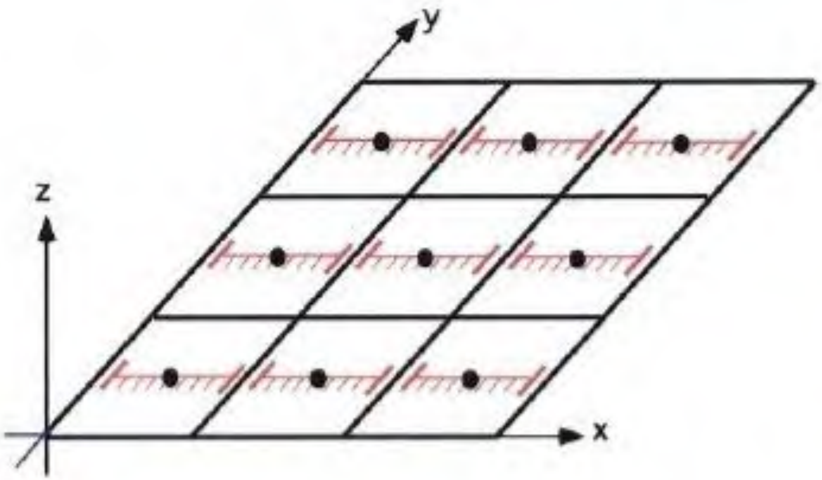
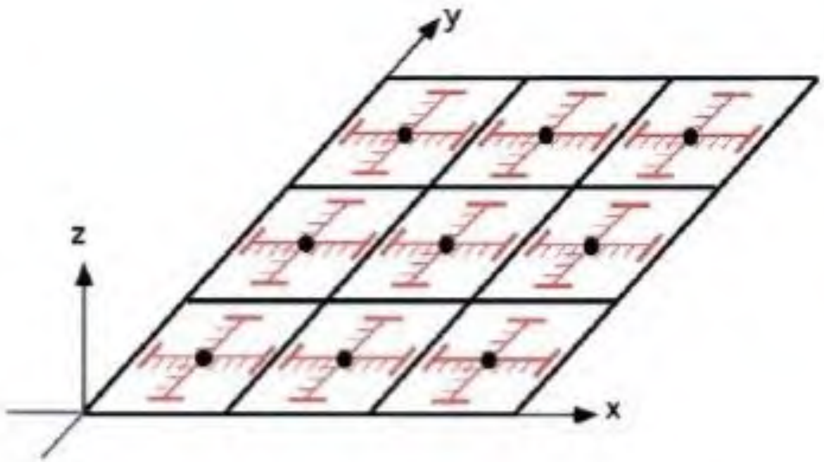
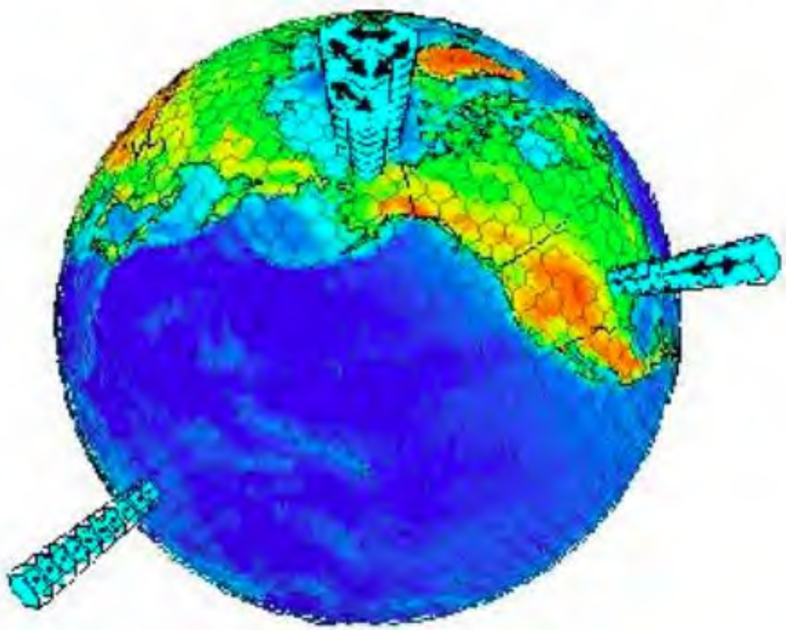
Day 4: Current Issues and Outlook,

1. superparameterization





Super-parameterization roots from Single-Column Modeling (SCM)



$$\frac{\partial \bar{s}}{\partial t} = \underbrace{-\overline{\nabla s V} - \frac{\partial \bar{s}\,\bar{\omega}}{\partial p}}_{LSForcing} + \underbrace{Q_1}_{Param's}$$

$$\frac{\partial \bar{q}}{\partial t} = \underbrace{-\overline{\nabla q V} - \frac{\partial \bar{q}\,\bar{\omega}}{\partial p}}_{LSForcing} - \underbrace{Q_2/L}_{Param's}$$

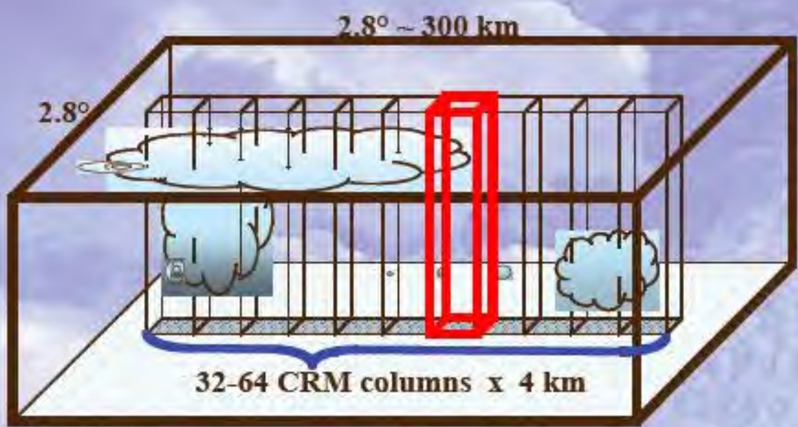
Column-Physics
Tendency
(parameterizations;
No horizontal scale Δx here)

The large-scale forcing data would come from observations (GATE, TOGA, ARM, KWAJEX, etc.)

All super-parameterization does is compute Q_1 and Q_2

Credit: Marat Khairoudtinov

Super-parametrization (SP)
Multiscale-Modeling Framework (MMF=GCM+SP)



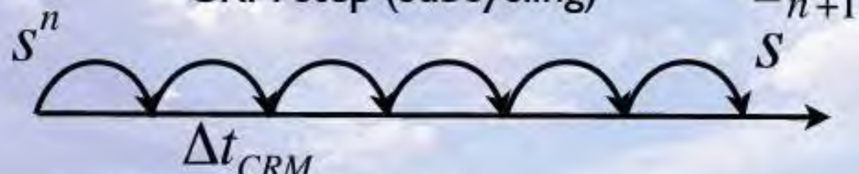
$$\frac{\partial \bar{s}}{\partial t} = -\overline{\nabla s V} - \frac{\partial \bar{s}\,\bar{\omega}}{\partial p} + Q_1$$

GCM Resolved

Column-Physics (SP)

Dynamics Step:

CRM step (subcycling)



CRM Forcing:

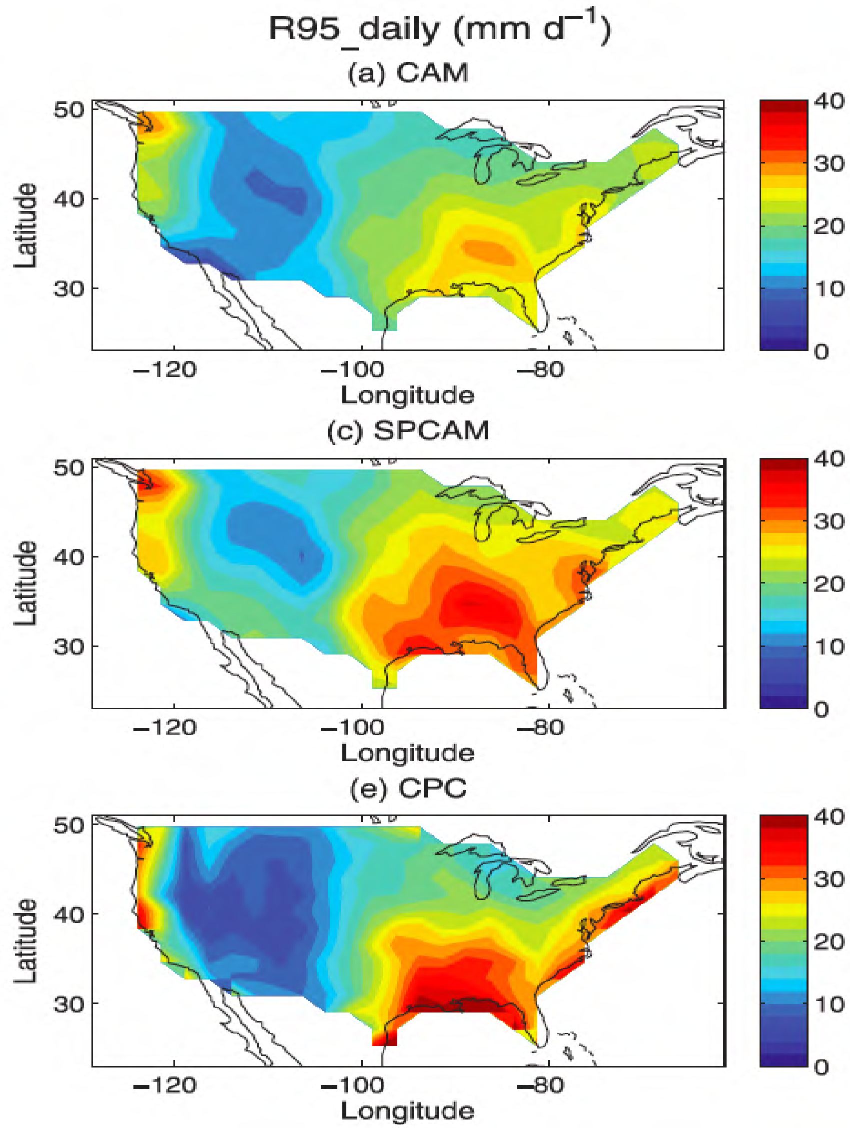
$$-\overline{\nabla s V} - \frac{\partial \bar{s}\,\bar{\omega}}{dp} = \frac{\bar{s}^* - \bar{s}^n}{\Delta t}$$

CRM Tendency:

$$Q_1 = \frac{\bar{s}^{n+1} - \bar{s}^*}{\Delta t}$$

Credit: Marat Khairoudtinov

Extreme Precipitation



2. Updraft vertical velocity

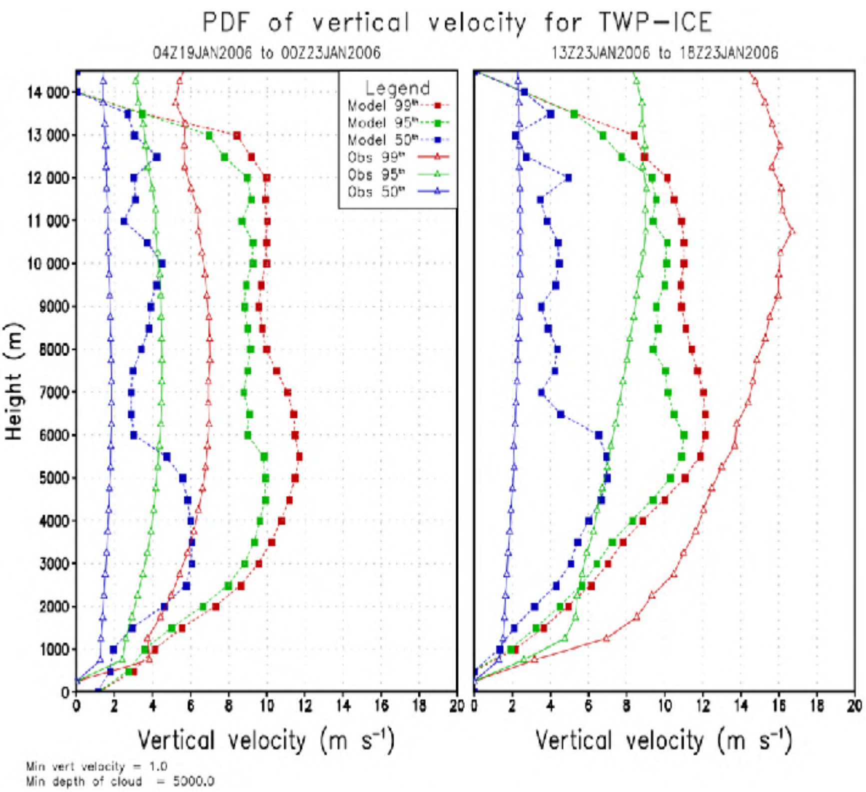
Why vertical velocity is needed?

- mass flux alone is not enough to characterize convection

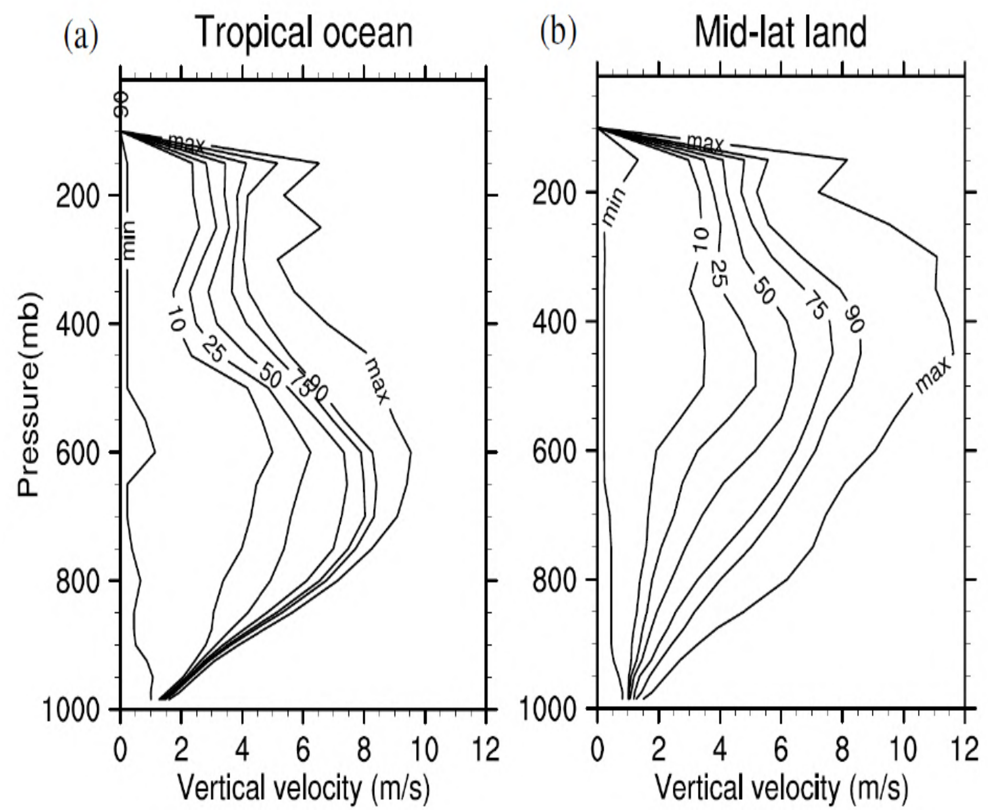
$$M_u = s r w$$

- microphysical processes depend nonlinearly on vertical velocity

Updraft vertical velocity



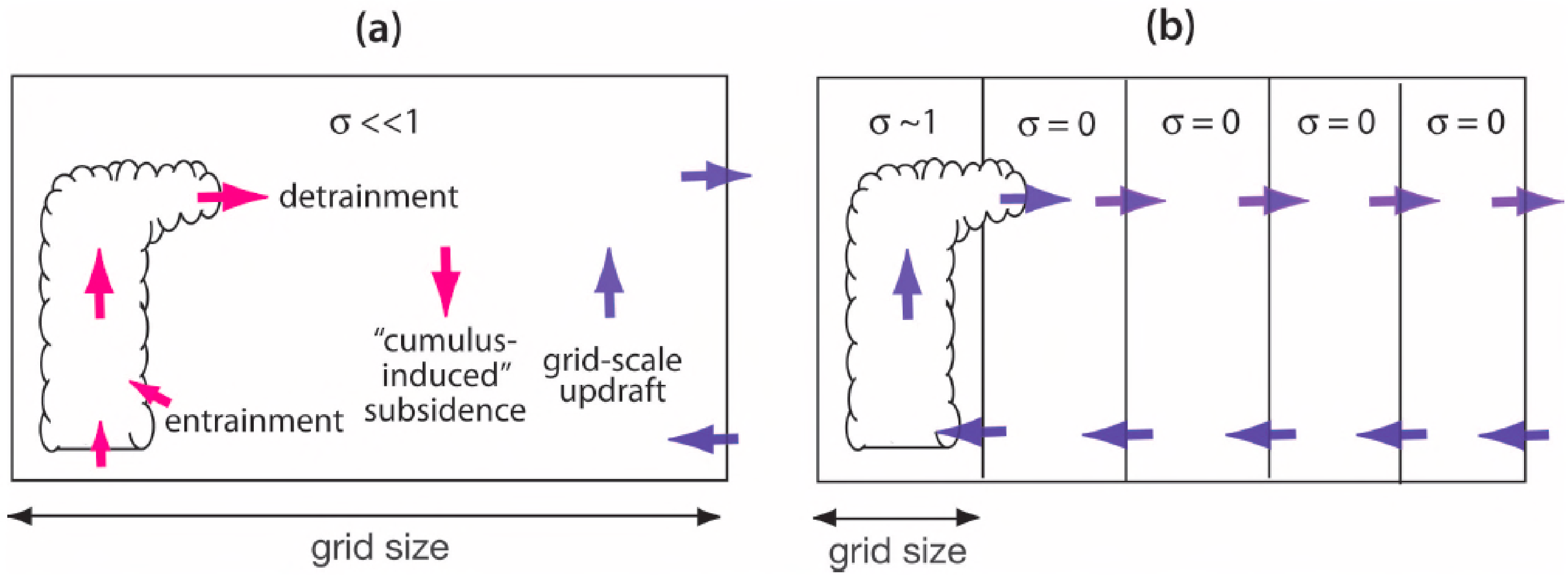
Donner et al. (2016)

