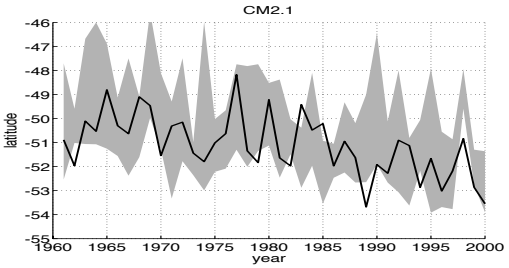
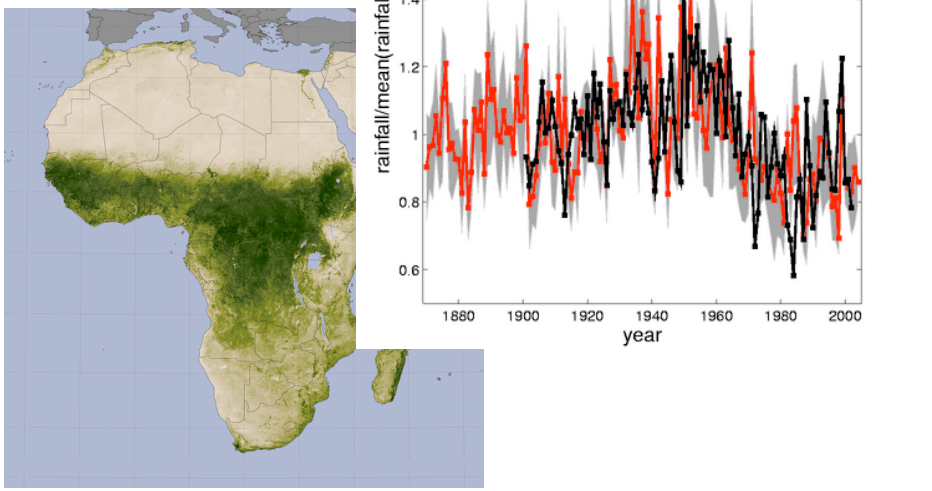
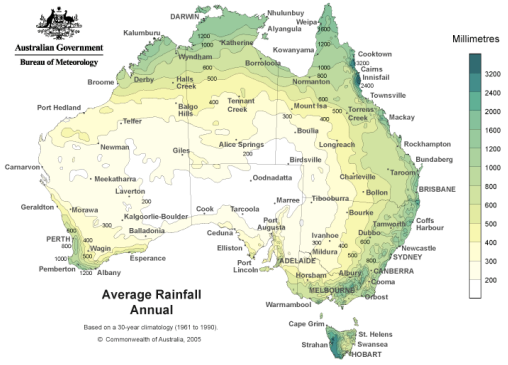
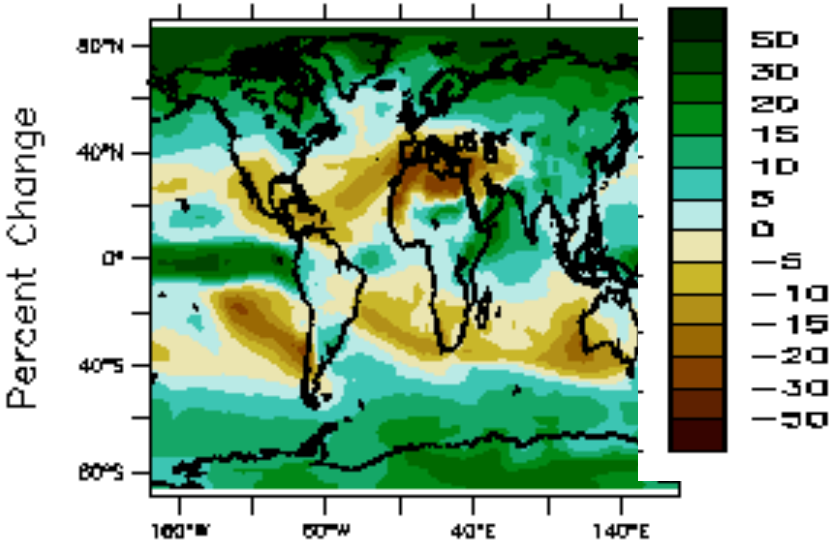
Subtropical Drying: a robust response to Global Warming

Isaac Held, ARCHES mini-conference July, 2007









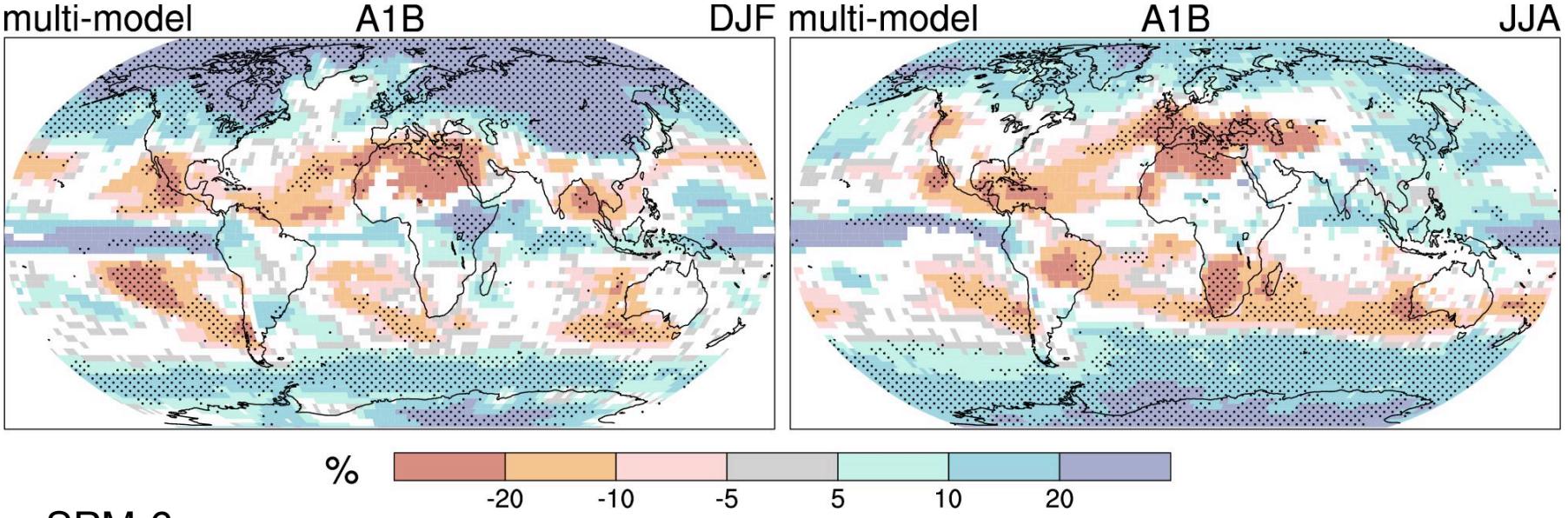
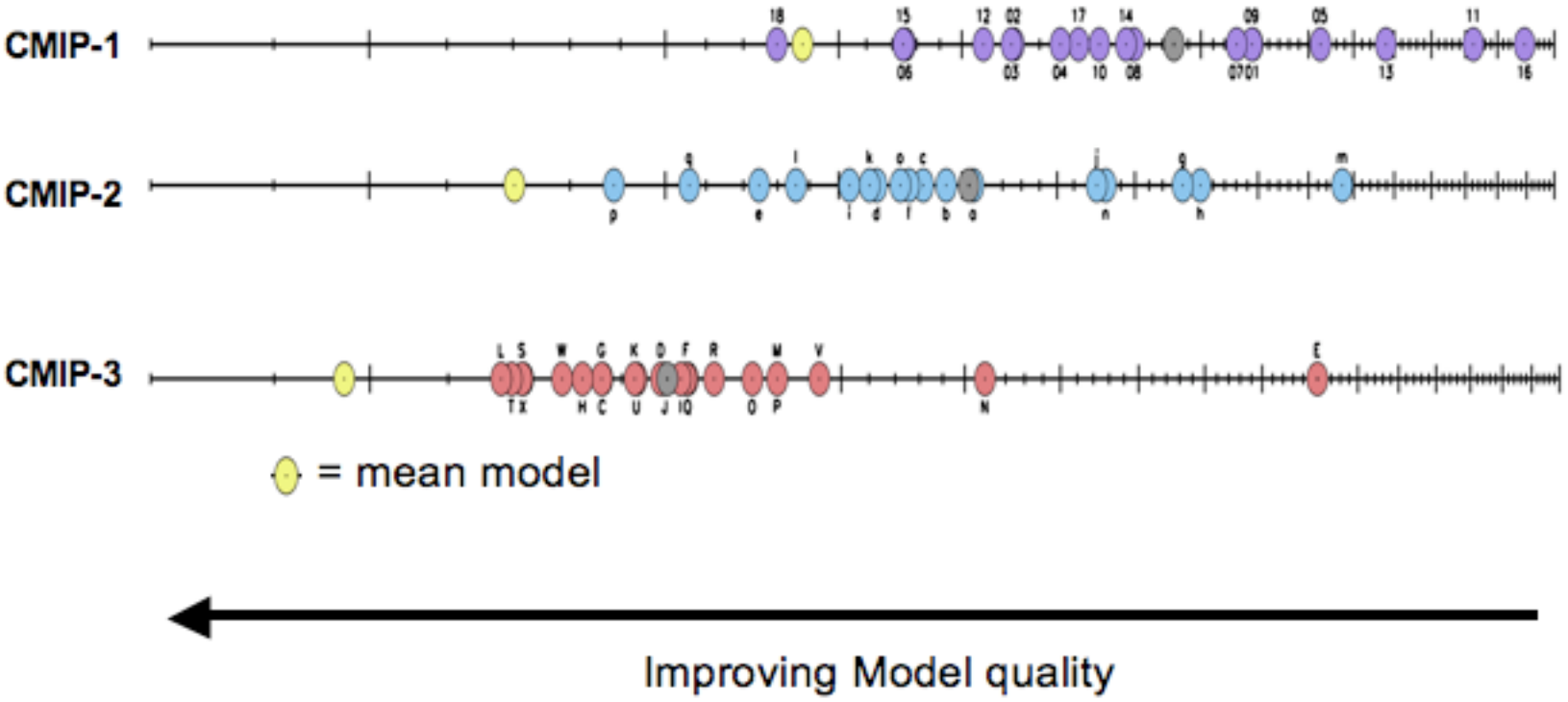


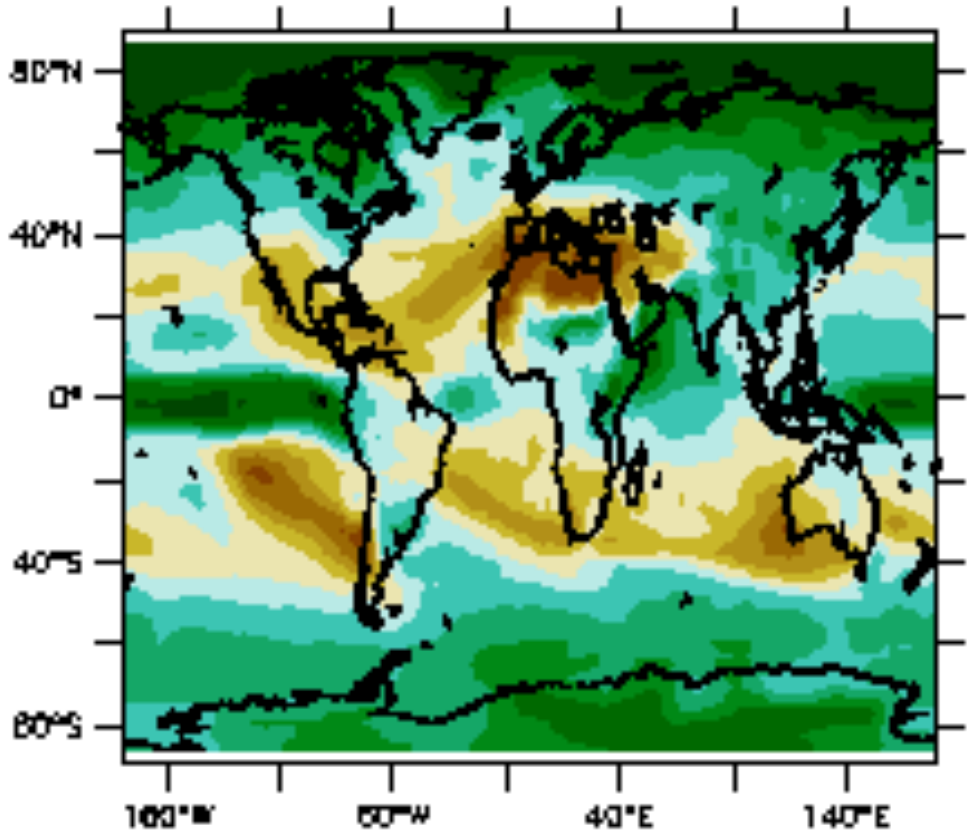
Fig. SPM-6

Stippled areas are where more than 90% of the models agree in the sign of the change

