Transient Simulation of Northern African Climate-Ecosystem in the Holocene:
----Climate Variability vs. Vegetation Feedback
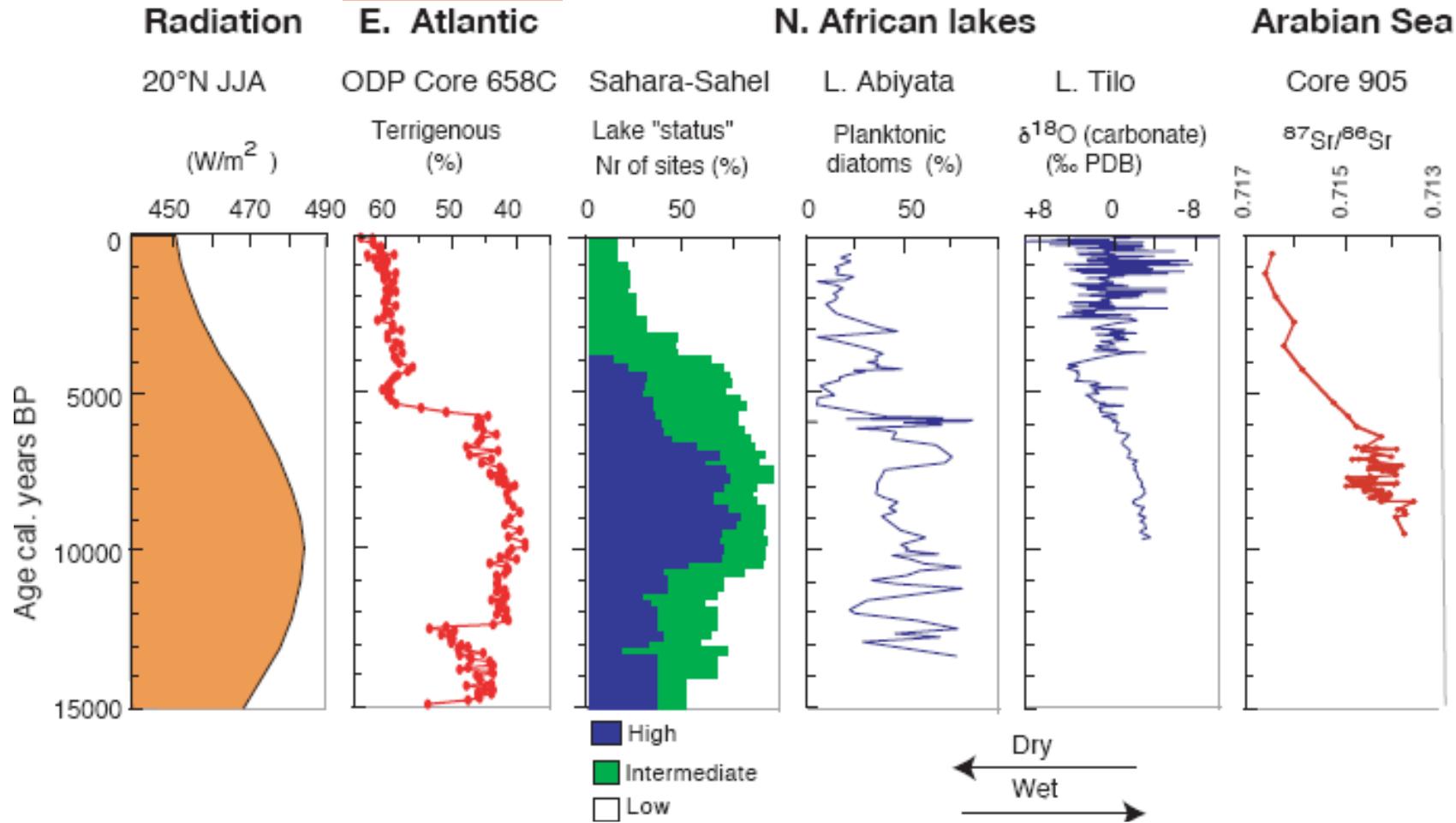
Z. Liu
**Center for Climatic Research**
University of Wisconsin-Madison

Collaborators
M Notaro, Y., Wang, R. Gallimore, **UW-Madison**
I.C. Prentice, **Dept. Earth Sciences, Univ. Bristol, Ul**
*R. Jacob,* **Argonne National Laboratory, DOE**

Abrupt !

Radiation — 20°N JJA (W/m²): 450, 470, 490

E. Atlantic — ODP Core 658C, Terrigenous (%): 60, 50, 40

N. African lakes
- Sahara-Sahel — Lake "status", Nr of sites (%): 0, 50
- L. Abiyata — Planktonic diatoms (%): 0, 50
- L. Tilo — $\delta^{18}O$ (carbonate) (‰ PDB): +8, 0, −8

Arabian Sea — Core 905, $^{87}Sr/^{86}Sr$: 0.717, 0.715, 0.713

Age cal. years BP: 0, 5000, 10000, 15000

Legend:
- High (blue)
- Intermediate (green)
- Low (white)

Dry ← / Wet →
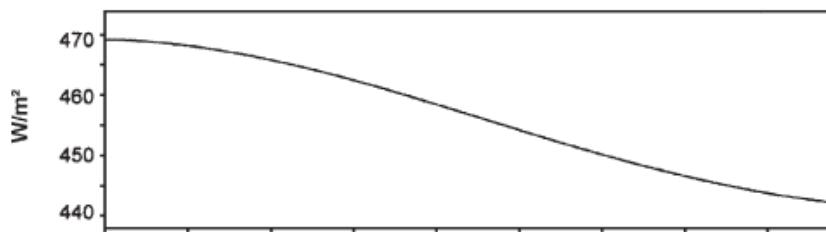
Motivation for Transition Simulation

abrupt changes
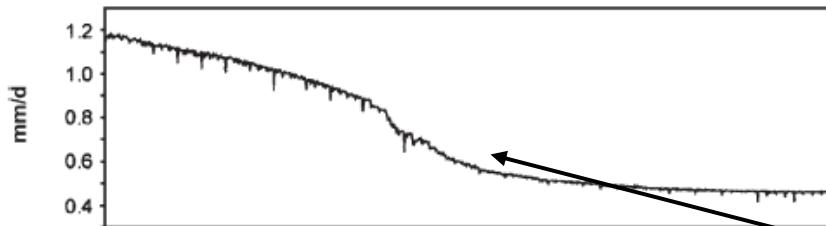
paleo model-data comparison

Int Atm.+ Int Veg (CLIMBER2)
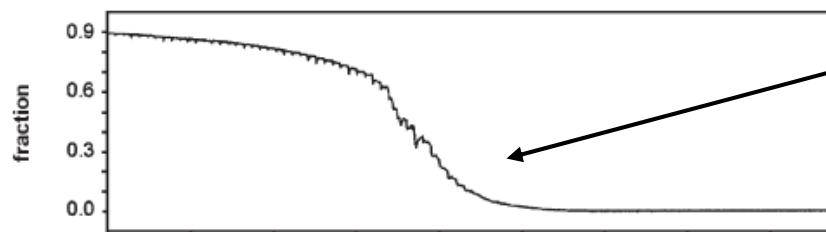
Insolation
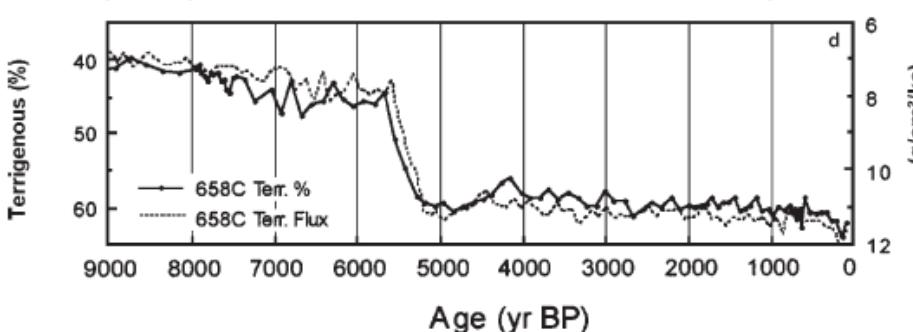
Precipitation

Vegetation

Obs (dust)

