Contrasting the physical mechanisms of low-cloud climate feedbacks in CAM4 and CAM5

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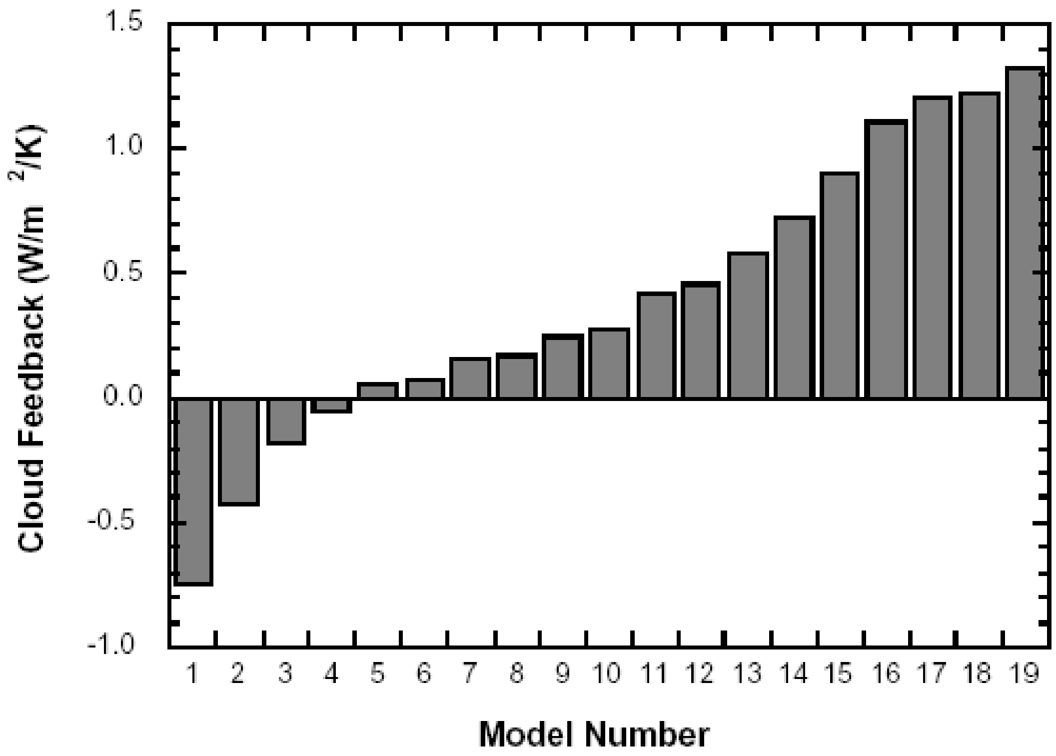
Stony Brook University / SUNY

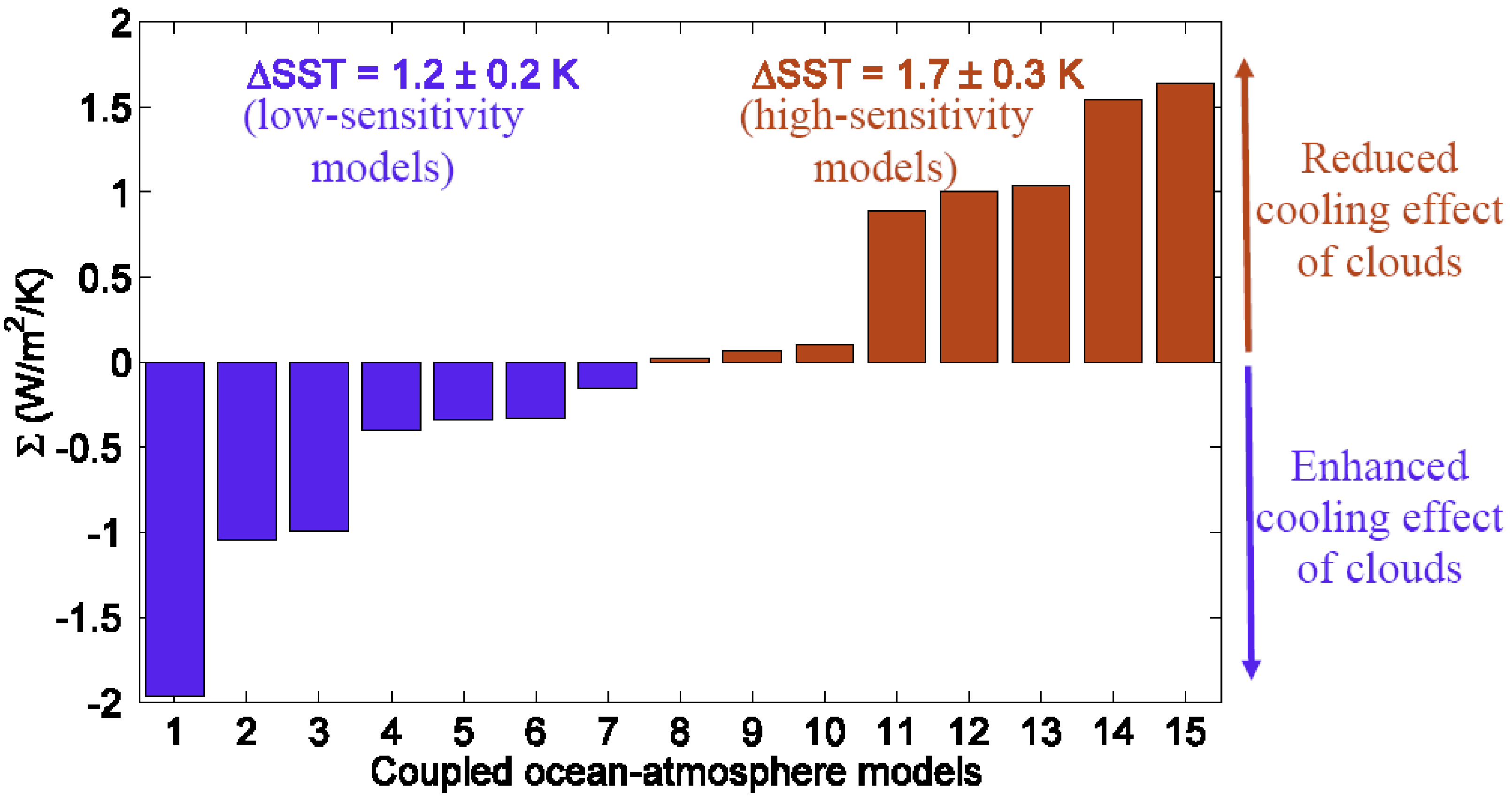
Acknowledgements:

CGILS Participants & NASA MAP

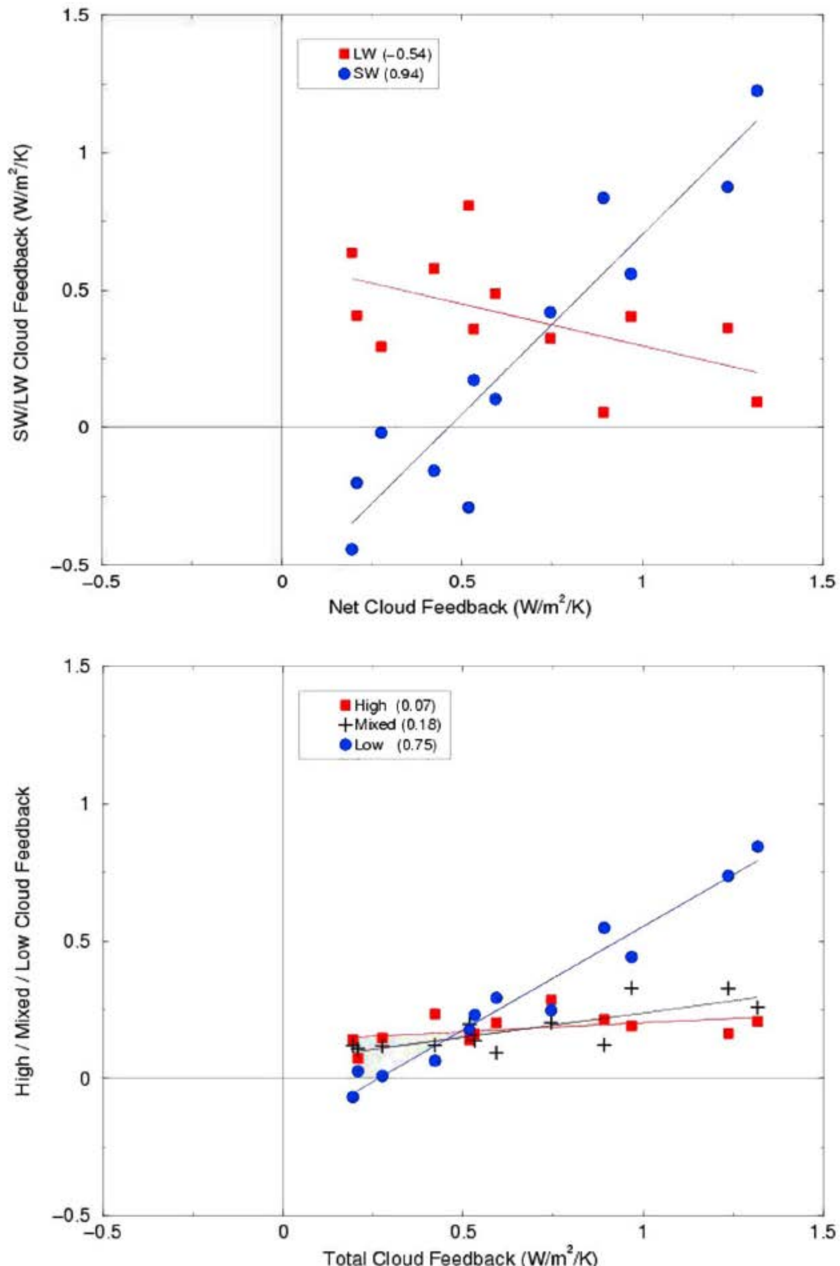


(Cess et al. 1990)

