Low-Latitude Cloud Feedbacks Climate Process Team – Findings and Experiences

Chris Bretherton

University of Washington, Seattle, USA

Goal: Better simulation and understanding of low-latitude cloud feedbacks in present and perturbed climates within NCAR, GFDL, GMAO AGCMs and in the superparameterized CAM.

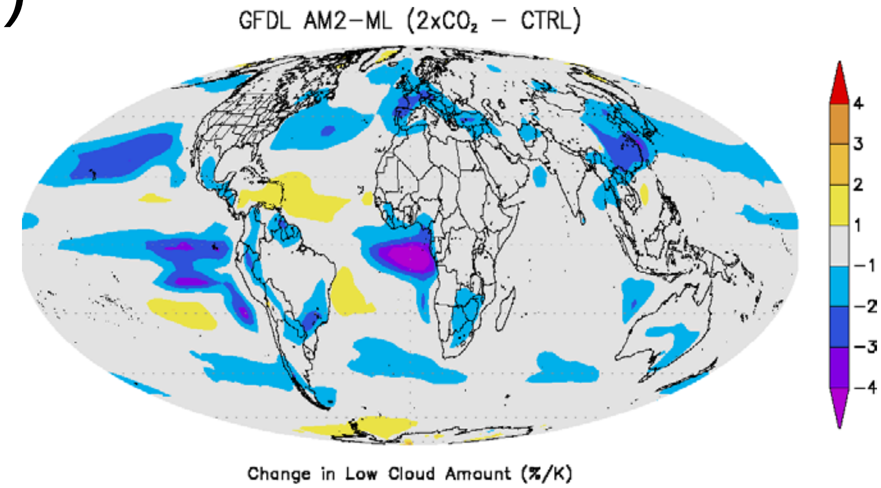
The CPT vision

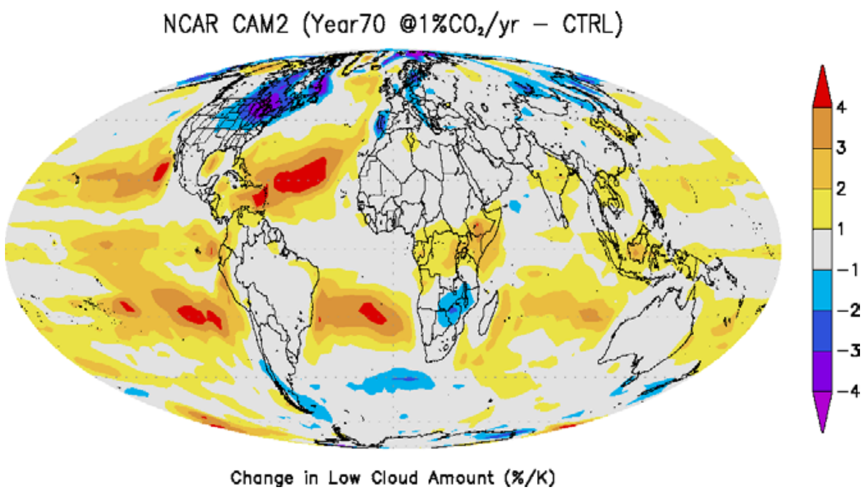
- Progress on key climate modeling problems (e. g. tropical wind and rainfall biases and variability, cloud simulation and feedbacks, hi-lat wintertime surface temperatures) has been slow.
- GCM physical parameterizations sometimes not up-to-date.
- CPTs were proposed by some of us within US CLIVAR five years ago as a way to accelerate improvement of parameterizations and model design of leading US coupled GCMs.
- The idea was to form ‘tiger teams’ including modeling groups and process scientists to work on particularly pressing issues.
- Vertical integration from process observations to climate simulation:
  - Funding for liaisons within modeling groups to work with CPT.
  - Group-focussed approach.
  - CPT involves at least two modeling centers for cross-talk.
  - CPT topics chosen by modeling centers.

The cloud feedbacks problem (ca. Feb. 2003)

With doubled CO2, low-latitude boundary layer clouds systematically:

- decreased in GFDL AM2 (positive albedo feedback) and $\Delta T = 4.5$ K
- increased in NCAR CAM2 (negative albedo feedback) and $\Delta T = 1.5$ K





The low-latitude cloud feedbacks CPT

- Oct. 2003 - Sept. 2006, NSF/NOAA funded via US CLIVAR...may be renewed w. reduced scope thru 2008.
- 8 funded PIs (Bretherton, Khairoutdinov, Lappen, Mapes, Pincus, B. Stevens, Xu, M. Zhang) + NCAR (Kiehl), GFDL (Held), GMAO (Bacmeister).

  Liaisons at NCAR (Hannay), GFDL (Zhao).
- Collaborations with CAPT, GCSS.
- Contributions to 8 submitted publications.
- CPT overviews: Spring 04, 06 US CLIVAR *Variations*.
- www.atmos.washington.edu/~breth/CPT-clouds.html

Clouds CPT strategy

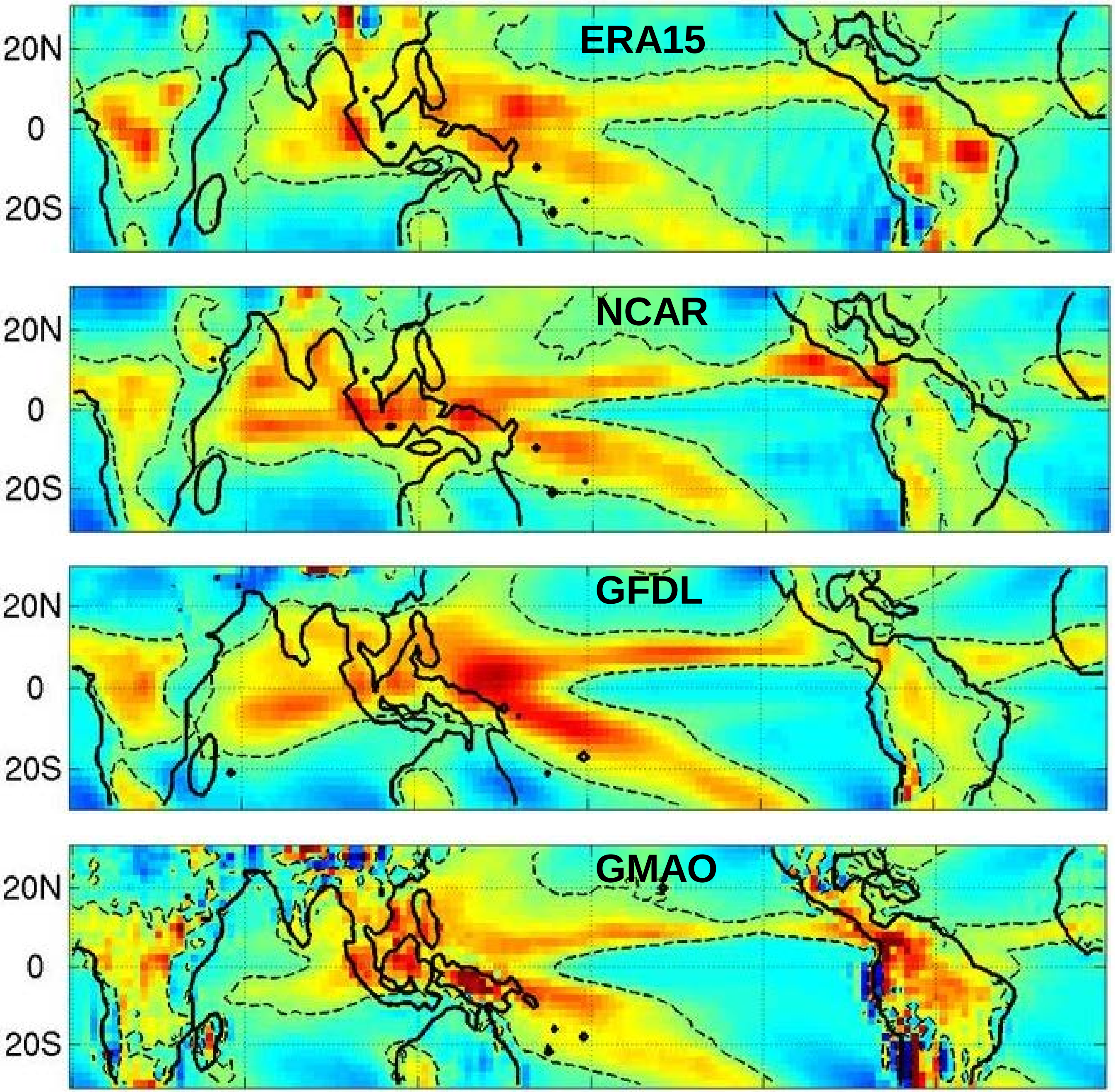
- Compare clouds and cloud feedbacks in participating models, including superparameterization, using modern diagnostics and data sets.
- Use single-column output (e.g. at ARM sites) and modeling (e. g. GCSS cases) to better understand cloud biases and feedbacks.
- Improve moist physics parameterizations accordingly (recognizing that clouds, turbulence, convection, radiation and surface processes all interact).
- Focus on low latitudes, where most cloud is tightly connected with subgridscale processes such as convection, and coupled-model biases are worst.