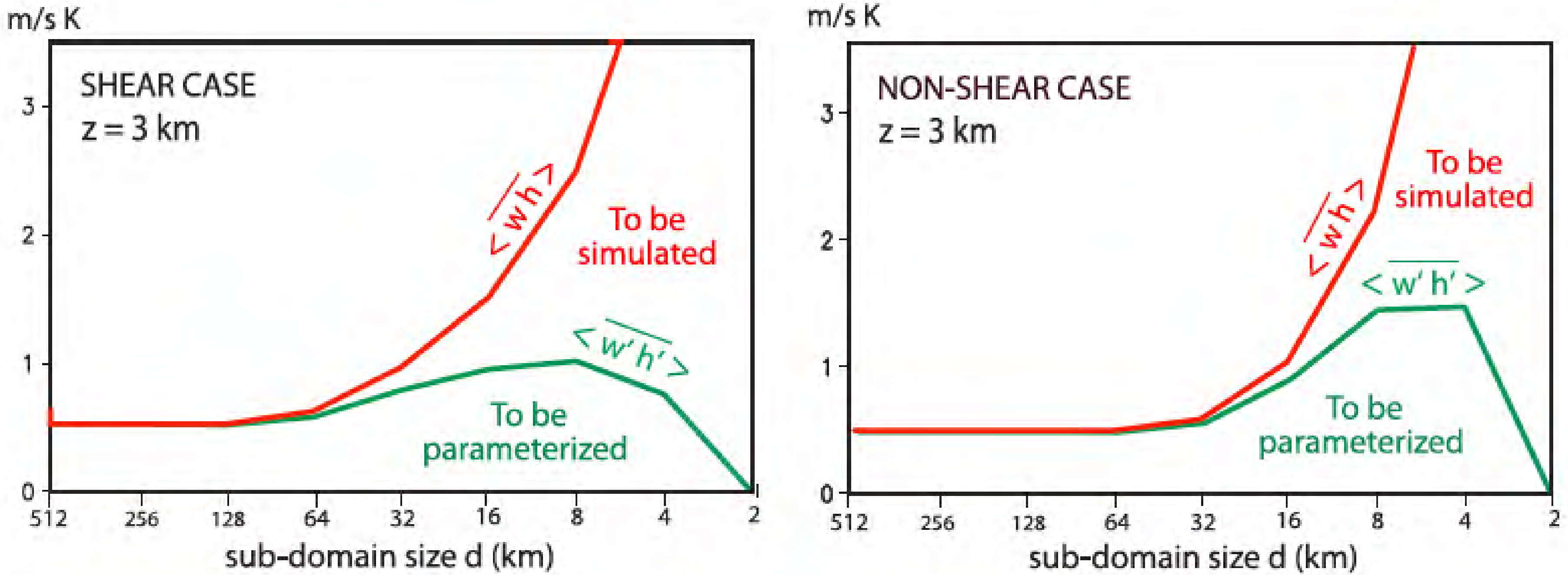


Song et al. (2012)

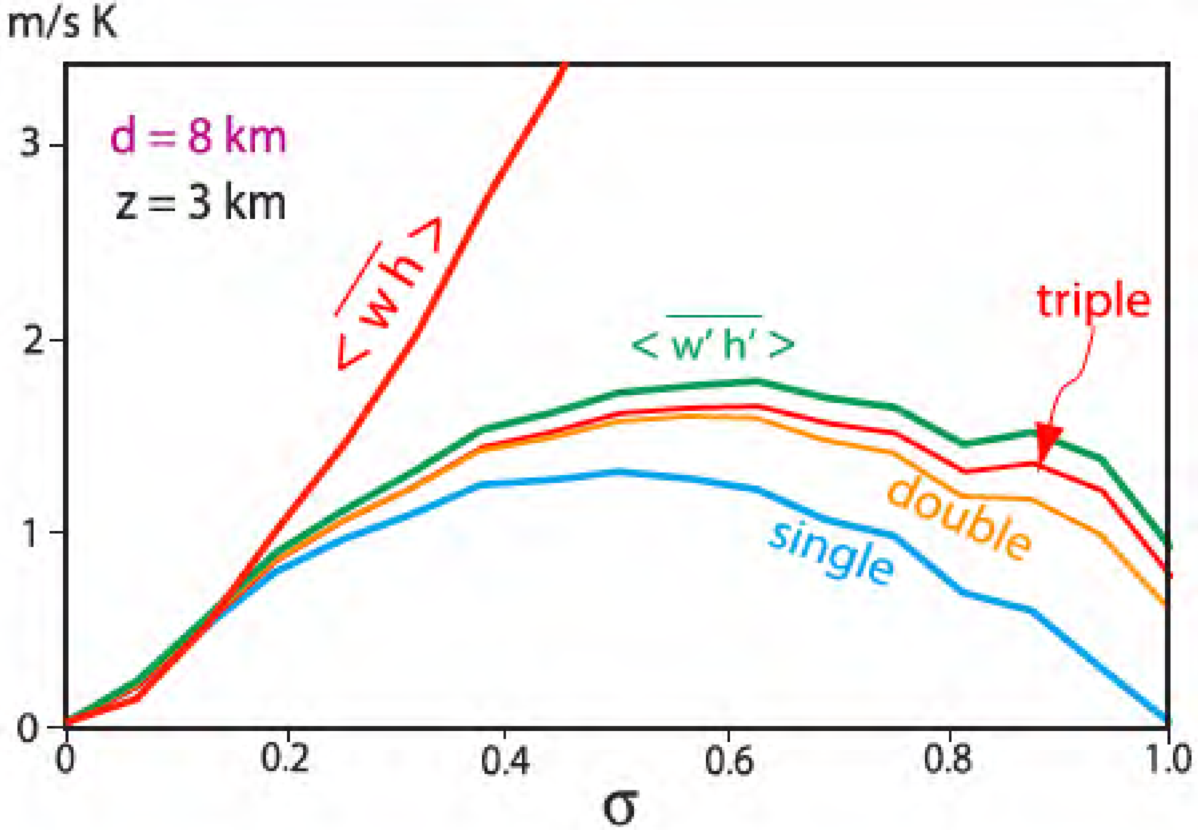
3. Scale-Awareness

$$\overline{w's'} = \frac{a}{1-a}(w_c - \bar{w})(s_c - \bar{s})$$

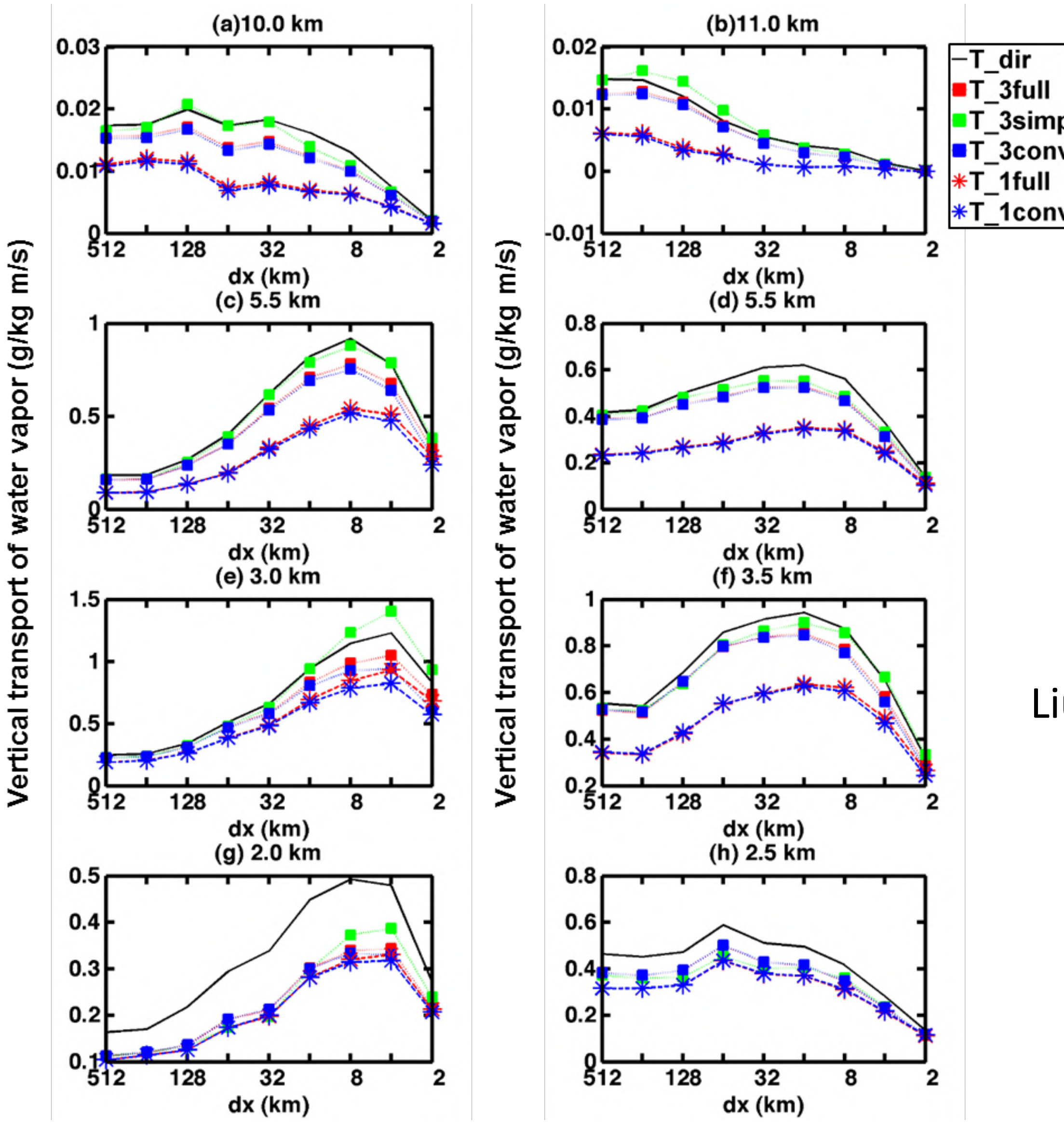




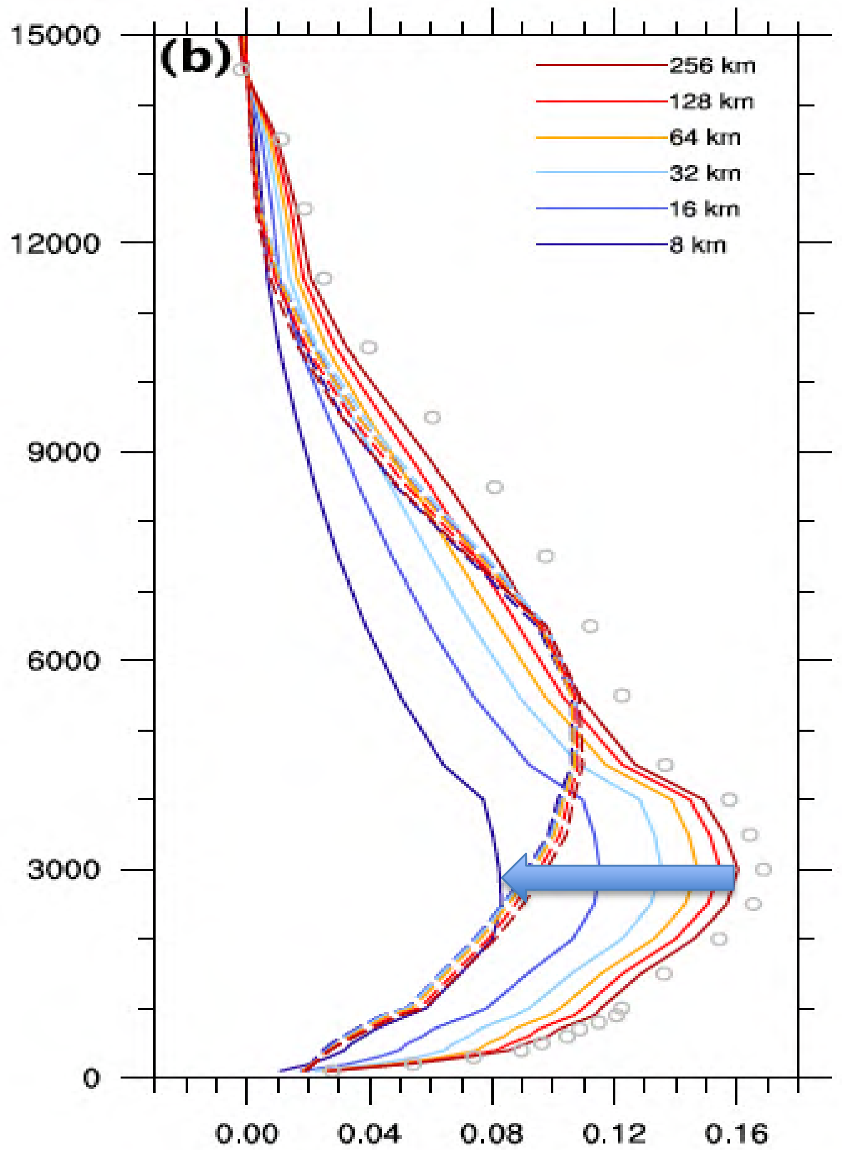
Arakawa and Wu (2013)



m/s K
d = 8 km
z = 3 km
< w h >
< w' h' >
triple
double
single
0
1
2
3
0
0.2
0.4
0.6
0.8
1.0
σ



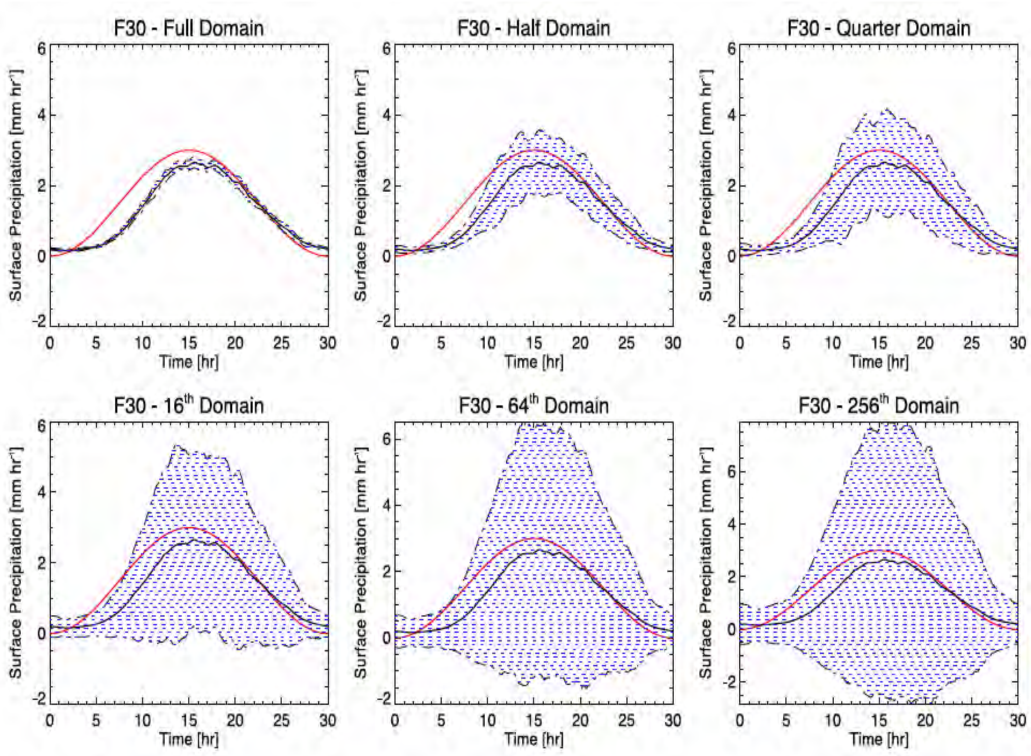
Liu et al. (2015)