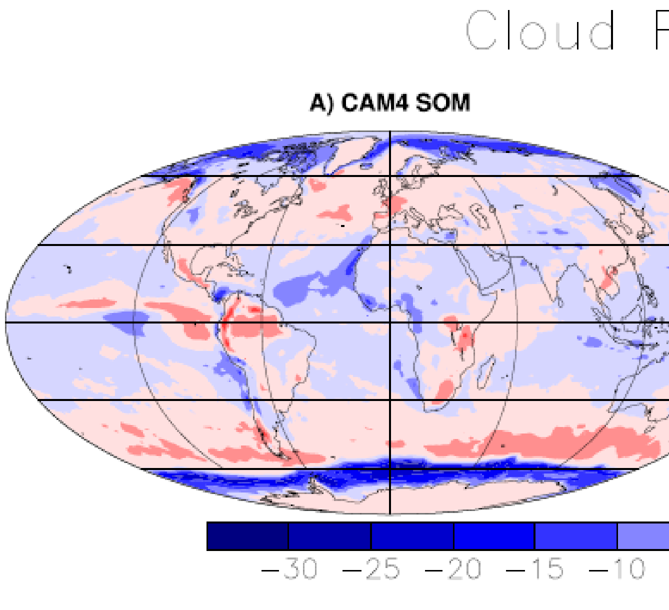
Sensitivity of the Tropical NET Cloud Radiative Forcing (CRF) to surface temperature change ($W/m^2/K$)



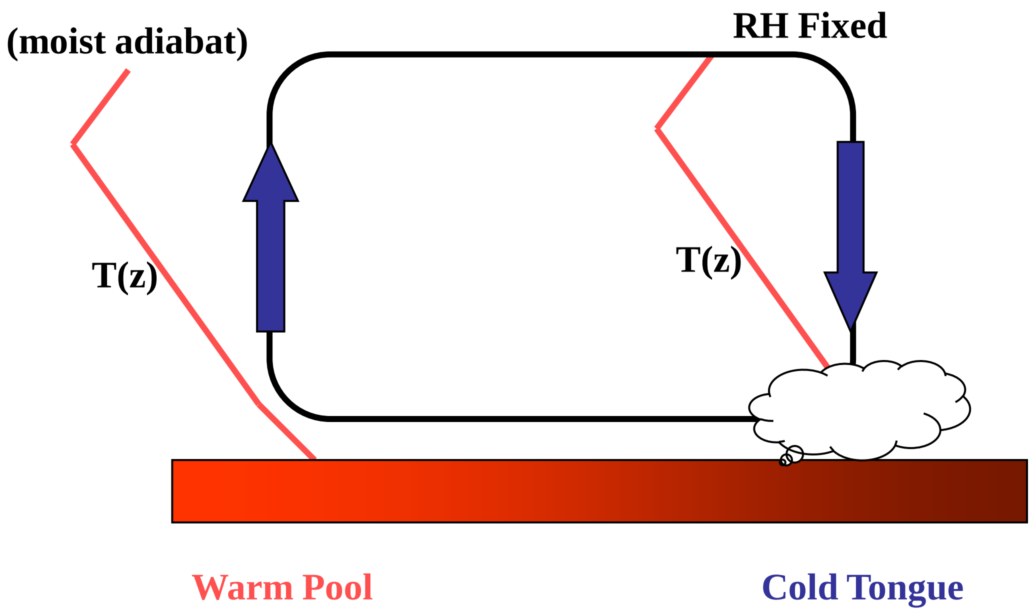
(Bony and Dufresne, GRL, 2005)



(Soden and Vecchi, 2011)

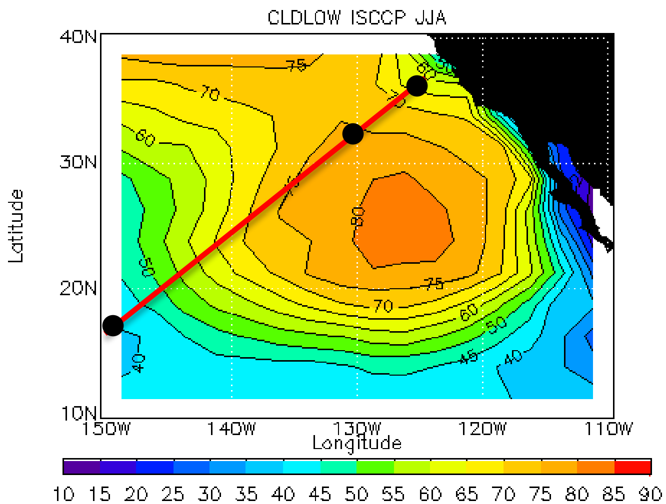


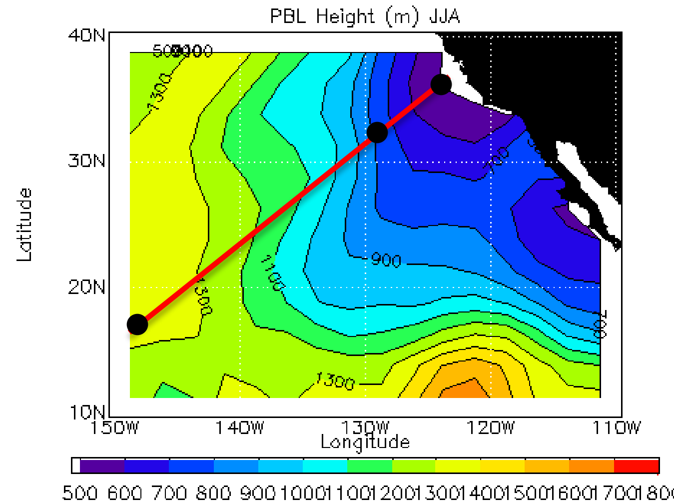
(Gettleman et al., 2011)

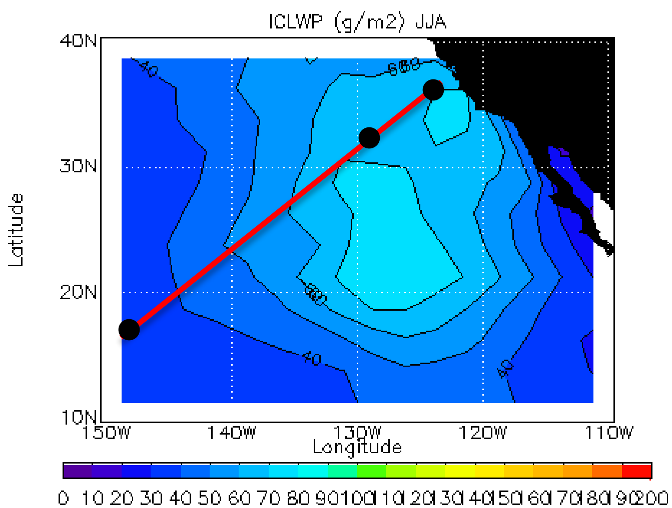


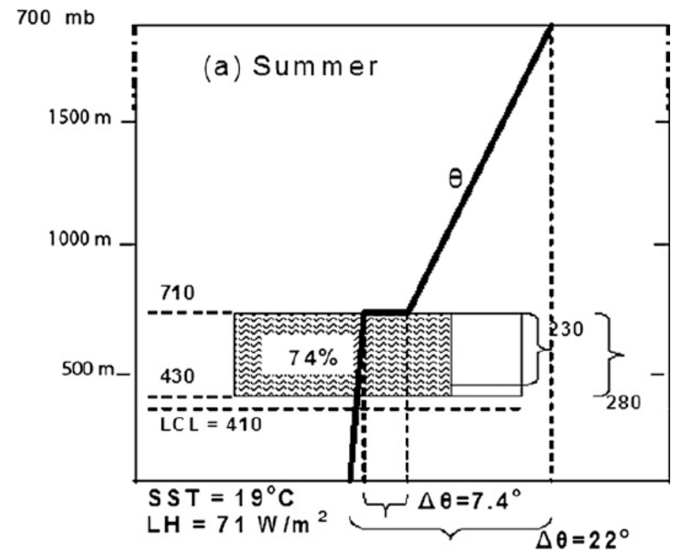
(Zhang and Bretherton, 2008)

