Assessing climate model errors by comparison of weather forecasts to observations

Presented to

Energy and Environment Directorate Review Committee

March 7-9, 2006

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Energy and Environment Directorate

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.
UCRL-PRES-XXXXXX

Climate model errors in the simulation of moist processes cause climate change uncertainty

- **Climate models are the primary tool used to make predictions of climate change**
- **These comprehensive models contain uncertain components to which the climate change predictions are very sensitive**
- **A component which causes a great deal of uncertainty is the representation of moist processes of the atmosphere (i.e. clouds)**
- **We are interest primarily in two impacts of clouds**
  - *Radiative Impact ← important for global mean temperature*
  - *Hydrologic Impact (i.e. precipitation) ← important for land surface and global circulation*

Climate model errors in the simulation of moist processes are due to a lack of resolution

- The representation of clouds is difficult in climate models because their horizontal resolution of order 100 kilometers is much greater than the scale of clouds which is of order 1 kilometer or less
- Climate models represent the effects of clouds by a "parameterization" which is a mathematical representation of cloud effects in terms of the variables resolved by the model. Because these "parameterizations" are approximate, models make significant errors in the simulation of moist processes
- How do we reduce the uncertainty of climate change predictions that is due to the uncertain and incorrect parameterization of moist processes?

The LLNL CAPT Project provides diagnostic assessment of climate model errors

- CAPT is an acronym for the *C*limate Change Prediction Program – *A*tmospheric Radiation Measurement *P*arameterization *T*estbed
- In CAPT, we initialize climate models with analyses of the atmosphere from weather forecast centers and perform integrations of short duration (for example, a 10 day simulation). This is similar to numerical weather forecasting
- The results are compared to state-of-the-art cloud observations such as those collected by the DOE Atmospheric Radiation Measurement (ARM) program
- In CAPT, we use the climate models of the National Center for Atmospheric Research (NCAR) and the Geophysical Fluid Dynamics Laboratory (GFDL)
- We test not only the default configuration of these models but new parameterizations that are under consideration for incorporation into the model

Why is weather forecasting the focus of the CAPT project?

- The weather time scale of hours to days is the time scale at which moist processes evolves
- Because the large-scale circulation of the atmosphere will be relatively close to observed in the forecasts we perform, errors in the simulation of moist processes are more likely due to errors in their parameterization
- Because climate model evaluation is not typically done at this time scale, the CAPT project is providing a new type of diagnostic assessment to aid in the improvement of climate models

I will now show examples of CAPT work related to the two key impacts of atmospheric moist processes – radiative & hydrologic

