Improvements in CAM5 :
Moist Turbulence, Shallow Convection, and Cloud Macrophysics

AMWG Meeting

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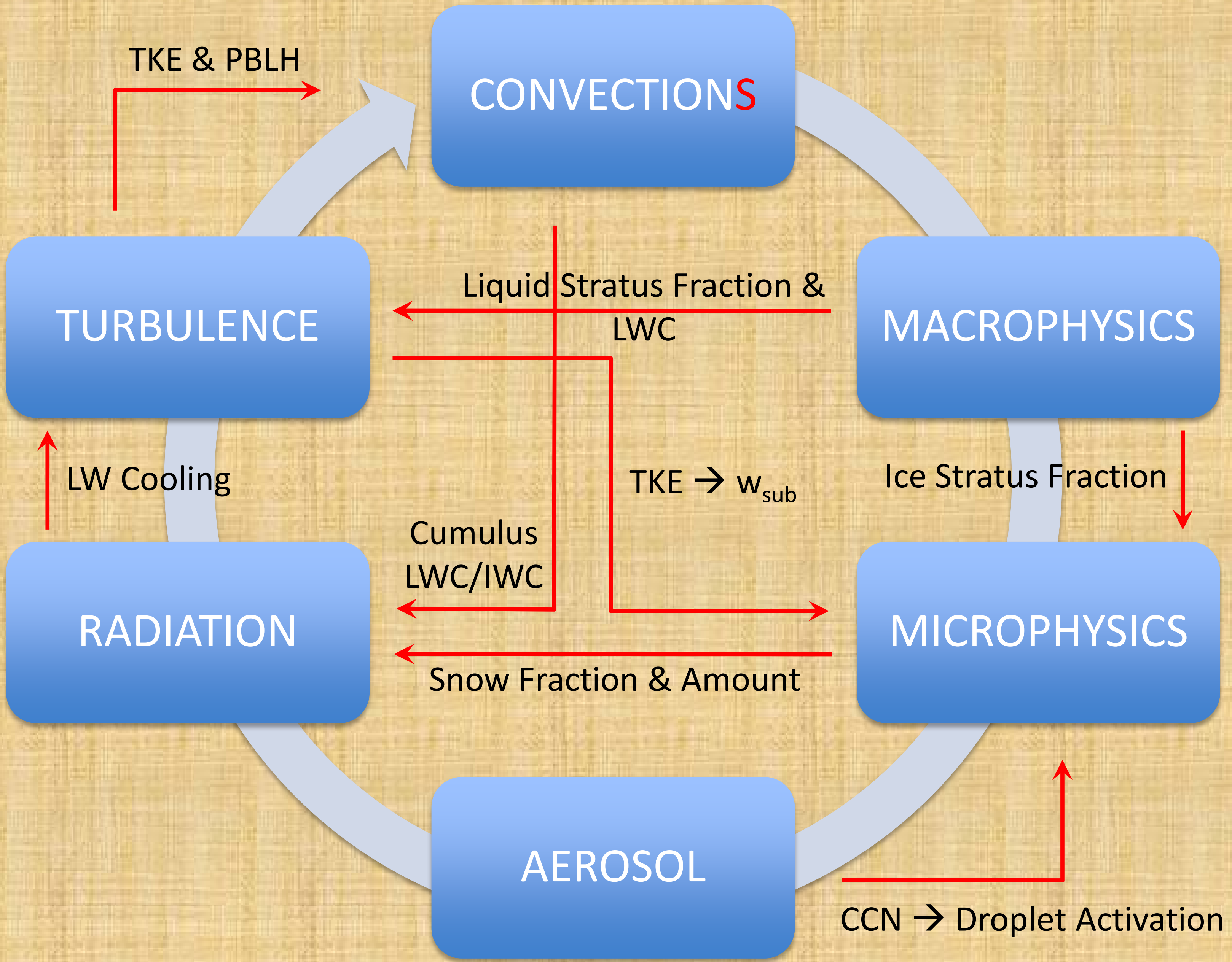
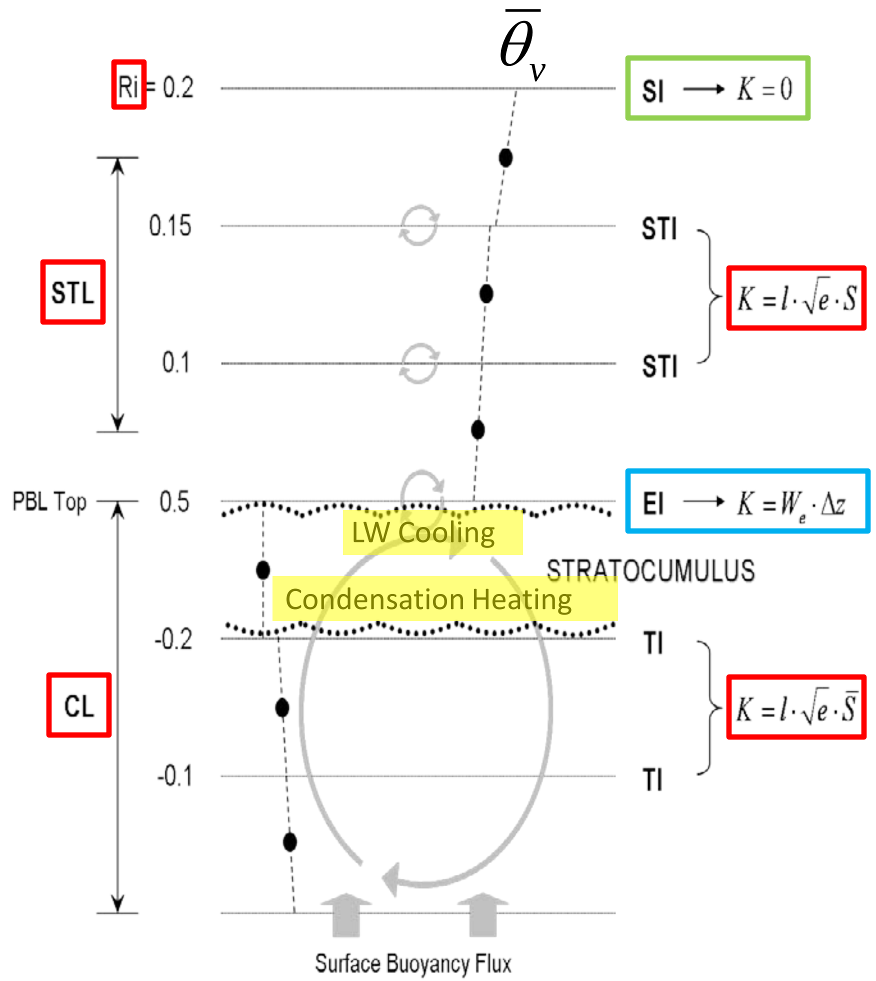
Physical Processes in CAM5