Observations







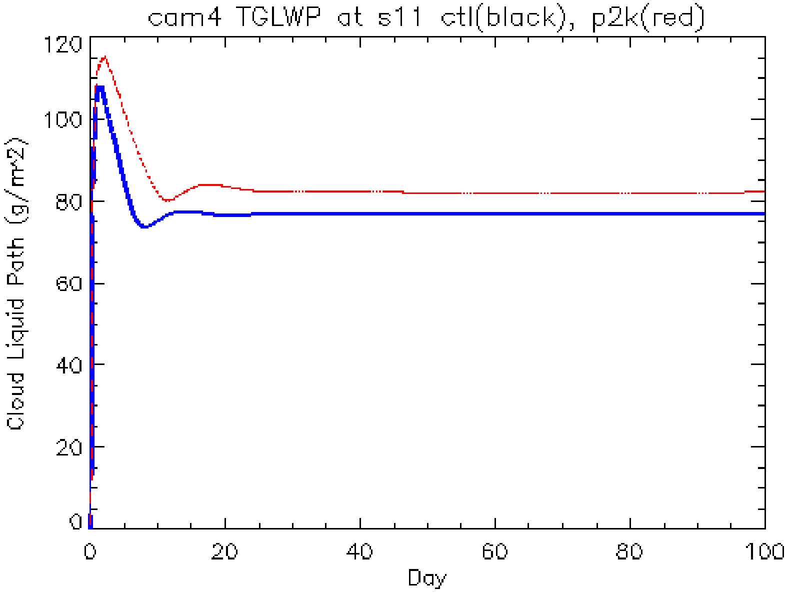


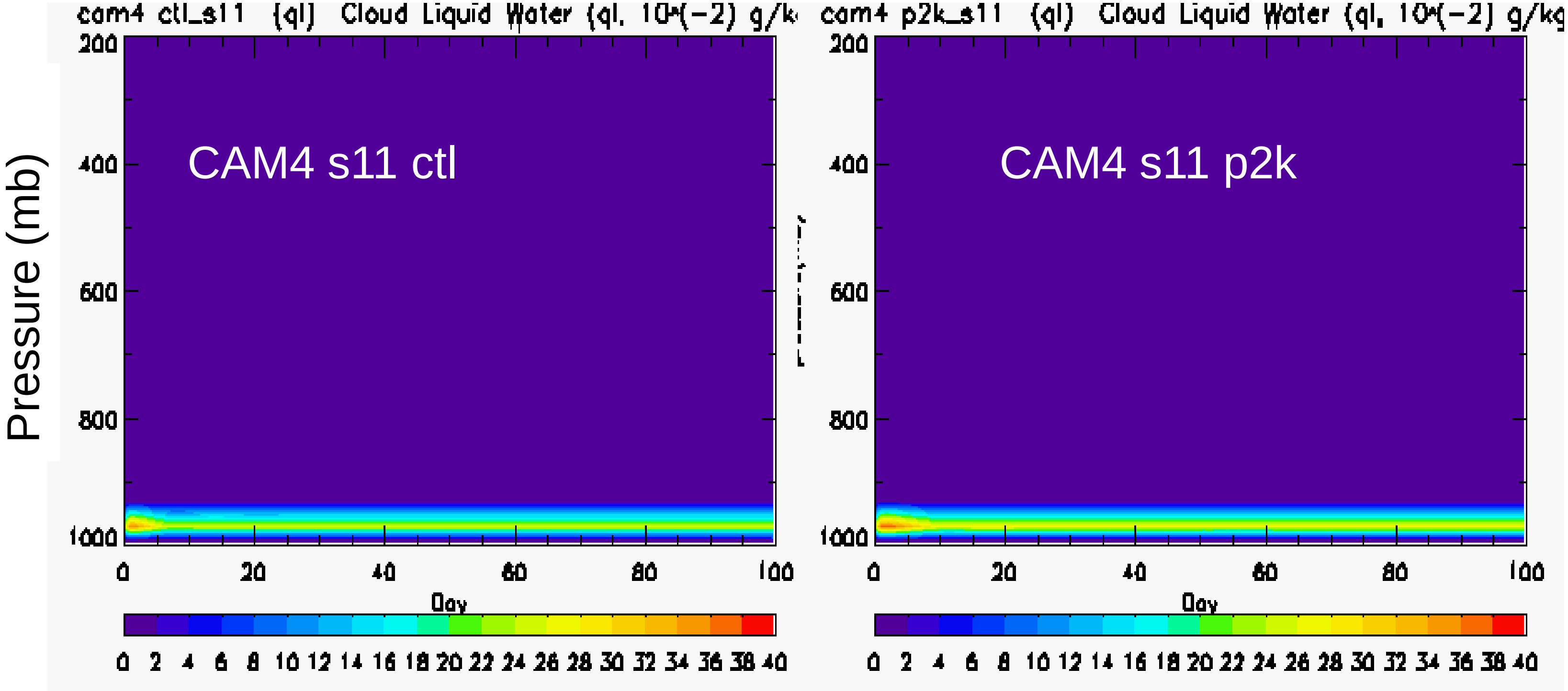
Lin, Zhang, Loeb (2009,JCL)