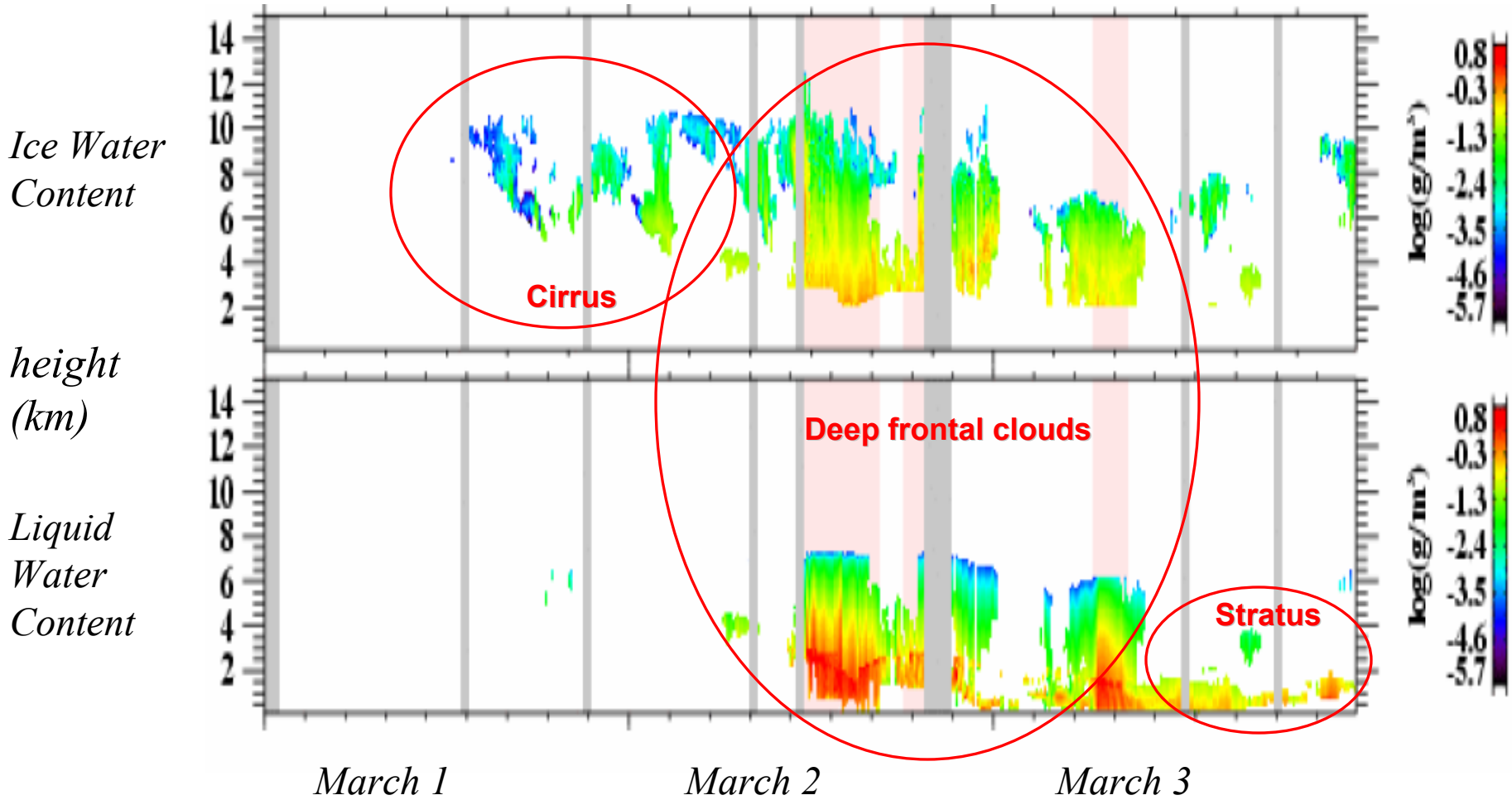
Evaluation of cloud radiative impacts using state-of-the-art observations from ARM

- **The radiative impact of clouds depends in order of priority on**
  - *Is there a cloud?*
  - *How much mass of liquid and ice is in the cloud?*
  - *What is the size of the particles in the cloud?*
- **The DOE ARM program has made great progress retrieving each of these aspects of clouds from remote sensors at its measurement sites**

Atmospheric Radiation Measurement Program Sites

Millimeter Wavelength Cloud Radar

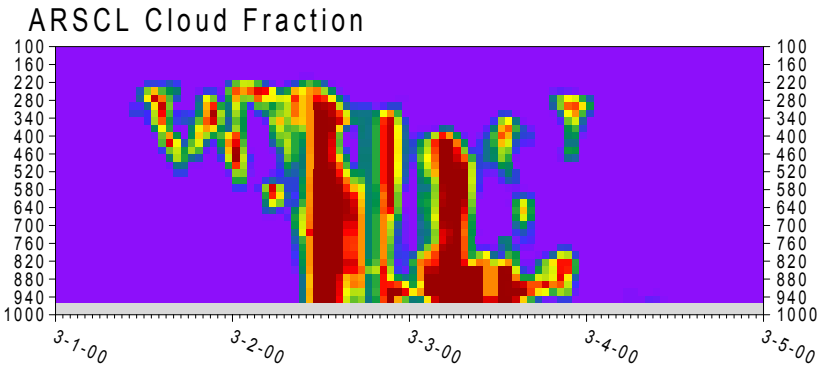
A cloud retrieval example from the ARM radar at the Southern Great Plains site



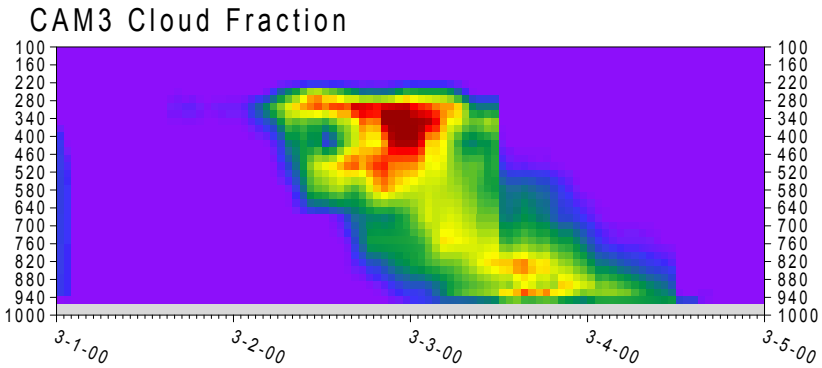
Data courtesy of G. G. Mace (U. Utah)