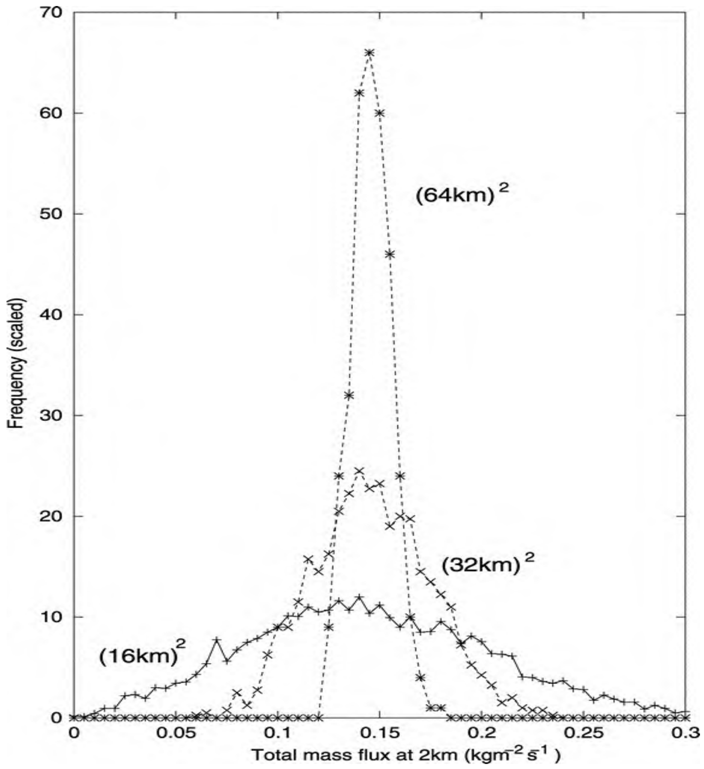
Xiao et al. (2015)

Convective transport of moist static energy

4. Stochastic convection Parameterization



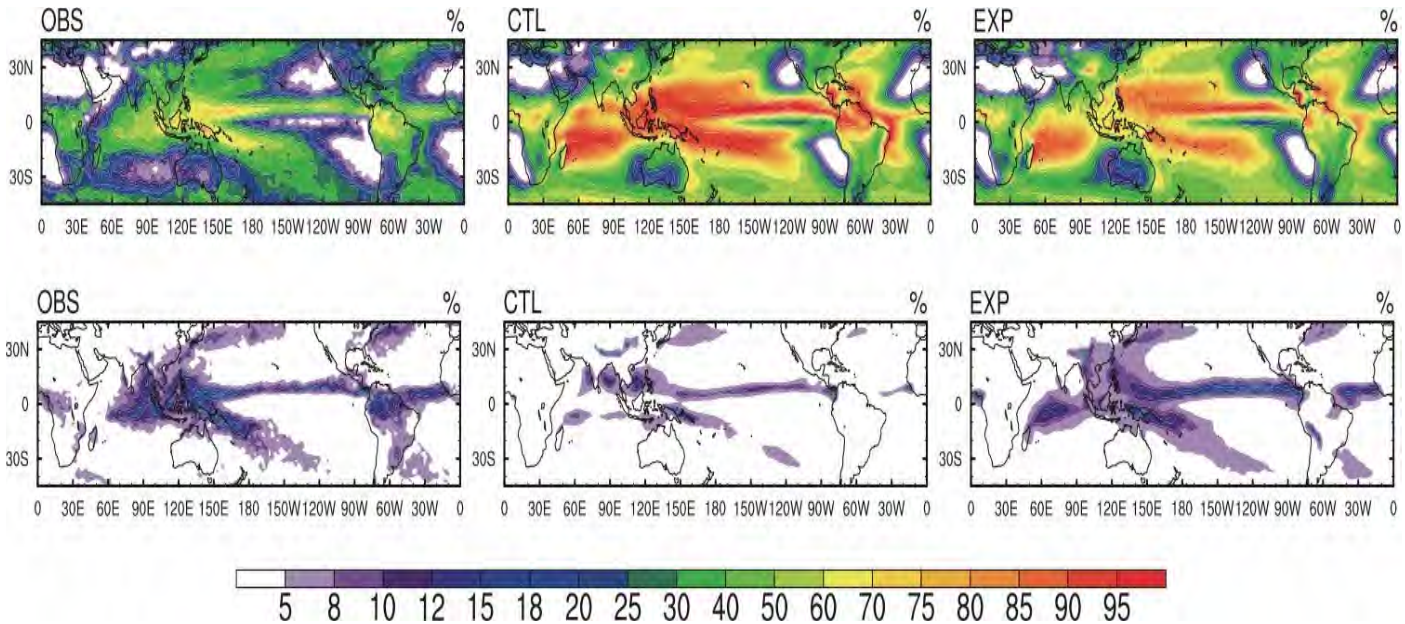
Jones and Randall (2011)



Plant and Craig (2008)

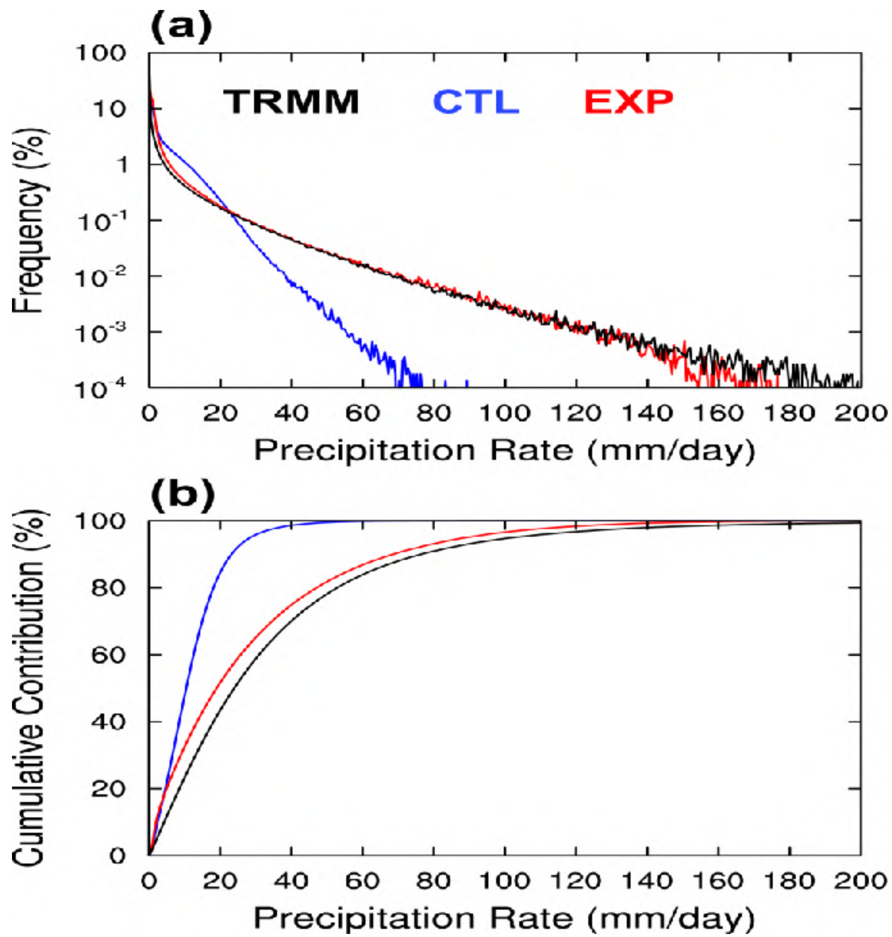
Effects of stochastic convection

Precipitation intensity variance



Wang et al. (2016)

Effects of stochastic convection

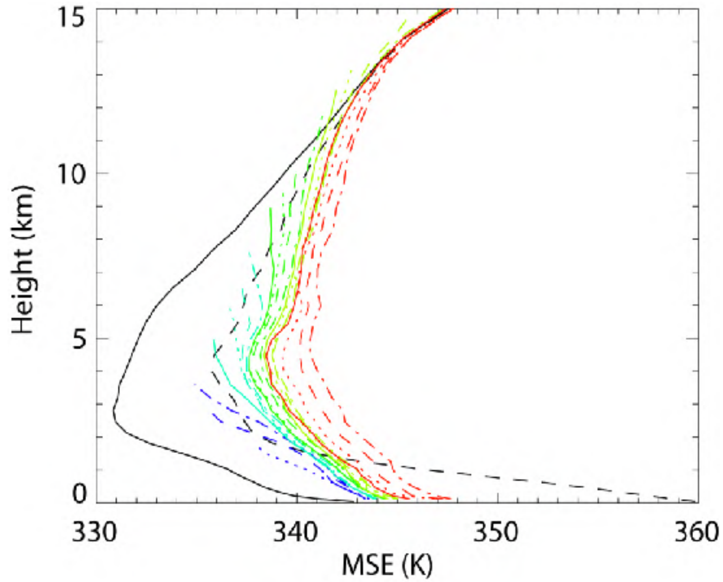


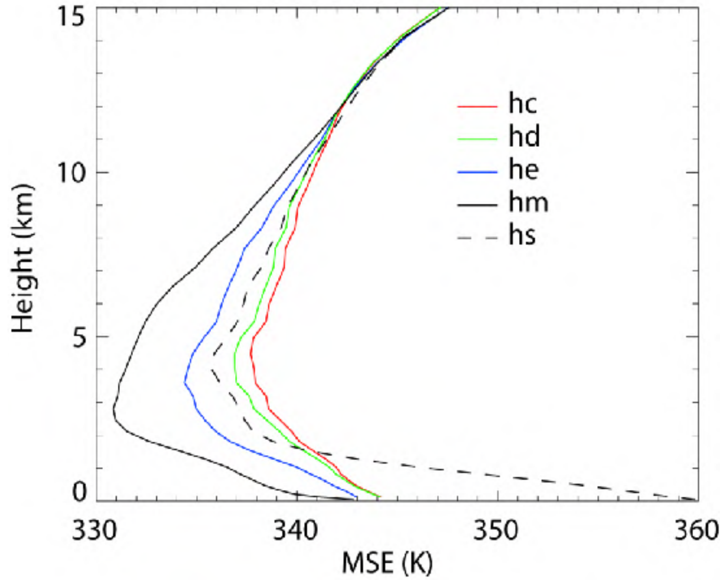
Wang et al. (2016)

5. Entrainment rate, an unresolved Issue

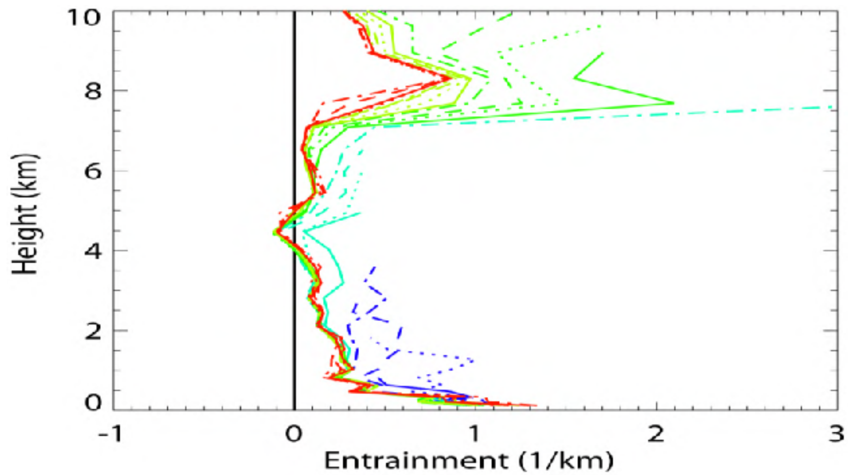
How much air is entrained into convective updrafts? How to parameterize it? What properties are entrained?

$$\varepsilon_{sim} = \frac{-\partial h_c / \partial z + \sigma \rho S_c / M_c}{h_c - \bar{h}}$$

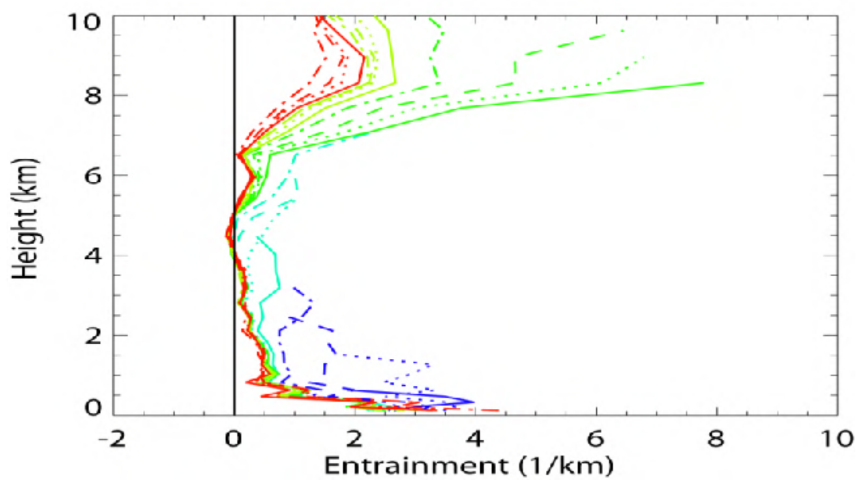




$$\varepsilon = \frac{-\rho\sigma \frac{\partial h_c}{\partial t} - \frac{\partial M_c}{\partial z}(h_c - h_d) - M_c \frac{\partial h_c}{\partial z} - \frac{\partial \rho\sigma (w'h')_c}{\partial z} + \rho\sigma S_c}{M_c(h_d - h_e)}$$

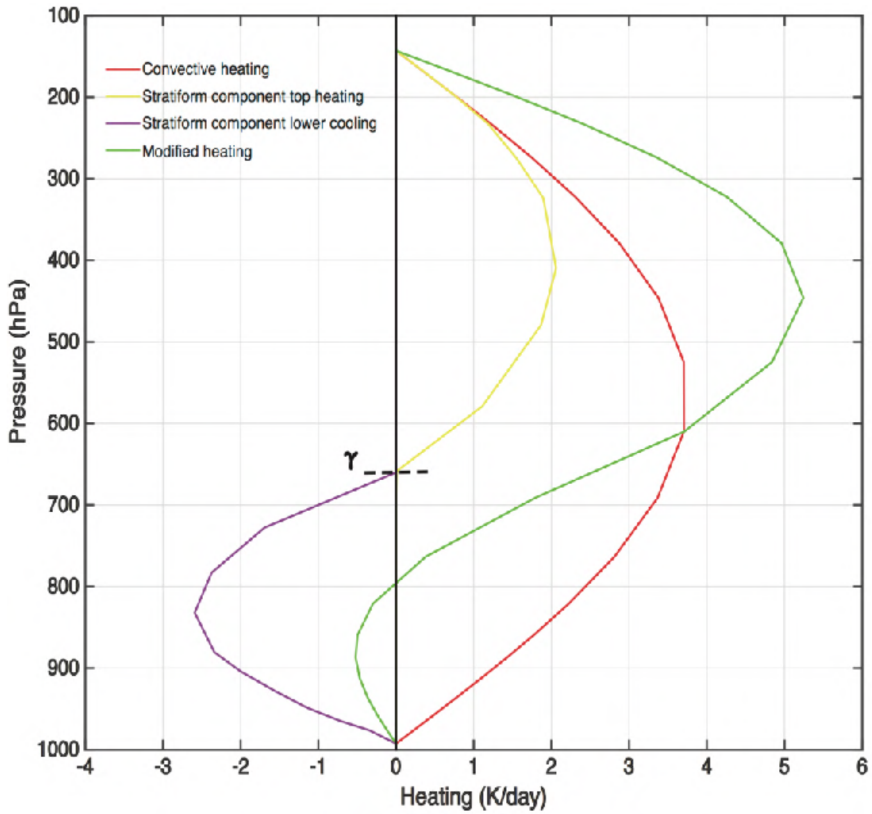


Zhang et al. (2015)

