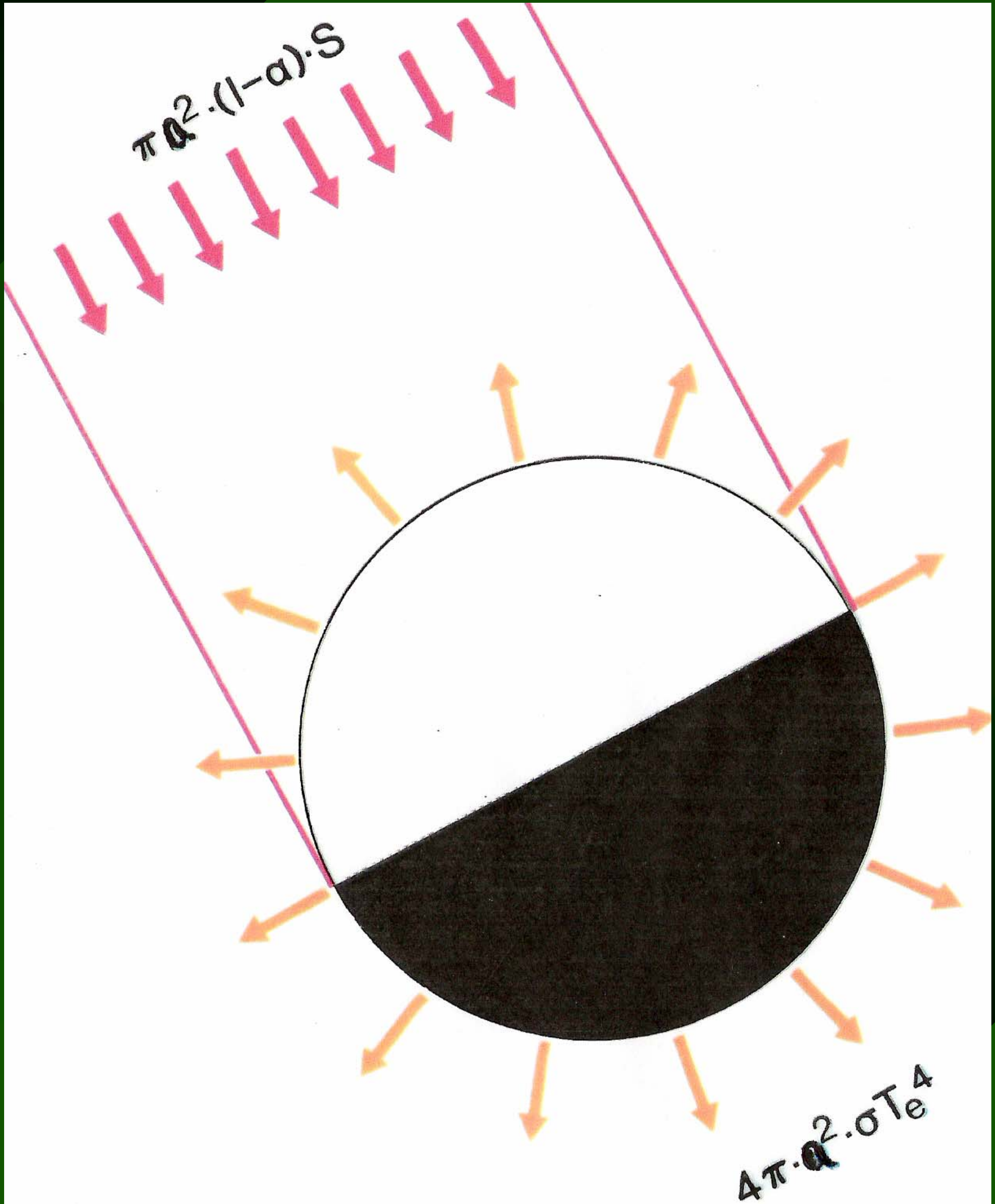
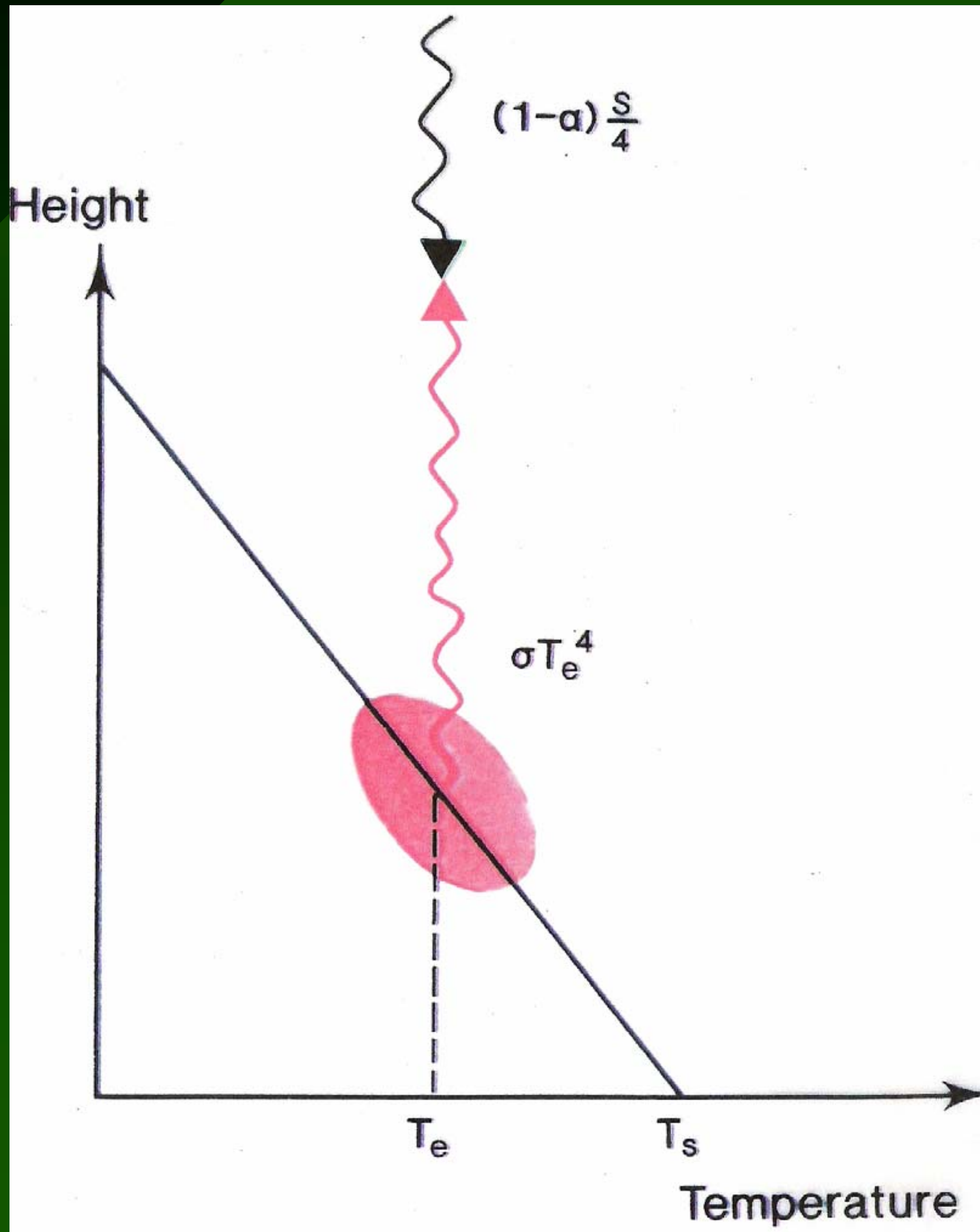
Global Change in Water Availability

How are river discharge and soil moisture going to change as global warming proceeds?

