Vegetation Dynamics and Sahel Climate

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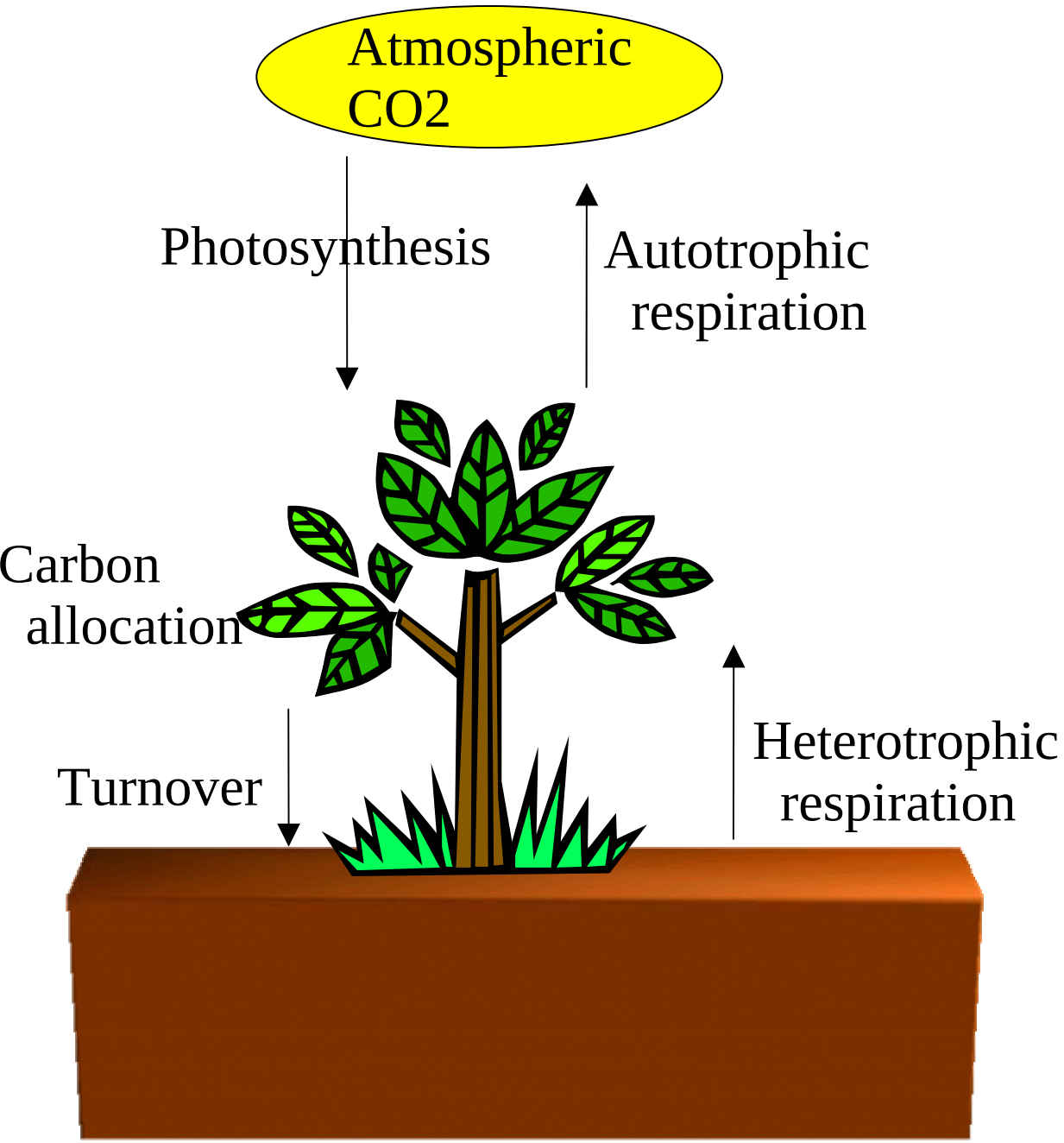
Outline of the Talk

- Climatology: multi-equilibria and nonlinearity
- Roles of SST vs. Land and vege processes
- Some complex issues in vegetation dynamics
- Basin SST contributions
- Vegetation/carbon response to future climate change

The VEgetation-Global Atmosphere-Soil Model (VEGAS)

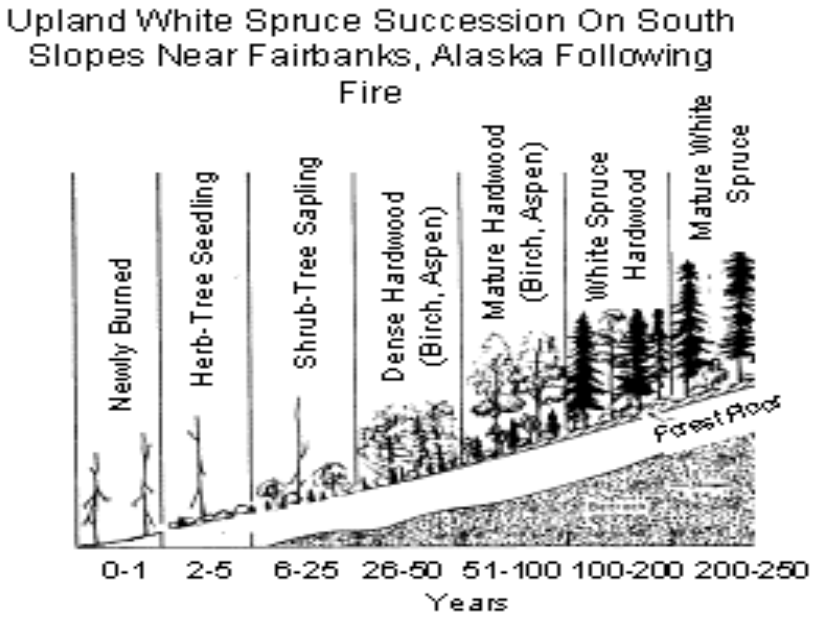


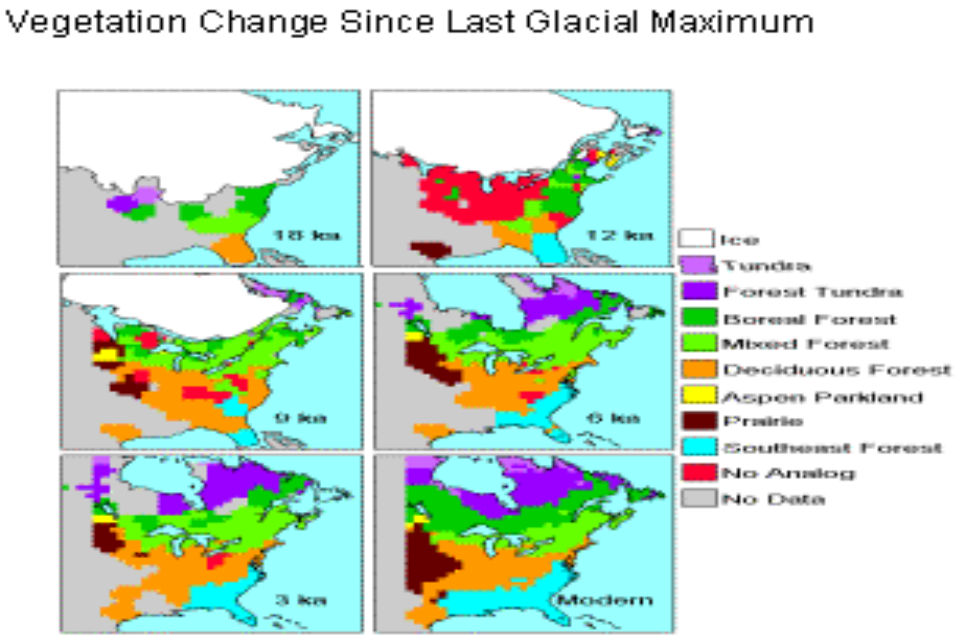
4 **Plant Functional Types**:
- Broadleaf tree
- Needleleaf tree
- C3 Grass (cold)
- C4 Grass (warm)