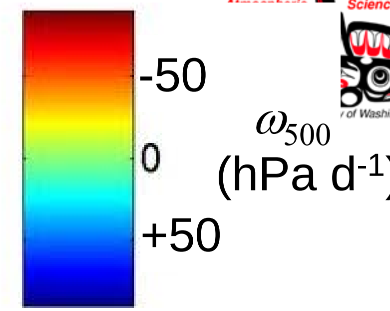
Modus operandi

- Diverse group of PIs active across many projects.
- Initial group activity was getting comparison AGCM simulations with hi-freq column output from centers. Led to nice diagnostic work involving small subset of PIs.
- Annual CPT meetings – intellectually exciting, partially successful at stimulating collaboration.
- Group telecons needed to maintain collaborative activities of external PIs.
- Liaisons crucial to collaborations with people-limited modeling centers.
- CPT successes:
  - new and insightful diagnostic work,
  - testing/nurturing parameterizations ‘in progress’,
  - but not yet implementing totally new parameterizations.

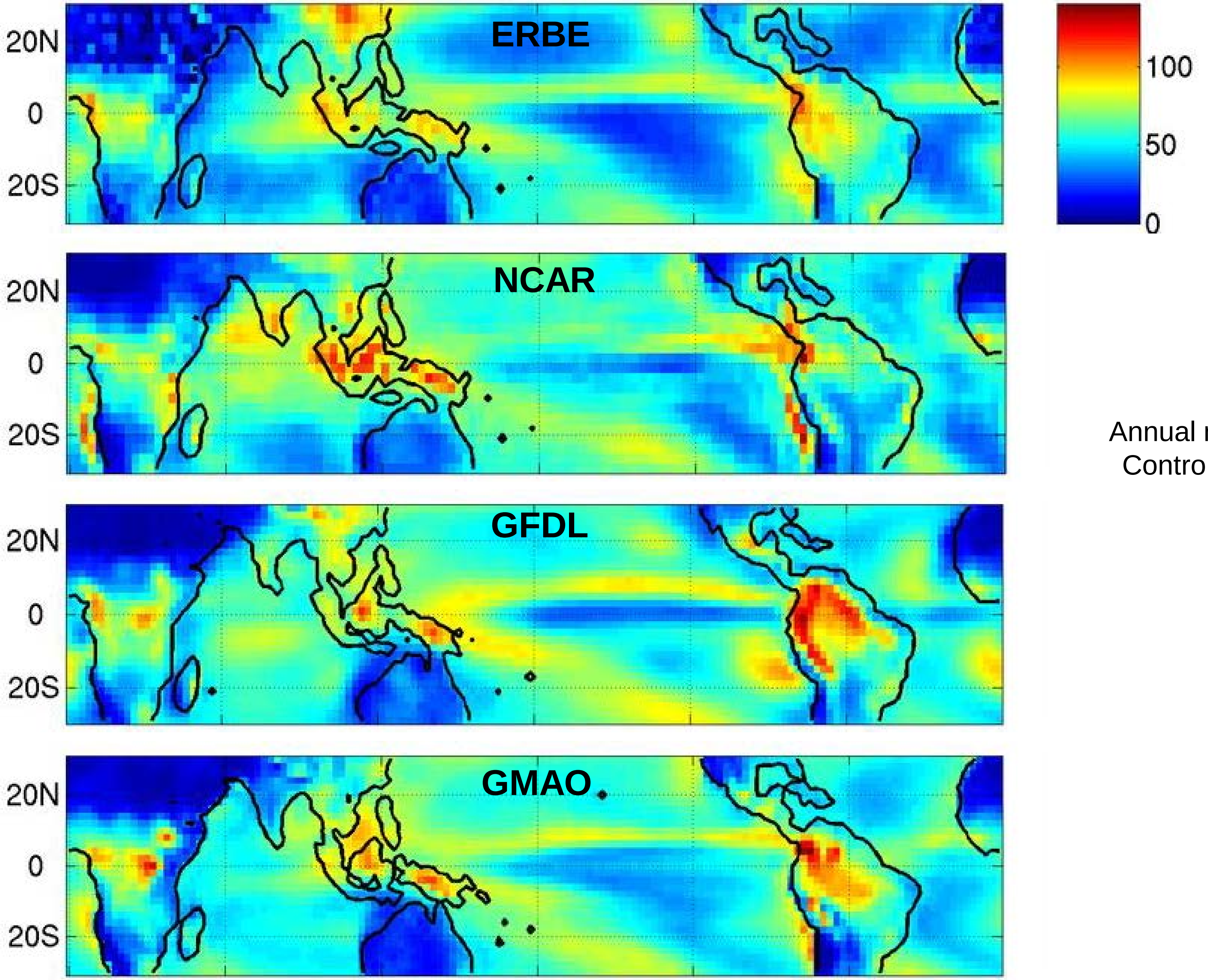
CPT scientific highlights

- Regime-sorted AGCM cloud climatology and feedbacks (including superparameterized CAM3-SP).
- Same boundary layer cloud biases+feedbacks evident in:
  - Single-column AGCM output
  - Idealized single-column modeling
  - Aquaplanet simulation.
  - CAPT forecast-mode simulations
- GFDL climate sensitivity and cumulus parameterization.





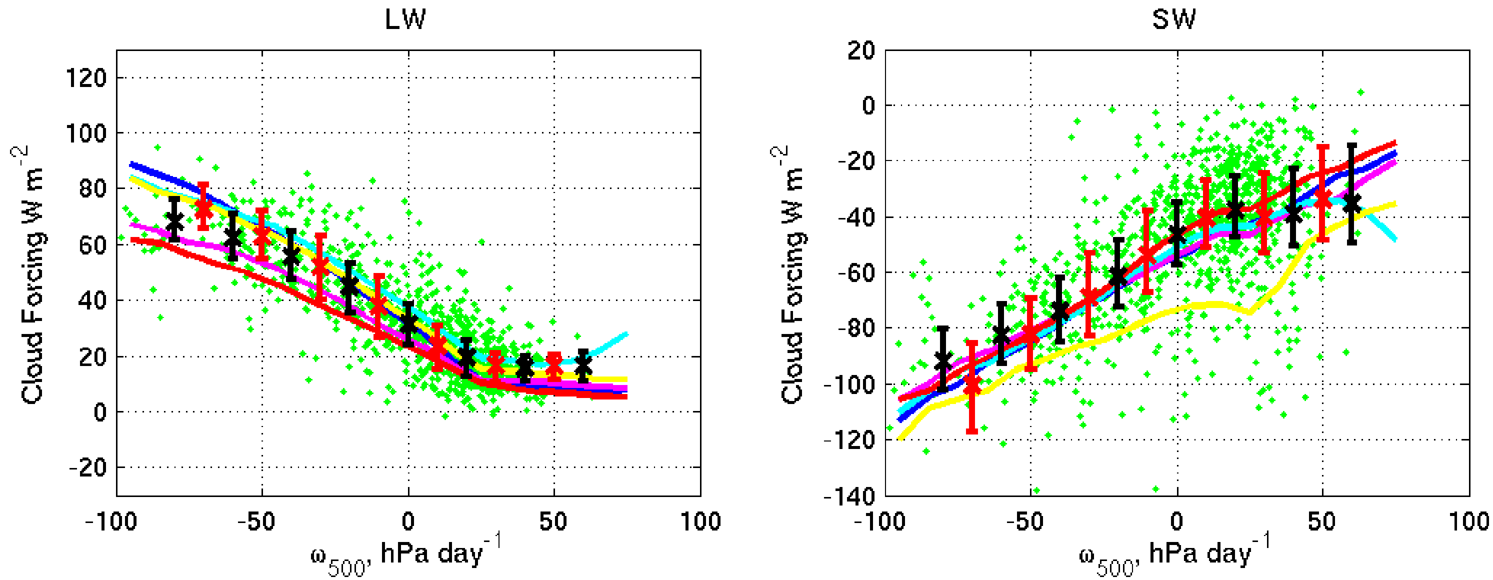
Annual mean
Control run

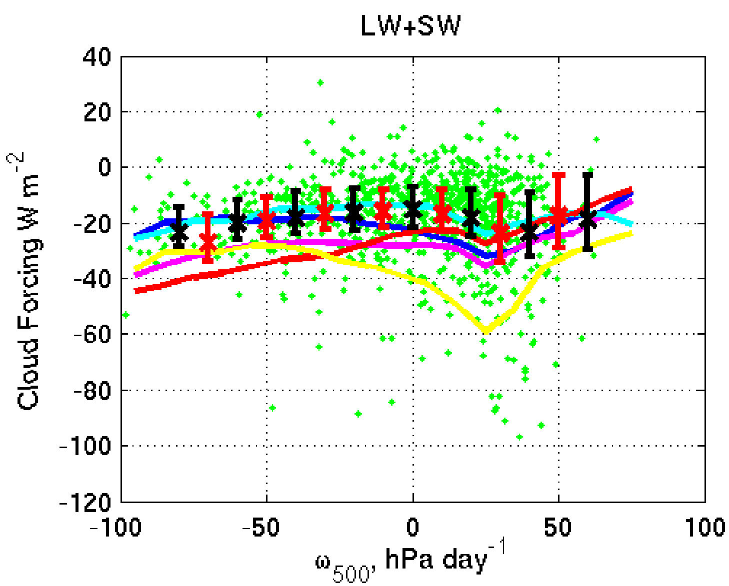


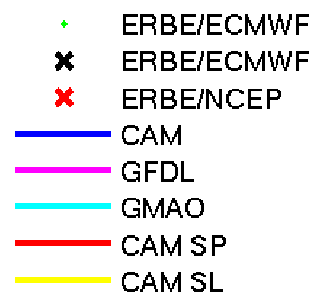
-SWCF
(W m^{-2})