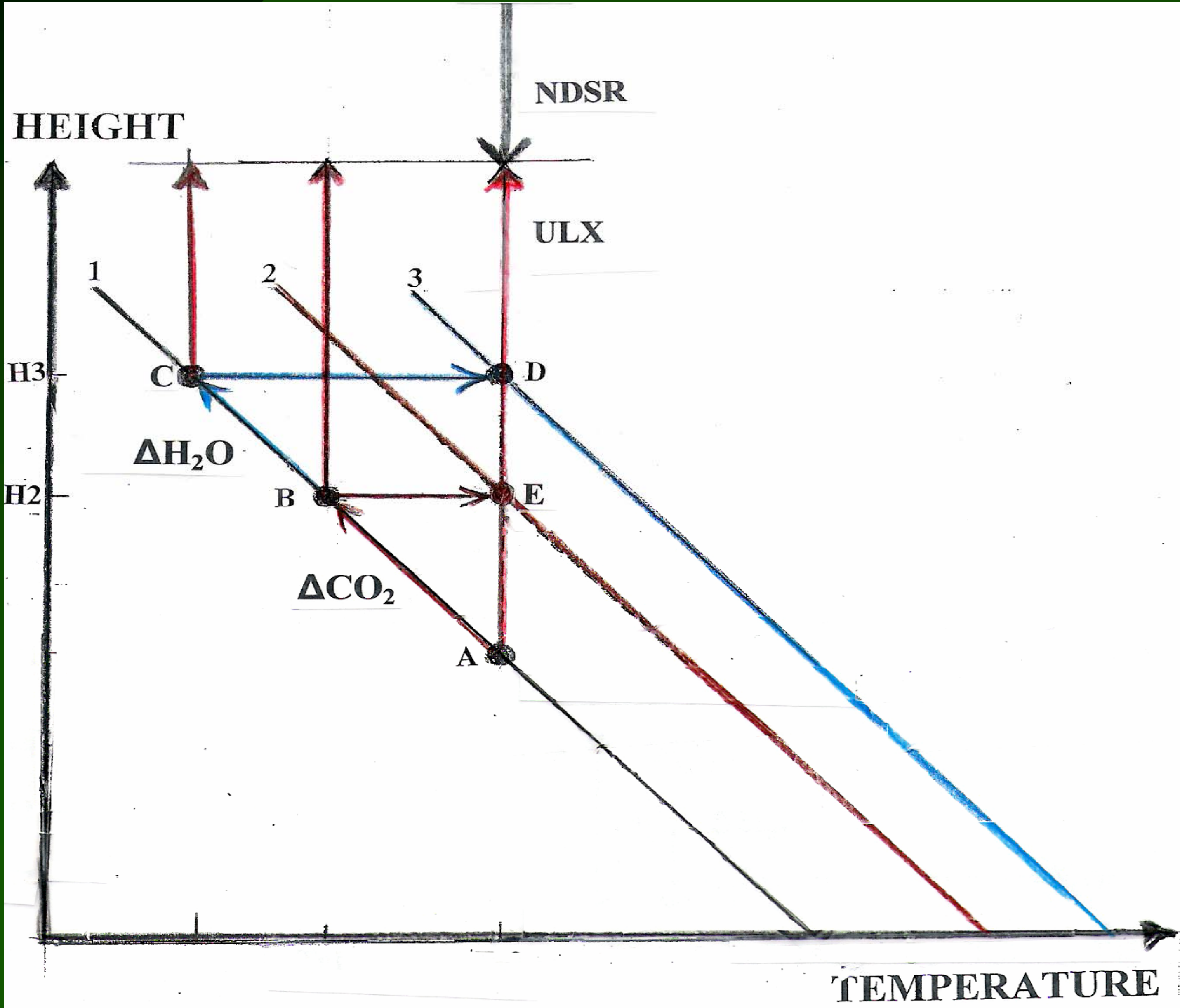
Radiation Budget of a Planet



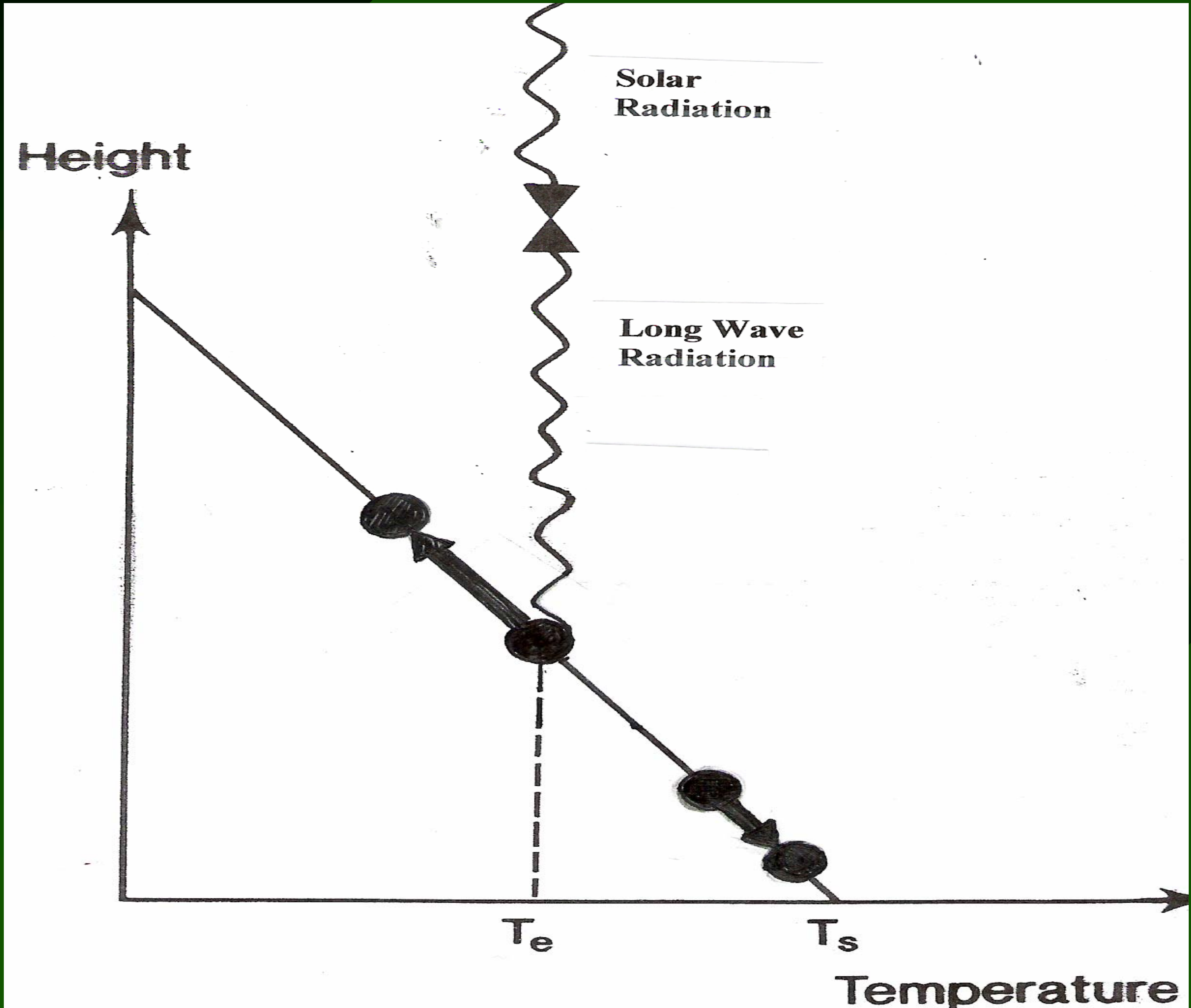
Greenhouse Effect of the Atmosphere



Water Vapor Feedback



CO_2-Induced Change in Effective Emission Source



Change in Surface Heat Budget →Change in Evaporation Rate

Surface Heat Balance:

NDSX = (ULX – DLX) + SH + LH

CO_2-Induced Heat Gain:

$\Delta_{CO2}Q = \partial(ULX - DLX)/\partial Ts + \partial(SH)/\partial Ts + \partial(LH)/\partial Ts,$

$\partial(UX - DX)/\partial Ts$; Small

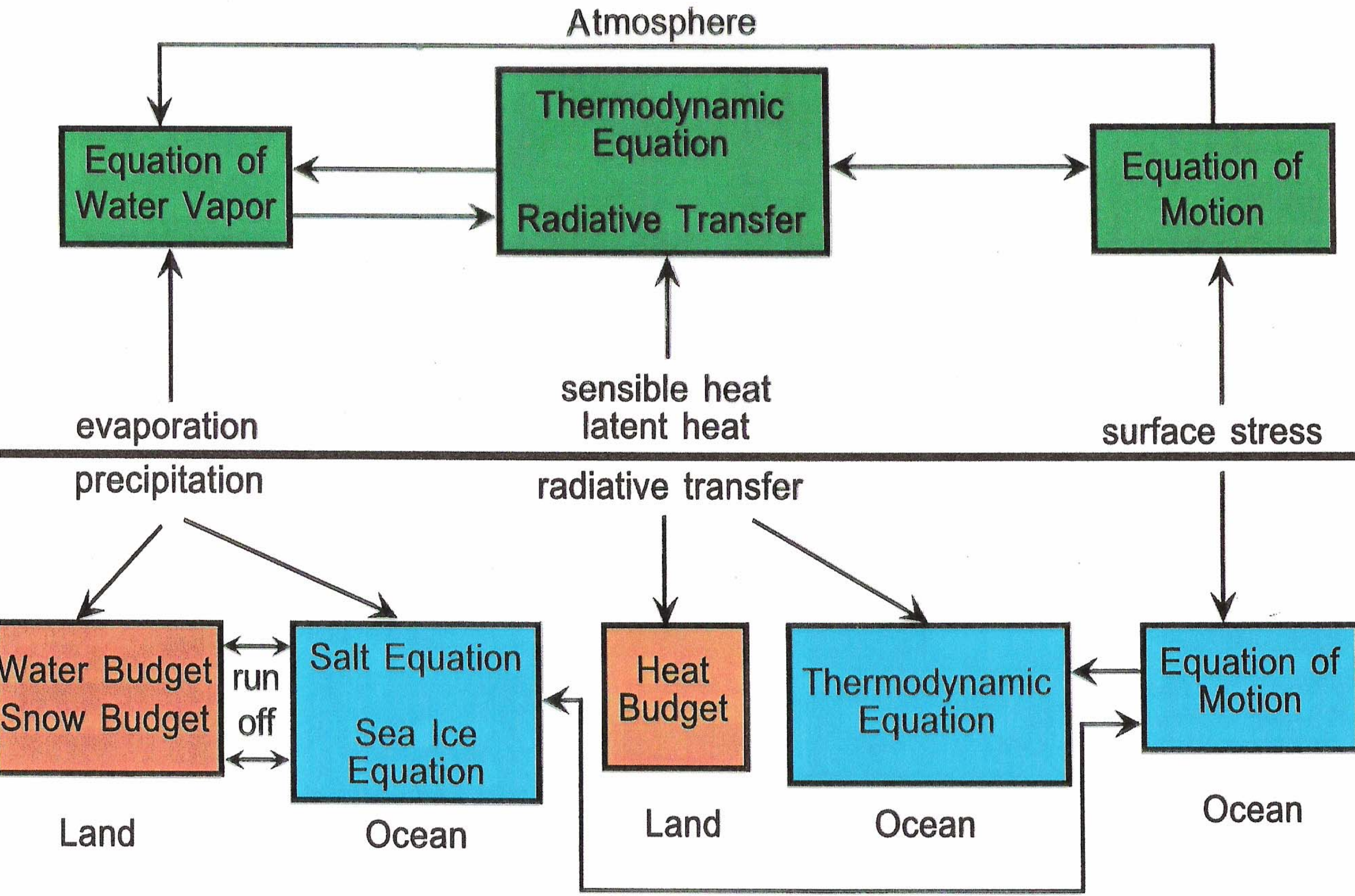
$\Delta_{CO2}Q \sim \partial(SH)/\partial Ts + \partial(LH)/\partial Ts$