3 Vegetation carbon pools:
- Leaf
- Root
- Wood

3 Soil carbon pools:
- Fast
- Intermediate
- Slow

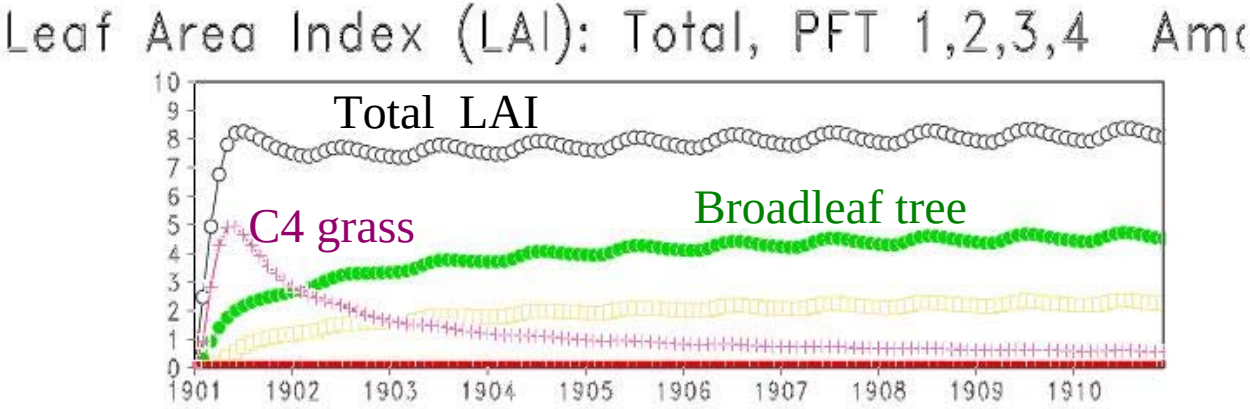
Succession Following Disturbance

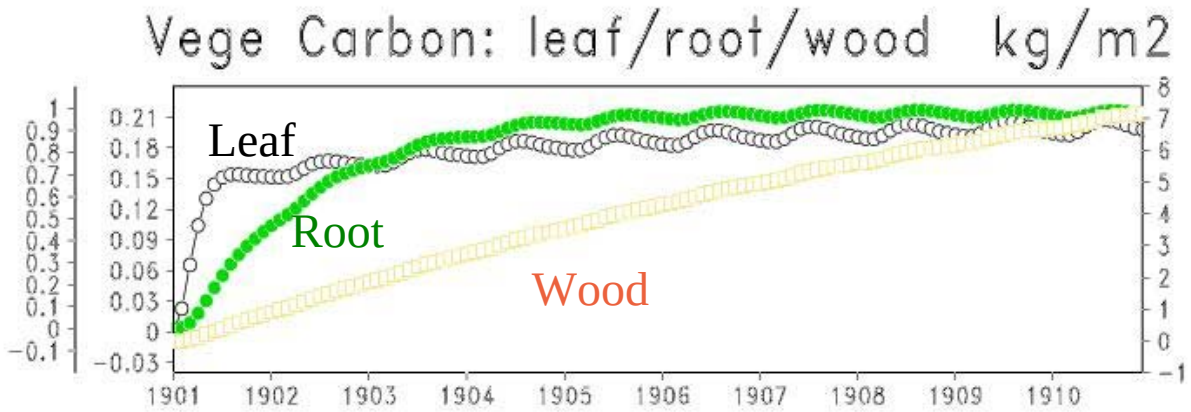


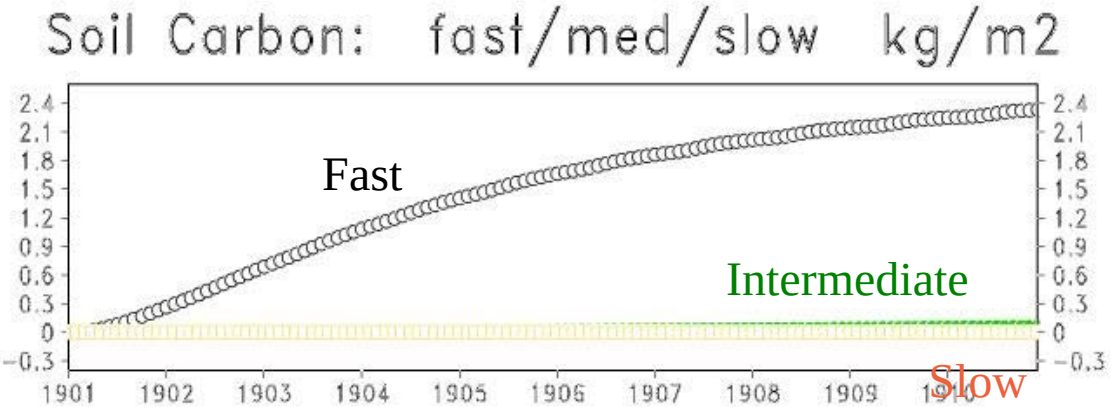


G. Bonan

Vegetation Dynamics after disturbance



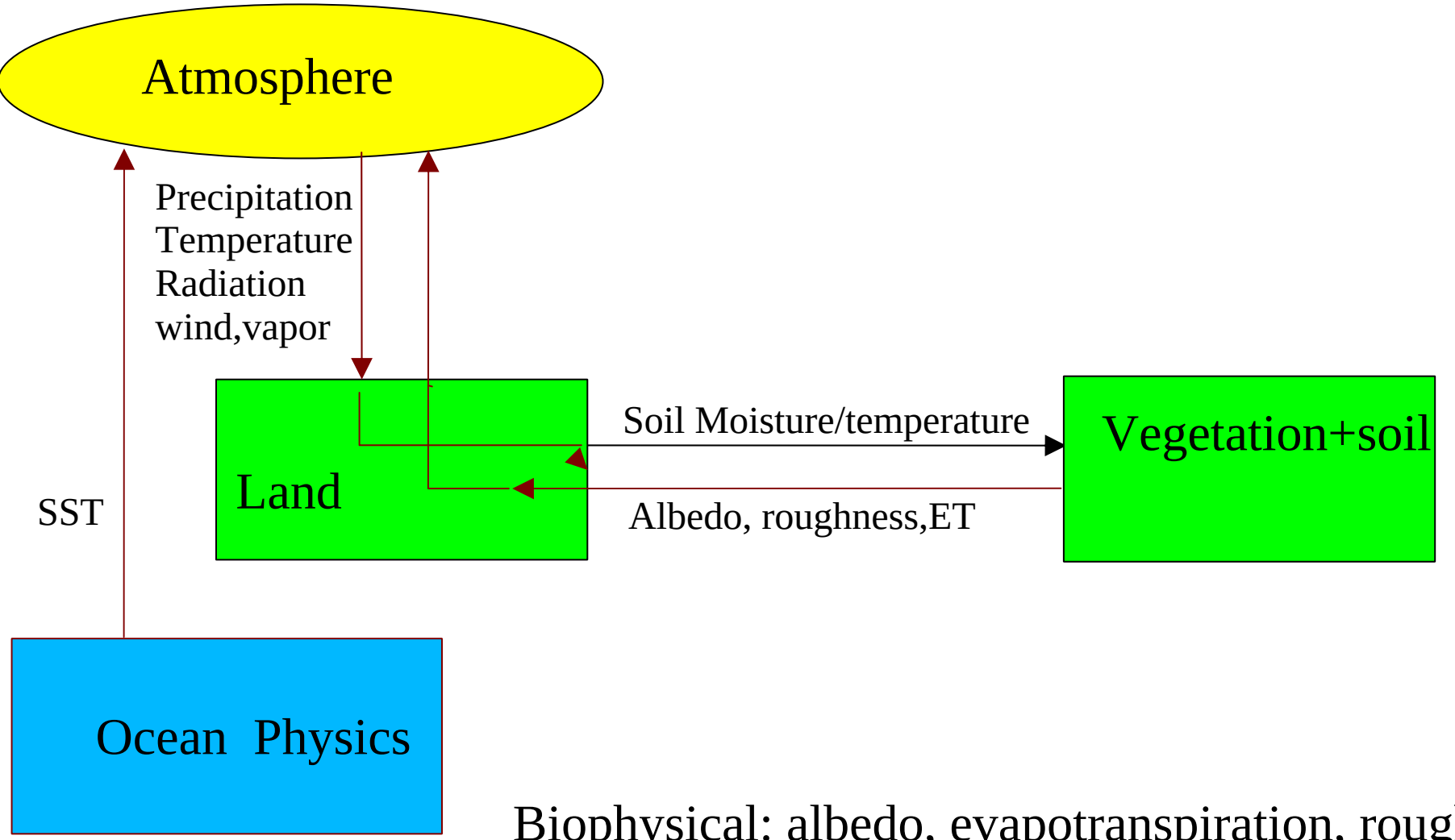




Fast regrowth in grass

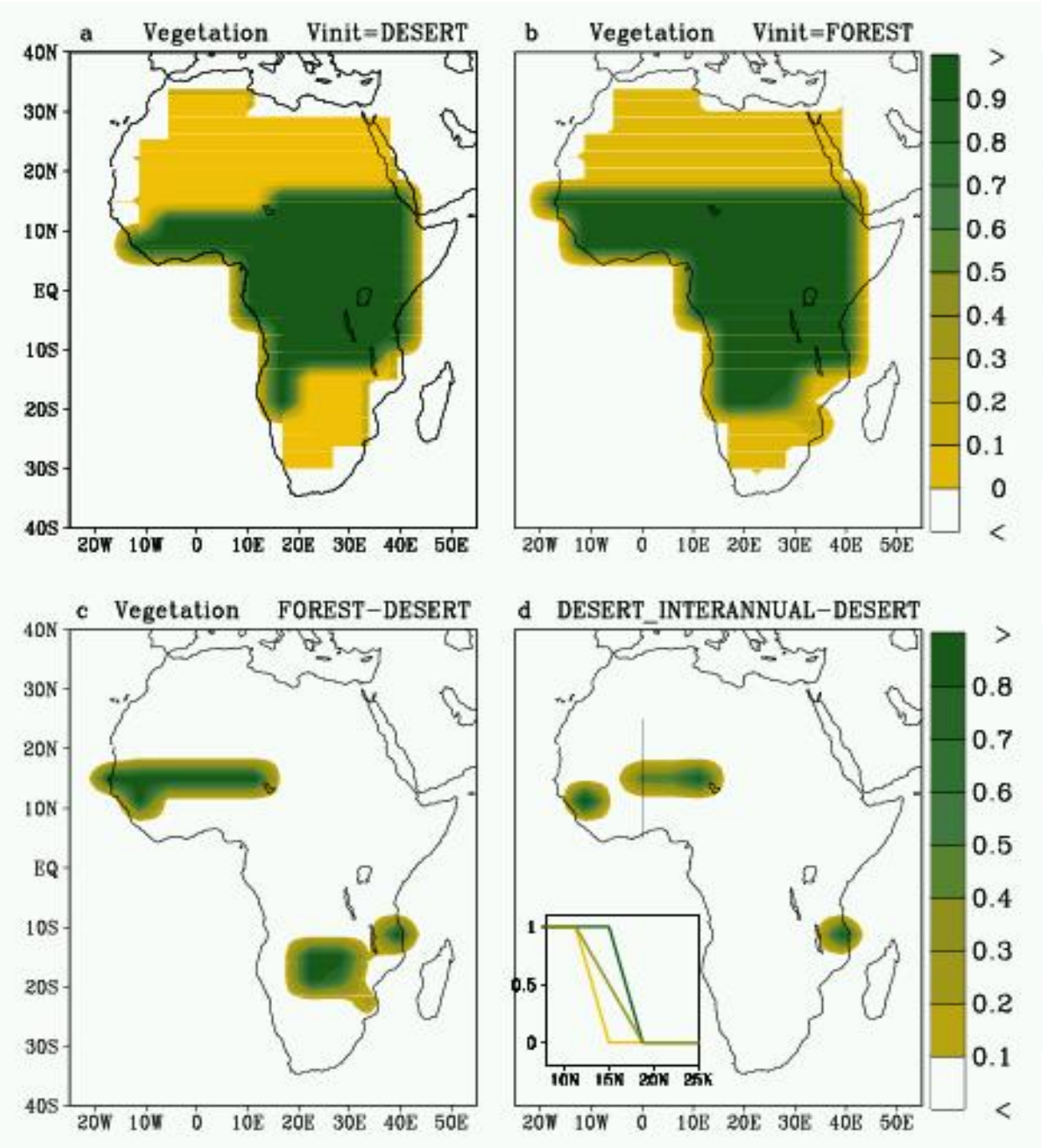
Slow for trees

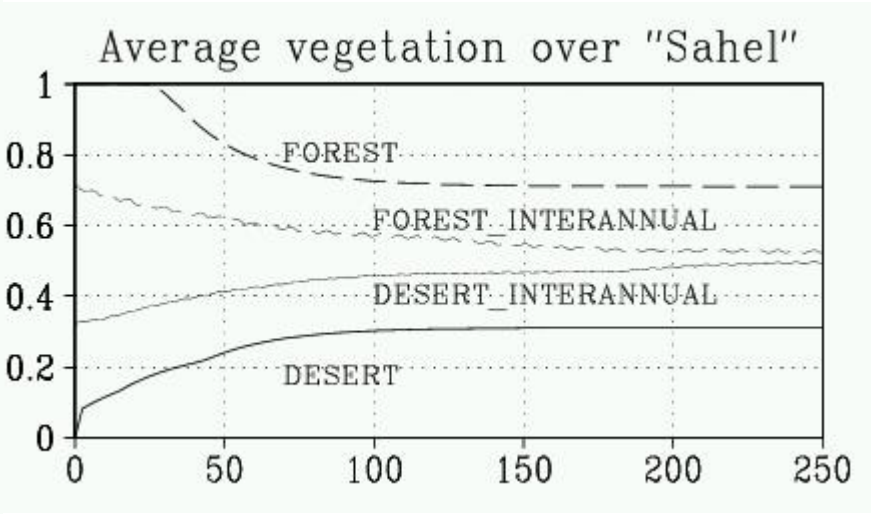
Effects of Vegetation Dynamics on Climate Variability
A ---A Case Study in West Africa Sahel

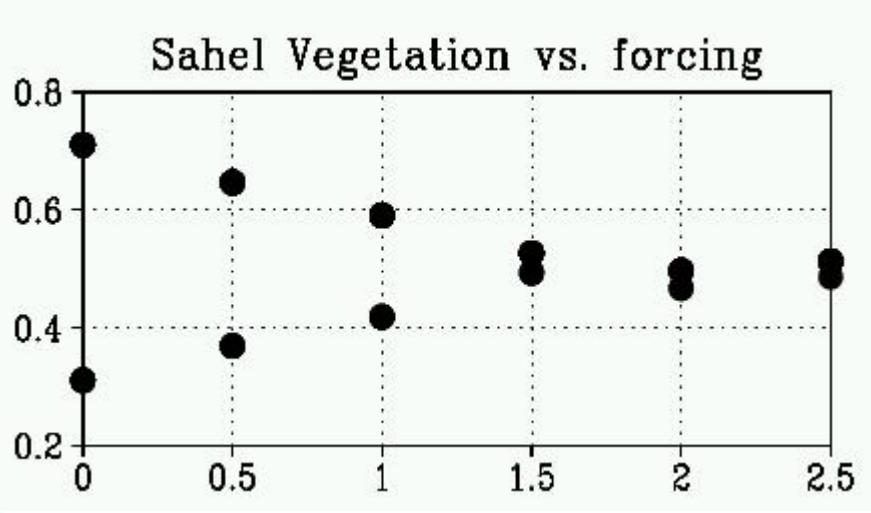


Biophysical: albedo, evapotranspiration, roughness,..
Biogeochemical: CO2, …

Multiple Equilibria due to Vegetation-Atmosphere Interaction but complicated by climate variability



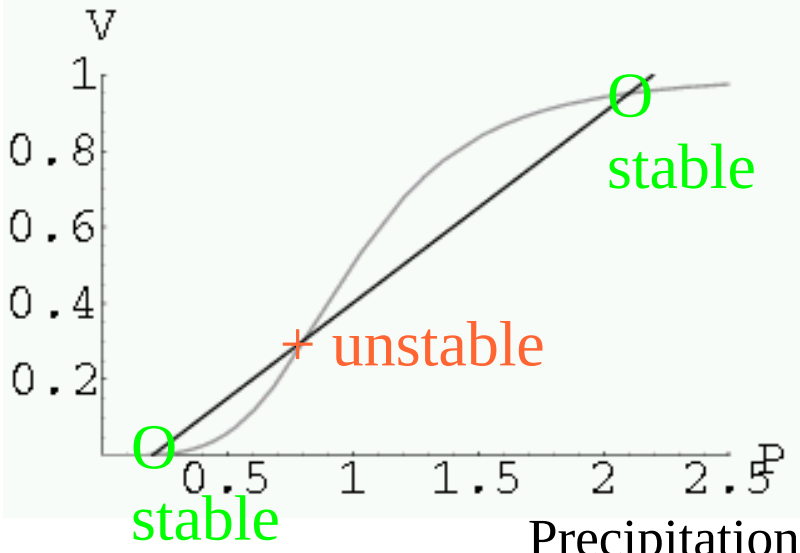




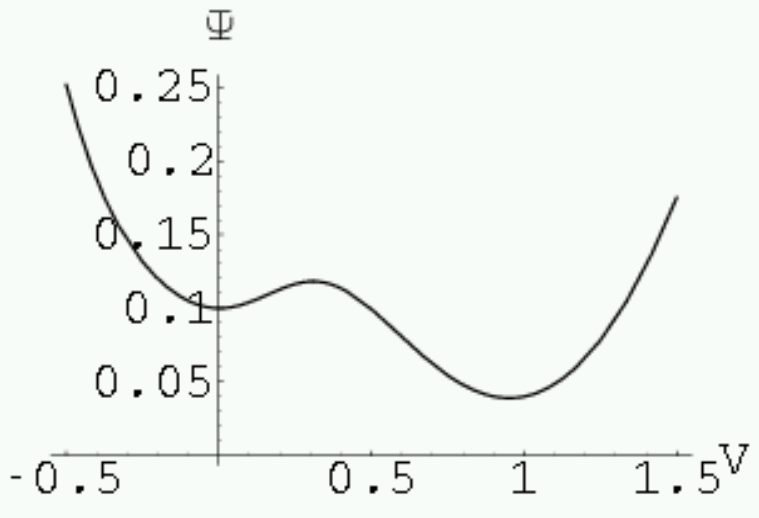
Zeng and Neelin (2000)

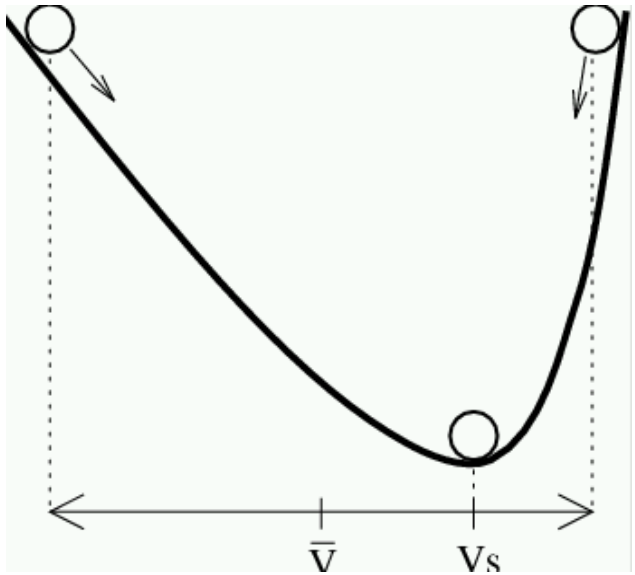
Lyapunov potential function

Vegetation



Precipitation



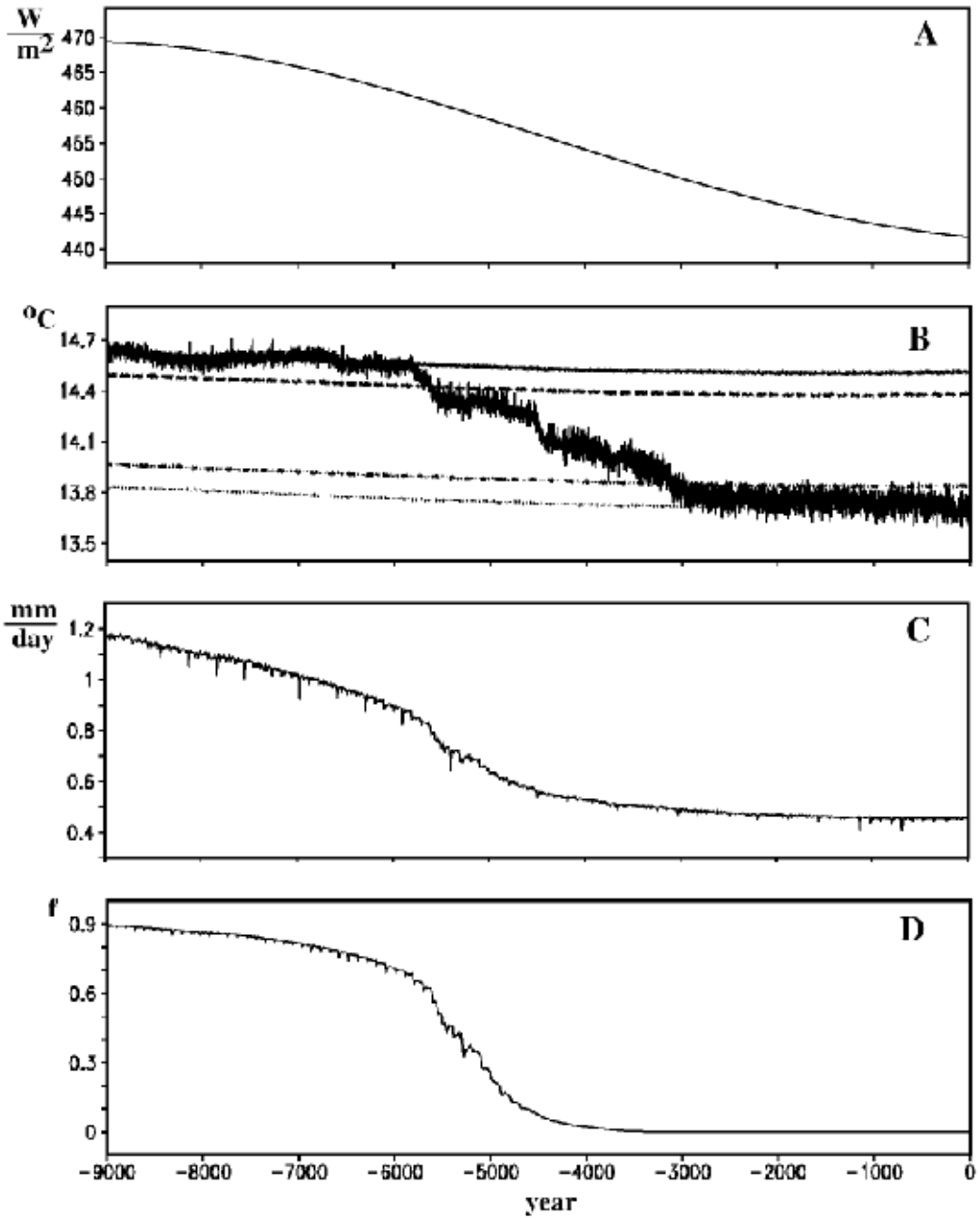


V -- Vegetation Normalized

P -- Precipitation

Zeng, Hales, Neelin (2002)