Annual mean
Control run

Tropical TOA Cloud Forcing



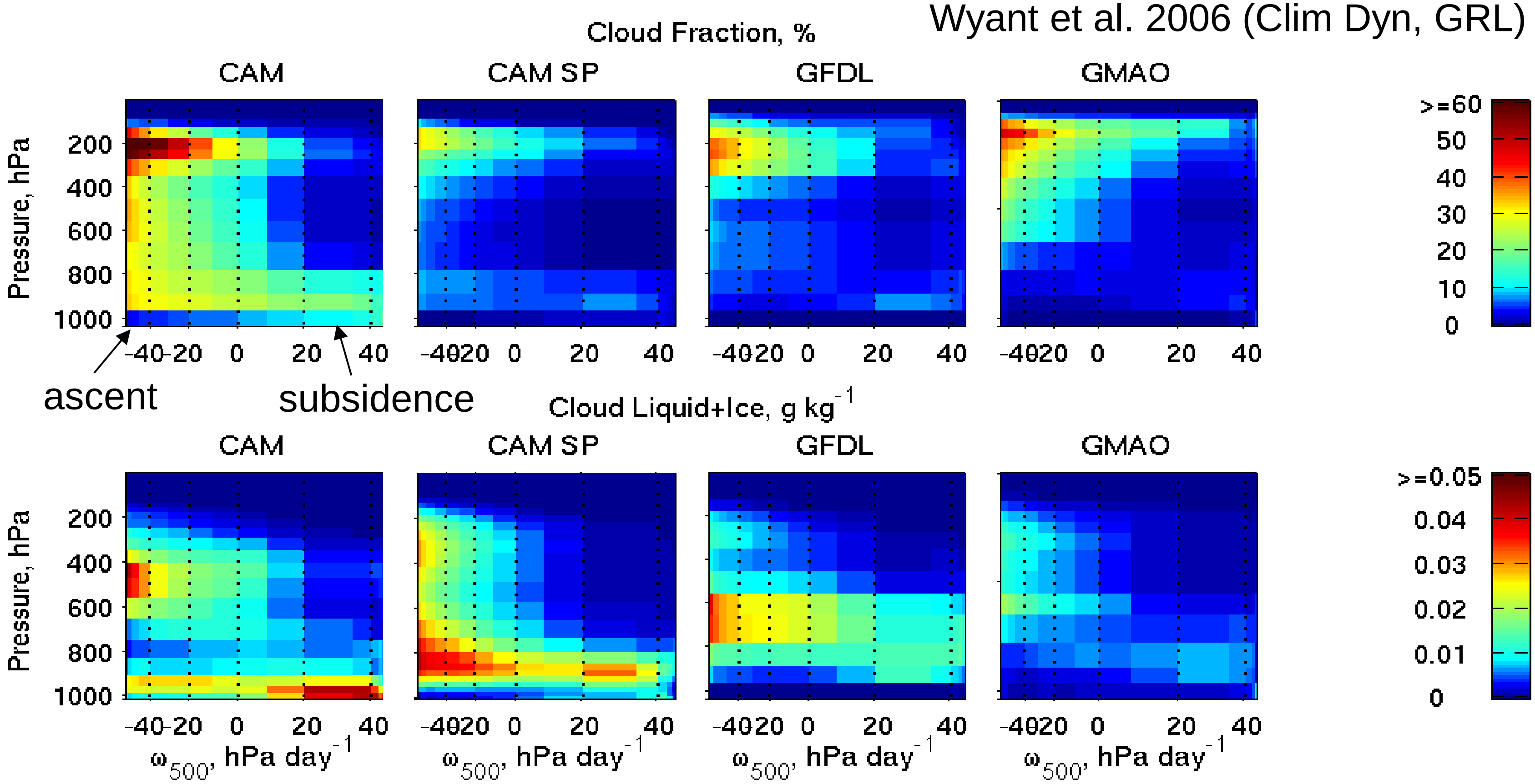




So far, AGCMs look rather good!

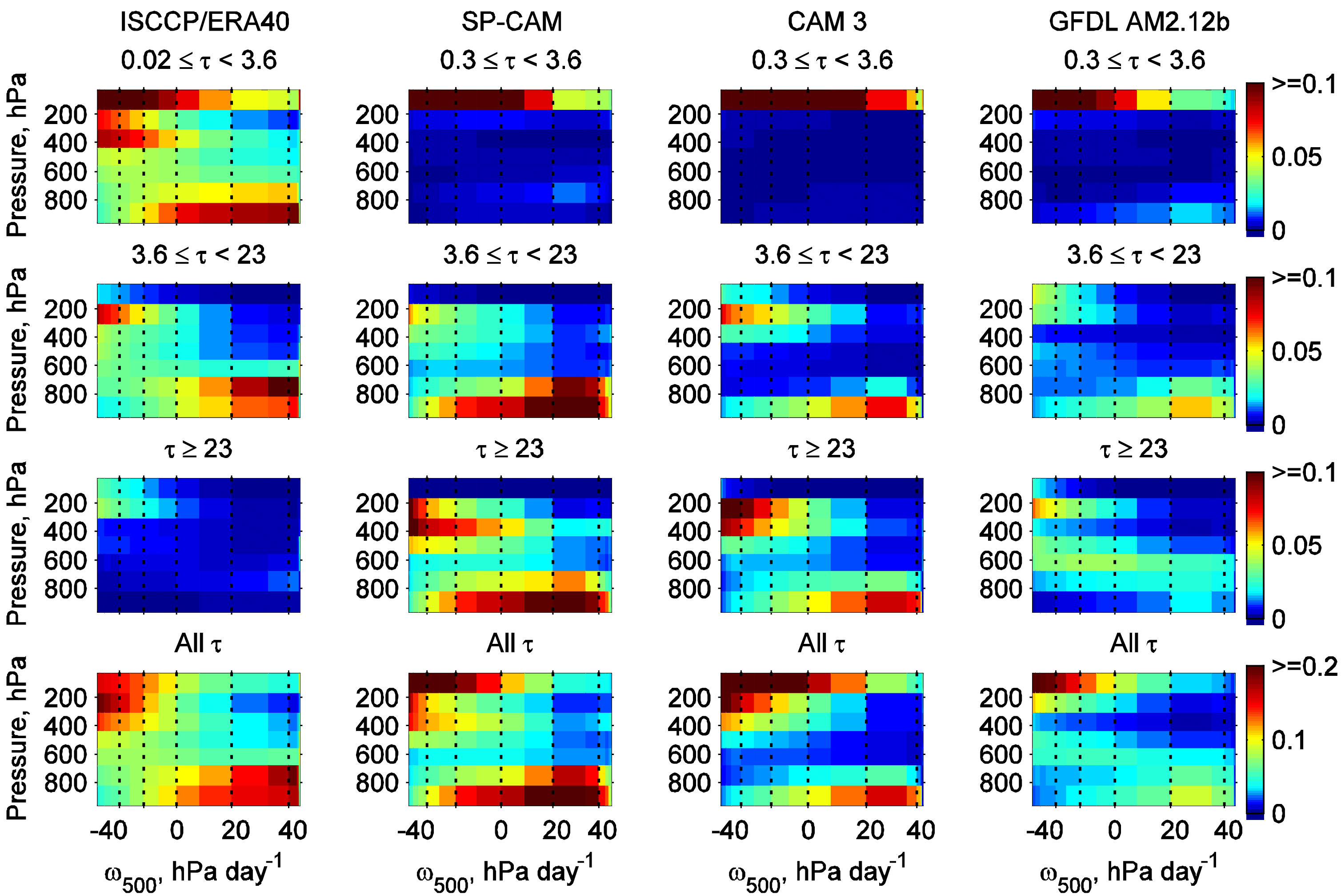
ω_{500} regime-binned 30S-30N cloud climatology

Wyant et al. 2006 (Clim Dyn, GRL)



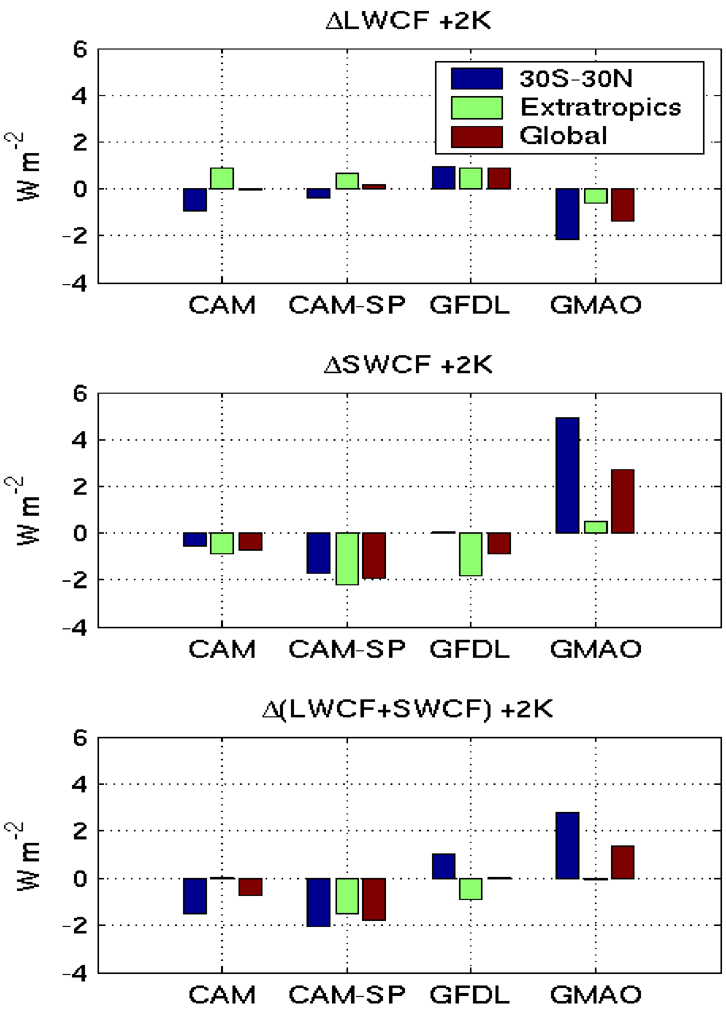
Cloud vertical profiles quite diverse!