$\sim \partial(LH)/\partial Ts$

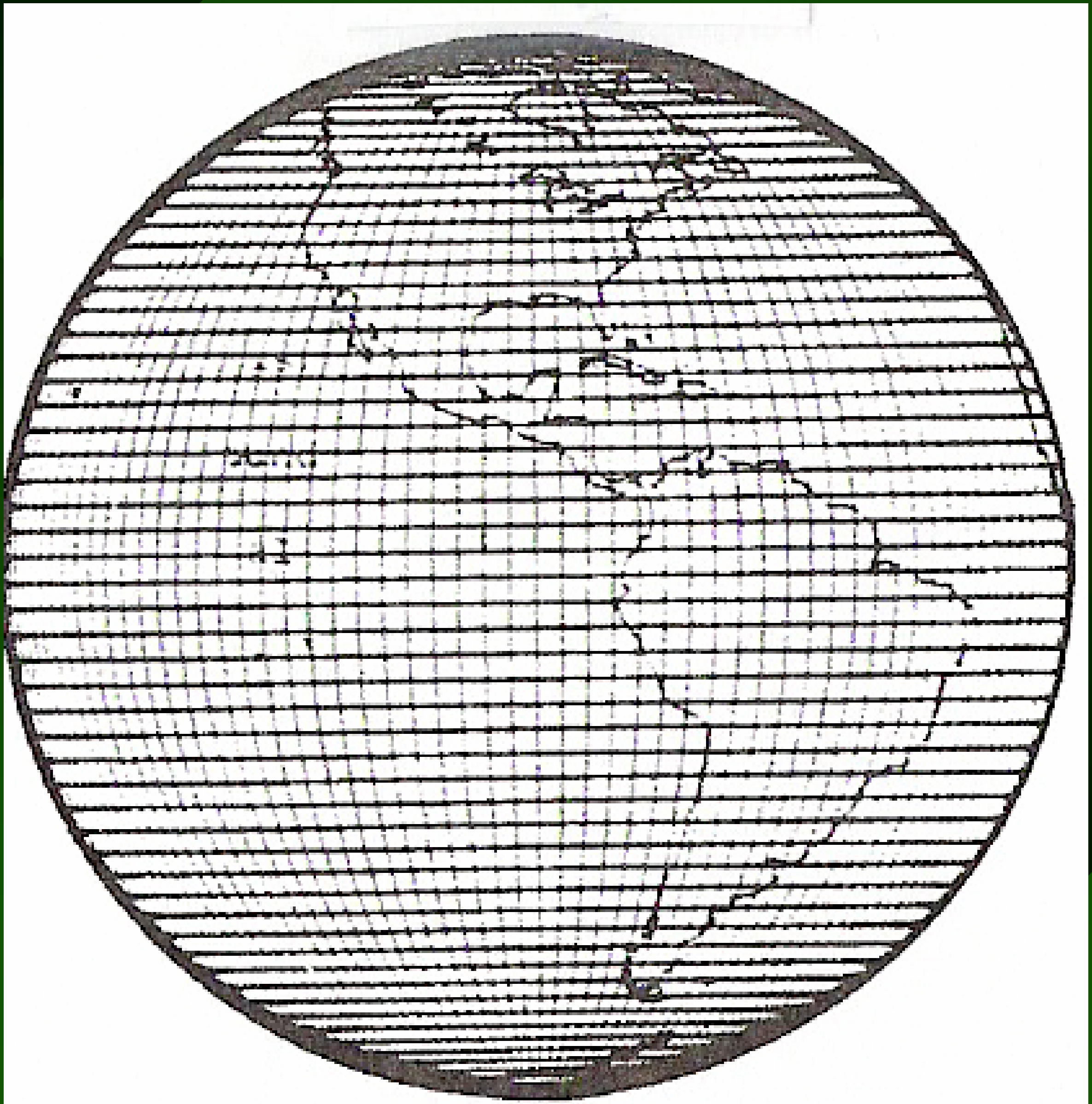
$= L \bullet \partial(E)/\partial Ts]$

→ Intensification of hydrologic cycle

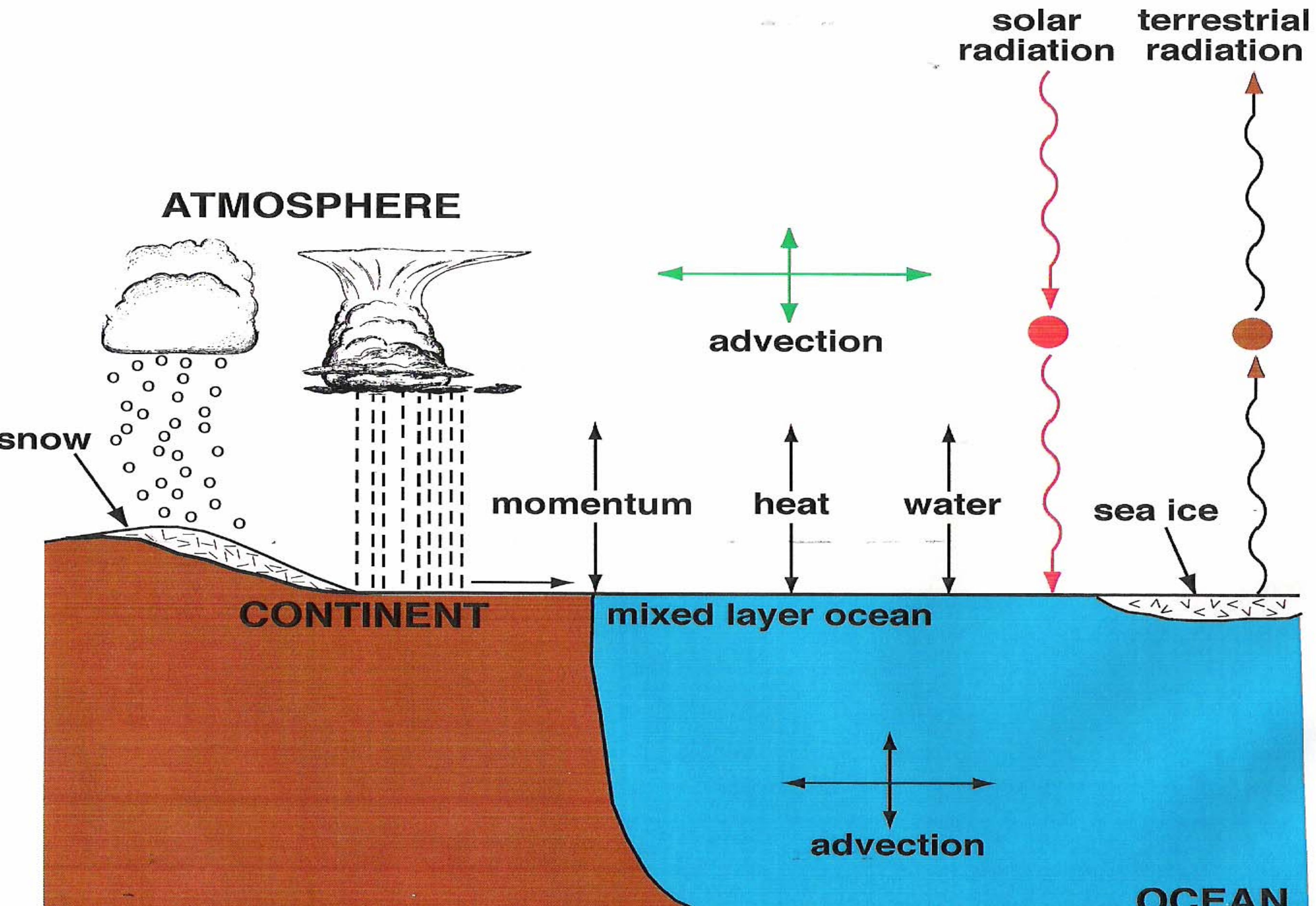
Coupled Ocean-Atmosphere-Land Model



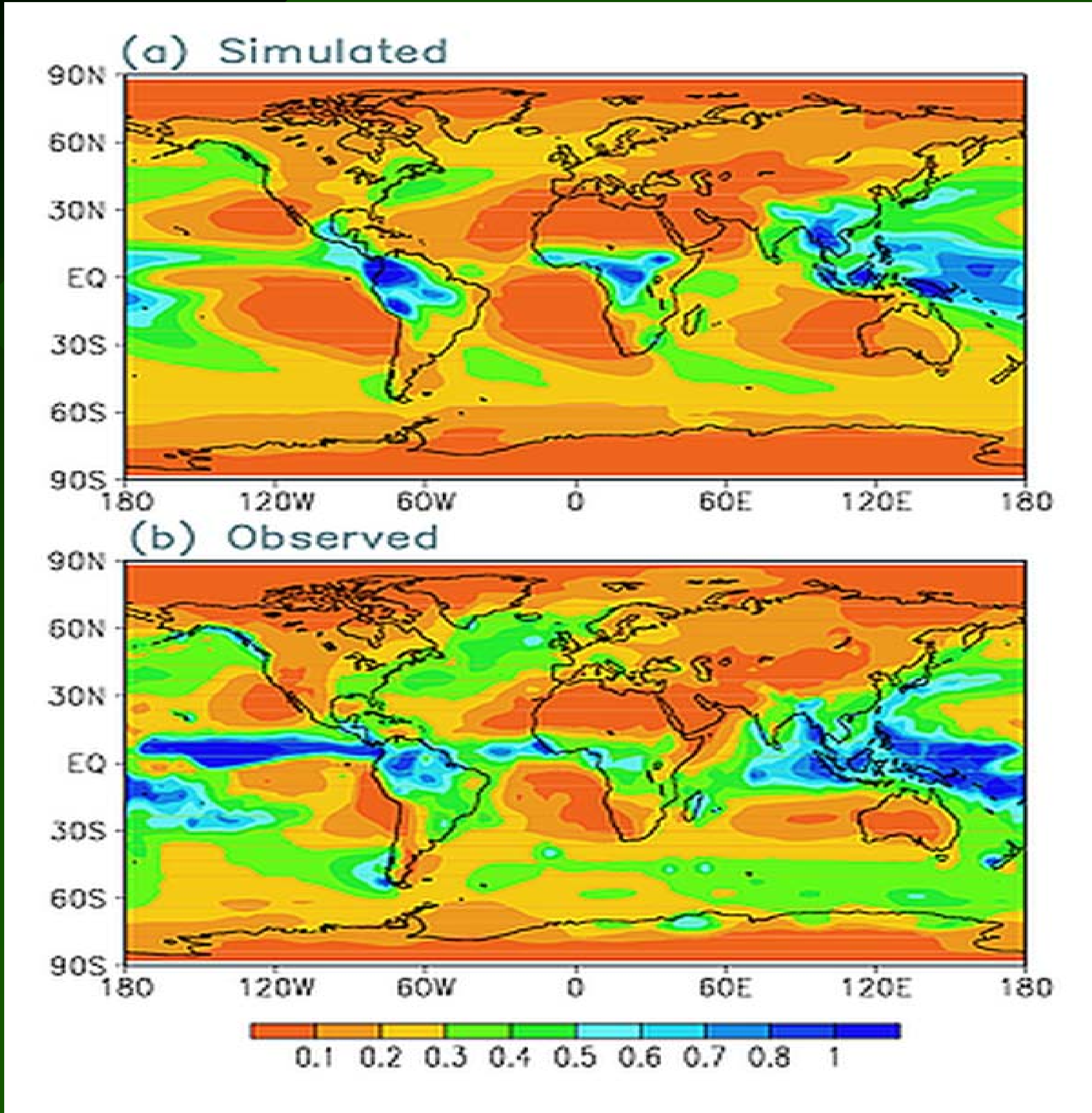
Global Grid System



Physical Processes in a Model



Annual Mean Precipitation, cm/day



Numerical Experiments

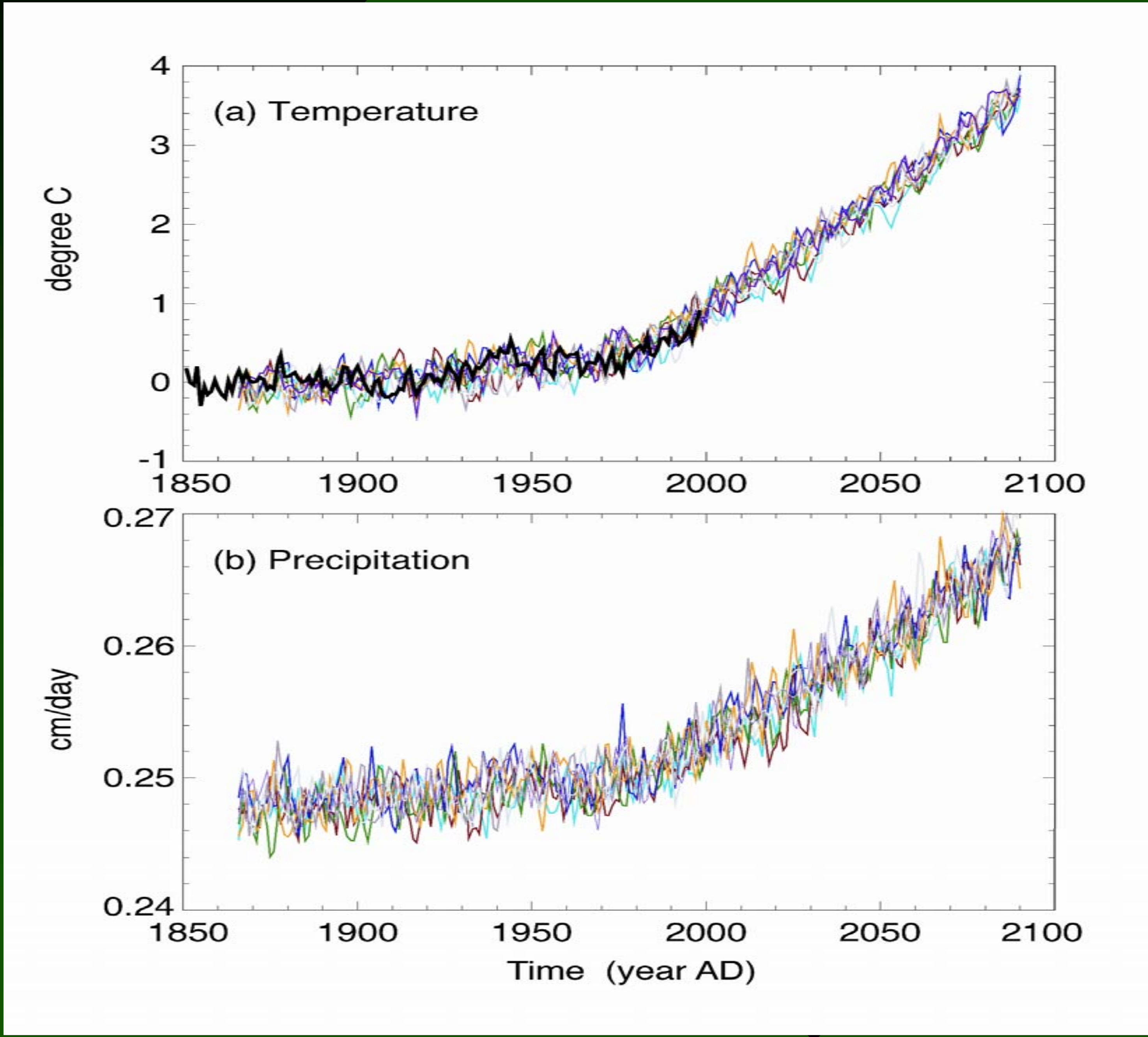
- **Eight Global Warming Experiments**

