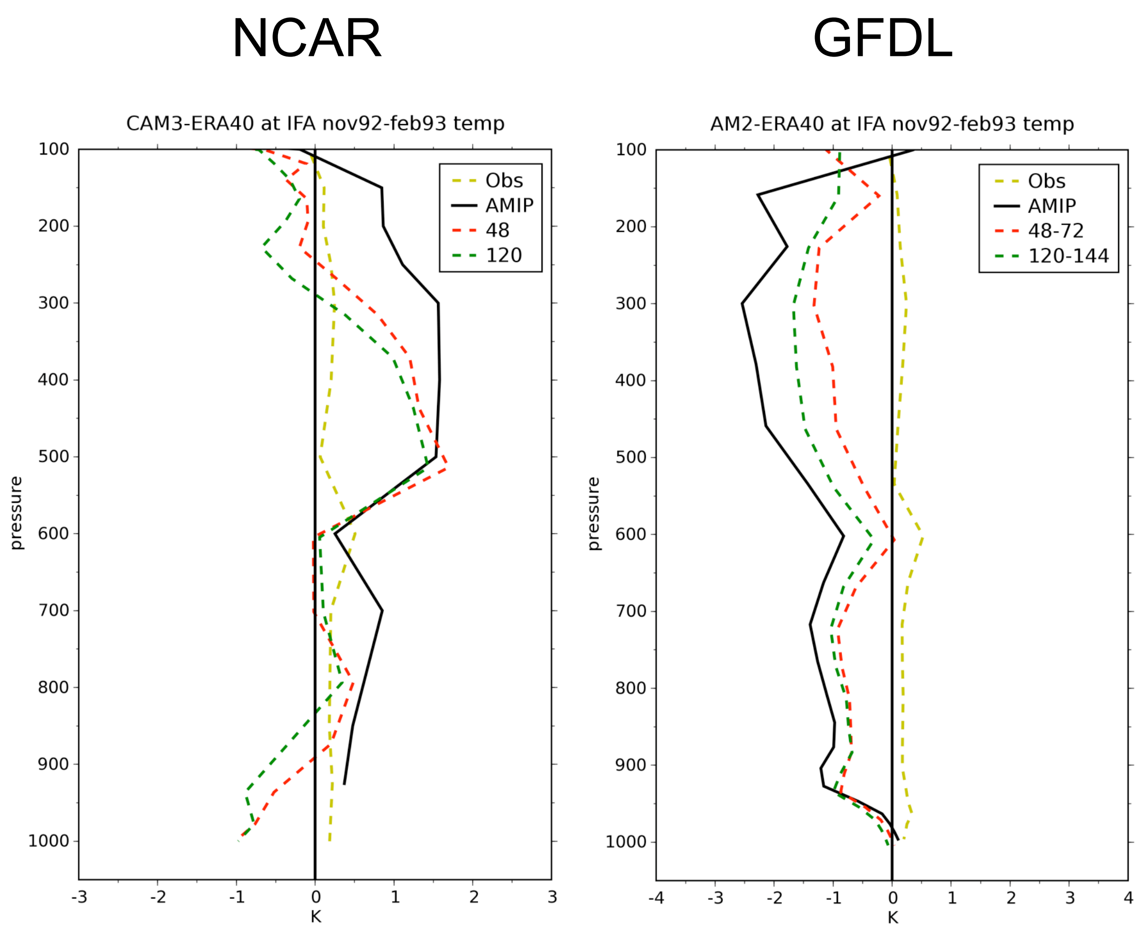
Q1 = diabatic heating

What does this tell you?