CAM4, stratocumulus regime

Negative cloud feedback

Cloud liquid water ql



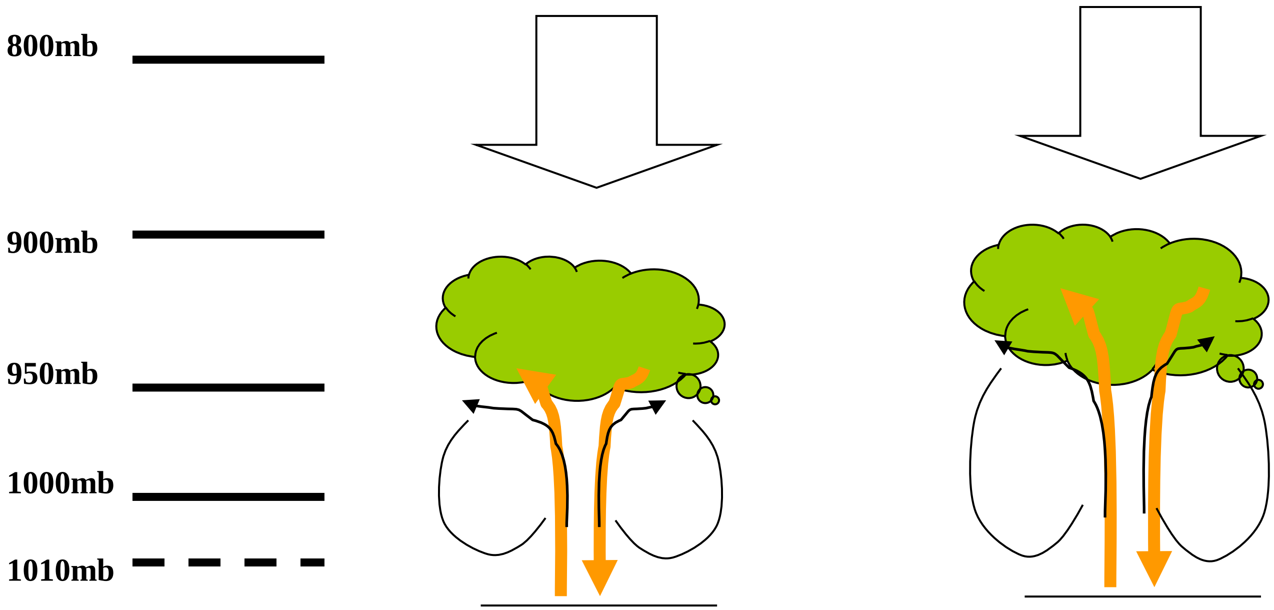


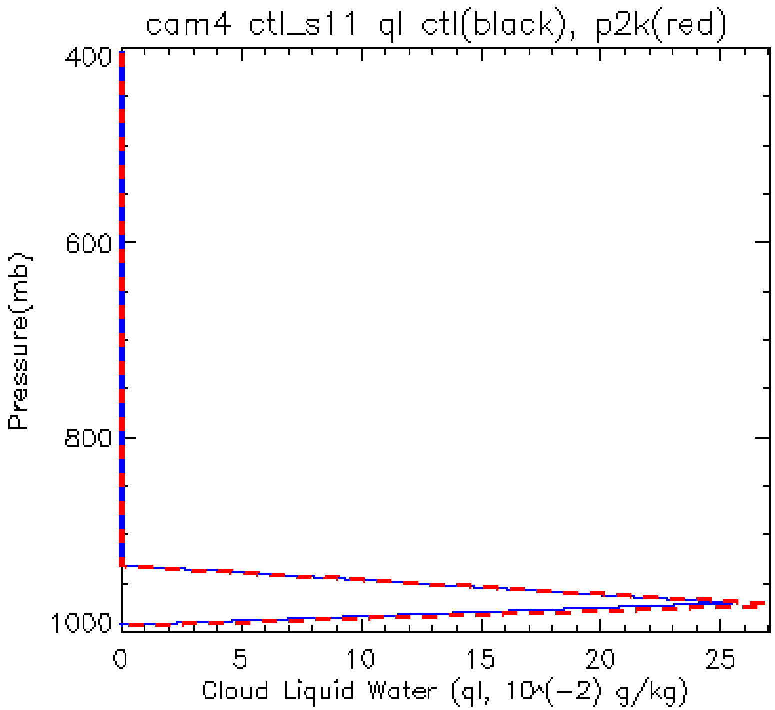
CAM4 Negative feedbacks

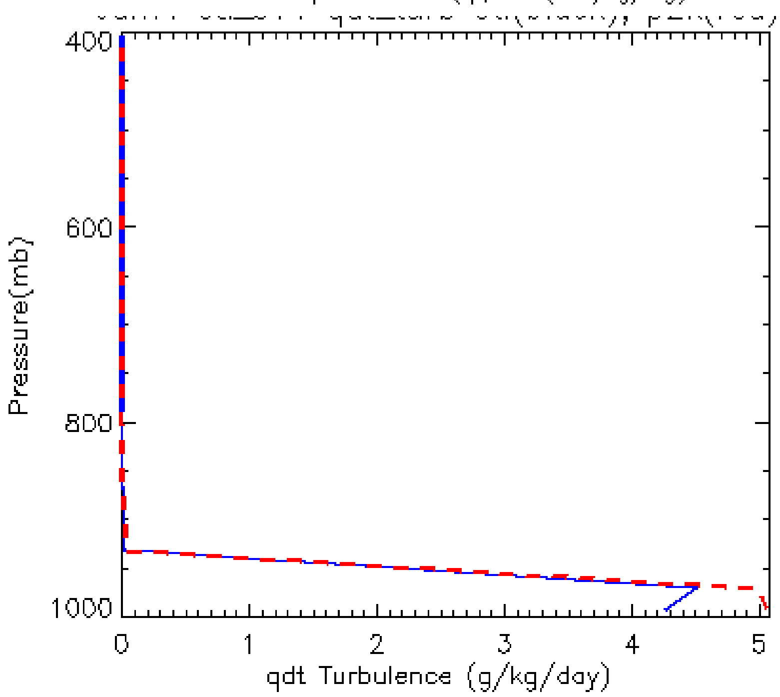
Stratocumulus clouds formed by surface-driven turbulence

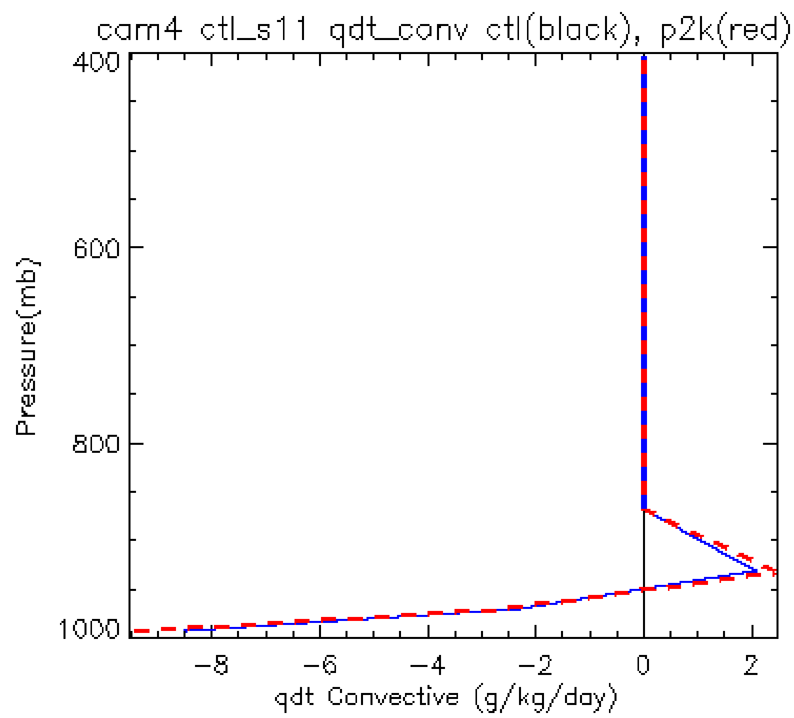
Deepened mixed layer in a warmer climate

(Shallow convection free tropospheric air with the whole PBL)

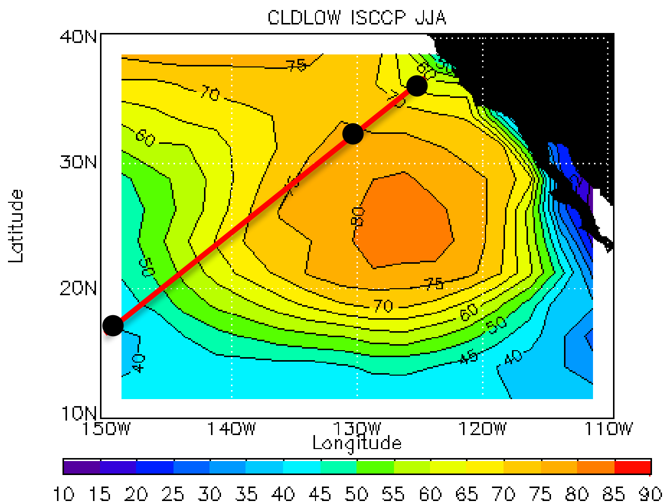


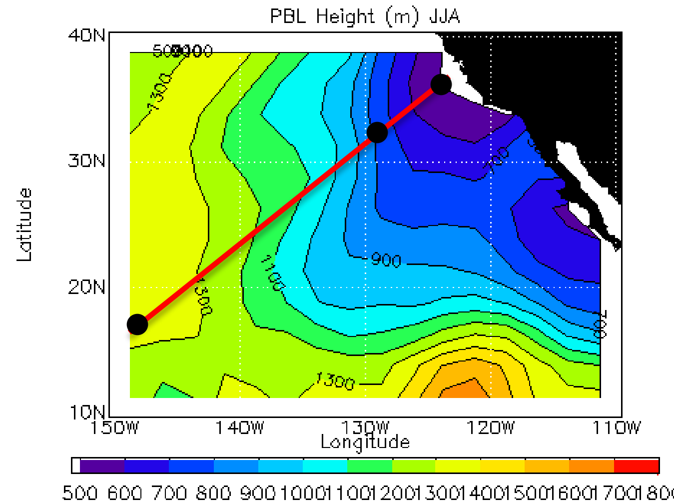

cam4 ctl_s11 ql ctl(black), p2k(red)
Pressure(mb)
400
600
800
1000
0
5
10
15
20
25
Cloud Liquid Water (ql, 10^(-2) g/kg)

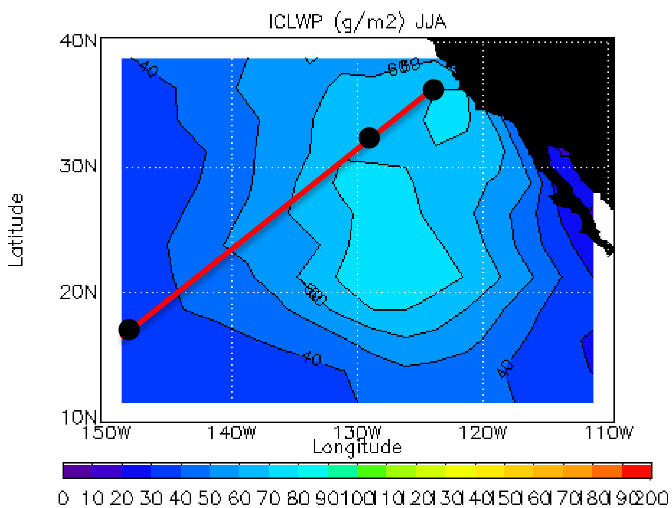

Pressure(mb)
400
600
800
1000
0
1
2
3
4
5
qdt Turbulence (g/kg/day)

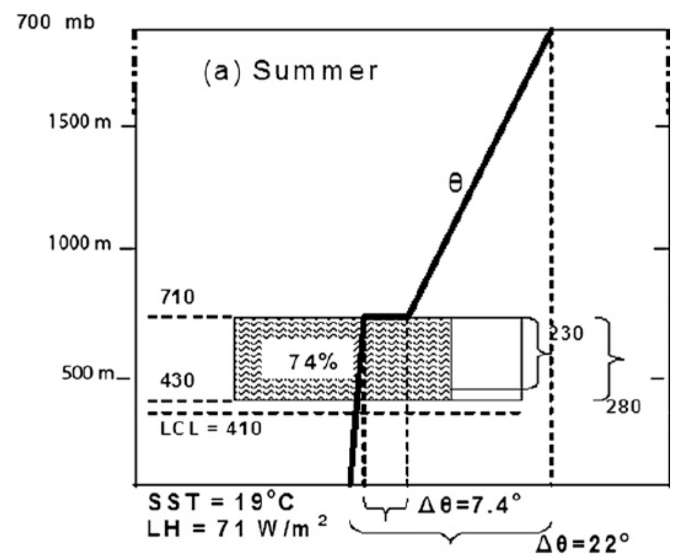

cam4 ctl_s11 qdt_conv ctl(black), p2k(red)
Pressure(mb)
400
600
800
1000
−8
−6
−4
−2
0
2
qdt Convective (g/kg/day)