ISCCP simulator results



- Superparameterization more realistic than GCMs, though not perfect. GCM CRF good due to ‘tuning’.

CAM3-SP SST+2 climate sensitivity



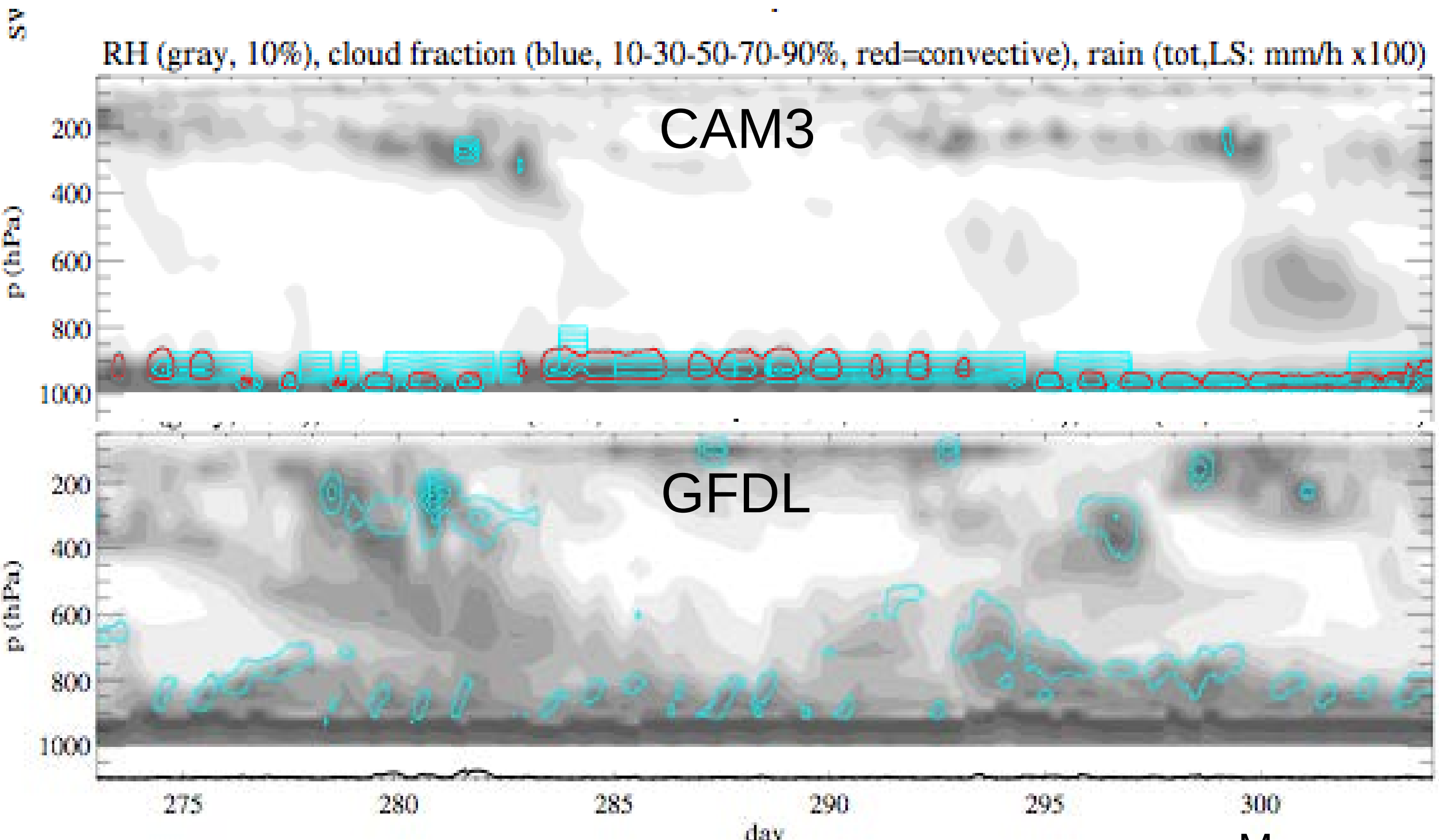
Wyant et al. 2006 (GRL)

- Based on 3.5 yr ctrl, SST+2 runs
- Strong negative shortwave cloud feedbacks in tropics, extratropics, esp. from subsidence regimes.
- Mean BL cloud thickness and fraction both increase
- CAM3-SP λ = 0.41 K/(W m^{-2})

  vs. CAM3 λ = 0.54 K/(W m^{-2})
- Global CRM, DARE results similar.

Single-column analysis

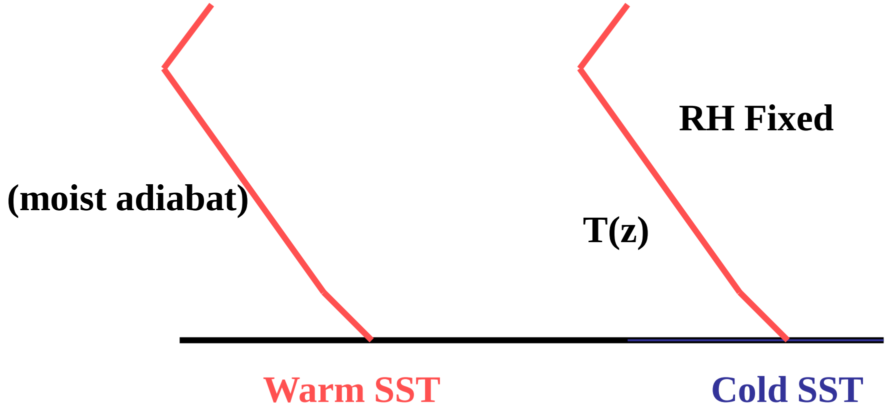
SE Pac Sc (85W 20S), October, every timestep



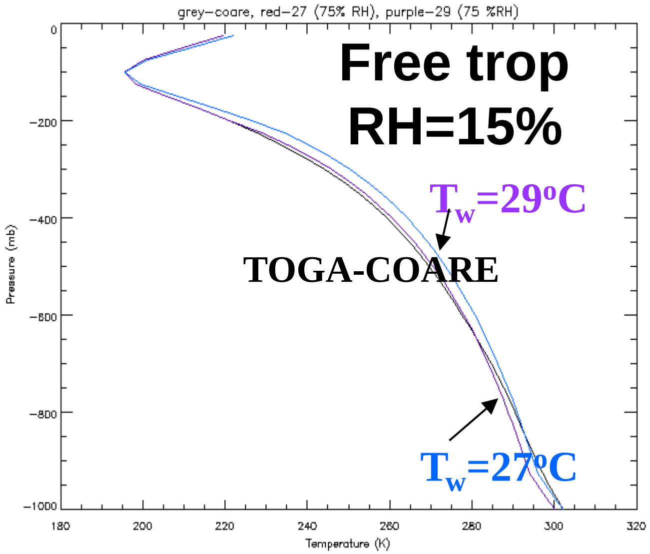
Mapes

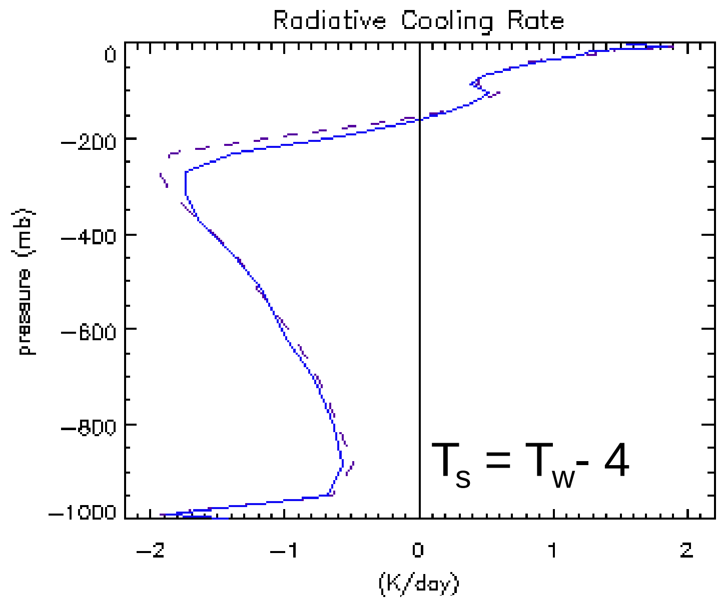
SCM intercomparison (a la Betts-Ridgway, Larsen et al)