MOIST TURBULENCE SCHEME in CAM5



$$\frac{\partial \overline{A}}{\partial t} = -\frac{\partial}{\partial z}\overline{w'A'} = \frac{\partial}{\partial z}\left(K\frac{\partial \overline{A}}{\partial z}\right)$$

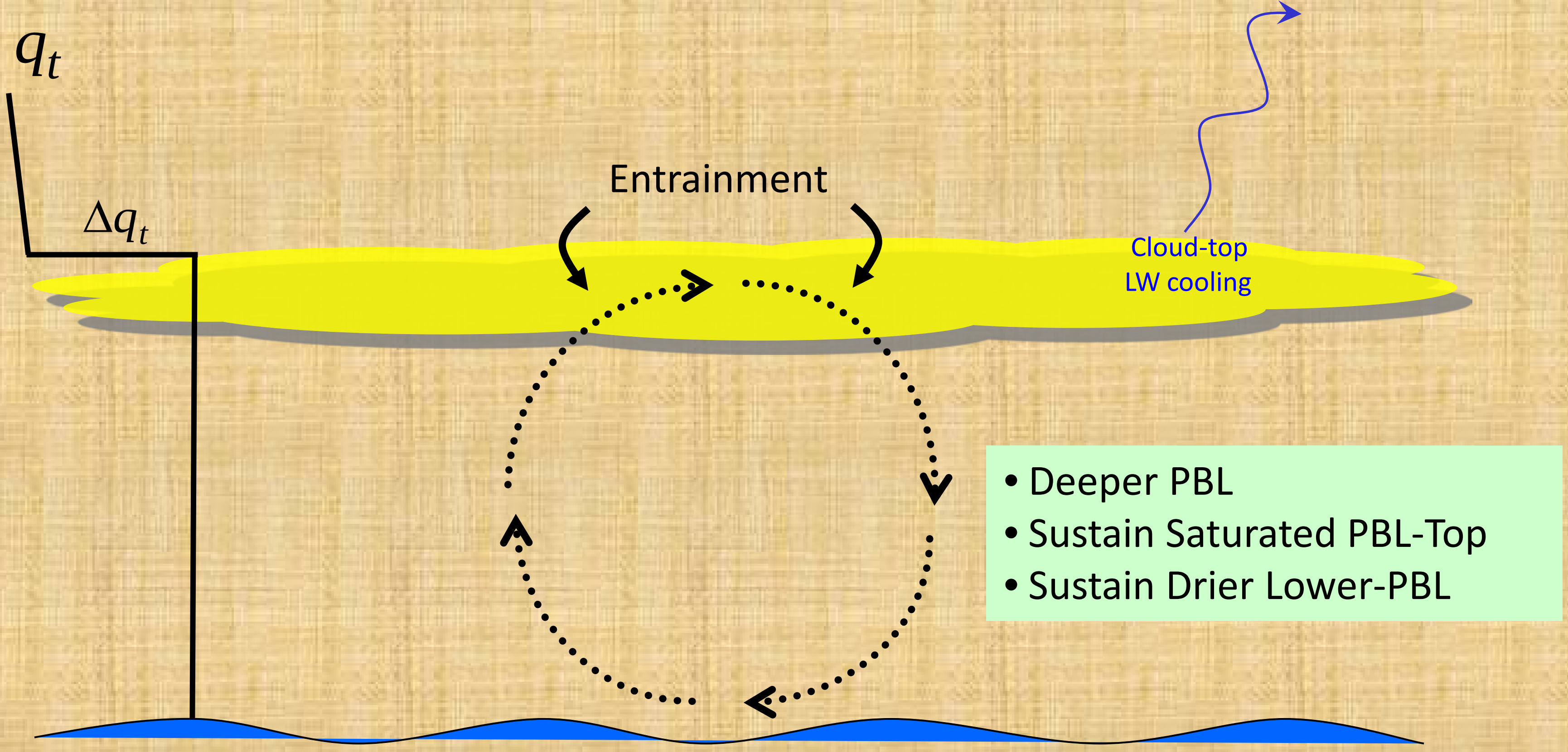
K : eddy diffusivity

Ri	: Moist Richardson Number
SI	: Stable Interface
STI	: Stably Turbulent Interface
EI	: Entrainment Interface
TI	: Turbulent Interface
STL	: Stably Turbulent Layer
CL	: Convective Layer
l	: Turbulent length scale
S	: Stability function (fcn of Ri)
e	: TKE
W_e	: Entrainment rate

Moist Turbulence Scheme in CAM5

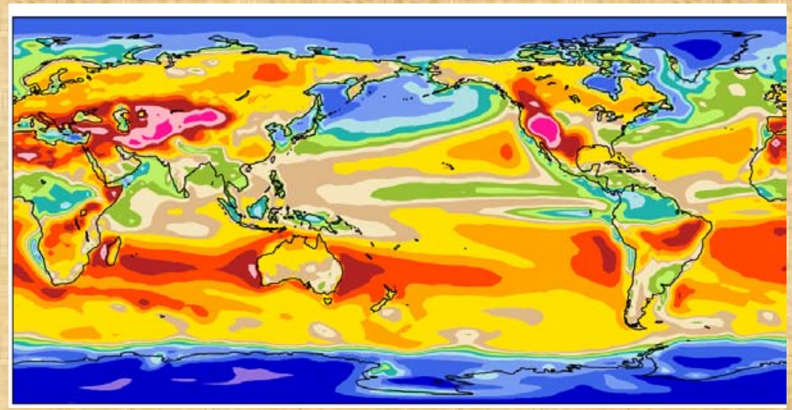
- Diagnostic TKE-based 1st order K diffusion scheme with entrainment param.
- Stratus-Top LW Cooling and In-Stratus Condensation Heating into TKE
  - Treatment of Stratus-Radiation-Turbulence Interactions
  - Handling of the 2nd aerosol indirect effect
  - Removal of the stability-based KH stratus fraction
- Activate in any layers above as well as within PBL
- Compared to CAM4 PBL scheme,
  - Much better performance in cloud-topped regime
  - Similar or superior performance in dry stable and convective regimes