Drying of the Sahel during the Holocene



Smooth change in solar forcing

Precipitation: in between

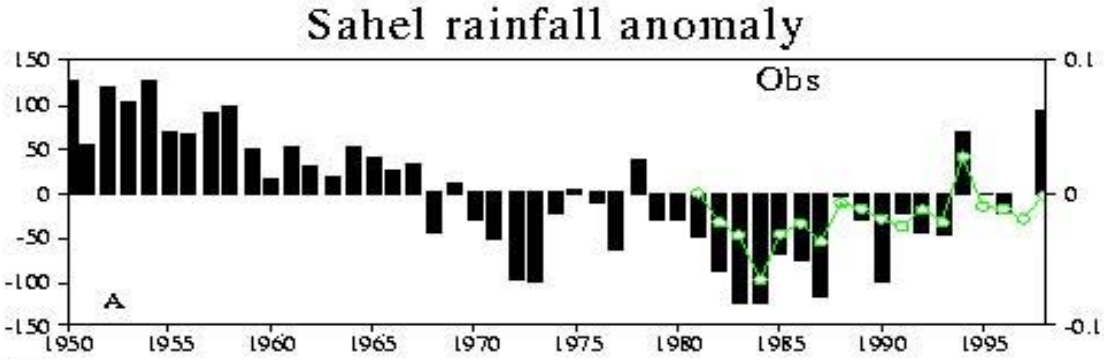
Abrupt change in vegetation
(needs strong feedback)

Claussen et al., (1999)

May be consistent with paleodata

What caused the drought in the Sahel?

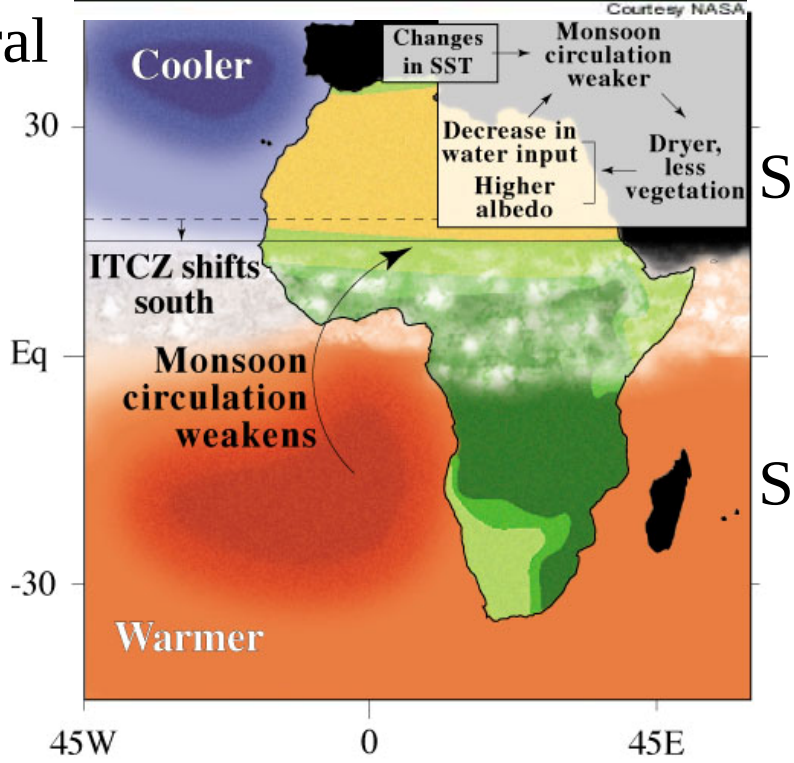
Human



Land use: Otterman (1974) speculation
Charney (1975) theory and model
Xue and Shukla (1993) model

Problem: actual human impact is not as large as assumed

Natural SST

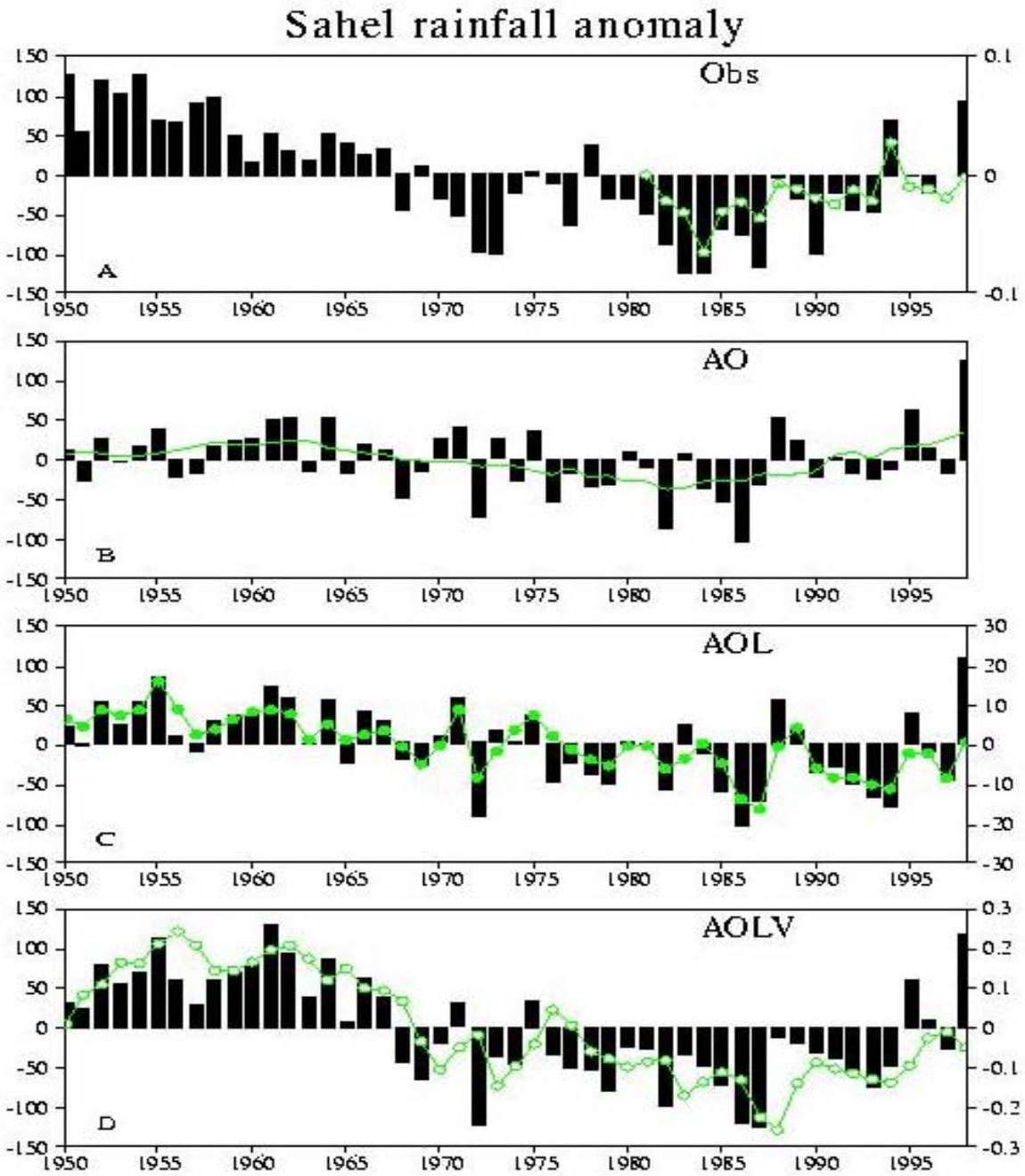


SST: Lamb (1977) correlation
Folland et al. (1986) model
and many many others (C20C)

Problem: amplitude too small

SST+land/vege feedback: Zeng et al. 1999
and some others

Problem: processes not well known; most models don't have interactive vege



The dramatic drying trend in the Sahel from the 1950s to the 1980s is initially forced by SST (b), but amplified by soilmoisture (c) and vegetation(d). Zeng, et al. 1999: Science, vol 286, 1537-1540.

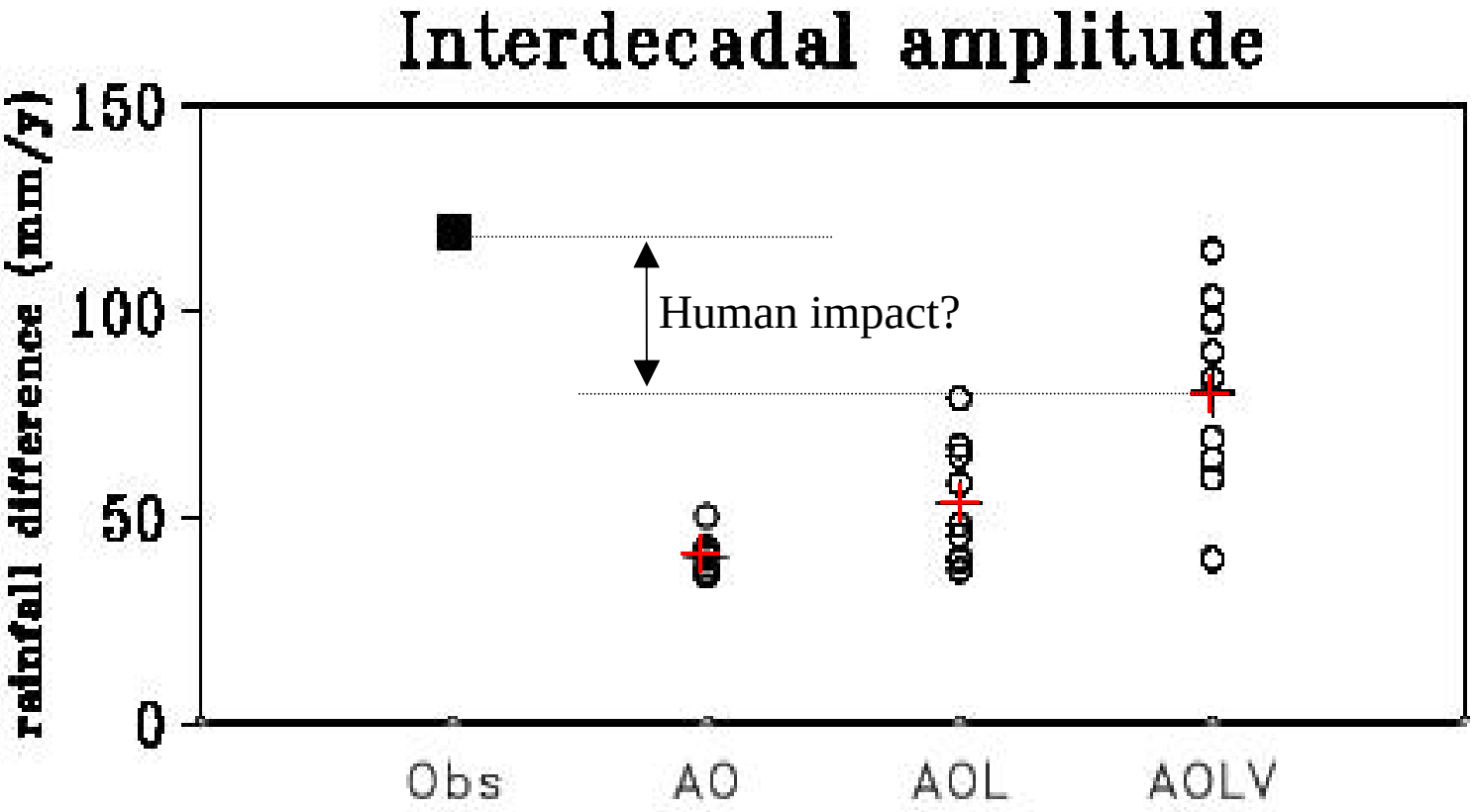
Observation

Atmosphere model forced by SST (AO)

Above+Soil moisture (AOL)

Above + Vegetation (AOLV)

Sahel Drought: Contribution from individual processes



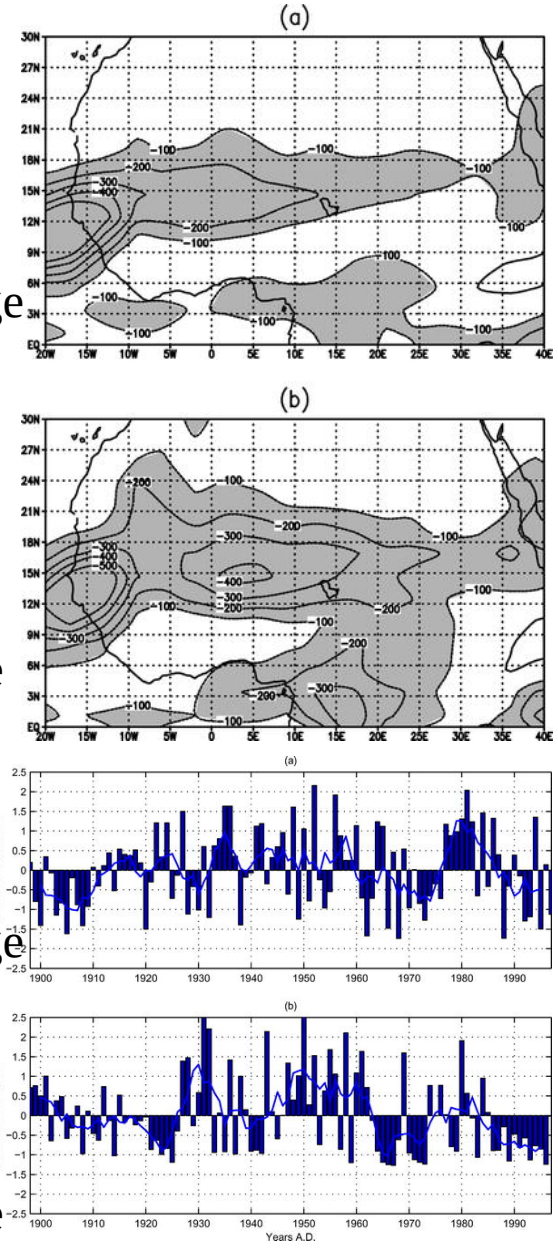
Land/vegetation enhances also internal variability