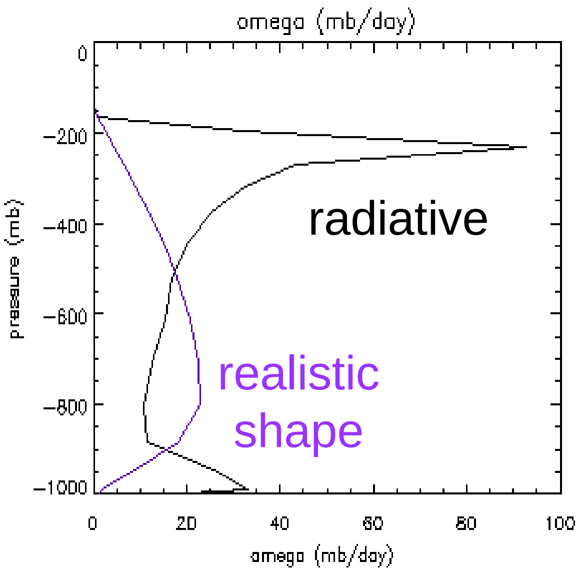
- Single column in subtropical subsidence regime
- Radiative/advective forcings maintain moist-adiabatic, fixed RH profile in free trop.
- Plausible framework for analyzing
  - intermodel CTBL structure differences (previous slide)
  - cloud response to climate warming.
- Led by Minghua Zhang

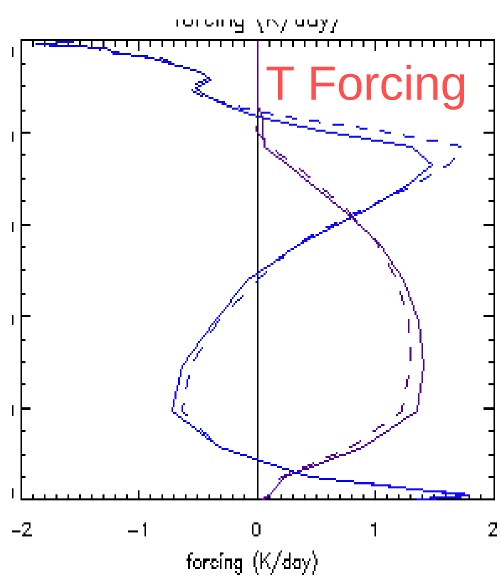


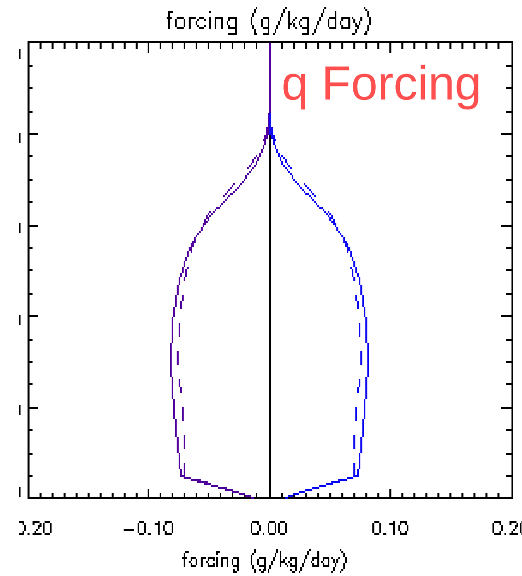
Forcings (maintain steady state w/o CTBL)





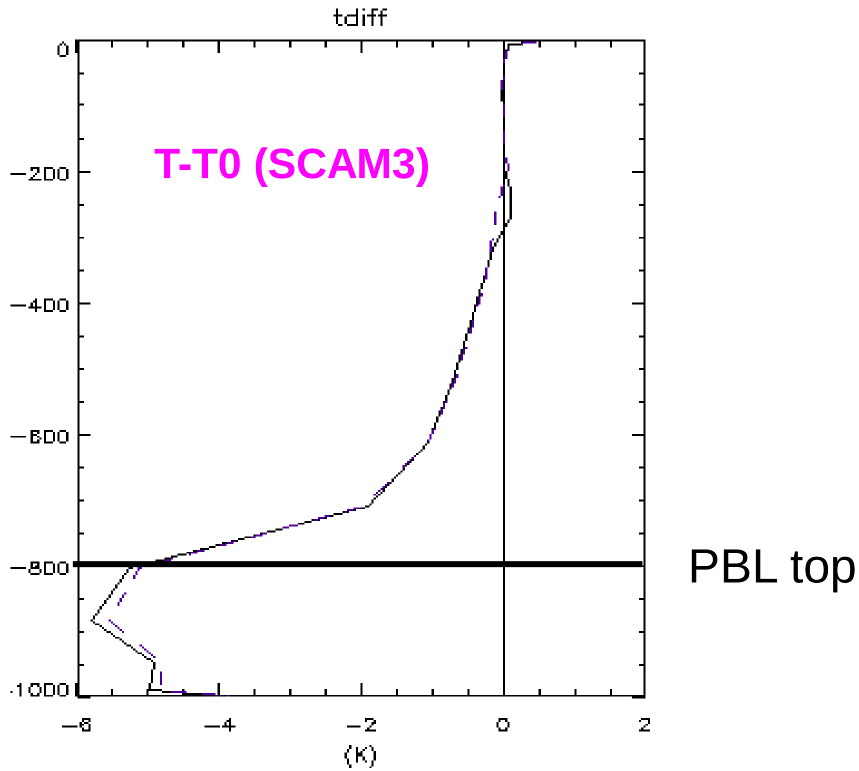






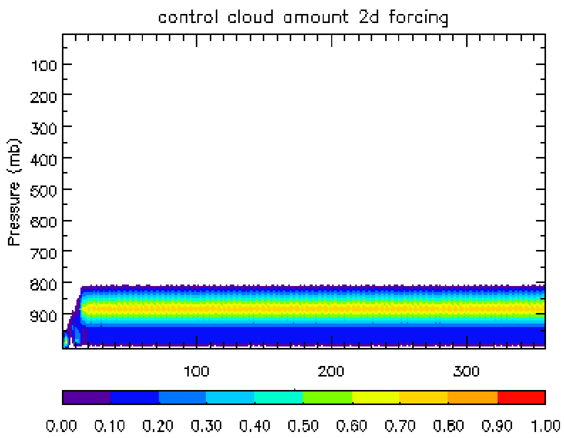
Interesting feedback

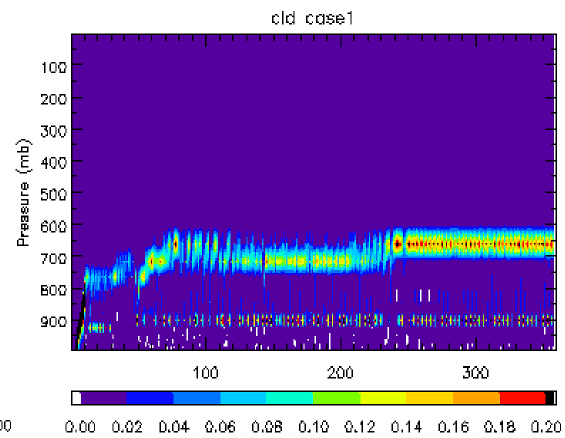
- Anomalous radiative cooling due to underlying cold boundary layer affects free trop. temperature profile.