Precipitation increases very likely in high latitudes

Decreases likely in most subtropical land regions

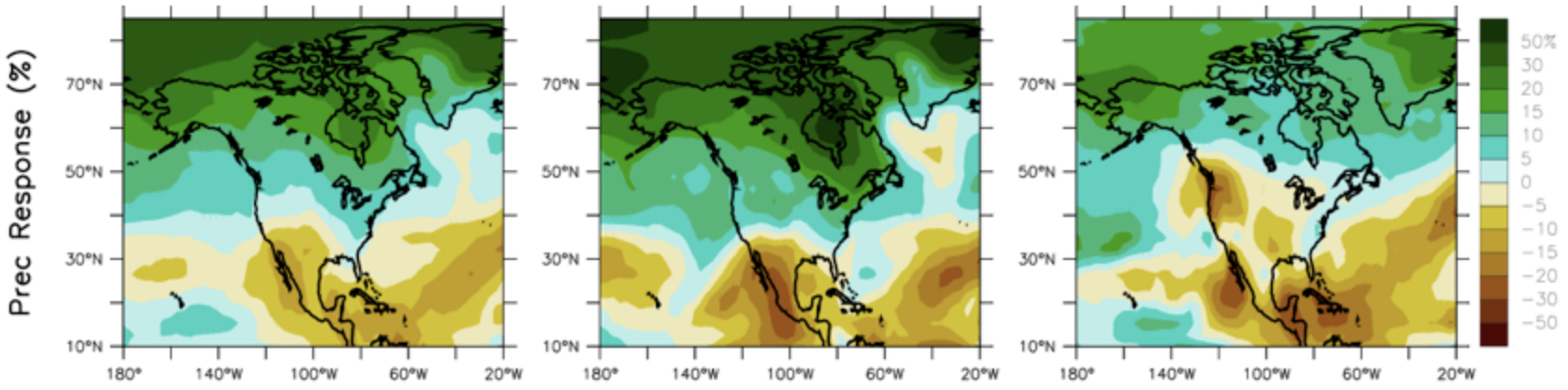

CMIP-1
CMIP-2
CMIP-3
= mean model
Improving Model quality

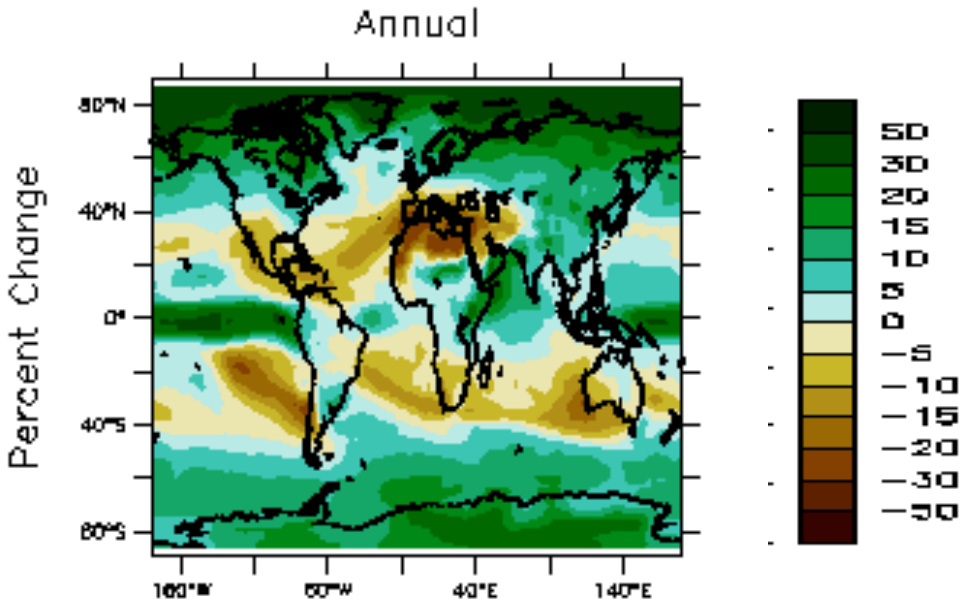


Average over year

Dec-Jan-Feb

June-Jul-Aug

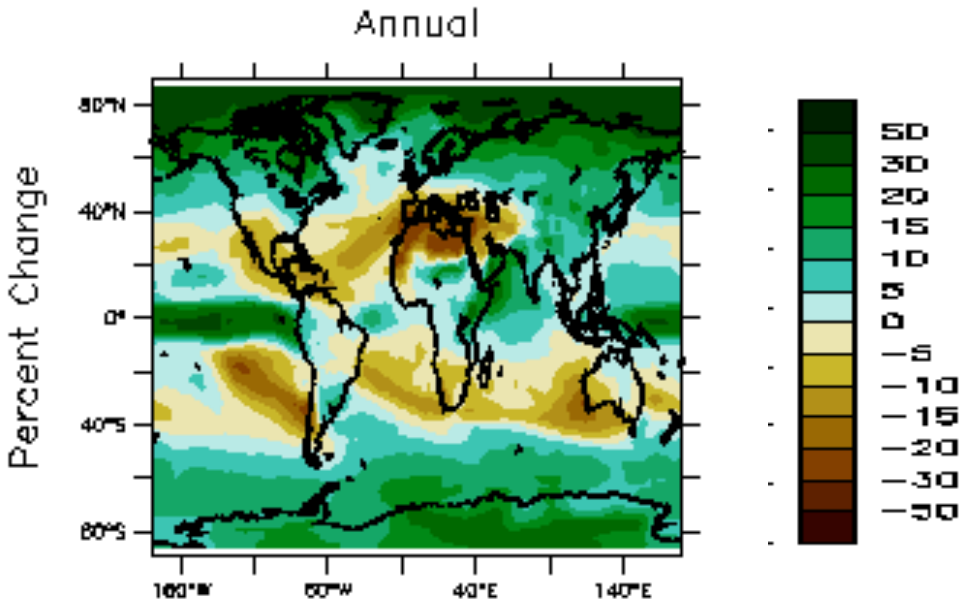




“the dry get drier and the wet get wetter”

the subtropics expand polewards

the tropical rain belts move towards the hemisphere that warms the fastest



"the dry get drier and the wet get wetter"

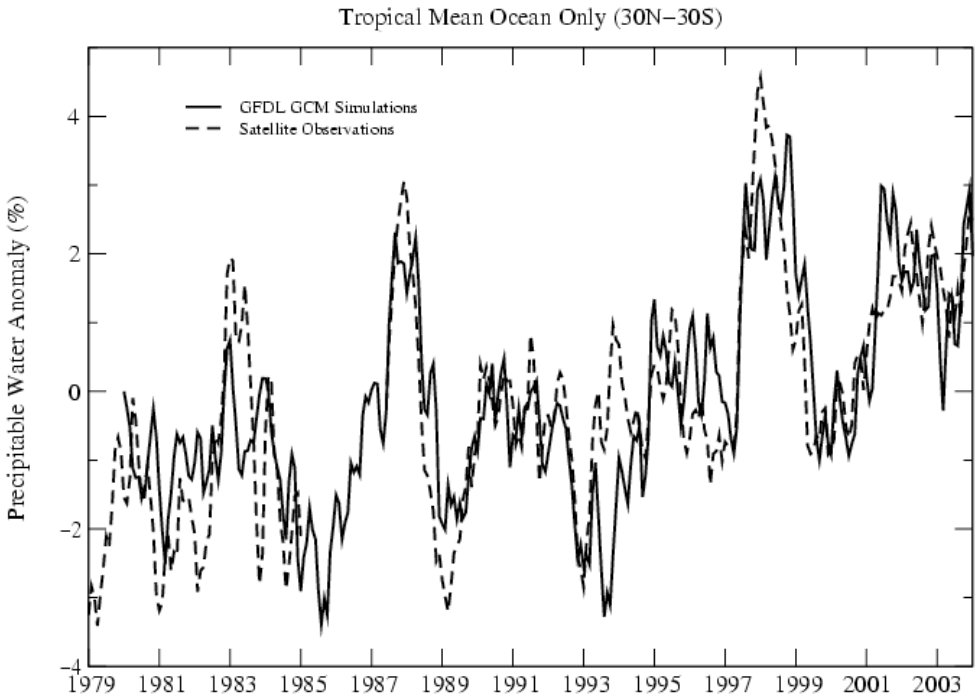
The subtropics expand polewards

the tropical rain belts move towards the hemisphere that warms the fastest

Total water vapor in the atmosphere has been increasing

Microwave satellite measurements (over oceans only)

Models match the observed trend and interannual variations
of tropical mean (ocean only) column water vapor
when given the observed ocean temperatures as boundary condition



Courtesy of Brian Soden

Local vertically integrated atmospheric moisture budget:

$$P - E = -\nabla \cdot F = -\nabla \cdot (\rho v q)$$

precipitation

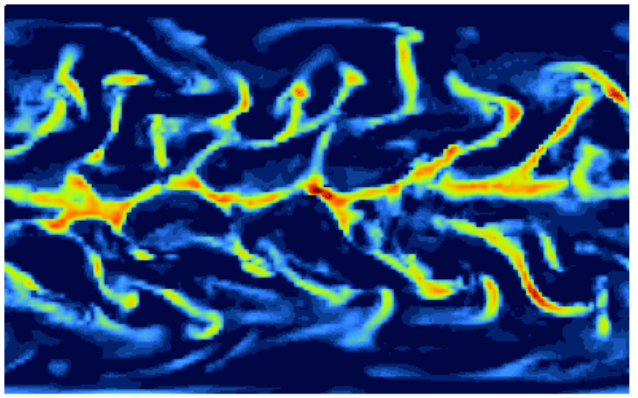
evaporation

vertically integrated moisture flux

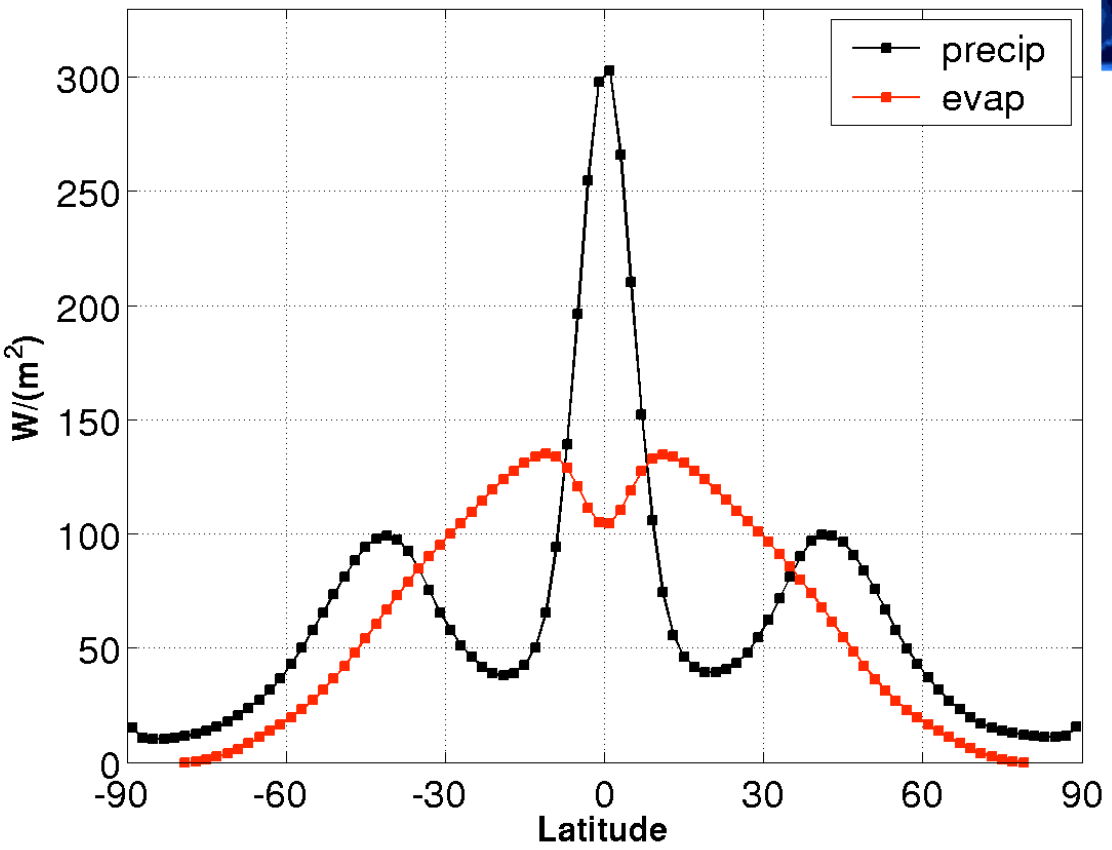
vapor mixing ratio

$$\frac{\delta F}{F} \approx \frac{\delta q}{q} \approx 0.07\,\delta T$$

Precipitation and evaporation
"Aqua_planet" climate model
(no seasons, no land surface)

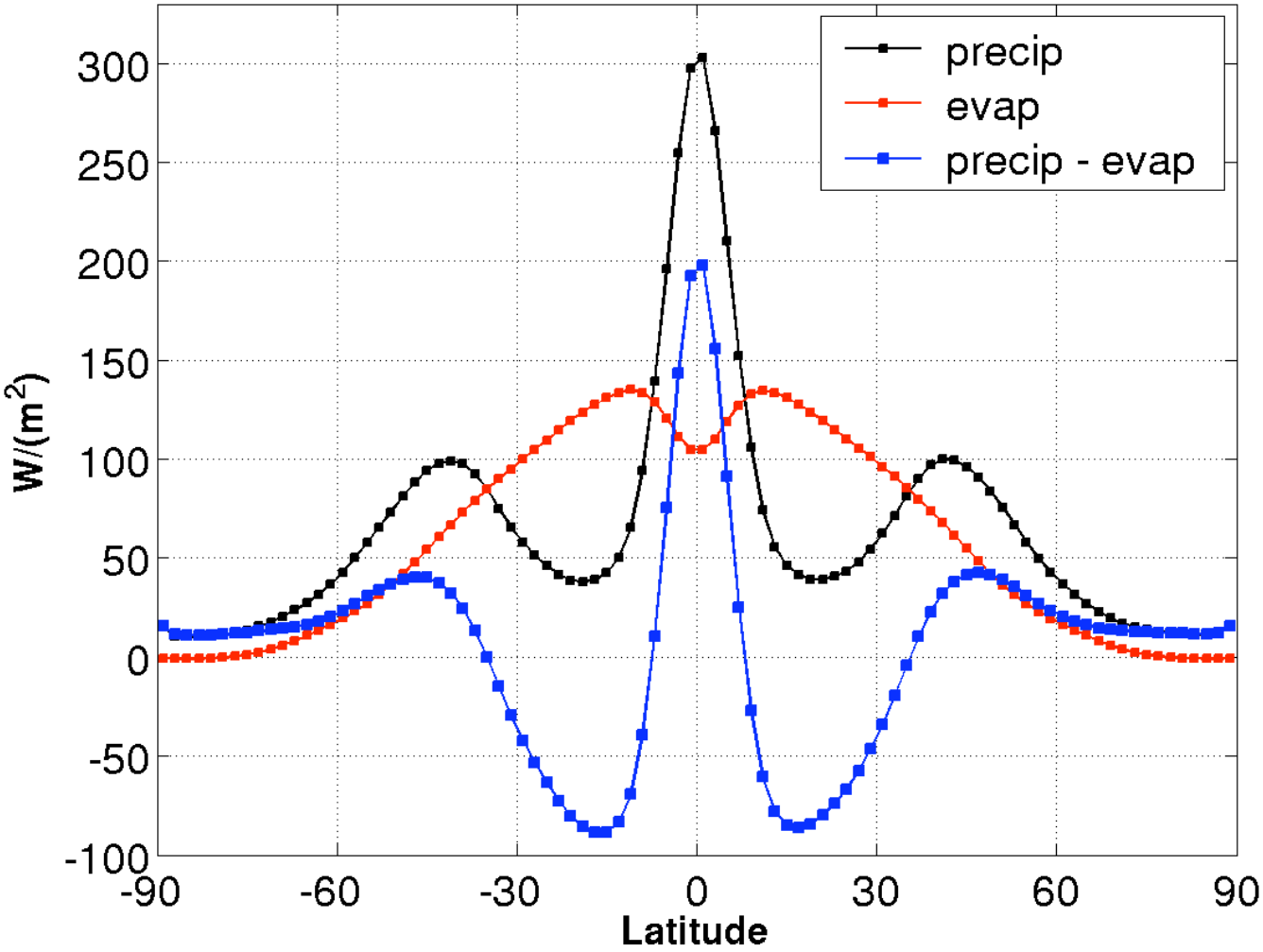


Instantaneous precip (lat,lon)