CAPT forecasts show reasonable agreement in frontal cloud occurrence for this example

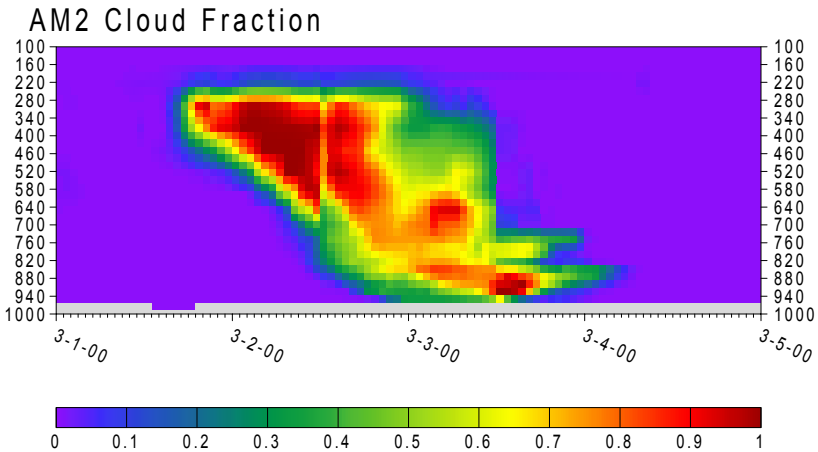
ARM Radar Observation



NCAR Climate Model

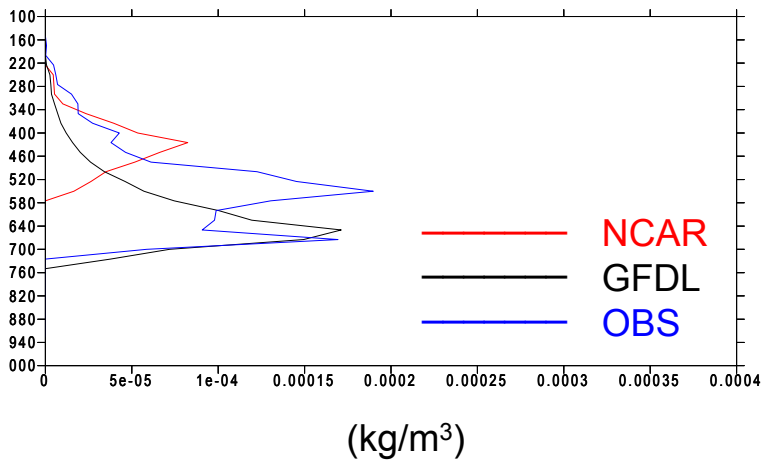


GFDL Climate Model



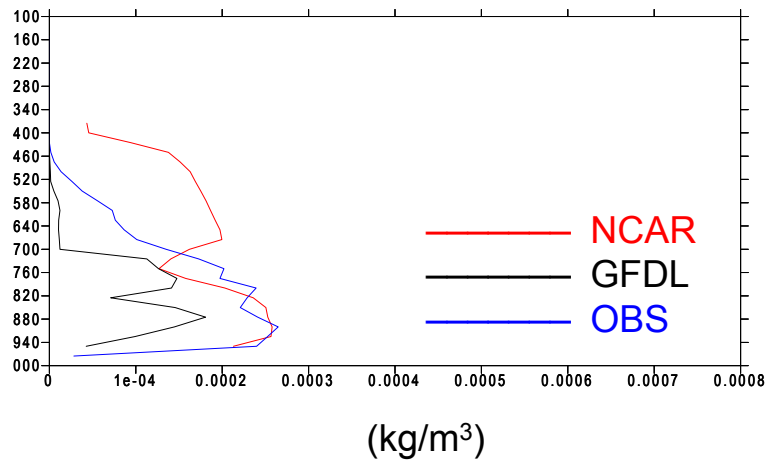
CAPT forecasts of condensate mass differ from each other and observations

Cirrus Ice Water Content



(kg/m^3)

