The CGILS Project to Understand the Physical Mechanism of Climate Feedbacks from Low Clouds

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and

CGILS Participants:

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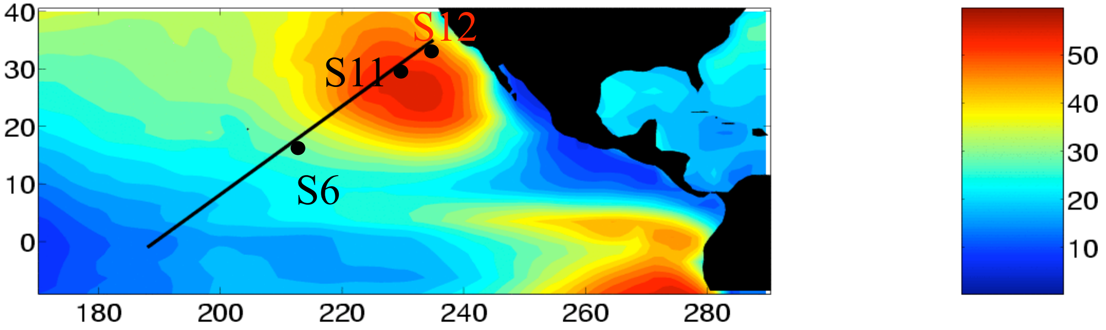
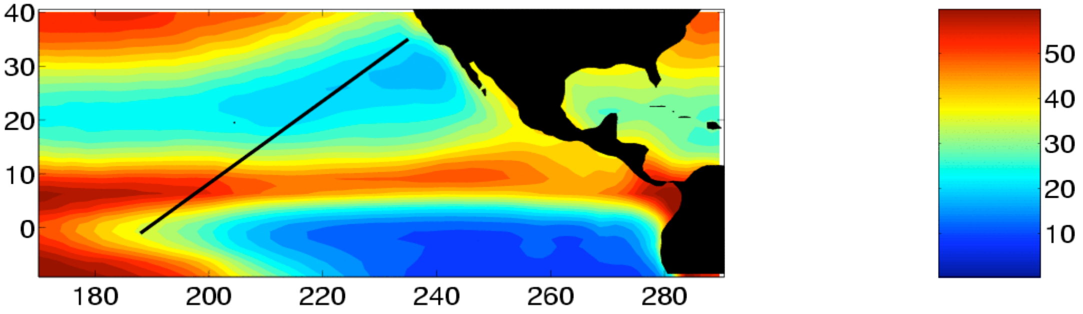
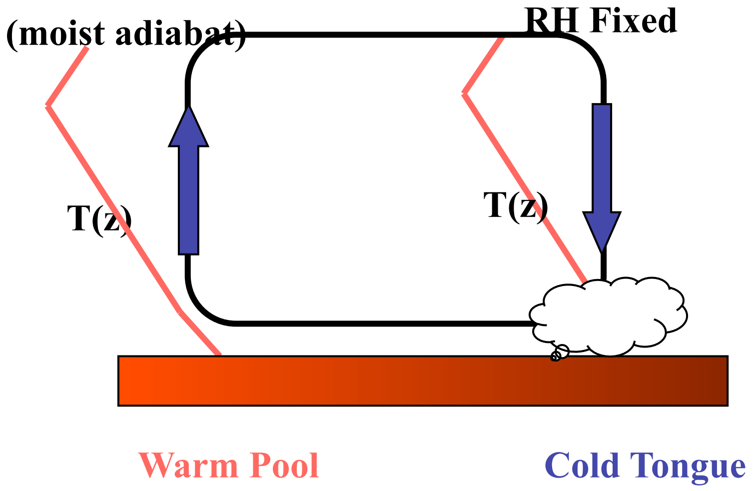
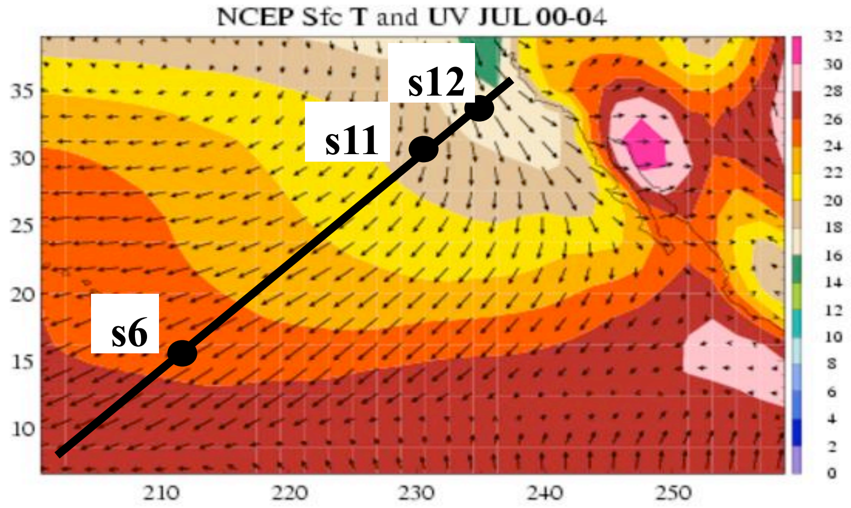

Low–level clouds (%), ISCCP, ANN


Middle and High–level clouds (%), ISCCP, ANN



(Zhang and Bretherton 2008)


NCEP Sfc T and UV JUL 00-04

The CGILS Study: CFMIP-GCSS Large Eddy and Single Column Model Study

Objectives:

1. To understand cloud feedbacks in SCMs
2. To evaluate SCM cloud feedbacks using LES
3. To interpret GCM cloud feedbacks by using SCM results

SCM (16)