\+ Ensemble mean

More complex models

No vege

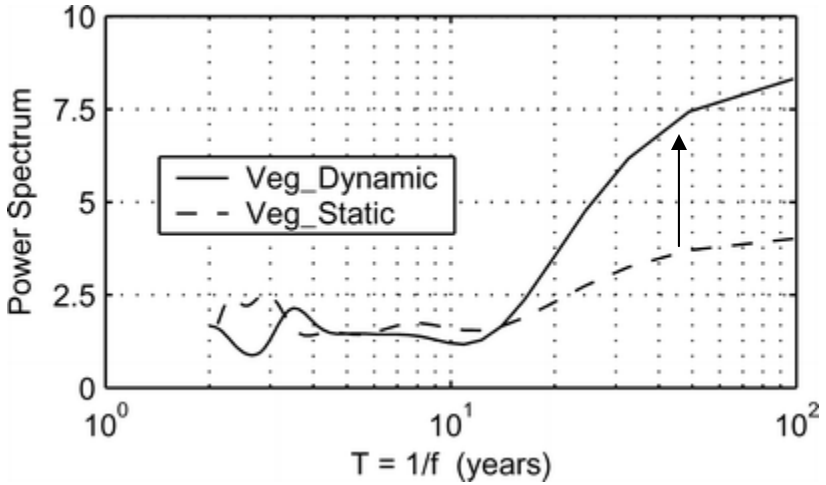
vege



No vege

vege

Power spectrum of rainfall

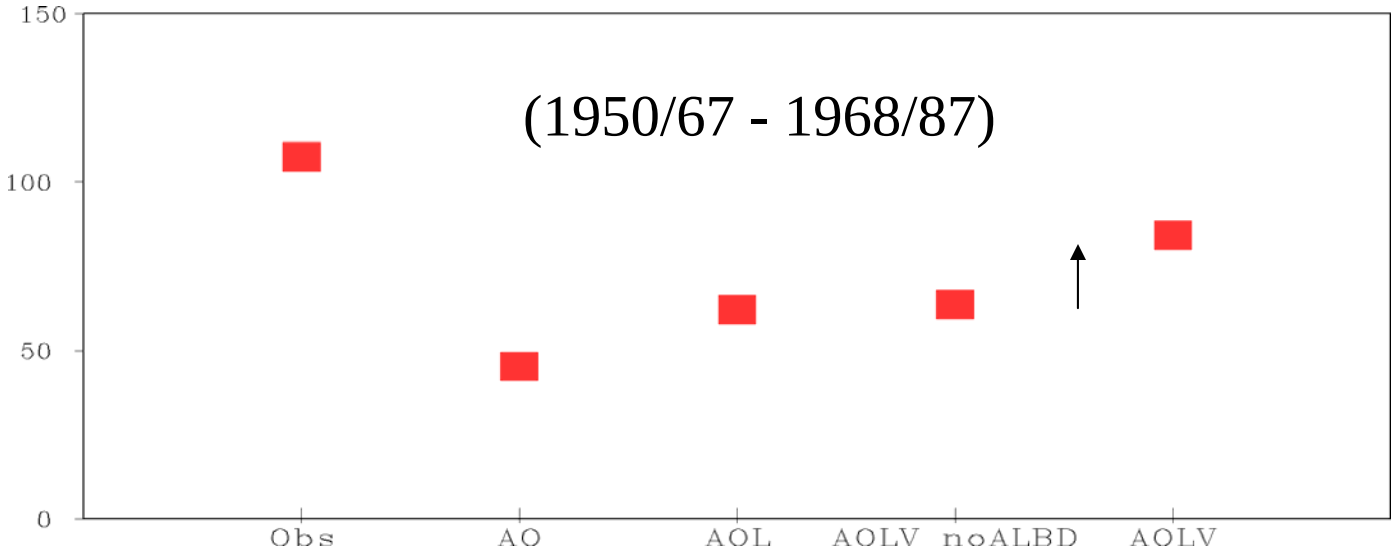


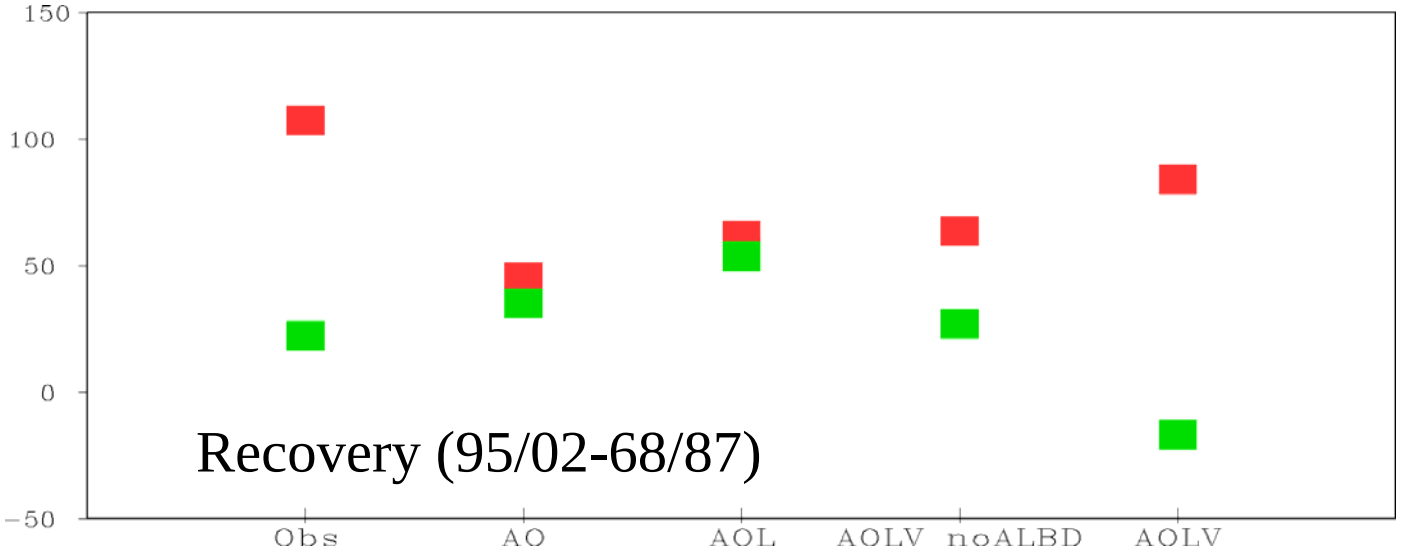
Vegetation effect stronger at low frequency! (predicted by a simple model)

Genesis/IBIS

Wang et al. (2004)

Albedo vs. Evapotranspiration





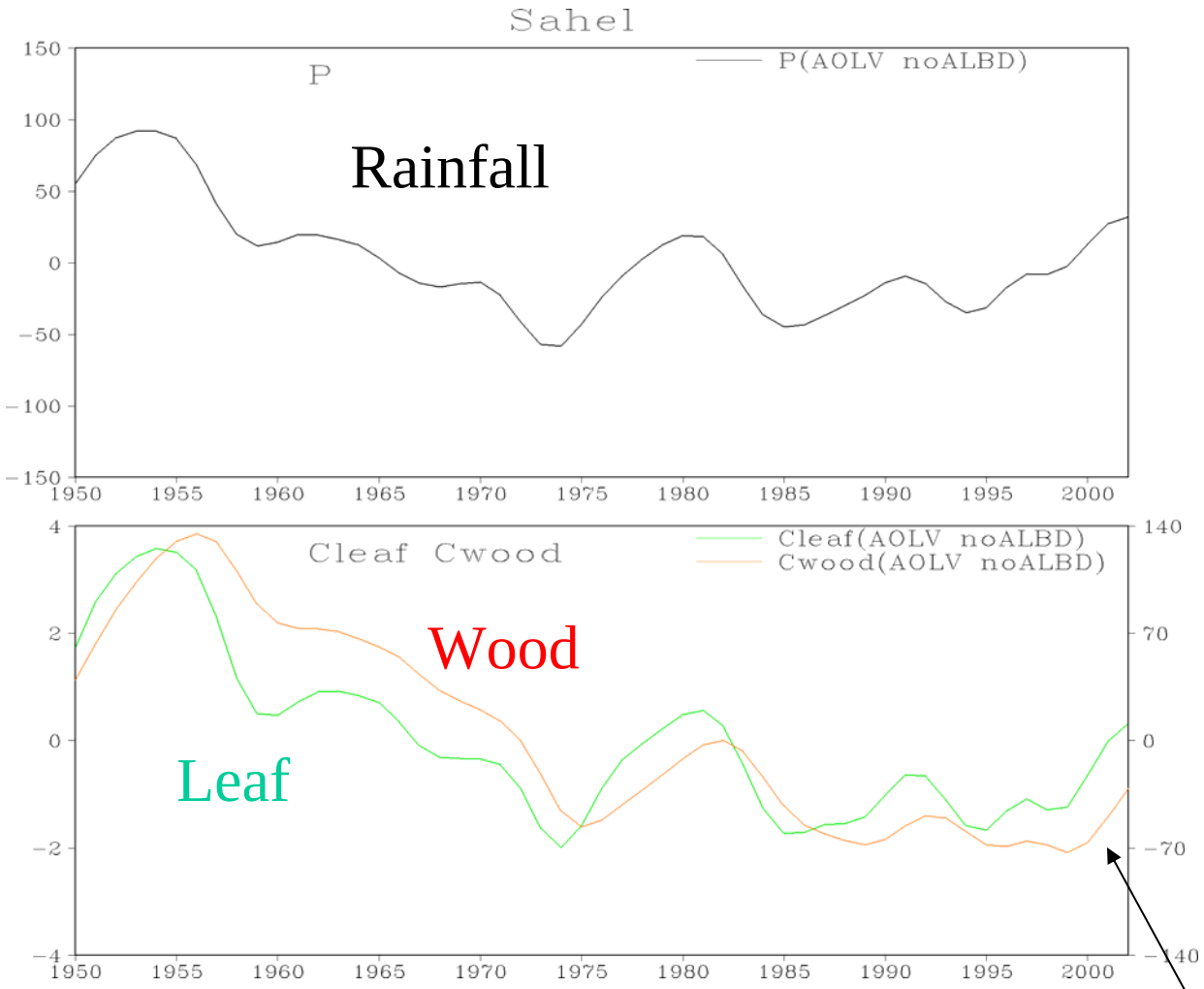
Albedo important:
not in most dynamic vegetation models

Soil moisture and even some vege effects are implicit in AMIP-style models!

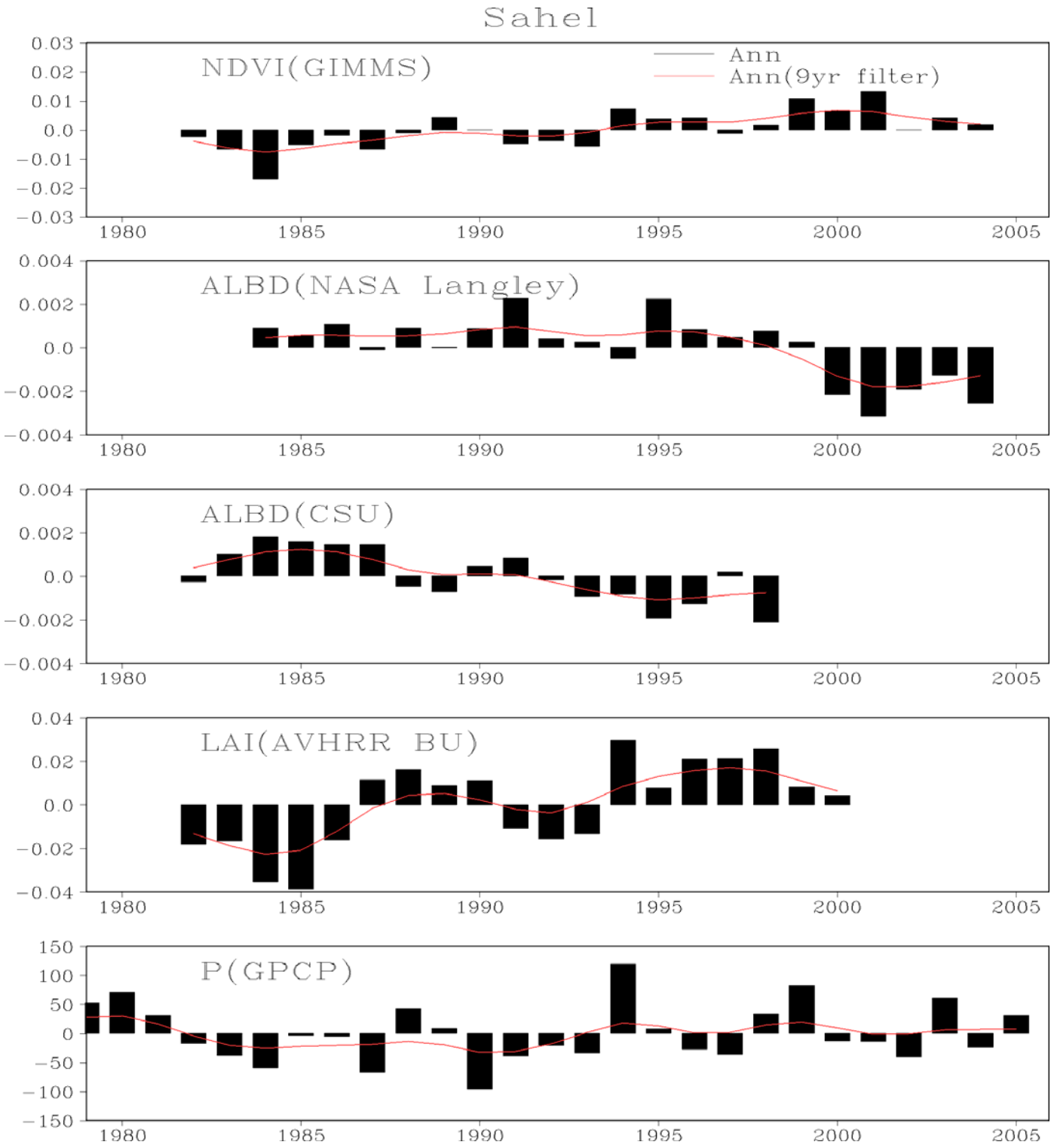
Result from CABO: an Earth system model at UMD (Zeng et al., 2004)