Stratus Liquid Water Content



(kg/m^3)

- **These observations of cloud properties can be used to understand errors in the simulations of cloud radiative impacts and when new parameterizations make improvements in the simulation of clouds**

Evaluation of cloud hydrologic impacts associated with atmospheric convection

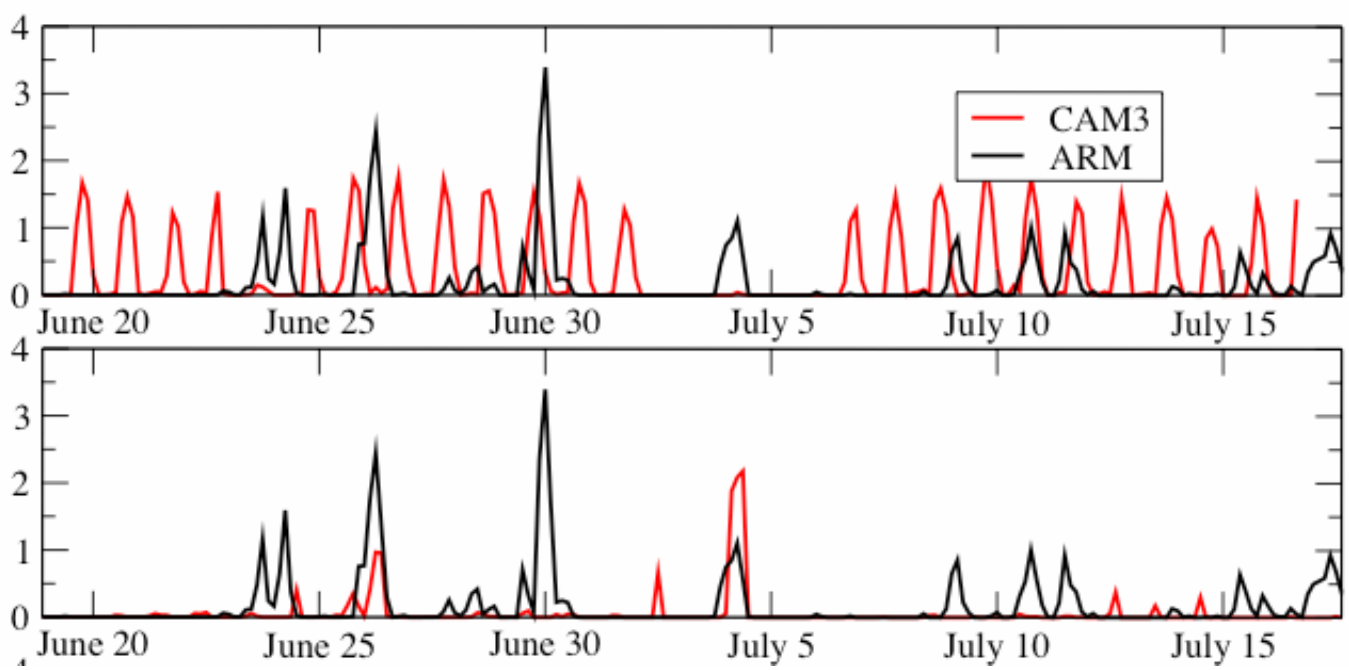
- Representing atmospheric convection in climate models is a very tough problem
- The choice of when convection occurs is critical
- In the current NCAR model, the only requirement for deep convection is that convective instability is present
- Recently, Guanf Zhang (U. Cal. – San Diego) has added an additional requirement for deep convection – the model resolved circulation is itself increasing the convective instability of the grid-box
- Should this change be included into the NCAR model?

CAPT forecasts of precipitation at the ARM Southern Great Plains site

- **The default convection scheme responds to the solar heating during the day and convects because instability is present.** *Nature does not do this!*
- **The modified convection scheme eliminates the spurious midday maximum of precipitation but significantly underestimates the amount of precipitation**