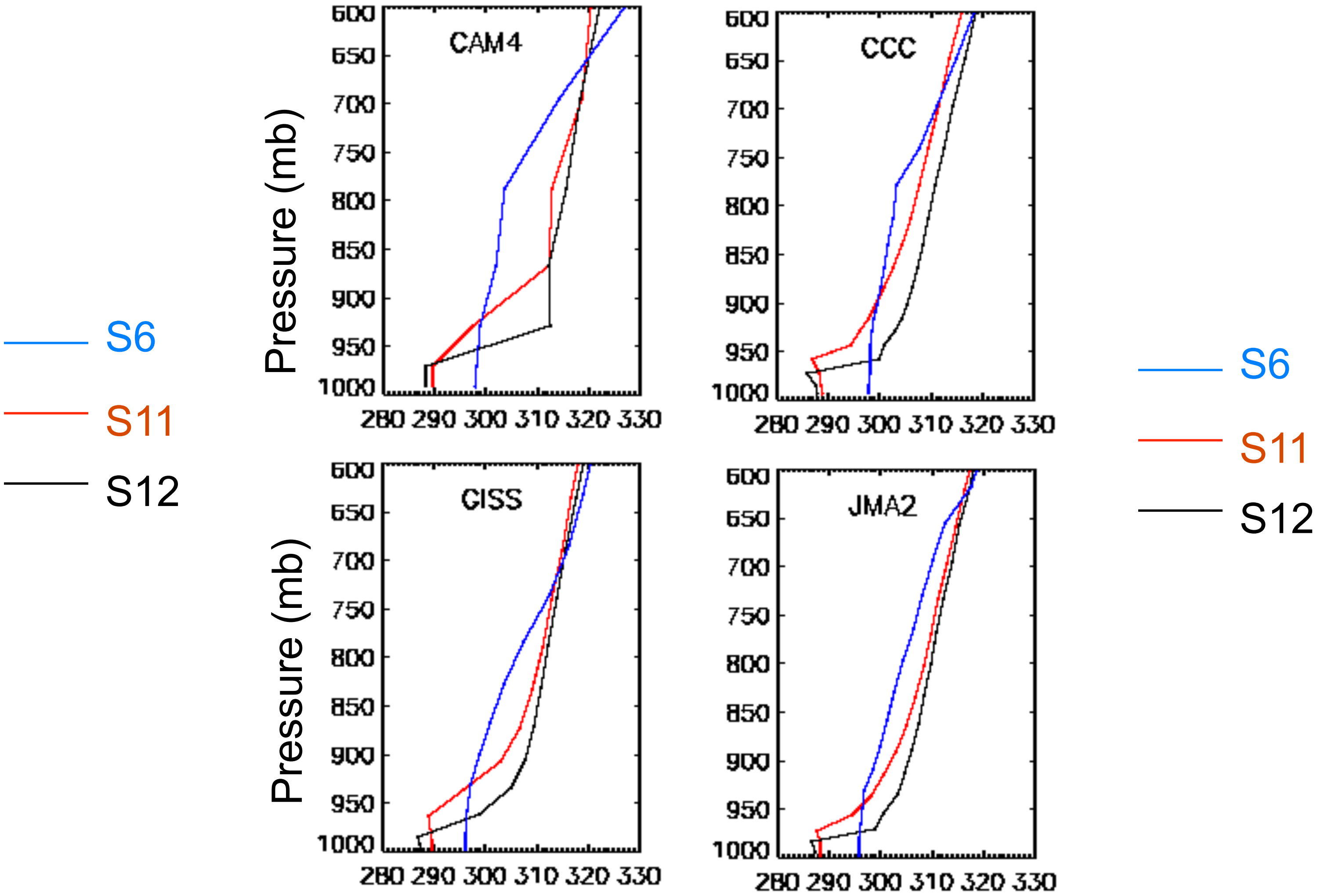
CAM4 (Hannay, Zhang)
CAM5 (Hannay, Zhang)
CCC (Austin)
CSIRO (Franklin)
ECHAM-ETH (Siegenthaler-LeDrian, Isotta)
ECHAM-MPI (Kumar, Stevens)
ECMWF (Koehler)
GFDL (Golaz, Zhao)
GISS (Wolfe, Del Genio)
GSFC (Molod, Bacmeister, Suarez)
JMA (Kawai)
LMD (Brient, Bony, Jean-Louis)
RACMO (Neggers)
SNU (Park, Kang)
UKMO (Webb, Lock)
UWM (Larson, Senkbeil)

LES (6)

DALES (de Roode, Siebesma)
SAM (Blossey, Bretherton, Khairoutdinov)
UCLA (Sandu, Stevens, Heus)
UCLA/LaRC (Cheng, Xu)
UKMO (Lock)
WRF (Endo, Liu)

Results from Control Simulations Under Steady Forcing

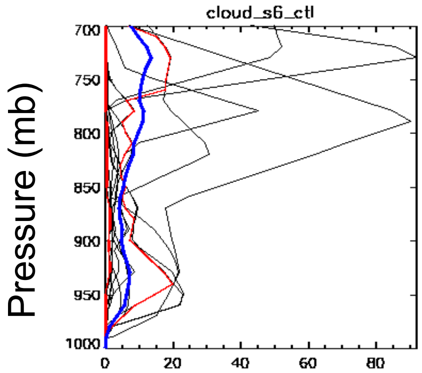
Liquid water potential temperature (K)

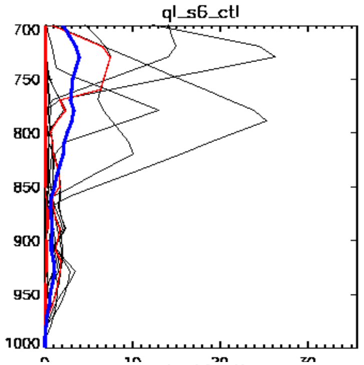


Cloud Amount (%)

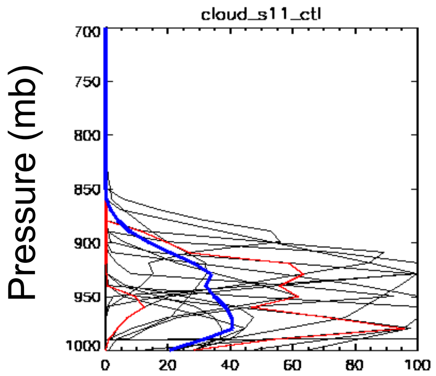
Cloud liquid water (10^{-2} g/kg)