Positive vegatation feedback
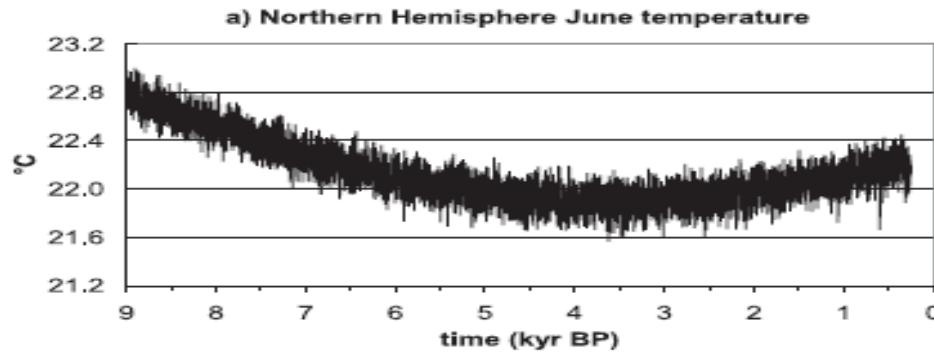
(Multiple equilibrium)
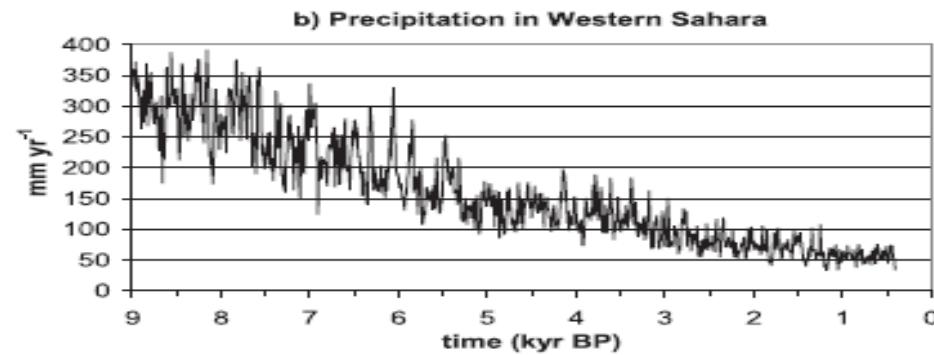
Abrupt

Change !

Unstable Collapse

Claussen et al., 1999, GRL

QG Atmosphere + Int Veg

June Temp

a) Northern Hemisphere June temperature

Precipitation

b) Precipitation in Western Sahara

Vegetation

c) Vegetation cover in Western Sahara

Abrupt ?

Renssen et al., 2003, GRL
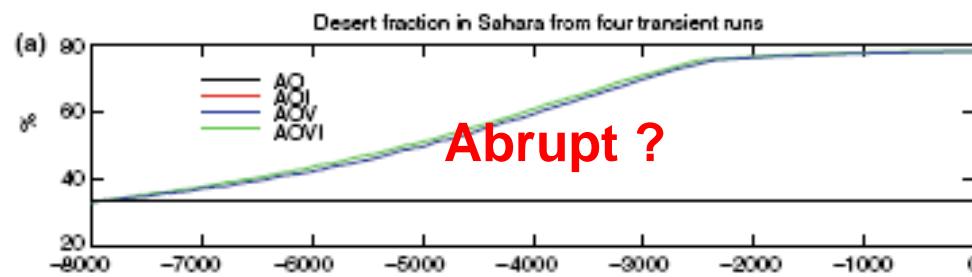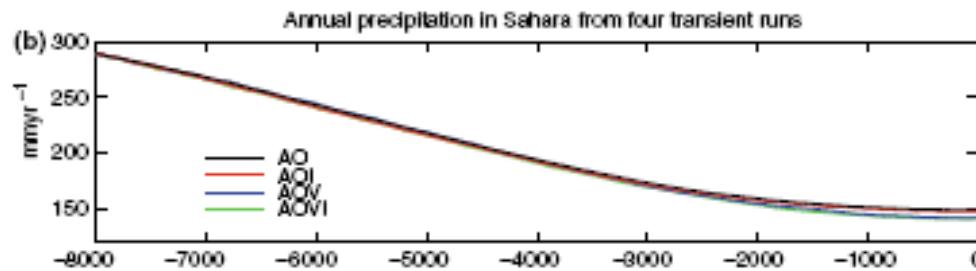
McGill Model: EBA + Int Veg

Desert fraction

Precipitation

Desert fraction in Sahara from four transient runs

Annual precipitation in Sahara from four transient runs

Abrupt ?

Wang et al., 2006

Summer Insolation decrease

↓

Vegetation decrease

abruptly !

5000 yrs BP !!

FOAM_LPJ Transient Simulation: 6500 ➔ 0 yrs
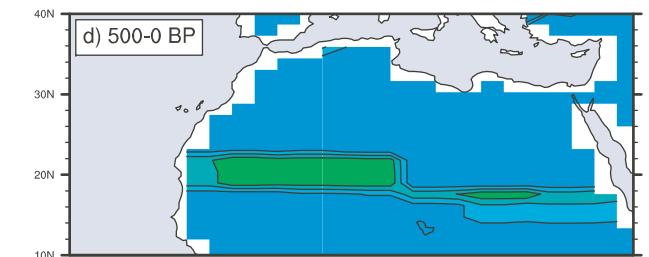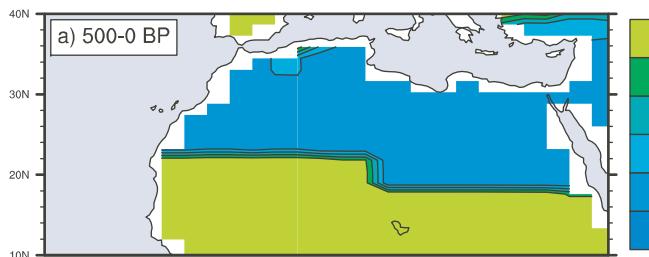
Vegetation Cover
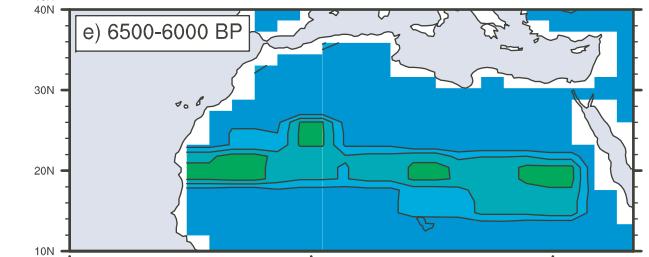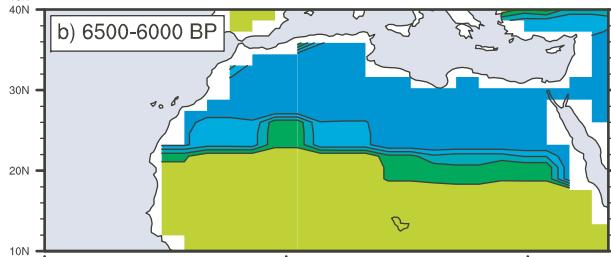
Total Veg   Grass

Africa Total Vegetation and Grass Fractions

Liu et al., 2006, GRL, Liu et al., 2007, QSR
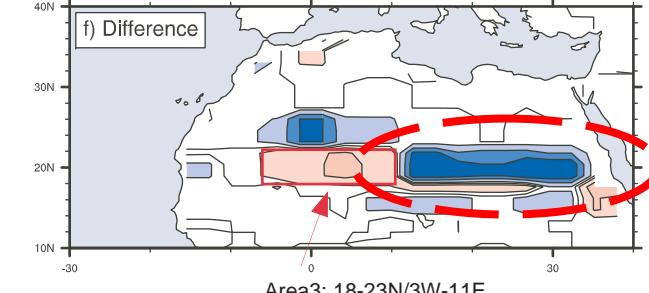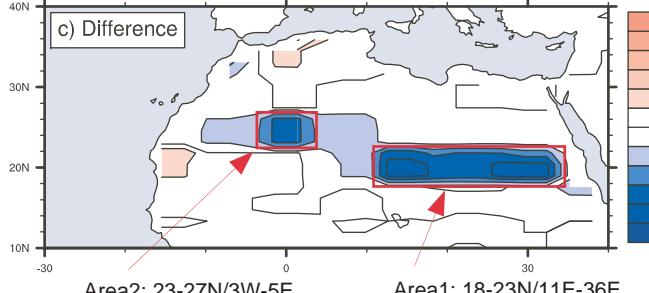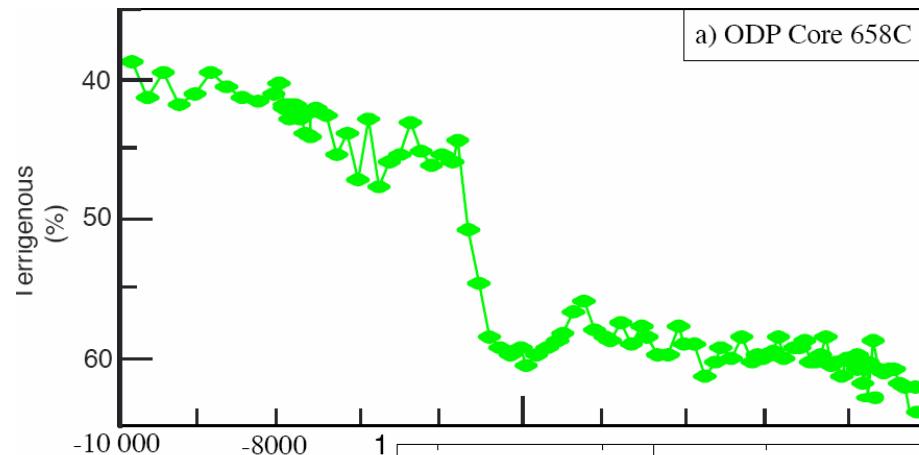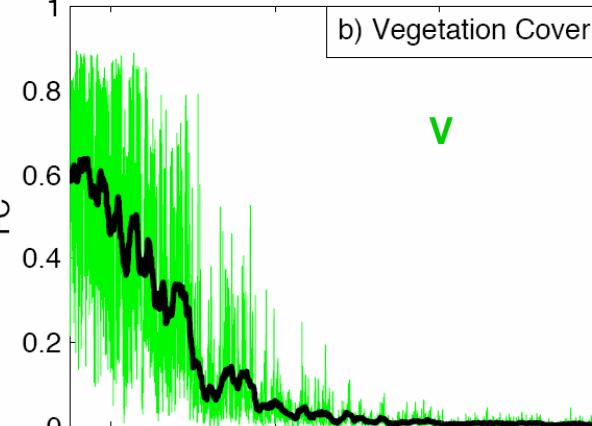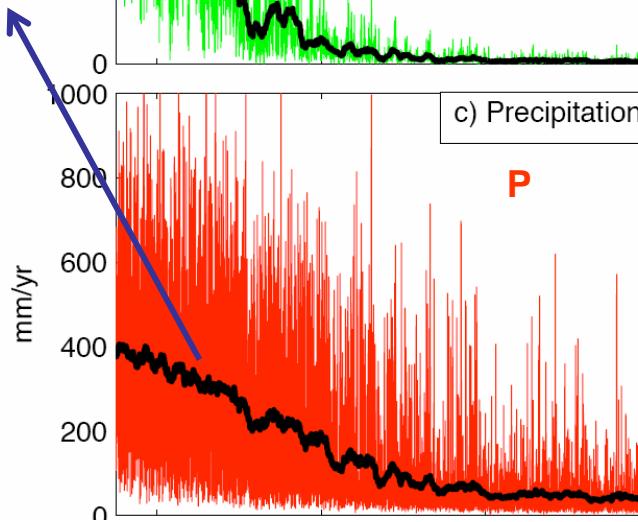
Observation