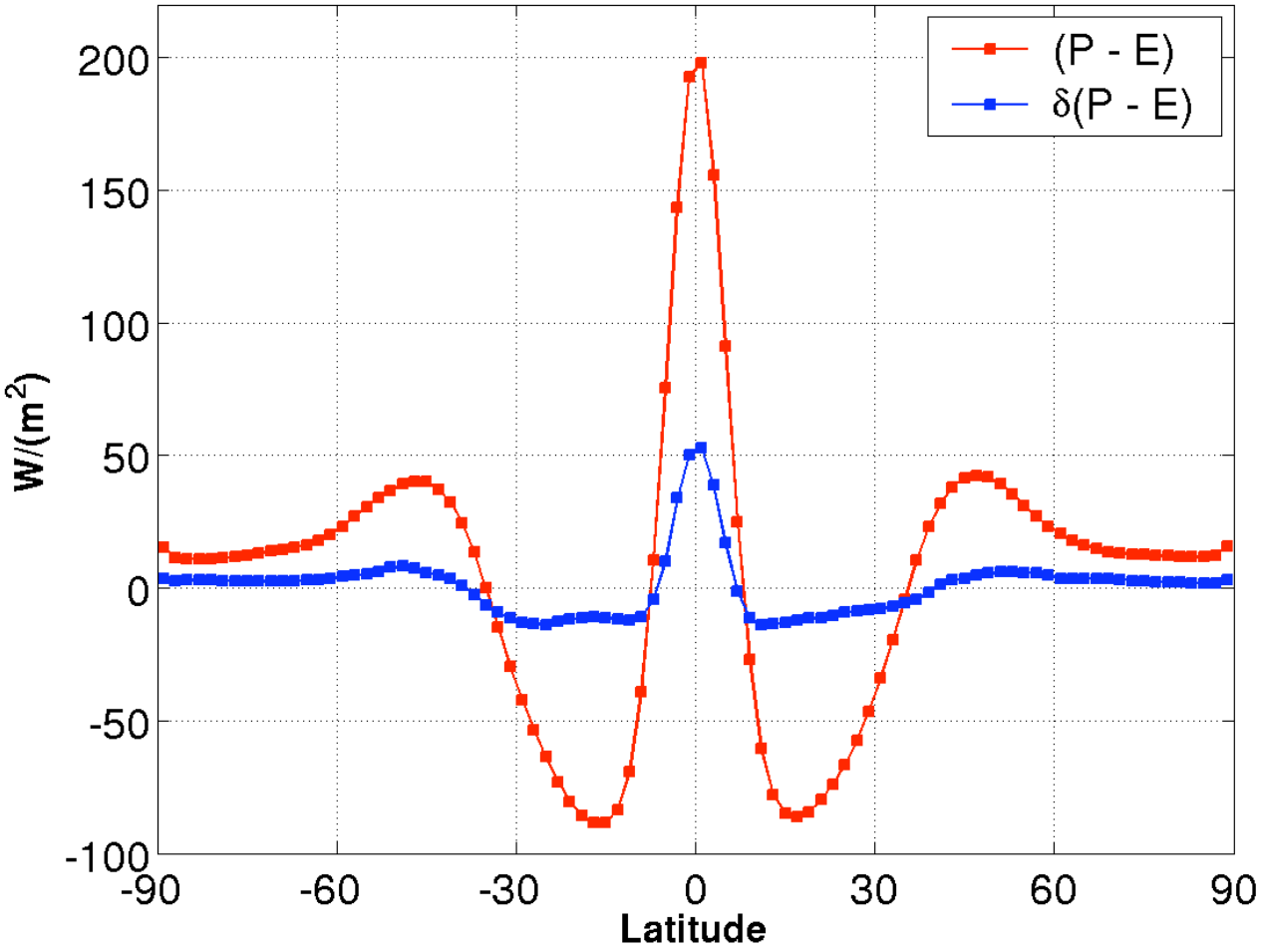


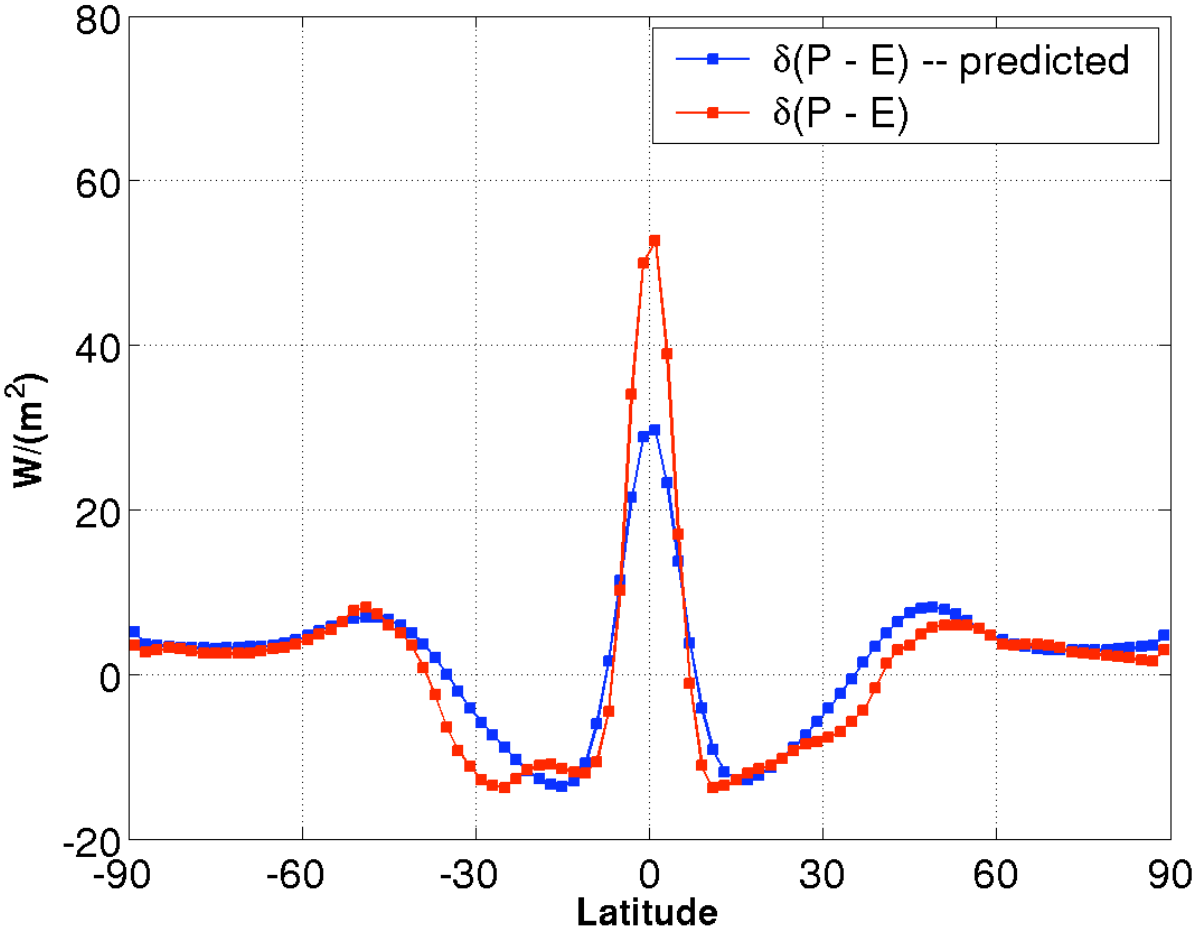
Time means

Precipitation minus evaporation



Aqua planet (P – E) response to doubling of CO_2

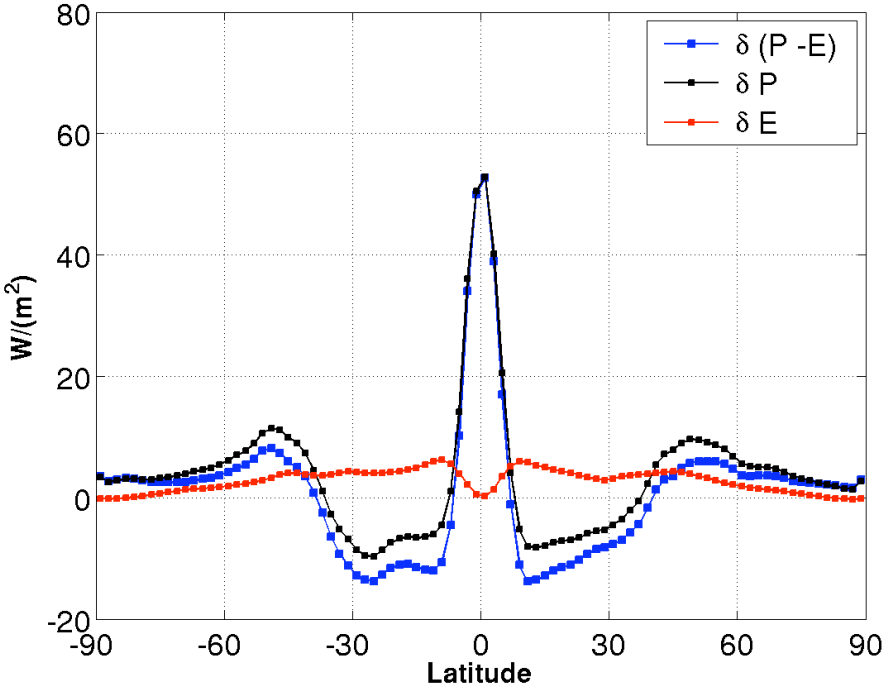




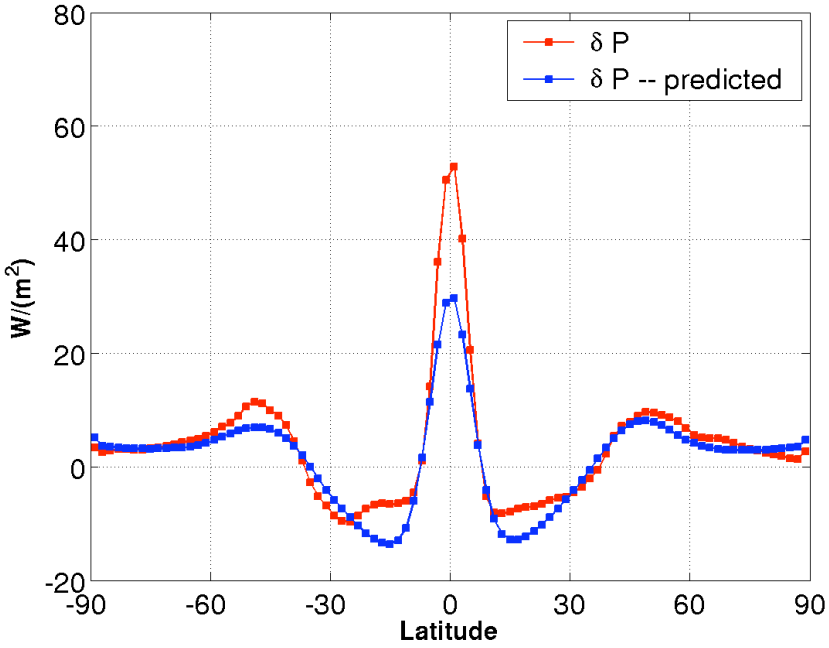
Prediction =>

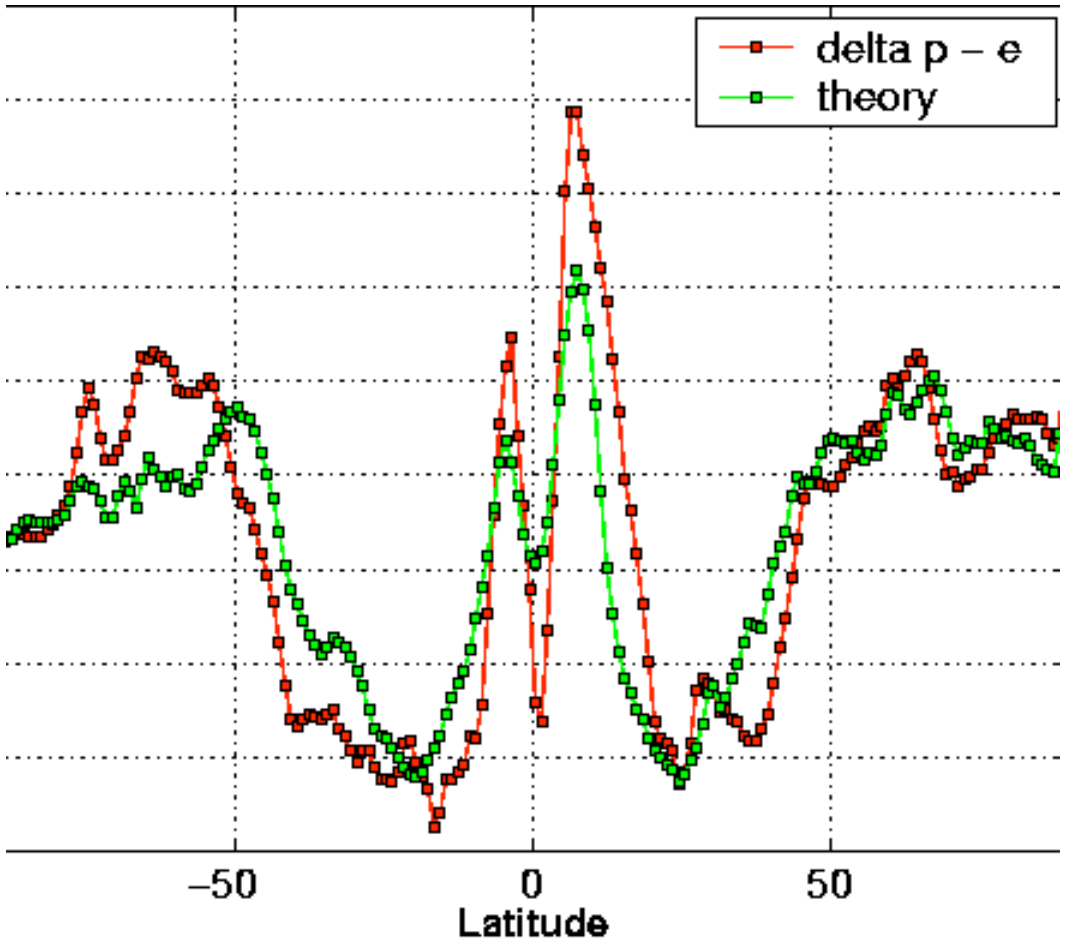
assume moisture flux changes only due to change in mixing ratio, computed holding relative humidity fixed and using model's predicted temperature response

