The CCPP-ARM Parameterization Testbed (CAPT):

Evaluating Climate Models in a Weather Forecasting Framework

Gerald L. Potter[1], David L. Williamson[2], Thomas J. Phillips[1], Richard T. Cederwall[1], James S. Boyle[1],
Michael Fiorino[1], Justin J. Hnilo[1], Jerry G. Olson[2], Shaocheng Xie[1], and J. John Yio[1]

[1] Lawrence Livermore National Laboratory (LLNL)

[2] National Center for Atmospheric Research (NCAR)

This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48 and was supported by the U. S. Department of Energy Office of Biological and Environmental Research (BER), Climate Research Division. This work also was partially supported at the National Center for Atmospheric Research (NCAR) by the Climate Change Prediction Program (CCPP), which is administered by the USDOE Office of Science, BER program. NCAR is sponsored by the National Science Foundation.

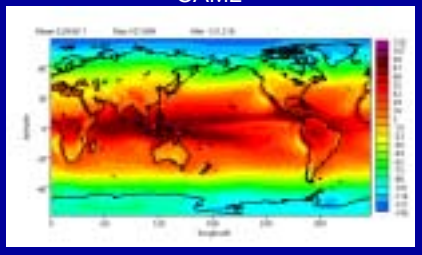
Outline

- What is CAPT - why do we need a new way to improve models?
- Description of the CAPT methodology
- Examples from implementation in NCAR GCM:
  - Identifying moisture prediction problems
  - Improving convective parameterization
- Future plans

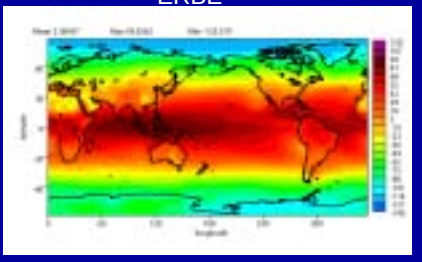
It is easy to identify large systematic errors that need correction in climate models

Annual Average net radiation at the top of the atmosphere

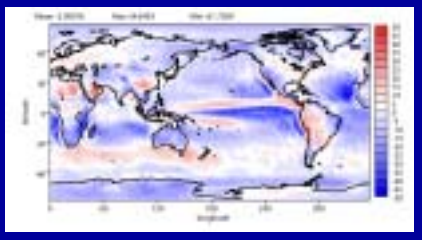
CAM2



ERBE

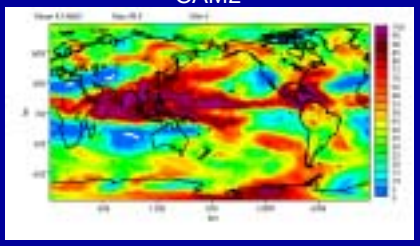


CAM2-ERBE

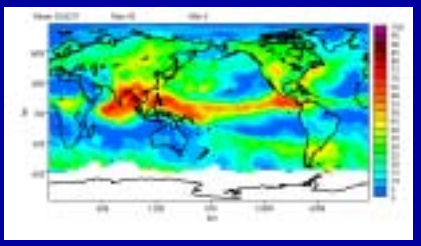


High clouds in the CAM2 compared with ISCCP

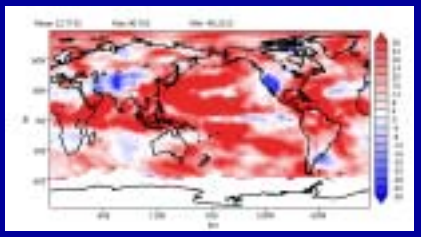
CAM2



ISCCP



CAM2 - ISCCP



Basic philosophy

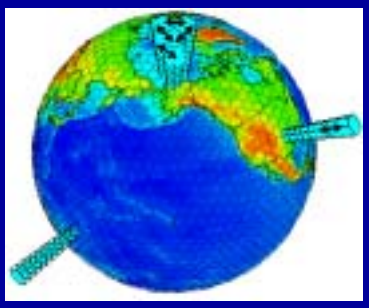
- Study progression of the model's drift away from initialization
  - Short simulations
  - Errors are likely in the parameterization of physics (not large scale motions)
  - Directly comparable to intensive observations - connection to CEOP

What is CAPT?