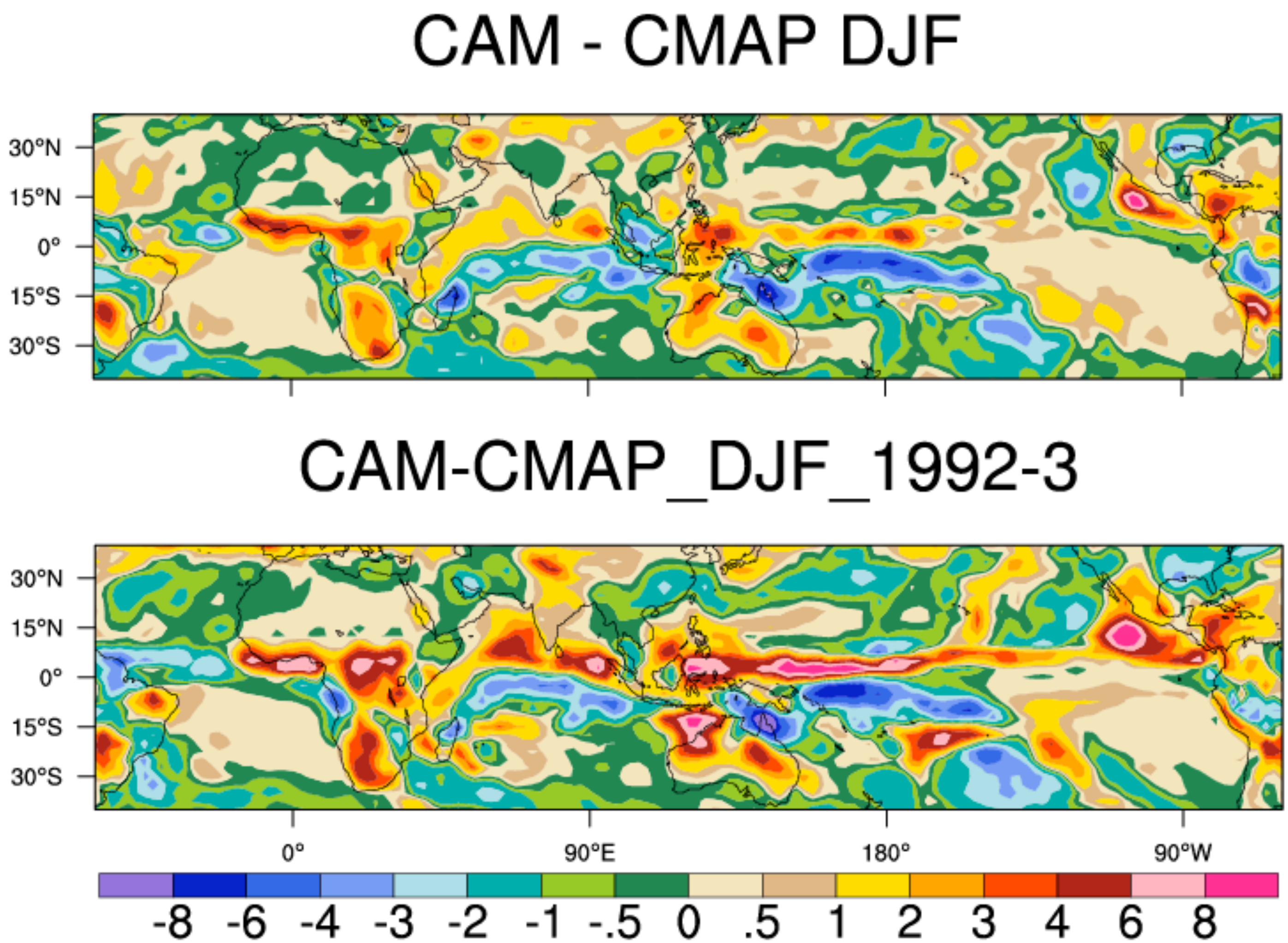
- If the model with the observed atmospheric state fails to convect when it should, why should you expect tropical variability in a freely running climate simulation to be done well?
- Indeed, the level of intraseasonal activity in the three models can be predicted from this ensemble of 3 day forecasts