Original Model

Modified Model



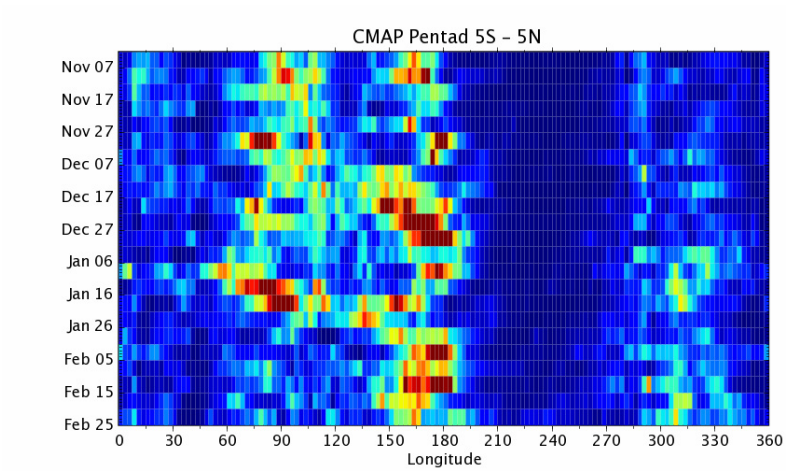
CAPT forecasts of tropical precipitation

- **Tropical convection is very important**
  - *The majority of tropical precipitation occurs through convective processes*
  - *The latent heat release in the clouds drives the large-scale circulation of the atmosphere not only in the tropics but globally*
  - *The response of convection to anomalous ocean conditions is crucial to the evolution of El Niño*
- **With CAPT we are simulating a period in 1992-93 during which a large field program called "TOGA-COARE" occurred in the western Tropical Pacific**
- **How does the parameterization change proposed by Guang Zhang affect the NCAR model simulations of tropical precipitation?**

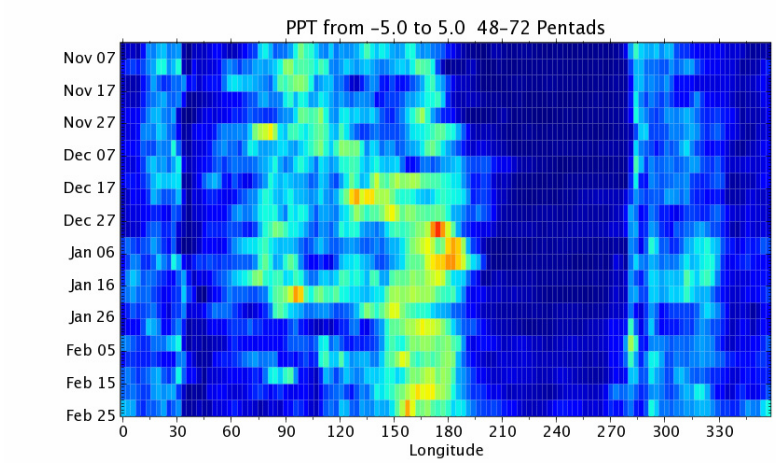
Different representations of convection can strongly affect precipitation intensity