$$d(P - E) \sim dP$$

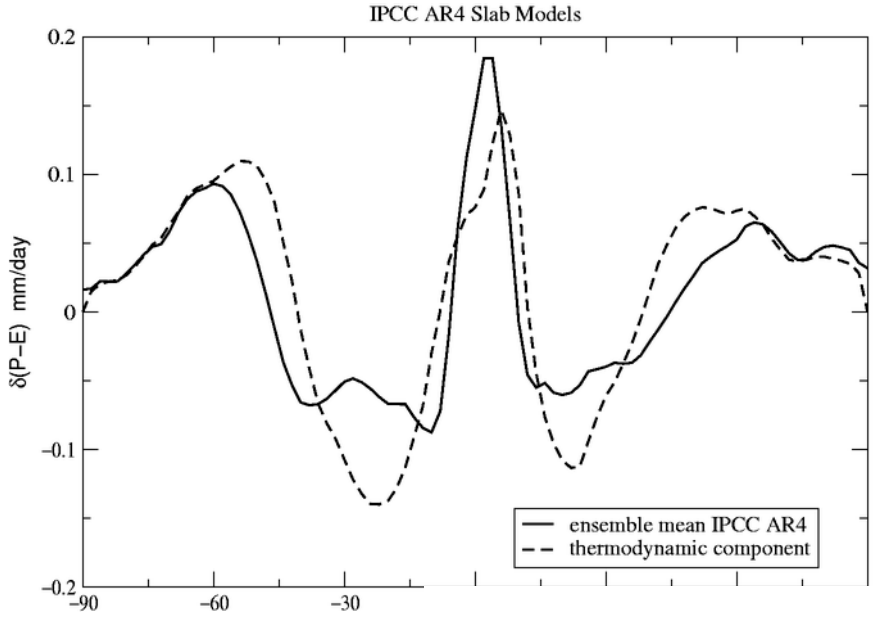


$$\Rightarrow dP \sim P - E$$

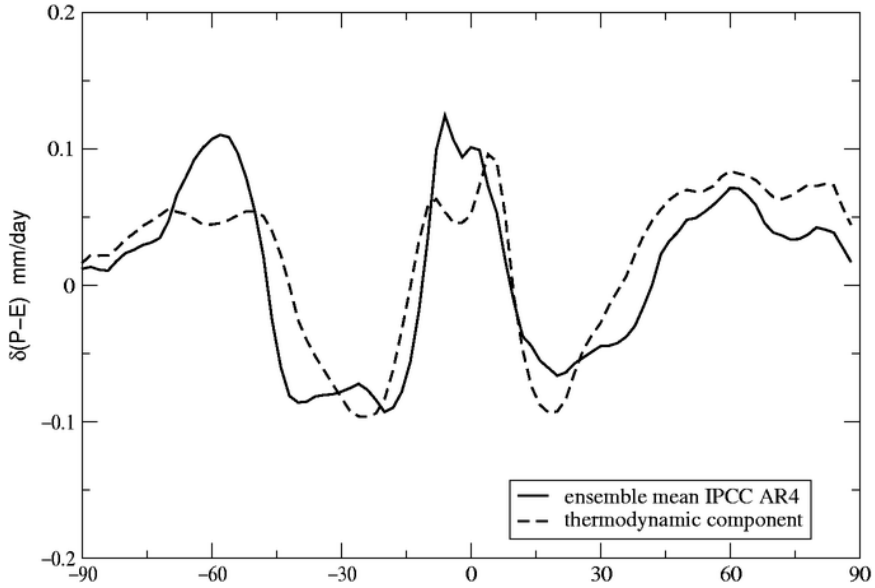


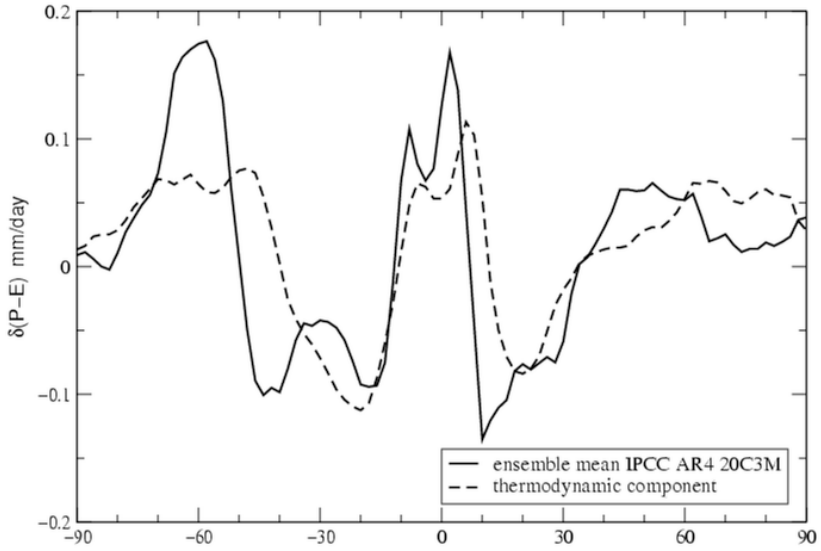

delta p – e
theory
–50
0
50
Latitude

Equilibrium 2x

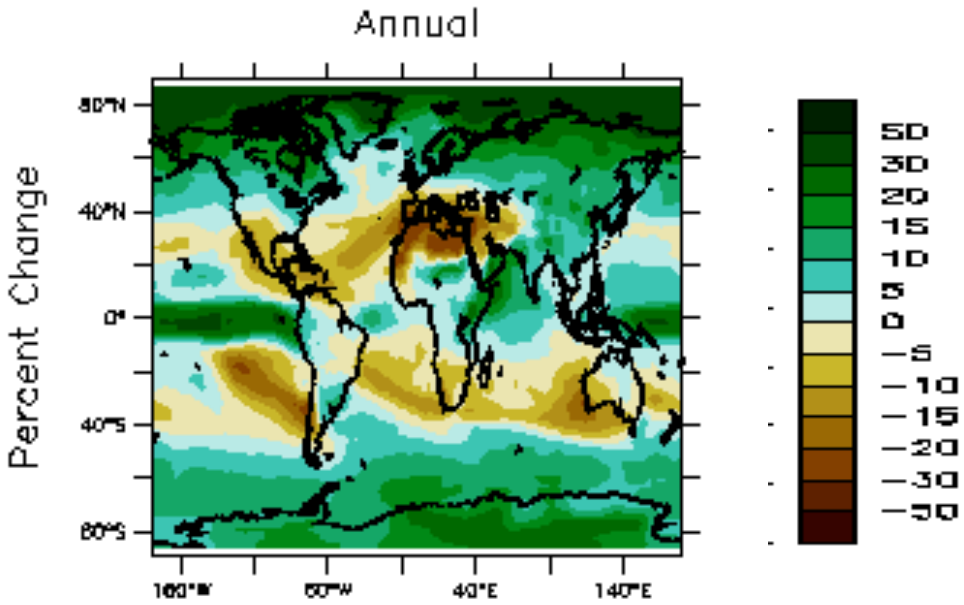


21st century A1B





20th century



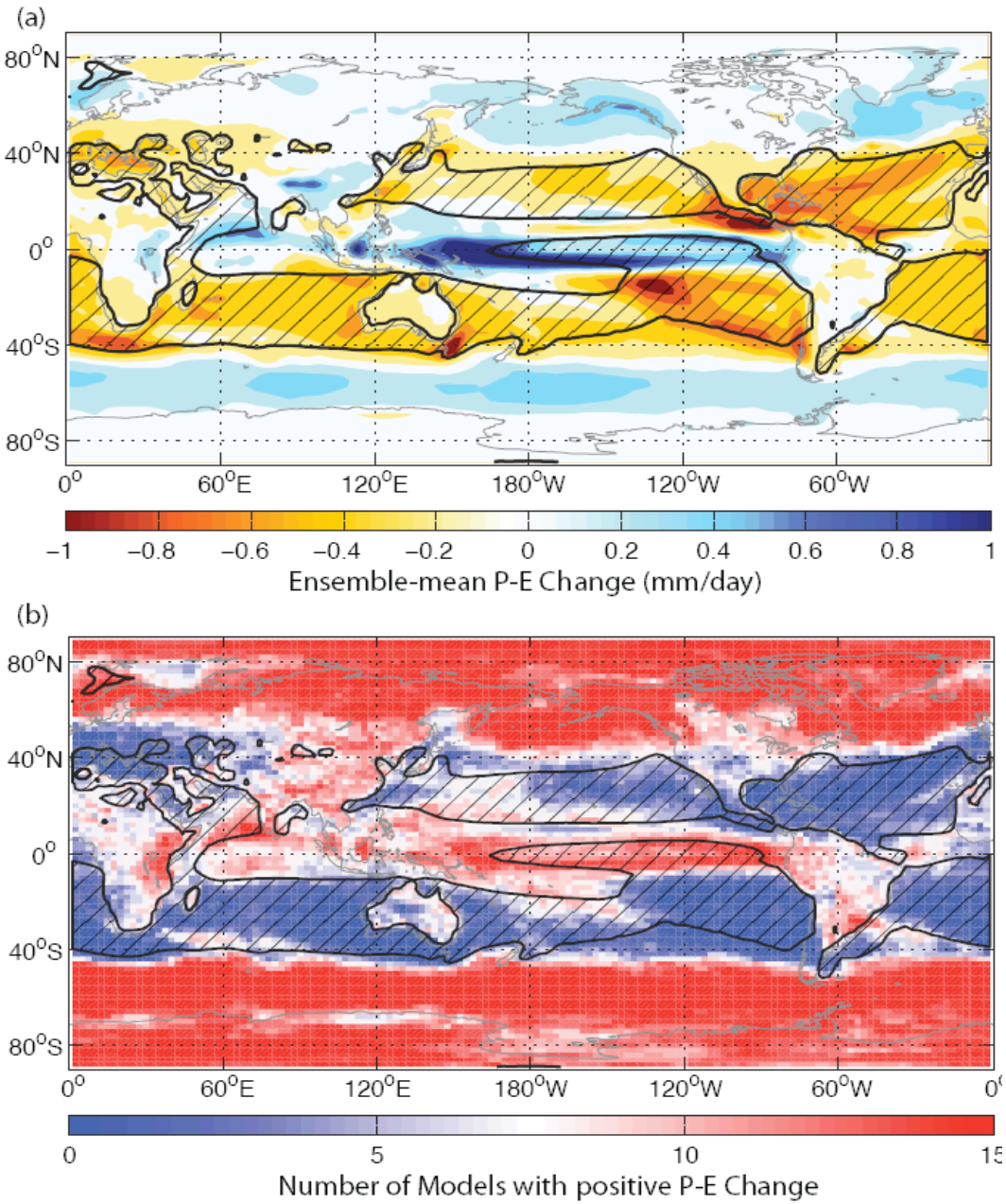
"the dry get drier and the wet get wetter"

the subtropics expand polewards

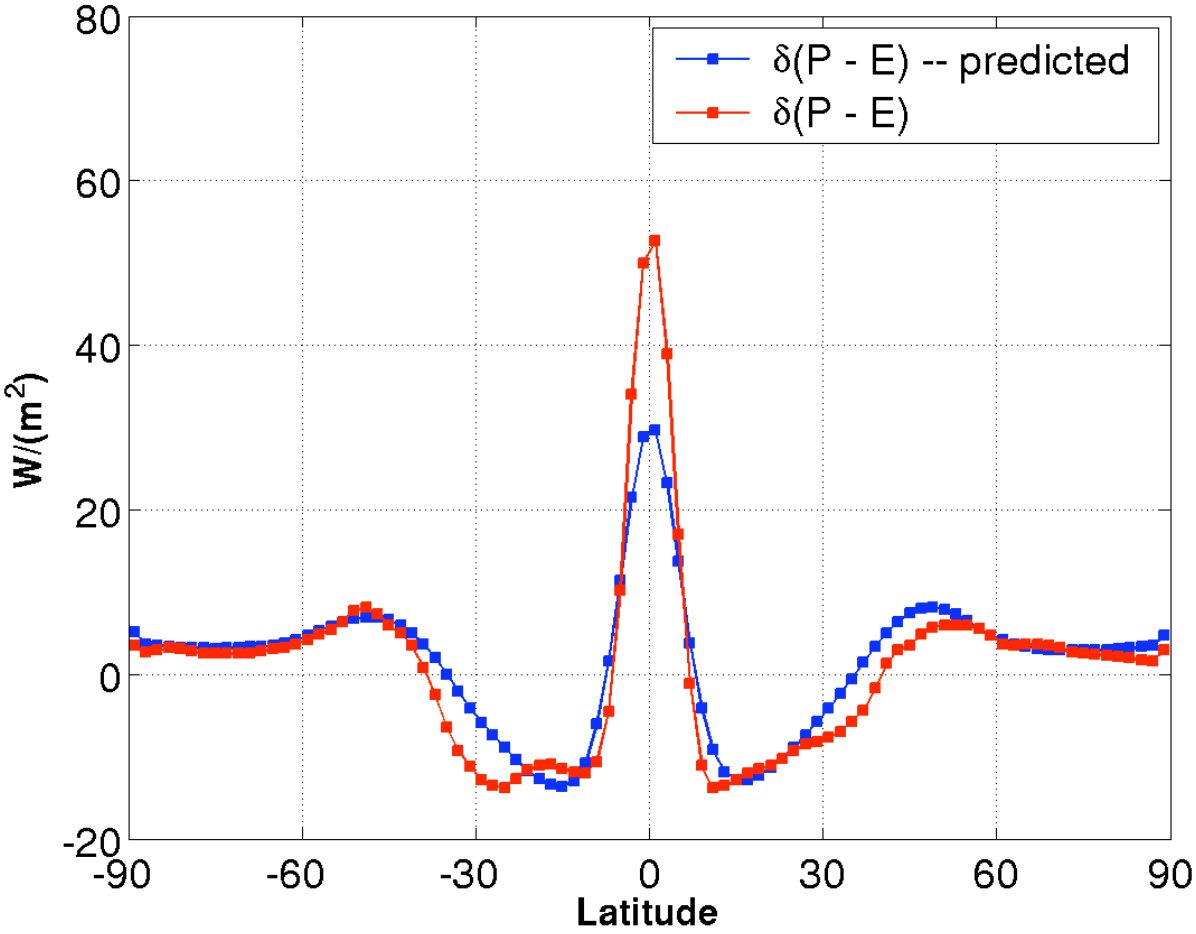
the tropical rain belts move towards the hemisphere that warms the fastest

Multi-model ensemble of δ(P-E)

- A2 scenario
- 15 models
- Annual mean
- Difference 2081_2100 minus 2001_2020



Lu, GRL, 2007



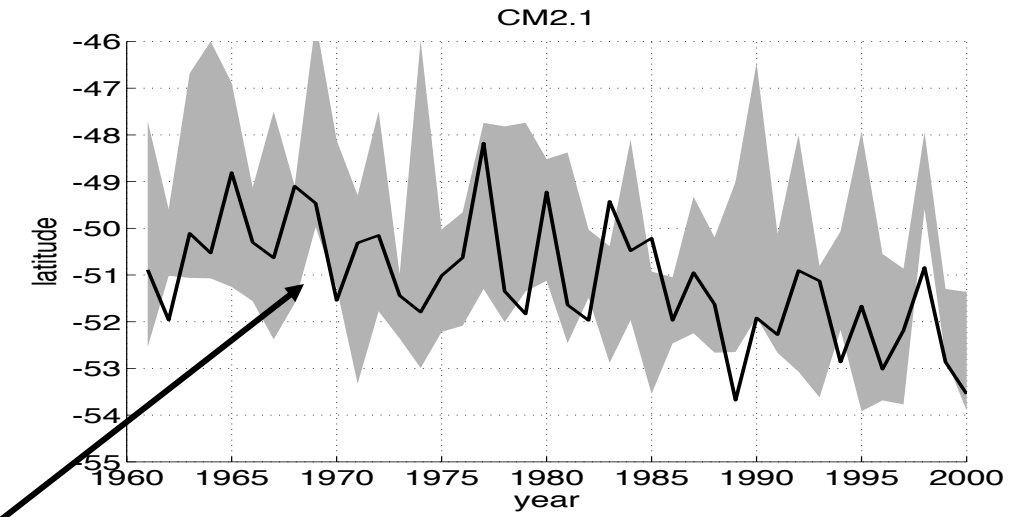
Prediction =>

assume moisture flux changes only due to change in mixing ratio, computed holding relative humidity fixed and using model's predicted temperature response