Comparison of Forecast Biases to Long-term Climate Biases

- Temperature biases at the IFA for Winter 1992/93



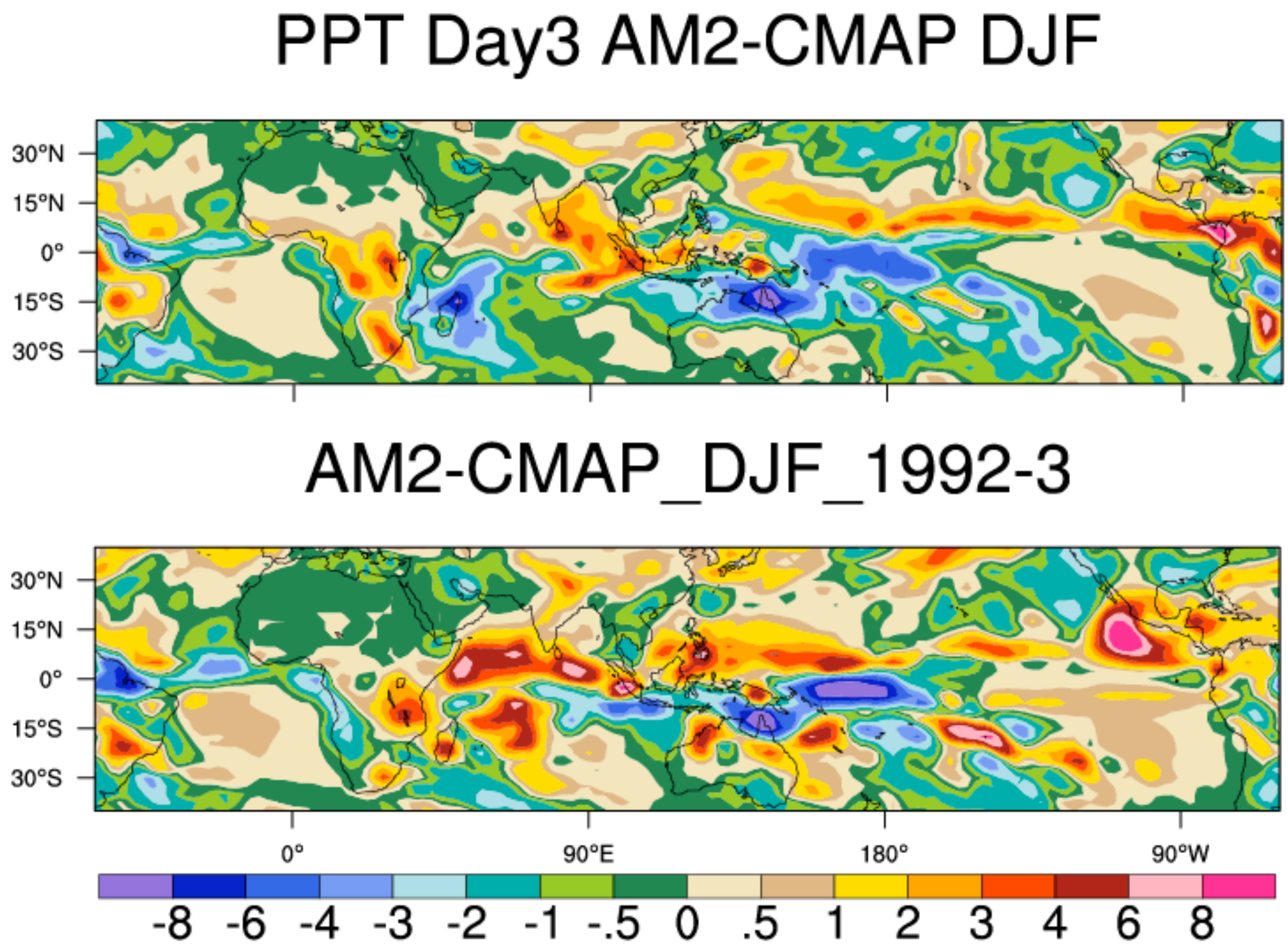
NCAR Precipitation Biases



Day 3 Error

AMIP Error

GFDL Precipitation Biases



Day 3 Error

AMIP Error

Final Remarks

Final Remarks

- The technique of weather forecasting is helpful to climate modelers for several reasons but I don't want to oversell it
- As is true of many diagnostic studies, it almost never tells you how to fix something
- It does tell something about how errors develop, rules out some potential causes, and facilitates the use of specialized field campaign data

Final Remarks

- Generally the differences between model simulations and observations are greater than the problems caused by adjustment to analysis from a foreign model – thus “model differences” are “model errors”
- The continuing improvement of analysis data facilitates this work

Acknowledgments

- We thank the *National Center for Environment Prediction* and the *European Centre for Medium-range Weather Forecasts* for assistance in acquiring their analyses
- We thank *David Bader, Anjuli Bamzai, Leo Donner, Wanda Ferrell, Jim Hack, Isaac Held, Christian Jakob, Jeff Kiehl, Tony Hollingsworth, Martin Miller,* and *V. Ramaswamy* who have provided advice and support to this project