Cloud-Radiation-Turbulence Interactions

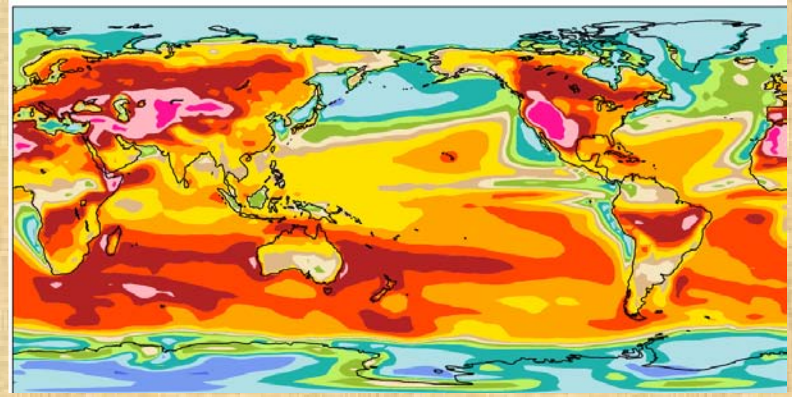


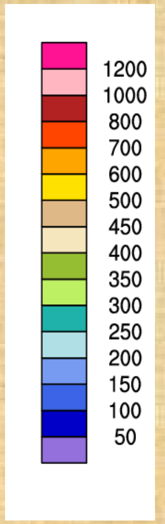
PBLH. JJA

CAM5

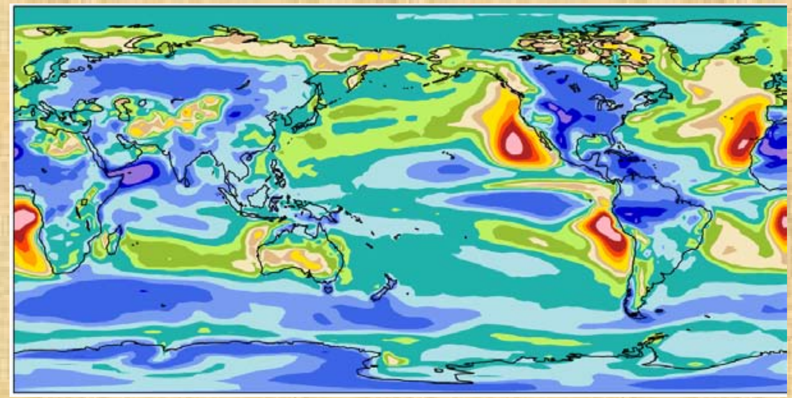


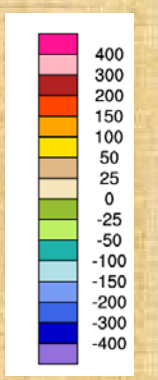
CAM4





CAM5 – CAM4

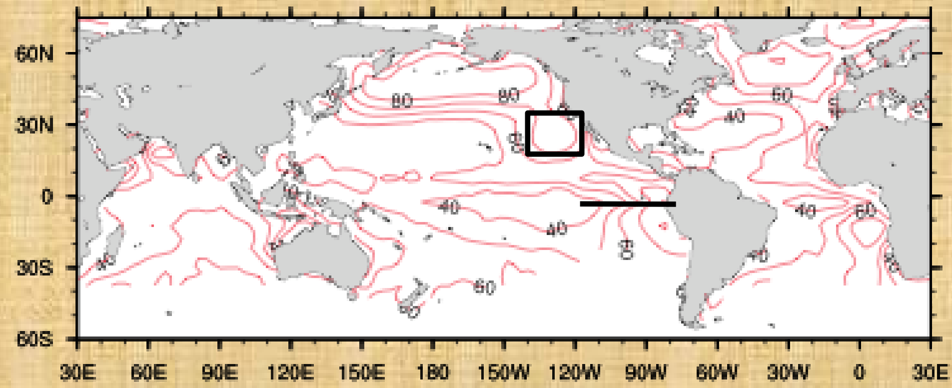




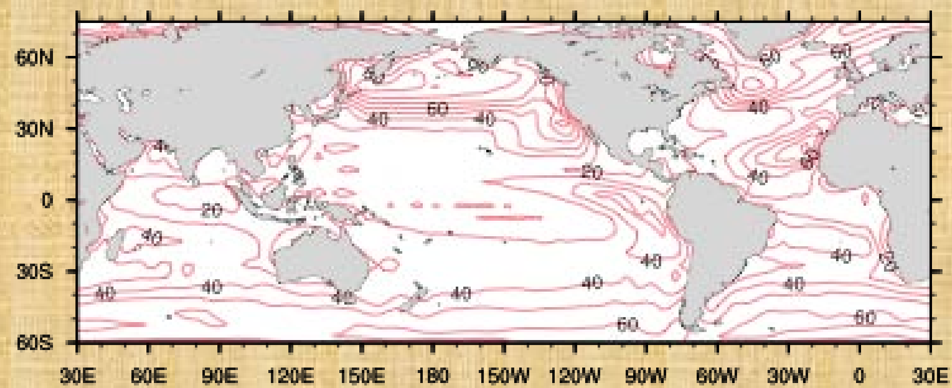
Deeper PBL
in Sc-Regime

Low Cloud Amount. JJA.