Complexities in vegetation effects

--Delayed response on decadal timescales



Slow response in vegetation



NDVI

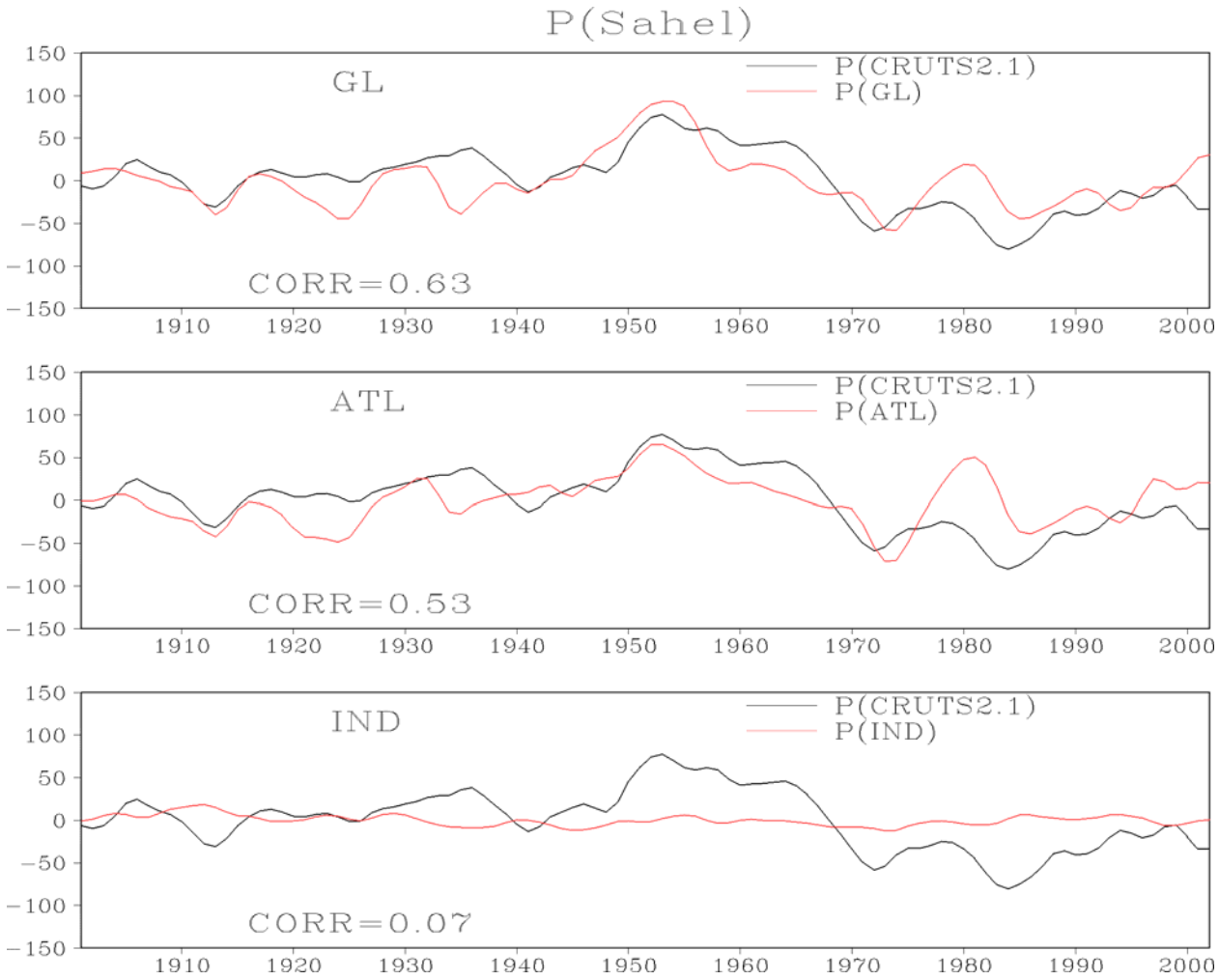
Albedo_Langley

Albedo_CSU

LAI

Precip

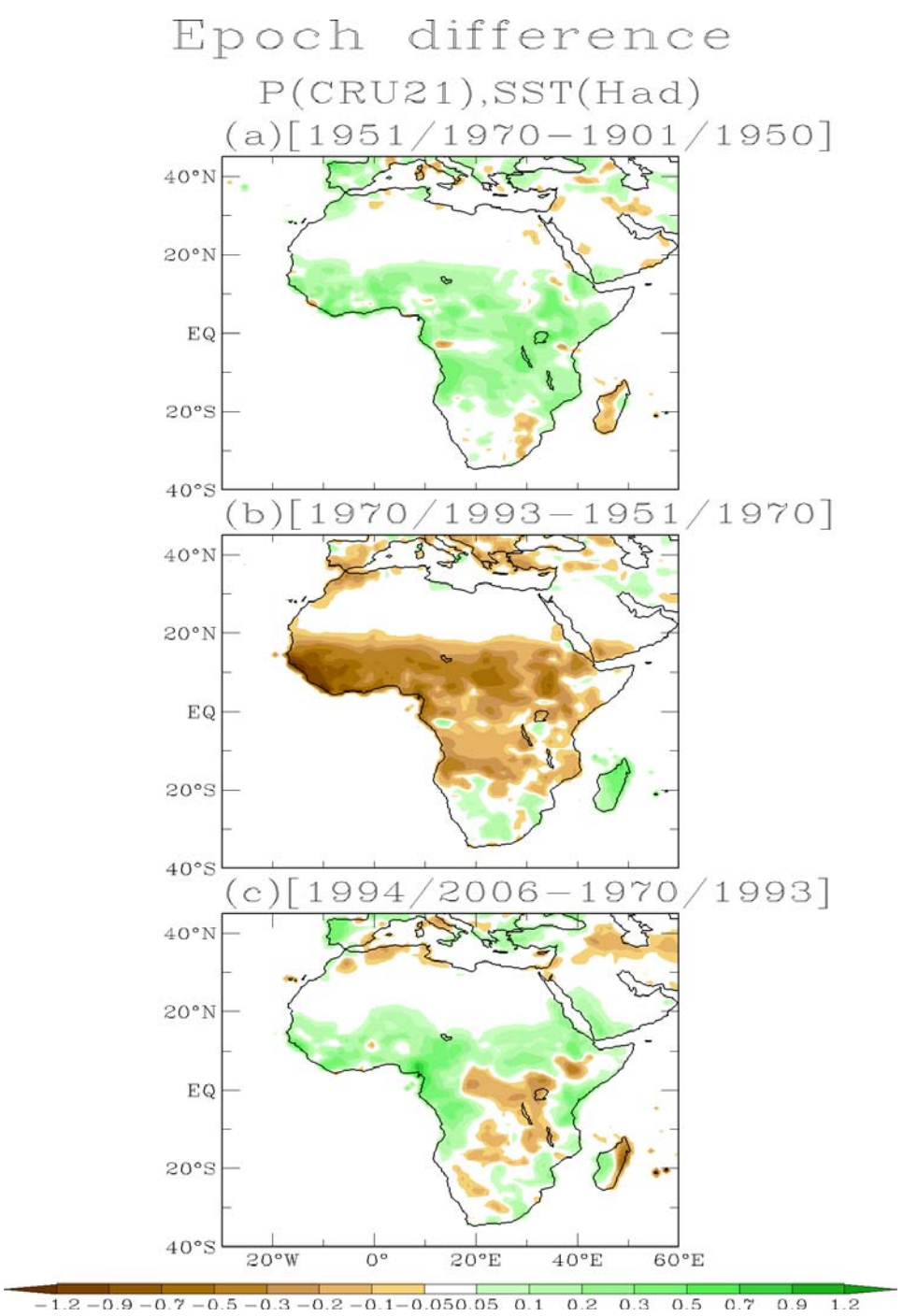
Contribution from basin SSTs



Global

Atlantic

Indian


Epoch difference
P(CRU21),SST(Had)
(a)[1951/1970−1901/1950]
(b)[1970/1993−1951/1970]
(c)[1994/2006−1970/1993]
40°N
20°N
EQ
20°S
40°S
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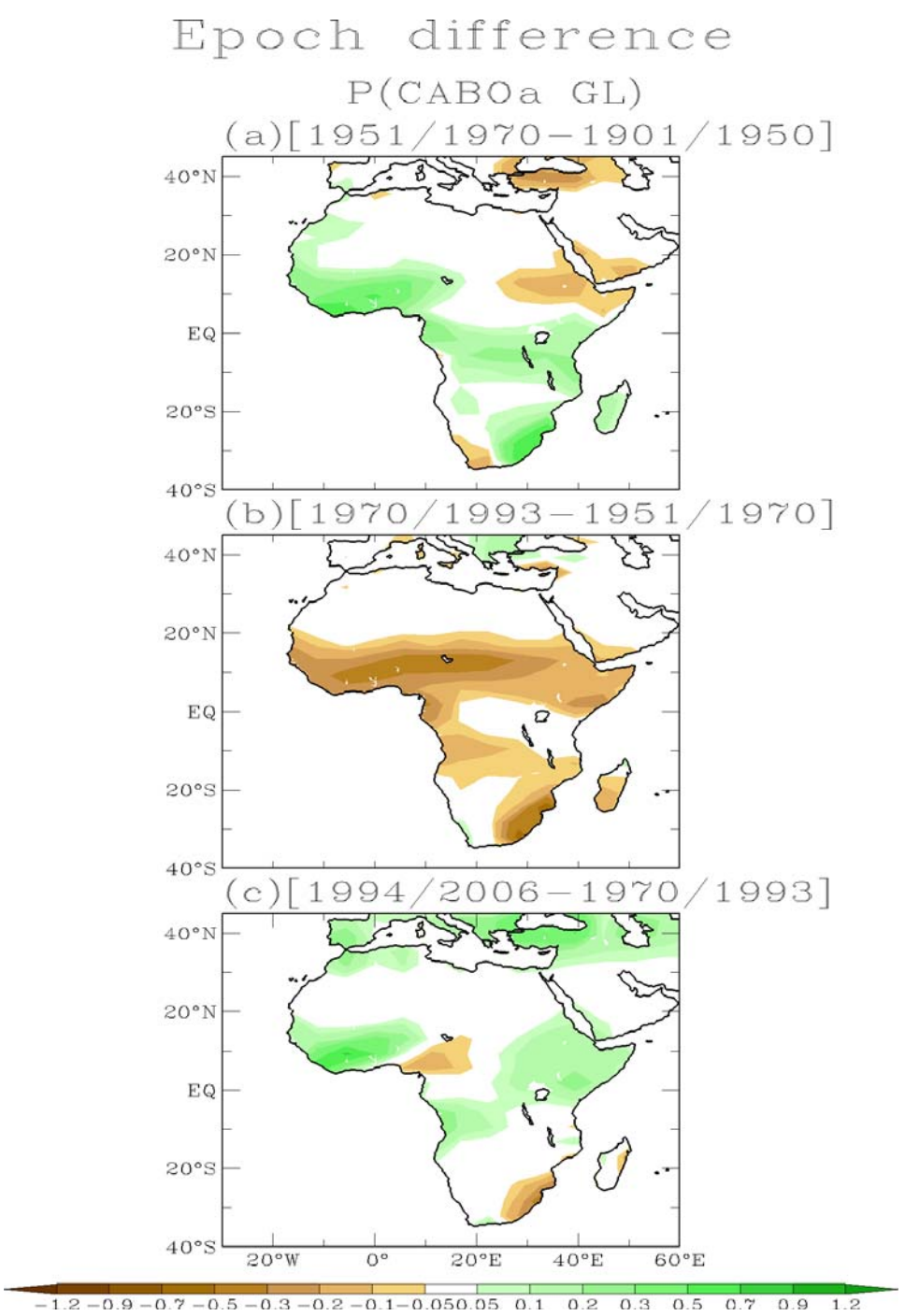
20°E
40°E
60°E
−1.2 −0.9 −0.7 −0.5 −0.3 −0.2 −0.1 −0.05 0.05 0.1 0.2 0.3 0.5 0.7 0.9 1.2


Epoch difference
P(CABOa GL)
(a)[1951/1970−1901/1950]
(b)[1970/1993−1951/1970]
(c)[1994/2006−1970/1993]
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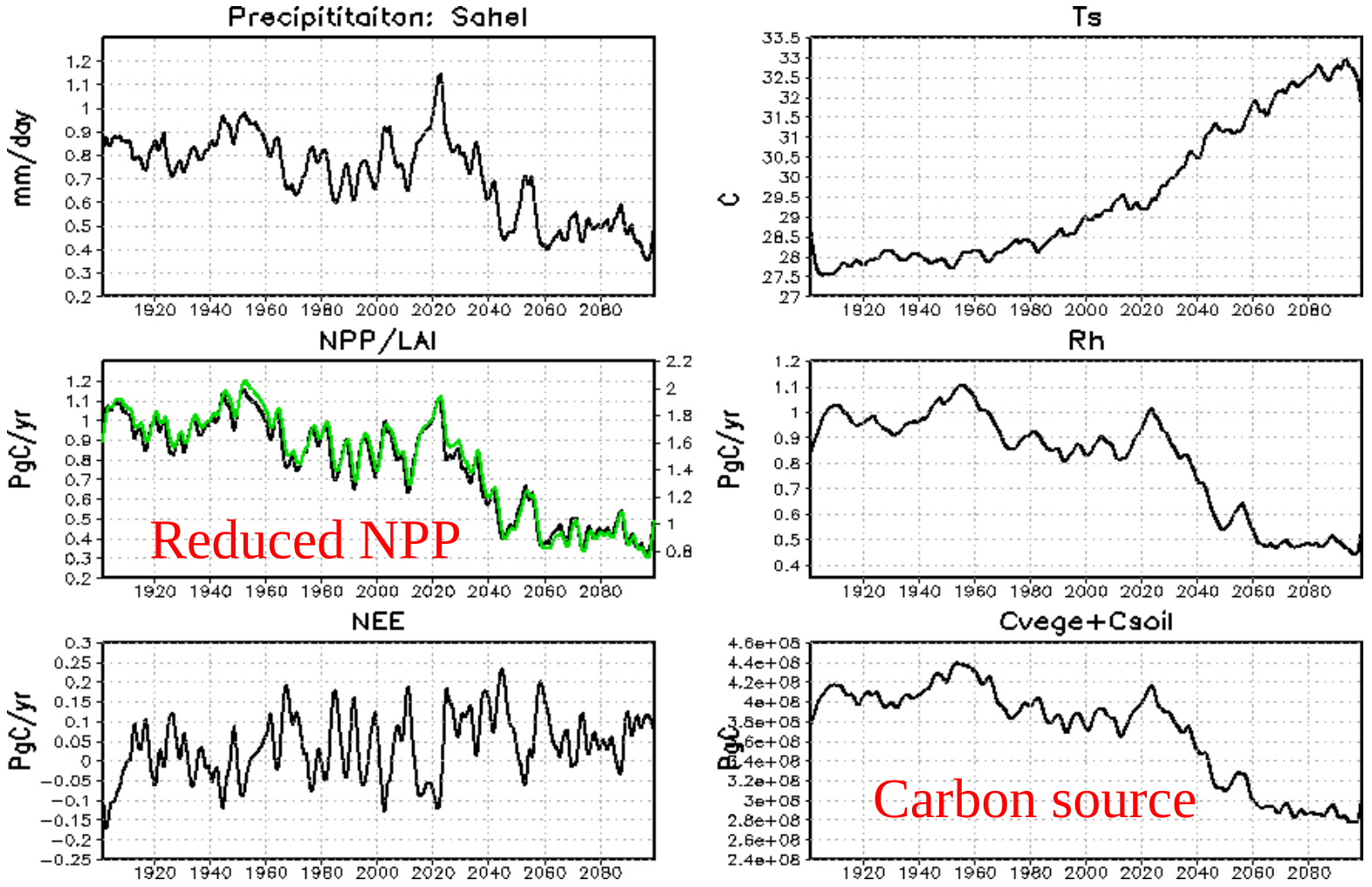
−1.2 −0.9 −0.7 −0.5 −0.3 −0.2 −0.1 −0.05 0.05 0.1 0.2 0.3 0.5 0.7 0.9 1.2

Vulnerability in the Future?