Model

Positive Vege Feedback??

Notaro et al., 2007

Global Change Biology

Implication:

- **Mechanism?**
- **Observation?**

A Conceptual Climate-Vegetation Model

Equilibrium

Transient

Veg.

$$V_E(P) = \begin{cases} 1 \\ (P - P_{C1})/D_C \\ 0 \end{cases}$$

$$\frac{dV}{dt} = \frac{V_E(P) - V}{\tau}$$

Atm.
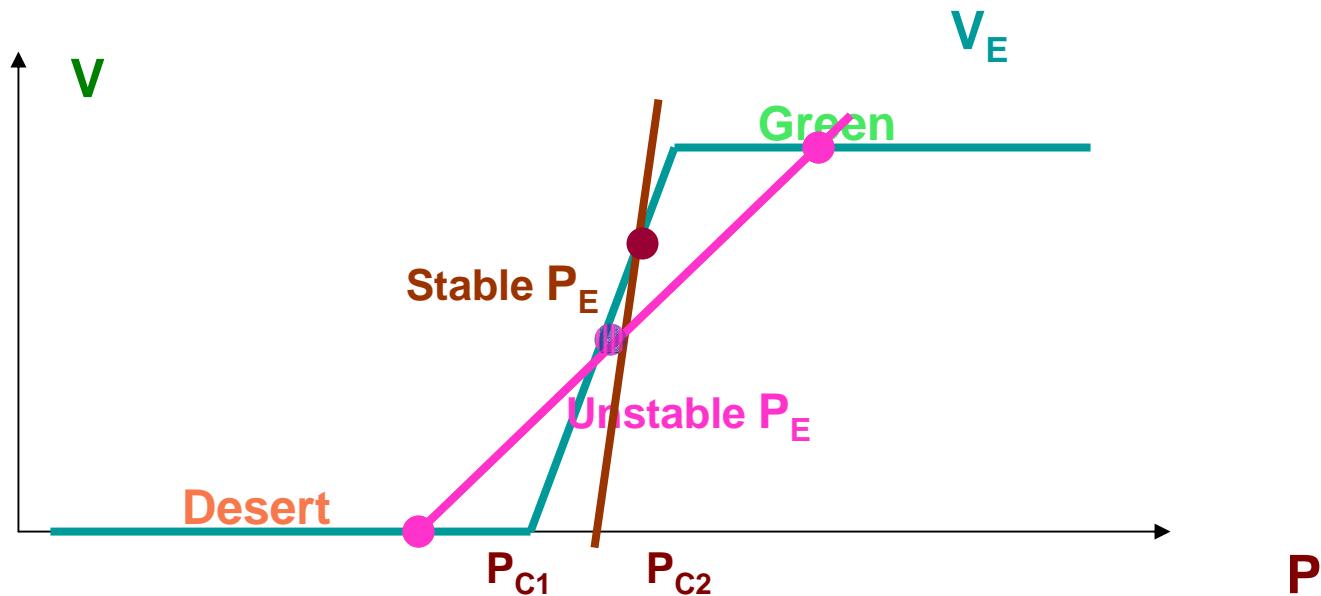
$$P_E(V,t) = P_d(t) + D_B V$$
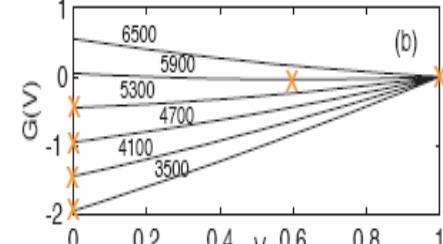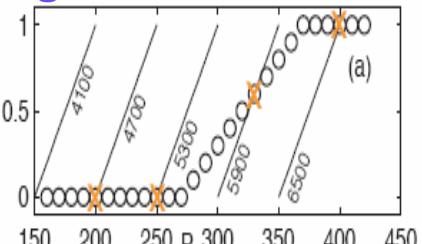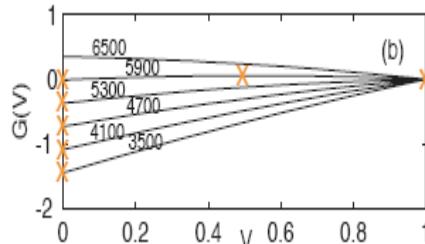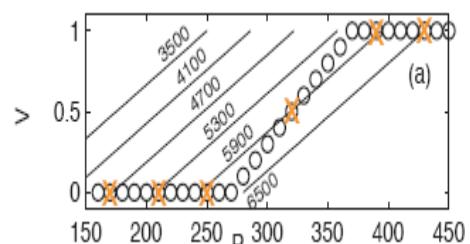
$$P(V,t) = P_E(V,t) + P_N(t)$$

Unstable Case

Stable Case

Forcing

Unstable Collapse

Steady

## Stable Decline

CLIMBER2

**McGill**
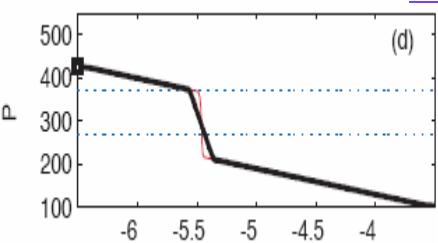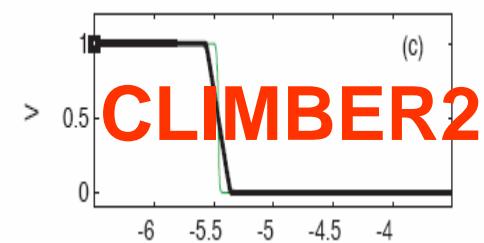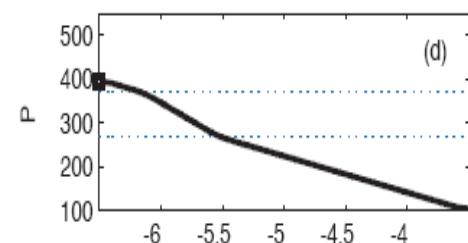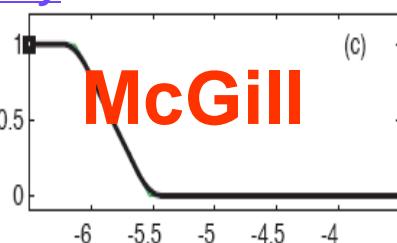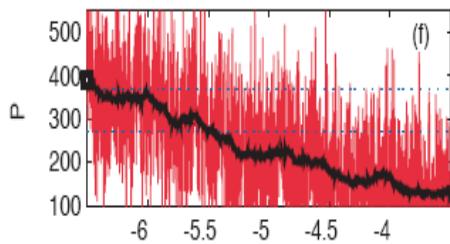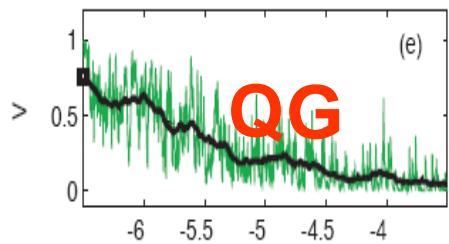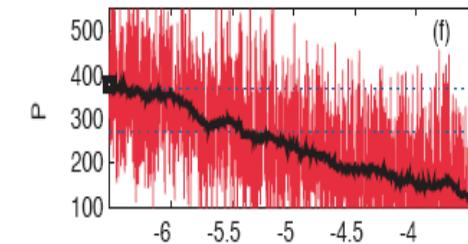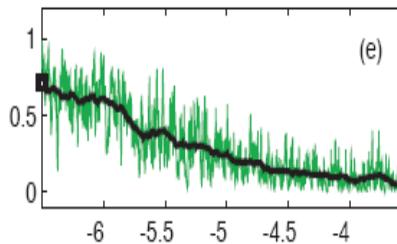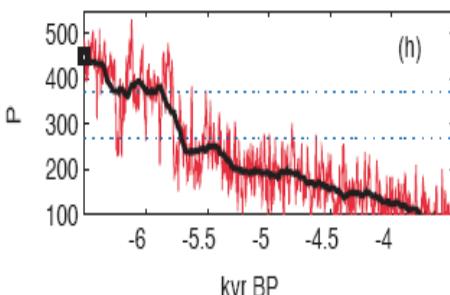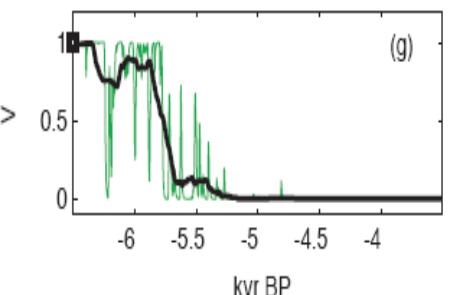
Stochastic suppression