CAPT = CCPP-ARM Parameterization Testbed

Organizational aspects

- *CAPT combines the strengths of 2 Dept. of Energy programs with complementary missions:*
  - **CCPP (*Climate Change Prediction Program*)–** focus on GCM climate performance
  - **ARM (*Atmospheric Radiation Measurement*)–** focus on column observations of radiation & cloud processes and their parameterization in GCMs
- *CAPT fosters collaborations between GCM developers (e.g. in* **CCPP***) and parameterization specialists (e.g. in* **ARM***)*



Graphic by Dave Randall

Other approaches to evaluate climate GCM parameterizations…

- In climate simulations nearly impossible to determine the direct causes of errors

  A "bottom line" test, but…
  - subject to interactions/compensating errors of all GCM components
  - only a statistical comparison, can't easily relate to particular processes
- In predictions of operational NWP GCMs

  Large-scale dynamics are realistic, *so that forecast errors are mainly due to deficiencies in physics parameterizations*, but
  - model resolution is much higher than that of typical climate GCM
  - parameterizations may not be designed for climate simulation - this is changing

Using CAPT to evaluate climate GCM parameterizations…

Initialize the climate GCM from a global NWP analysis (or reanalysis), then make short-range (~ 5-day) weather forecasts

- GCM dynamics start close to "truth" - initialized with T, U, V, Q, and Ps
  - The remaining fields are from the model history
- GCM systematic errors then are mainly due to physics parameterizations

Evaluate these model predictions using high-frequency weather/physics analyses & observations:

- GCM evaluation linked to specific processes (i.e. not just statistical comparison)
- More comprehensive parameterization testing than in SCM/CRM setting
  - All feedbacks are included
  - less stringent observational requirements than in SCMs/CRMs (since all dynamical forcings are supplied by the GCM)

CAPT = CCPP-ARM Parameterization Testbed

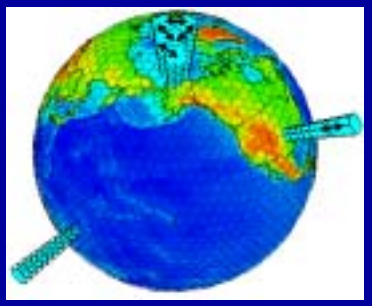
Methodological aspects

CAPT strives to provide a flexible user environment for running a climate GCM in weather-forecast mode, and for evaluating its parameterizations in this setting:

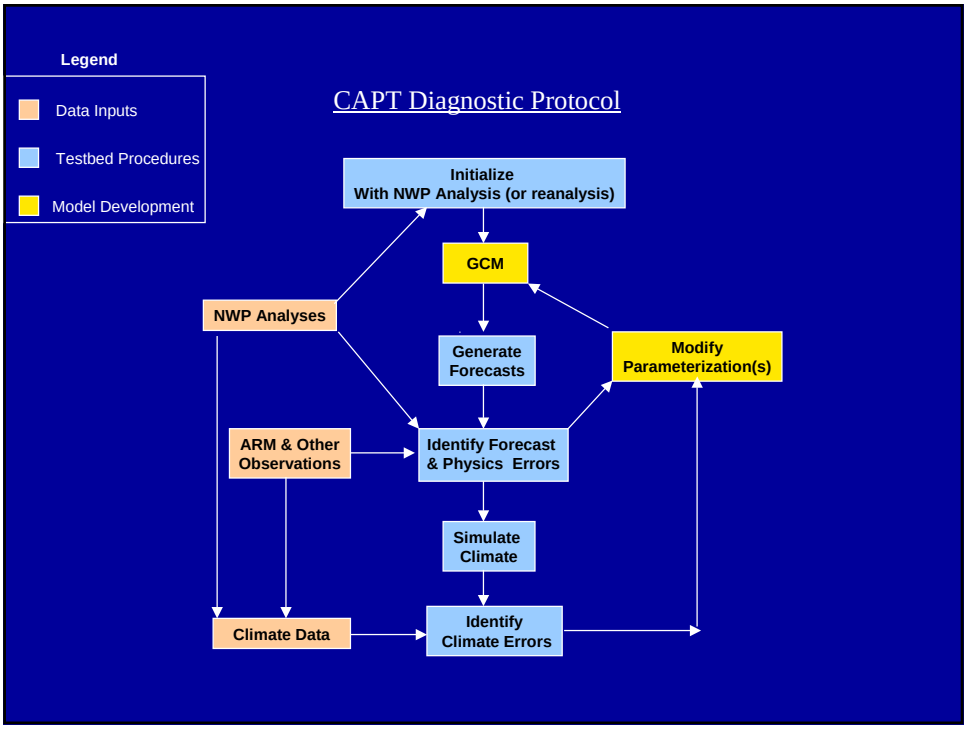
- Apply 6-hourly reanalyses both to initialize the model and to evaluate global forecasts of state variables

- Use high-frequency (~ 3-hourly) ARM observations to identify deficiencies in GCM physics parameterizations, and to test scheme modifications

- Develop algorithms/software to make this process convenient for GCM and parameterization developers

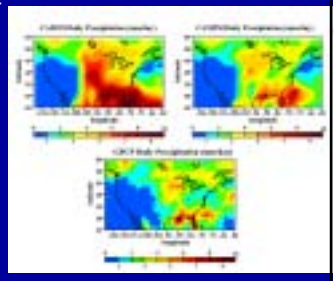


Graphic by Dave Randall



Implementation for NCAR Community Atmosphere Model (CAM2)

1. Initialize CAM2 for each day of the June/July 1997 ARM/SGP IOP using ECMWF ERA40 and NCEP R2 6-hourly reanalyses that are mapped to the model's T42 L26 resolution.
2. Every day of the June/July 1997 IOP (~June 18 to July 17), generate 5-day forecasts
3. Compute the mean (systematic) departures of CAM2 forecasts from ARM/SGP observations.
4. Diagnose these systematic forecast errors, which are indicative of parameterization deficiencies.
5. Use insights on systematic forecast errors to modify these parameterizations → *test impact by repeating Steps 1 - 4 .*
6. Evaluate impact of parameterization changes on CAM2 large-scale climate simulation.