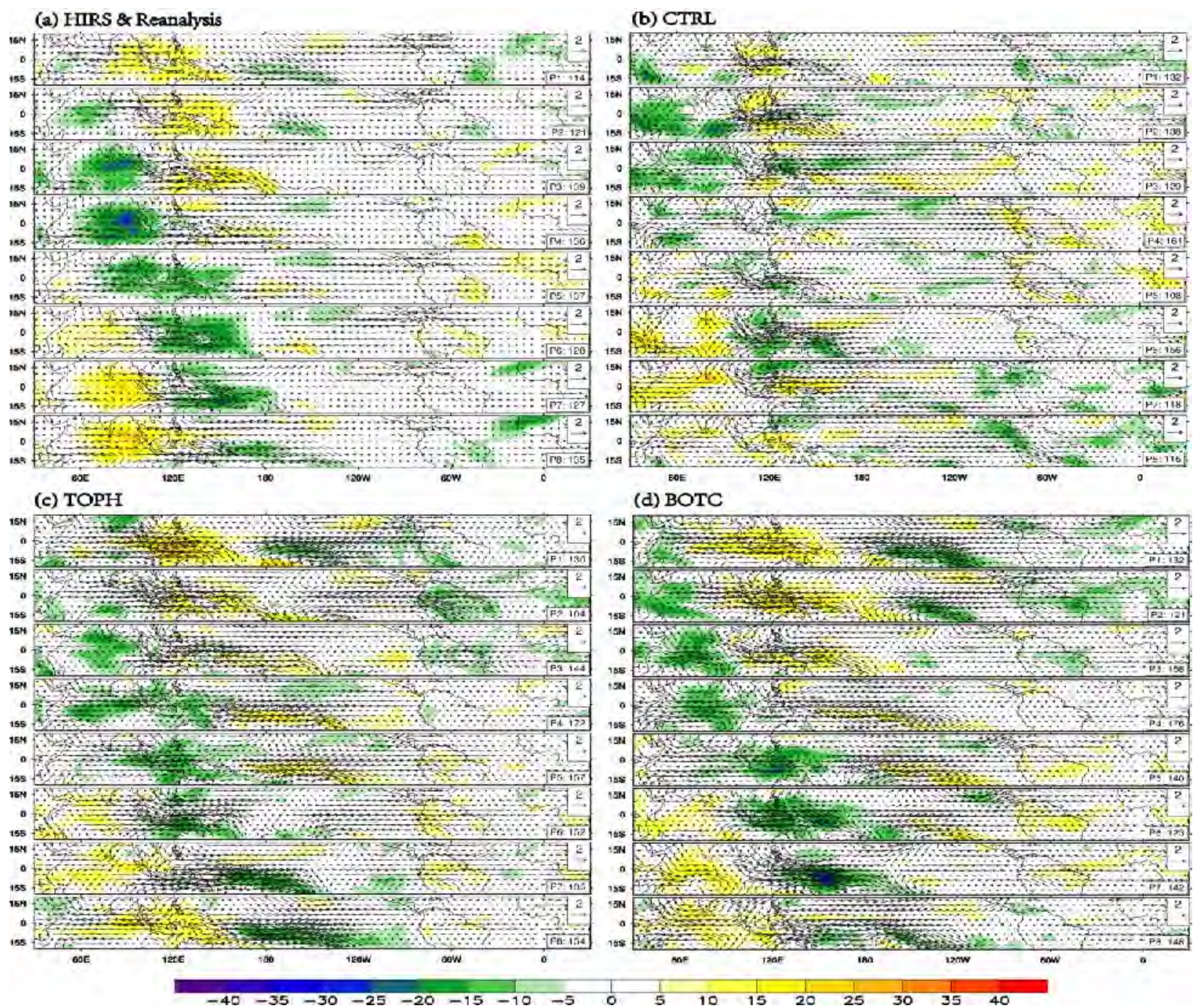


6. Convective Organization

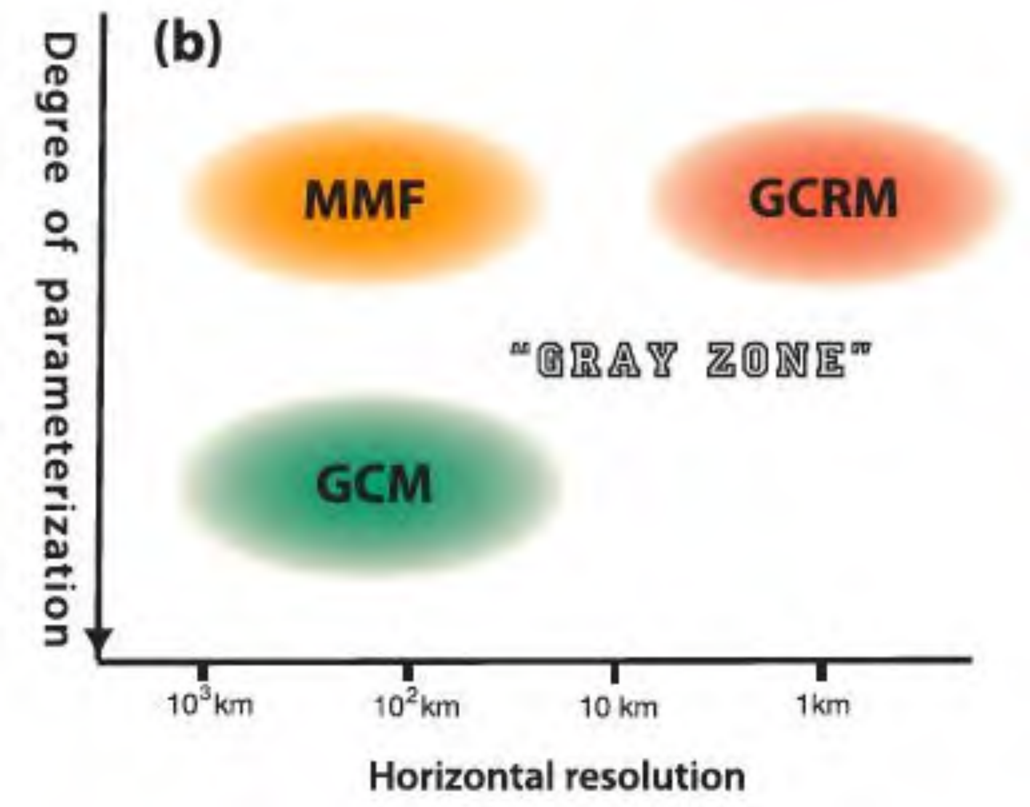
organized convection has very different characteristics than individual cells.



MJO simulation including mesoscale heating structure



Future: co-existence of 3 approaches

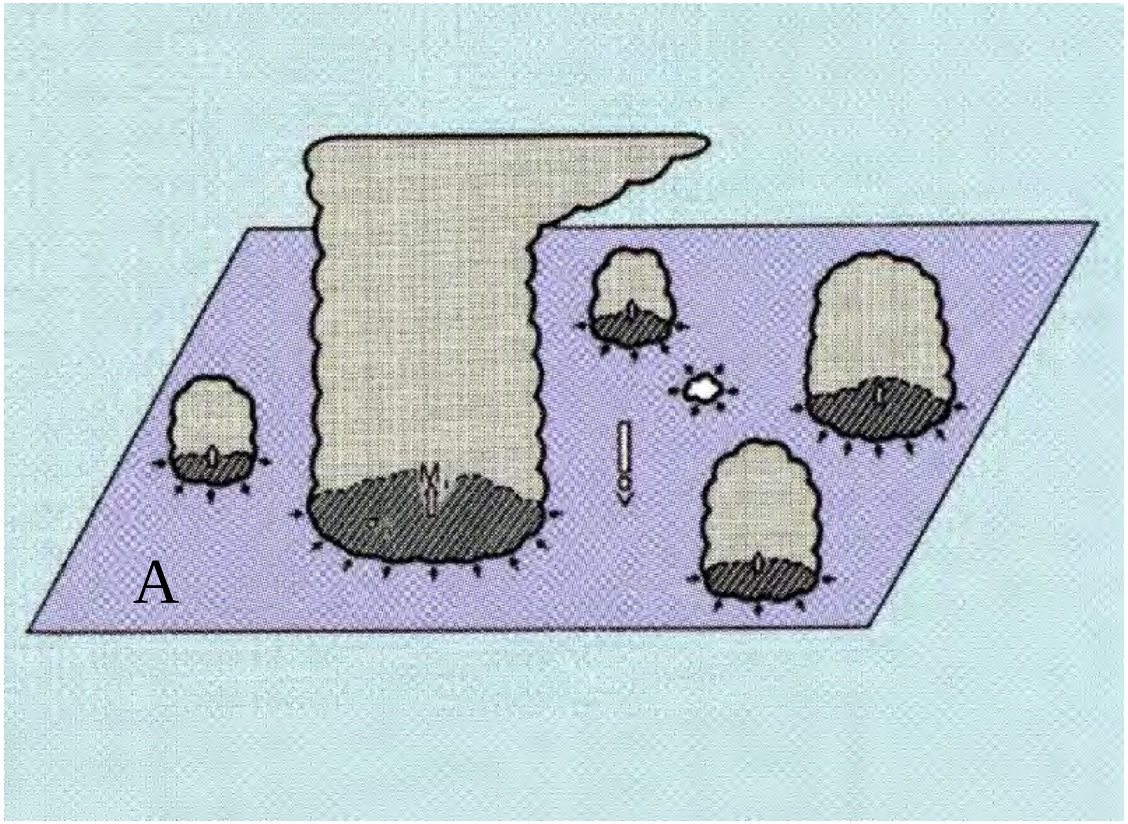


Effects of Convection in GCMs: An Example from the NCAR CCSM

Outline

- Introduction of convection parameterization
- NCAR CAM3 coupled to slab ocean model runs (to understand local ocean feedback)
- Fully coupled CCSM3 runs (to understand feedback from ocean heat transport)
- Examine the simulation, including precipitation, SST, salinity, and ocean currents in the tropical Pacific
- Identify mechanisms that can relate convection parameterization to these changes

This is what convection parameterization is about



$$CAPE = \int_{p_t}^{p_b} R_d (T_{vp} - T_{ve}) d \ln p$$

CAPE variation consists of two parts: contributions from the boundary layer (parcel's) changes and contributions from the free tropospheric (parcel's environment) changes:

$$\frac{dCAPE}{dt} = \frac{dCAPE_{parcel}}{dt} + \frac{dCAPE_{env}}{dt}$$

Traditional convective quasi-equilibrium closure:

$$\frac{dCAPE}{dt}=\left(\frac{dCAPE}{dt}\right)_{cu}+\left(\frac{dCAPE}{dt}\right)_{ls}\approx 0$$

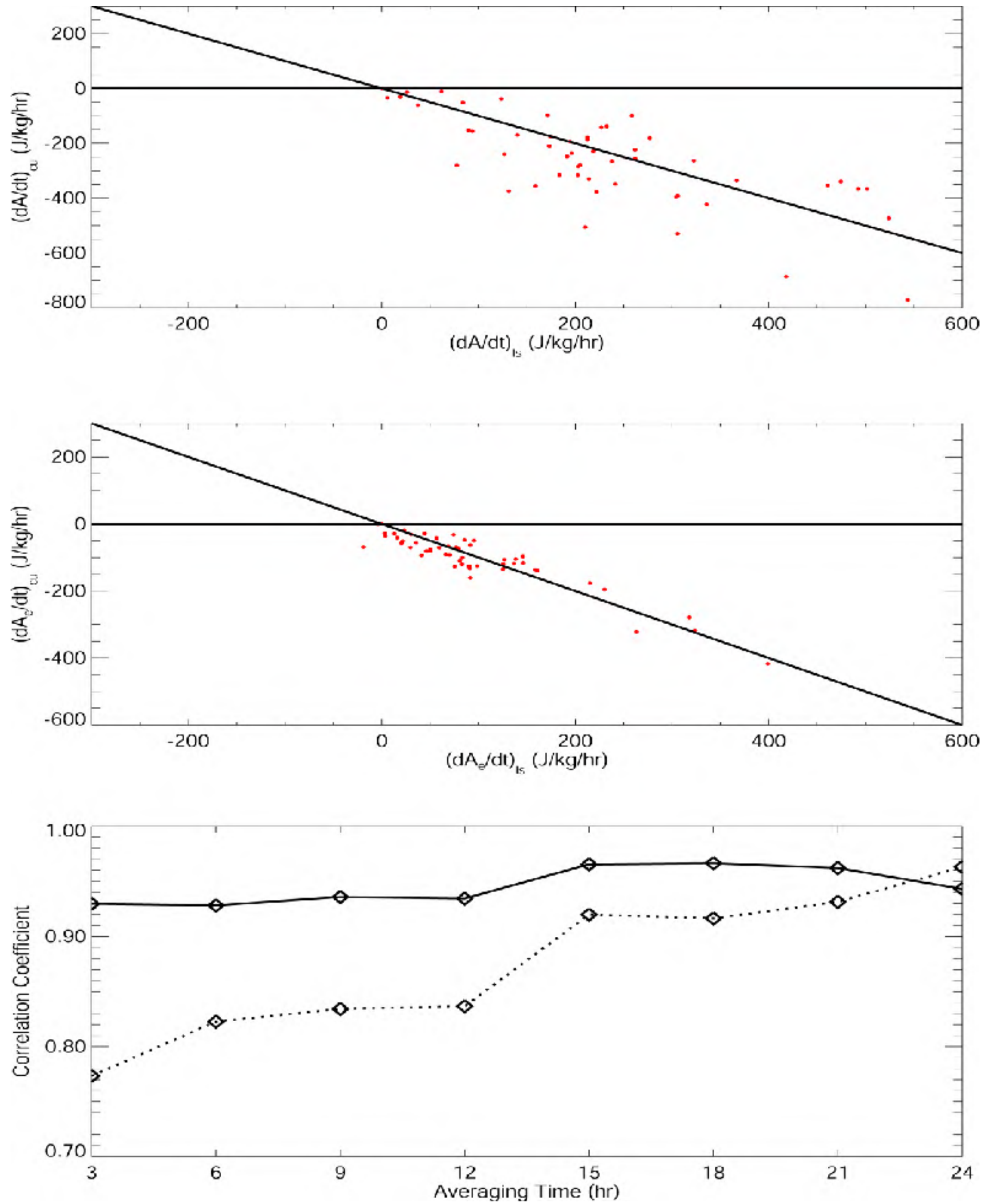
Free Tropospheric Quasi-equilibrium Closure:

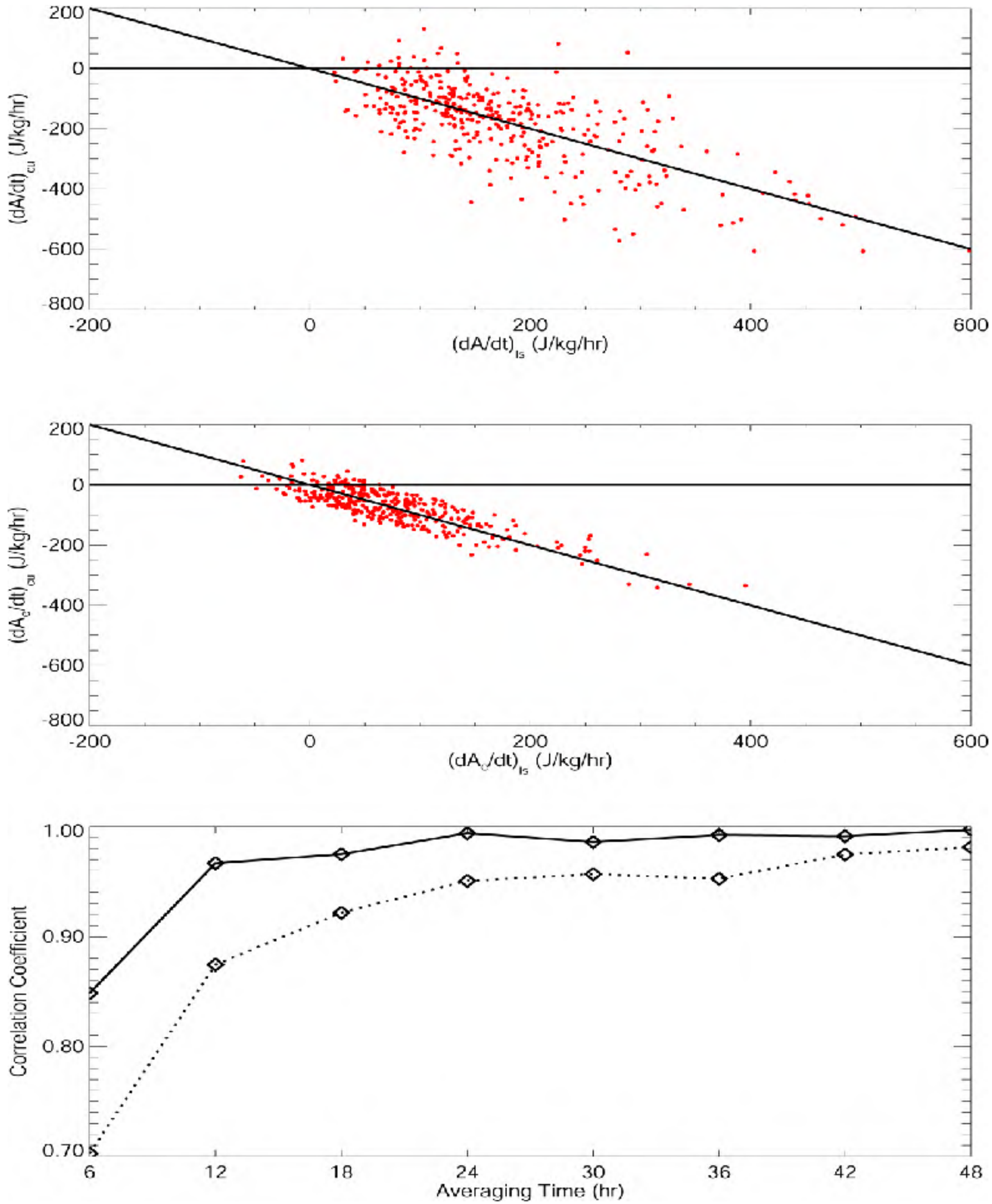
Free tropospheric portion of the large-scale (non-convective) forcing is balanced by convection. The boundary layer portion of the large-scale forcing is stored in the atmosphere to maintain the net CAPE variation.

$$\frac{dCAPE_{env}}{dt} = \left(\frac{dCAPE_{env}}{dt}\right)_{cu} + \left(\frac{dCAPE_{env}}{dt}\right)_{ls} \approx 0$$

$$\frac{dCAPE}{dt} \approx 0 \Rightarrow$$

$$\frac{dCAPE_{env}}{dt} \approx 0 \Rightarrow$$



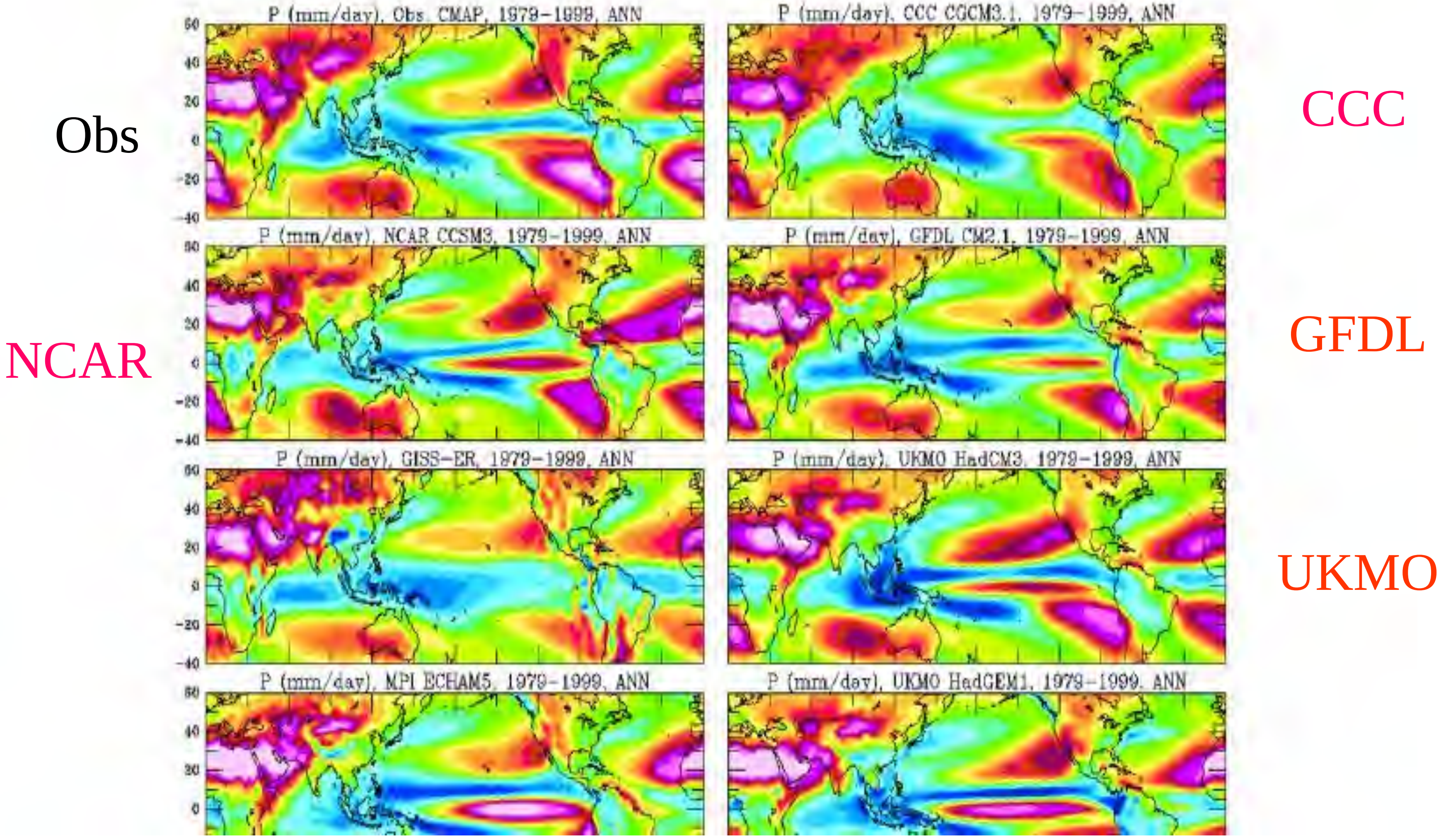


200
0
-200
-400
-600
-800
-200
0
200
400
600
(dA/dt)cu (J/kg/hr)
(dA/dt)ls (J/kg/hr)
(dAc/dt)cu (J/kg/hr)
(dAc/dt)ls (J/kg/hr)
1.00
0.90
0.80
0.70
6
12
18
24
30
36
42
48
Correlation Coefficient
Averaging Time (hr)

Numerical Simulations

- CAM3 coupled to slab ocean model runs (to understand local ocean feedback)
- Fully coupled CCSM3 runs (to understand feedback from ocean heat transport)