Annual Stochastic

Stochastic suppression

QG
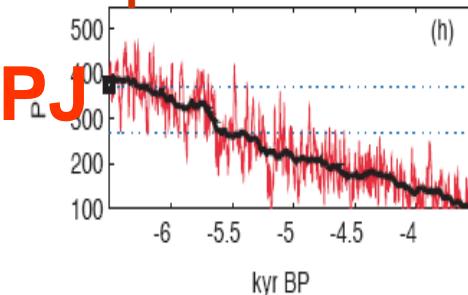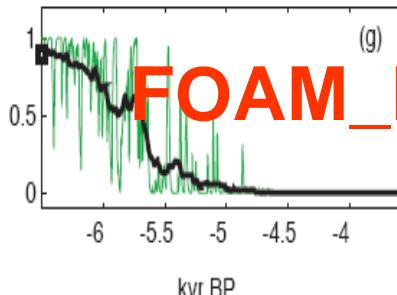
## Unstable Collapse

## Decadal Stochastic

Stable Collapse

FOAM_LPJ
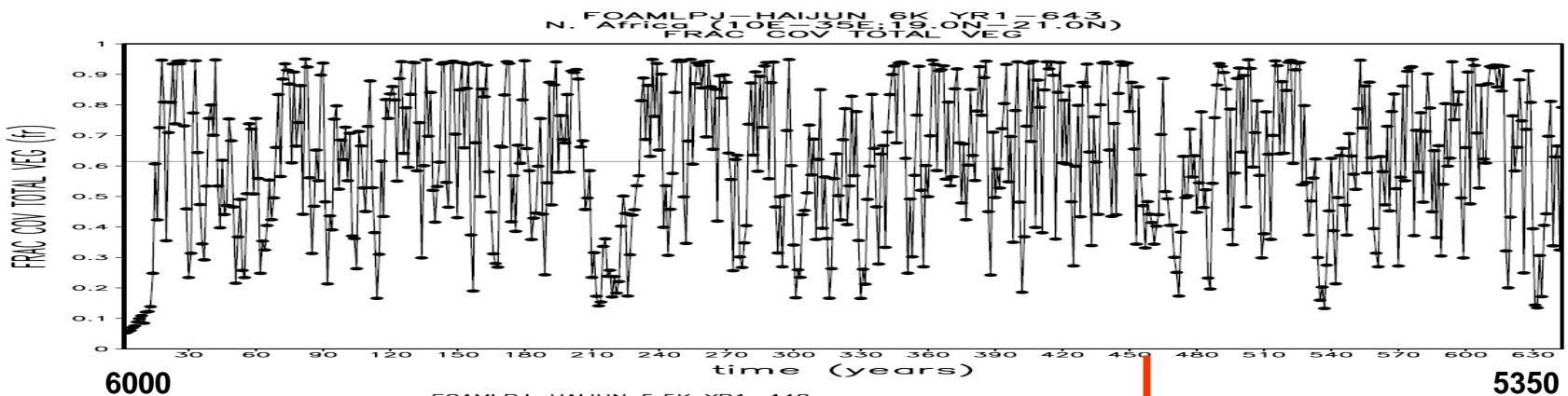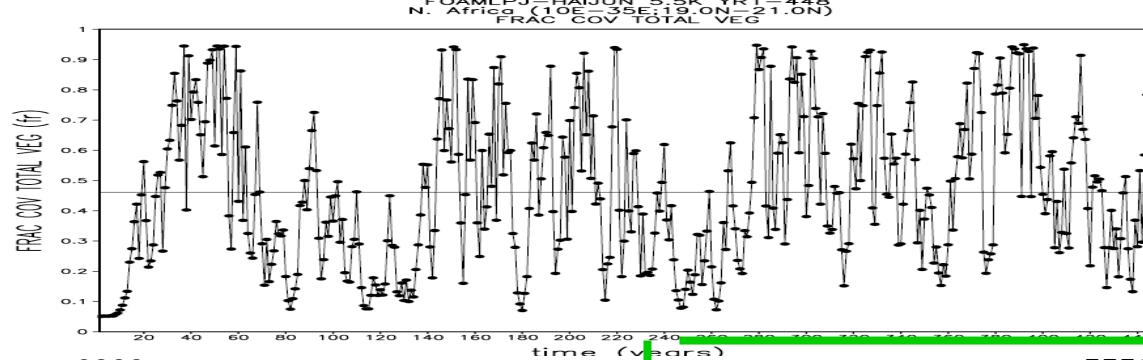
# Vegetation Cover: Sensitivity Experiments with Fixed Orbital Forcing

Timing ~ 5ka

6ka:

650 yr
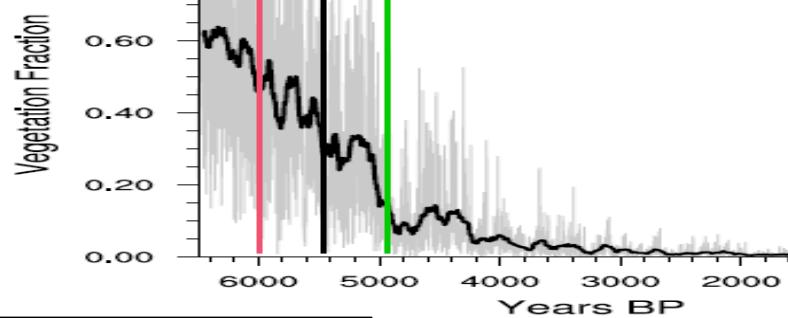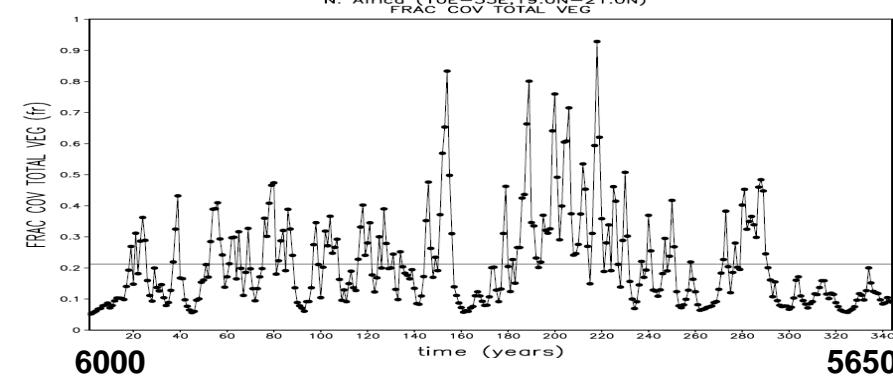
5.5ka:

450 yr

5ka:

**350 yr**

An Early Try

a1) NH Insolation

a2) Tree Cover 60N-90N

a3) JJA Land Surface Temperature 60N-90N

a4) Tree Cover 0-30N

a5) JJA Land Precipitation 0N-30N

6.5ka

b1) Total Veg Cover N.E. Canada

b2) Tree Cover Mid-West US

N. Africa Vegetation

b3) Total Veg Cover N. Africa

4.5ka

b4) Nino3.4 Annual SST

time (years bp)
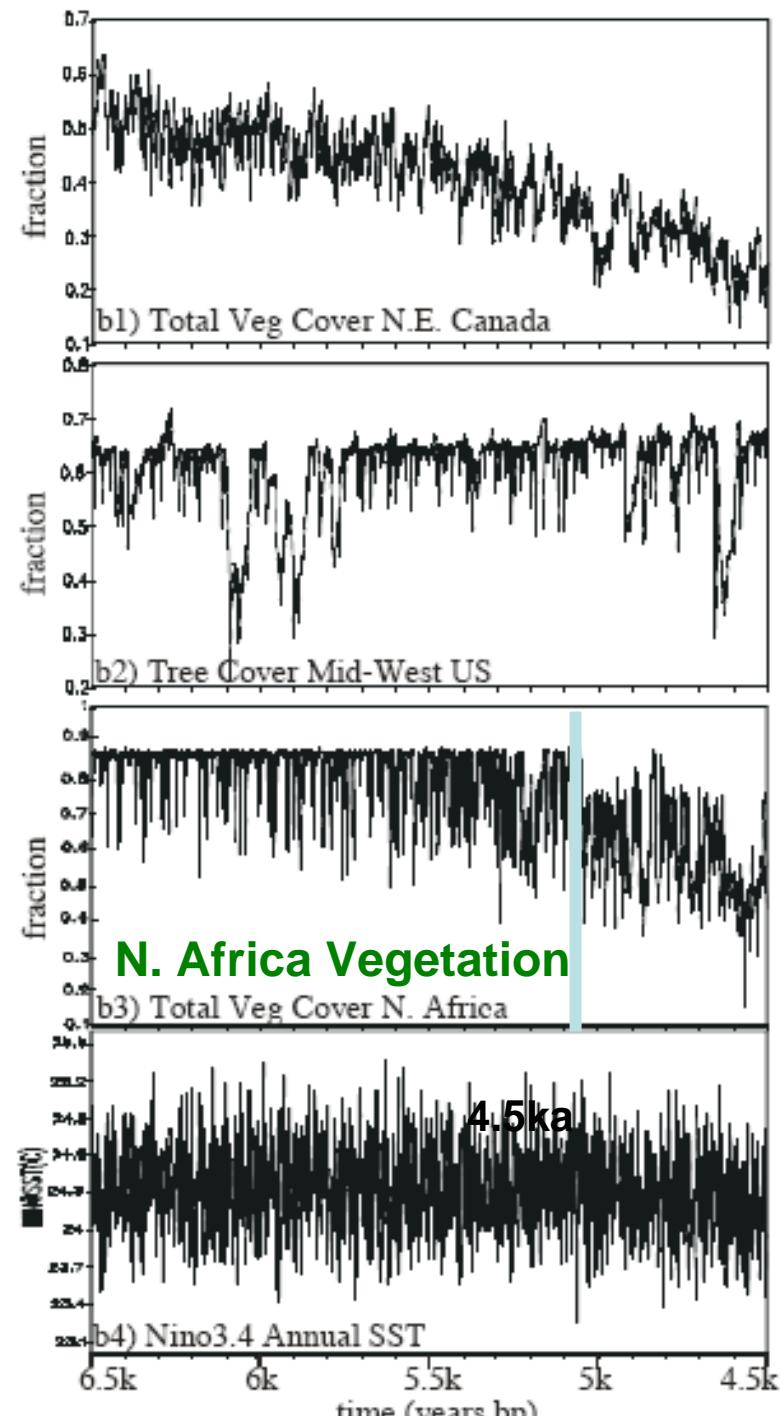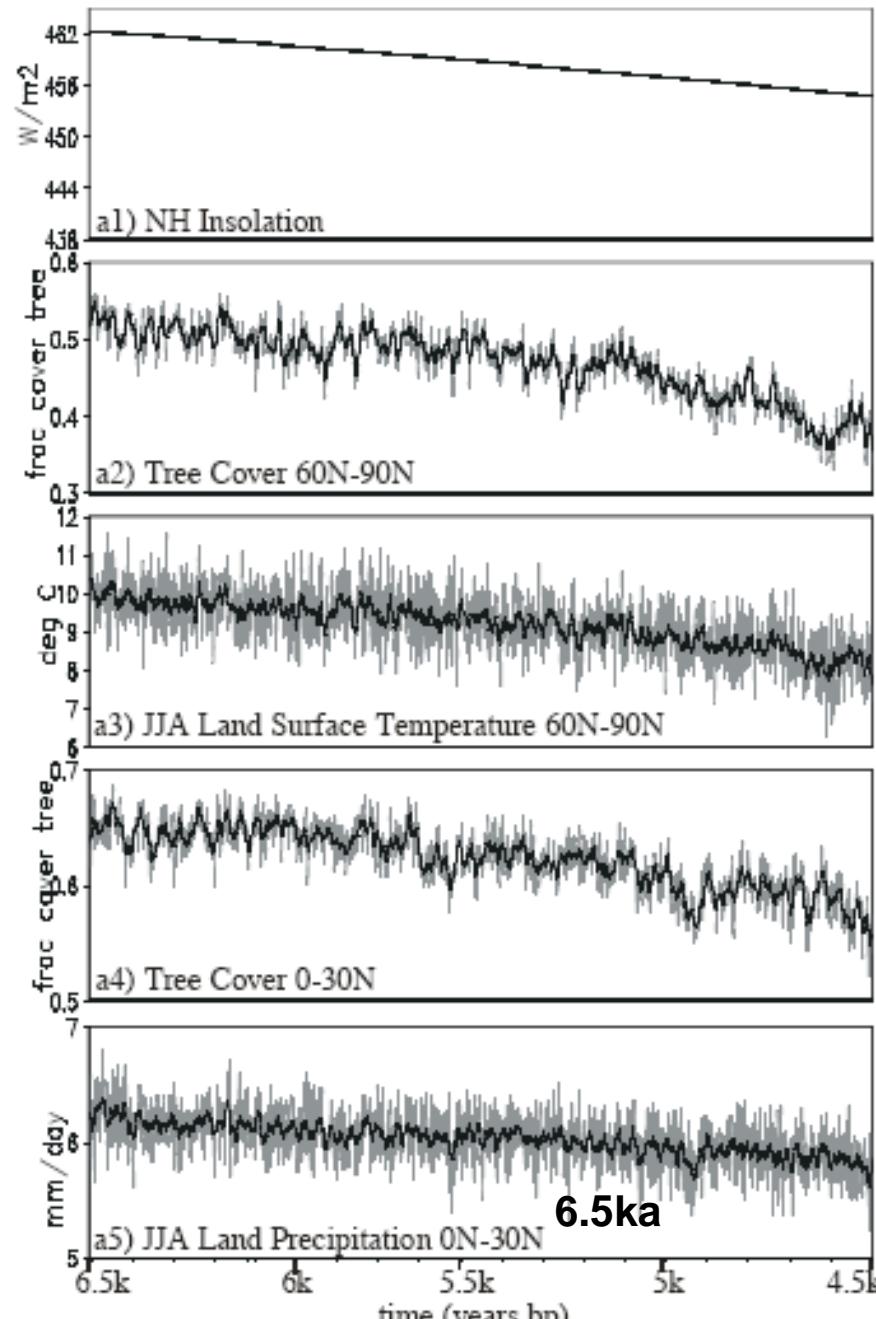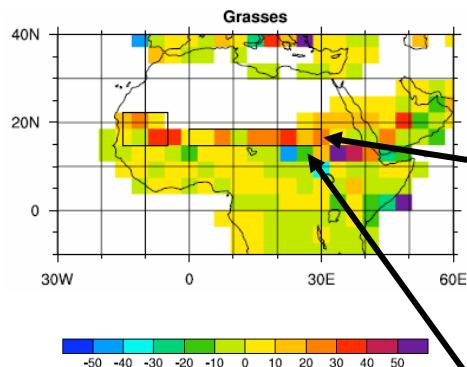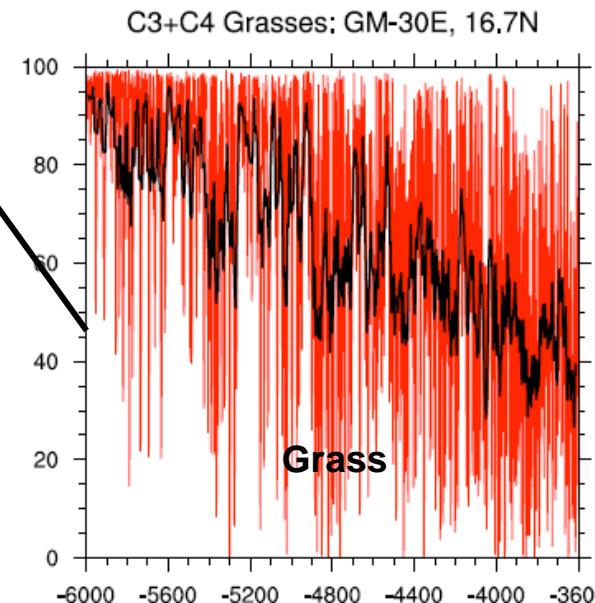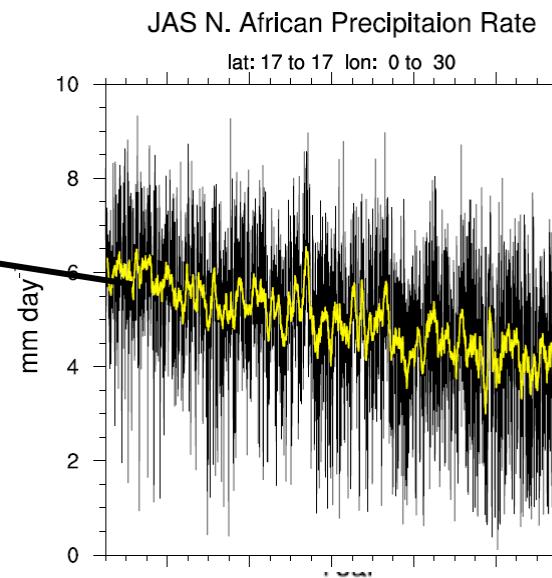
CCSM3-CLM-LPJ Simulation, 6000-3000 BP

CCSM PaleoWorking Group (Brady et al. Poster)

Grass Change

6000 --- 3600 BP

Prep

Grass

Summary

Vegetation collapse

Caused possibly by strong decadal climate variability and soil moisture memory, in the absence of strong positive vegetation feedback, in FORM-LPJ.