Latitude of maximum surface westerlies in Southern Hemisphere

Ensemble of climate model runs

"Roaring 40's" are moving polewards



noaaresearch

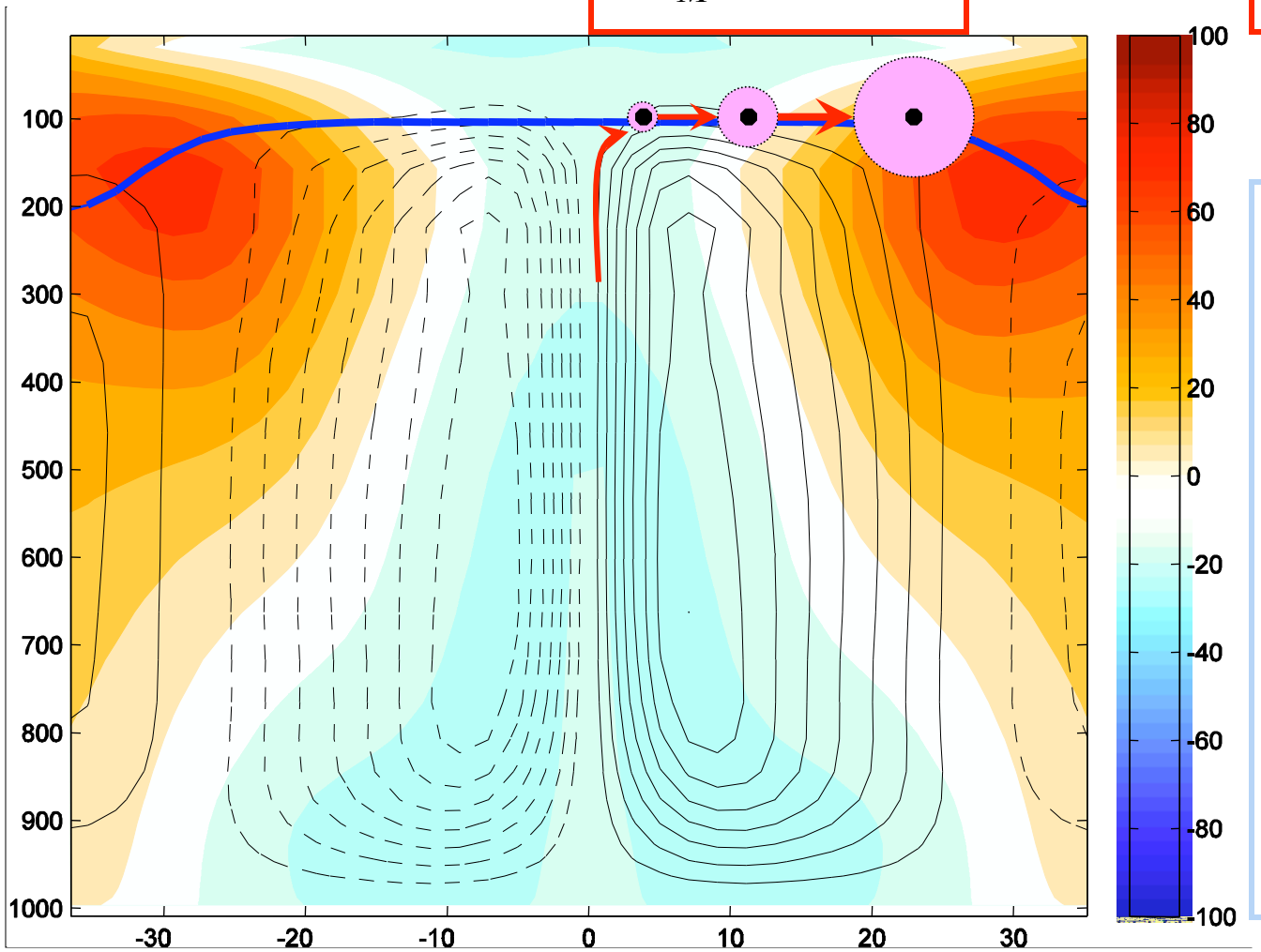
observations

Held (2000)

$$U_M \approx \Omega a \theta^2$$

=

$$U_1 = \frac{N^2 H^2}{2\Omega a} \frac{\cos\theta}{\sin^2\theta}$$



$$U_1 - U_2 \approx \beta \lambda^2$$

where

$$\lambda^2 = \frac{g^* H}{f^2} = \frac{N^2 H^2}{f^2}$$

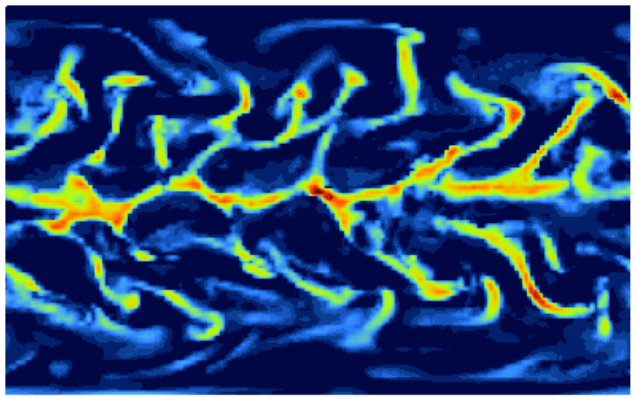
$$g^* = \frac{\Theta_2 - \Theta_1}{\Theta_0} g = N^2 H$$

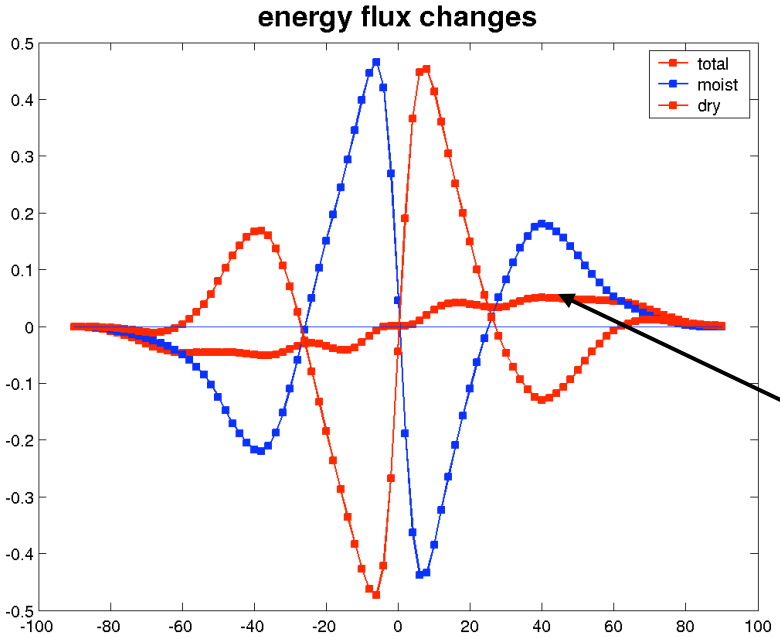
Δ_V gross stability

Aqua mixed layer AM2

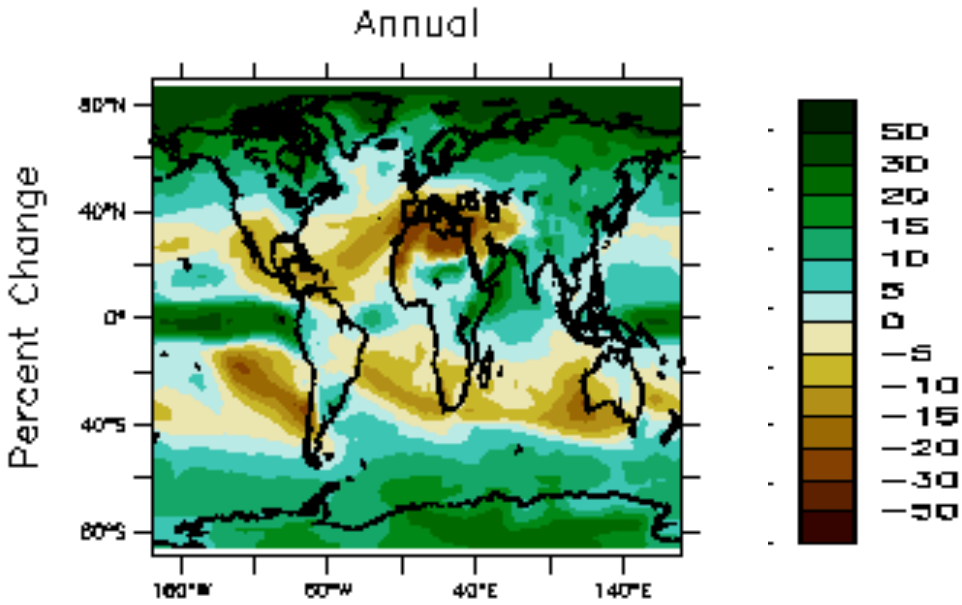
Poleward energy flux
Response to doubling CO_2

Latent ↑ Sensible ↓





Total flux increases slightly



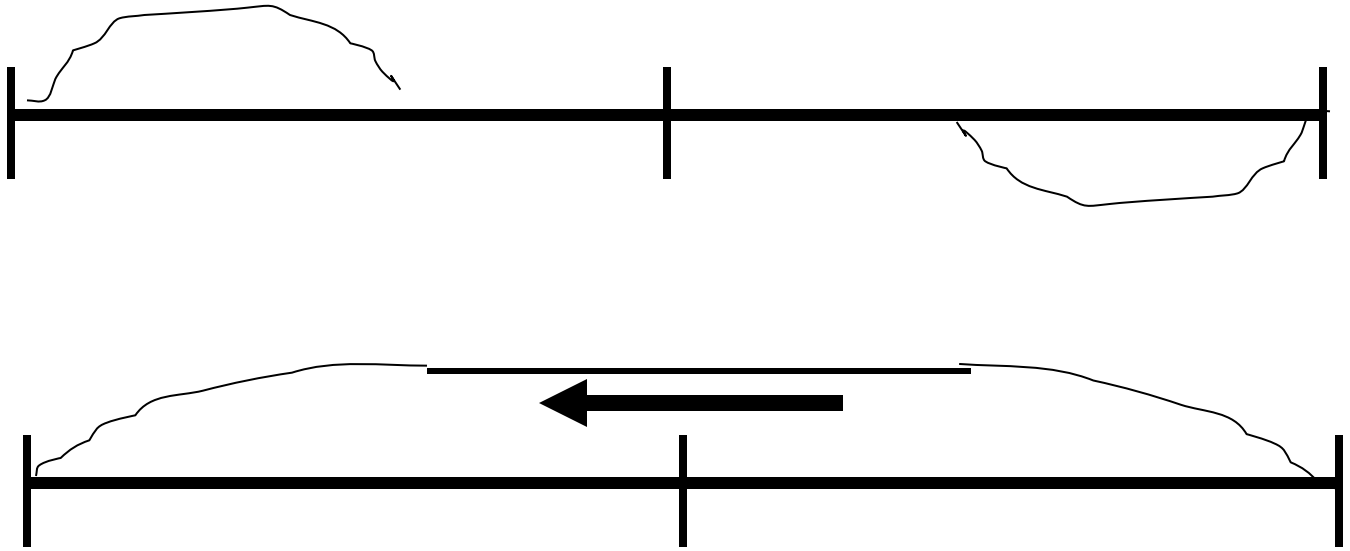
“the dry get drier and the wet get wetter”

the semi-arid subtropics expand polewards

the tropical rain belts move towards
the hemisphere that warms the fastest

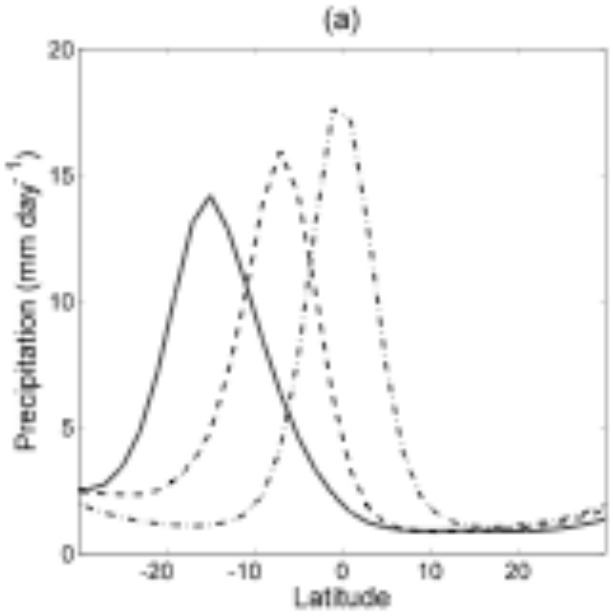
Sarah Kang, Princeton

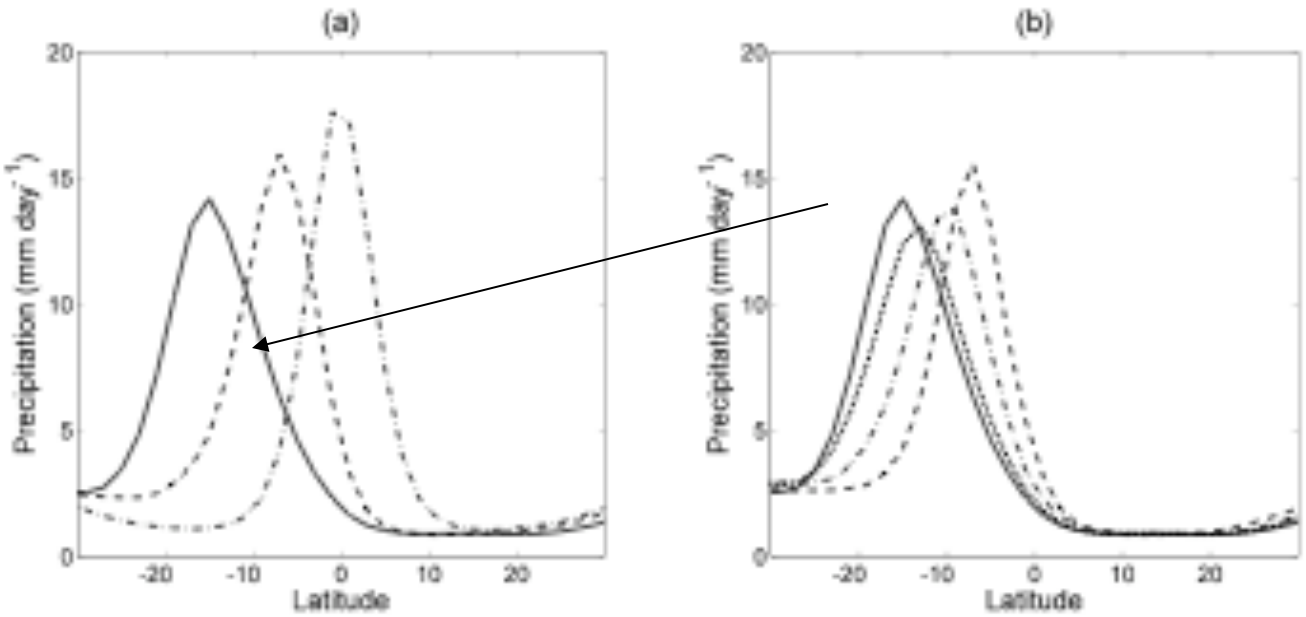
Aqua planet/slab ocean



Model A: Frierson et al 2006 -- idealized moist GCM
(no clouds -- water water vapor feedback)