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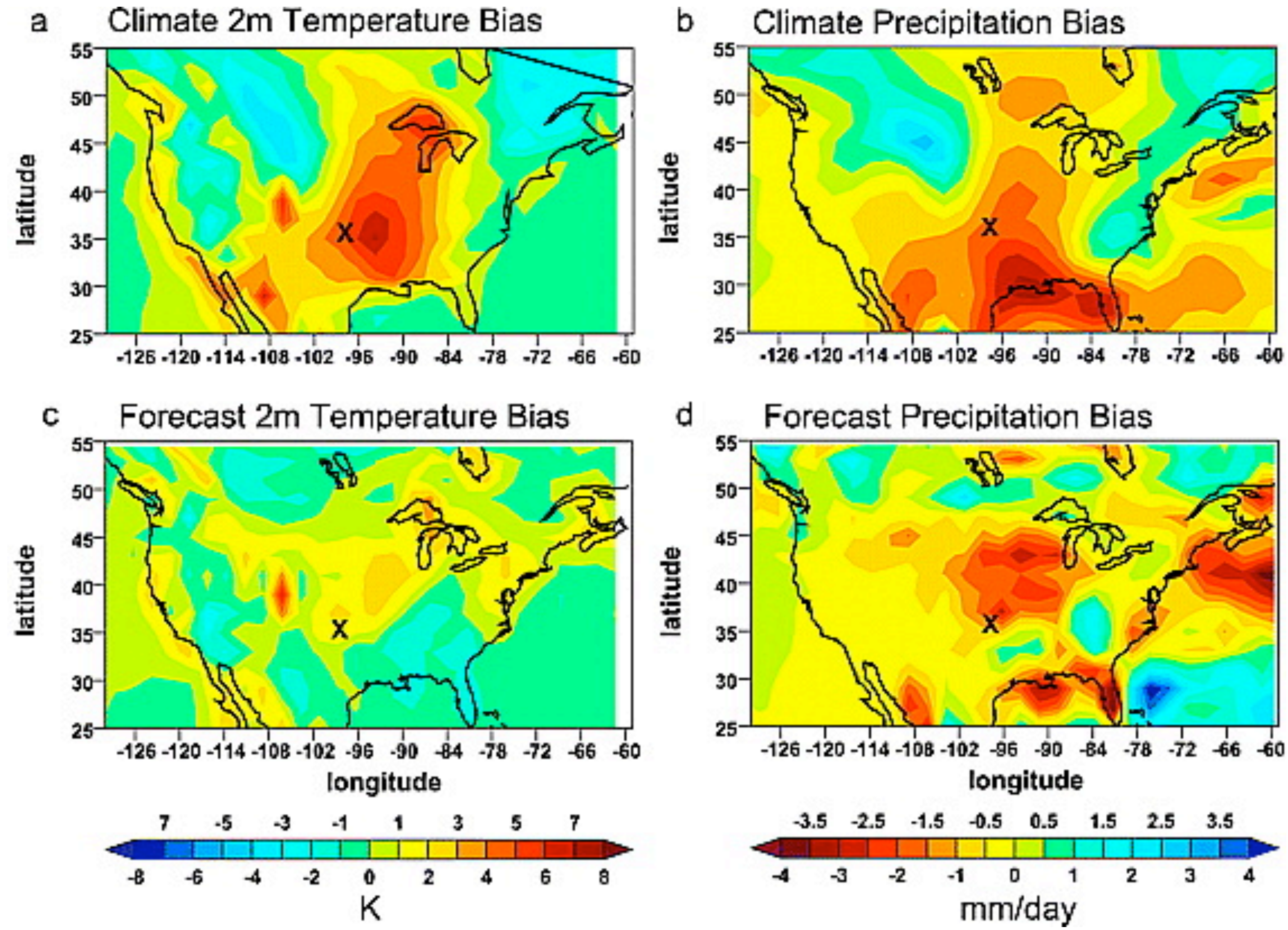
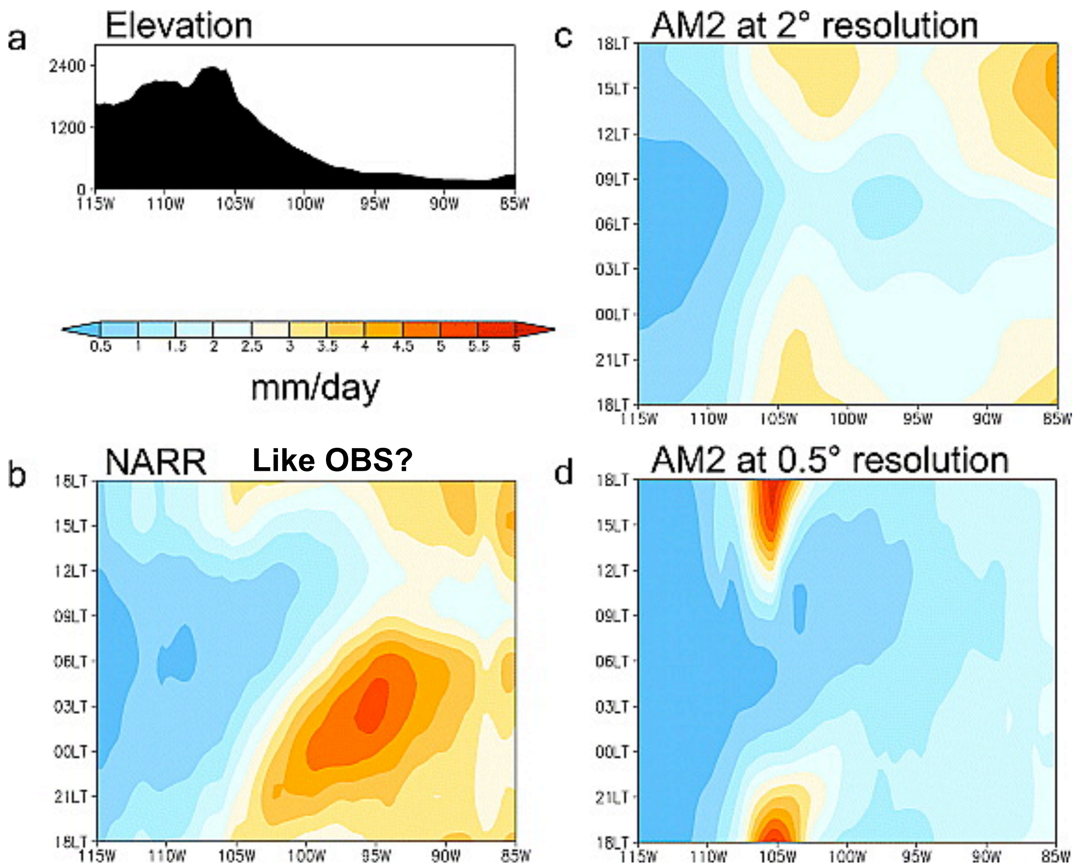
The End