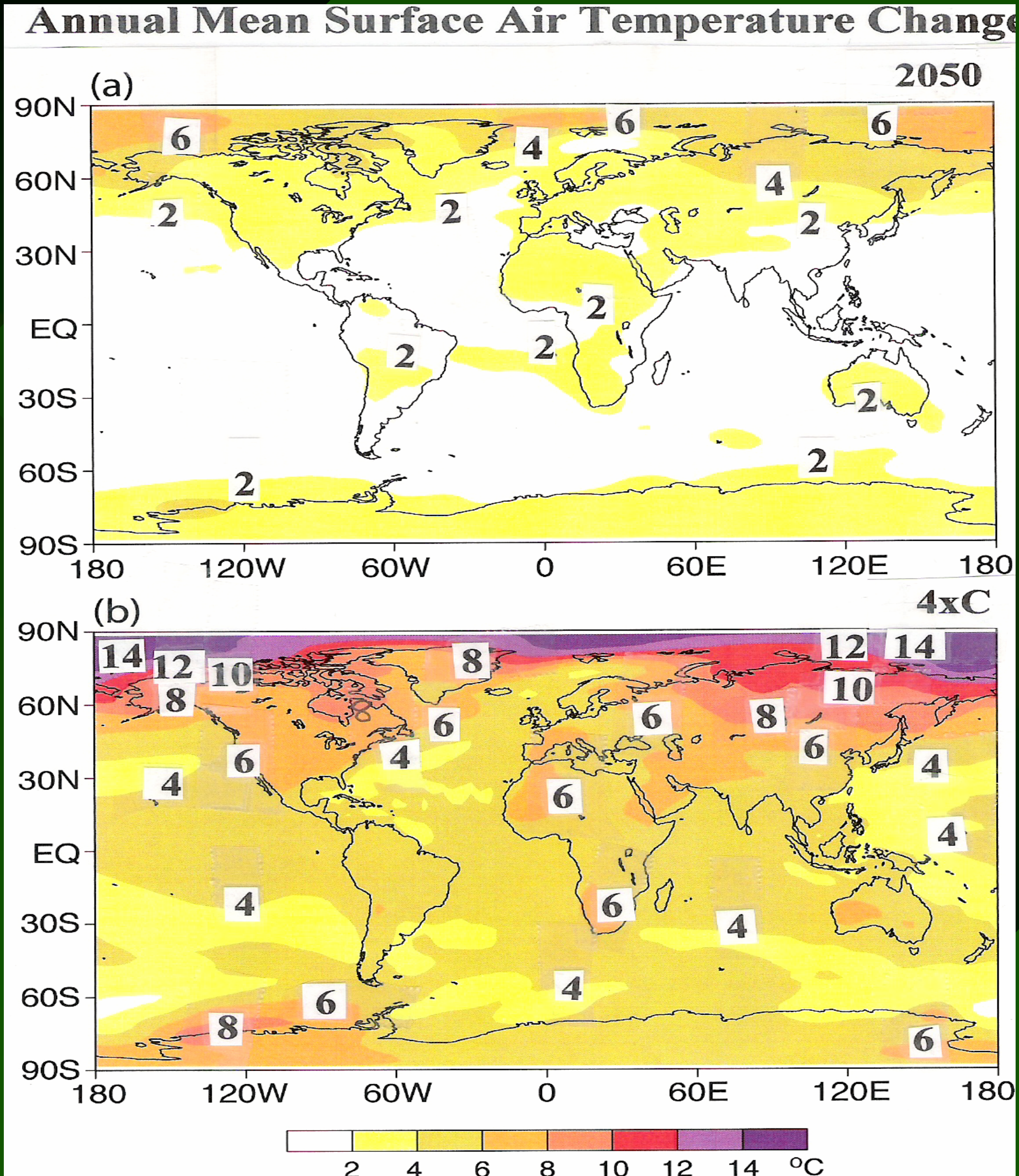
  "IS92a Scenario" with sulfate
  [CO_2 doubles ~2050]

- **CO_2-Quadruppling Experiment**

  Extension of IS92a Senario without sulfate
  [CO_2 quadruples ~2120, and remains unchanged thereafter]

Time Series from Global Warming Expts



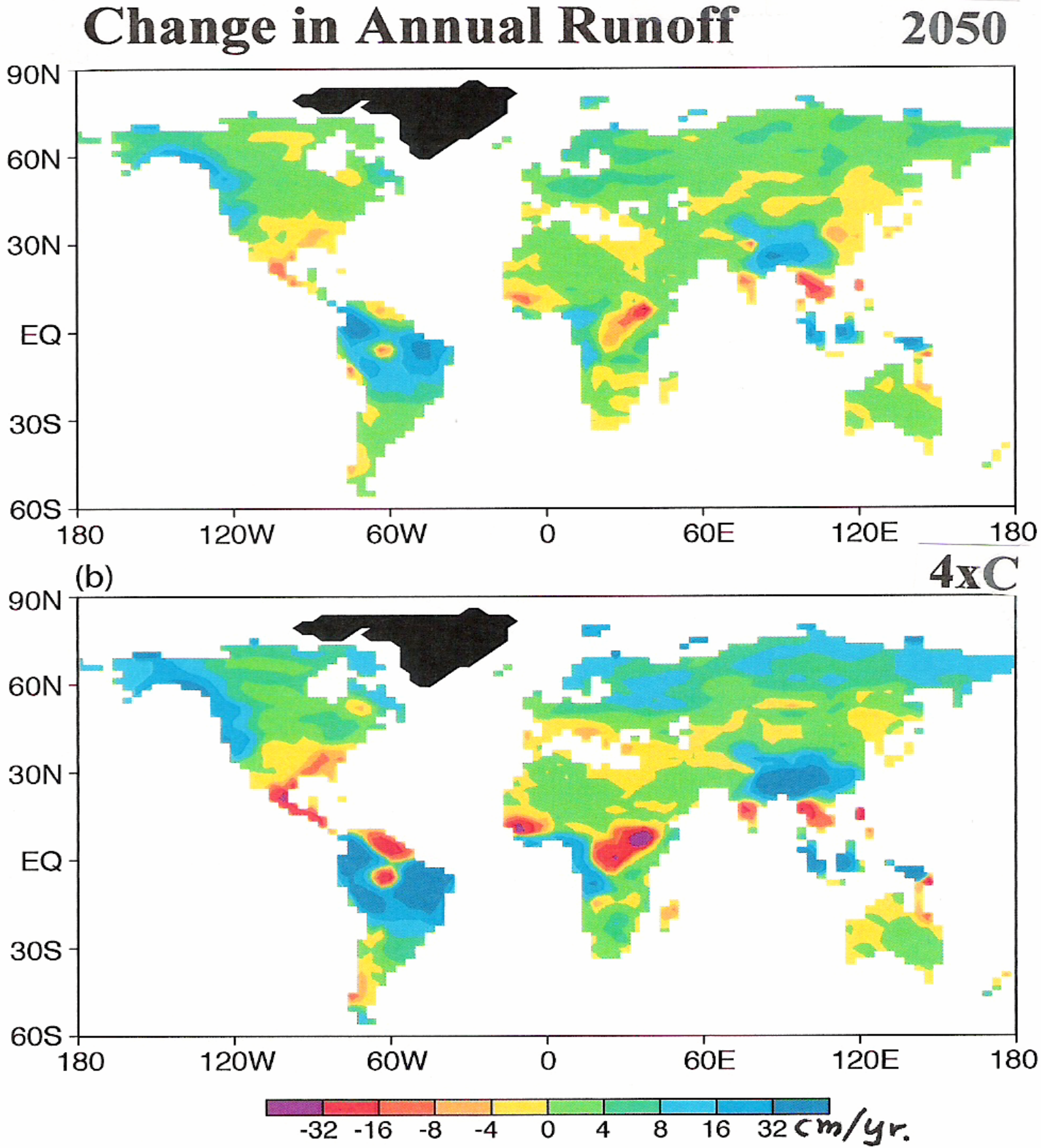


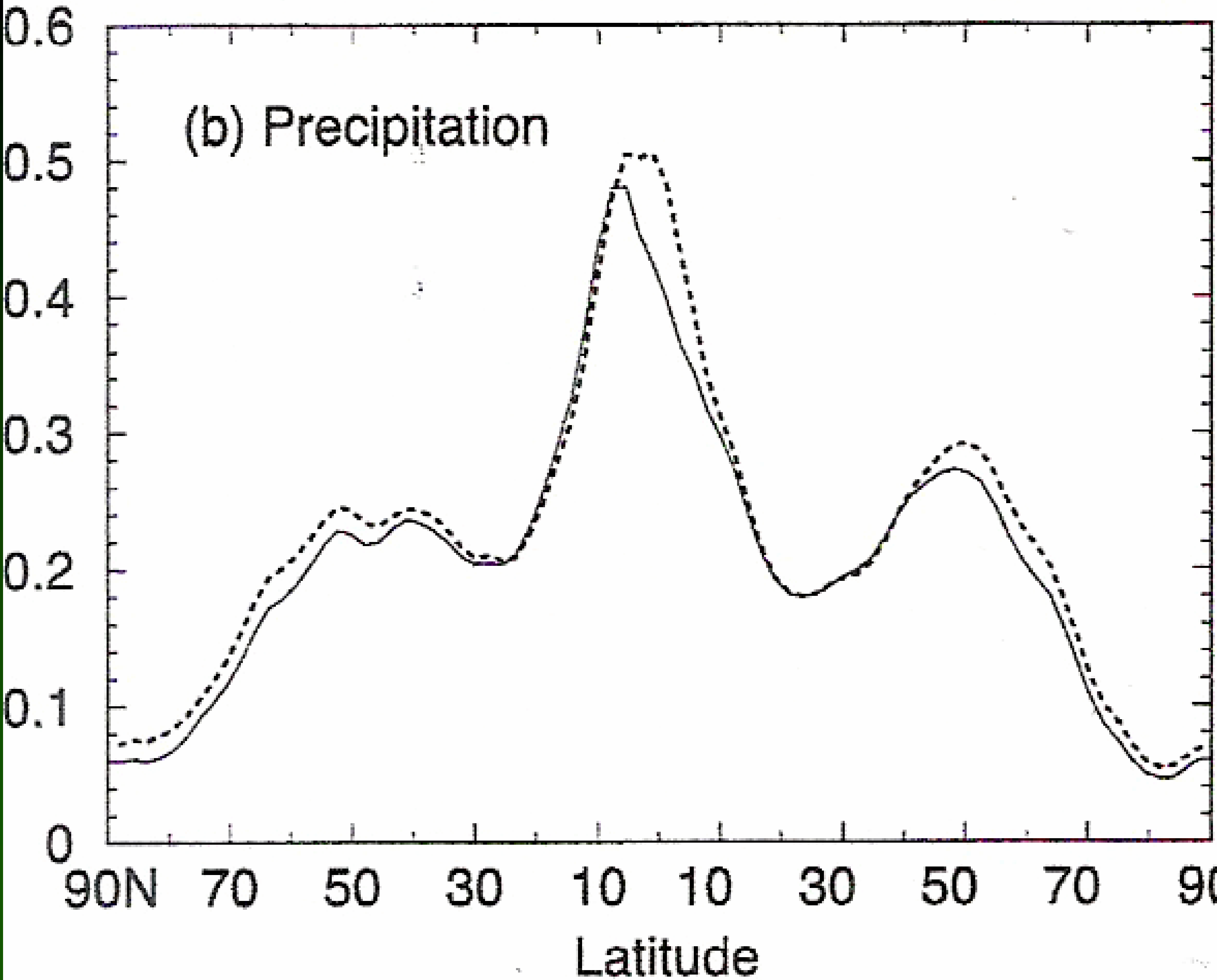
Annual Mean Surface Air Temperature Change
(a)
2050
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
(b)
4xC
2
4
6
8
10
12
14
oC