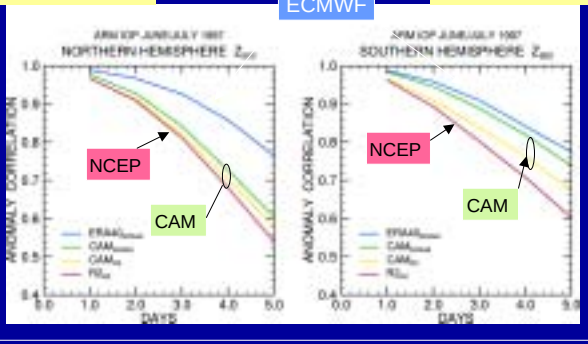


Forecasting with CAM2 - large scale dynamic features

Hemispheric-average 500mb height anomaly correlations in June/July 1997

Northern Hemisphere | Southern Hemisphere

ECMWF

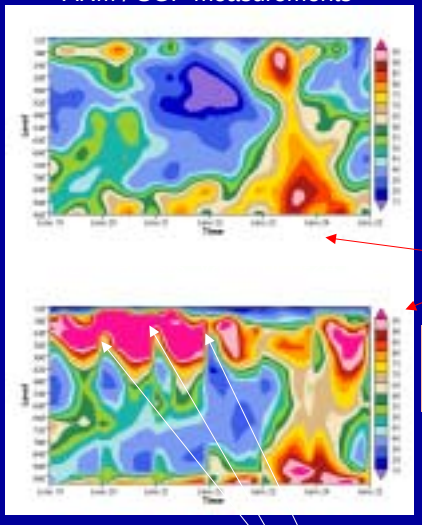


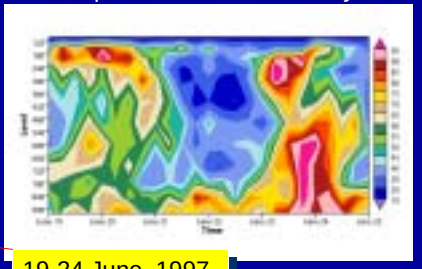
CAM2 500 mb dynamical forecast skill is “competitive” with that of the ECMWF and NCEP reanalysis models

Relative humidity at ARM (SGP) is indicative of a major systematic error

ARM / SGP measurements

Interpolated ECMWF reanalysis



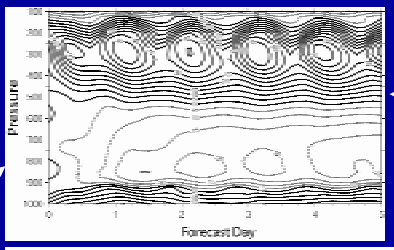


19-24 June, 1997

CAM2 forecasts of atmospheric moisture don’t compare as favorably with observations, in particular at the ARM / SGP site.

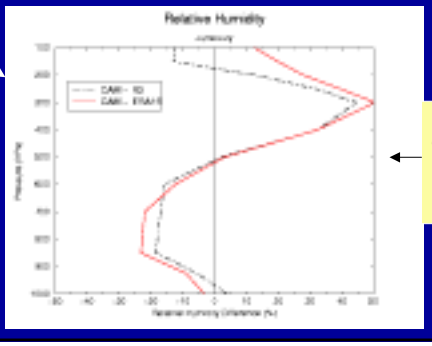
Model re-initialized daily

***At the ARM/SGP site,* a similar error structure is seen in the CAM2's mean 5-day forecasts of atmospheric relative humidity for June/July 1997, as well as in a 10-year June/July climatology:**



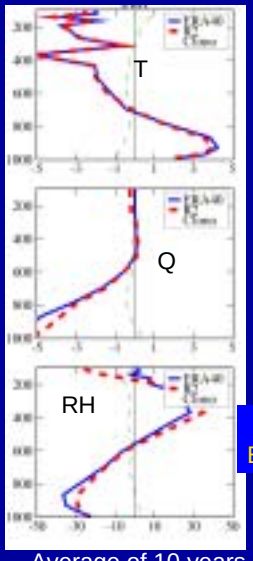
Mean June/July 1997 CAM2 ***forecast errors*** relative to ARM observations

ARM/SGP Site



10-year June/July CAM2 ***climatology errors*** relative to interpolated ECMWF & NCEP reanalyses

CAM2-observed ERA and R2 (climatology June)