Implication to Paleo-observation

Vegetation collapse,

is it accompanied by a gradual climate change?

Implication of Stable Collapse

Abrupt change can occur even for a strongly nonlinear stable system, forced by strong low frequency variability. Climate variability and abrupt change are closely related to each other.

Implication to Long Term Transient Simulation

A Big Gamble!
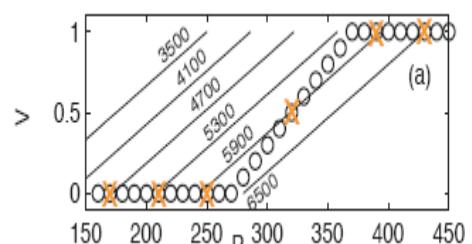
Challenging:

      Abrupt change

      timing

      mechanism
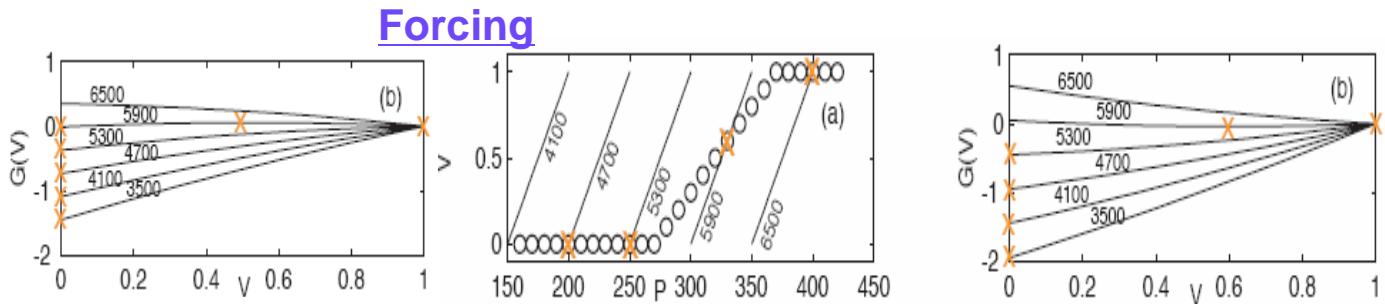
Small model drift matters!

Can some acceleration methods help?

Unstable Case

Stable Case

Forcing
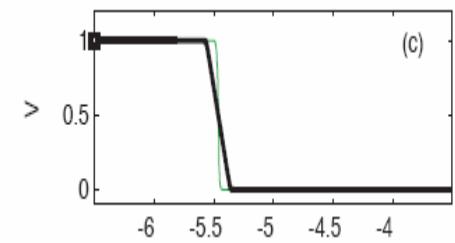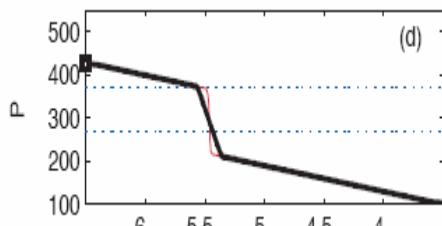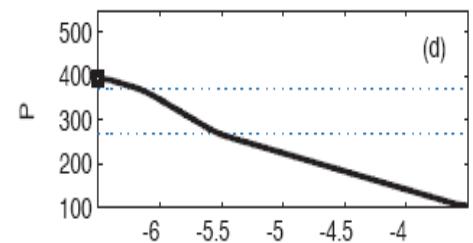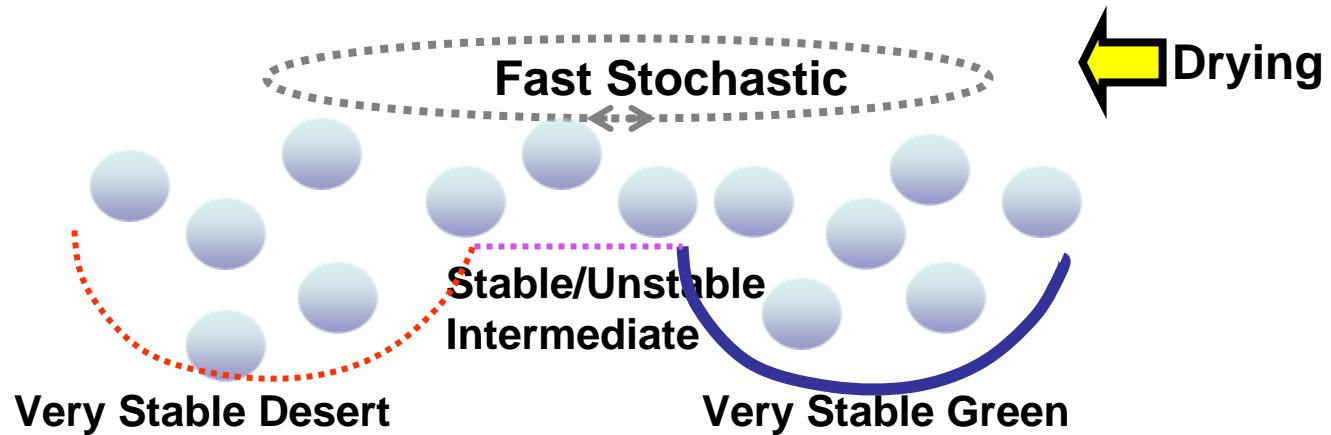
Unstable Collapse