Observations







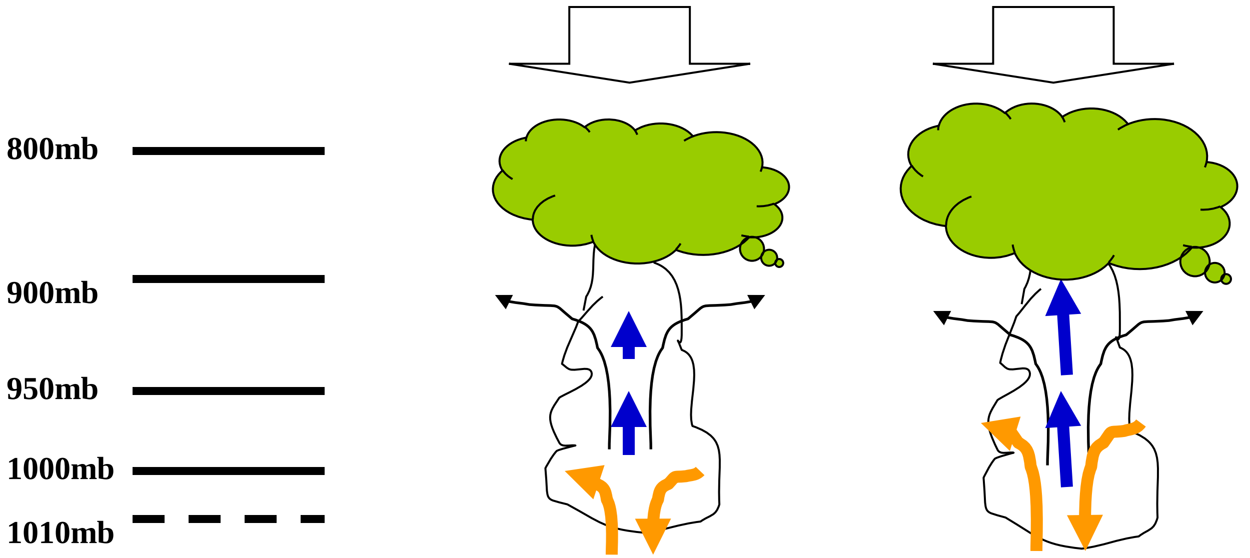


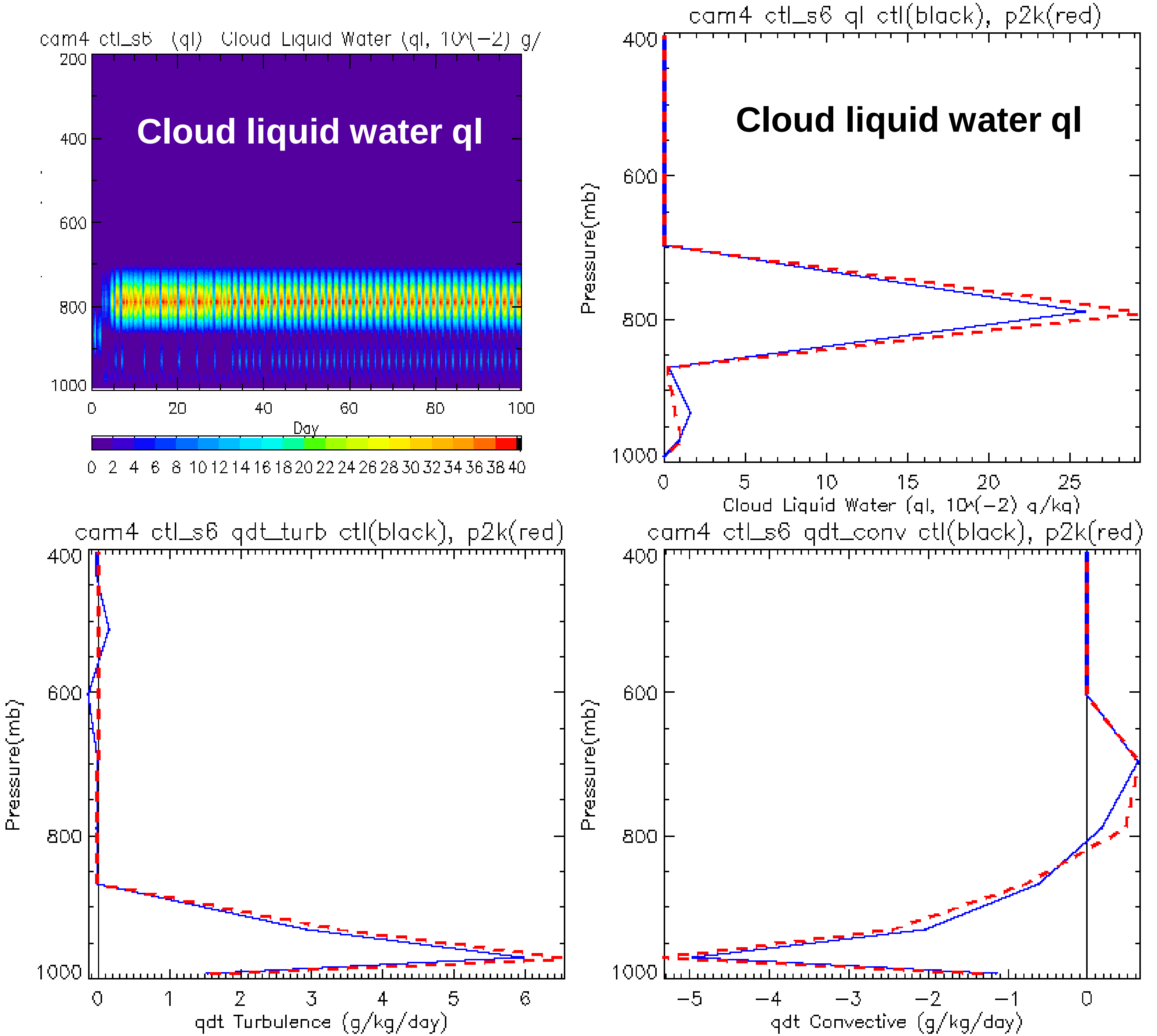
Lin, Zhang, Loeb (2009,JCL)

CAM4 Negative feedbacks

Shallow cumulus clouds formed by convective transport and detrainment

Larger transport and detrainment in a warmer climate




cam4 ctl_s6 (ql) Cloud Liquid Water (ql, 10^(-2) g/
Cloud liquid water ql
Day
cam4 ctl_s6 ql ctl(black), p2k(red)
Cloud liquid water ql
Pressure(mb)
Cloud Liquid Water (ql, 10^(-2) g/kg)
cam4 ctl_s6 qdt_turb ctl(black), p2k(red)
Pressure(mb)
qdt Turbulence (g/kg/day)
cam4 ctl_s6 qdt_conv ctl(black), p2k(red)
Pressure(mb)
qdt Convective (g/kg/day)

CAM5:

PBL explicit cloud top entrainment:

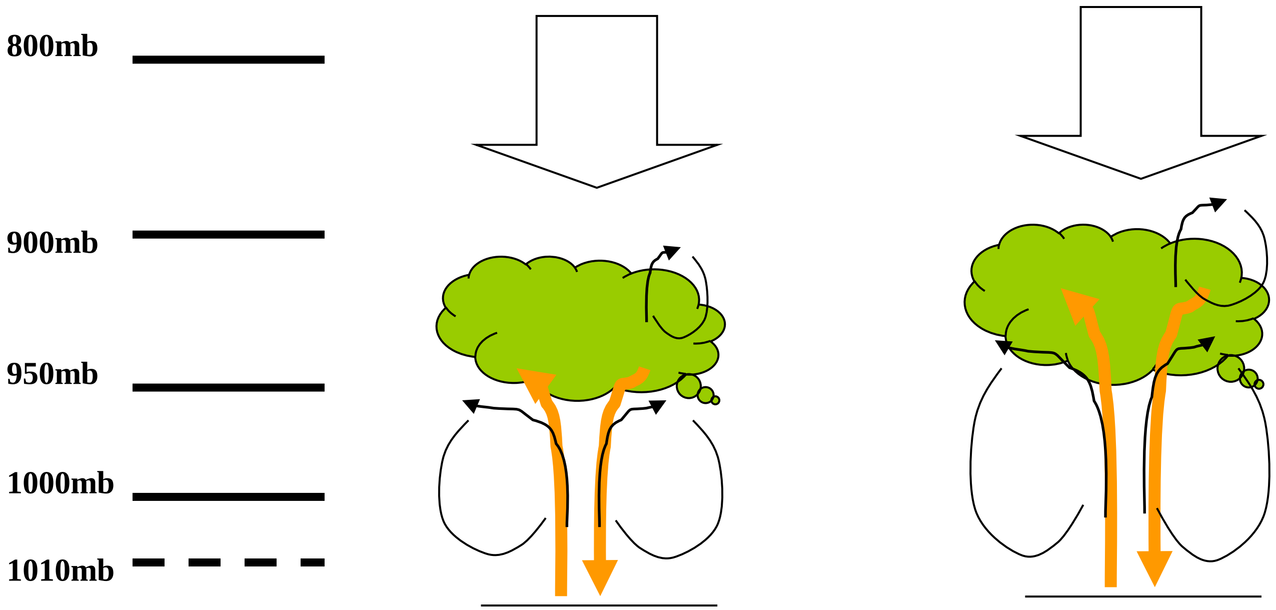
$$w_e = w_e(F_{rad}, E_{evap})$$

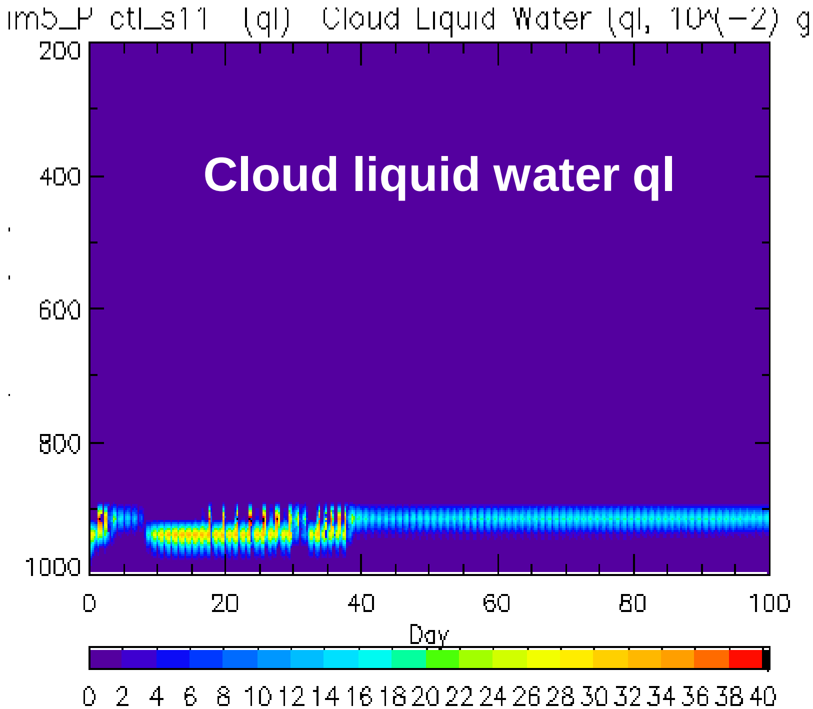
Shallow convection: lateral mixing explicitly depends cloud liquid