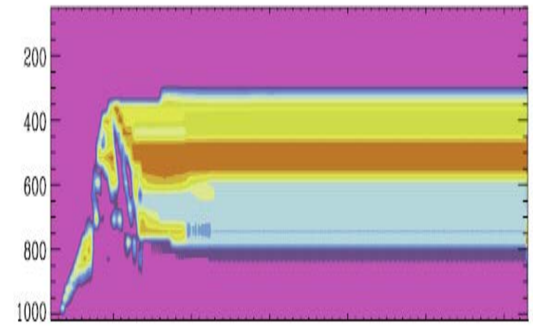


SST=23ºC,25ºC

SCM intercomparison



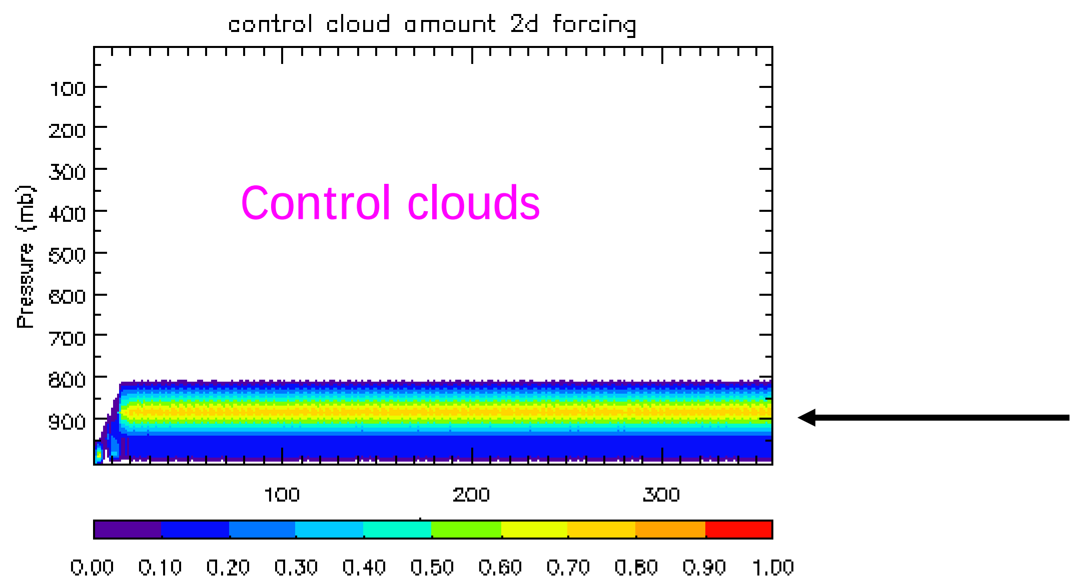




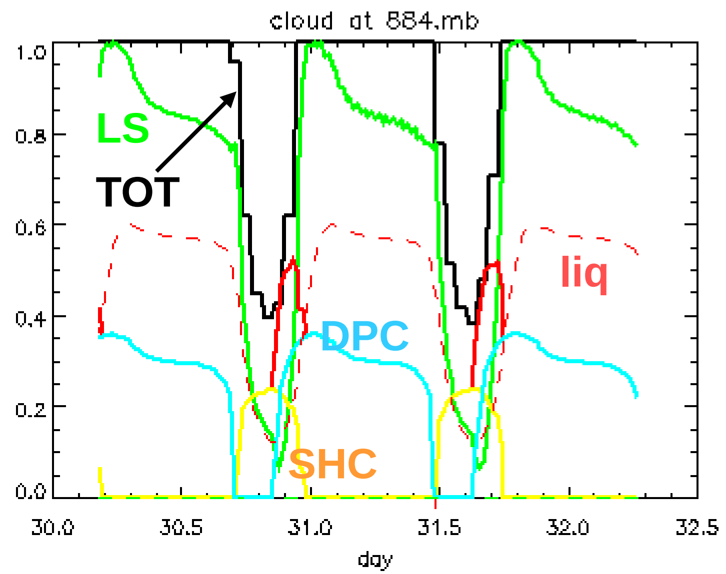
M. Zhang CPT1_A_cpt_model_a_nn

- Cloud profiles in the single-column versions of our 3 GCMs exhibit very similar biases to those seen in our Bony analysis of the full models.
- SCM +2K cloud feedbacks also analogous to full GCMs.

SCAM3 equilibrium

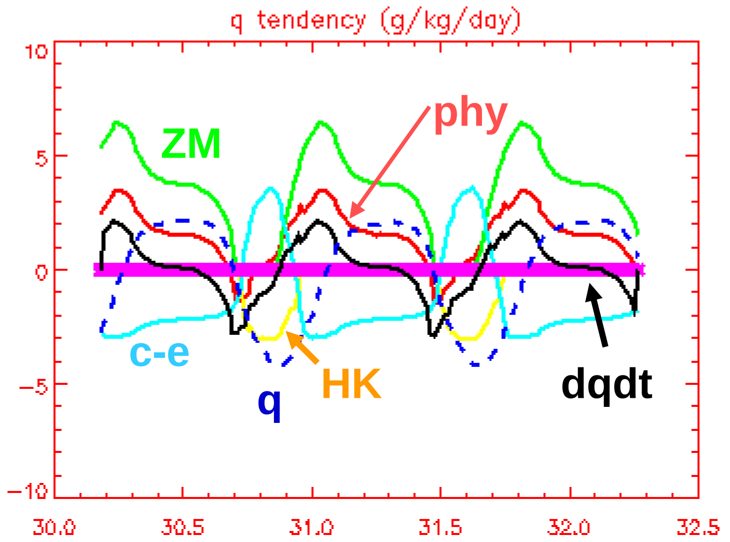


Time Series of clouds at 900 mb



Days

Time Series of q tendency at 900 mb



Days

M. Zhang

The Cycle:

ZM and Surface Turbulence – Quasi-equilibrium

Evaporative cooling aloft activates PBL scheme

PBL scheme kills the ZM scheme

PBL scheme activates Hack scheme, wiping out cloud.

The Hack scheme stabilizes itself

The Hack scheme dries the air aloft

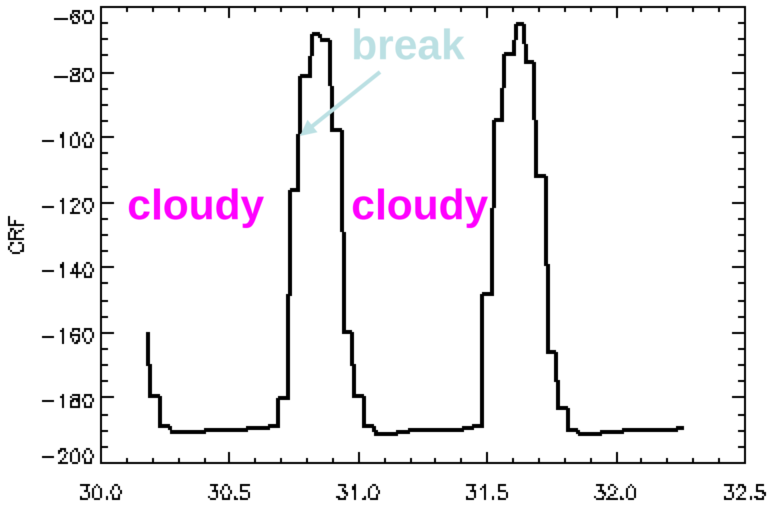
Surface evaporation and the dry air aloft re-activates the ZM scheme

Clouds are formed from the ZM water source

M. Zhang

Time Series of SW CRF in SCAM3 control

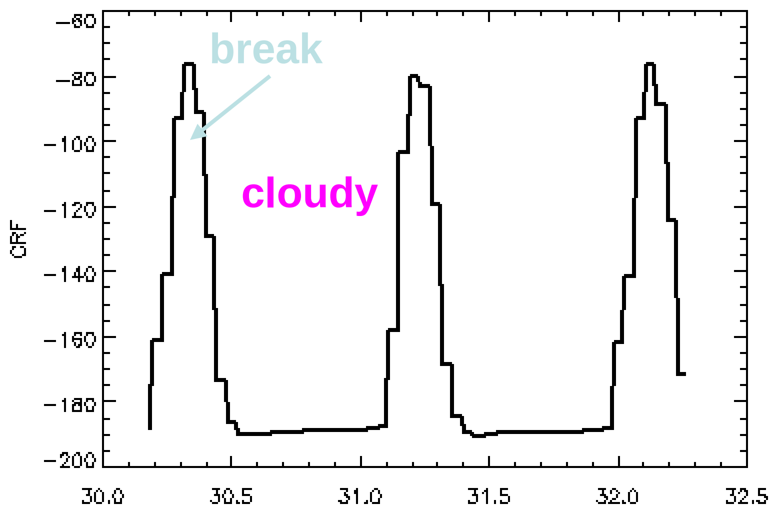
Control



SWCRF

Time Series of SW CRF in +2K Run

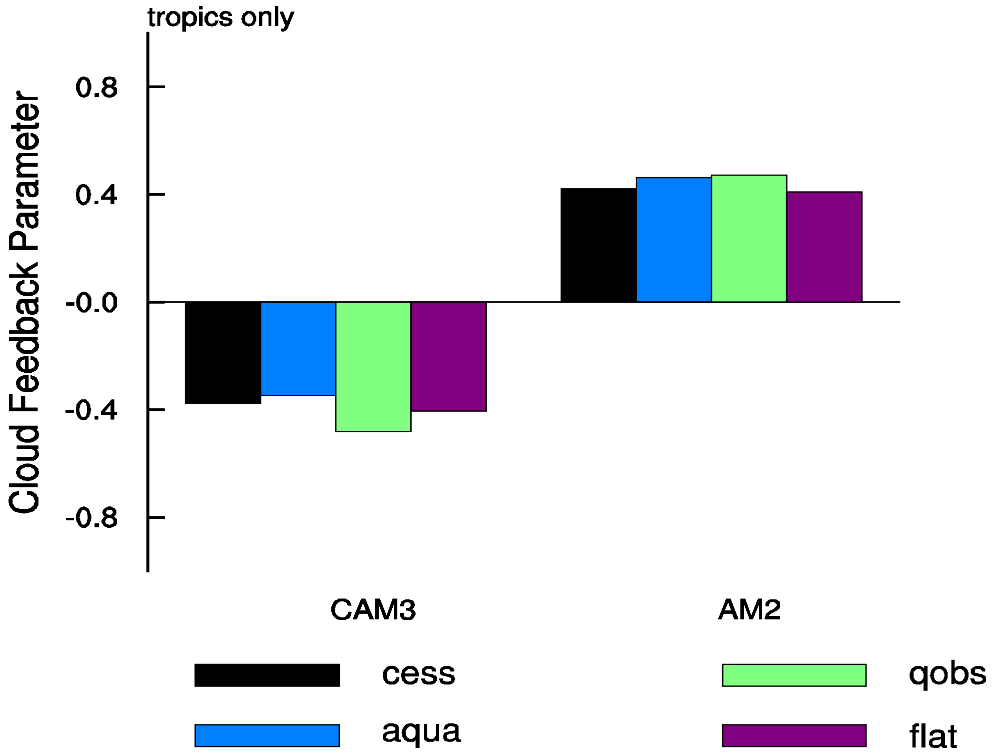
SST+2K Run



Boundary-layer clouds last longer, break shorter in +2K run (negative climate feedback like in full CAM3). Deep convection scheme plays an unexpectedly important role in this response.