Steady
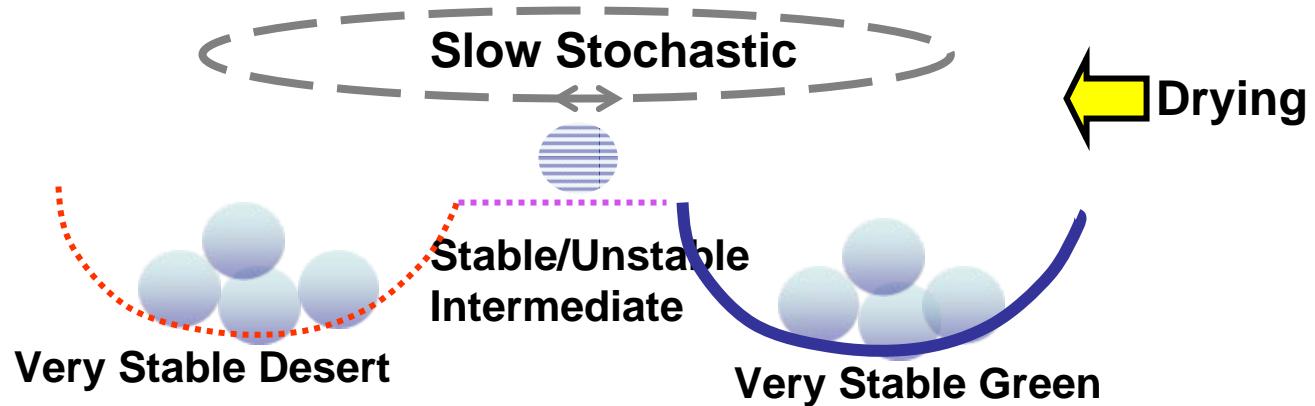
Stable Decline

Stochastic Suppression

Fast Stochastic

Drying

Stable/Unstable Intermediate

Very Stable Desert

Very Stable Green

Stable Collapse

Slow Stochastic

Drying

Stable/Unstable Intermediate

Very Stable Desert

Very Stable Green
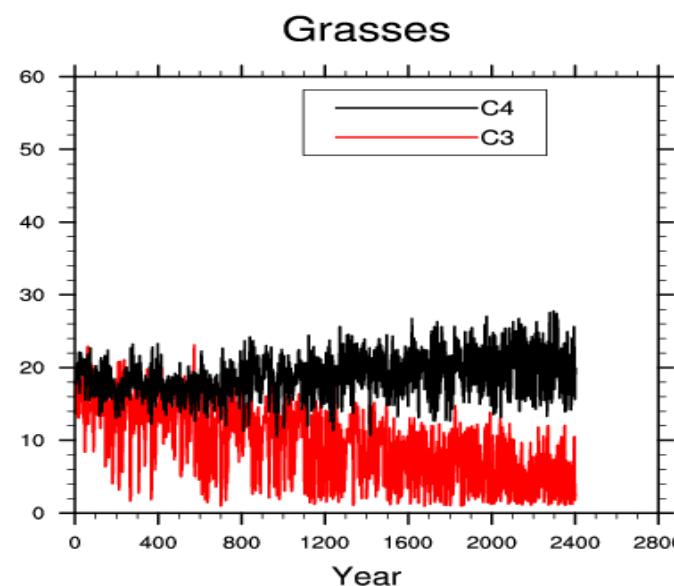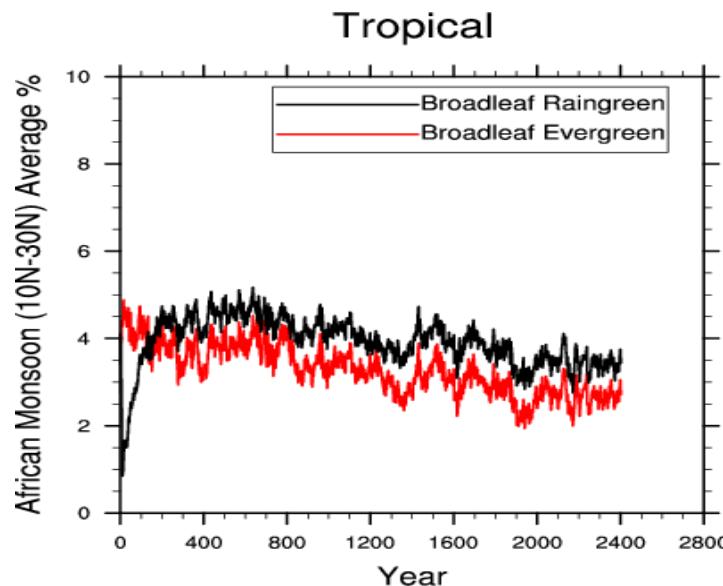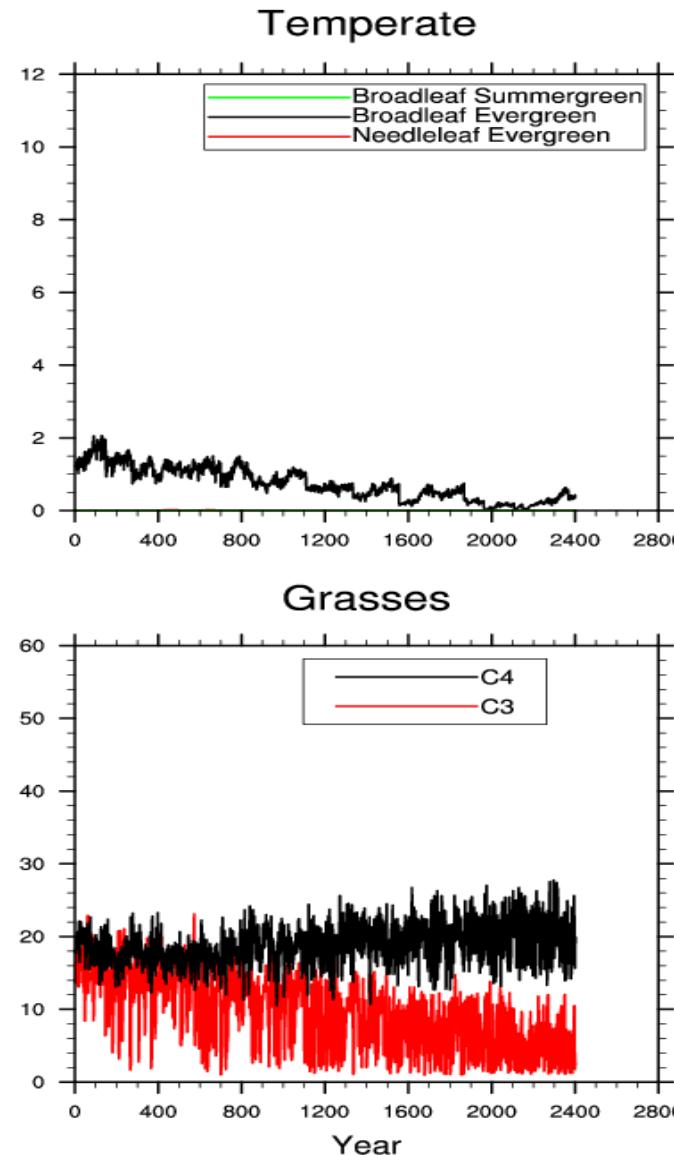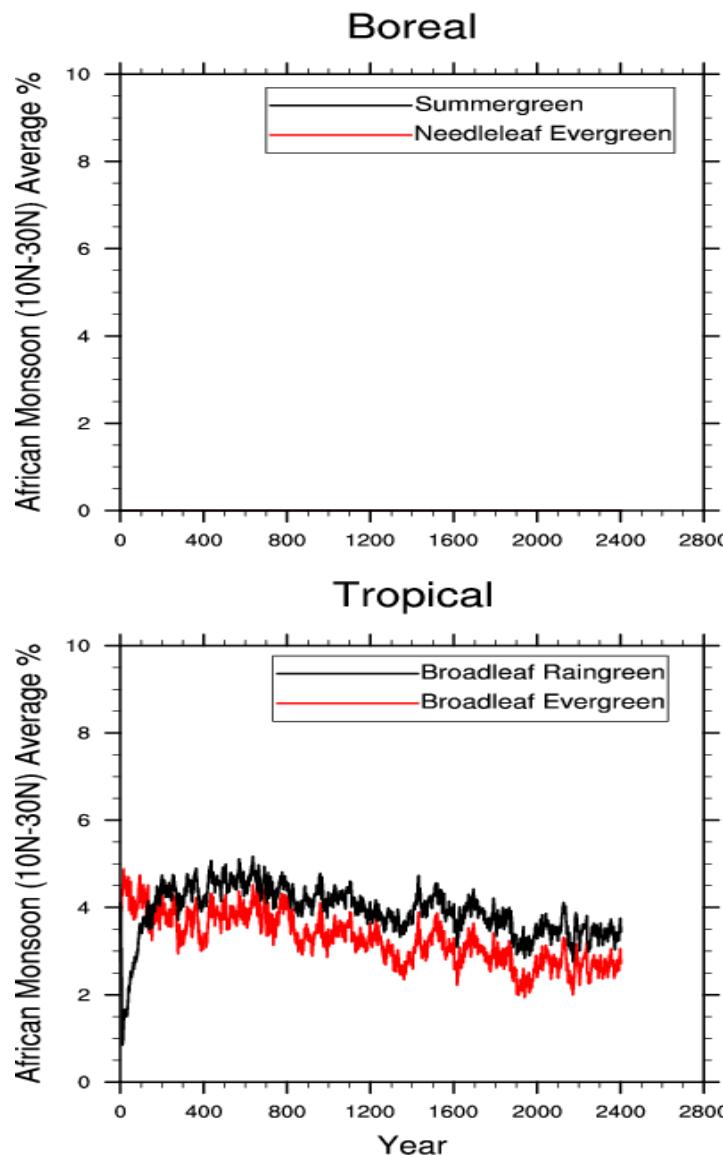
CCSMT31-CML+LPJ: Transient Holocene Run

African Monsoon Average Dynamic Vegetaion b30.108

Abrupt ?