Observation

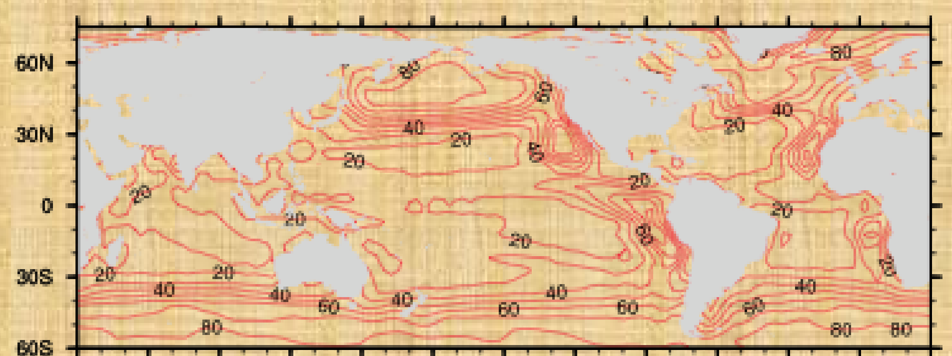


CAM4



Use
KH's stratus fraction

CAM5

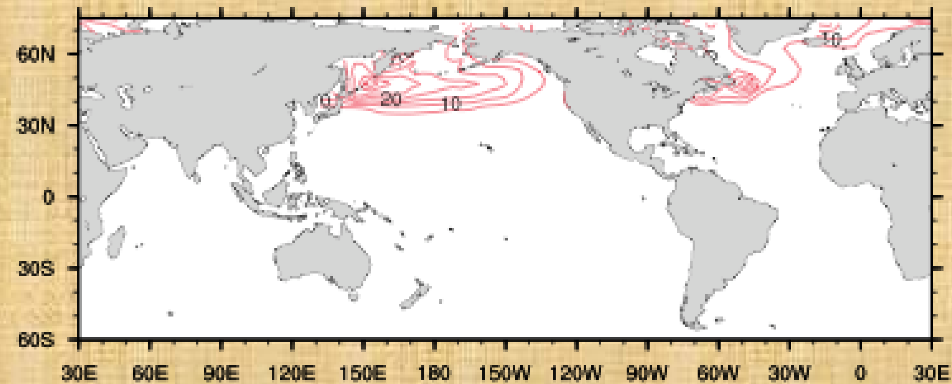


Do not use
KH's stratus fraction

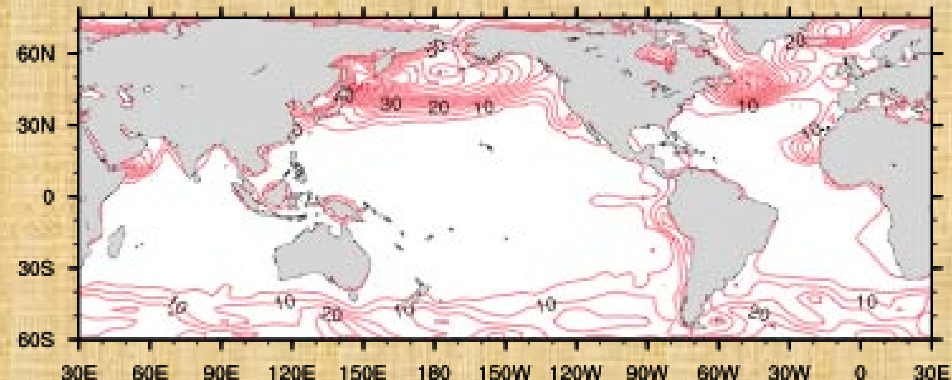
Sustain Saturated
PBL Top

Fog Amount. JJA.

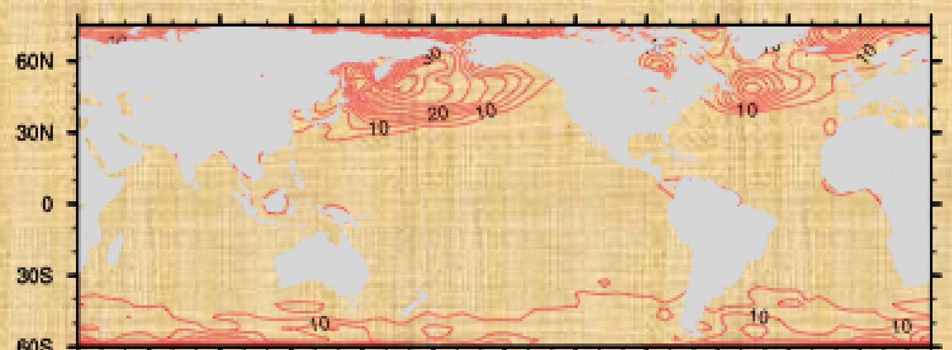
Observation



CAM4

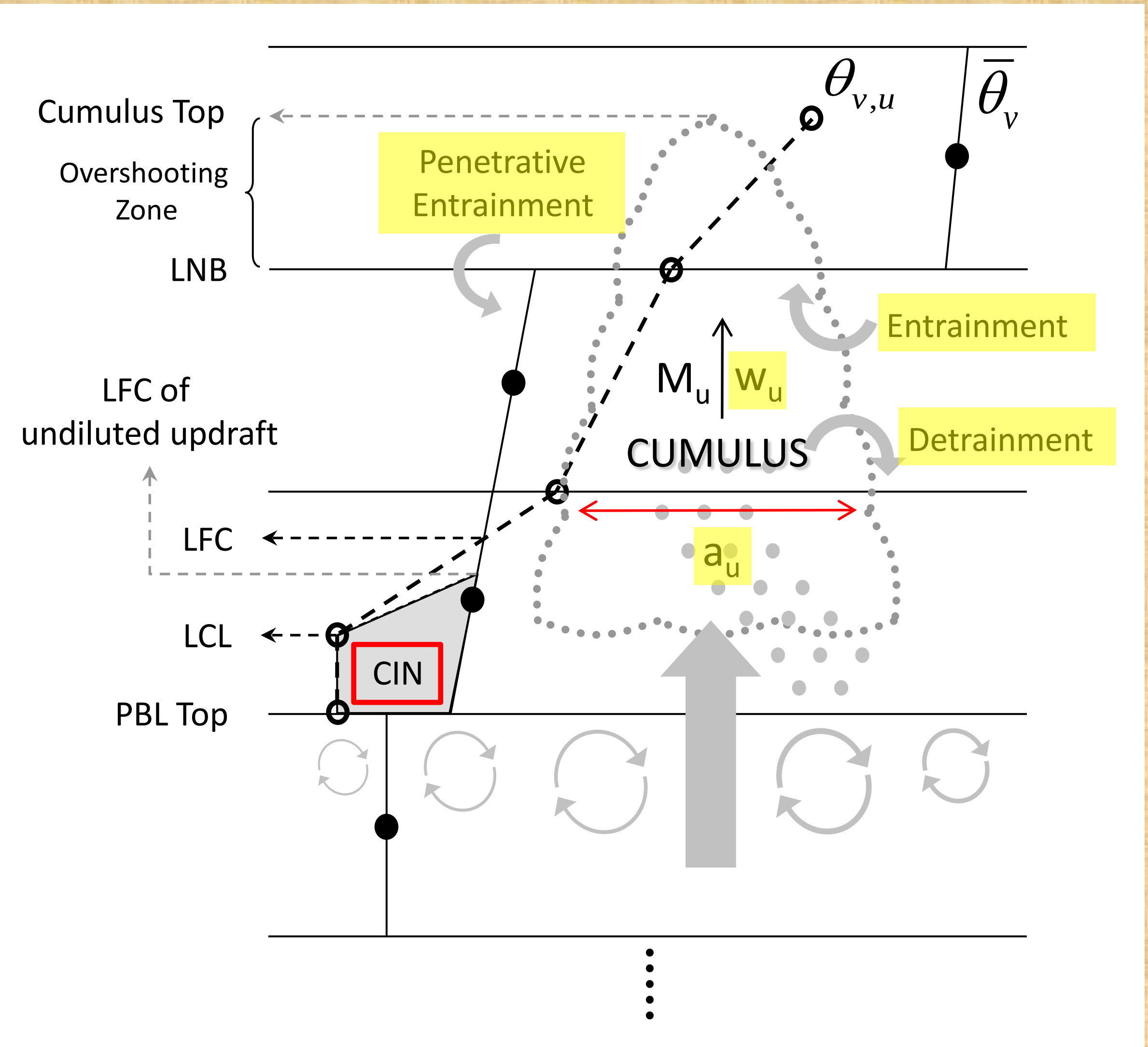


CAM5



Sustain Drier Lower-PBL

SHALLOW CONVECTION SCHEME in CAM5



$$\overline{w'A'} = \rho \cdot M_u \cdot (A_u - \overline{A})$$

M_u : updraft mass flux

A_u : updraft scalar

CIN	: Convective INhibition
LCL	: Lifting Condensation Level
LFC	: Level of Free Convection
LNB	: Level of Neutral Buoyancy
w_u	: Updraft vertical velocity
a_u	: Updraft fractional area