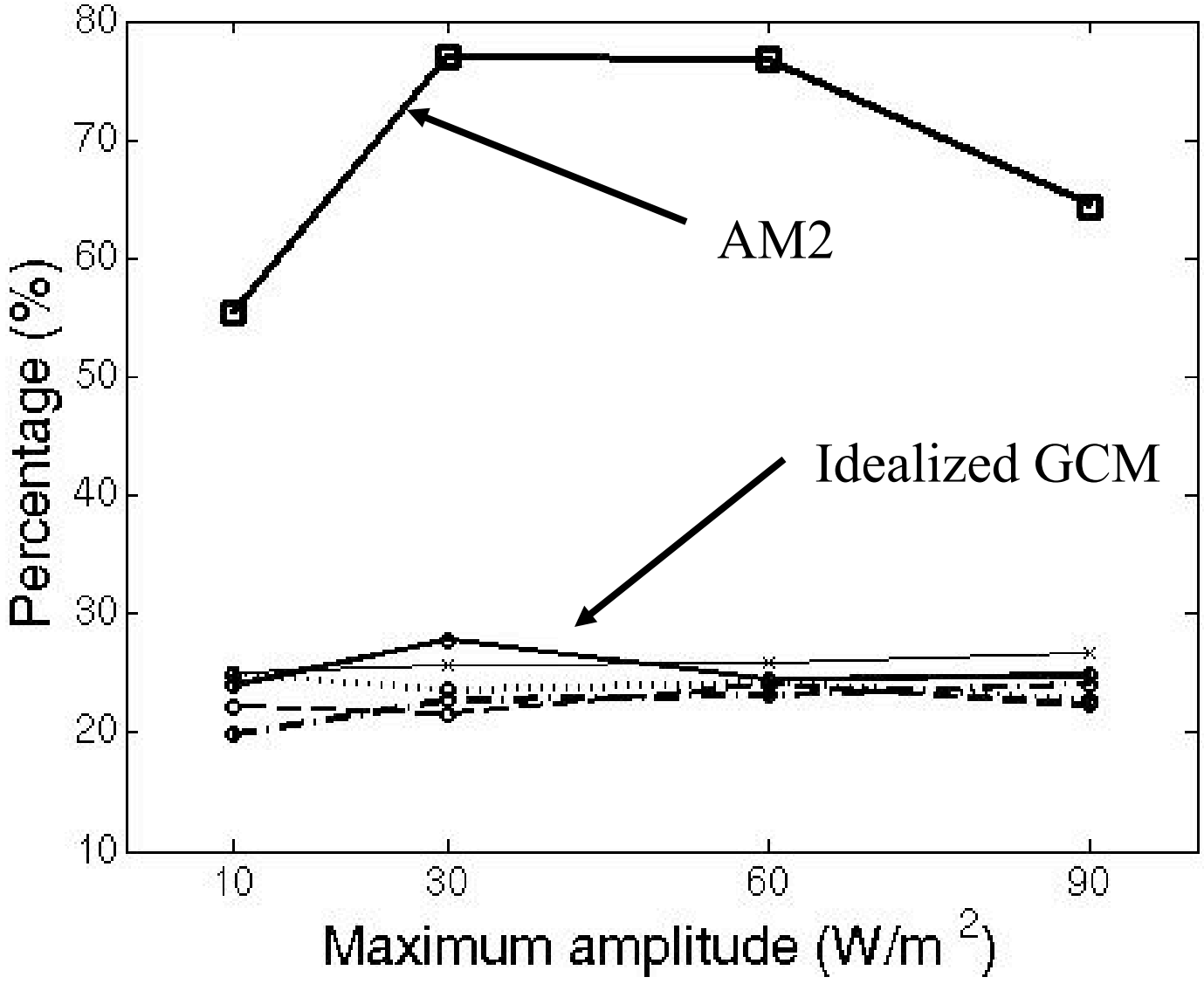
Model B: AM2

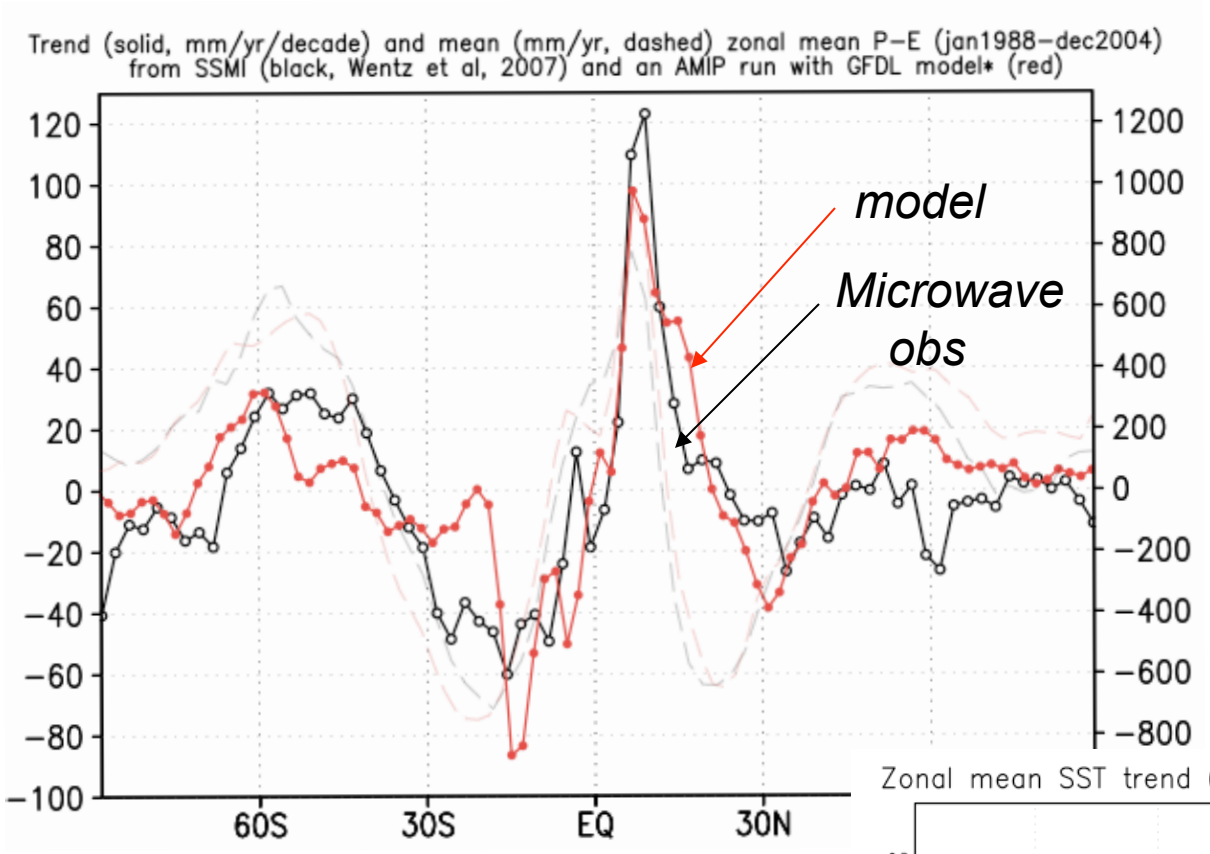

(a)
Precipitation (mm day^{-1})
20
15
10
5
0
-20
-10
0
10
20
Latitude



Changing a parameter in the convection scheme

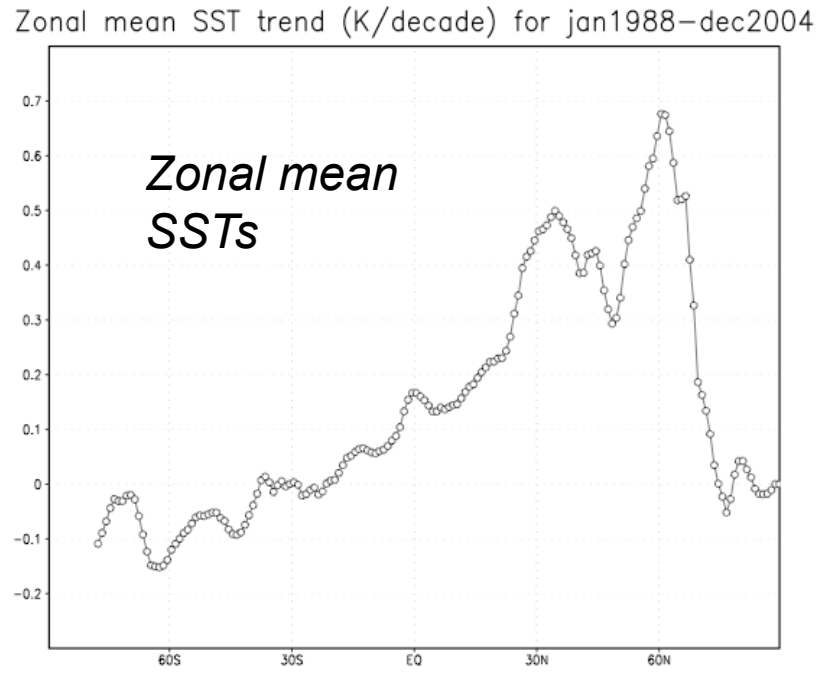
Compensation at equator



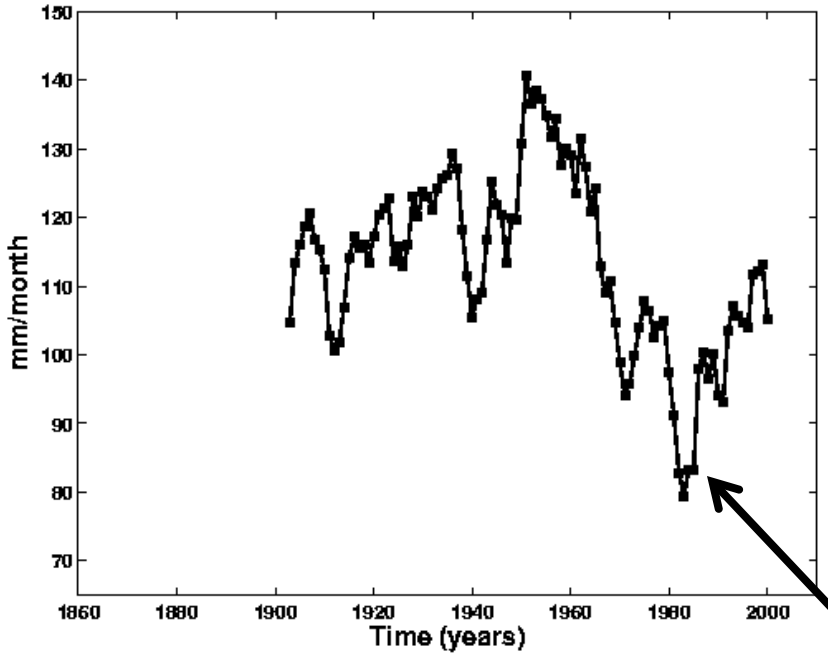


Zonal mean P - E

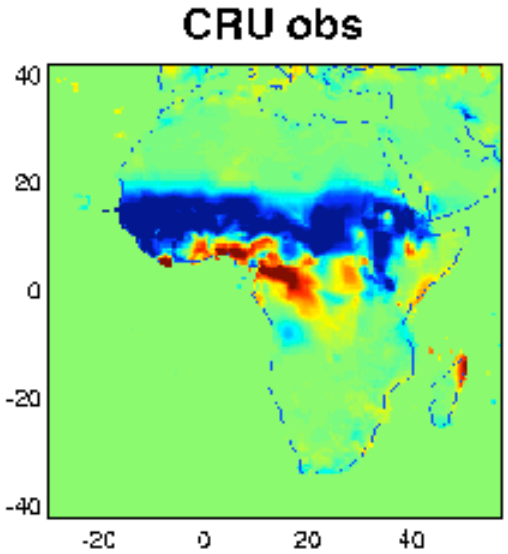
1988-2004 trends



Observed (CRU) summertime precipitation
in Sahel (4yr running mean)