Global Mean Changes

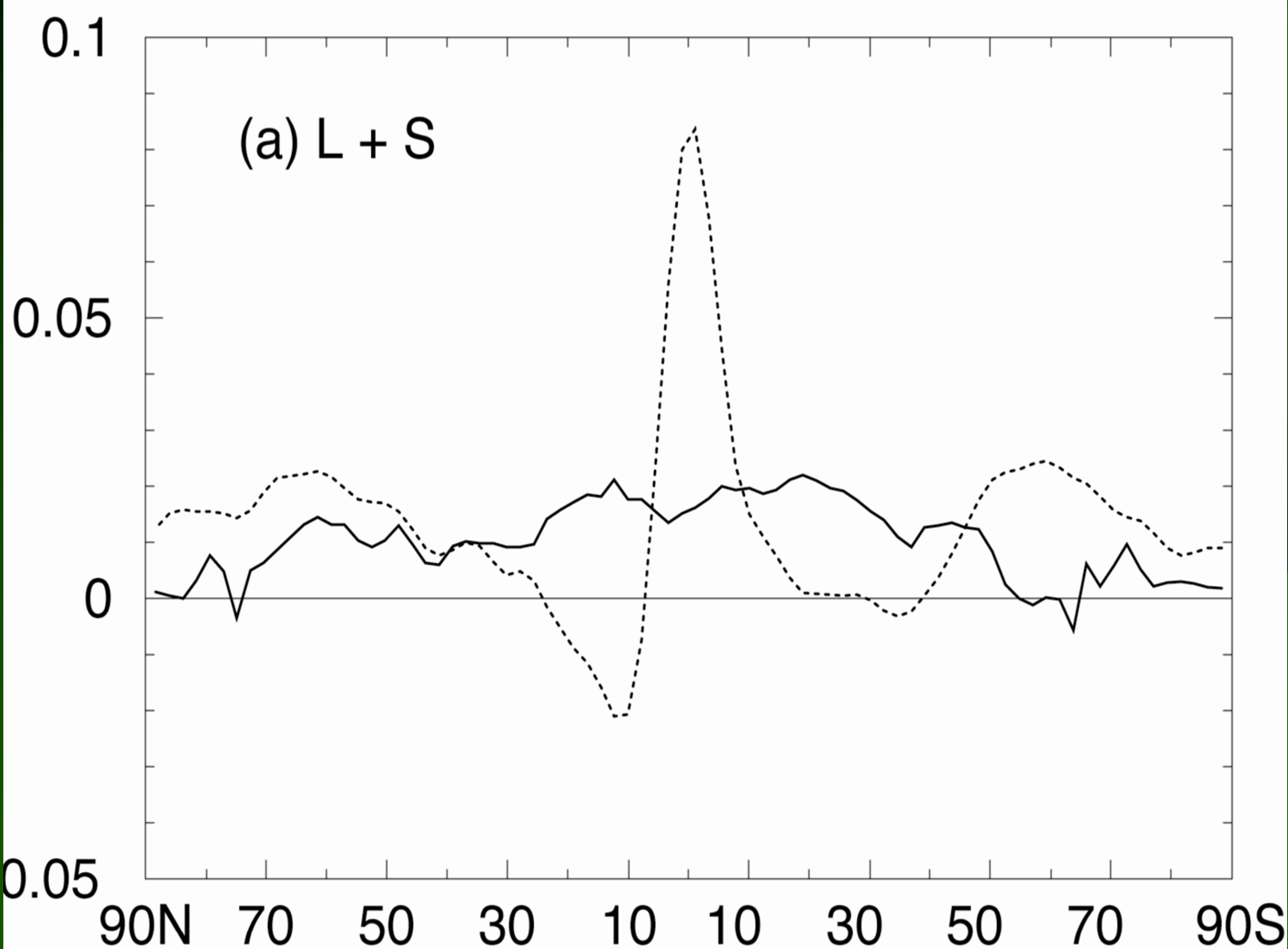
	ΔT_s^G	ΔPrecip. = ΔEvap.	ΔRunoff
2050	+2.3°C	+5.3%	+7.3%
4xC	+5.5°C	+12.7%	+14.8%

Change in Annual Runoff




(b) Precipitation
0.6
0.5
0.4
0.3
0.2
0.1
0
90N
70
50
30
10
10
30
50
70
90
Latitude

Changes in the rates of Precip. & Evap. (by 2050)



River Discharge ($10^3 m^3 s^{-1}$)
High Latitudes, Europe & NW-region of N. America

	Rate	Change	Change
Name	S. (Obs.)	2050	4xC
Yukon	10 (7)	+21%	+ 47%
Mackenzie	9 (9)	+21%	+40%
Yenisei	13(18)	+13%	+24%
Lena	15(17)	+12%	+26%
Ob'	6(13)	+21%	+42%
Subtotal	53(63)	+16%	+34%
Rhein/Elbe/-	3(4)	+25%	+20%
Volga	5(8)	+25%	+59%
Danube/-	7(9)	+21%	+9%
Columbia	6(5)	+21%	+47%
Subtotal	21(26)	+23%	+34%

River Discharge ($10^3 m^3 s^{-1}$)
(Middle Latitudes)

	Rate	Change	Change
Name/River	S.(Obs.)	2050	4xC
S.Lawrence/Ottawa/-	12(12)	+6%	+12%
Mississippi/Red	10(18)	+0%	-7%
Amur	9	-1%	+3%
Zambezi	31	-1%	+2%
Huang He	17	+0%	+18%
ChangJiang	54(29)	+4%	+28%
Paraná/Urguay	24	+24%	+54%

River Discharge ($10^3 m^3 s^{-1}$)
(Low Latitudes)

	Rate	Change	Change
Name/River	S.(Obs.)	2050	4xC
Amazonas/Jari/ Maicuru/	234(194)	+11%	+23%
Ganga/ Bramaputra	49(33)	+18%	+49%
Congo	122(40)	+2%	-1%
Niger	58	+5%	+6%
Nile	50(3)	-3%	-18%
Orinoco	28(33)	+8%	+1%
Mekong	29(9)	-6%	-6%
Subtotal	512(313)	+7%	+13%

Change (%) in River Discharge)

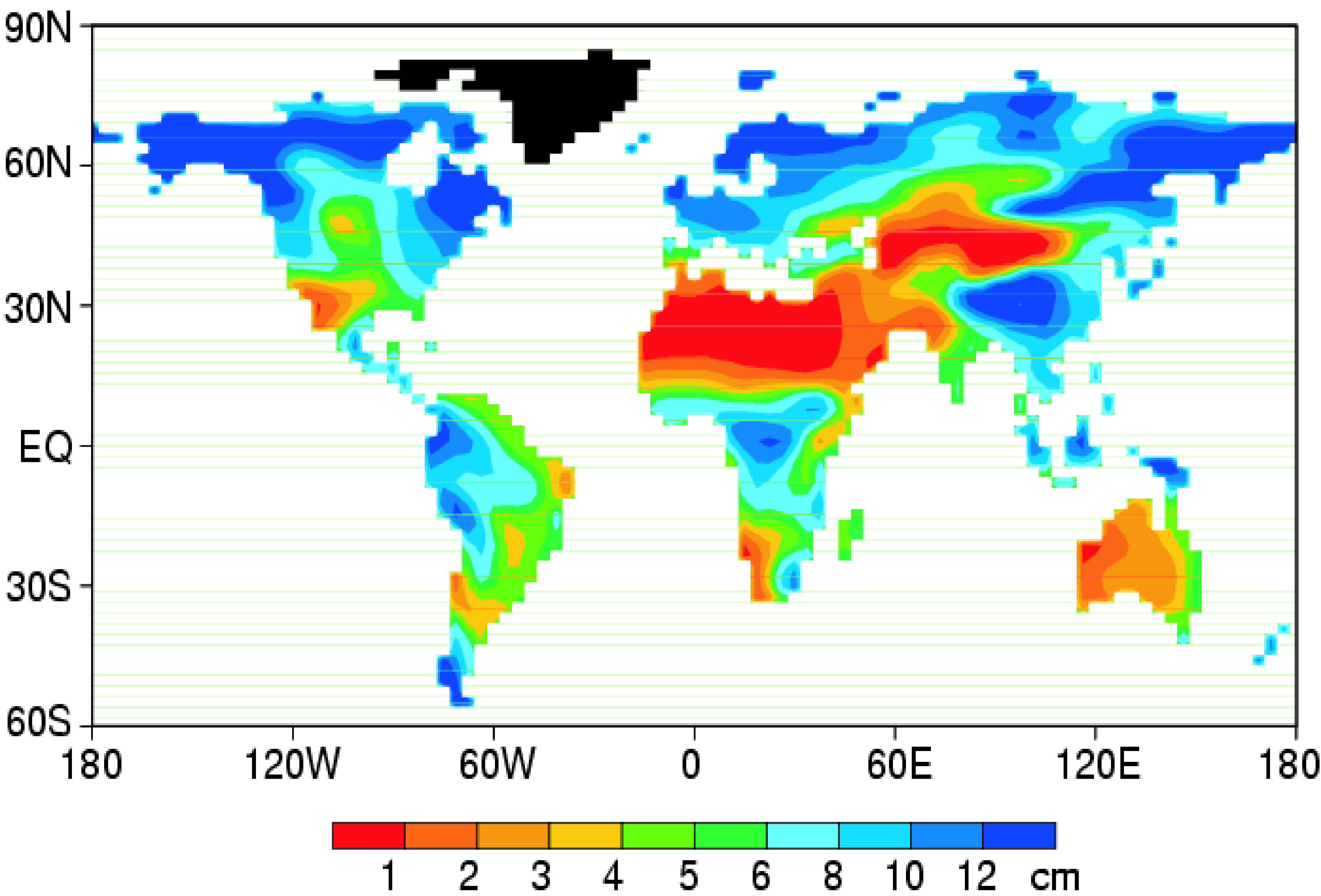
- High Lat.; Marked increase in Arctic rivers
- Middle-High Lat.; Marked Increase in Europe, &

  northwest coast of North America
- Middle-Low Lat.; Relatively small change
- Tropics; Large increase at Ganga/Brahmaputra