Shallow Convection Scheme in CAM5

- An entraining-detraining buoyancy-sorting updraft plume with a penetrative entrainment parameterization
  - Mass flux closure based on TKE and Convective Inhibition (CIN)
  - Computes cumulus fraction and LWC, vertical velocity, updraft mass flux
  - Direct influence on the global radiation budget

- (Much) Less sensitive to vertical resolution than CAM4

- Simulate the '*real*' convective activity

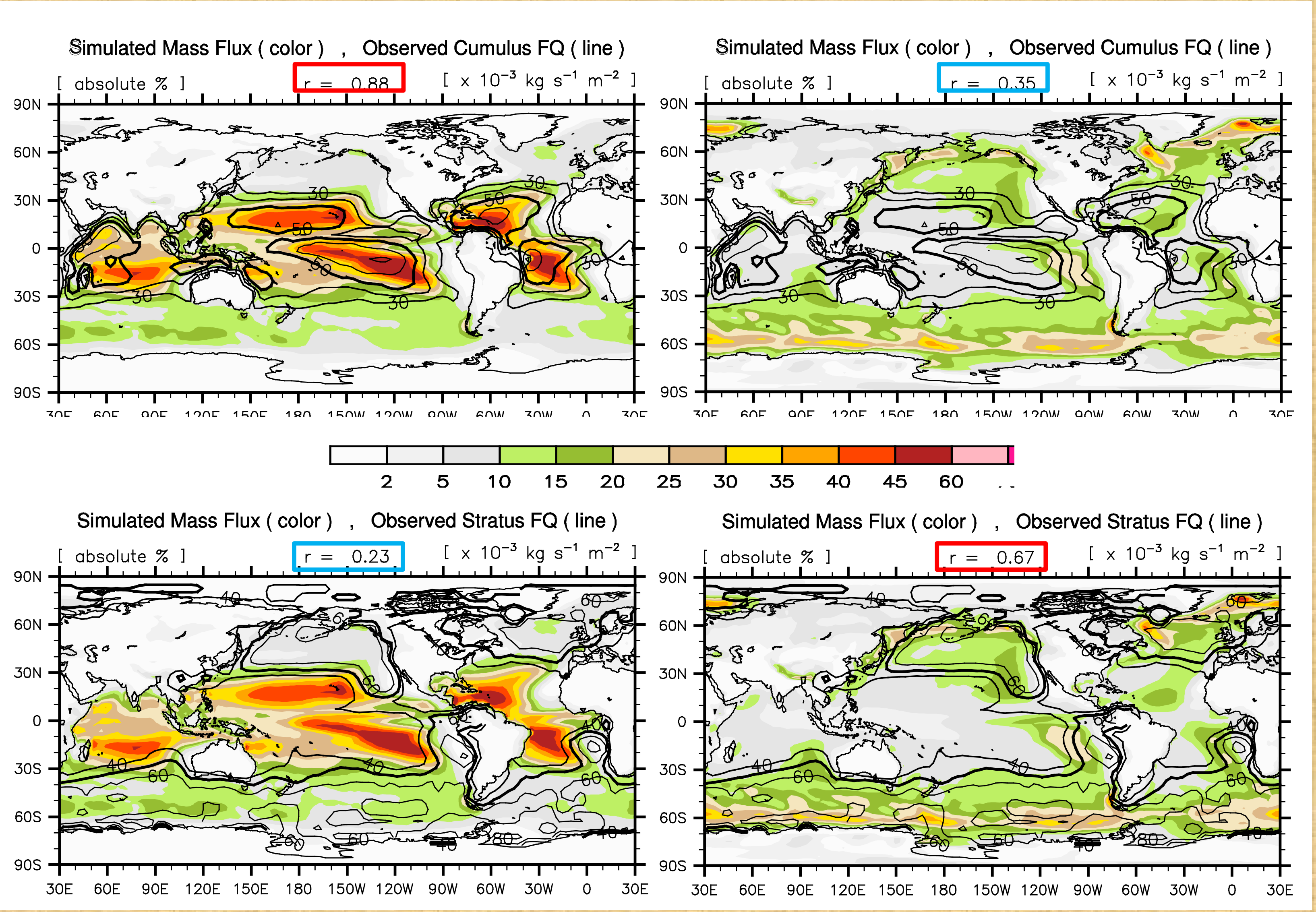
Shallow Convective Mass Flux at Cloud Base. Annual.