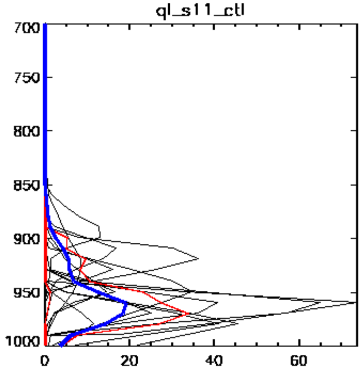
S6



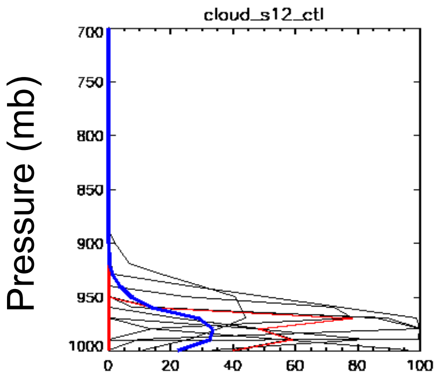


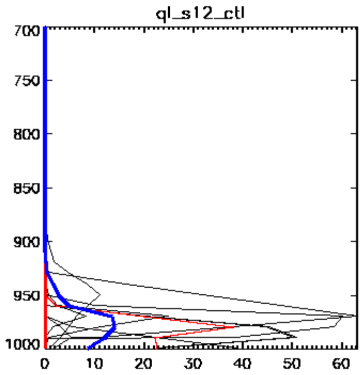
S11



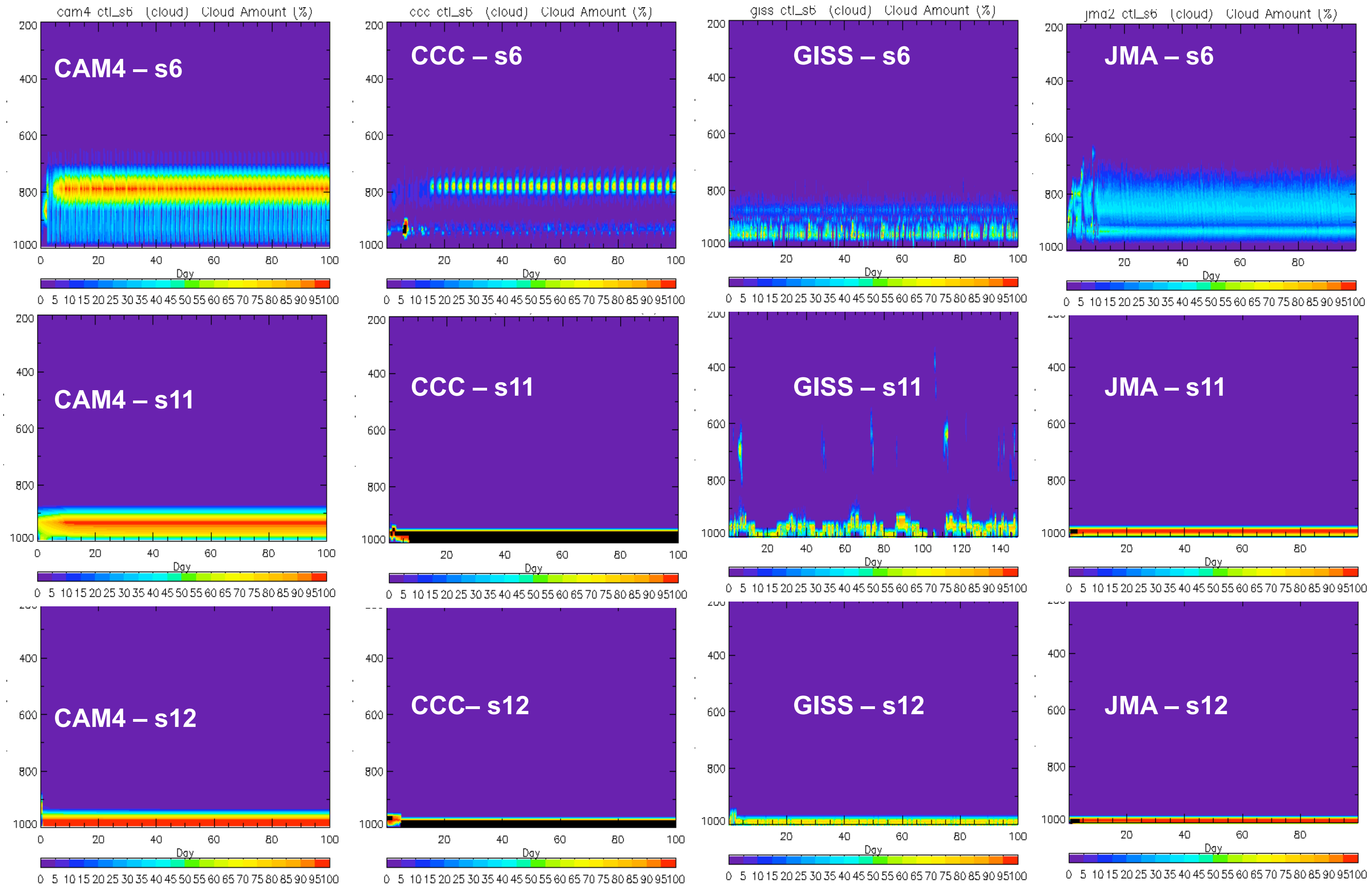


S12





Cloud Amount in Control Simulation

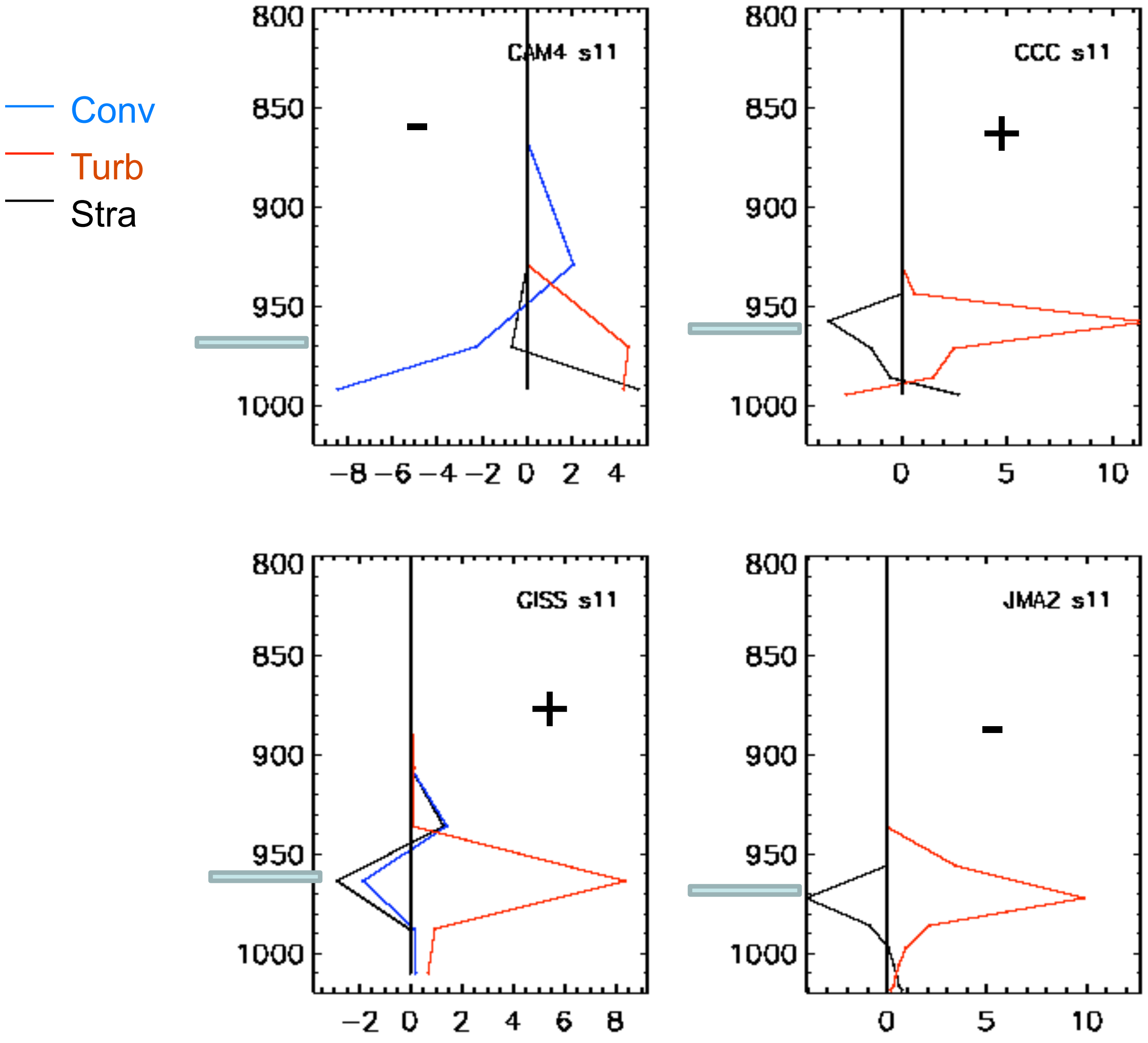


$$\frac{\partial q}{\partial t} = -c + e - \frac{\partial \overline{\omega' q'}}{\partial p} + \left(\frac{\partial q}{\partial t}\right)_{LS} \approx 0$$