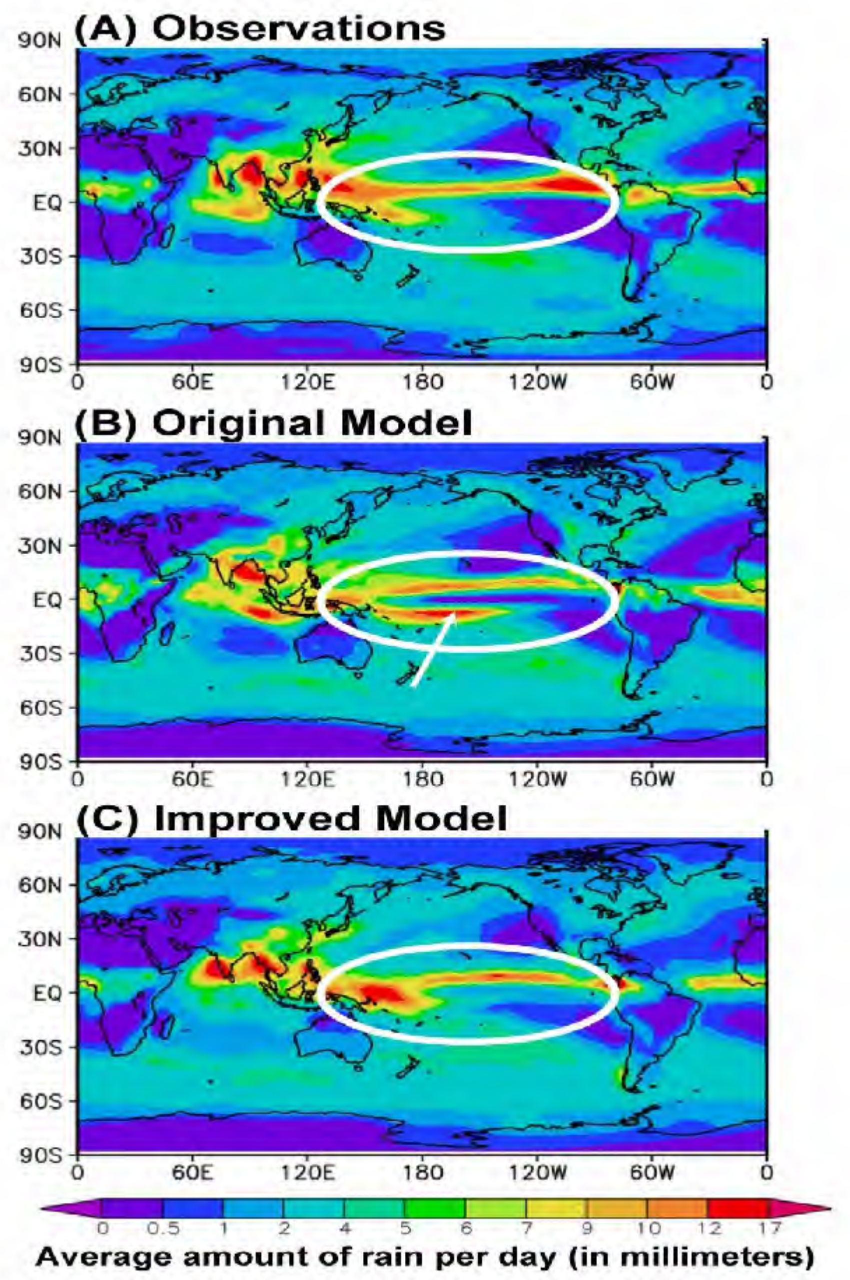
From Dai 2006

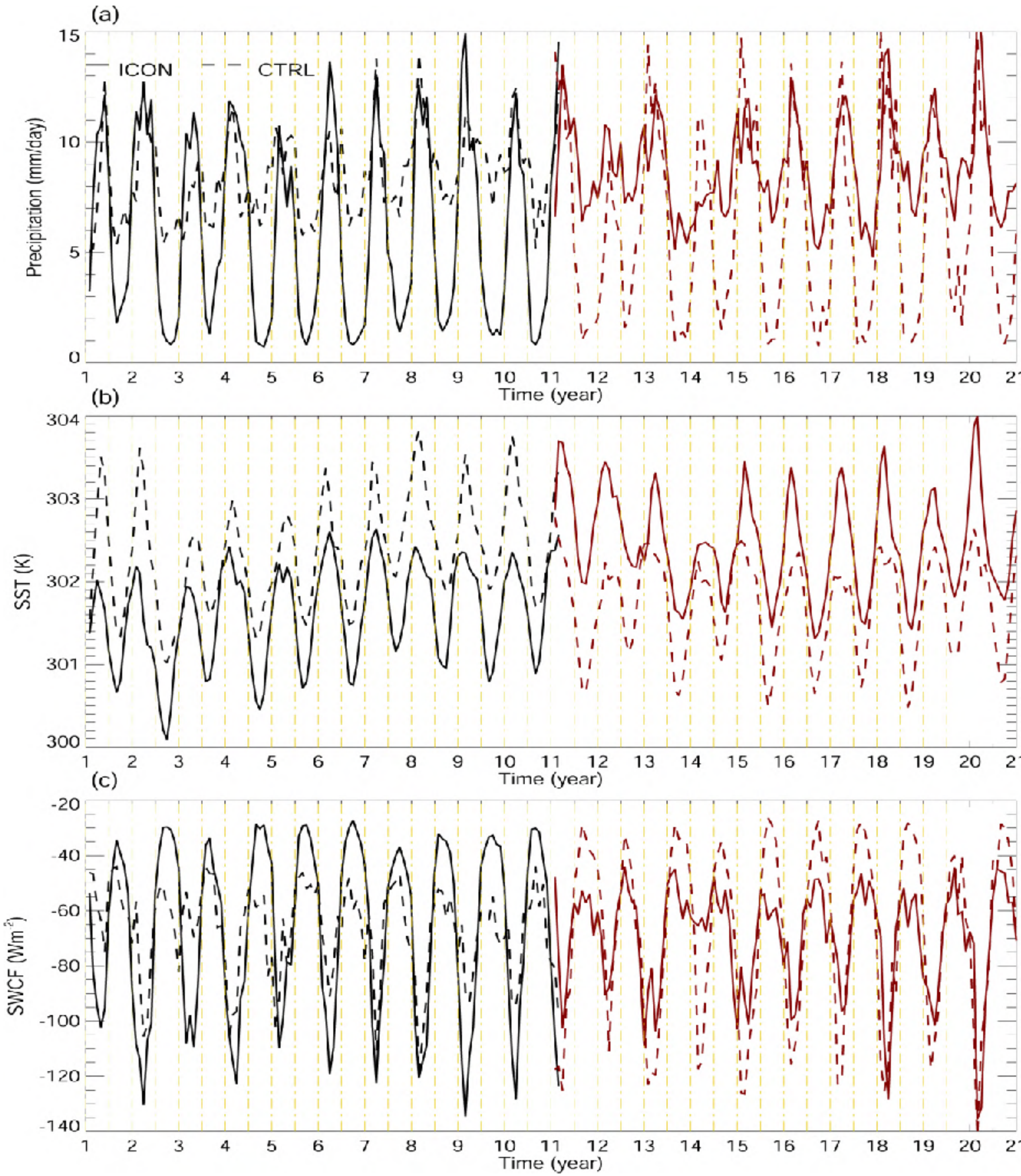


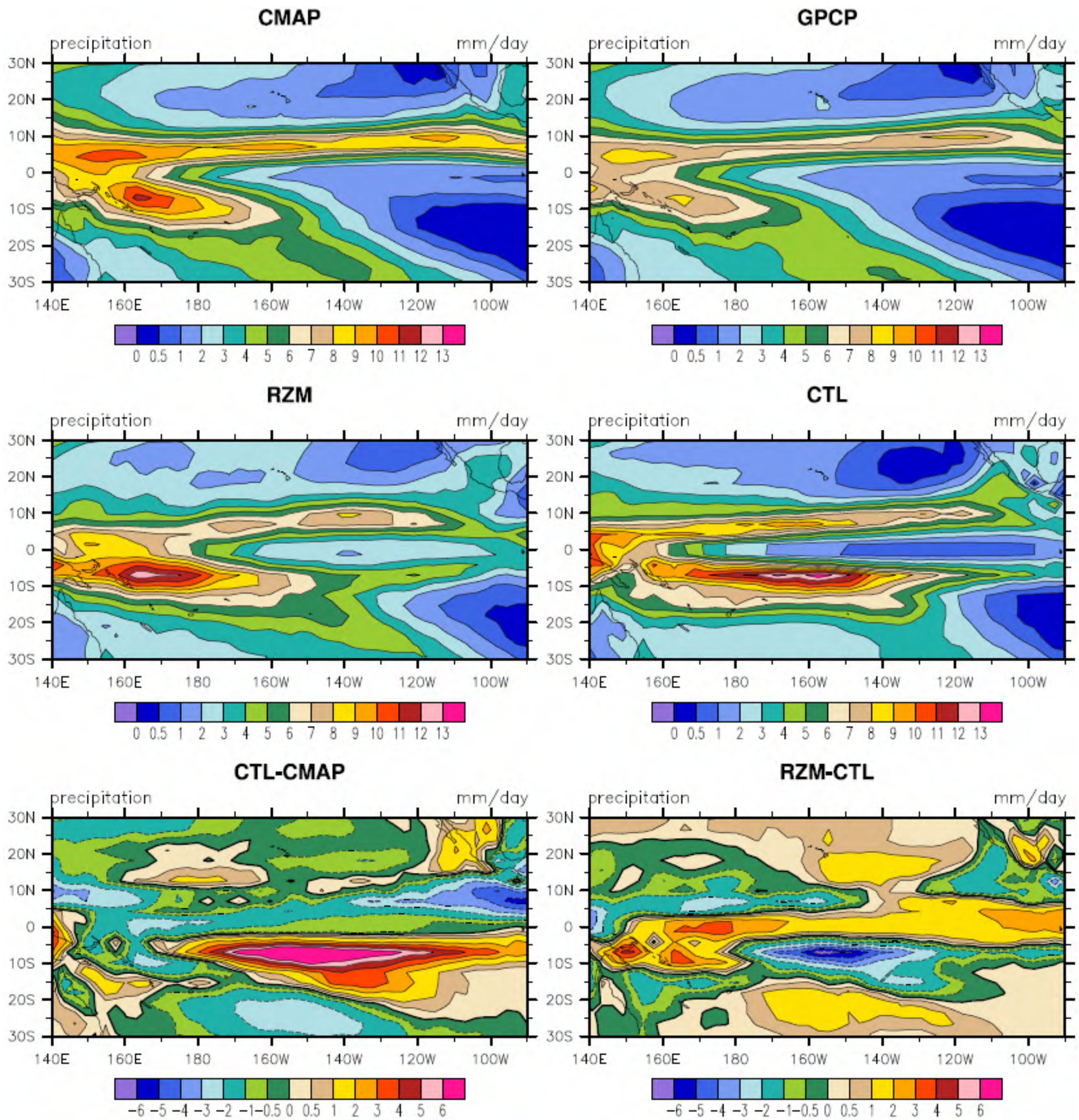
Obs

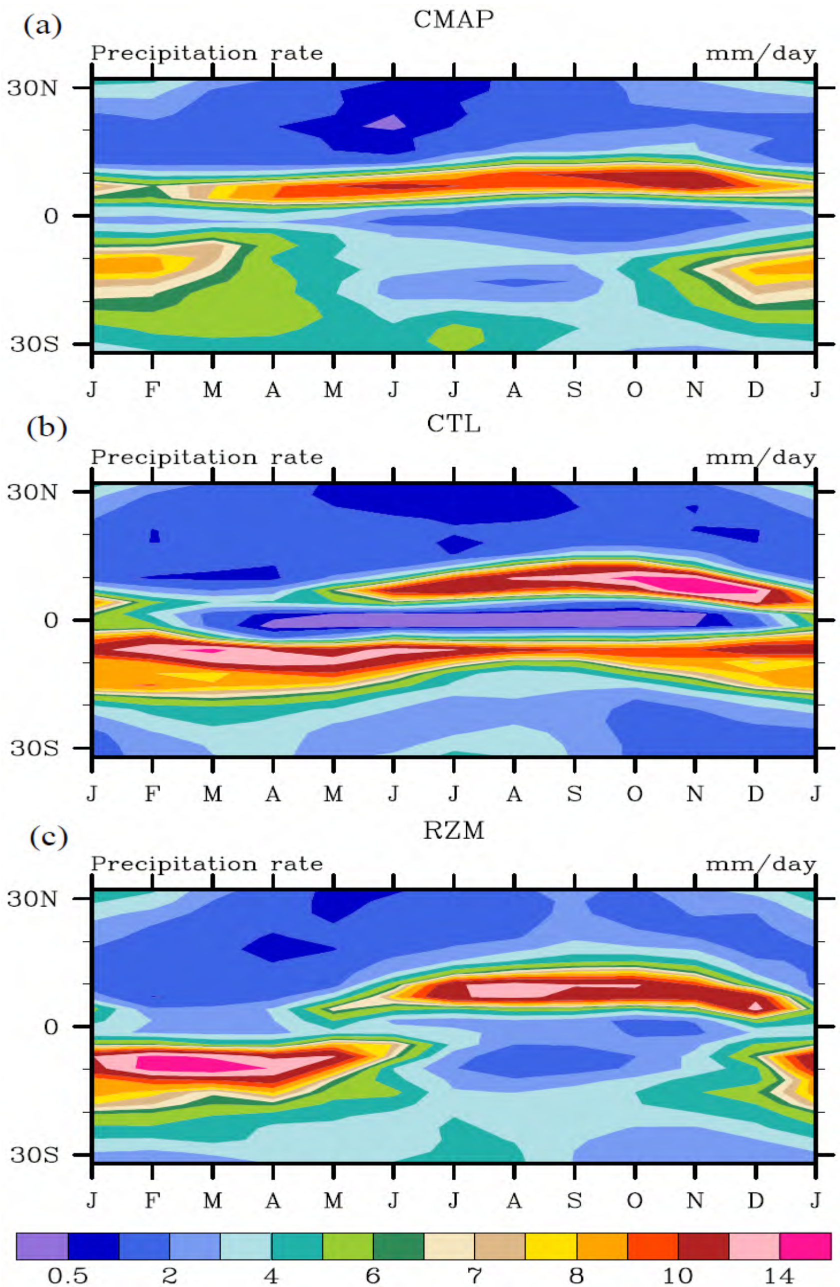
CCSM3 Ctrl

CCSM3 Exp

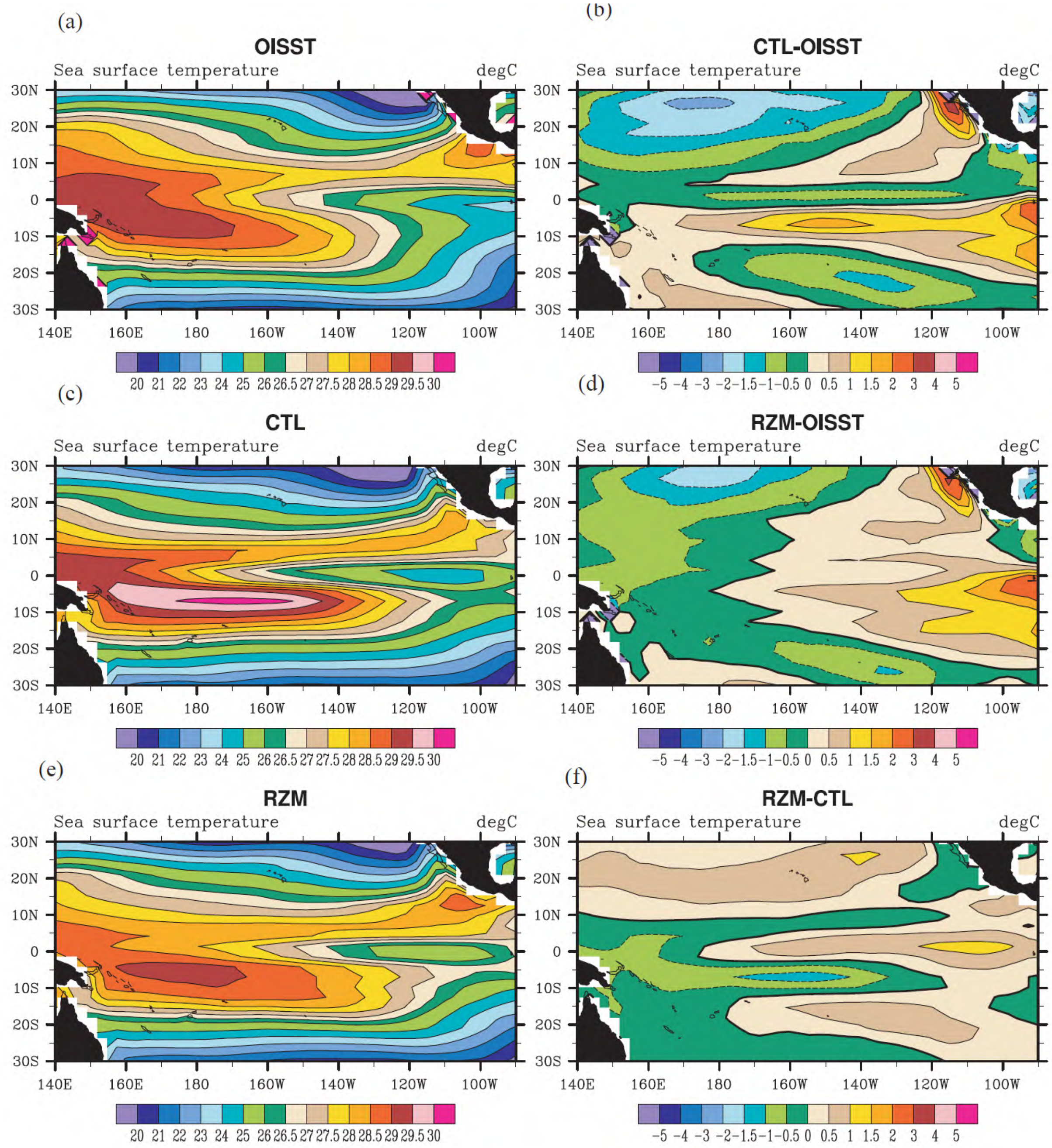



(a)
ICON
CTRL
Precipitation (mm/day)
Time (year)
(b)
SST (K)
Time (year)
(c)
SWCF (Wm-2)
Time (year)

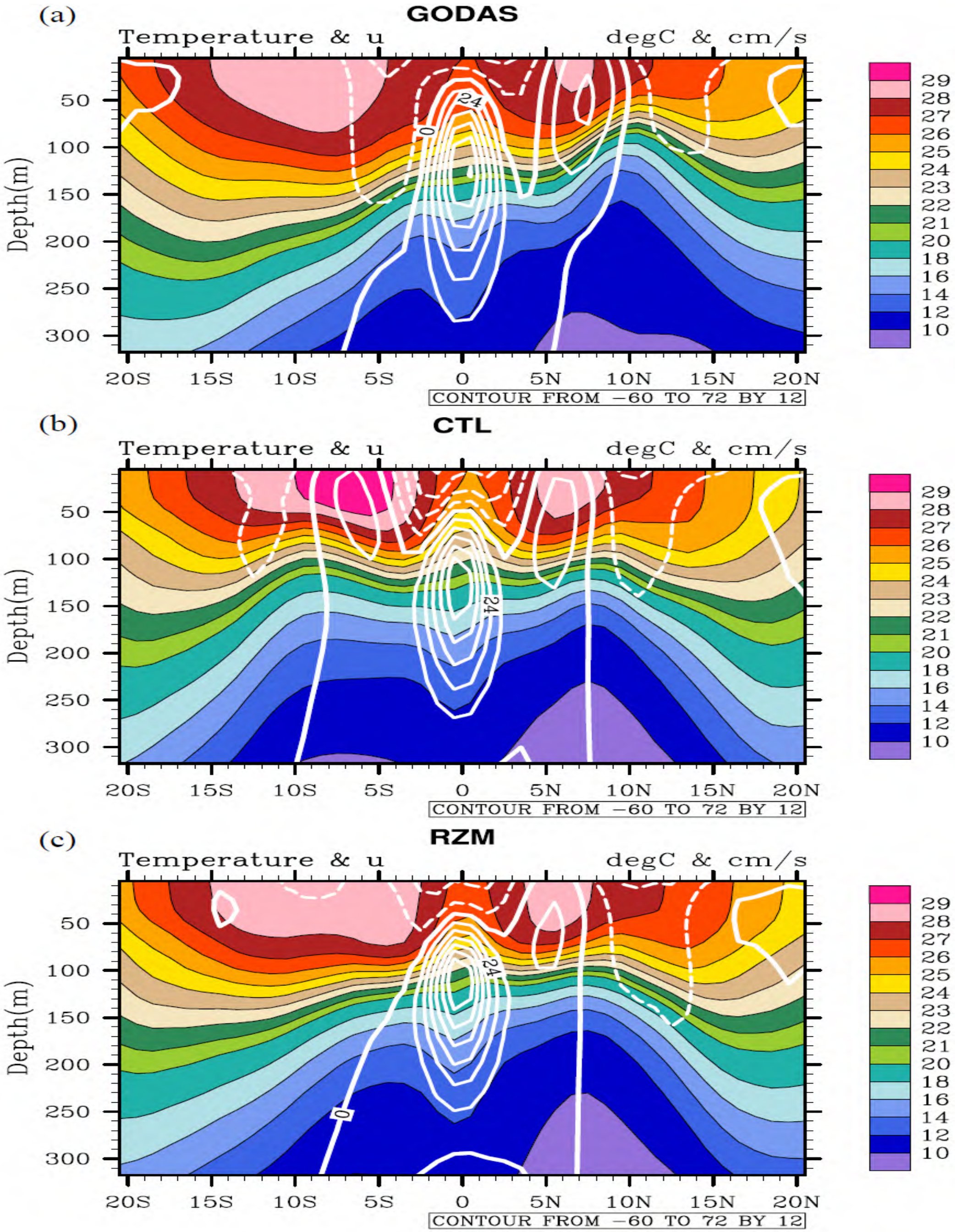

CMAP
precipitation
mm/day
30N 20N 10N 0 10S 20S 30S
140E 160E 180 160W 140W 120W 100W
0 0.5 1 2 3 4 5 6 7 8 9 10 11 12 13
GPCP
precipitation
mm/day
30N 20N 10N 0 10S 20S 30S
140E 160E 180 160W 140W 120W 100W
0 0.5 1 2 3 4 5 6 7 8 9 10 11 12 13
RZM
precipitation
mm/day
30N 20N 10N 0 10S 20S 30S
140E 160E 180 160W 140W 120W 100W
0 0.5 1 2 3 4 5 6 7 8 9 10 11 12 13
CTL
precipitation
mm/day
30N 20N 10N 0 10S 20S 30S
140E 160E 180 160W 140W 120W 100W
0 0.5 1 2 3 4 5 6 7 8 9 10 11 12 13
CTL-CMAP
precipitation
mm/day
30N 20N 10N 0 10S 20S 30S
140E 160E 180 160W 140W 120W 100W
−6 −5 −4 −3 −2 −1 −0.5 0 0.5 1 2 3 4 5 6
RZM-CTL
precipitation
mm/day
30N 20N 10N 0 10S 20S 30S
140E 160E 180 160W 140W 120W 100W
−6 −5 −4 −3 −2 −1 −0.5 0 0.5 1 2 3 4 5 6



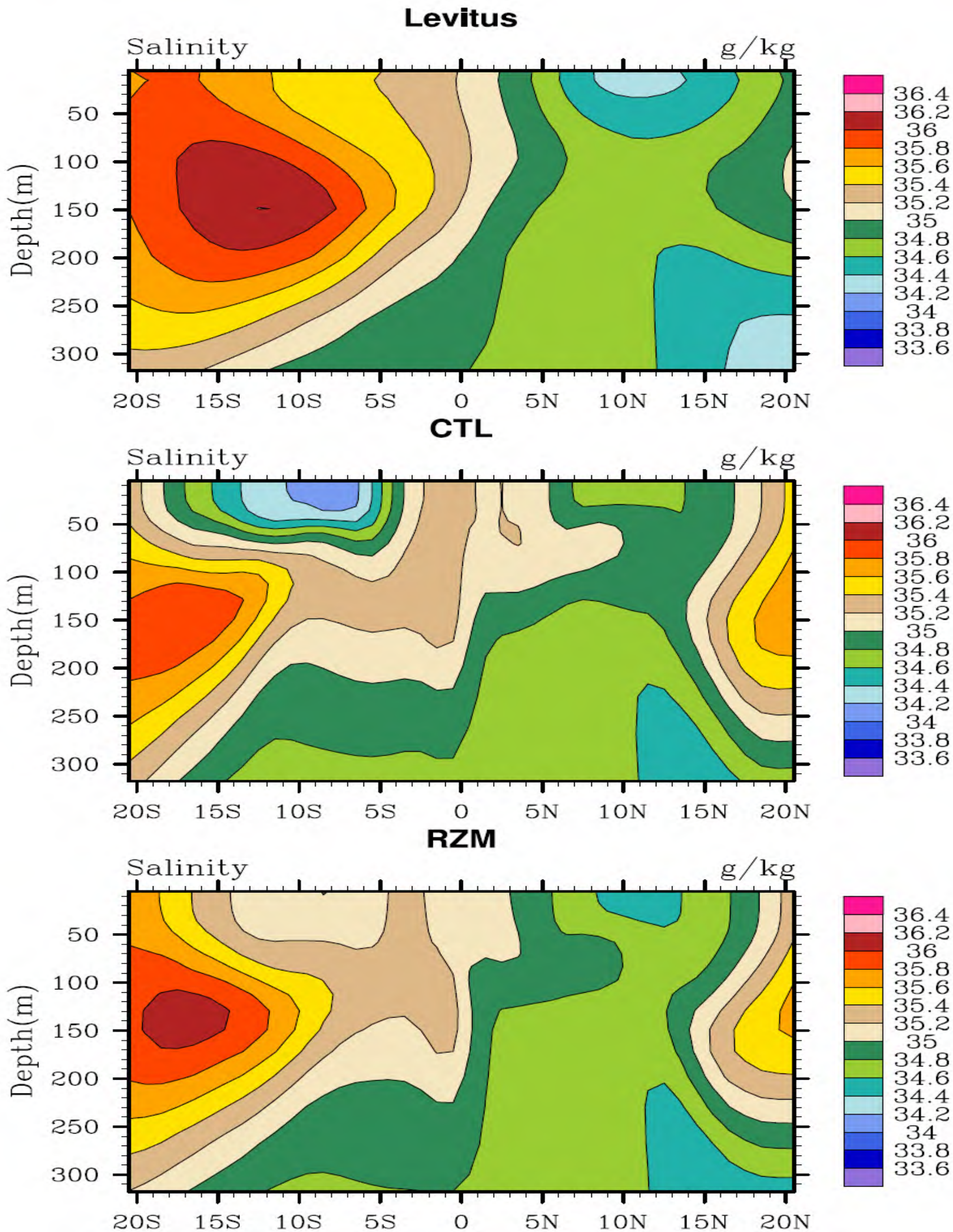
(a)
CMAP
Precipitation rate
mm/day
30N
0
30S
J F M A M J J A S O N D J
(b)
CTL
Precipitation rate
mm/day
30N
0
30S
J F M A M J J A S O N D J
(c)
RZM
Precipitation rate
mm/day
30N
0
30S
J F M A M J J A S O N D J
0.5 2 4 6 7 8 10 14