CAM5:

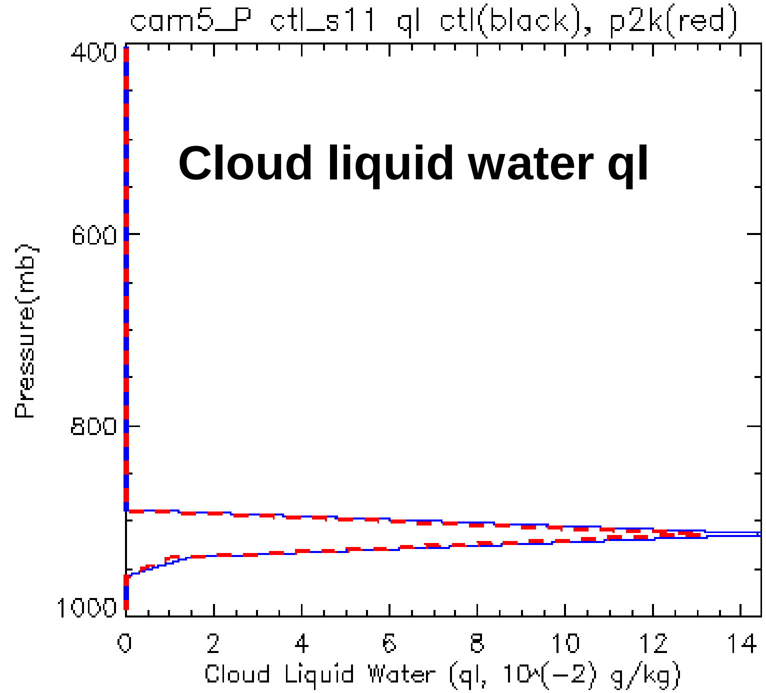
Stratocumulus clouds formed by surface-driven turbulence, but diluted by cloud top mixing

The two effects compensate each other

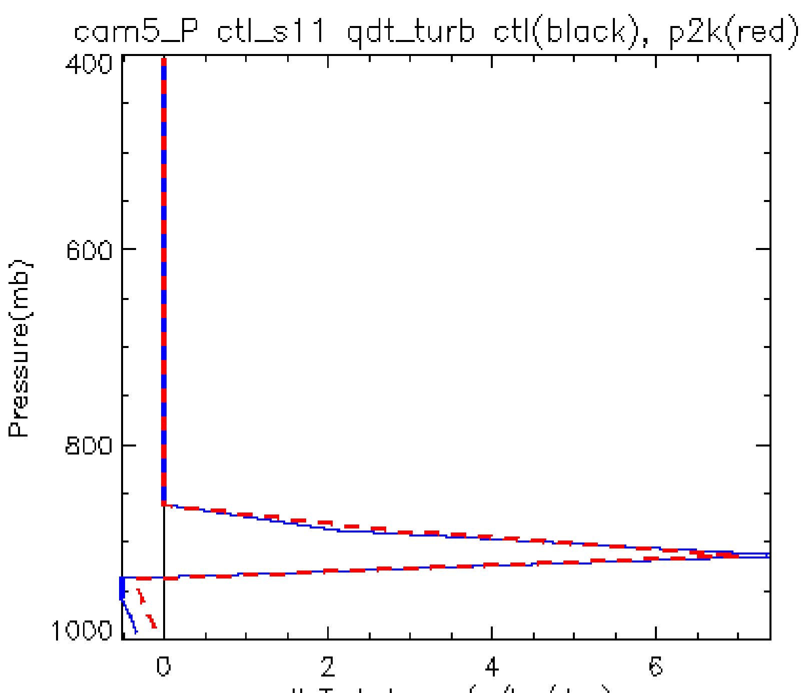




ım5_P ctl_s11 (ql) Cloud Liquid Water (ql, 10^(-2) g
Cloud liquid water ql
200
400
600
800
1000
0 20 40 60 80 100
Day
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40



cam5_P ctl_s11 ql ctl(black), p2k(red)
Cloud liquid water ql
Pressure(mb)
400
600
800
1000
0 2 4 6 8 10 12 14
Cloud Liquid Water (ql, 10^(-2) g/kg)

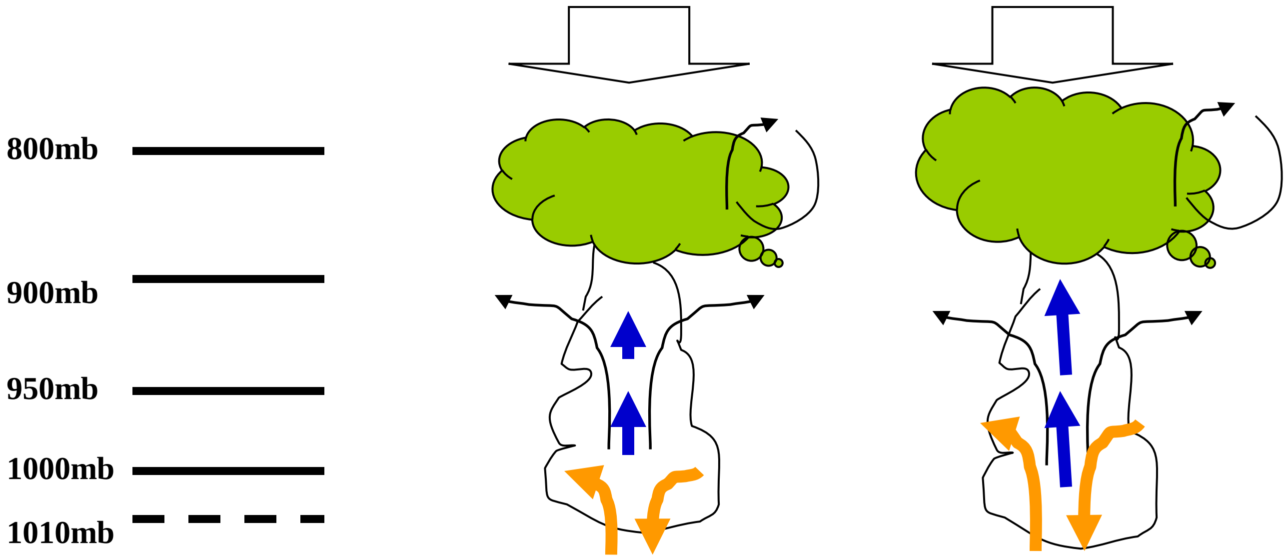


cam5_P ctl_s11 qdt_turb ctl(black), p2k(red)
Pressure(mb)
400
600
800
1000
0 2 4 6