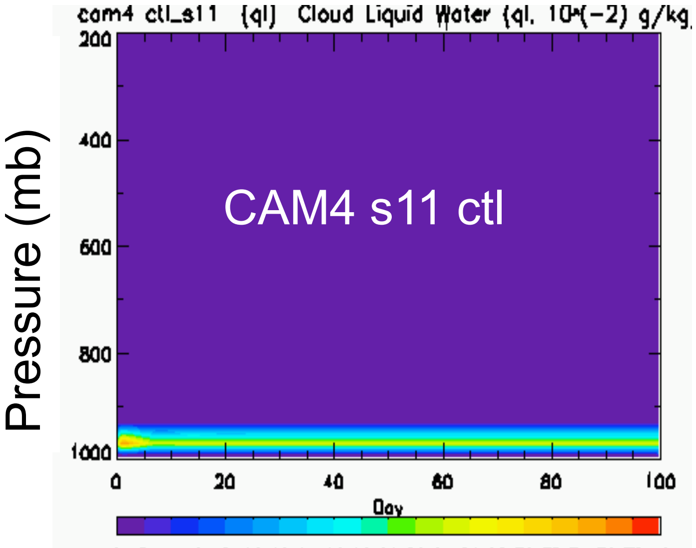
$$\overline{\omega' q'} = (\overline{\omega' q'})_{PBL} + (\overline{\omega' q'})_{Convection}$$