(a)
OISST
Sea surface temperature
degC
(b)
CTL-OISST
Sea surface temperature
degC
(c)
CTL
Sea surface temperature
degC
(d)
RZM-OISST
Sea surface temperature
degC
(e)
RZM
Sea surface temperature
degC
(f)
RZM-CTL
Sea surface temperature
degC
30N 20N 10N 0 10S 20S 30S
140E 160E 180 160W 140W 120W 100W
20 21 22 23 24 25 26 26.5 27 27.5 28 28.5 29 29.5 30
−5 −4 −3 −2 −1.5 −1 −0.5 0 0.5 1 1.5 2 3 4 5



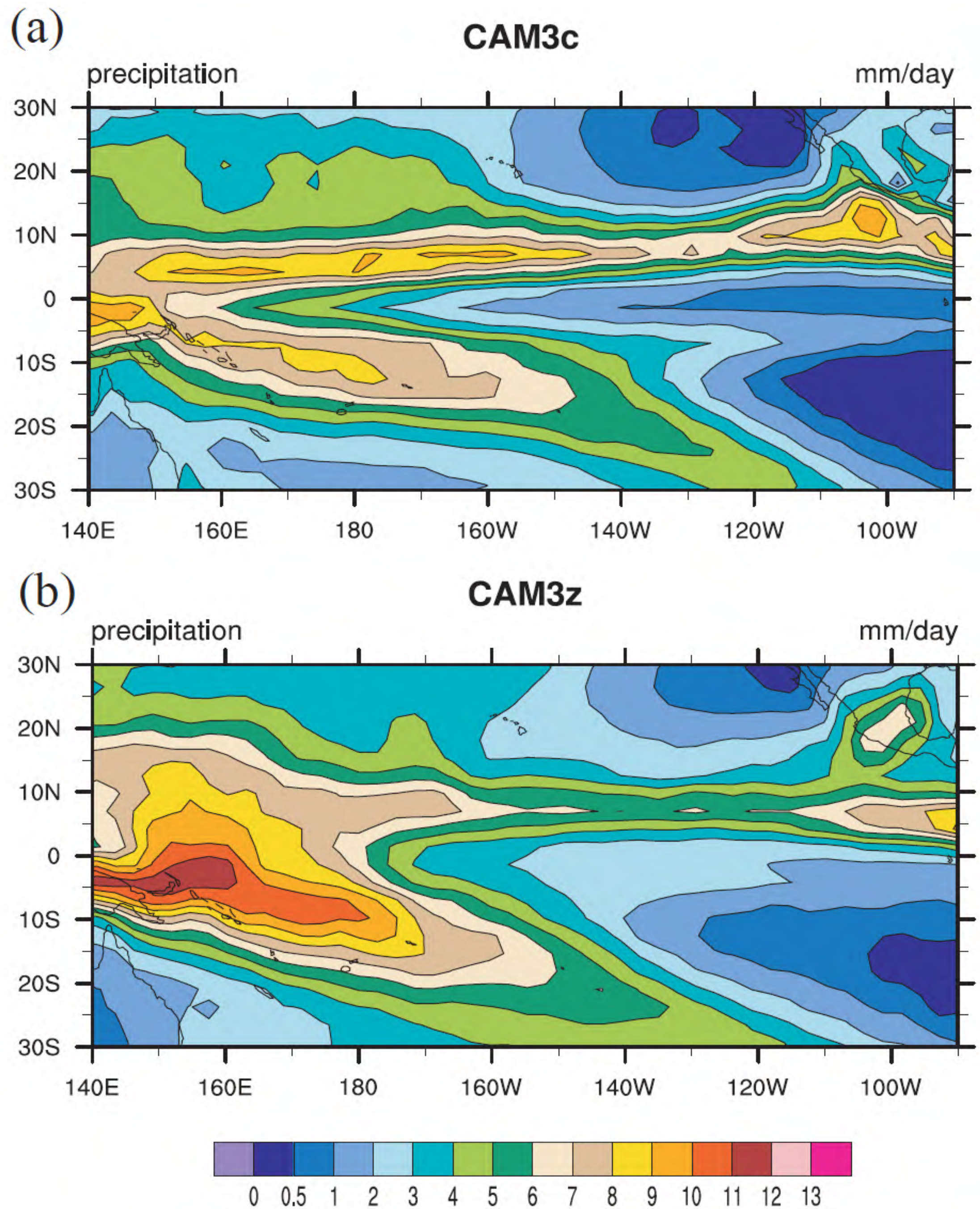
upper ocean temperature and zonal current (180-130W)



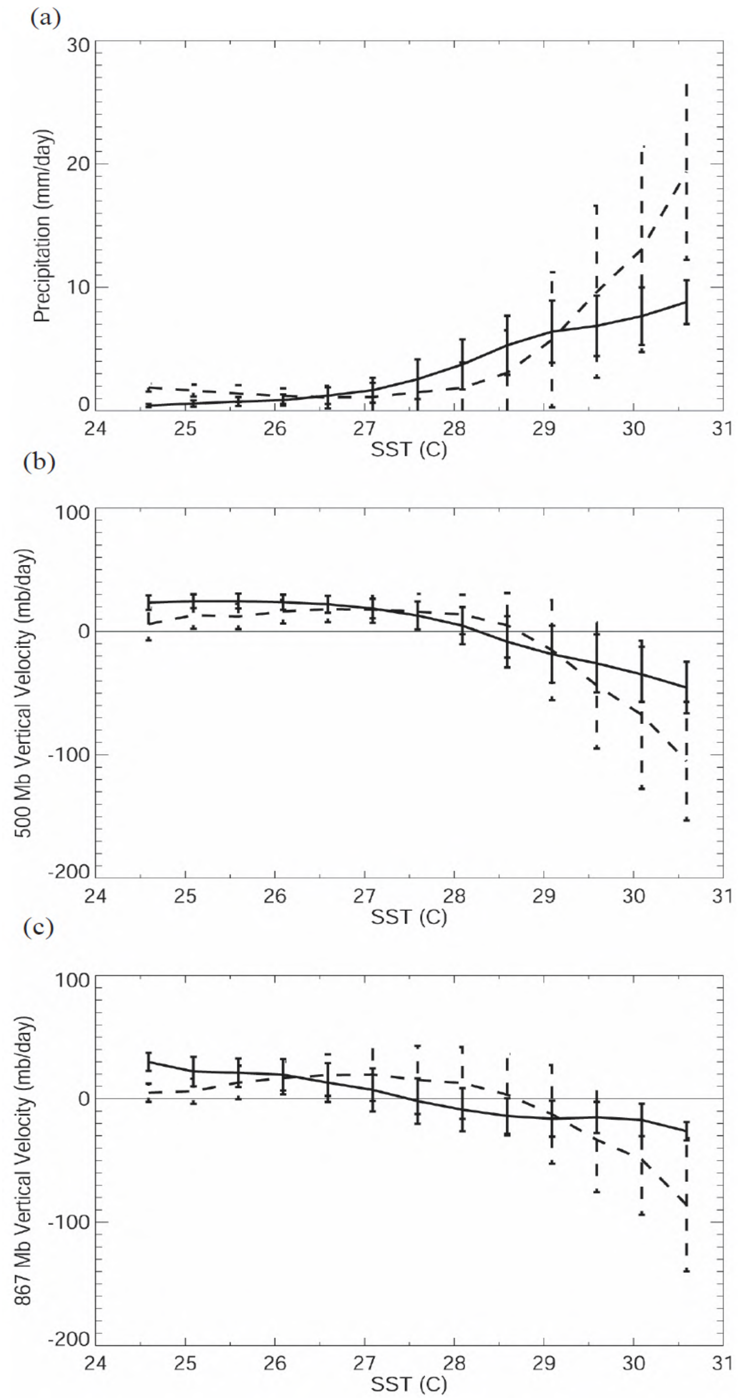
upper ocean salinity
(180-130W)

How do changes in convection parameterization lead to improved coupled model simulation?

- Biases in the atmospheric model
- Ocean-atmosphere feedback to amplify them

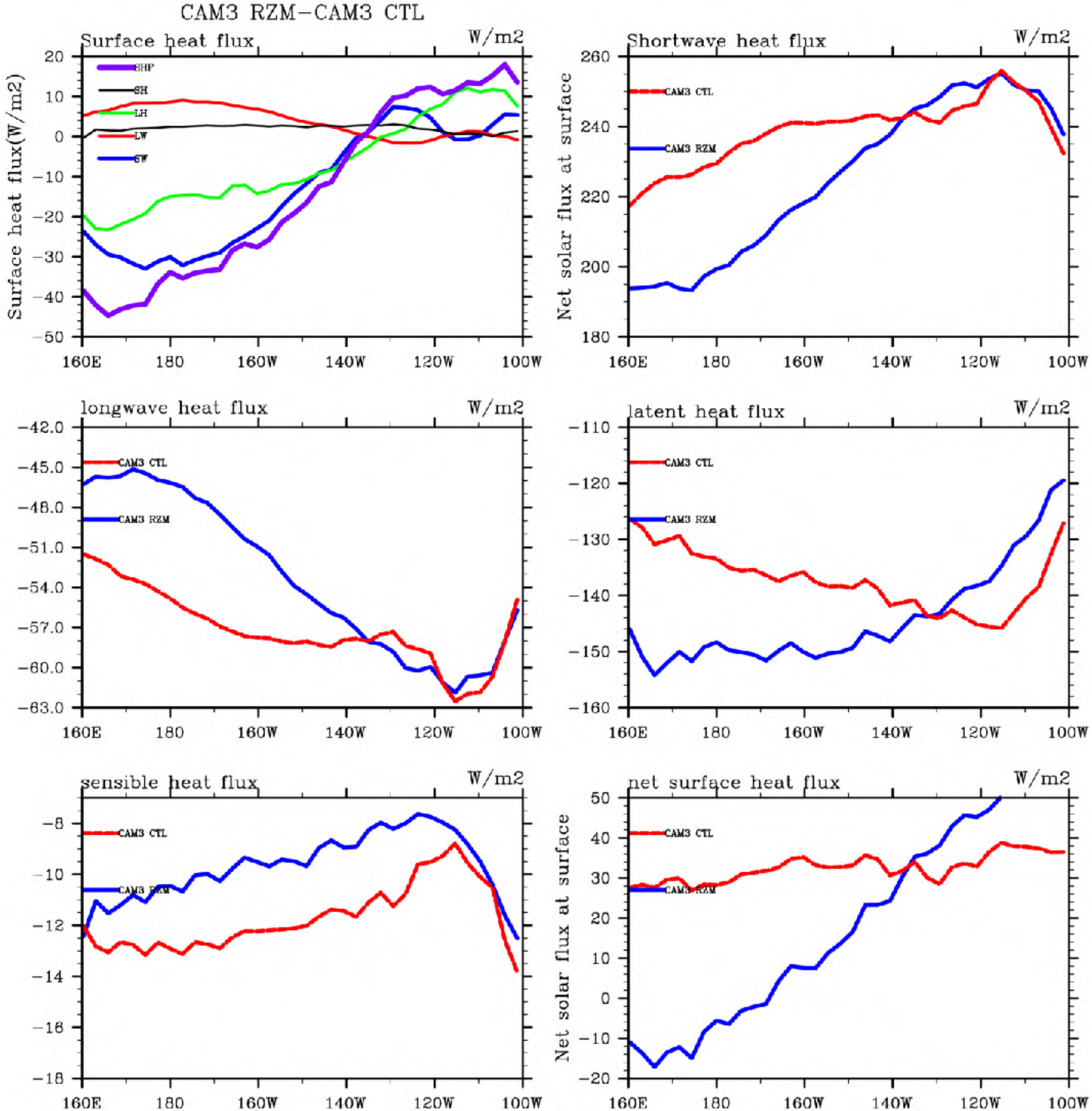


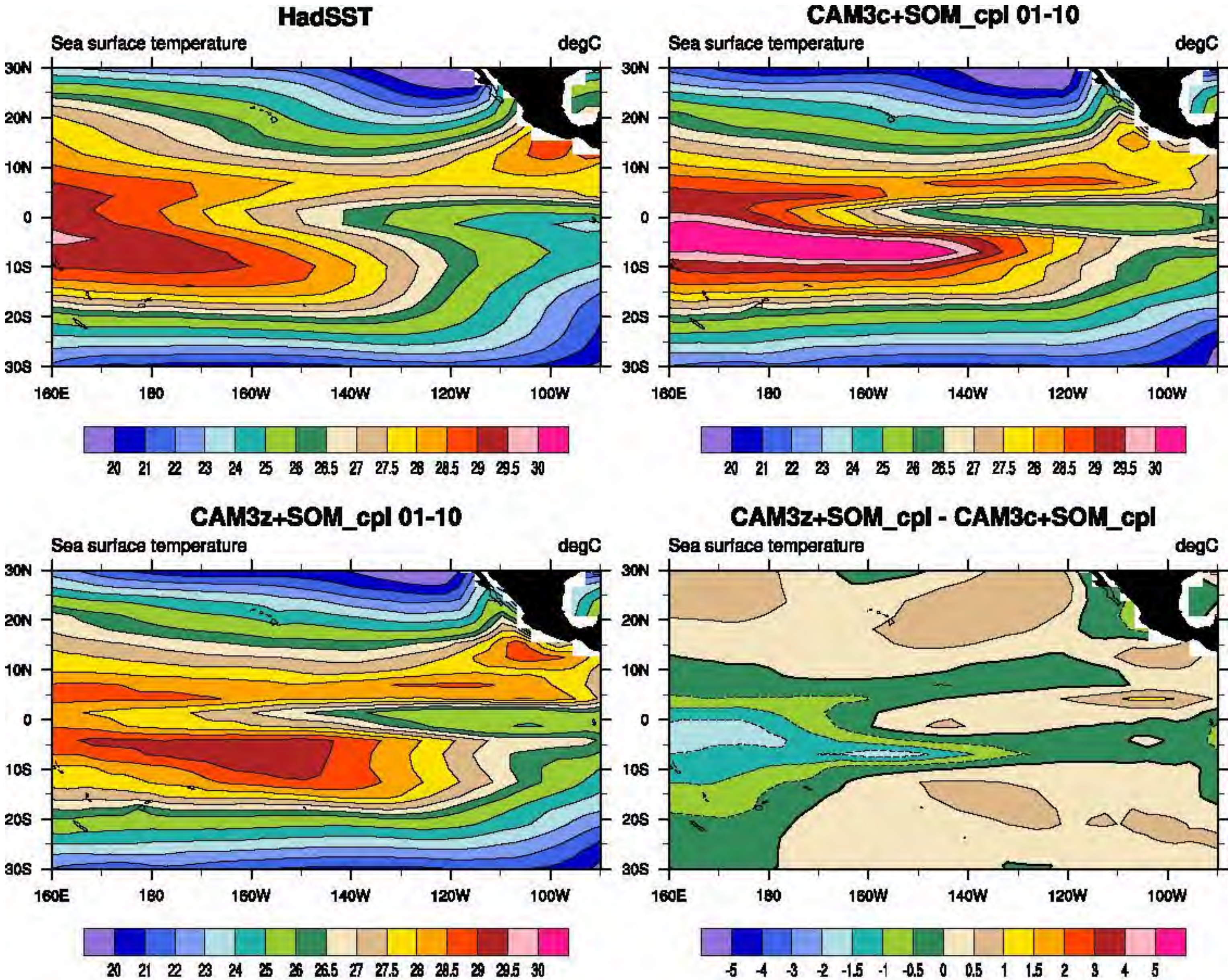
(a)
CAM3c
precipitation
mm/day
30N
20N
10N
0
10S
20S
30S
140E
160E
180
160W
140W
120W
100W
(b)
CAM3z
precipitation
mm/day
30N
20N
10N
0
10S
20S
30S
140E
160E
180
160W
140W
120W
100W
0
0.5
1
2
3
4
5
6
7
8
9
10
11
12
13