Extra Slides

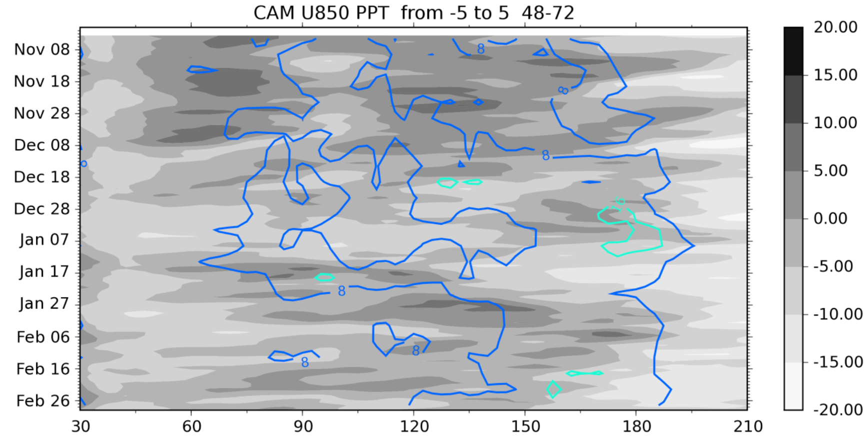


Klein et al. 2006, Geophys. Res. Lett.