$$c \propto q_l$$

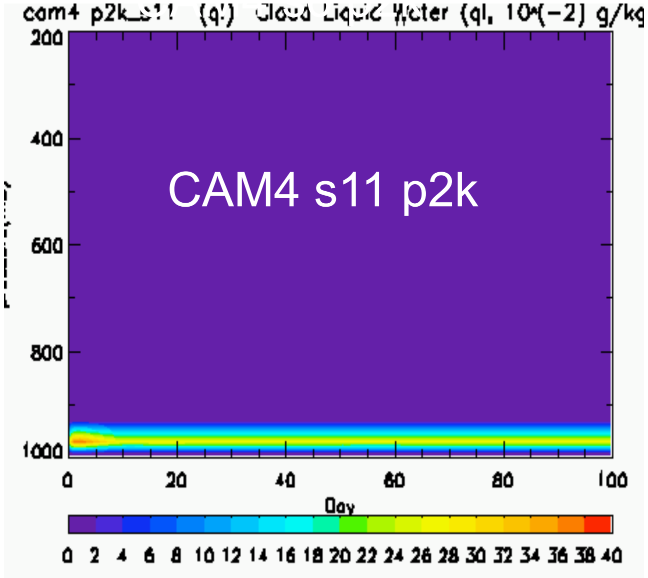
Moisture tendency (g/kg/day) at S11



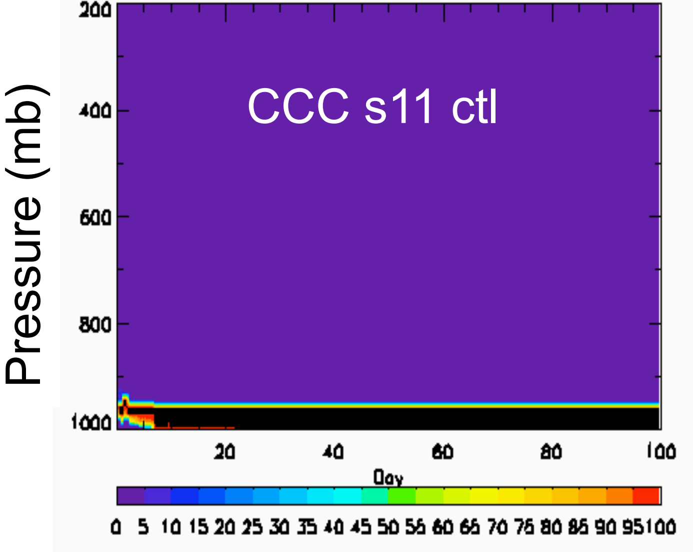
Cloud Feedbacks Under Steady Forcing


cam4 ctl_s11 (ql) Cloud Liquid Water (ql, 10*(-2) g/kg

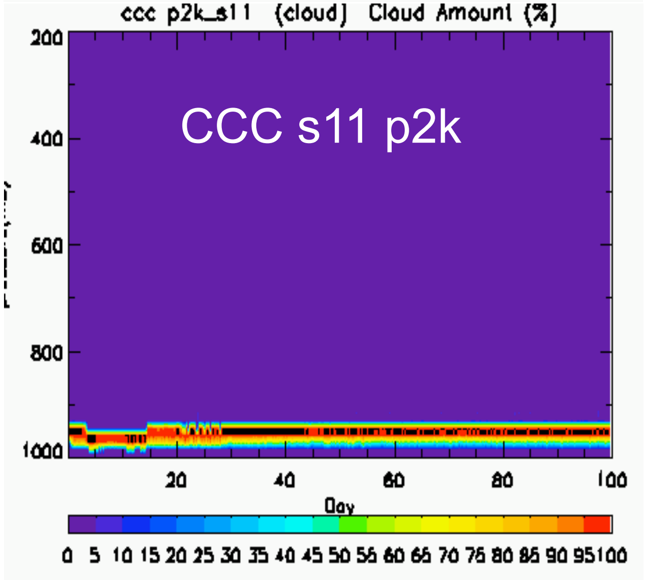
CAM4 s11 ctl


cam4 p2k_s11 (ql) Cloud Liquid Water (ql, 10*(-2) g/kg

CAM4 s11 p2k

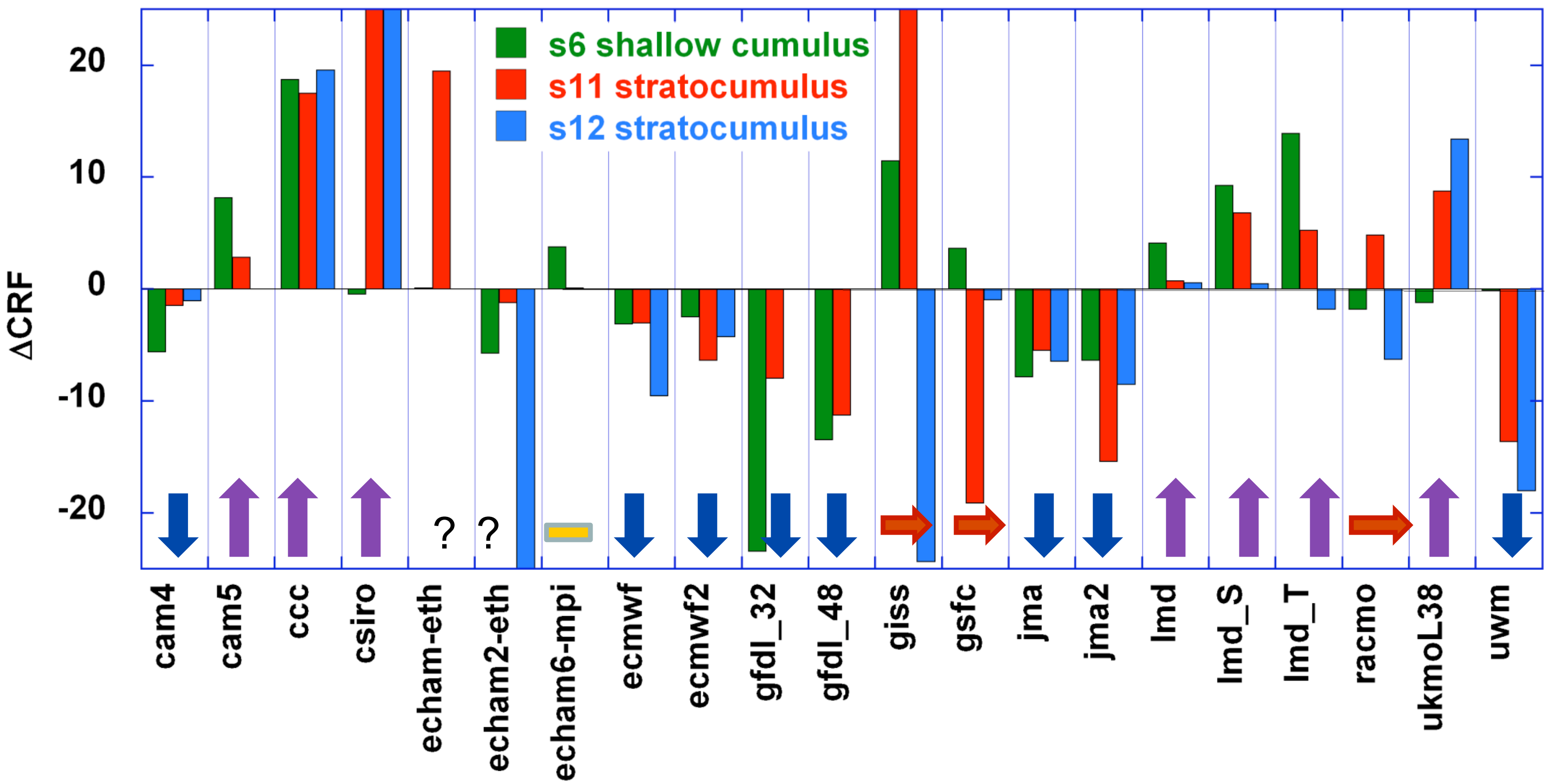

ccc ctl_s11 (cloud) Cloud Amount (%)

CCC s11 ctl


ccc p2k_s11 (cloud) Cloud Amount (%)

CCC s11 p2k

Cloud Feedback at All Three Locations: ΔCRF (W/m2)



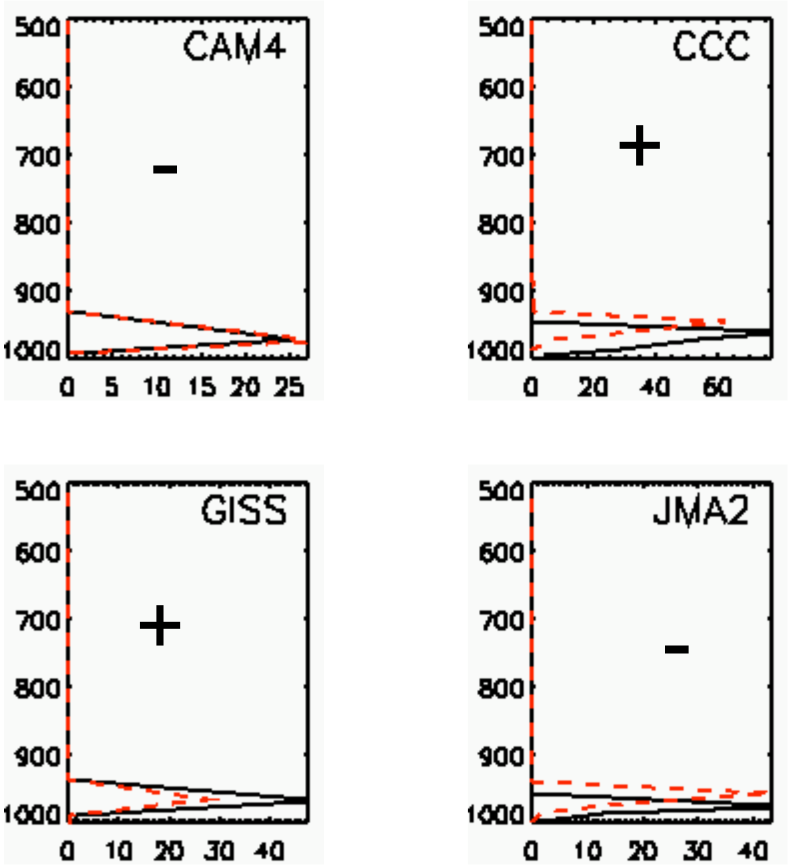
⬆ **5 models with positive feedback: CAM5, CCC, CSIRO, LMD, UKMO**

⬇ **5 model with negative feedback: CAM4, ECMWF, GFDL, JMA, UWM**

▬ **1 with little feedback: ECHAM-MPI; ? 1 to equilibrate ECHAM-MPI**

➡ **3 models with different signs at the three locations: GISS, GSFC, RACMO**

Cloud liquid water (10^{-2} g/kg) at S11, dashed for warmer climate



A reference case: well mixed boundary layer: (non-local, counter-gradient)

Cloud bottom: z_{cb} : $RH_s \times q^*(T_s) = q^*(T_s - \Gamma z_{cb})$

$$\frac{\partial z_{cb}}{\partial T_s} = \frac{1}{\Gamma}\left(1 - \frac{T_{v,z_{cb}}^2}{T_{v,s}^2}\right)$$

changes little

Cloud top:

Scaled by surface buoyancy flux or bulk Richardson number

$$R_{ib} = \frac{g}{\bar{\theta}} \frac{[\theta_v(z_{ct}) - \theta_{vs}] \times z_{ct}}{u^2(z_{ct}) + v^2(z_{ct})}$$

$$\theta_{vs} = \theta_s[1 + \varepsilon RH \times q^*(T_s)]$$

z_{ct} : **increases with Ts**

Cloud top liquid water increases with Ts: $q_l = RH \times q^*(T_s) - q^*(T_{z_{ct}})$

Negative cloud feedback

Other factors:

(1) explicit cloud top entrainment:

$$w_e = w_e(B_s, F_{rad}, E_{evap}) = w_e(B_s, C, q_l) \approx \overline{w}(z_{ct})$$