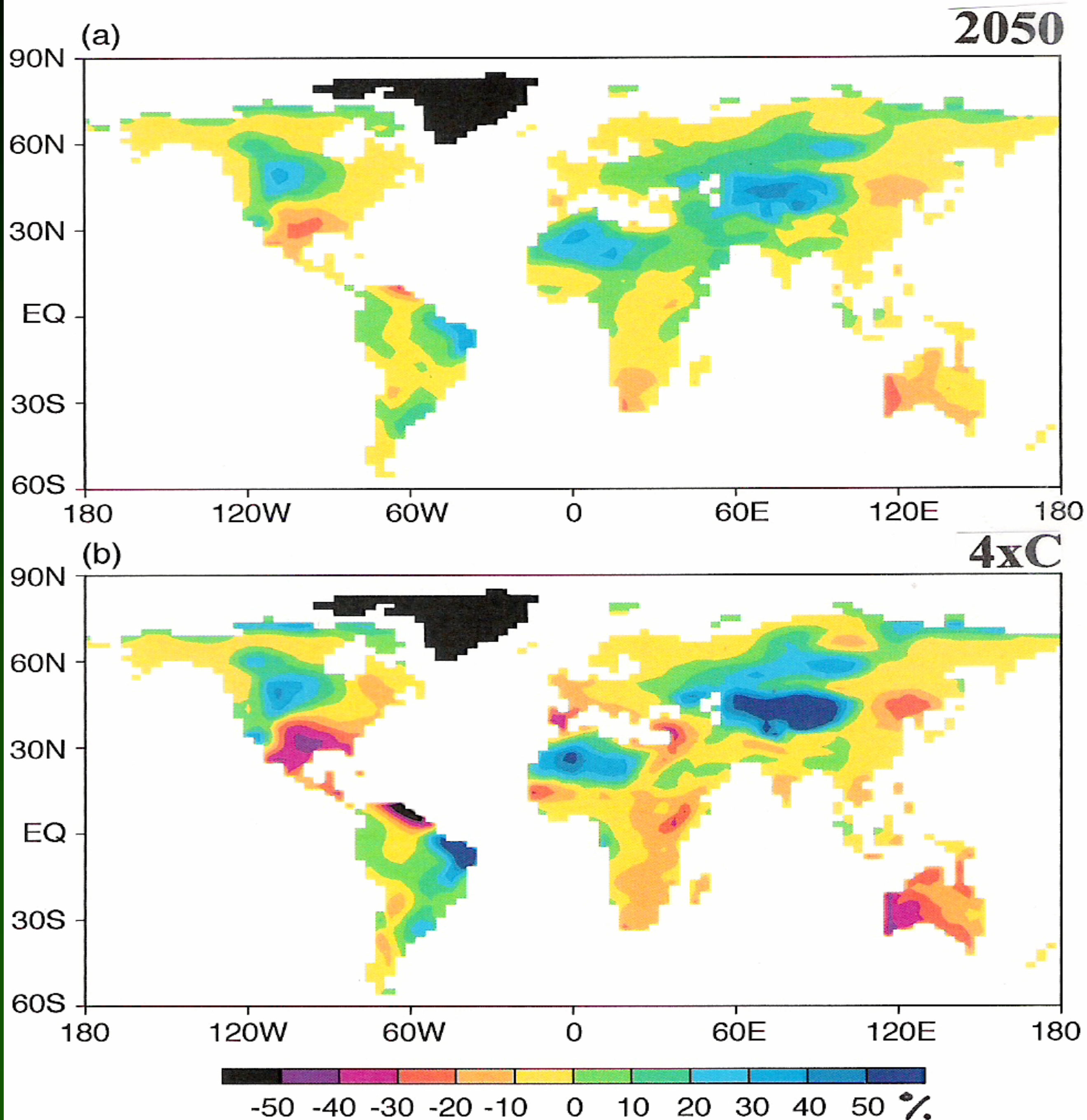
  Moderate Increase at Amazonas

  Changes of both signs in other rivers

Annual Mean Soil Moisture, Simulated



% Change in Annual Mean Soil Moisture



Reduction of Soil Moisture in Semi-Arid Regions

Surface Water Balance:

P ~ E, **(r$_f$;** Relatively small**)**

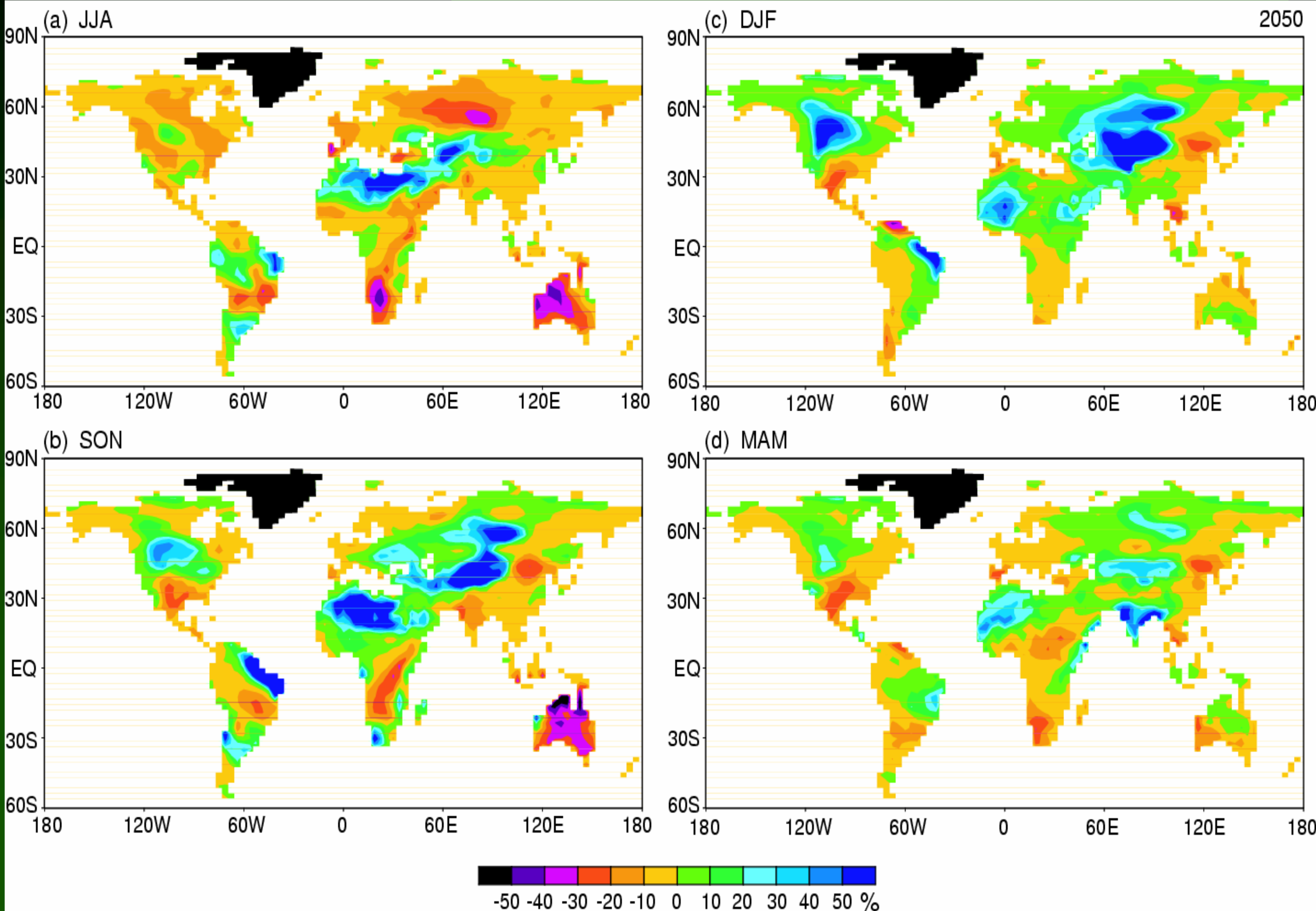
ΔP ~ ΔE

~ Δ [E$_P$• w/w$_{FC}$]

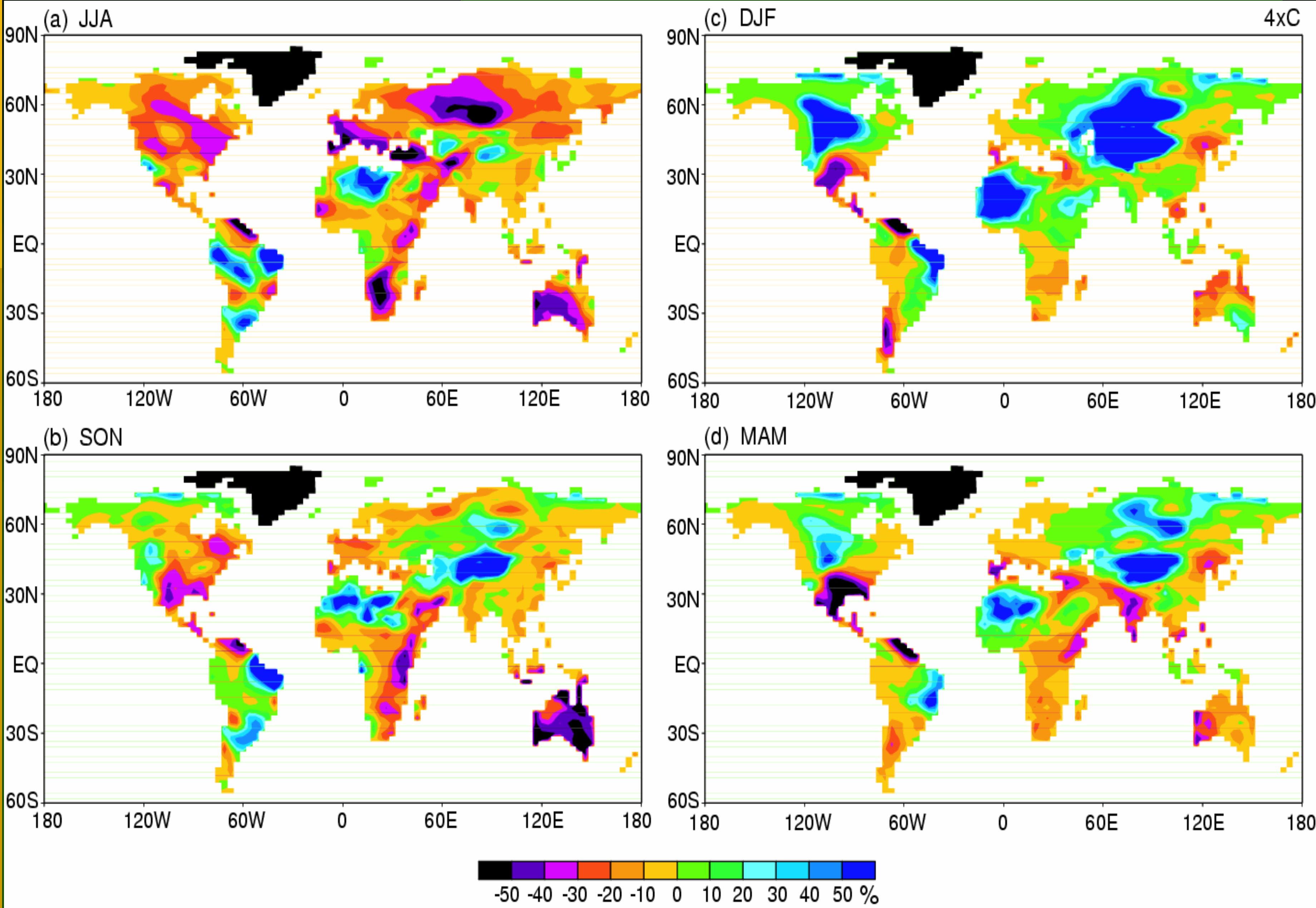
- Little change in Precipitation (**P**)
- Increase in Potential Evaporation (**E$_P$**)

→Reduction in Soil Moisture (**w**)

Soil Moisture Change (%) by 2050



Soil Moisture Change (%), 4xC



Summary (Soil Moisture)