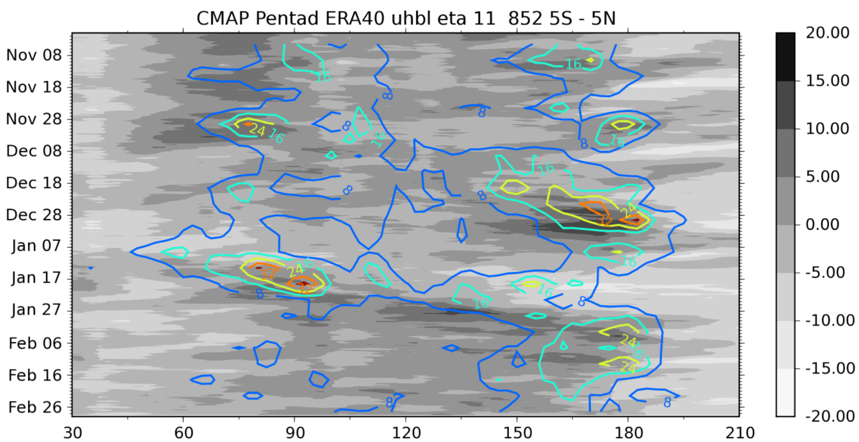


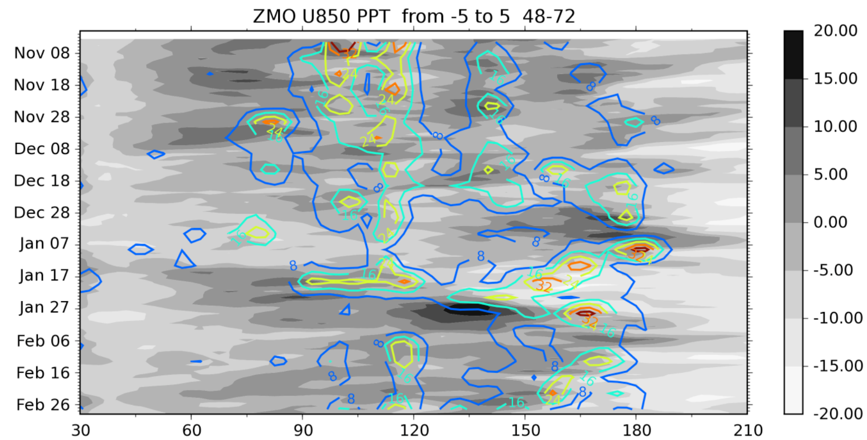
- Diurnal cycle of precipitation over the Great Plains
- Lack of propagating nocturnal precipitation (even at 0.5 degrees resolution)

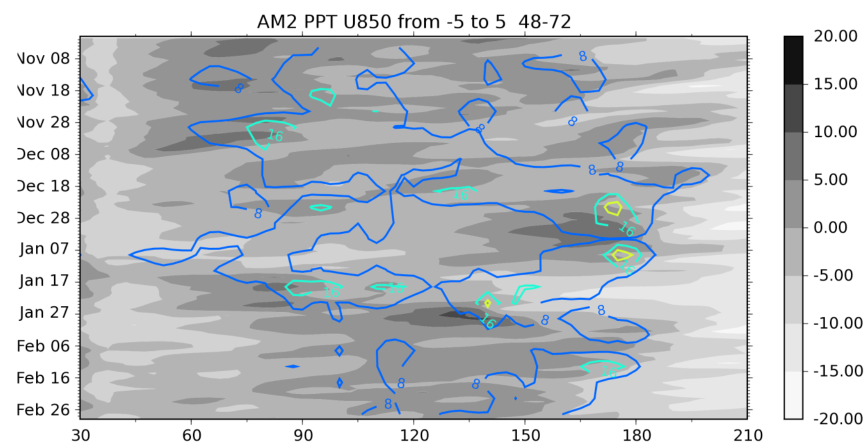
Precipitation (contours) and U850 (shading) Hovmollers (Day 3 Forecasts)