CAM5

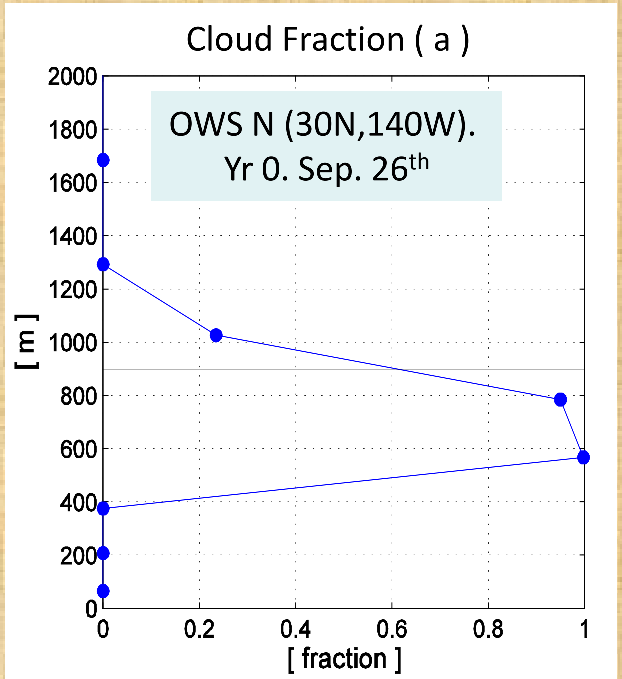
CAM4

Observed Cumulus

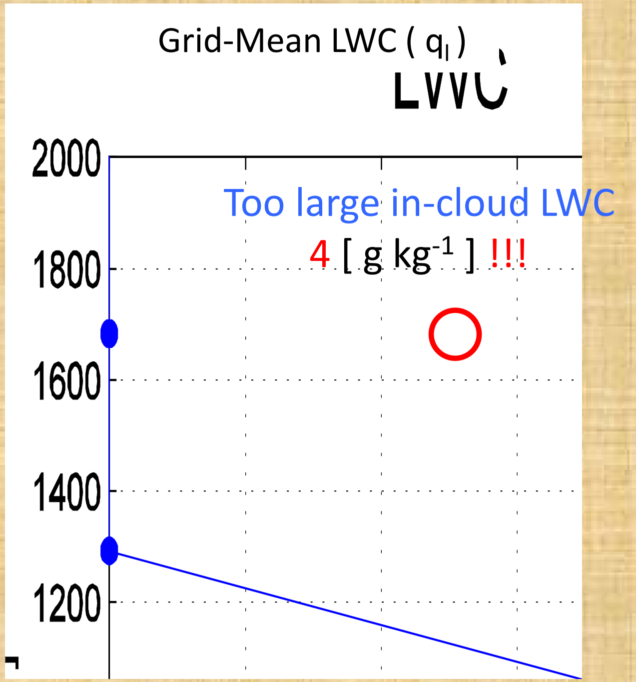
Observed Stratus



Inconsistency between 'Stratus Fraction' and 'In-Stratus LWC' in CAM4



PBL top



→ distorts LW cooling profile

→ too strong inversion at the PBL top

→ too weak entrainment rate

→ too shallow and moist PBL

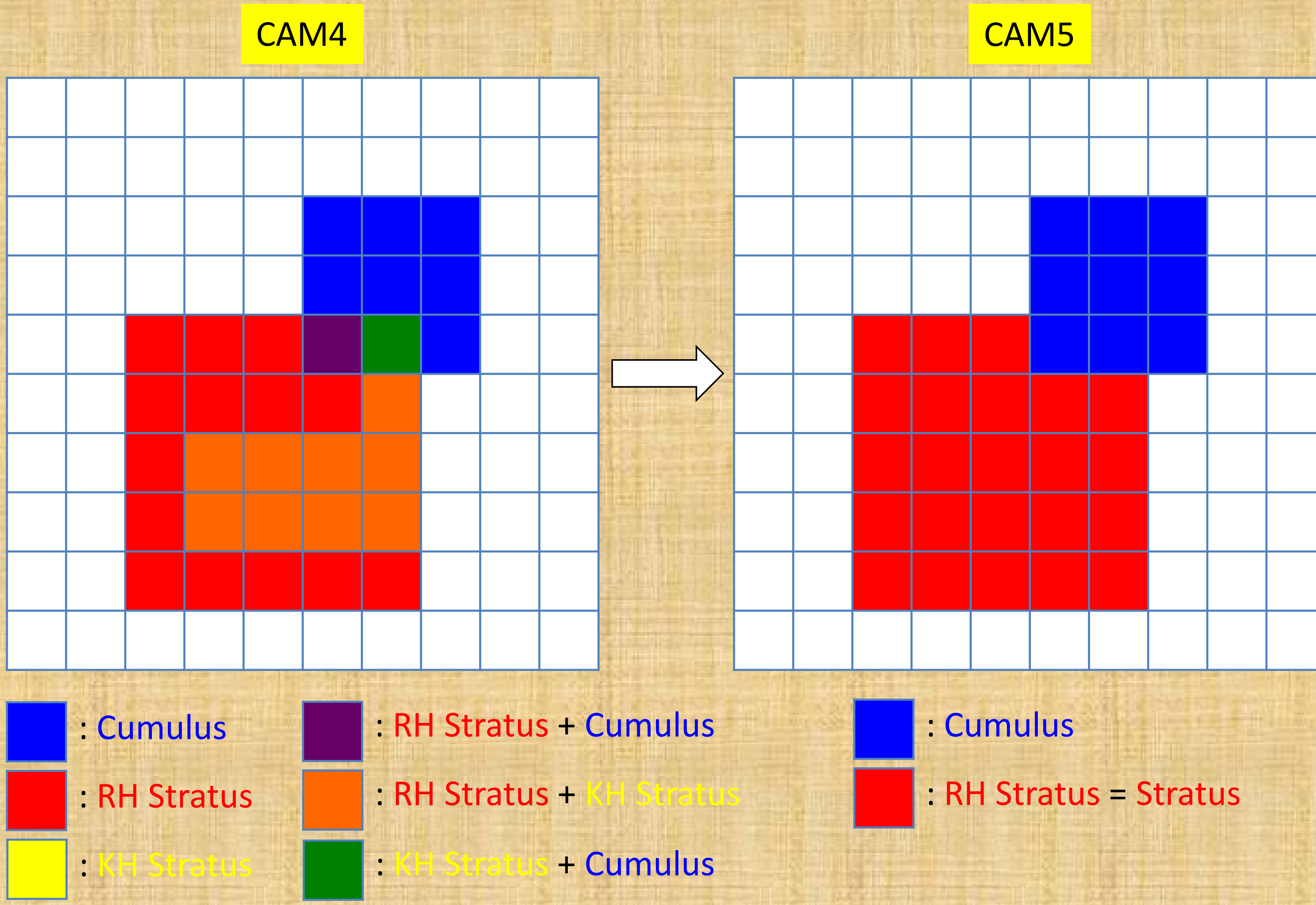
Macrophysics Scheme in CAM5

- Enhance consistency between stratus fraction and in-stratus LWC
- Remove 'empty' ($a>0$, $q_{l,cloud}=0$) and 'dense'($a=0$, $q_{l,cloud}>0$) stratus
- Liquid stratus fraction based on triangular PDF of q_t
- Removal of KH's stability based stratus fraction

- Separate treatment of liquid condensation and ice sublimation
- Separate diagnose of liquid and ice stratus fractions

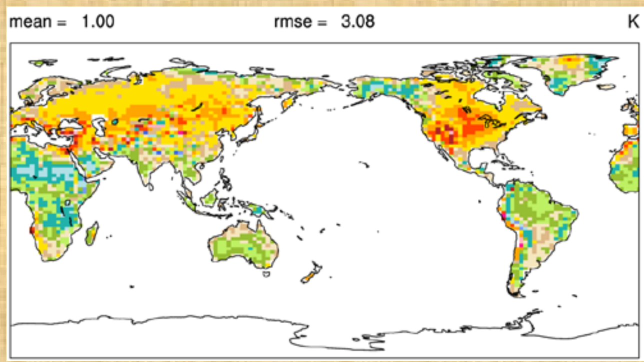
- Cumulus is non-overlapped with stratus in each layer.
- Cumulus has its own in-cumulus LWC.
- Cumulus is radiatively active.