CAM5

Shallow cumulus clouds formed by convective transport and detrainment

Larger transport and detrainment in a warmer climate



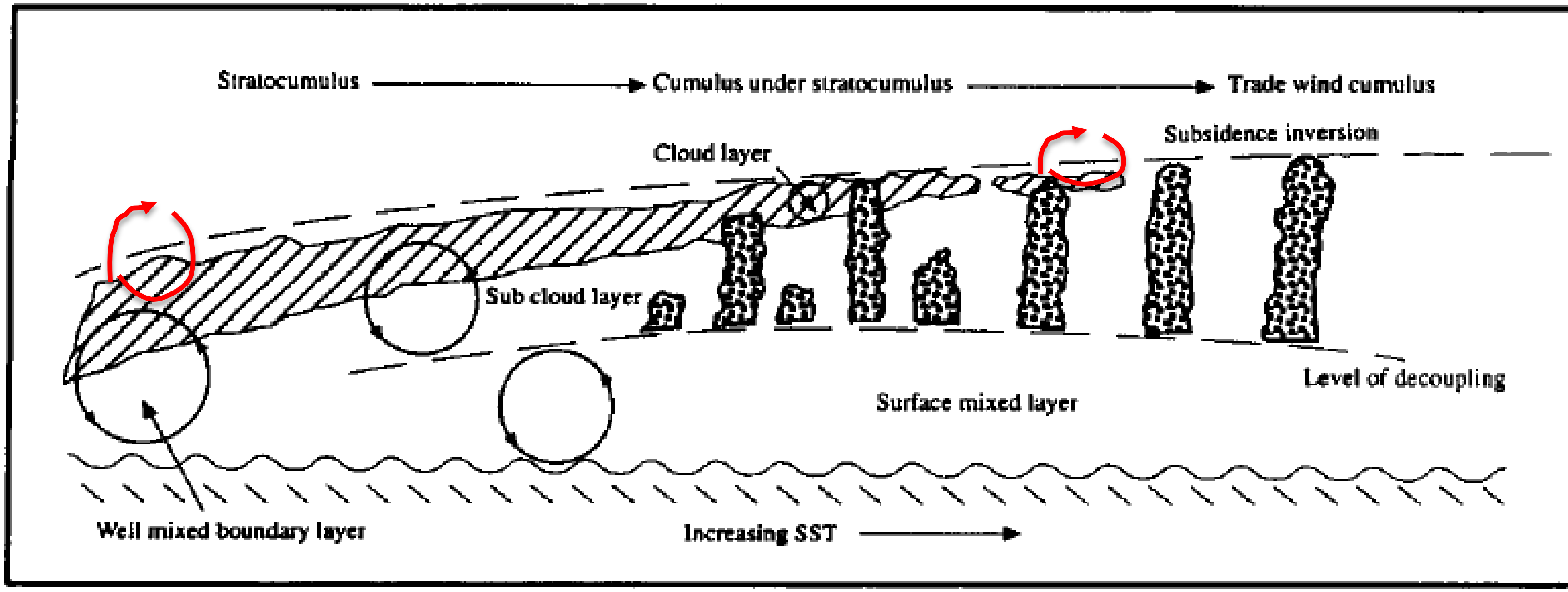


FIG. 4. A schematic of the transition from stratocumulus to trade wind cumulus.

(Albrecht 1996)

What’s Next

1. Large-eddy simulations (LES)
2. Hypothesis test of mechanisms in GCMs
3. Test on observed seasonal variation of low clouds

CGILS:

CFMIP-GCSS Intercomparison of Large Eddy Models and Single Column Models on Low Cloud Climate Feedbacks

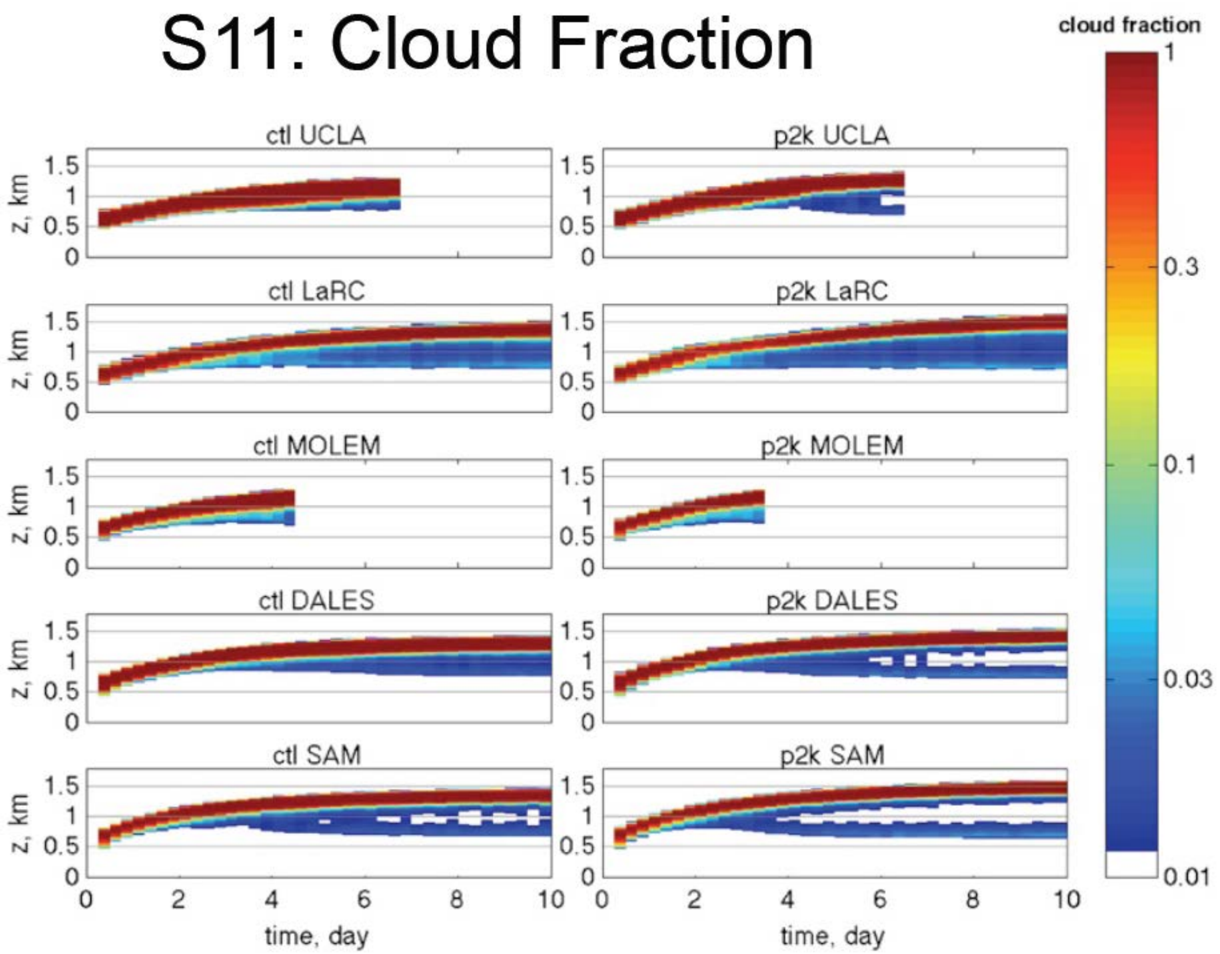
SCM (16)

CAM4 (Hannay, Zhang, Rasch)
CAM5 (Hannay, Zhang, Rasch)
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 (5)

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

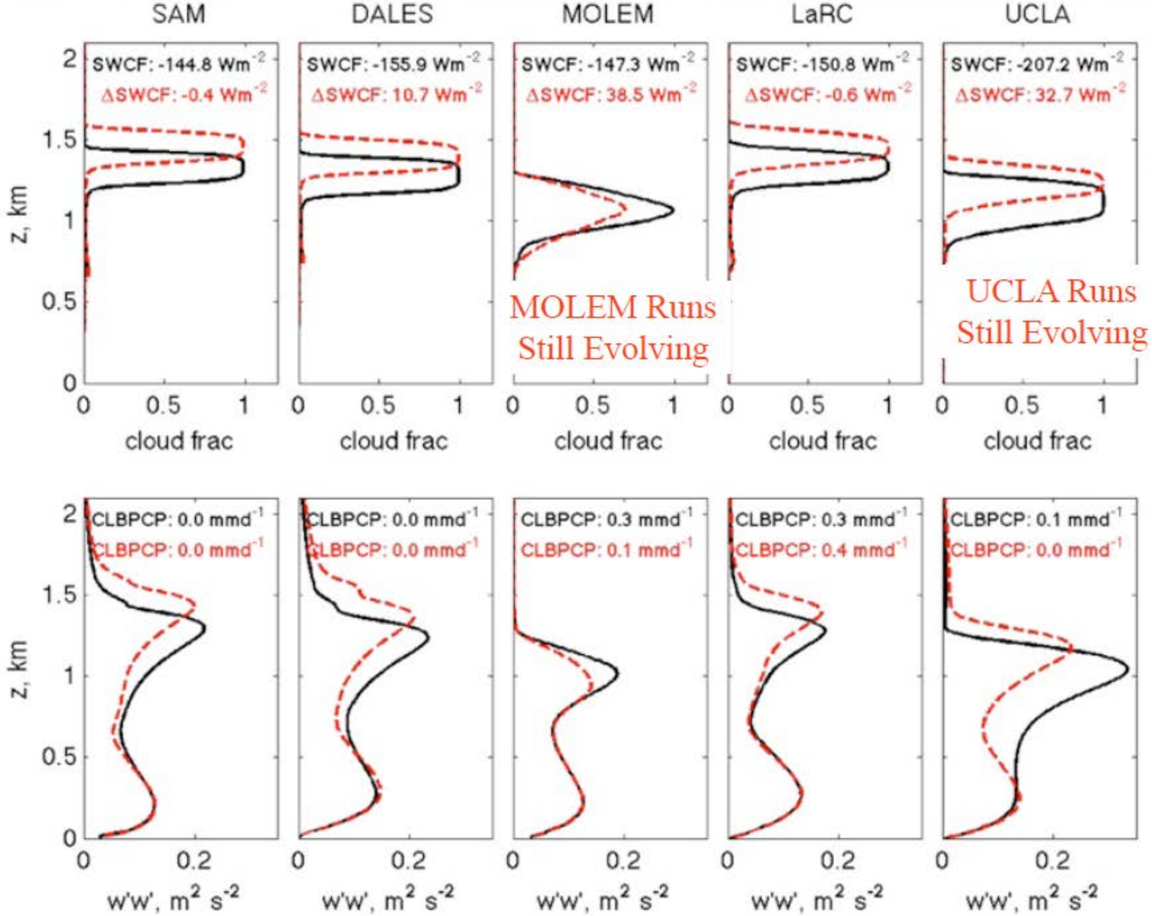
Stratocumulus clouds in five LES models



(Blossey et al. 2011)