M. Zhang

Aquaplanet climate sensitivity

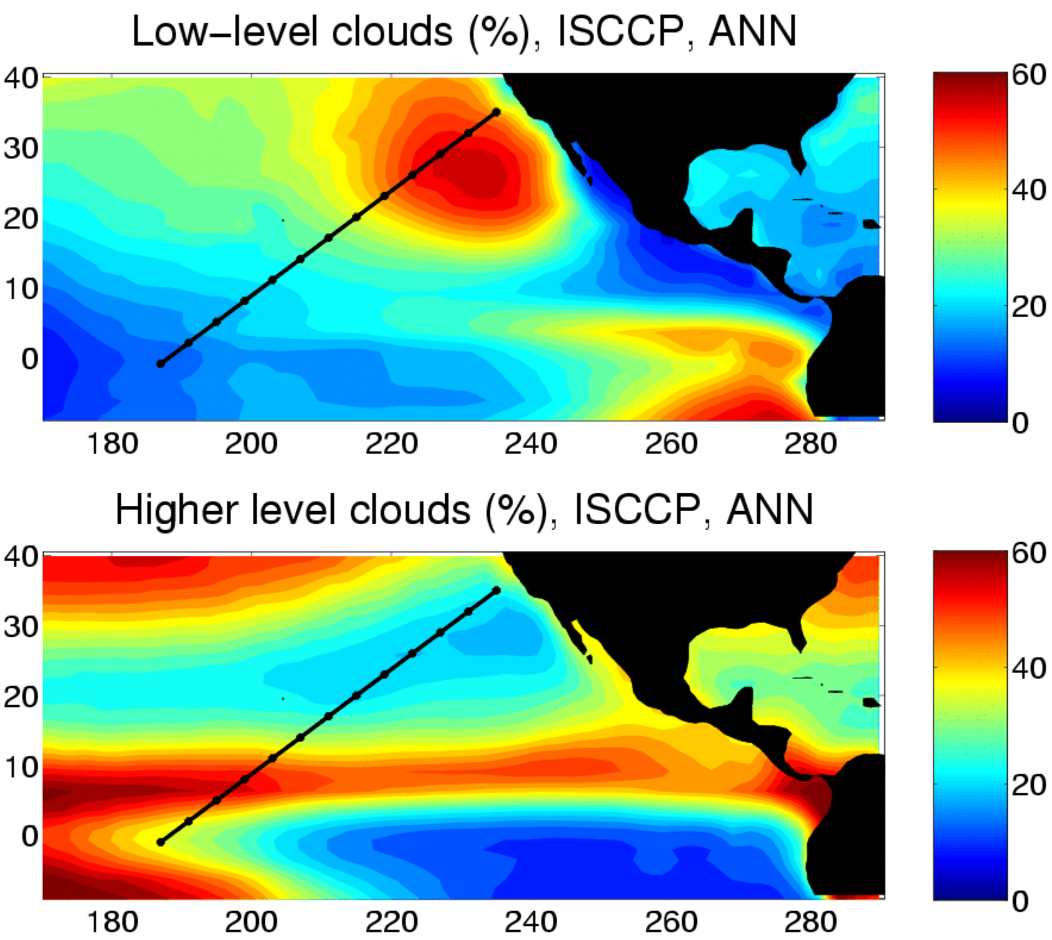


Meideiros/Stevens (UCLA)

Aquaplanet simulations are simpler but show remarkably similar low-lat cloud feedbacks to full +2K Cess runs.

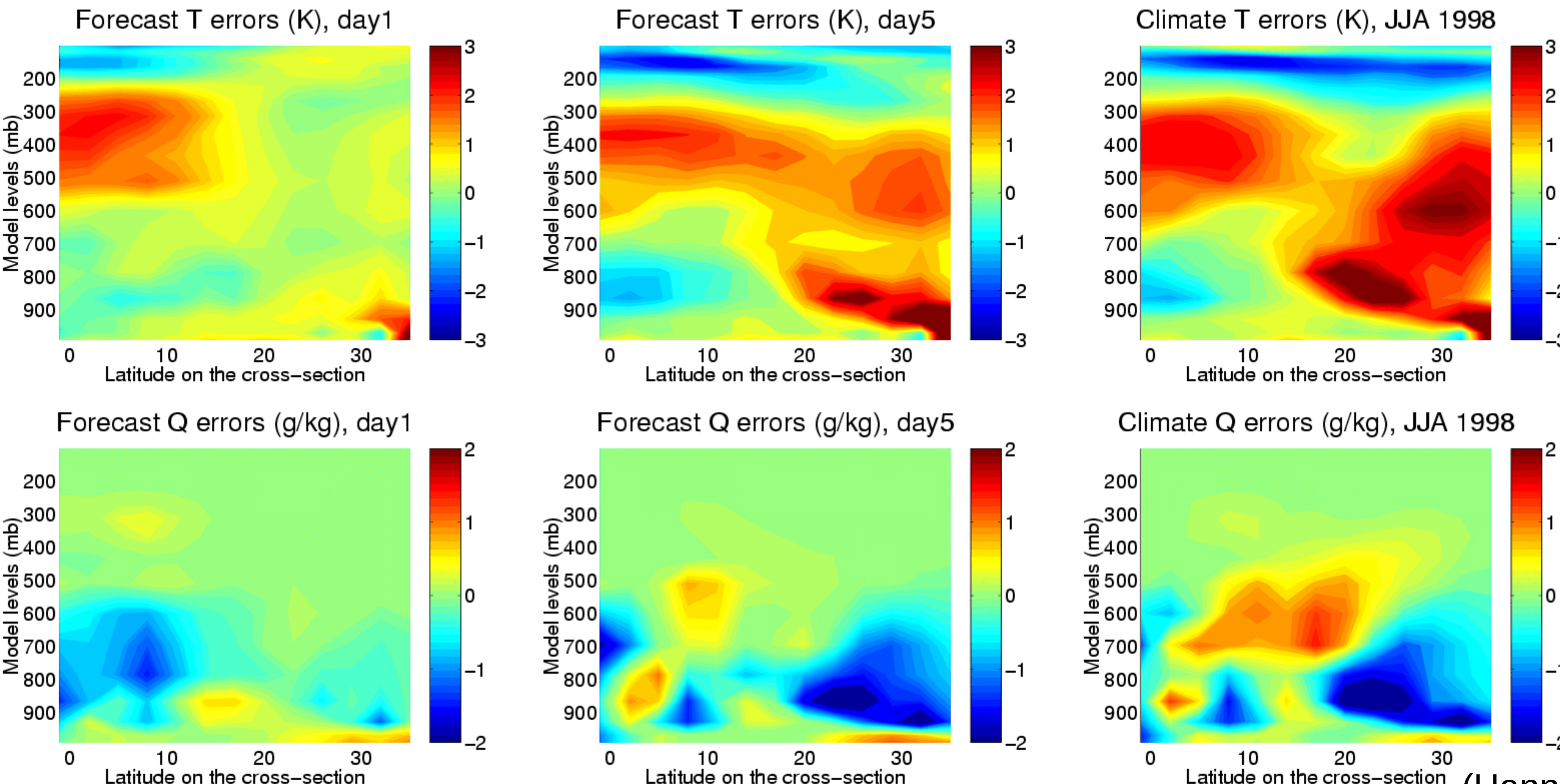
CAPT forecast mode analysis (Hannay/Klein)

- CAM3, CAM3-UW so far, AM2 soon.
- JJA 1998, GCSS NE Pacific cross-section.



- EUROCS project
  JJA 1998
- GCSS intercomparison
  JJA 1998/2003
- Observations
  ISCCP data
  SSM/I product
  TOVS atmosphere
  GPCP precipitation
  AIRS data
- Reanalyses
  NCEP/ERA40

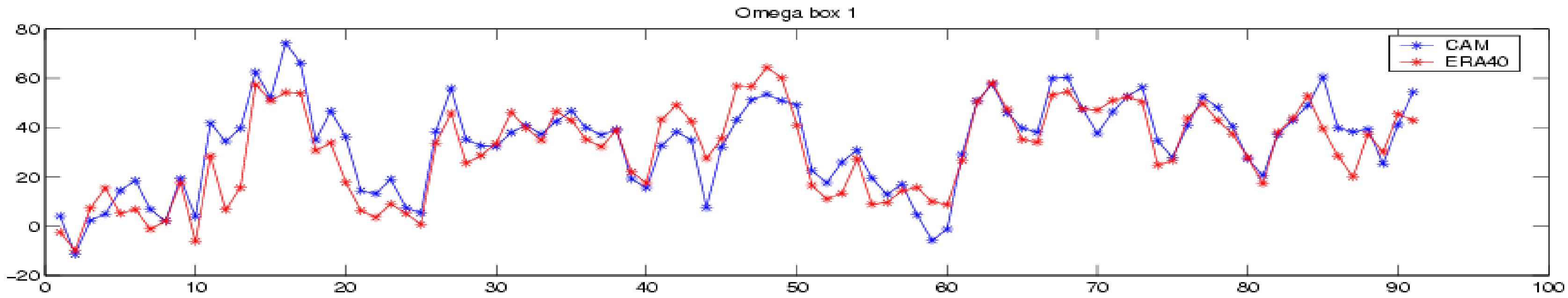
Mean errors from CAM3 T42 daily forecasts



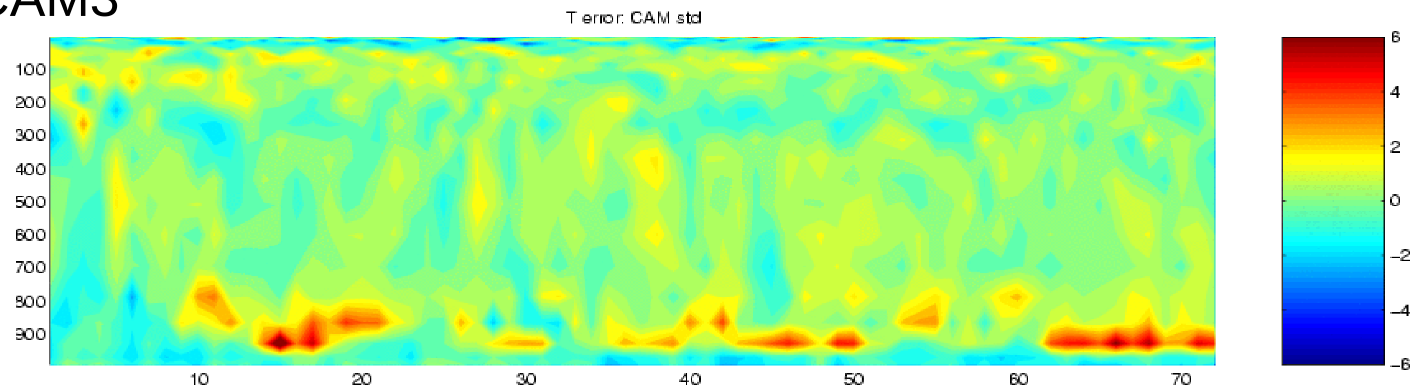
(Hannay)

- Systematic biases set up fast (1 day in ITCZ, 5 days in subtropics).
- Can investigate cloud errors from satellite observations.