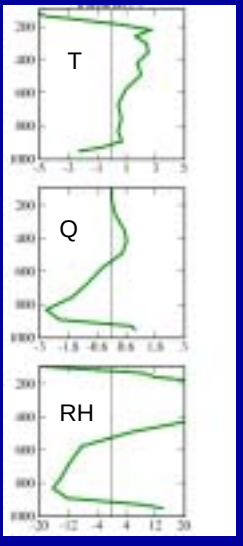


Average of 10 years

At the grid point corresponding to the ARM site ~37N 97W

Looks the same
But for different reasons

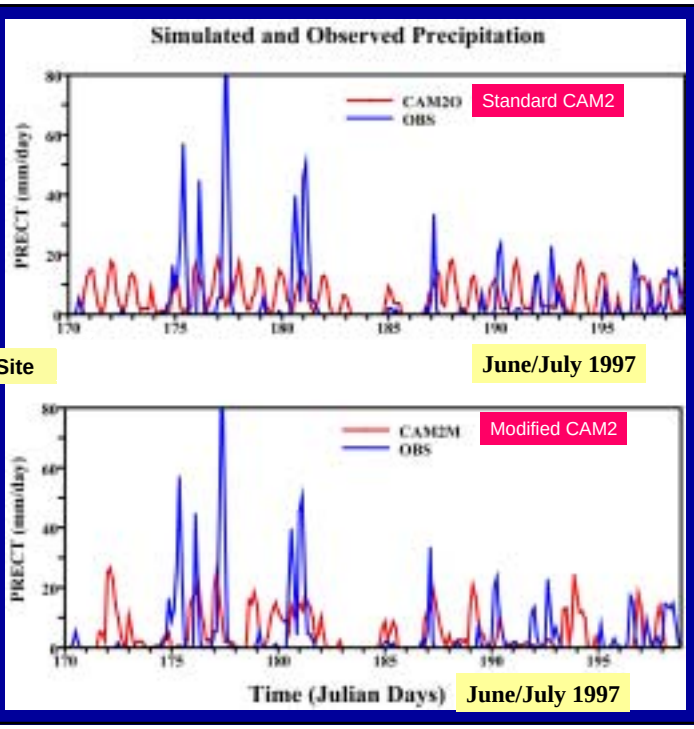
CAM2-observed ARM (June 1997)



Average of 24-hour forecasts

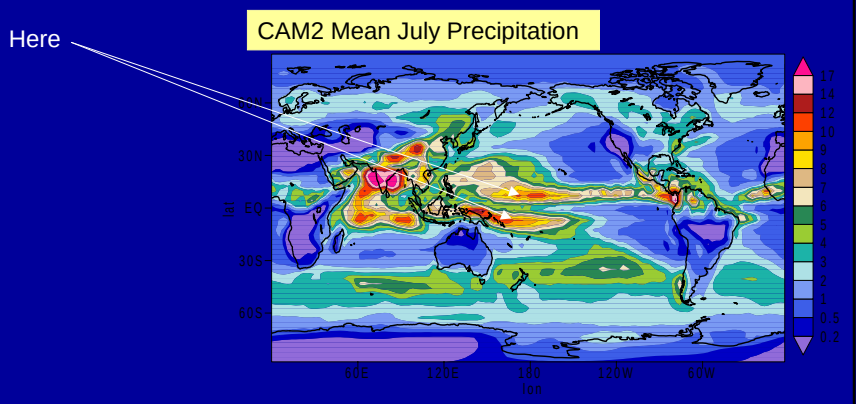
Further work on CAM2 June/July 1997 case study…

- The CAM2 atmospheric humidity error manifests itself in other ways:
  - much more frequent rain-out of moisture,
  - but with substantially lower intensity than in ARM/SGP observations.
- This pattern is reminiscent of what has been found in GCM convective parameterizations tested in single-column models for the ARM/SGP IOP
- In this SCM context, a new convective trigger function (based on dynamical convective available potential energy—DCAPE) showed promise-- see S. Xie and M. Zhang 2000 *J. Geophys. Res.*, 105, 14983-14996.
- Shaocheng Xie has recently implemented the DCAPE convective trigger function in the CAM2.

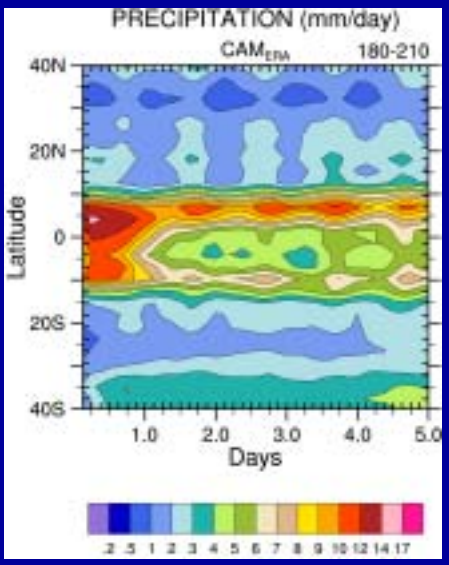


Does this change in CAM2 convective triggering also improve the *large-scale climate simulation* ?