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

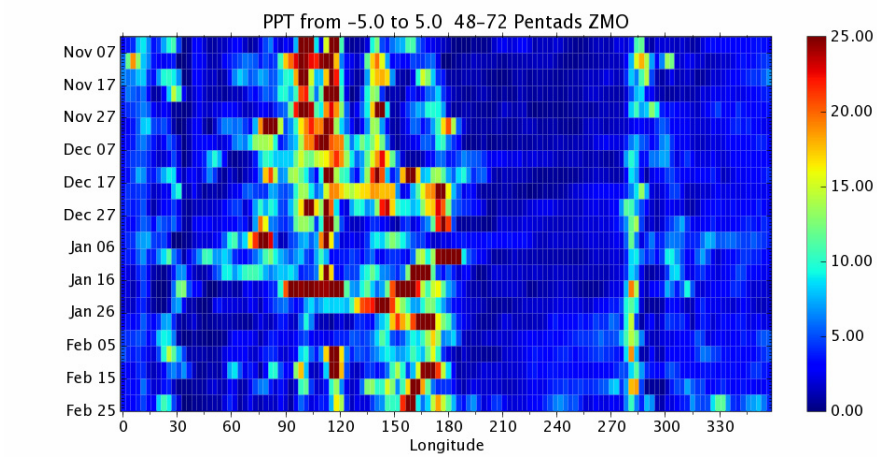
Satellite observations



Original Model



Modified Model



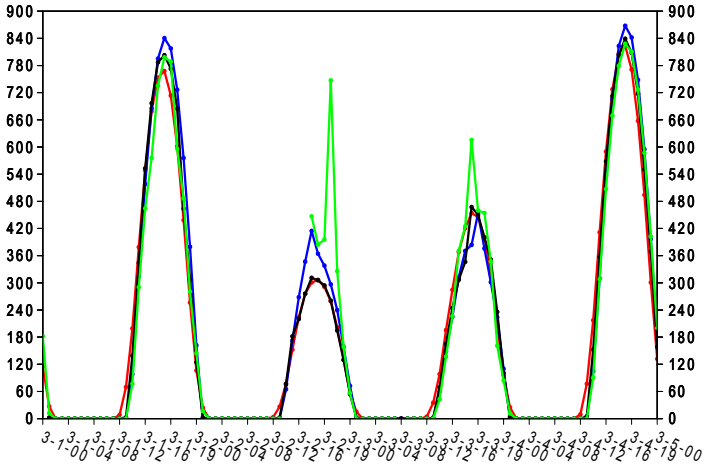
The CAPT project aids in the improvement of climate models

- **The CAPT project provides diagnostic assessment of the simulations of moist processes by climate models at the weather time scale**
  - *The tests of model simulations against data is a necessary step to creating improved climate models*
- **Reasons for optimism**
  - *Increasingly advanced observations of clouds*
  - *Climate models are increasingly getting clouds to happen in the right places*
  - *The advanced observations permit understanding of the processes associated with clouds – this understanding then can be incorporated with ingenuity in improved parameterizations of cloud processes*