VEGAS forced by GFDLCM2.0 forcing

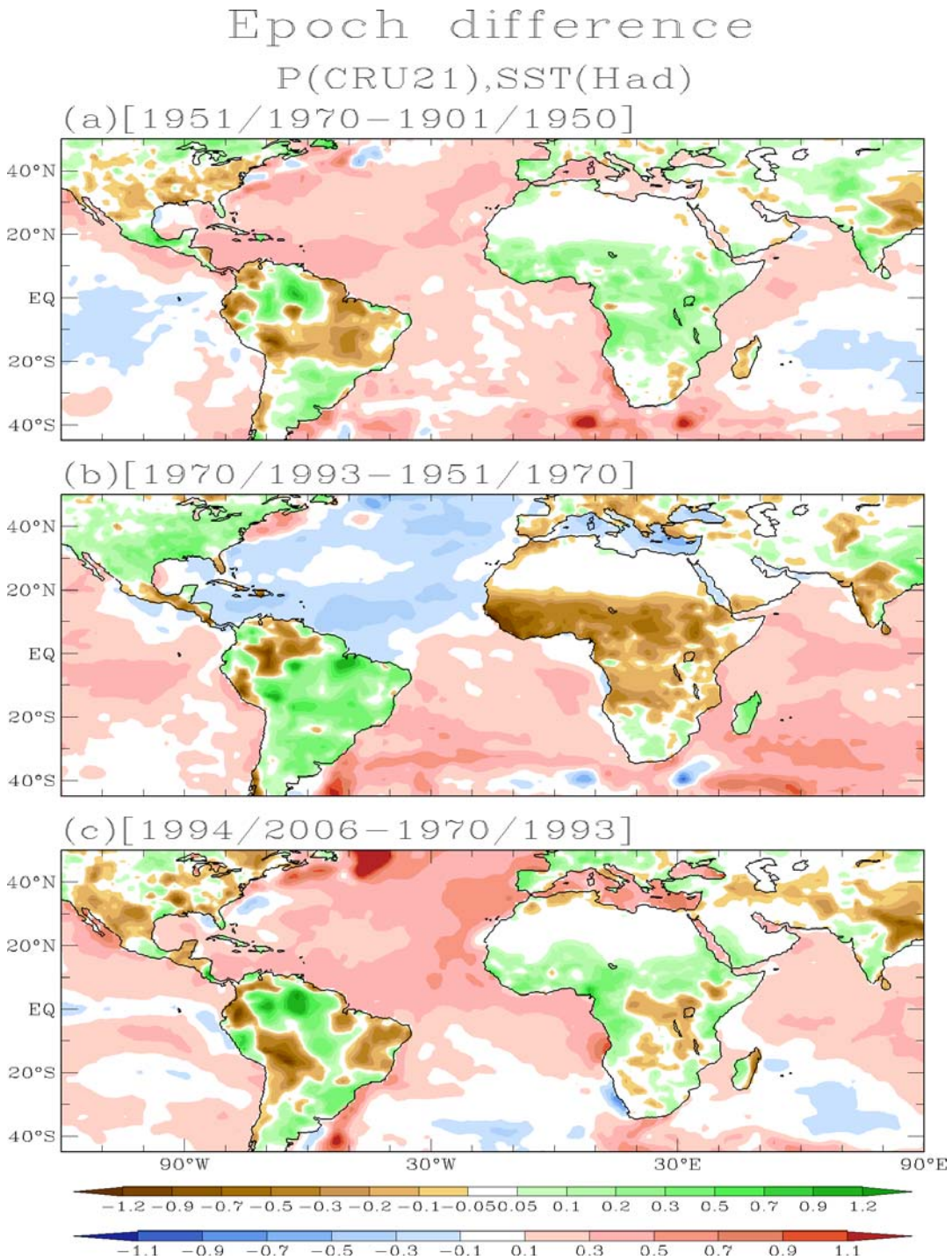


1901

2100

Land experiments under C20C?

- Interactive soil moisture (AOL): standard
- Fixed soil moisture (AO) — Easy
  - Climatology of soil moisture from AOL
- Dynamic Vegetation
  - Complex
  - Simple: dLAI/dt <= (swet) — Relatively easy
    LAI => Albedo, Evaporation
- Land use — More complex