Daily T42L30 CAM3 forecasts initialized with ERA40.

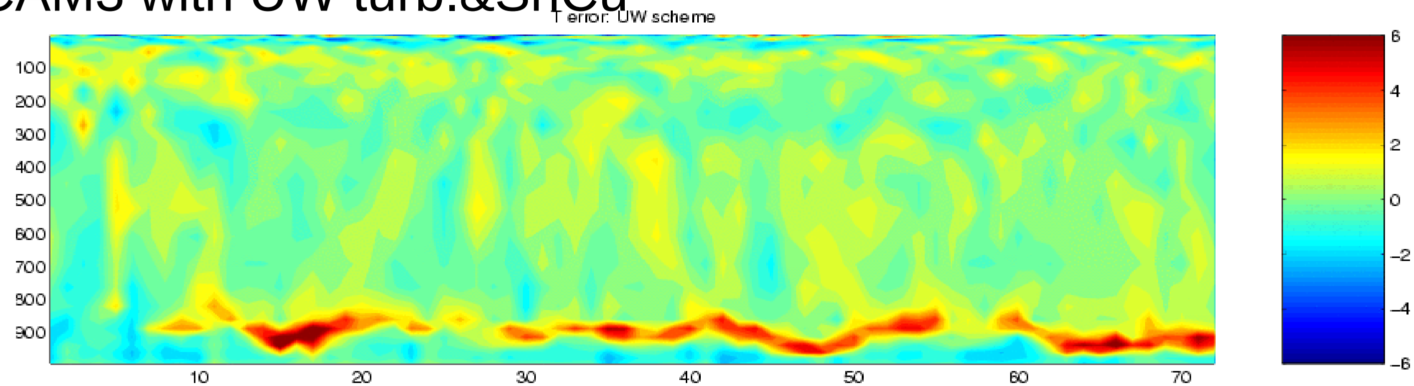


CAM3



1-day error relative to ERA40

CAM3 with UW turb.&ShCu



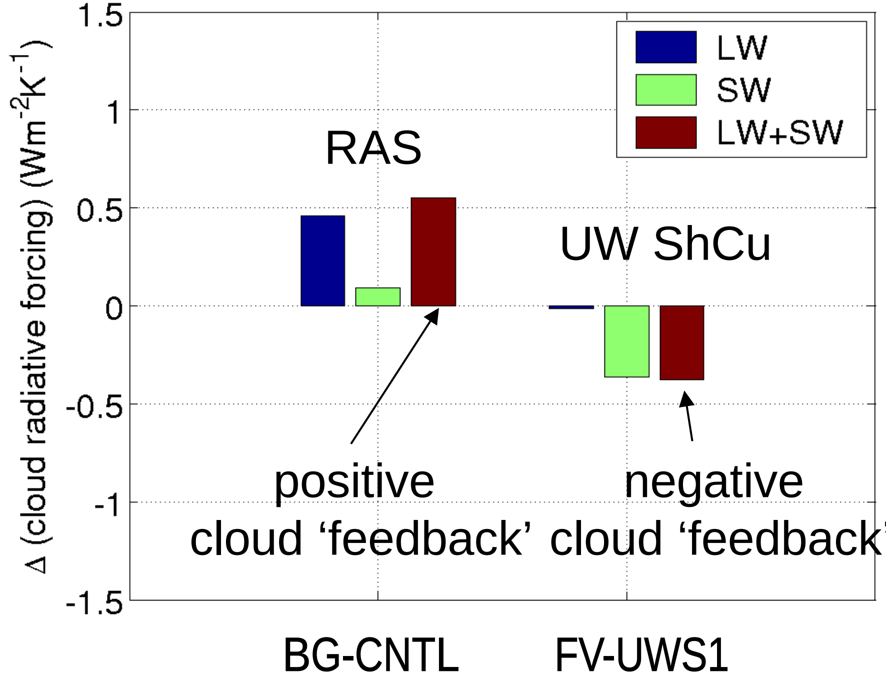
CAM3 and CAM3-UW both quickly lower inversion height

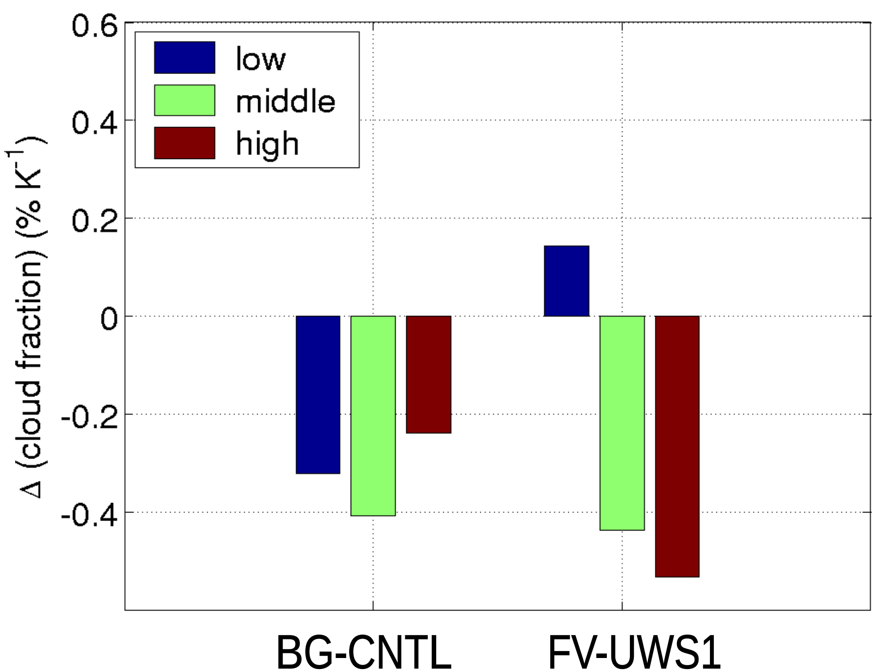
GFDL AM2.12

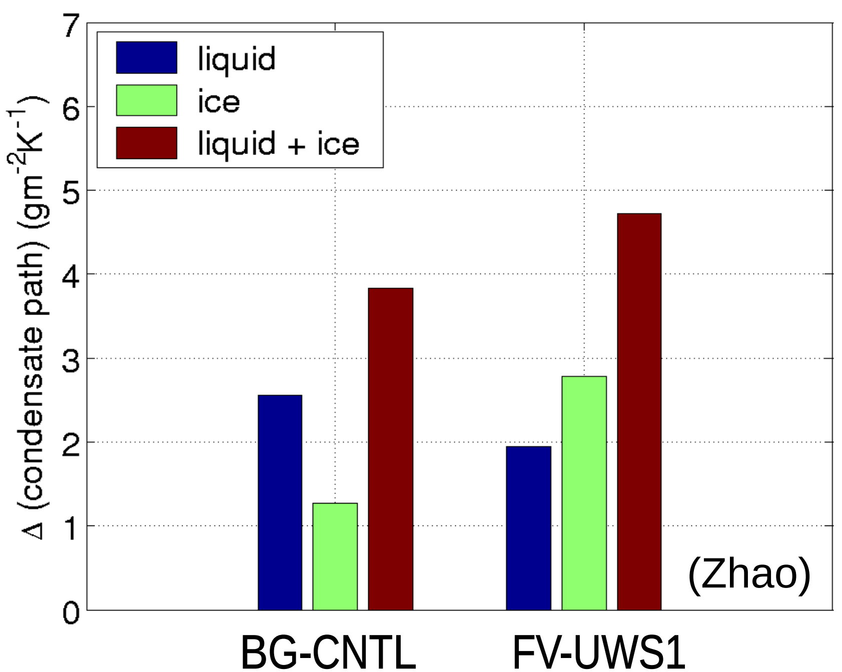
(+2K − Control)

30N-30S cloud feedback

Change from RAS to UW for shallow cumulus param. reduces climate sensitivity.







Clouds CPT Ongoing Work

1. Direct comparisons of single-column versions of the three AGCMs, LES, bulk models for idealized CTBLs, with focus on understanding climate sensitivity.
2. Improved parameterization of shallow convective cloud cover and microphysics.
3. Incorporation of an LES into a superparameterization (MMF) framework for better CTBL simulations.
4. CAPT forecast-mode and climate-mode column analysis of low-latitude CTBLs in the three GCMs, incl. ARM Nauru/SGP sites.
5. Zonally symmetric aquaplanet low cloud sensitivity.

Although the clouds CPT doesn't yet have better answers to the cloud feedbacks question, we have developed intellectual frameworks that may give us those answers in the next two years.