One of the persistent errors in the CAM2 (and other GCMs is a double ITCZ

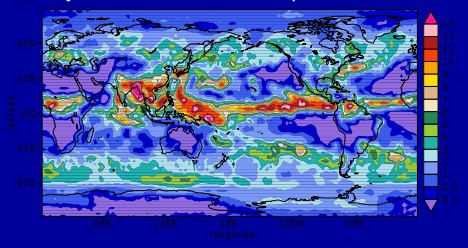


The split ITCZ develops very early in the CAM2 5-day precipitation forecasts.

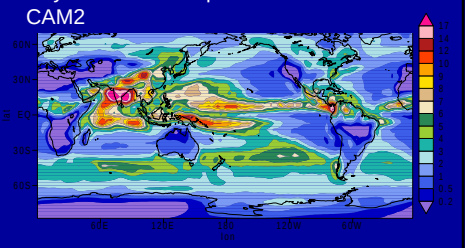


The new trigger suggest a major improvement

July observed GPCP Precipitation



July modeled Precipitation in Standard CAM2



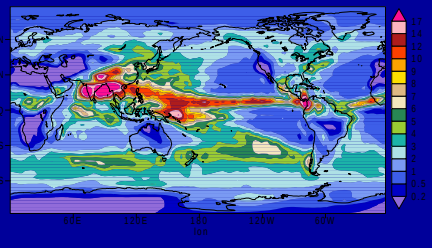
$DCAPE = \{CAPE^*(T^*, q^*) - CAPE(T,q)\}/\Delta t$