Epoch difference
P(CRU21),SST(Had)
(a)[1951/1970−1901/1950]
(b)[1970/1993−1951/1970]
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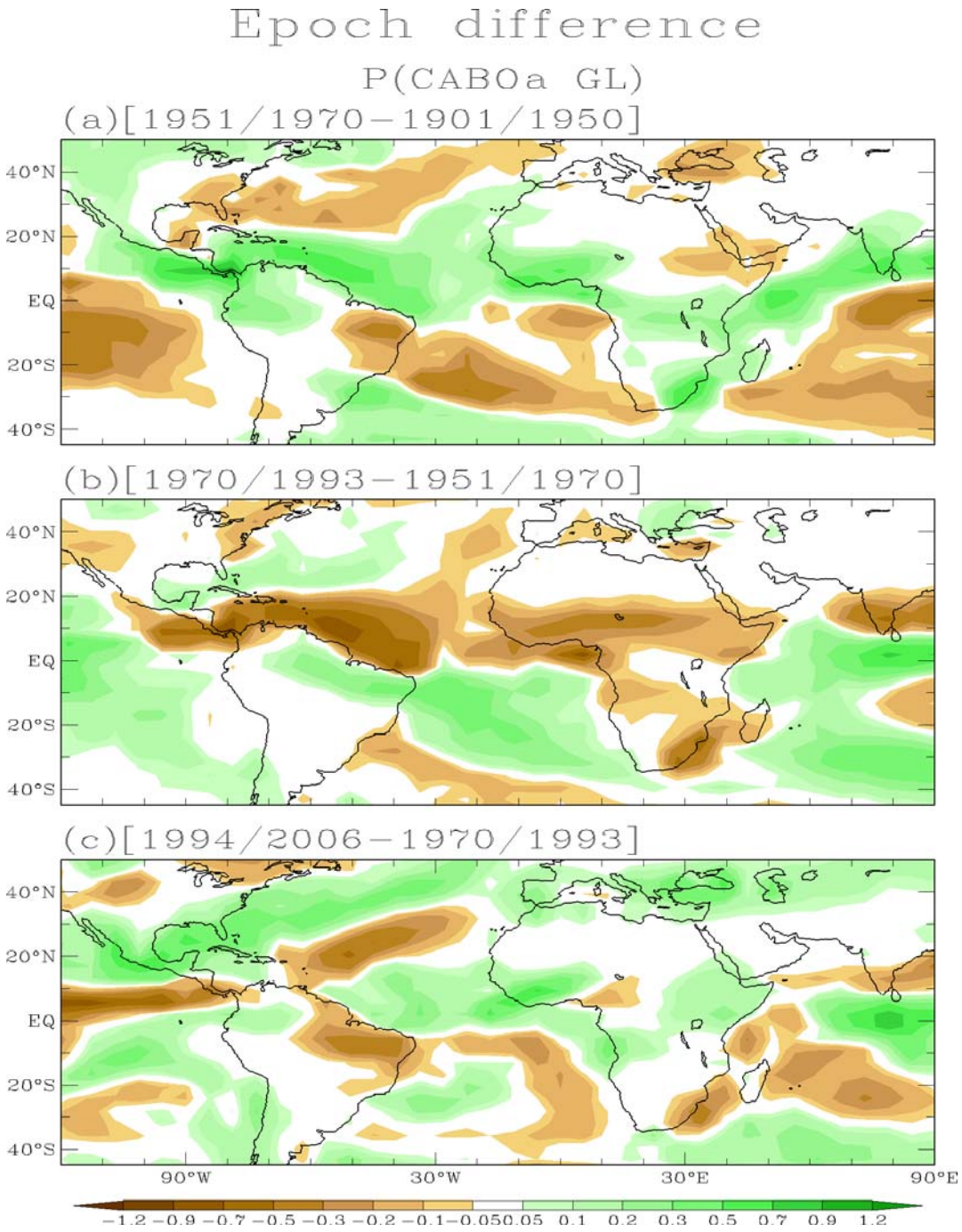
Epoch difference
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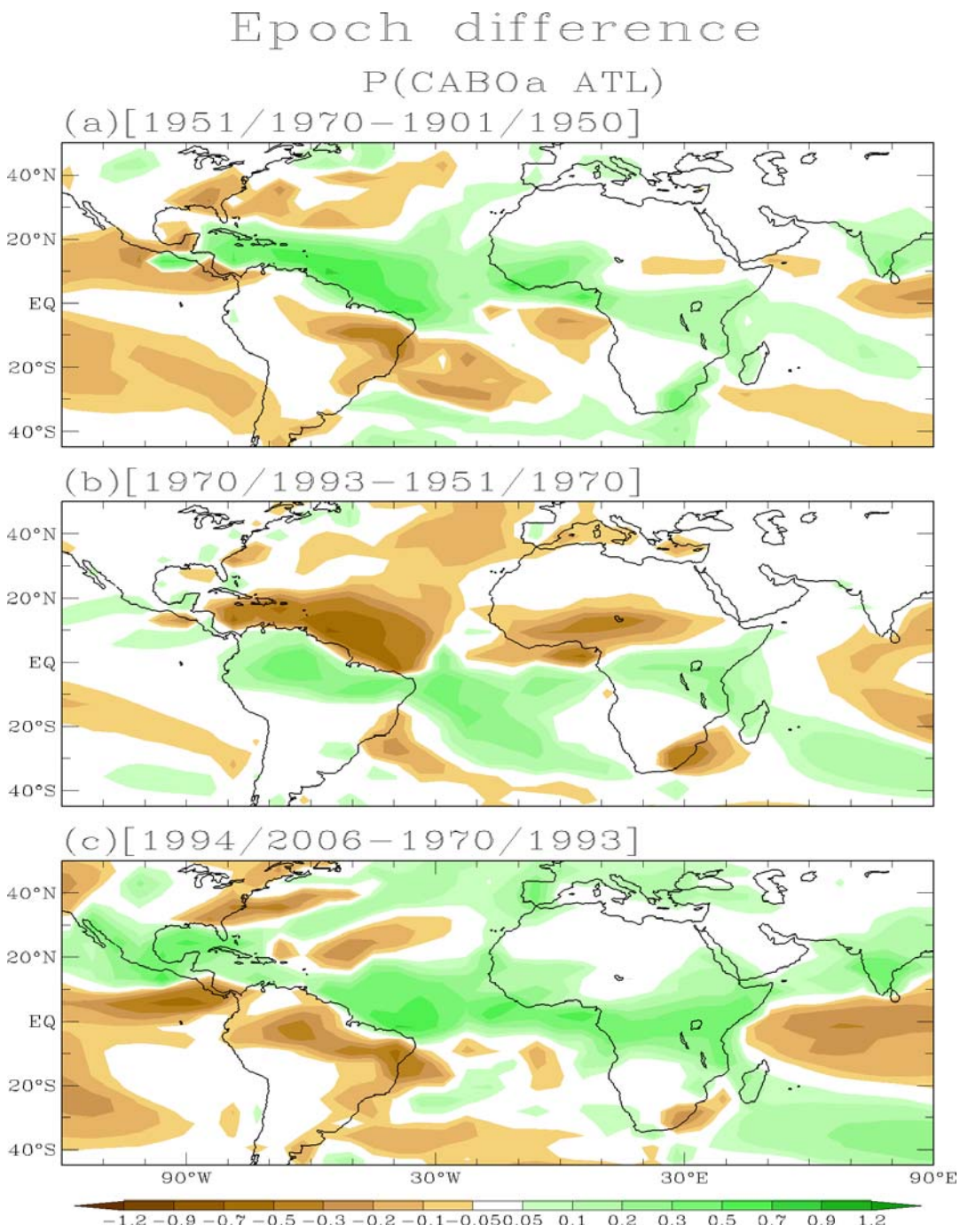
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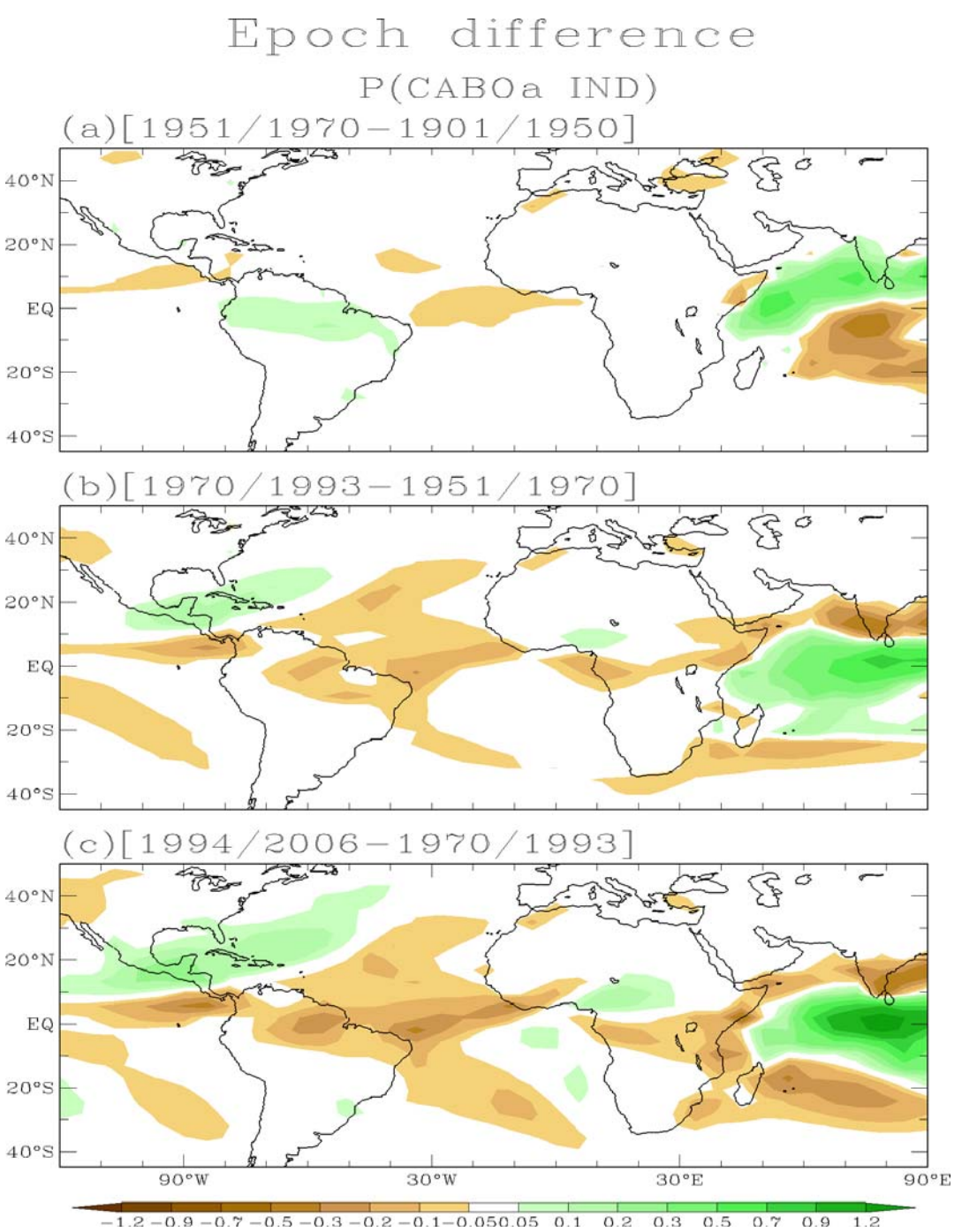
Epoch difference
P(CABOa IND)
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(b)[1970/1993−1951/1970]
(c)[1994/2006−1970/1993]
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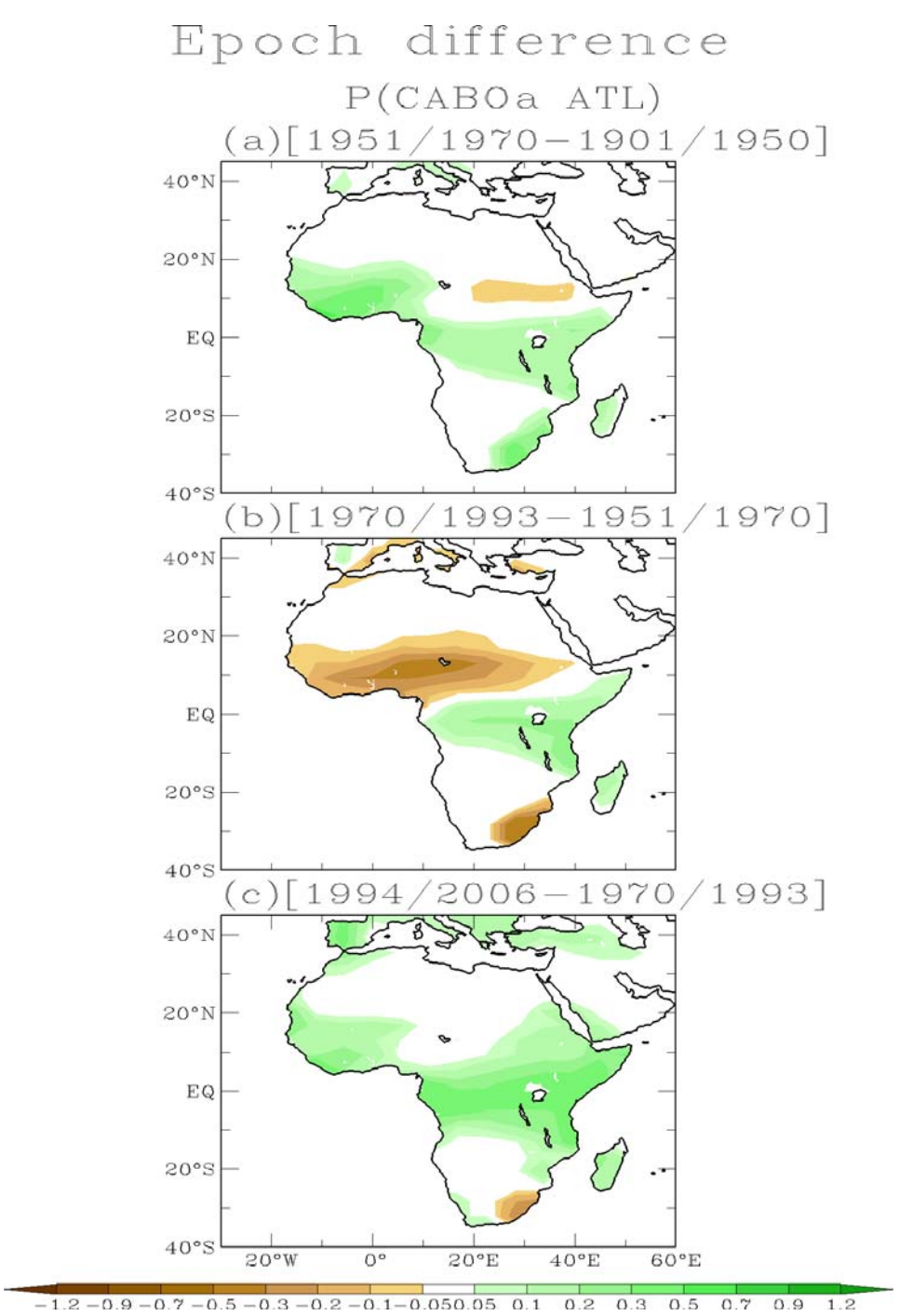
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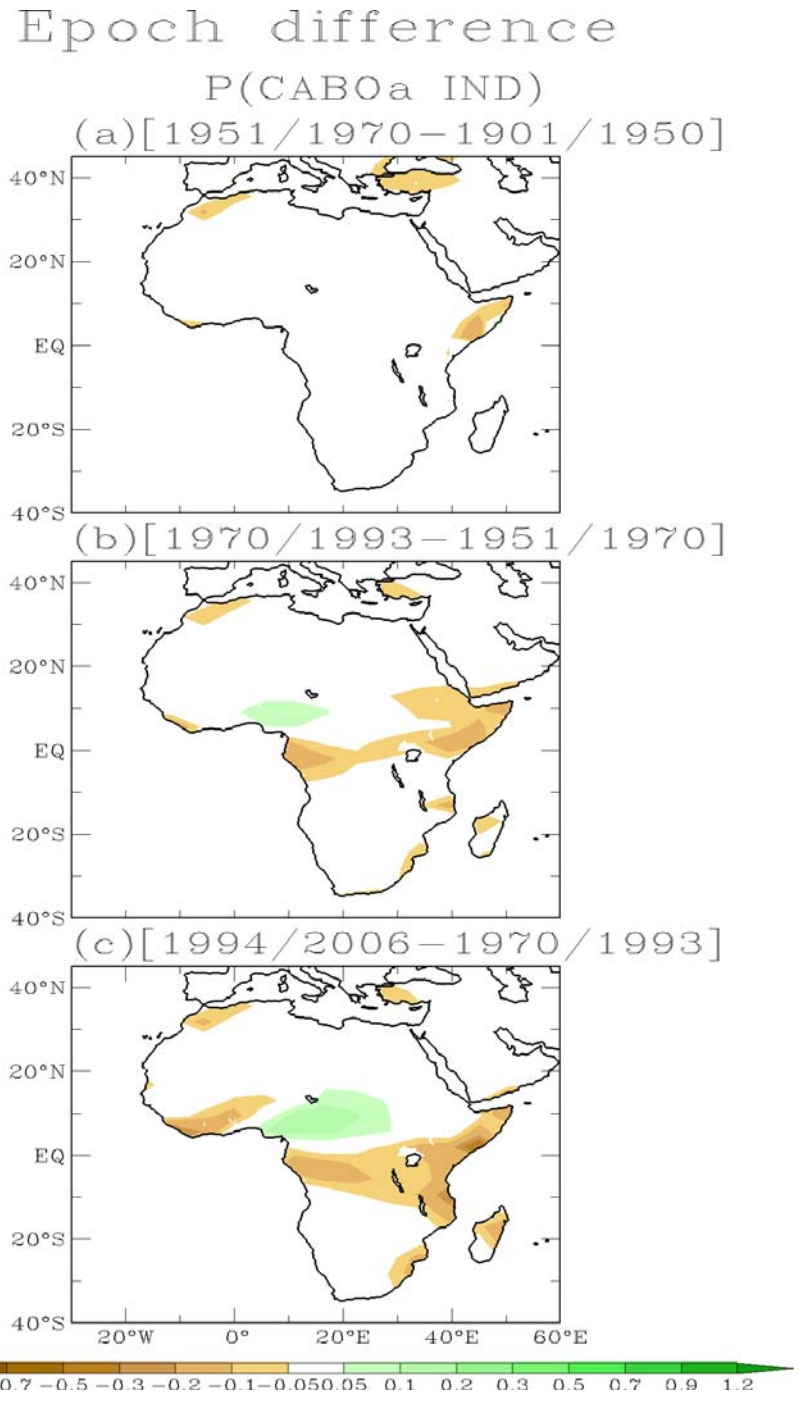
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P(CABOa IND)
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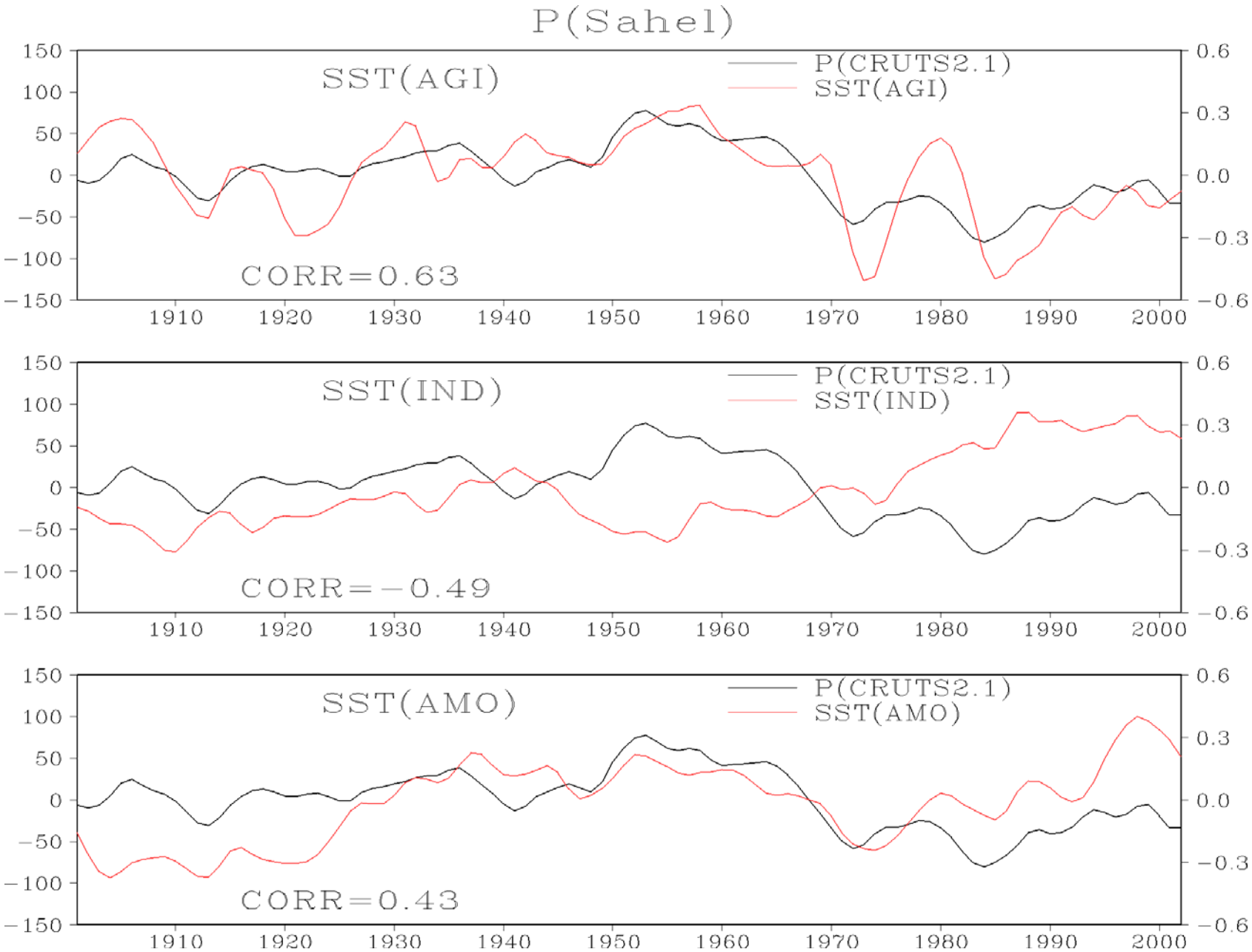
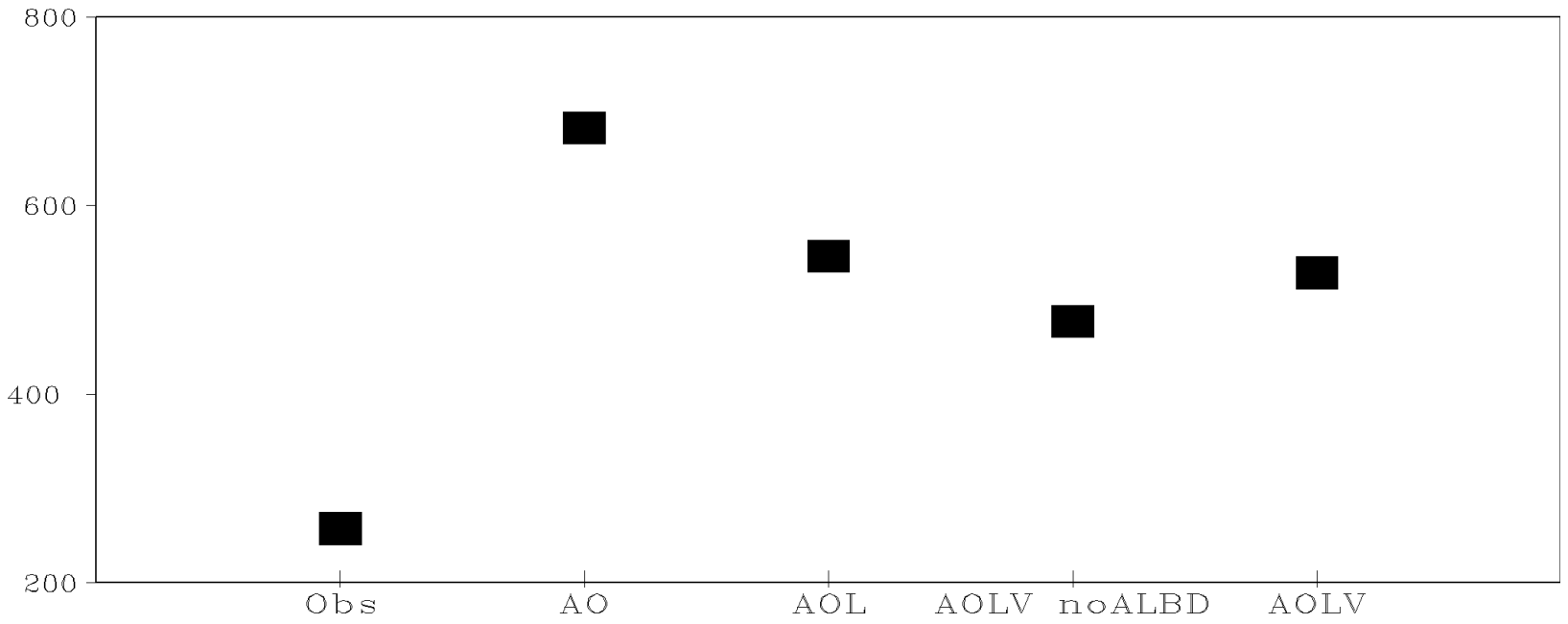
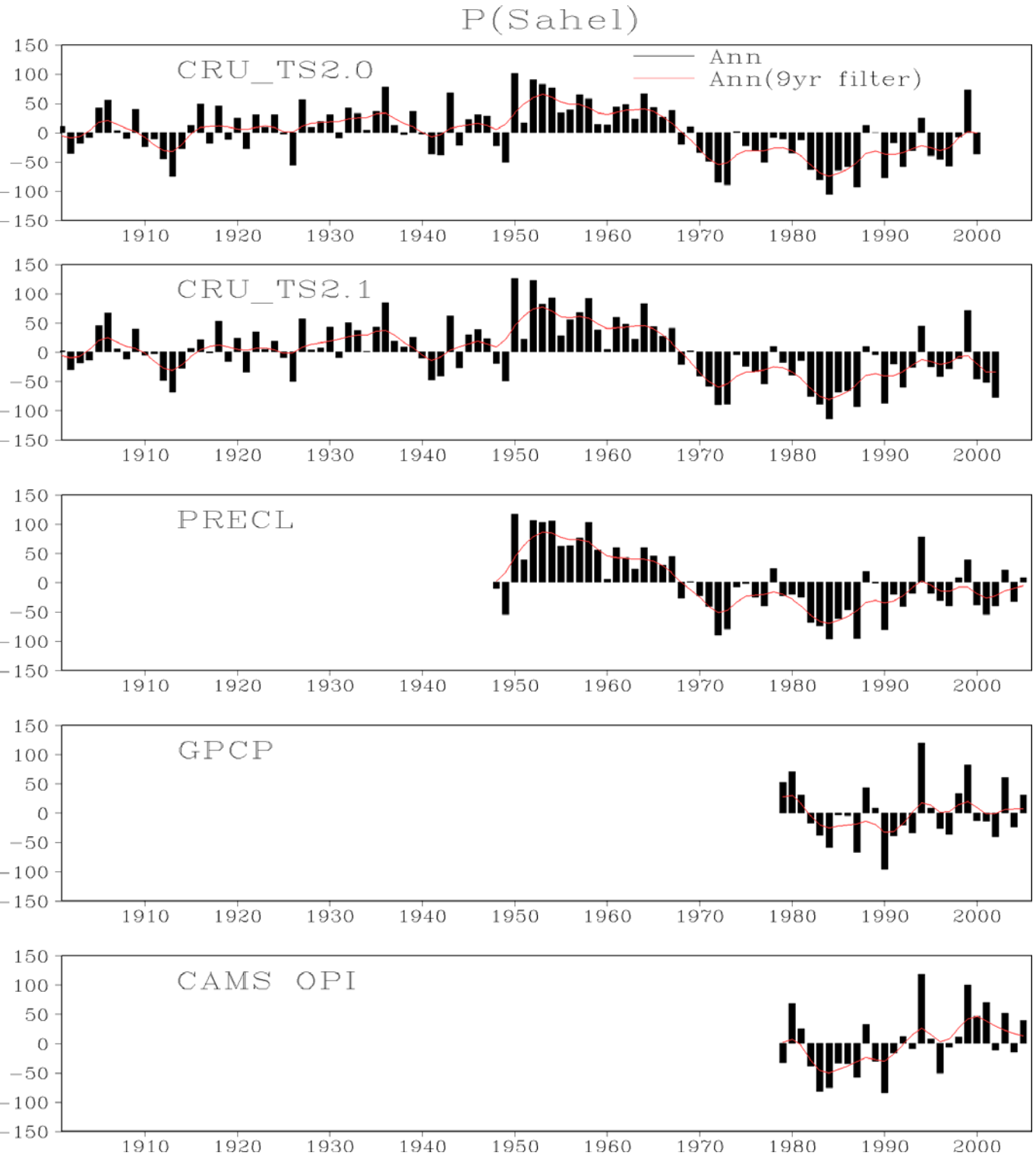
Sahel rainfall and SST indices