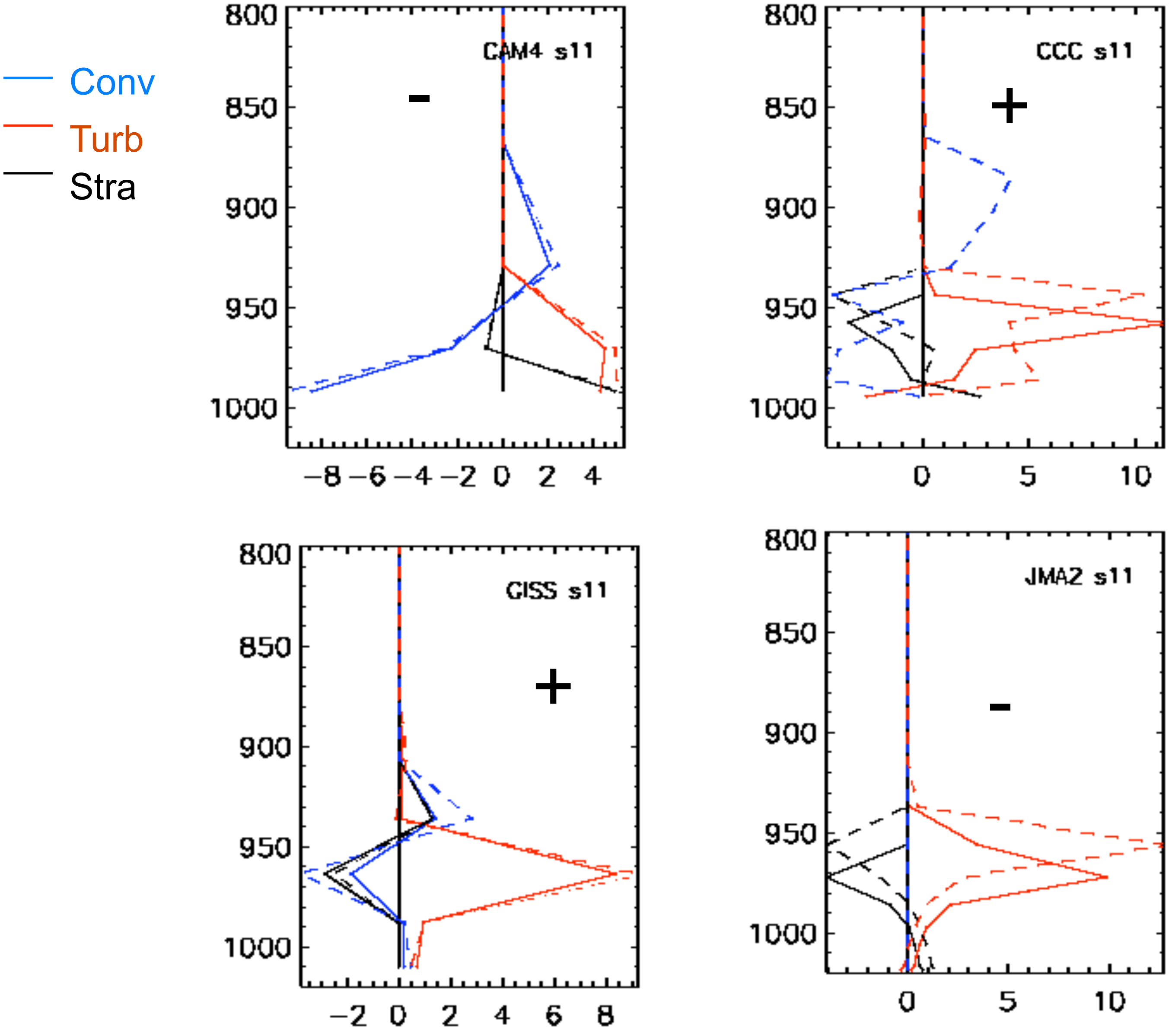
→ Tend to be similar to well mixed (negative feedback)

(2) Shallow convection:

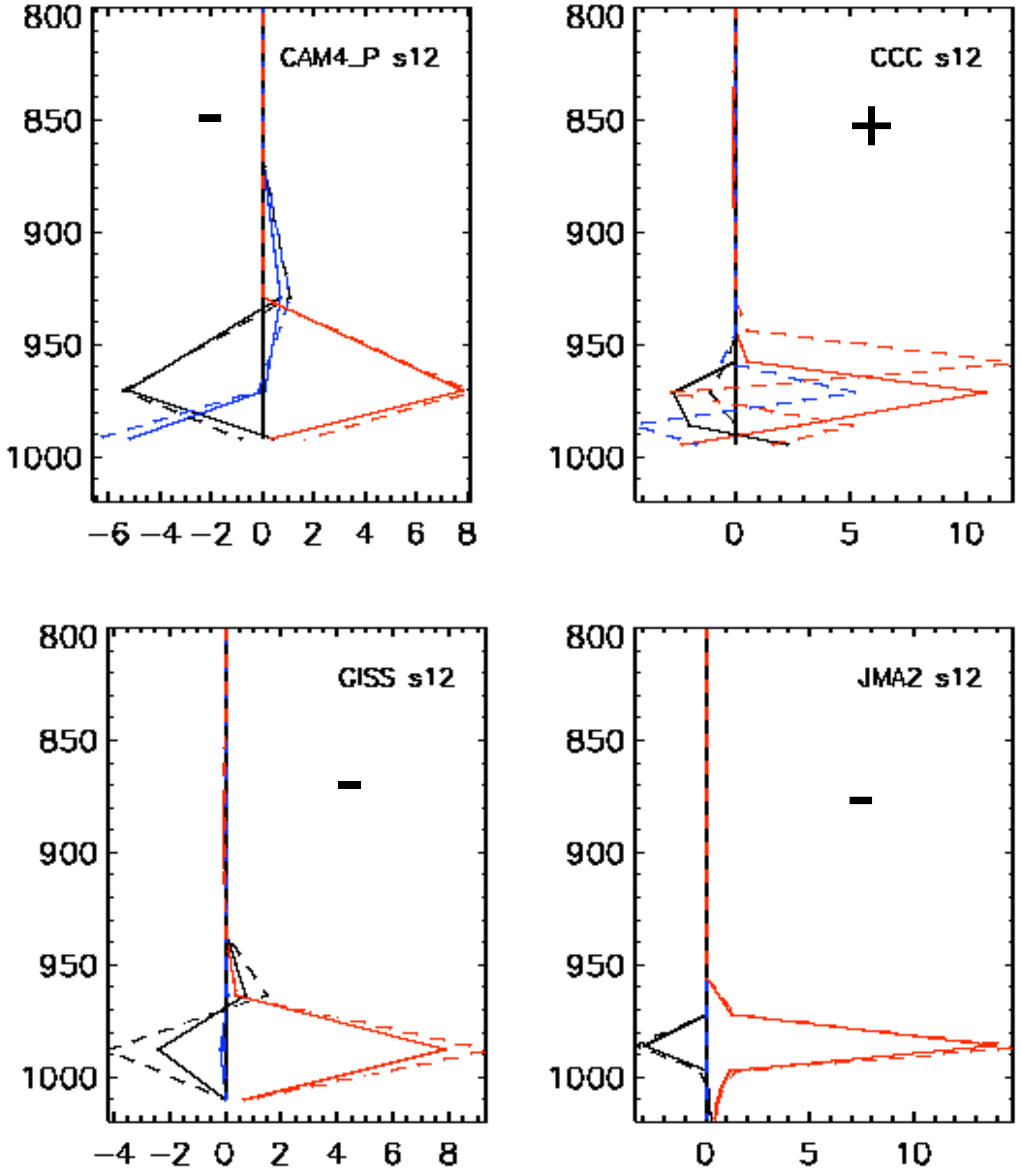
1. Mixing of air below and above cloud layer
→ Tend to be similar to well-mixed layer model (negative feedback)