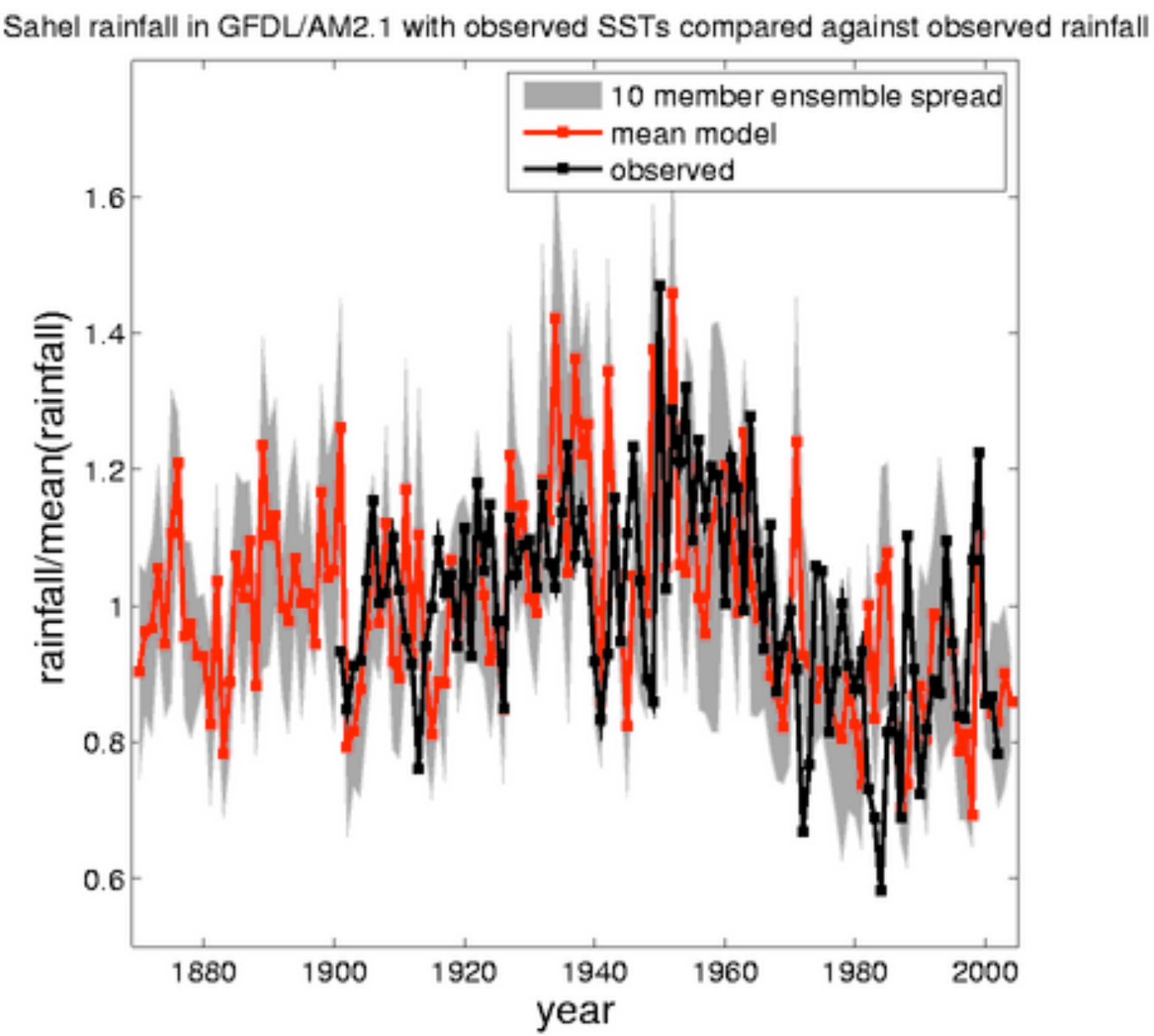


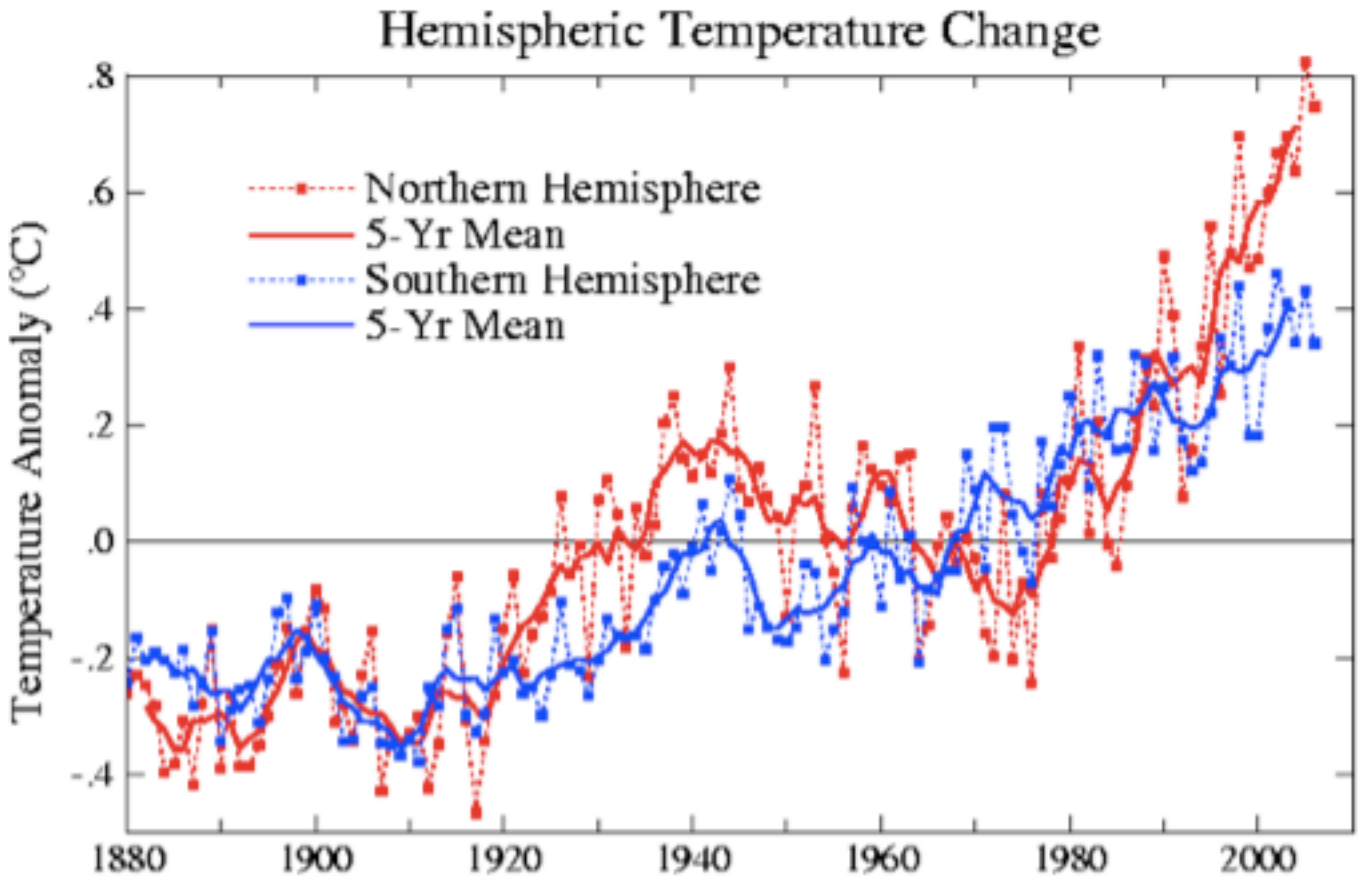
2000-1980 Minus 1960-1940

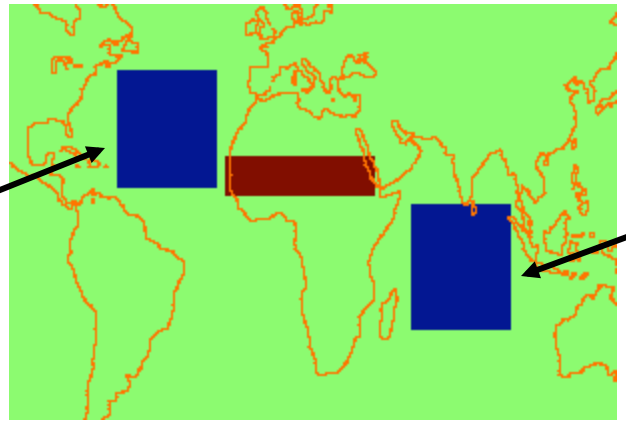


Severe drought in 70s-80s

noaa research


Sahel rainfall in GFDL/AM2.1 with observed SSTs compared against observed rainfall
10 member ensemble spread
mean model
observed
rainfall/mean(rainfall)
1.6
1.4
1.2
1
0.8
0.6
1880
1900
1920
1940
1960
1980
2000
year


Hemispheric Temperature Change
Temperature Anomaly (°C)
.8
.6
.4
.2
.0
-.2
-.4
1880
1900
1920
1940
1960
1980
2000
Northern Hemisphere
5-Yr Mean
Southern Hemisphere
5-Yr Mean



Regress: P(%) = I * Ind + N * NA

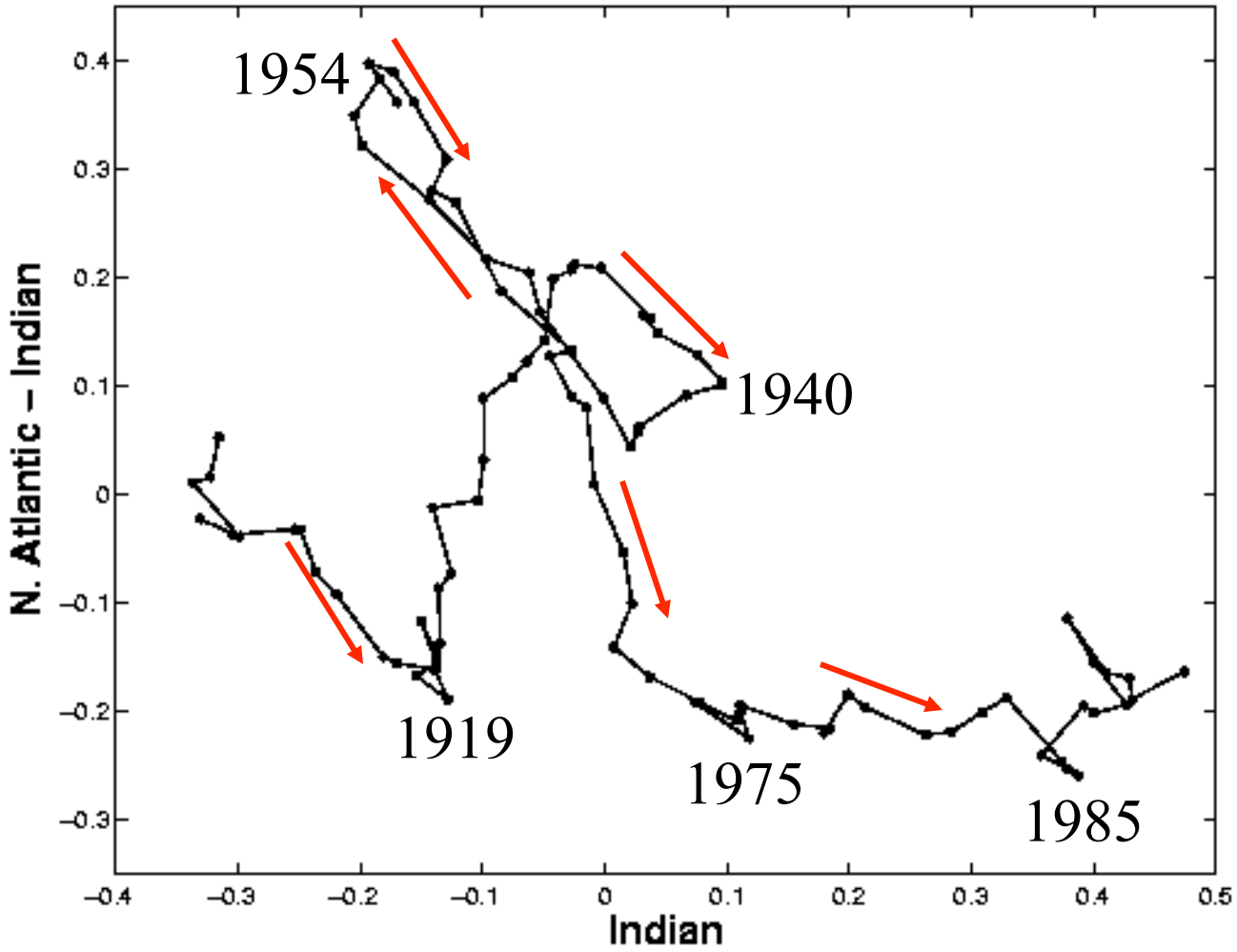
= U * Ind + N * (NA – Ind)

(U = I – N)

Ind => Stabilization of troposphere?

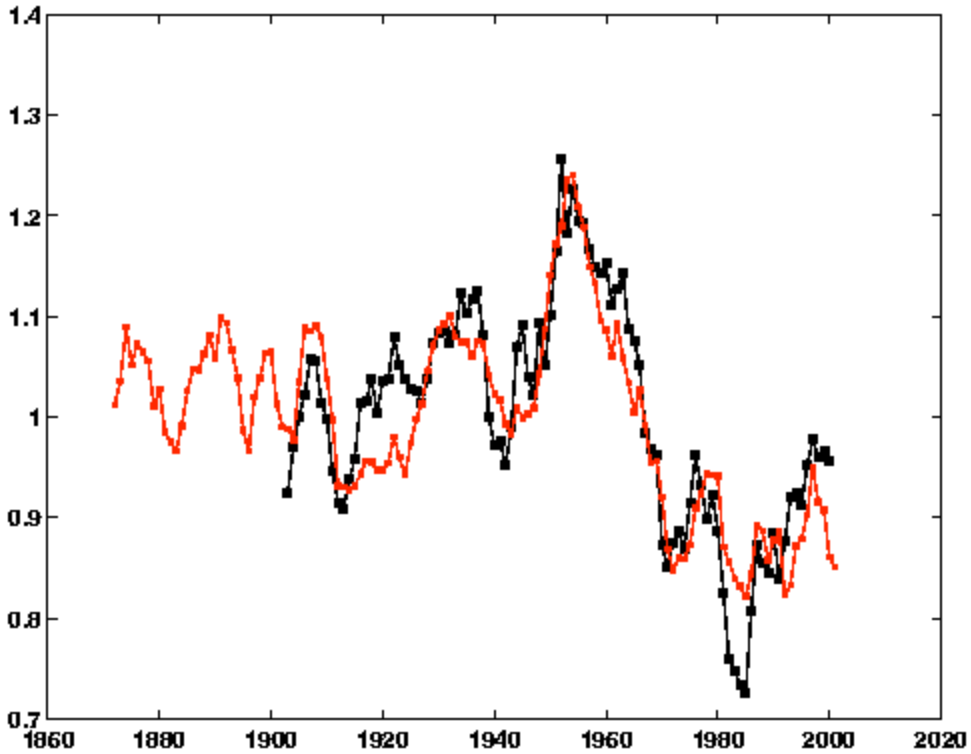
NA => ITCZ displacement? Moisture supply?