OBS

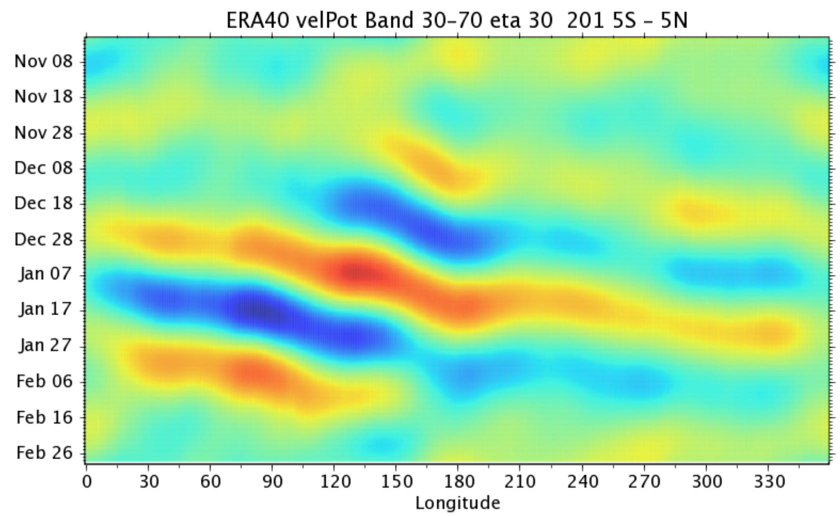




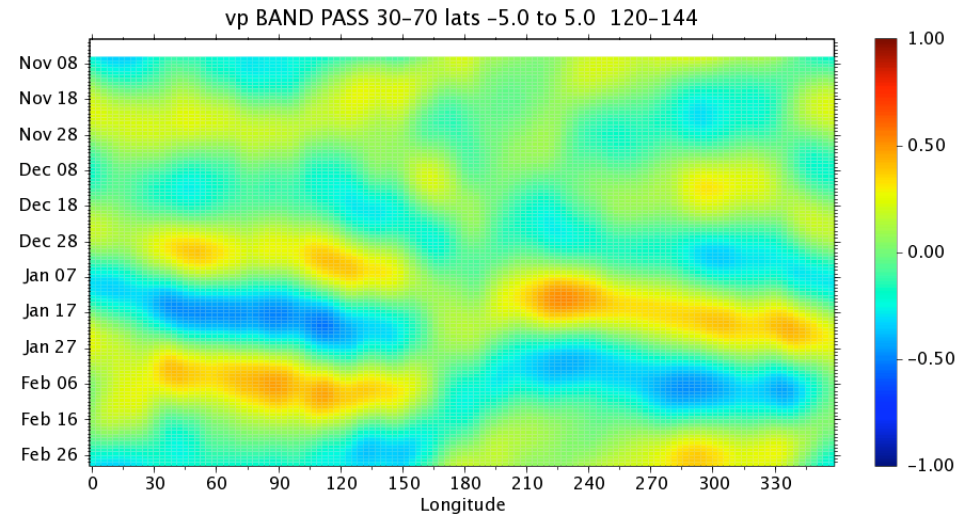


Intraseasonal Variability in 200 hPa Velocity Potential

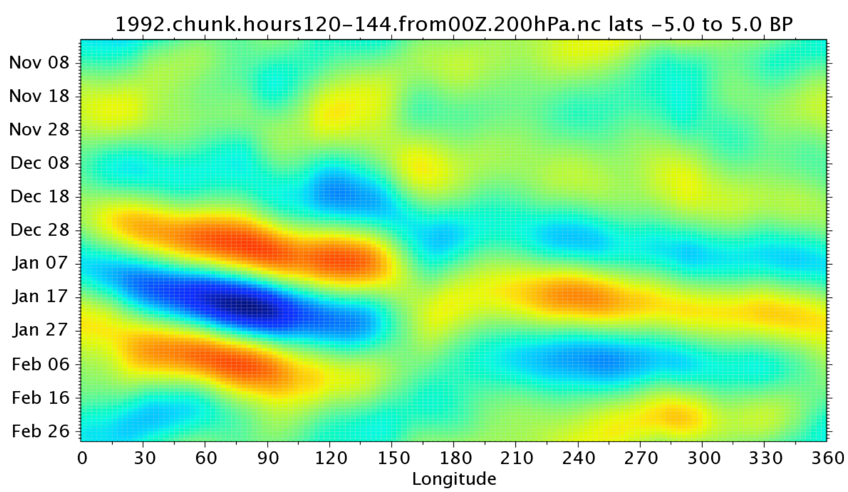
ERA 40



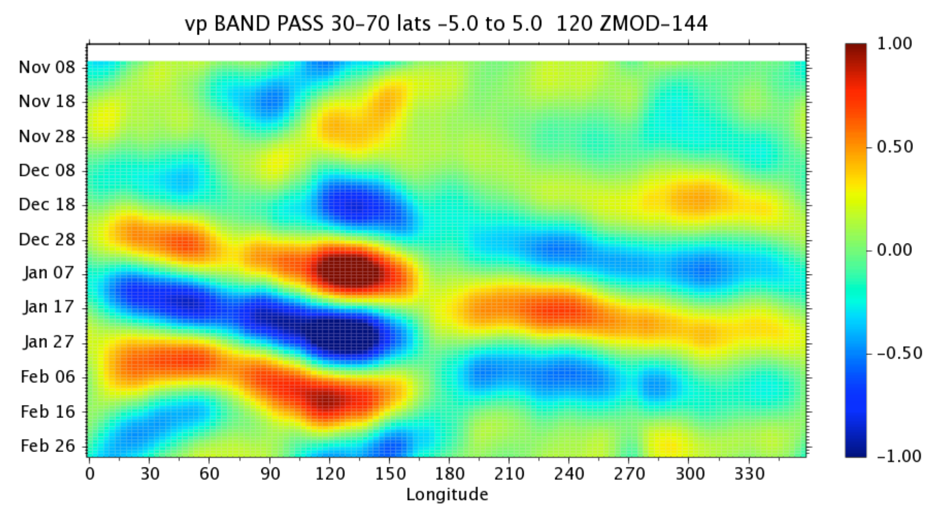
Day 6 – CAM 3



Day 6 – AM2



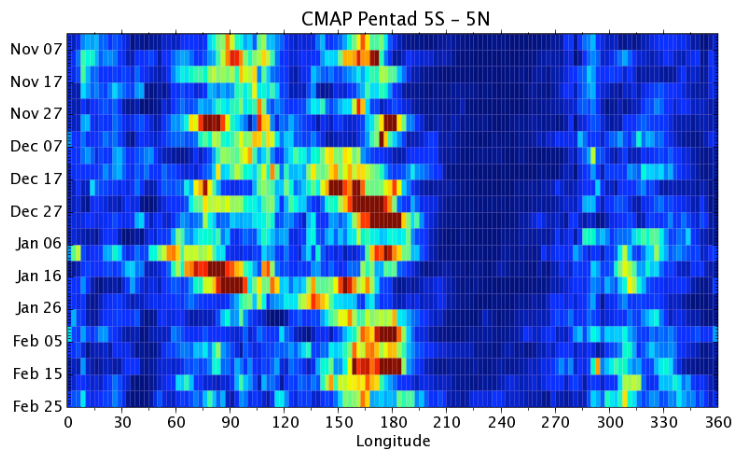
Day 6 – CAM 3 with new closure