S11: CTL→+2K Cloud/Turbulence Changes

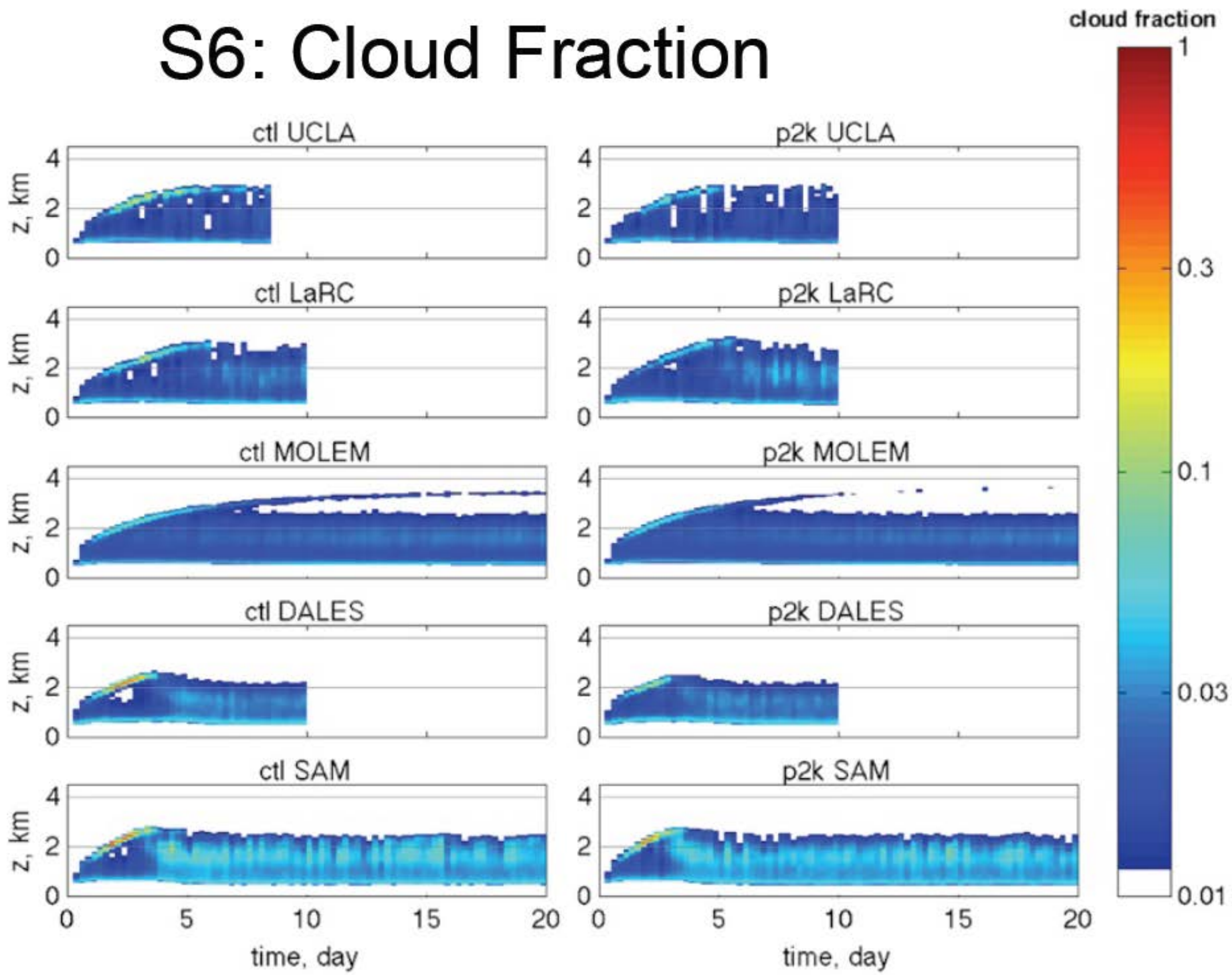
Averages over last 2.5 days

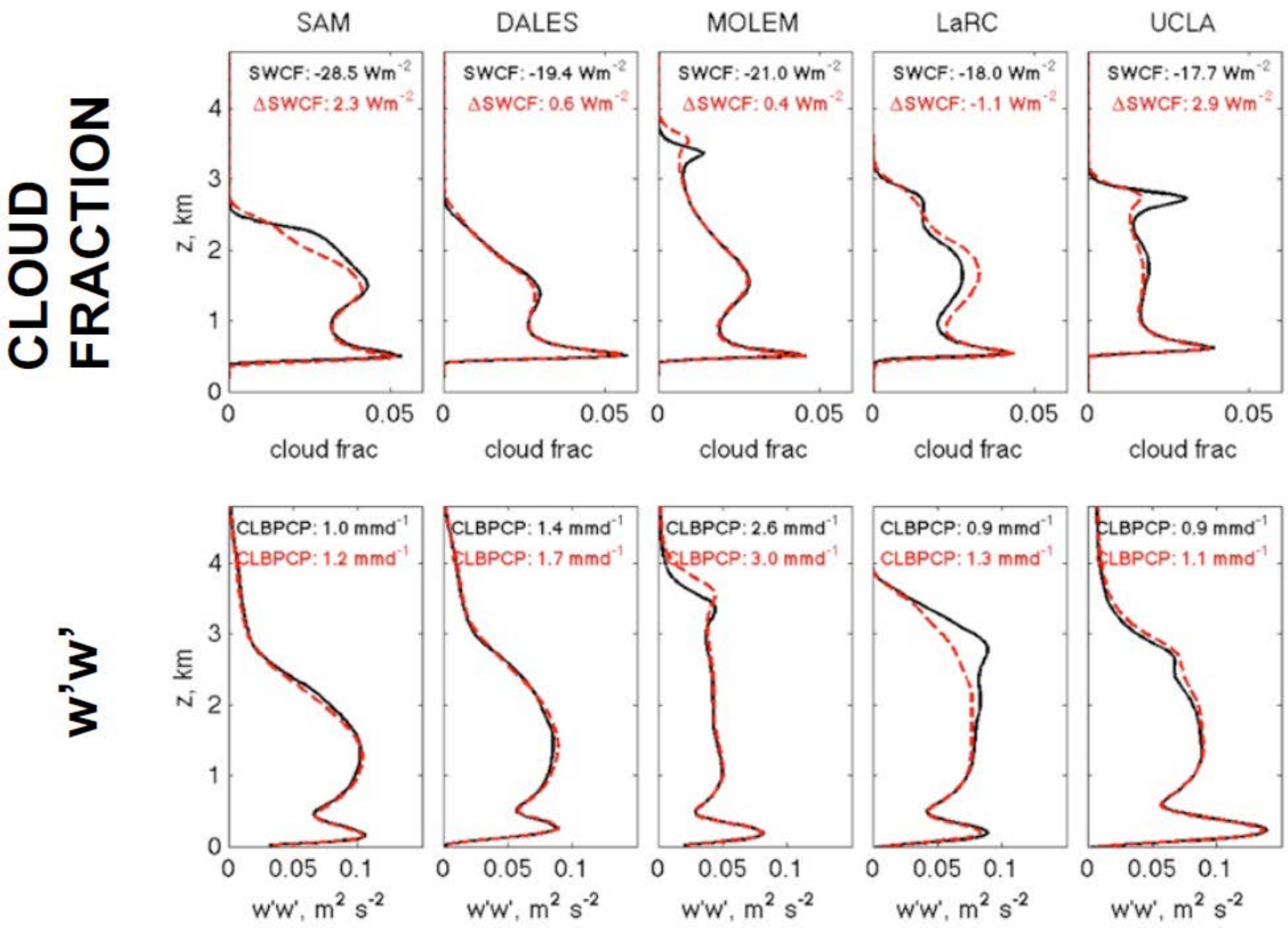


CLOUD FRACTION

w'w'

LES Cloud Feedback




CLOUD FRACTION
w'w'
SAM
DALES
MOLEM
LaRC
UCLA
SWCF: -28.5 Wm-2
ΔSWCF: 2.3 Wm-2
SWCF: -19.4 Wm-2
ΔSWCF: 0.6 Wm-2
SWCF: -21.0 Wm-2
ΔSWCF: 0.4 Wm-2
SWCF: -18.0 Wm-2
ΔSWCF: -1.1 Wm-2
SWCF: -17.7 Wm-2
ΔSWCF: 2.9 Wm-2
CLBPCP: 1.0 mmd-1
CLBPCP: 1.2 mmd-1
CLBPCP: 1.4 mmd-1
CLBPCP: 1.7 mmd-1
CLBPCP: 2.6 mmd-1
CLBPCP: 3.0 mmd-1
CLBPCP: 0.9 mmd-1
CLBPCP: 1.3 mmd-1
CLBPCP: 0.9 mmd-1
CLBPCP: 1.1 mmd-1
z, km
cloud frac
w'w', m2 s-2

Summary

1. CAM4, negative feedback; CAM5, positive feedback, for both stratocumulus and shallow cumulus

2. In CAM4, both cloud types are driven by surface buoyancy flux. Warmer climate leads to deeper PBL, and more convective transport of moisture, more clouds.

3. In CAM5, both are driven by surface buoyancy flux AND cloud-property dependent mixing of cloudy air with free tropospheric air. Warmer climate can lead to more dilution of clouds.