Observed evolution of Ind and NA - Ind, 11yr running means

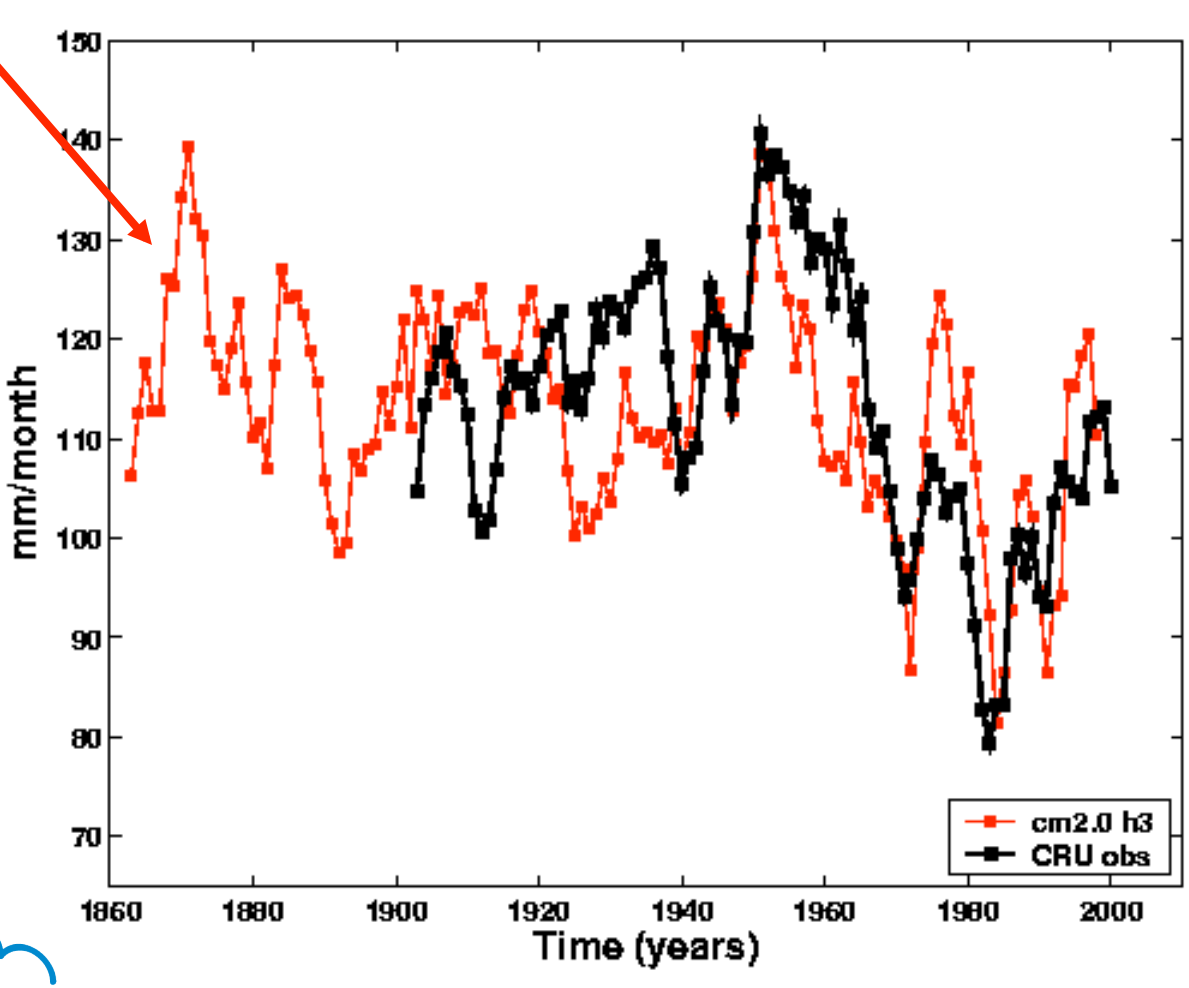


Regressing observed rainfall vs observed Ind and NA =>

$$P = -0.12\ \mathrm{Ind} + 0.38\ (\mathrm{NA} - \mathrm{Ind})$$



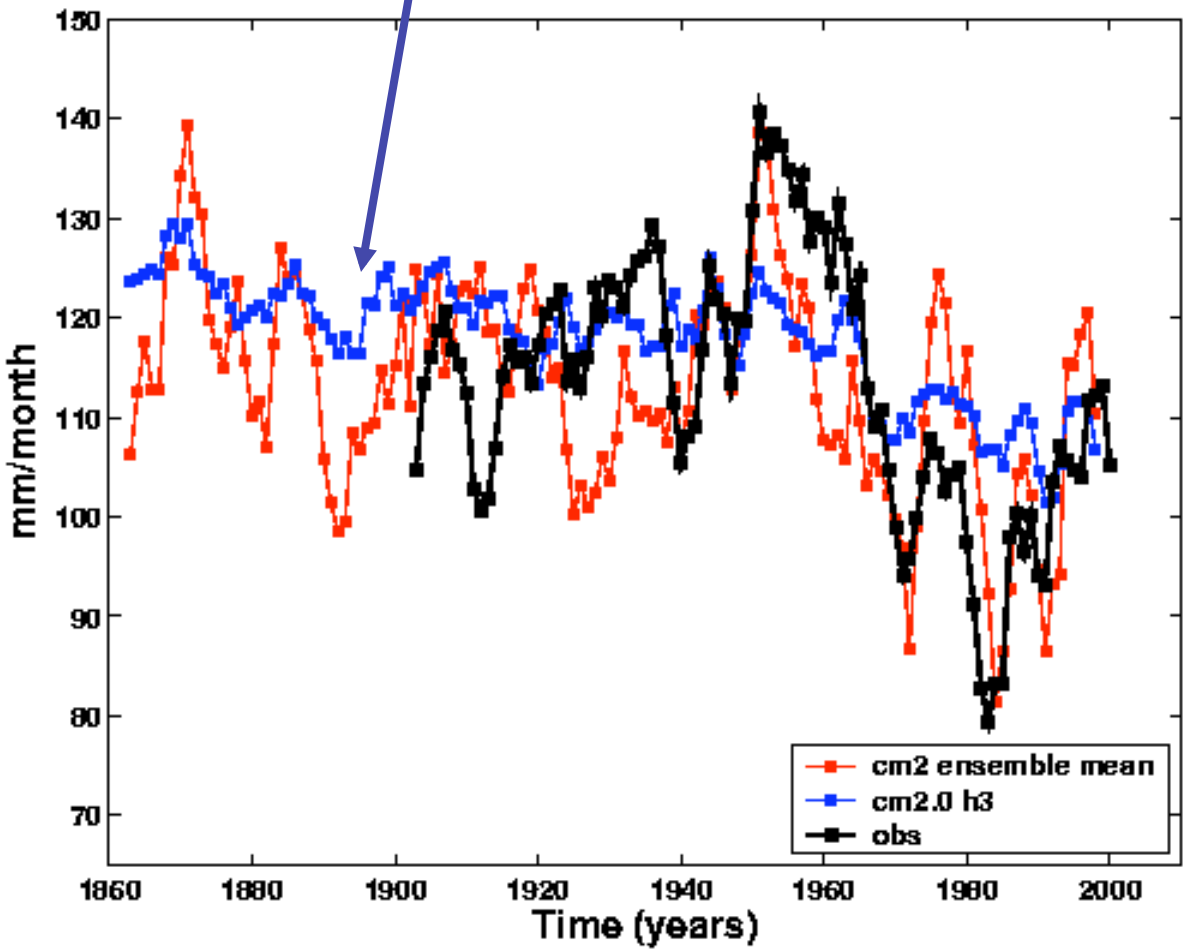
Single realization of CM2
(greenhouse gases; aerosols, solar, volcanoes, land use)



noaaresearch

Geophysical Fluid Dynamics Laboratory
GFDL
NOAA

Mean of 8-member ensemble



noaaresearch

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NOAA

Regressing observed rainfall vs observed Ind and NA =>

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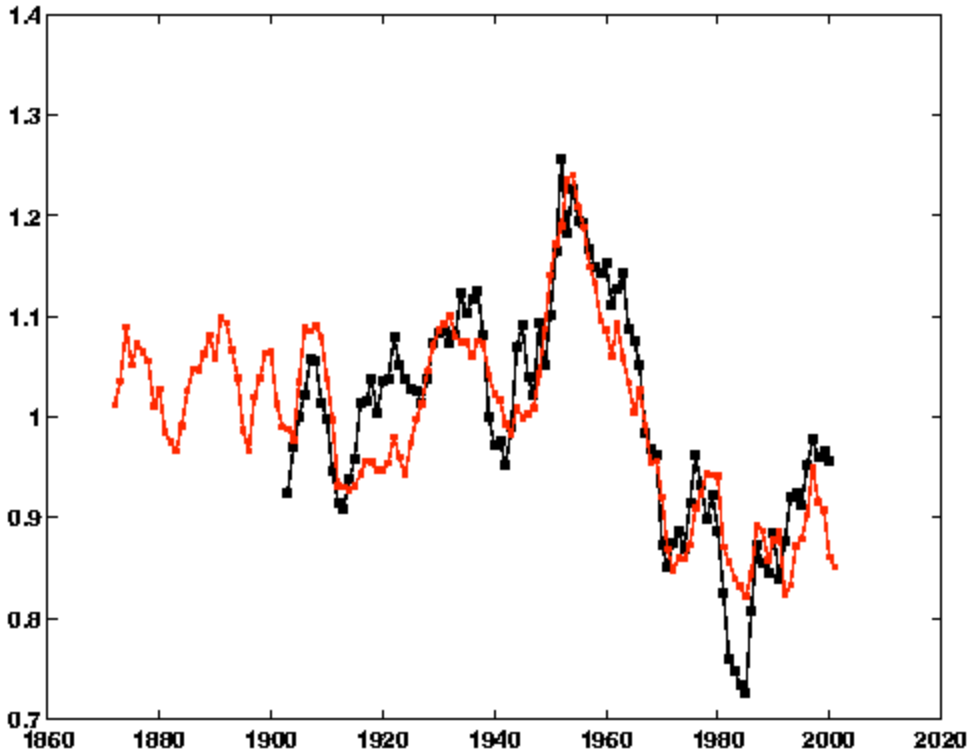
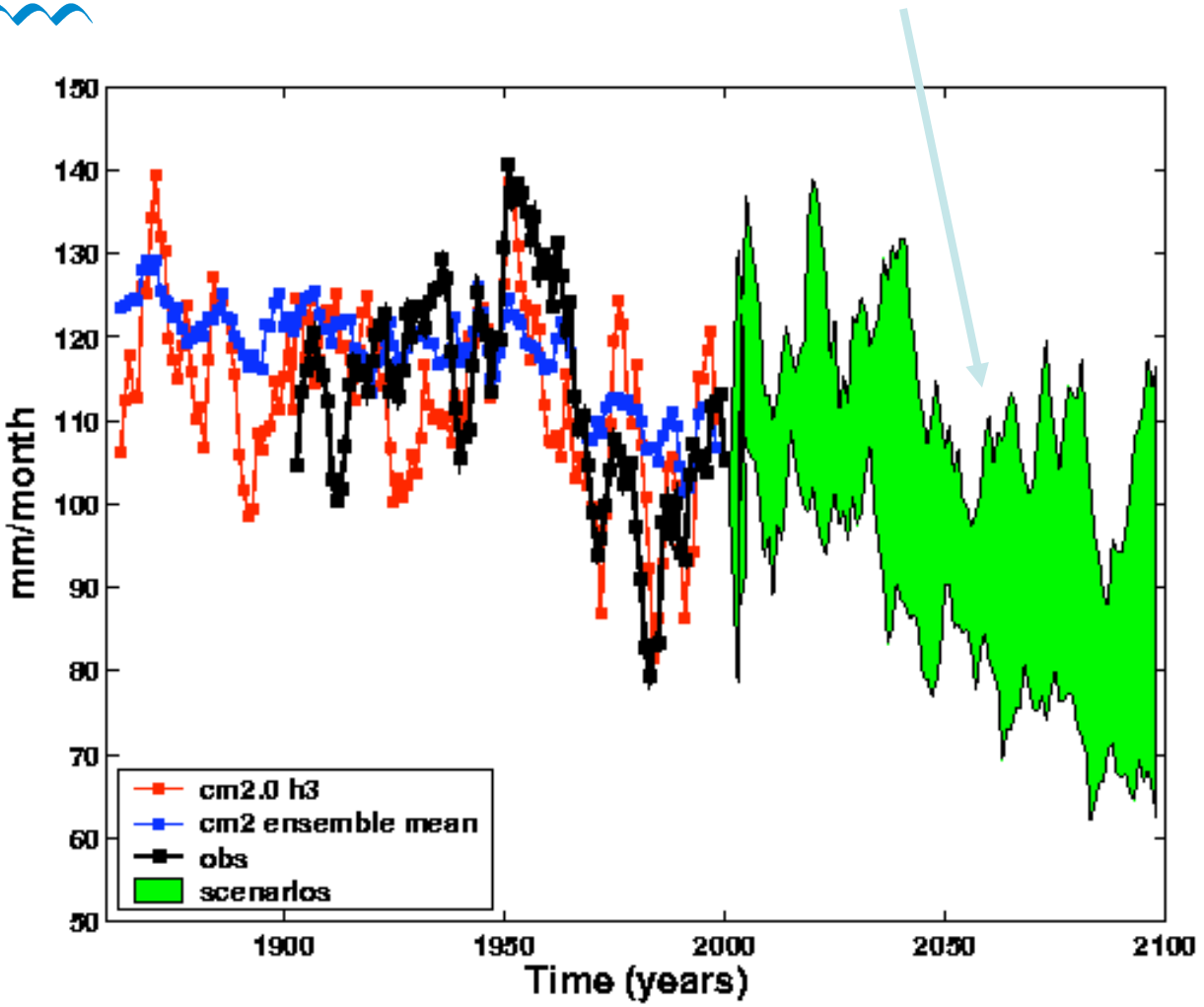
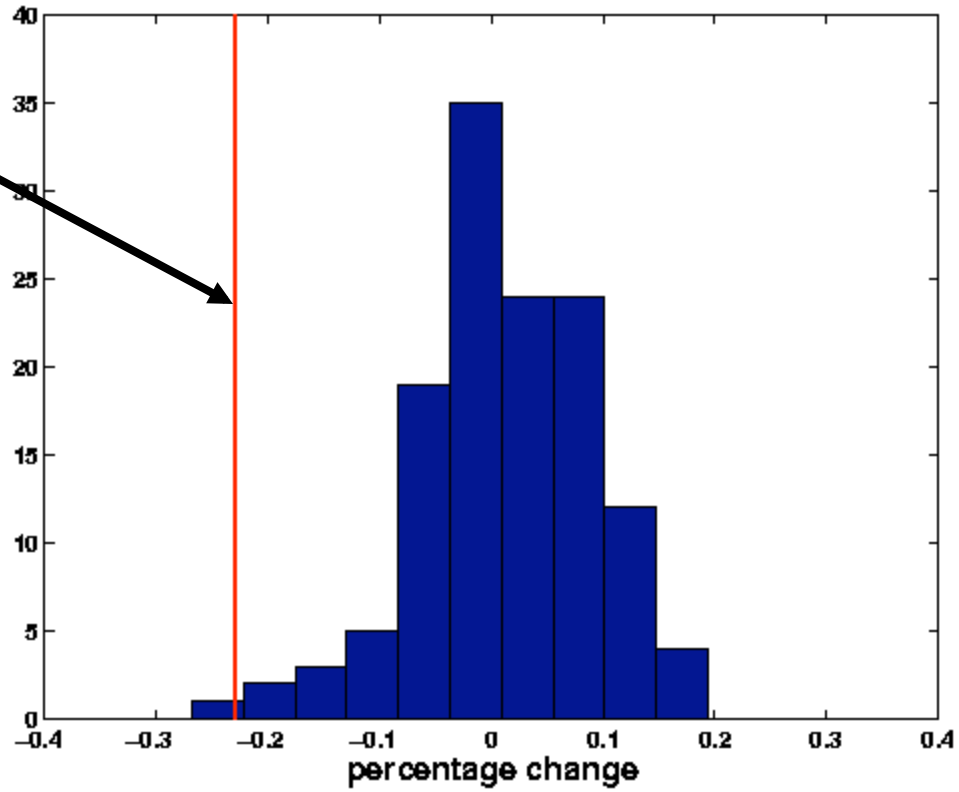


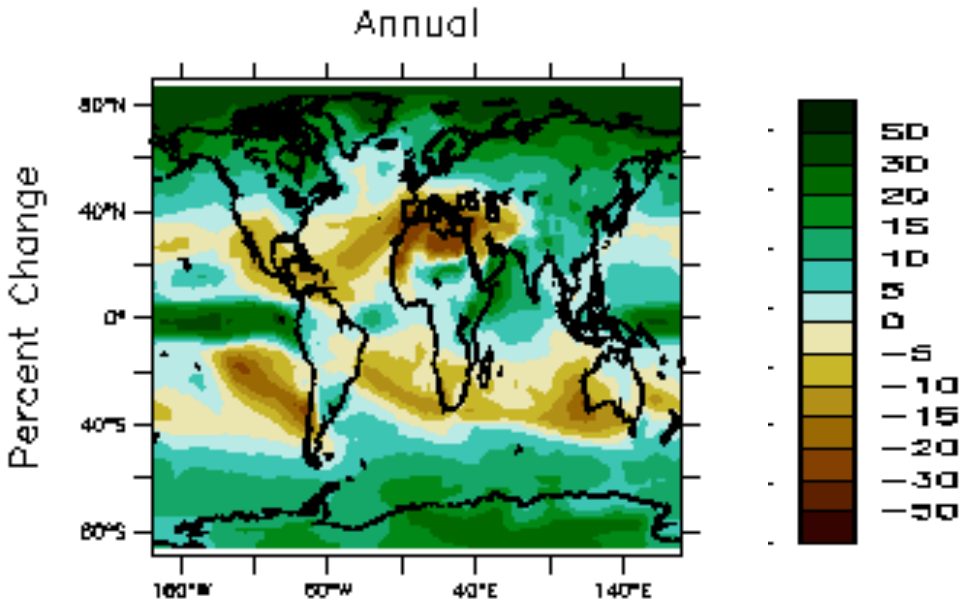
Range of SRES scenarios



QUMP: 129 different mixed layer models
(courtesy of Matthew Collins, Hadley Center)
% Sahel precip response to 2xCO2

CM2.0





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