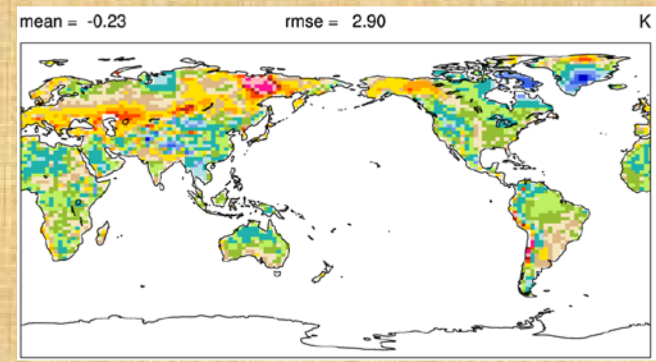
Horizontal Geometry of Clouds in CAM



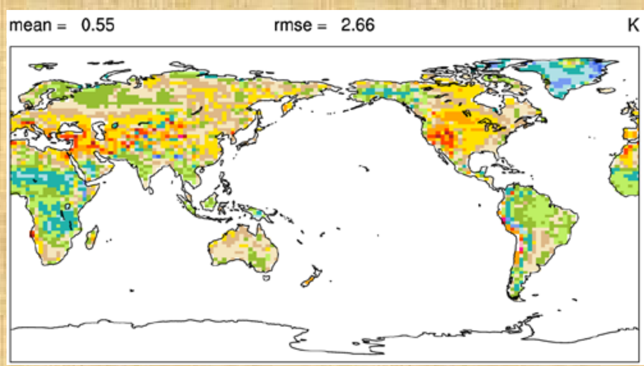
ΔT_{2m}

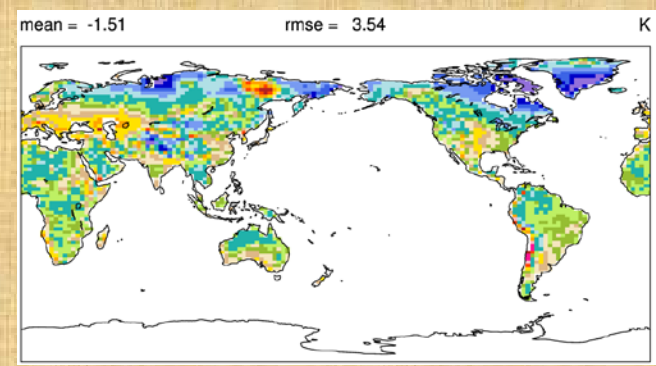
JJA | **DJF**



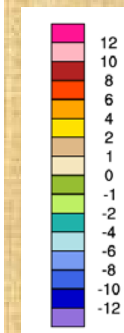


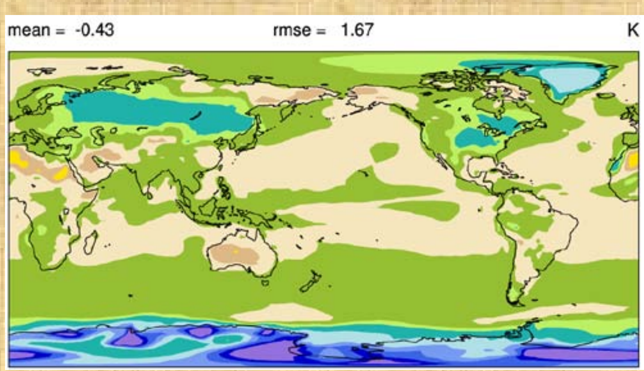
CAM4 – Obs.

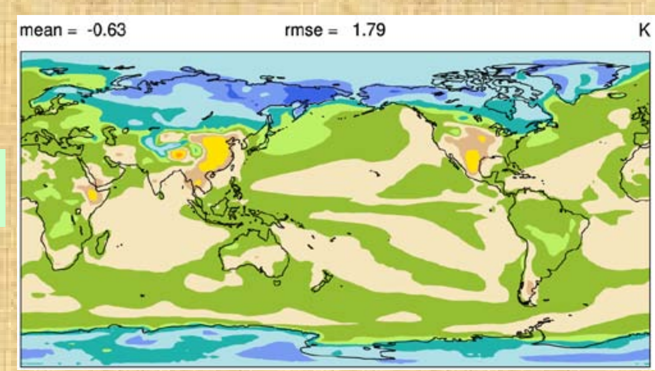




CAM5 – Obs.