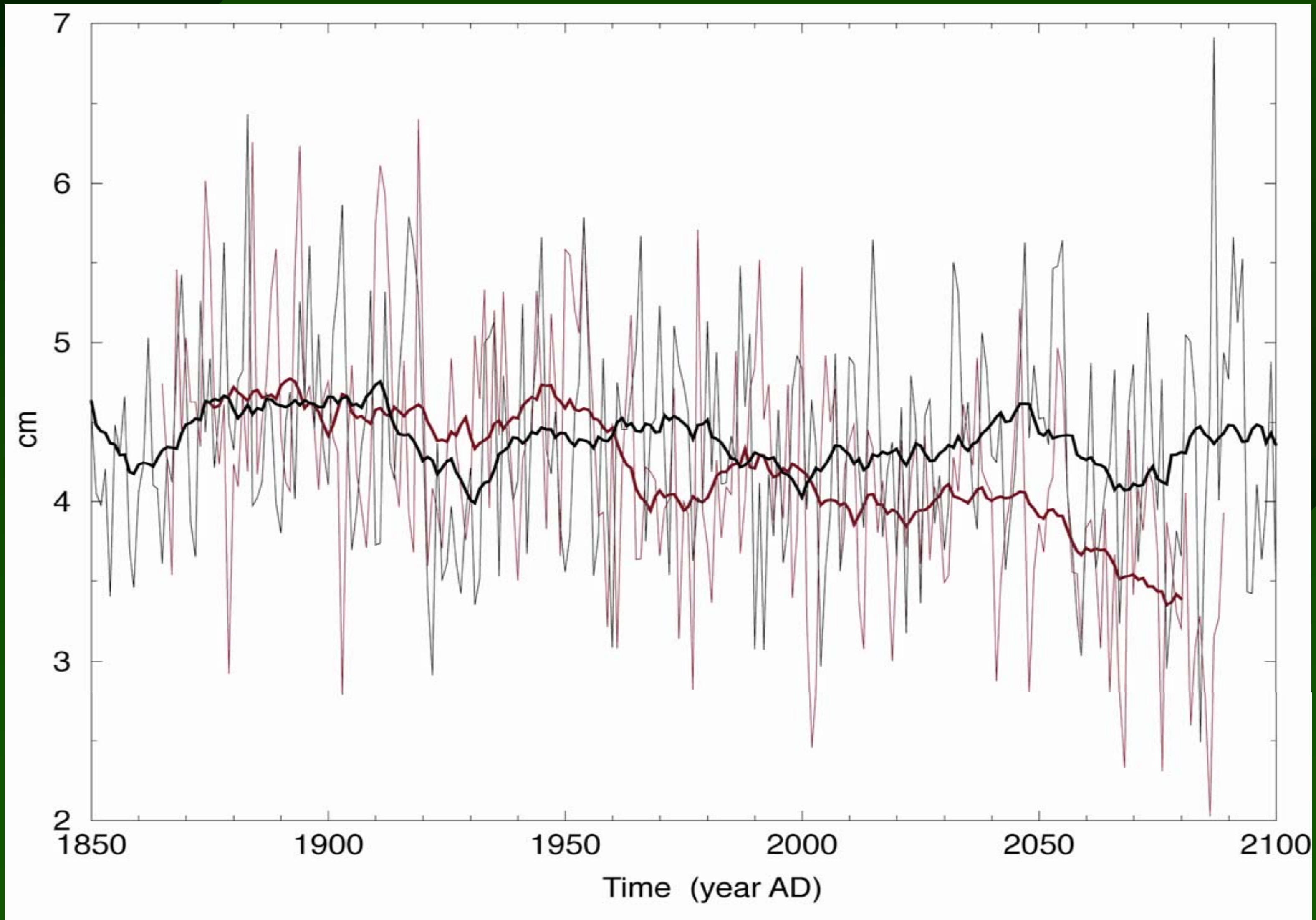
Semi-Arid Regions:

- Reduction during much of a year particularly during dry season
- Gradual expansion of deserts

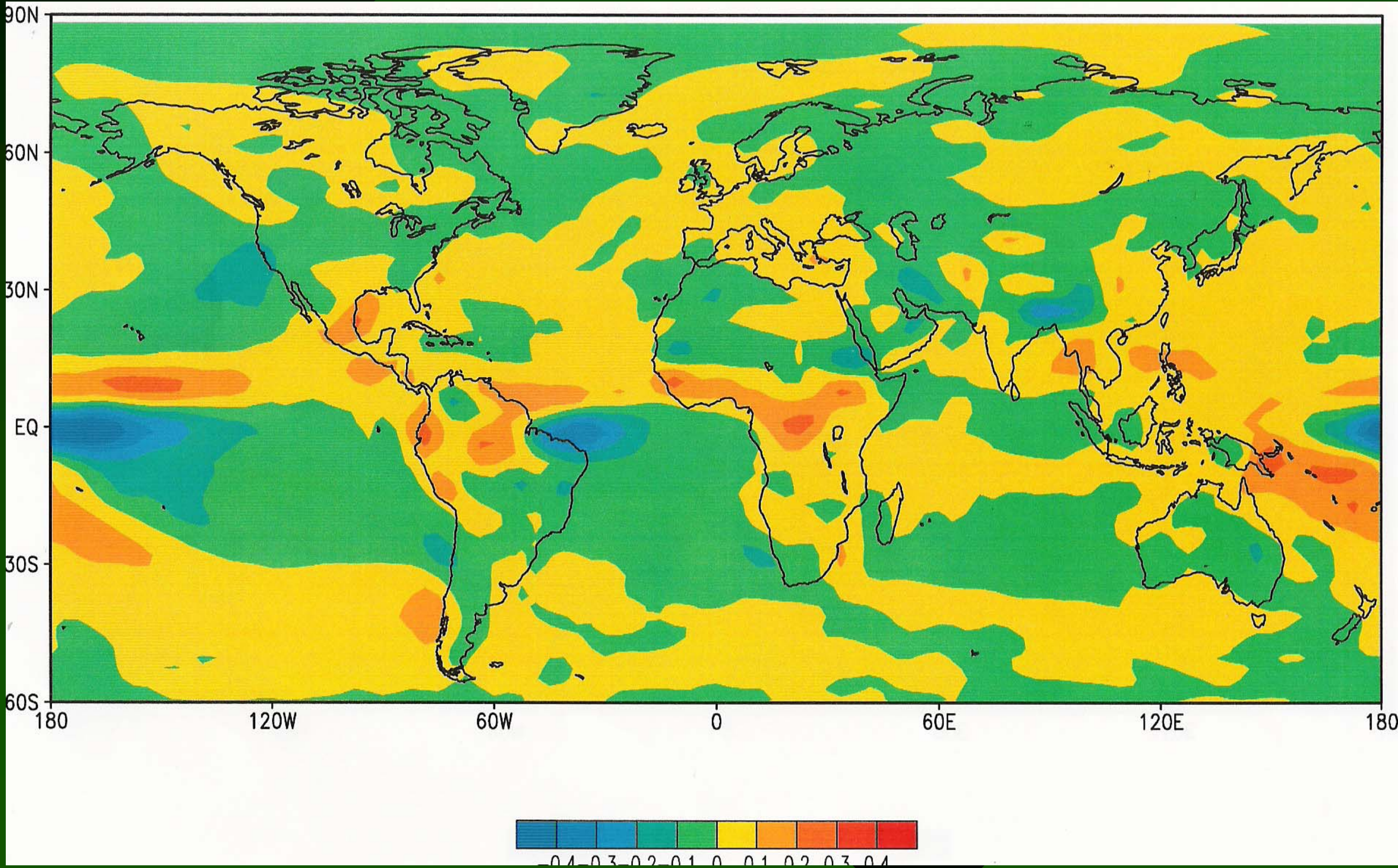
From Middle to High Latitudes:

- Reduction in summer
- Increase in winter

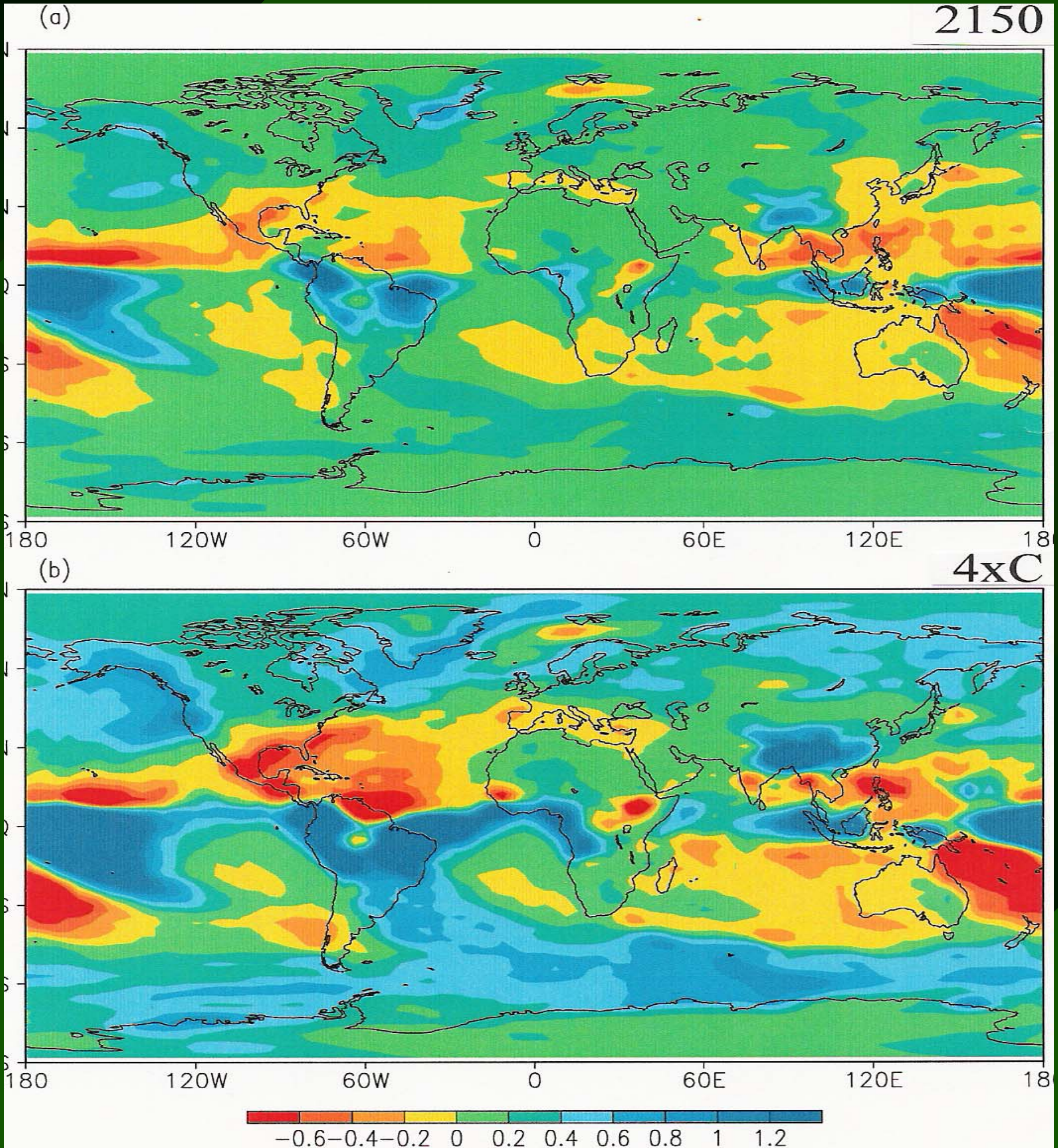
Time series of annual mean soil moisture in southwestern region of North America