2. Mixing with extrainment and detrainment
→ Tend to be similar to cloud-top entrainment (positive feedback)

Moisture tendency (g/kg/day) at S11, dashed for warmer climate

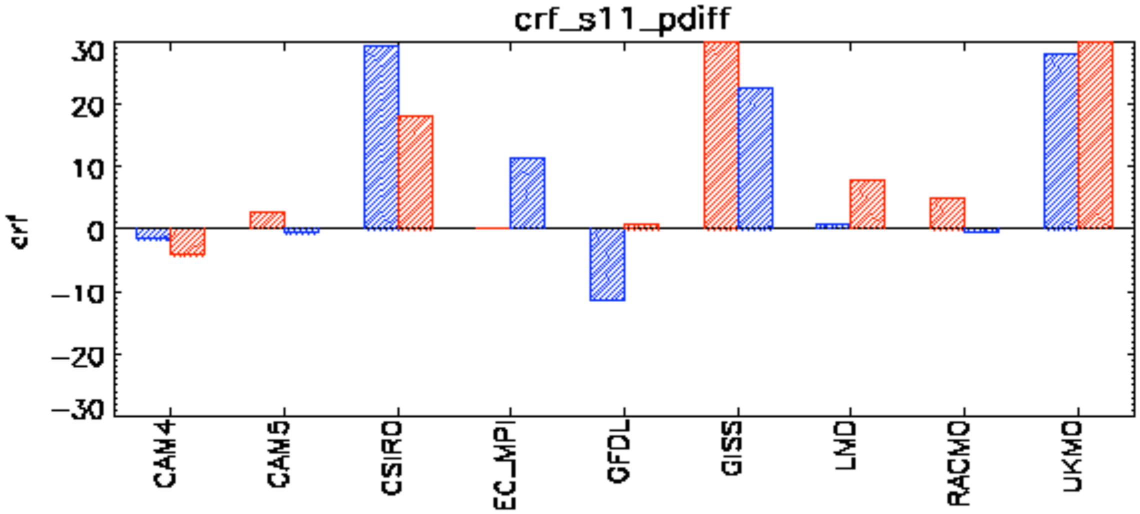


Moisture tendency (g/kg/day) at S12, dashed for warmer climate



Results from Transient Forcing

Cloud Feedback (W/m2/K) at S11

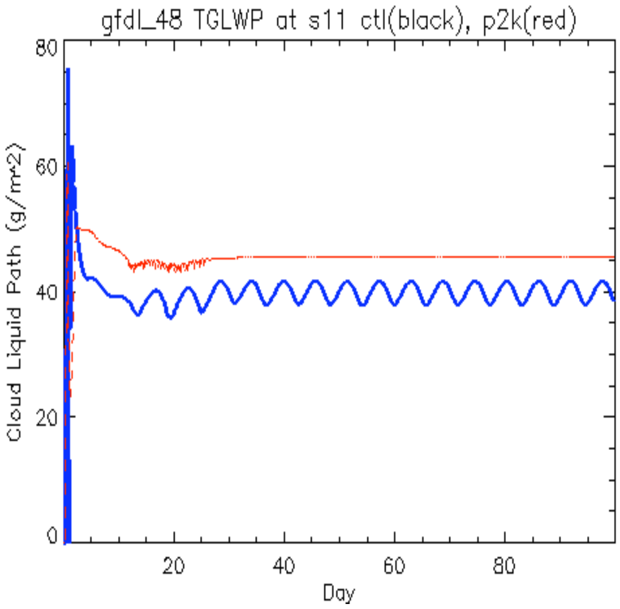


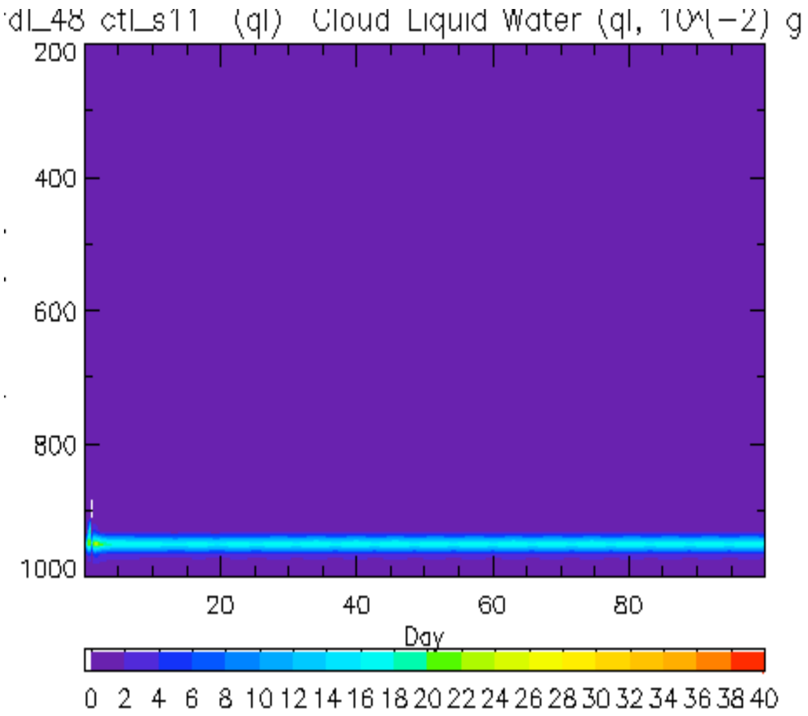
Blue: Steady forcing

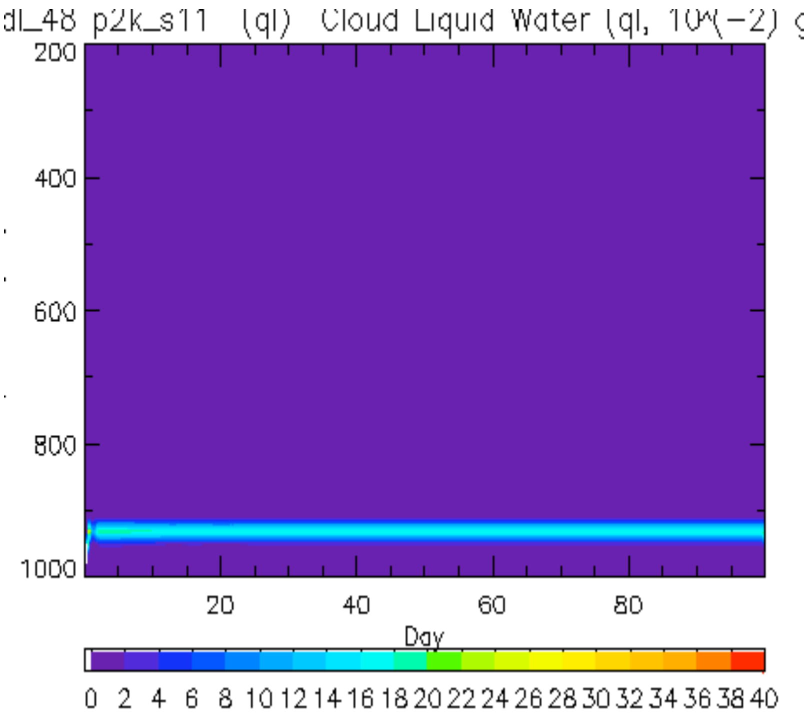
Red: Transient Forcing

GFDL L48 Constant Forcing
Cloud Liquid Water