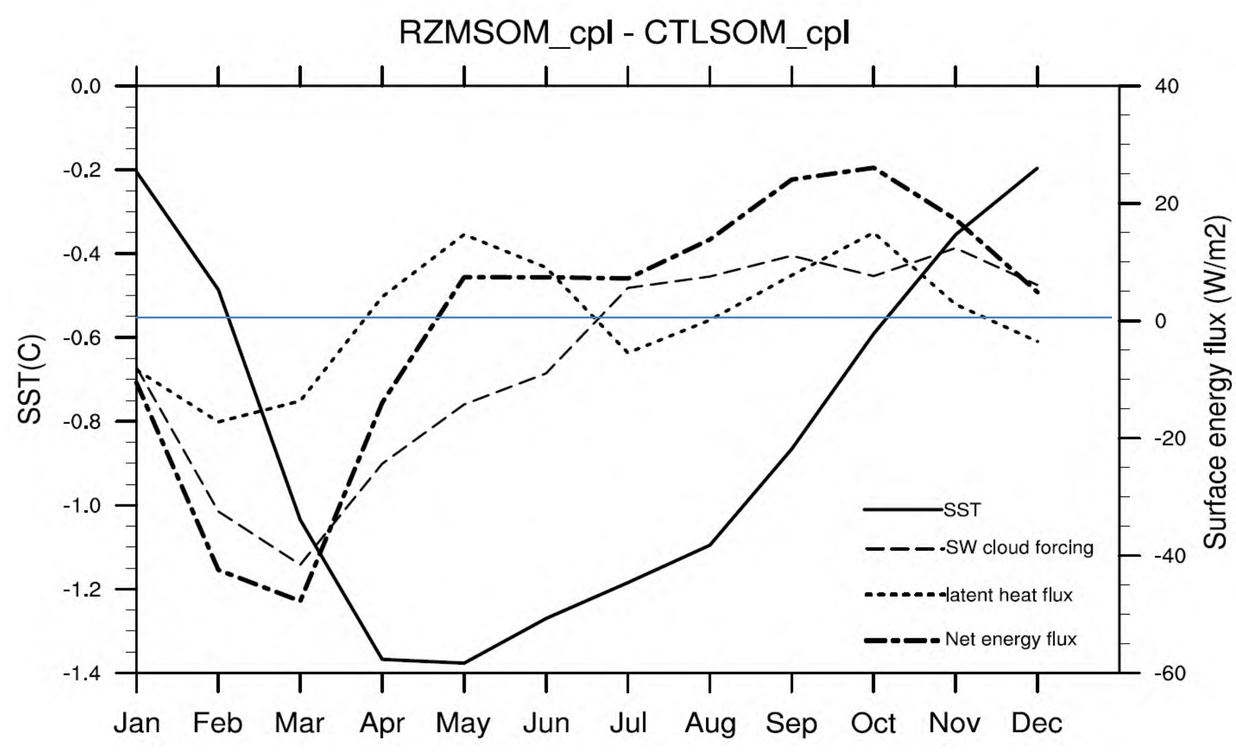


Solid: CTRL

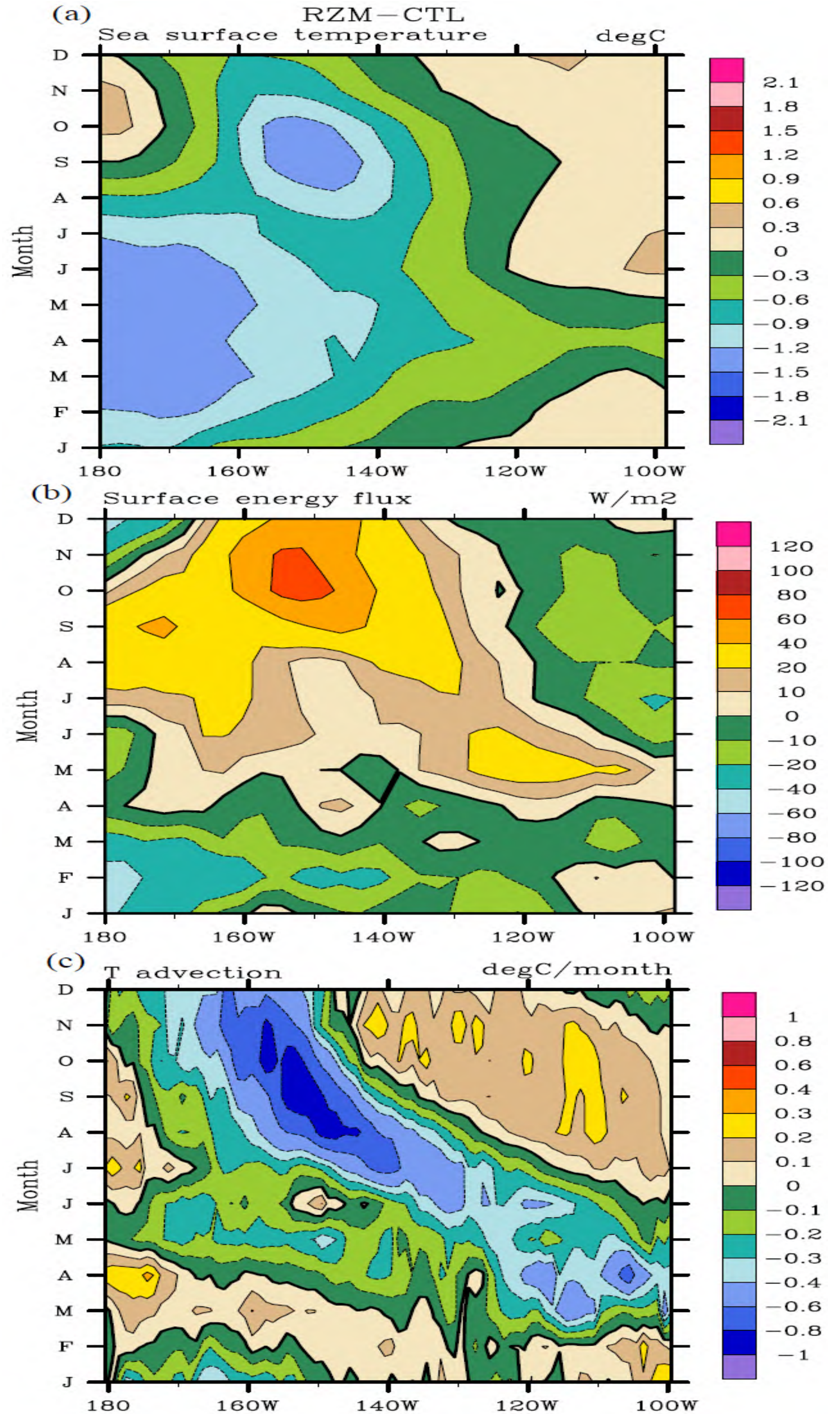
Dashed: RZM


CAM3 RZM−CAM3 CTL
Surface heat flux
W/m2
Surface heat flux(W/m2)
SHF
SH
LH
LW
SW
Shortwave heat flux
W/m2
Net solar flux at surface
CAM3 CTL
CAM3 RZM
longwave heat flux
W/m2
CAM3 CTL
CAM3 RZM
latent heat flux
W/m2
CAM3 CTL
CAM3 RZM
sensible heat flux
W/m2
CAM3 CTL
CAM3 RZM
net surface heat flux
W/m2
Net solar flux at surface
CAM3 CTL
CAM3 RZM
160E
180
160W
140W
120W
100W

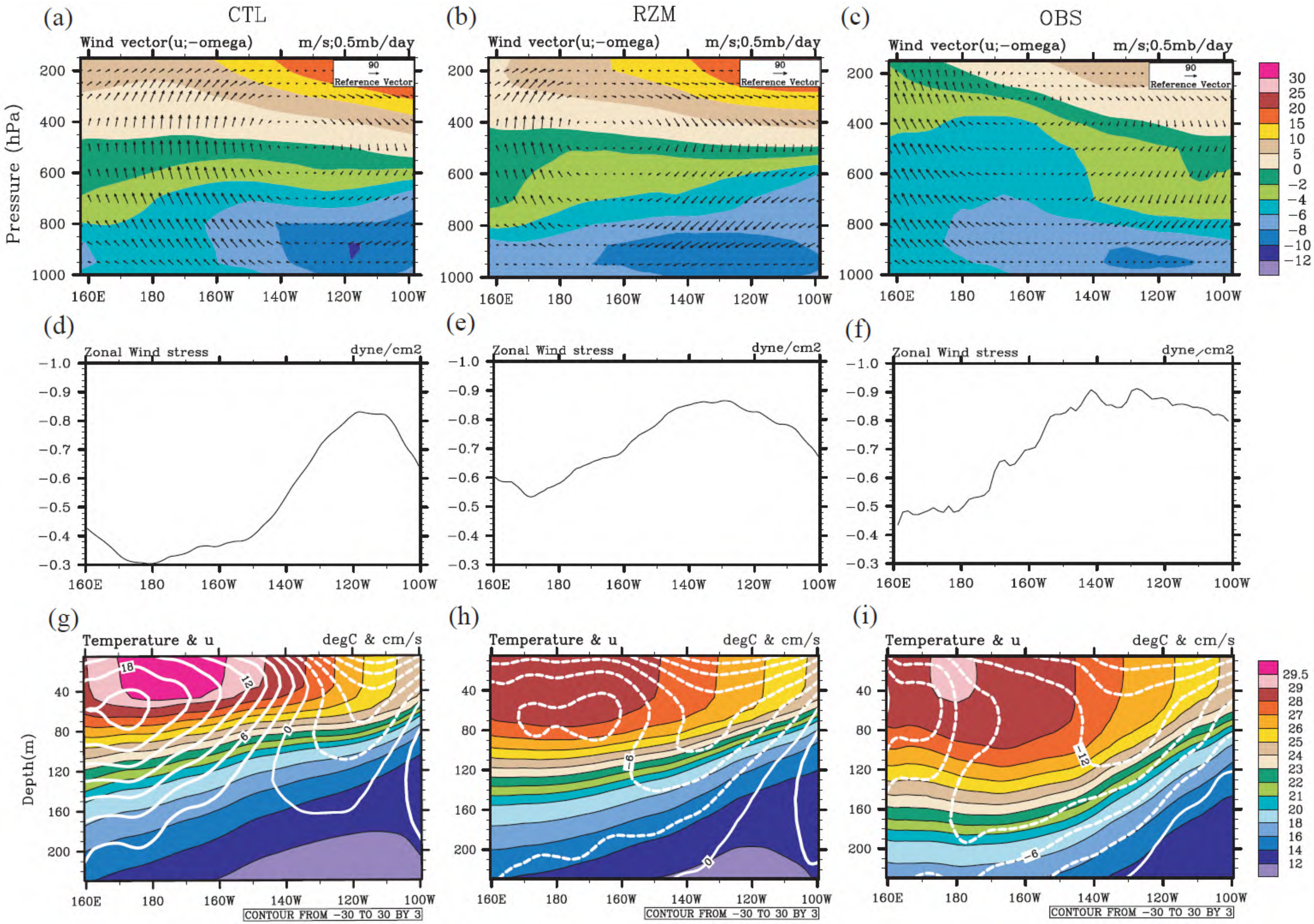

HadSST
Sea surface temperature
degC
CAM3c+SOM_cpl 01-10
Sea surface temperature
degC
CAM3z+SOM_cpl 01-10
Sea surface temperature
degC
CAM3z+SOM_cpl - CAM3c+SOM_cpl
Sea surface temperature
degC
30N 20N 10N 0 10S 20S 30S
160E 180 160W 140W 120W 100W
20 21 22 23 24 25 26 26.5 27 27.5 28 28.5 29 29.5 30
-5 -4 -3 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 3 4 5



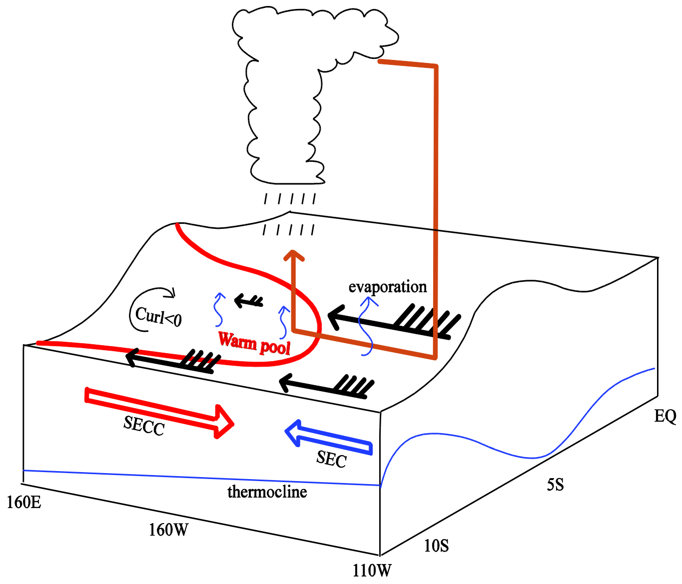
RZMSOM_cpl - CTLSOM_cpl
SST(C)
Surface energy flux (W/m2)
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
40
20
0
-20
-40
-60
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
SST
SW cloud forcing
latent heat flux
Net energy flux



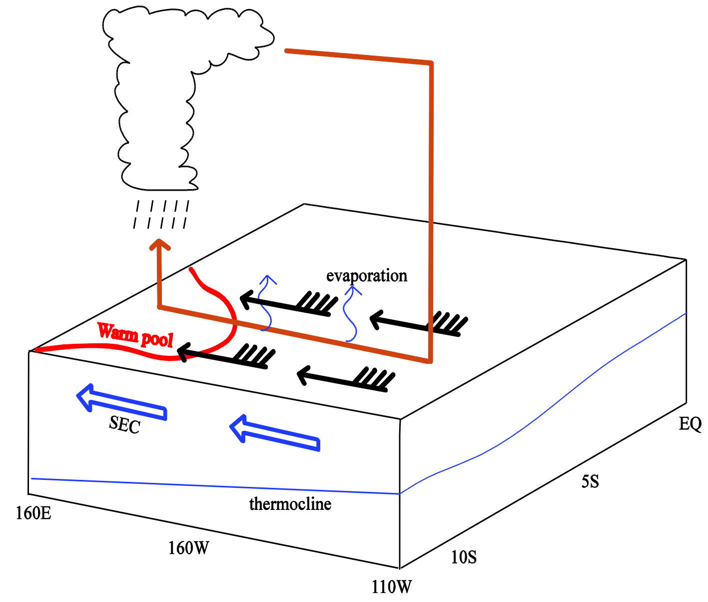
(a)
RZM−CTL
Sea surface temperature
degC
(b)
Surface energy flux
W/m2
(c)
T advection
degC/month
Month
D
N
O
S
A
J
J
M
A
M
F
J
180
160W
140W
120W
100W
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
−0.3
−0.6
−0.9
−1.2
−1.5
−1.8
−2.1
120
100
80
60
40
20
10
0
−10
−20
−40
−60
−80
−100
−120
1
0.8
0.6
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.6
−0.8
−1



(a) CTL
(b) RZM
(c) OBS
Wind vector(u;-omega)
m/s;0.5mb/day
90
Reference Vector
Pressure (hPa)
(d)
(e)
(f)
Zonal Wind stress
dyne/cm2
(g)
(h)
(i)
Temperature & u
degC & cm/s
Depth(m)
CONTOUR FROM -30 TO 30 BY 3



CCSM3



CCSM3 Exp

Summary

- There is significant improvement in reducing the double ITCZ in CCSM3
- The associated ocean temperature, currents and salinity fields are also better simulated
- The role of the coupled feedback is explored…

Feedback Differences

- SST, large-scale circulation, evaporation feedback:

For control: more convection in the central Pacific leads to lower surface winds, which in turn leads to lower evaporation.

For RZM: more convection in the western Pacific leads to stronger surface winds in the central Pacific, thus more evaporation there.

Feedback Differences (con’t)

- In CAM3, SST, convection, shortwave flux feedback:

For control: convection in central Pacific leads to small shortwave flux reduction.

For RZM: convection leads to large reduction in surface shortwave flux in the central Pacific.

Feedback Differences (con’t)

- In CCSM3, ocean heat transport feedback:

For control: more convection in central Pacific (and weak surface wind stress) leads to warm ocean advection.

For RZM: more convection in the western Pacific leads to cold ocean advection.

- All combined, there is positive feedback for the control and negative feedback for the RZM run