Where

$T^* = T + (\partial T/\partial t)_{adv} * \Delta t$

$q^* = q + (\partial q/\partial t)_{adv} * \Delta t$

July modeled Precipitation in Modified CAM2

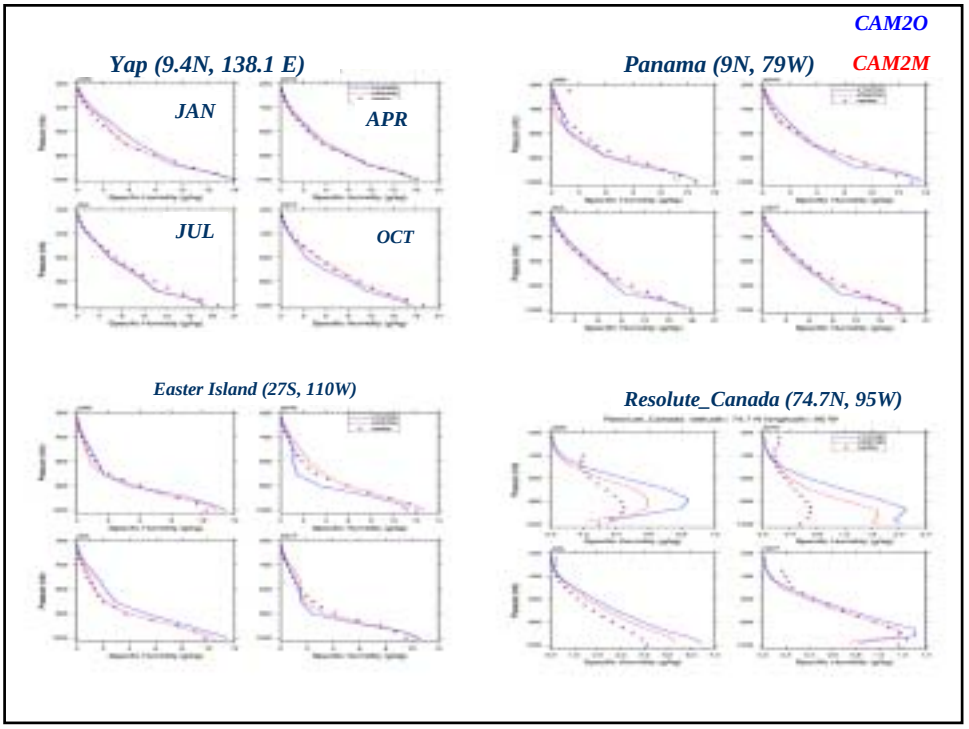


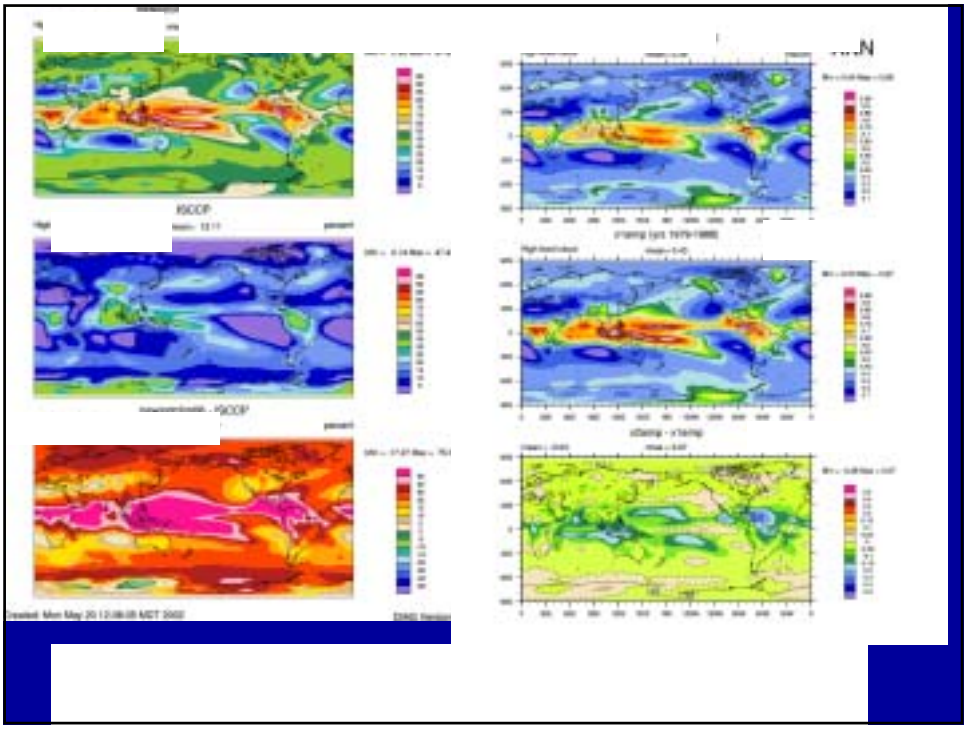
Future Plans

- Publish CAPT methodology and analysis of CAM2
  - Produce quick look plots of all fields for ARM (and CEOP) sites
  - SGP
- Adapt approach for other ARM sites (e.g. Alaska, Tropical West Pacific) and other ARM-like data sets (e.g. GEWEX/CEOP)
- Develop collaborations with other parameterization specialists
- Implement CAPT methodology in more models (e.g. GFDL's GCM)
- Refine CAPT techniques/software (initialization, model diagnostics, etc.), produce MOLTS
- Make the test bed available to the broader GCM community

Announcement: AMS call for papers. San Diego, 2005

…" In addition, there will also be a half-day session on development of in situ, satellite, and model data focused on hydrometeorological processes in the atmosphere and land surface to improve process understanding and development of enhanced climate models…."


CAM2O
CAM2M
Yap (9.4N, 138.1 E)
JAN
APR
JUL
OCT
Panama (9N, 79W)
Easter Island (27S, 110W)
Resolute_Canada (74.7N, 95W)


KSCOP
KSCOP