Annual Total Rainfall over SAHEL




P(Sahel)
CRU_TS2.0
Ann
Ann(9yr filter)
CRU_TS2.1
PRECL
GPCP
CAMS OPI
150
100
50
0
−50
−100
−150
1910
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1940
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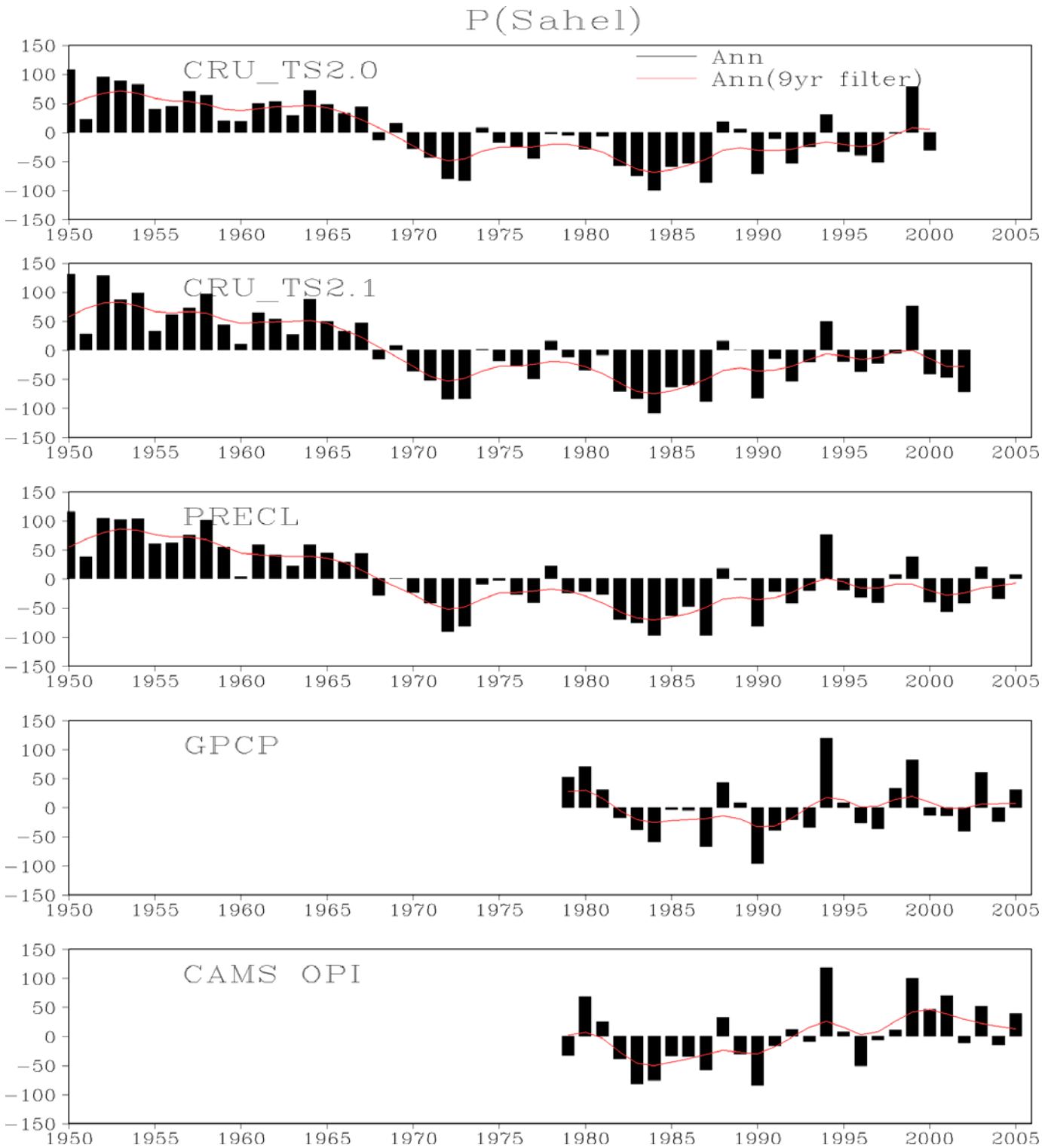
1990
2000


P(Sahel)
CRU_TS2.0
Ann
Ann(9yr filter)
CRU_TS2.1
PRECL
GPCP
CAMS OPI
150
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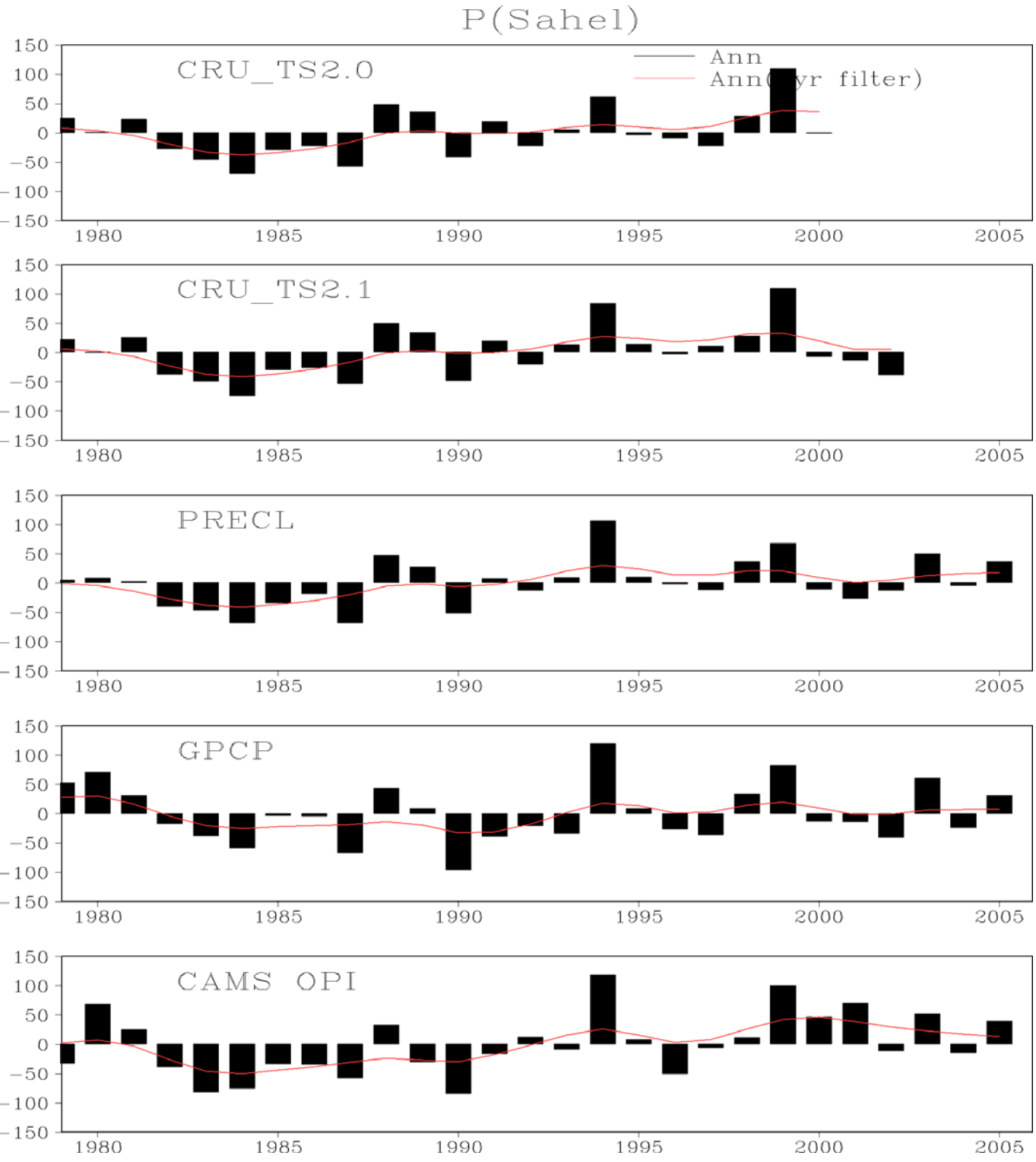
2005


P(Sahel)
CRU_TS2.0
Ann
Ann(5yr filter)
CRU_TS2.1
PRECL
GPCP
CAMS OPI
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100
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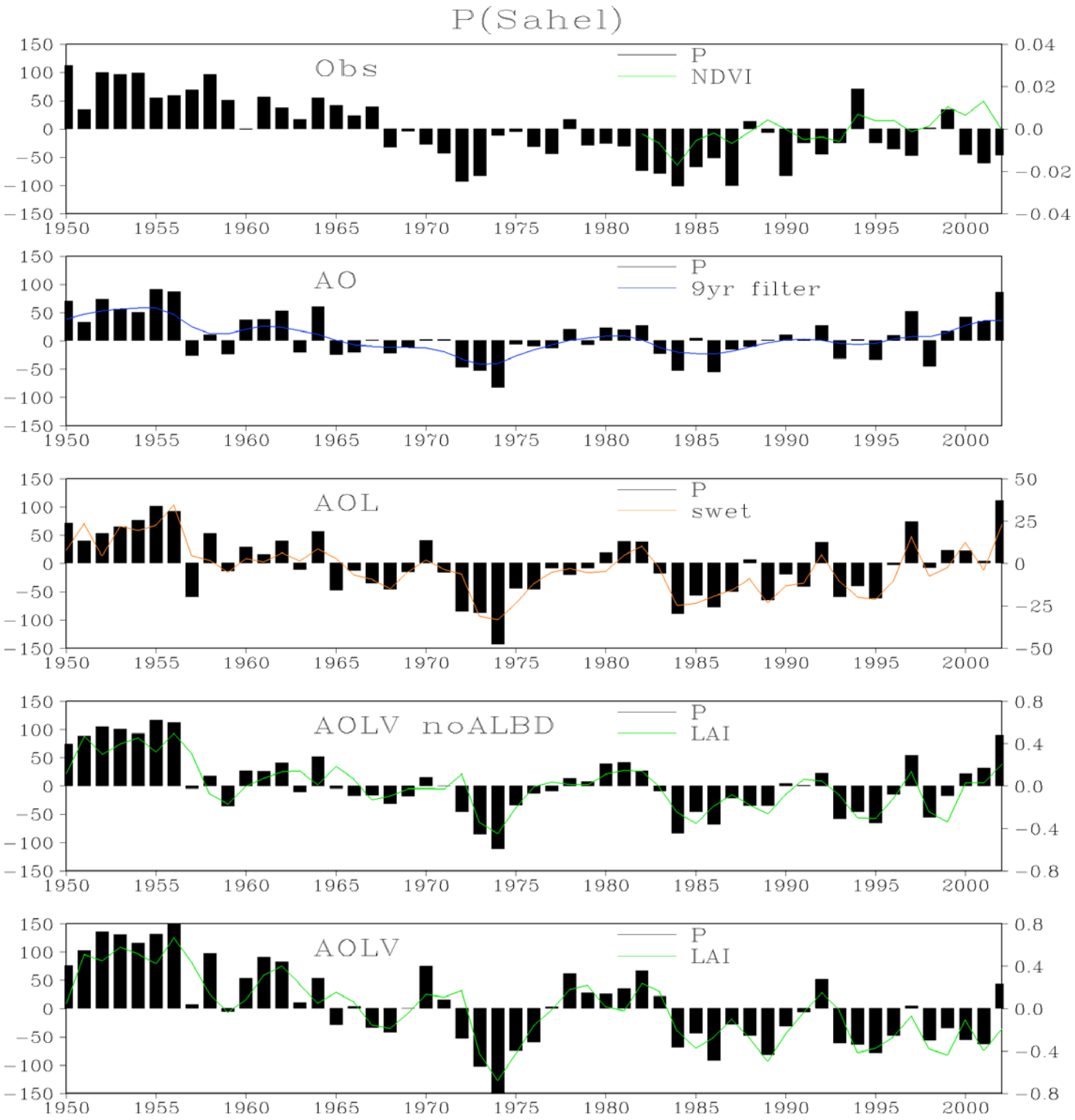
0
−50
−100
−150
1980
1985
1990
1995
2000
2005


P(Sahel)
Obs
P
NDVI
AO
P
9yr filter
AOL
P
swet
AOLV noALBD
P
LAI
AOLV
P
LAI
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000