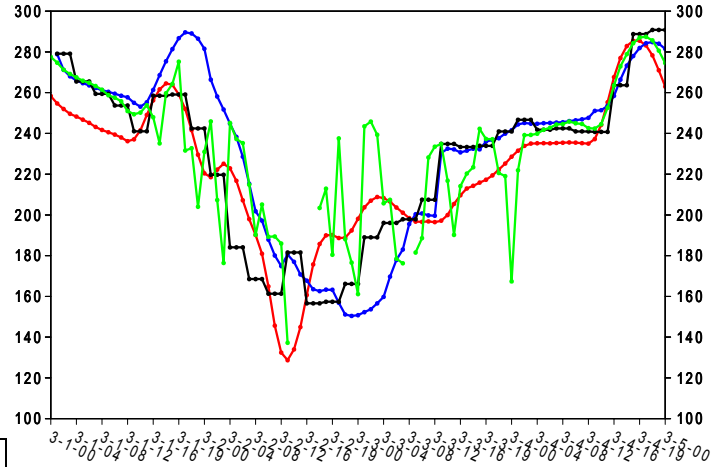
EXTRA SLIDES

Radiative simulations for March 1-3, 2000

SW TOA

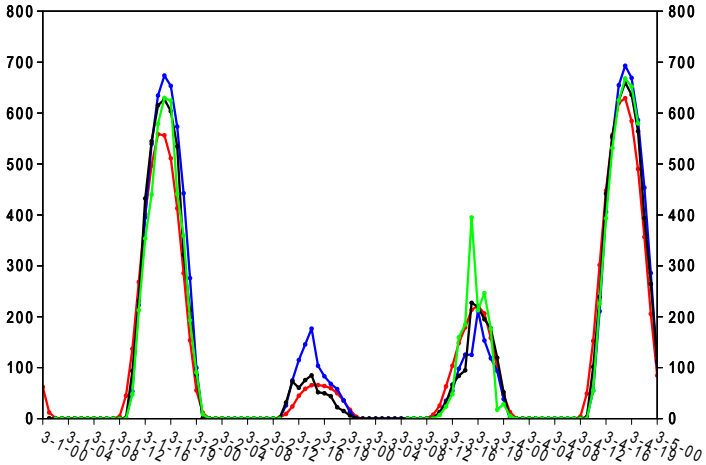


LW TOA

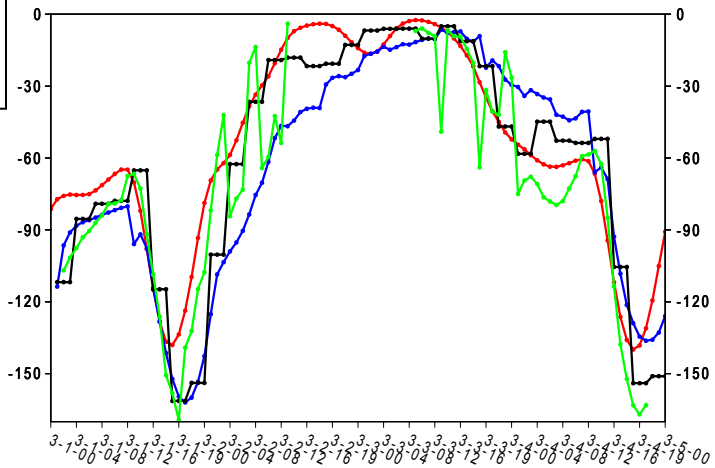


Red = ARM
Black = GFDL
Green = ARM CF
Blue = NCAR

SW SFC



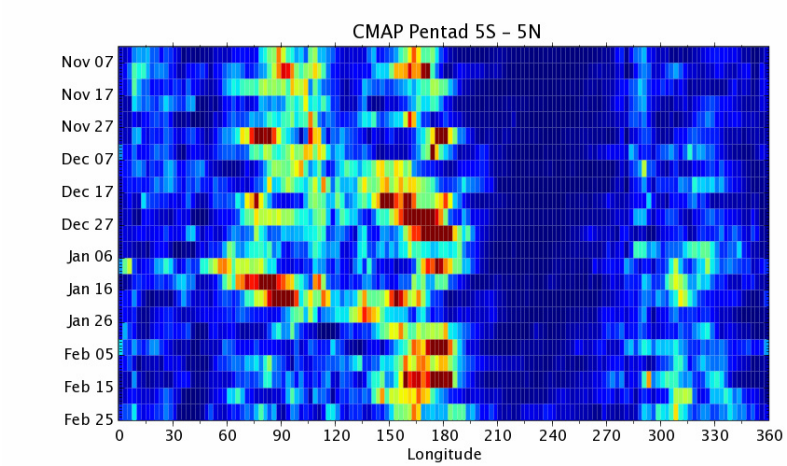
LW SFC



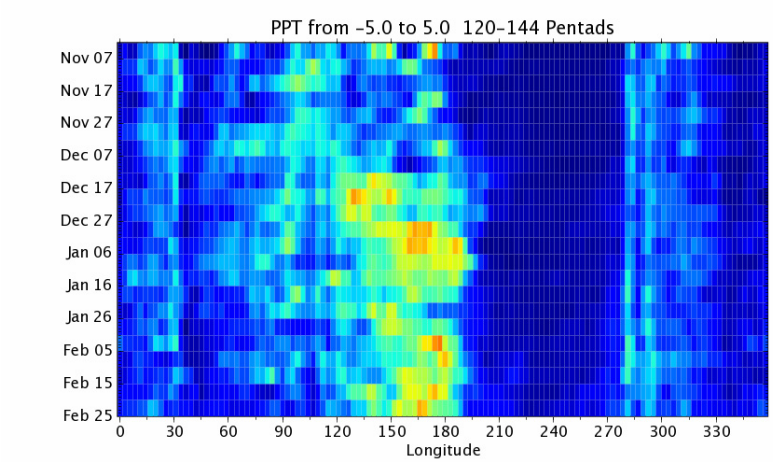
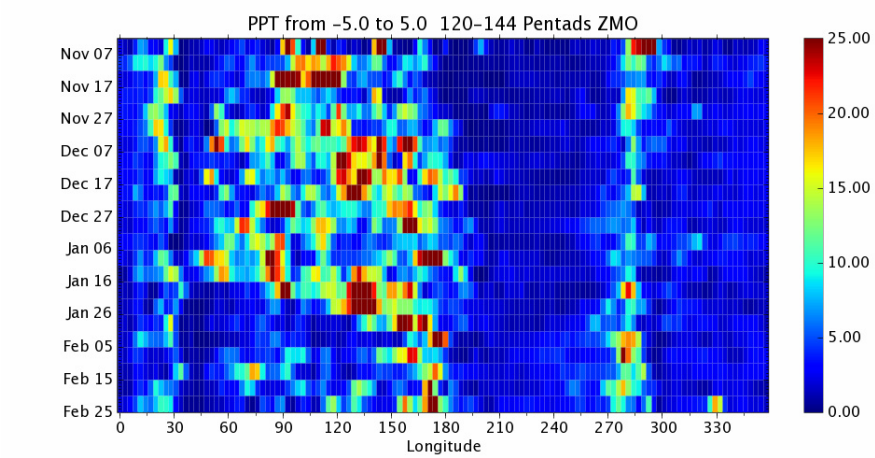
Day 6 simulations of tropical precipitation

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

Satellite observations



Original Model



Modified Model