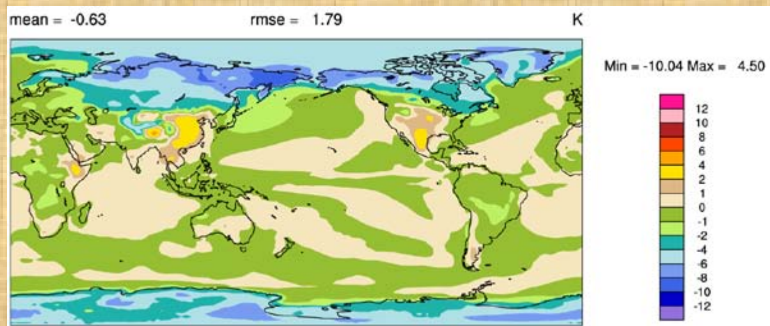




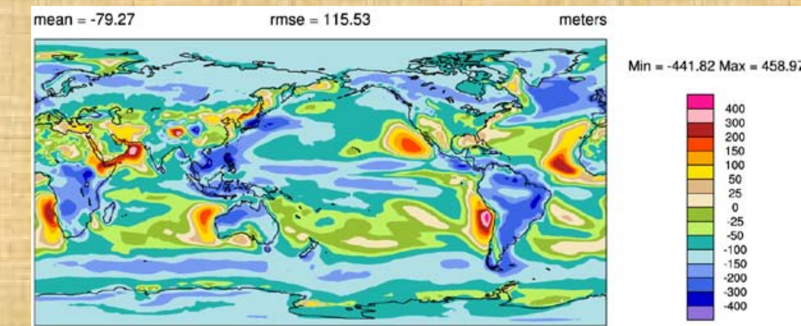
CAM5 – CAM4

CAM5 – CAM4. DJF

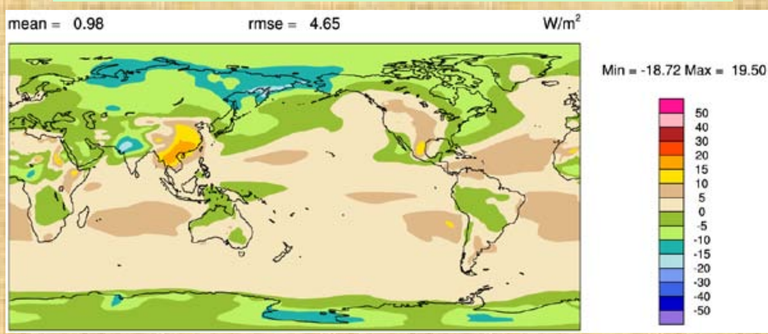
Δ T_{2m}



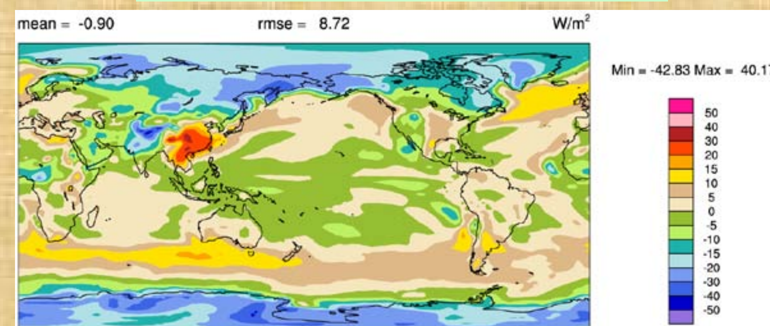
Δ PBLH



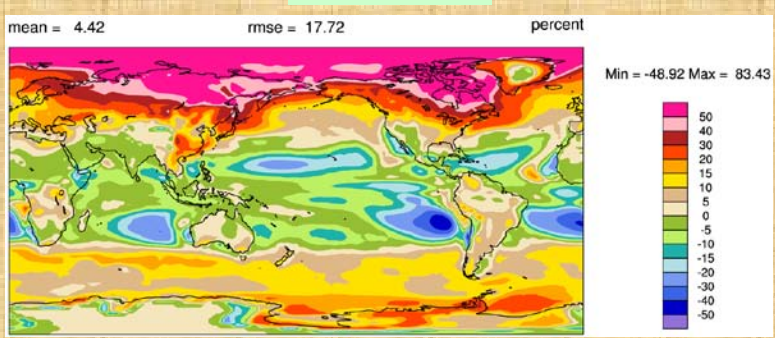
Δ Clear-Sky Downward LW Rad. at Surface



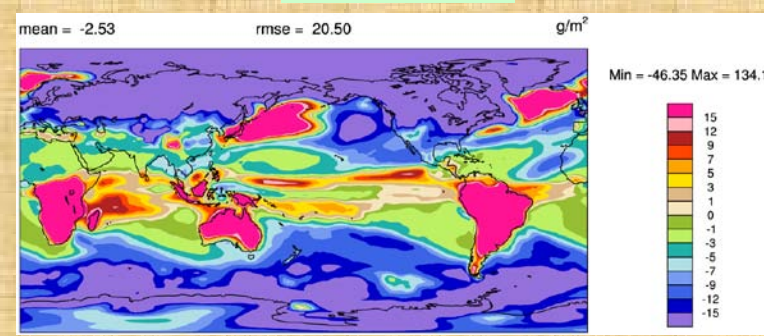
Δ Downward LW Rad. at Surface



Δ CLDLOW



Δ TGCLDIWP



SUMMARY

- CAM5 has much better physics and interactions among the physics than CAM4, without arbitrary kludges (e.g., stability based LCA etc.).

- CAM5 can simulate many important features in a physically reasonable way, especially the ones associated with cloud processes themselves and cloud-climate interactions (e.g., marine stratocumulus clouds, cumulus, cloud-SST interaction, cloud-sea ice interaction, 1st and 2nd aerosol indirect effects, etc.).

- Some important biases in CAM5:
  - Too cold near surface air over the Northern Continent in DJF.

Improvements of Cloud Treatment in CAM5

- Removal of 'KH Stratus'

  ← New Moist Turbulence Scheme

- Realistic 'Cumulus Fraction' and 'Cumulus LWC'

  ← New Shallow Convection Scheme and Revised Deep Convection Scheme

- Enhanced Consistency between 'Stratus Fraction' and 'Stratus LWC'

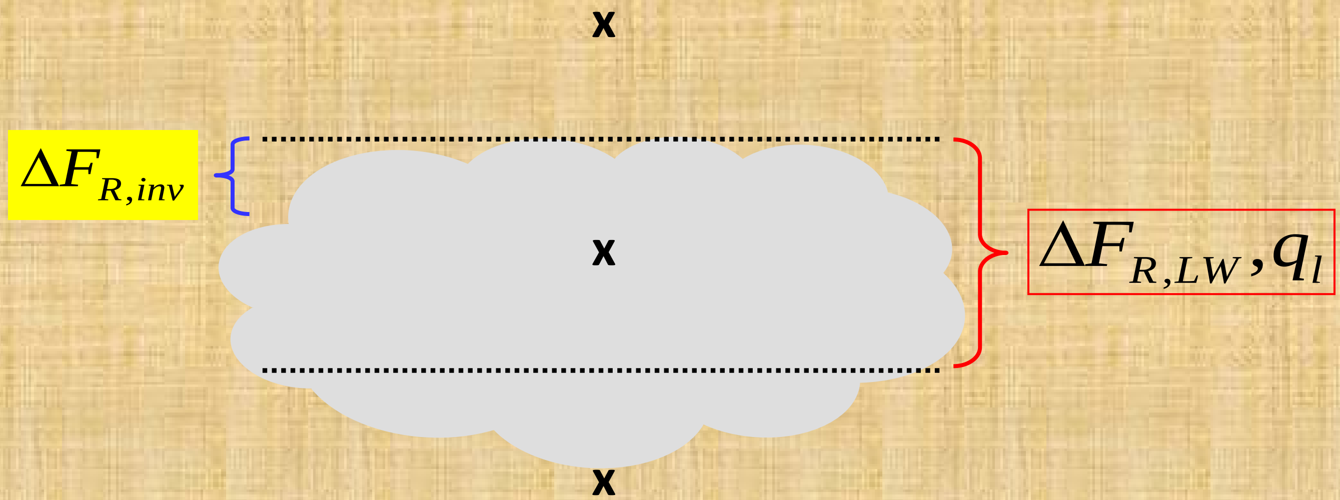
  ← Revised Macrophysics

- Simulation of 'Interactive Cloud Droplet Number' as well as 'LWC/IWC'

  ← New 2-Moment Microphysics and Modal Aerosol Model

- More Realistic Radiative Properties of Clouds

  ← New Cloud Optics



$$\tau = 156 \cdot \rho \cdot q_l \cdot \Delta z$$

$$f_R = \left\lfloor \frac{\tau \cdot (\tau + 4)}{\tau^2 + 6 \cdot \tau + 24} \right\rfloor$$

$$\Delta F_{R,inv} = f_R \cdot \Delta F_{R,LW}$$