Control versus Warmer Climate





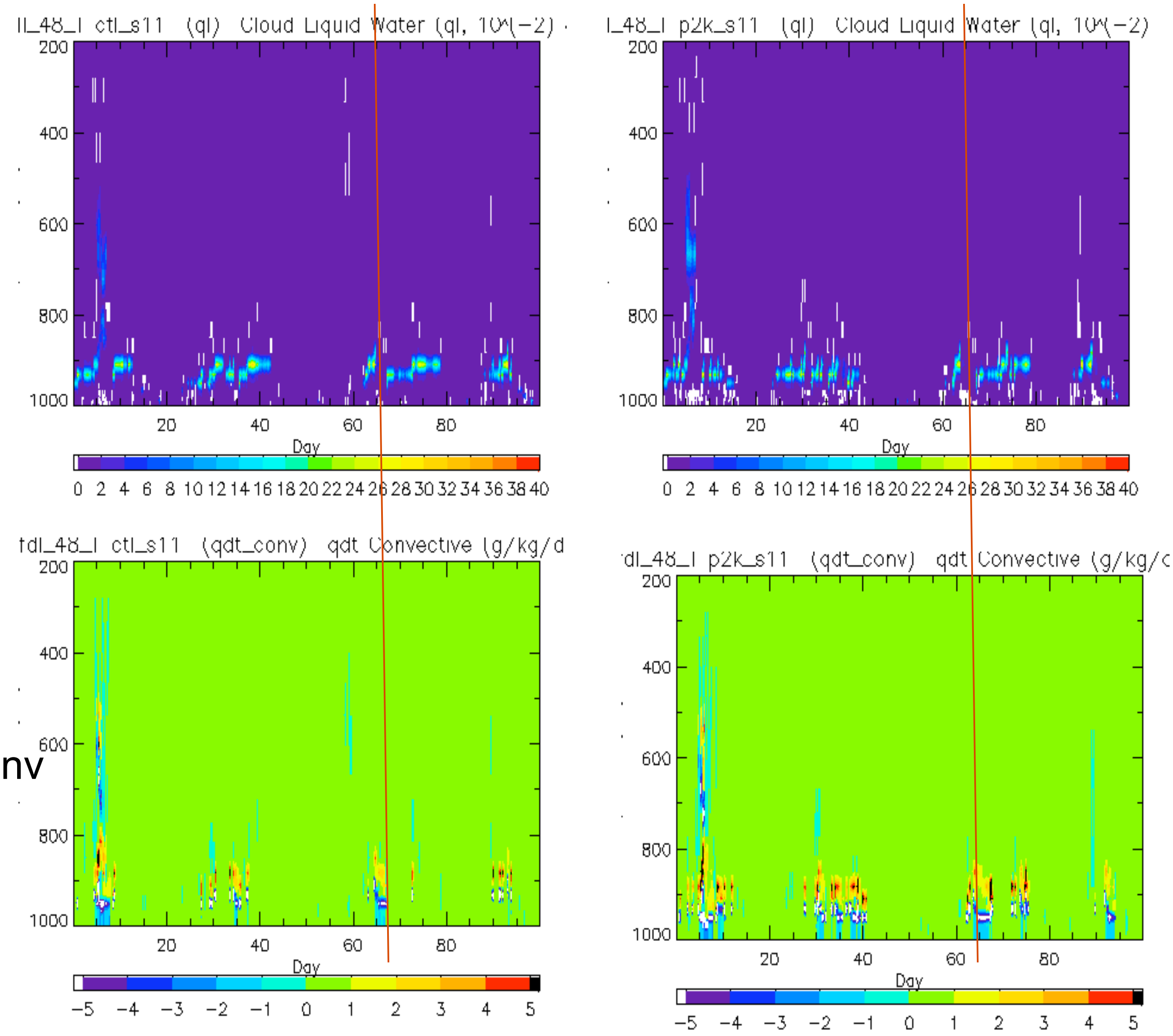


Control

Warmer

ql

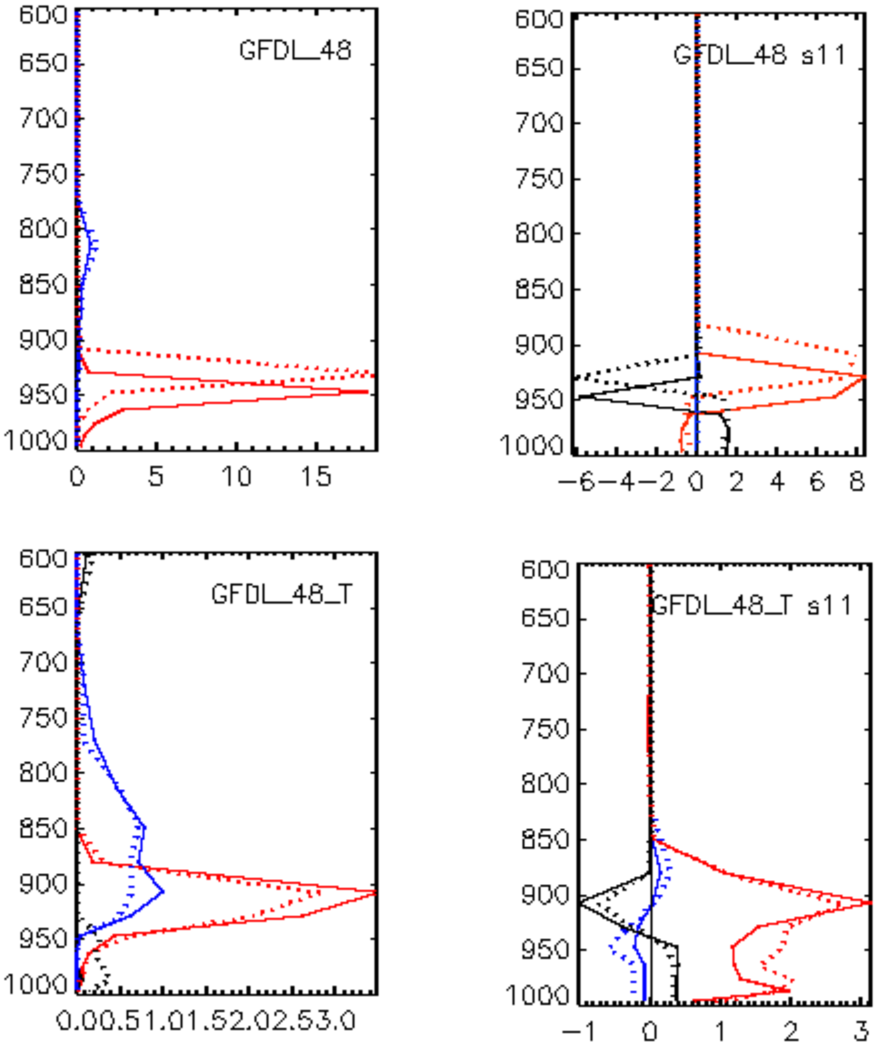
dq/dt_conv



— S6

— S11

— S12



Steady forcing

— Conv

— Turb

— Stra

Transient forcing

Summary

Mechanisims:

1. K diffusivity (negative feedback)
    - non-local
    - counter-gradient
    - local Ri, but coarse resolution, including TKE Level 2.5 or higher

2. Explicit entrainment at top of PBL (toward positive feedback)

3. Shallow convection acts as the entrainment process, drawing dry and warm air down (toward either positive or negative)