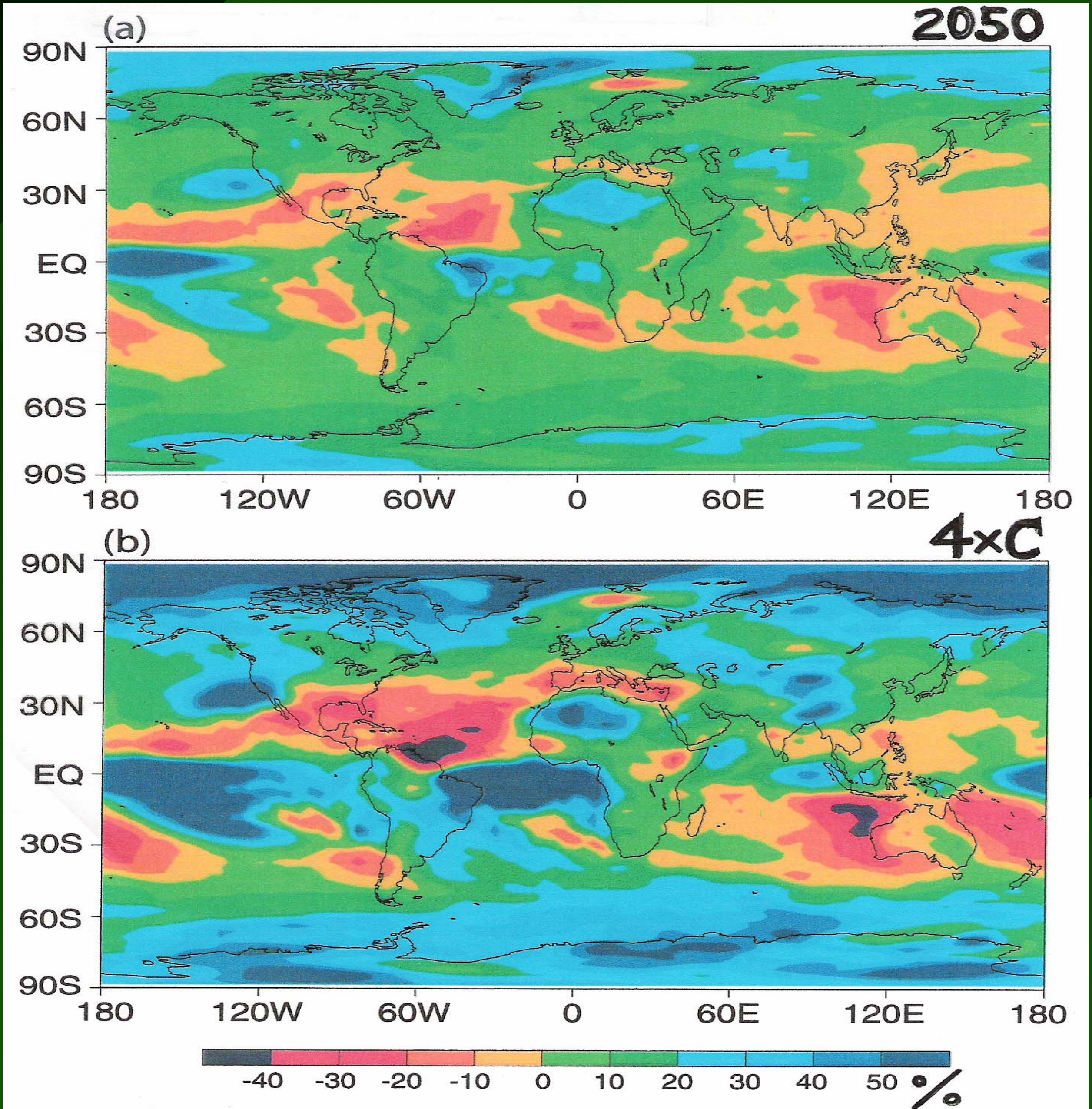
Δ(Vertical p-velocity), 4xC – 1xC

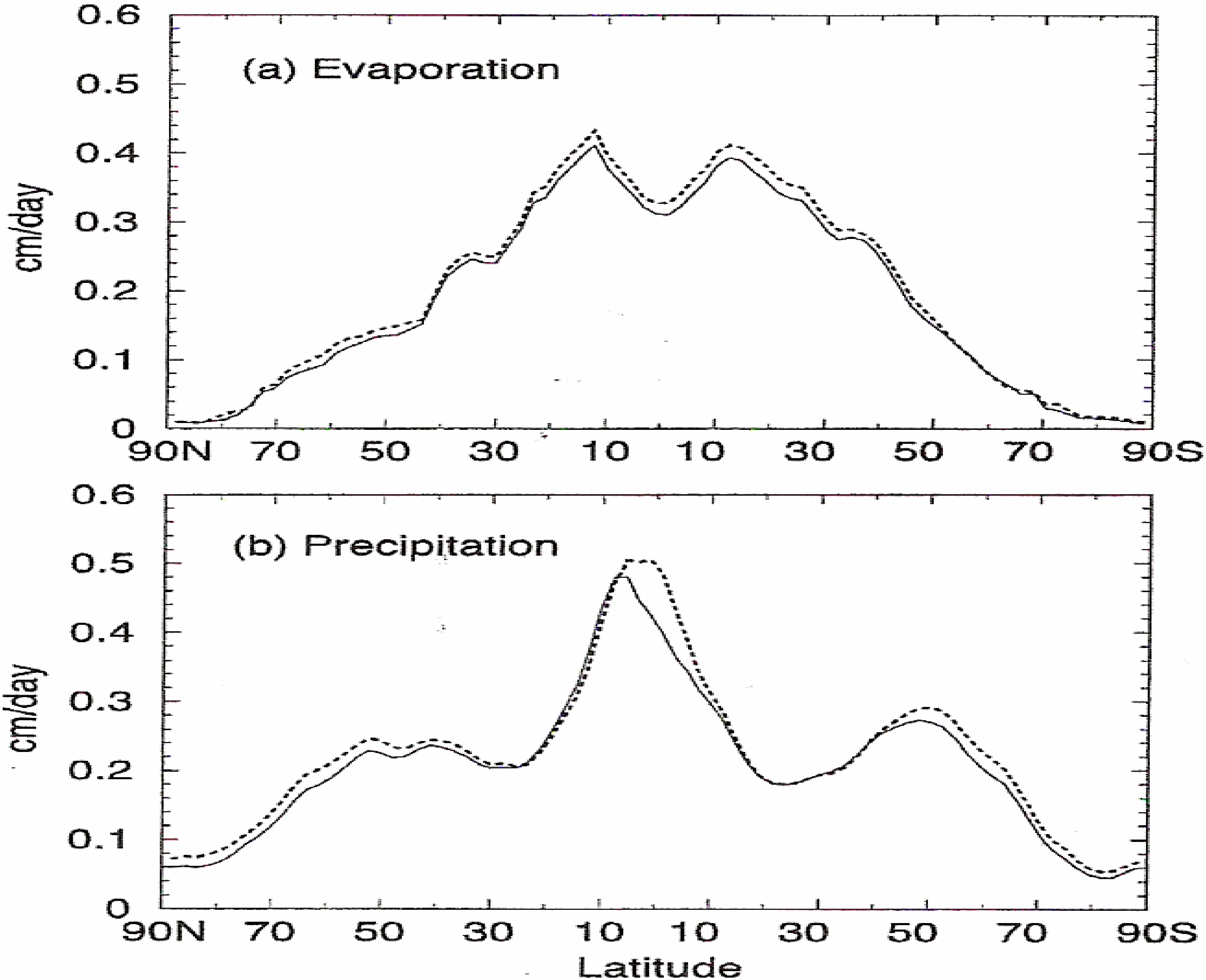


Change in Annual Precipitation Rate mm/day

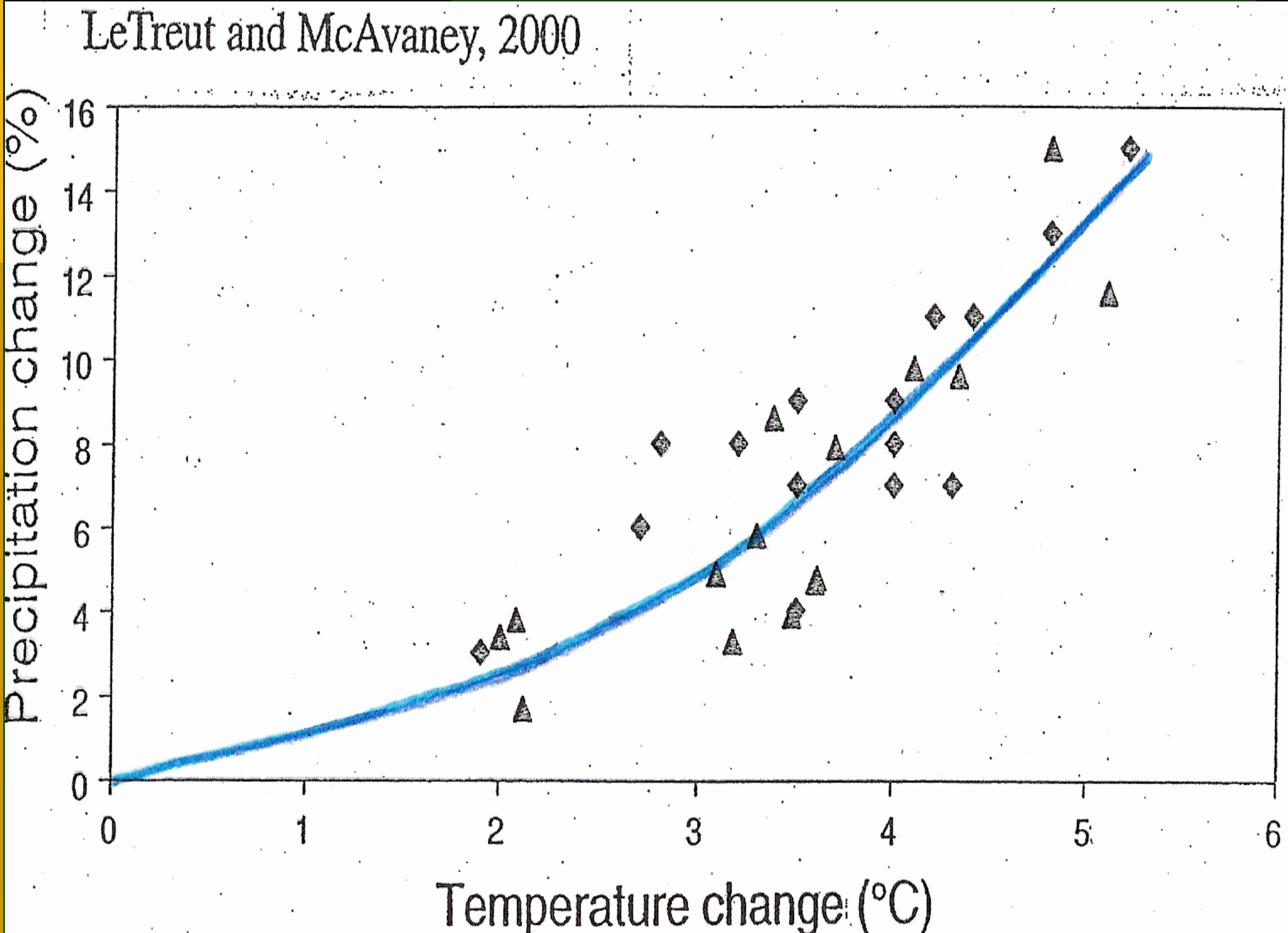


% Change in Annual Precipitation




(a) Evaporation
cm/day
0.6
0.5
0.4
0.3
0.2
0.1
0
90N
70
50
30
10
10
30
50
70
90S
(b) Precipitation
cm/day
0.6
0.5
0.4
0.3
0.2
0.1
0
90N
70
50
30
10
10
30
50
70
90S
Latitude

Global Mean Changes



Numerical Experiments

- **Control Experiment**

  Integrated over 1,000 years

- **Eight Global Warming Experiments**

  Integrated over 1865-2090 AD

  "IS92a Scenario" with sulfate

- **CO_2-Quadruppling Experiment**

  Integrated over 300 years

  Increase at 1% / yr.

  →Quadruples at 140th yr.

Analysis Period

- <u>Eight Global Warming Experiments</u>

  Analysis Period: 2035-2065AD

  30yrs x 8 = <u>240yrs</u>

- <u>CO_2-Quadruppling Experiments</u>

  Analysis Period: 200th – 300th

  ~ <u>100yrs</u>

Coupled Ocean-Atmosphere-Land Model
with Simple Parameterization

- **Atmospheric Component**

  R30 Spectral GCM (2º Lat. X 4º Long.)

  Saturated Convective Adjustment

- **Oceanic Component**

  Finite Difference (2º Lat. X 2º Long.)

  Simple Sea Ice Model

- **Land Component**

  Bucket Model