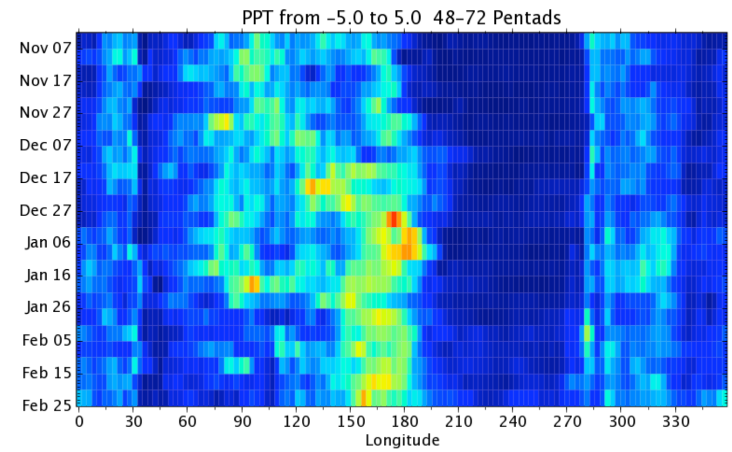
Tropical Precipitation Variability

Precipitation averaged over 5-day intervals and averaged from 5N to 5S between November 1992 and February 1993

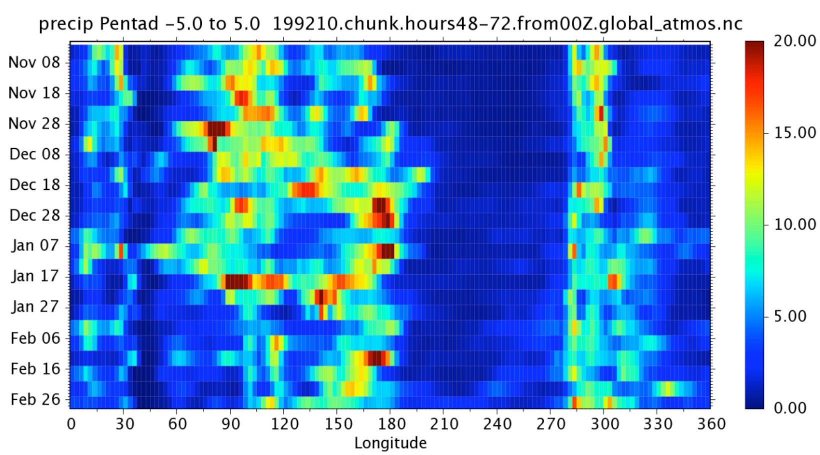
Satellite observations



CAM3 (Day 3)



AM2 (Day 3)



CAM3 with new closure (Day 3)