Courtesy, B. Otto-Bliesner, and CCSM paleo working group

# Sensitivty FOAM-LPJ Experiments with different Initial Conditions
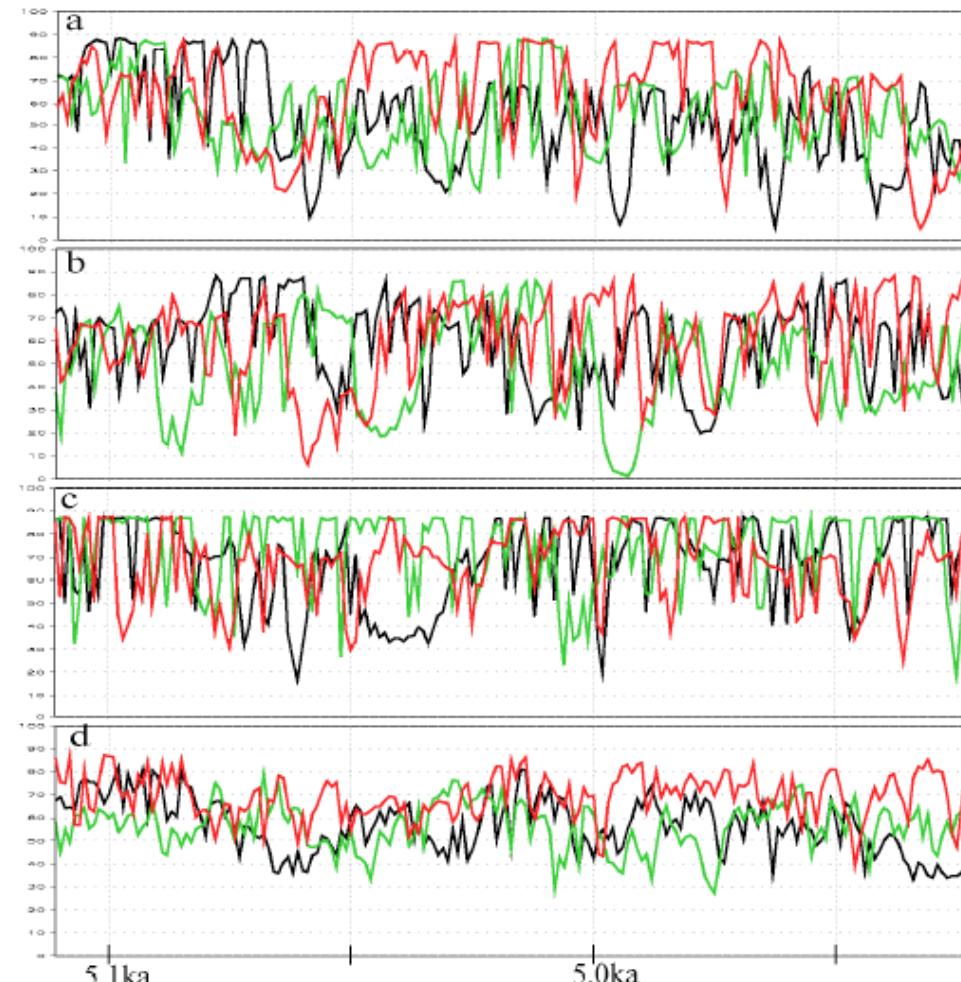
Figure 6 Fractional coverage of area-average vegetation for the eastern Sahel derived from three sets of (3-member) short ensemble simulations in FOAM-LPJ. All experiments start at 5.12ka, (about 50 years before the vegetation collapse in the 2000-year simulation (Fig.1b3)), and are integrated for 200 years. (a) Set 1 (control set) is forced by the same continuing changing orbital forcing as the 2000-year simulation (Fig.1a1), but with different initial conditions, taken from the 2000-year simulation at 5.12ka (black) and 5.12ka +/- one year (green/red). The black takes the original initial condition of the starting time and therefore is identical to the original 2000-year simulation. However, neither of the other two runs repeats the details of the original. The green has a more gradual decline; the red has an abrupt decline but then recovers toward the initial value for a century before again declining. This suggests a strong dependence of the timing and character of abrupt changes on the initial conditions, and in turn, internal climate variability (here due
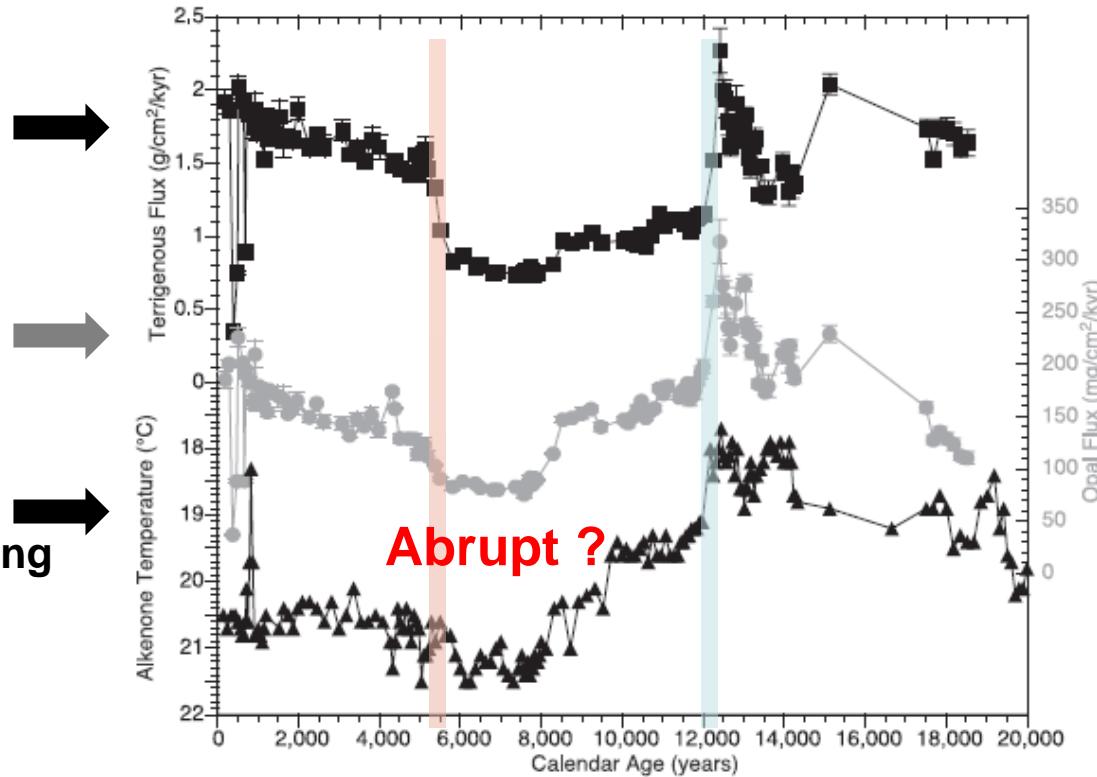
ODP 658C: Marine Sediment
An Indirect Evidence?

Dust flux:

Abrupt Increase

Upwelling:

Gradual Increase

SST:

**Even more gradual cooling**
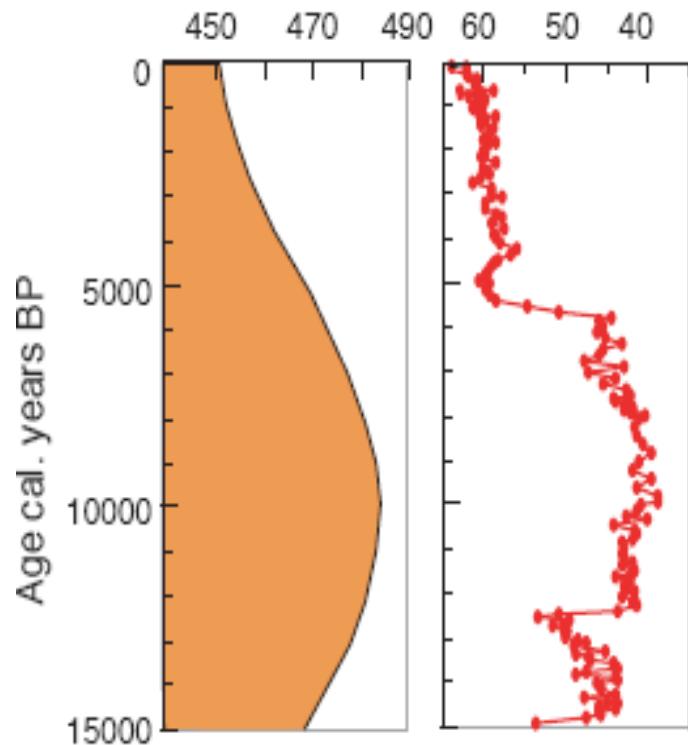
Abrupt ?

Adkins et al., 2006

Summer Radiation

20°N JJA

(W/m^2)

Dust Flux E. Atlantic

ODP Core 658C

Terrigenous (%)
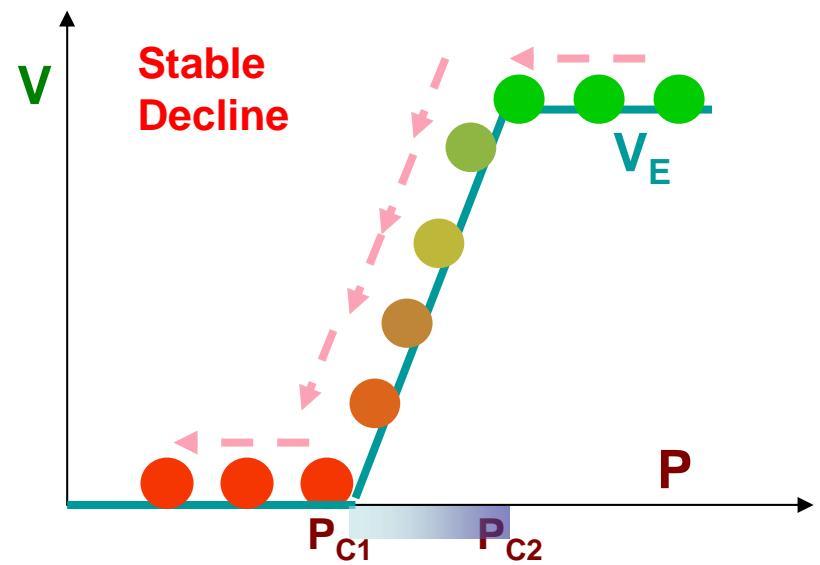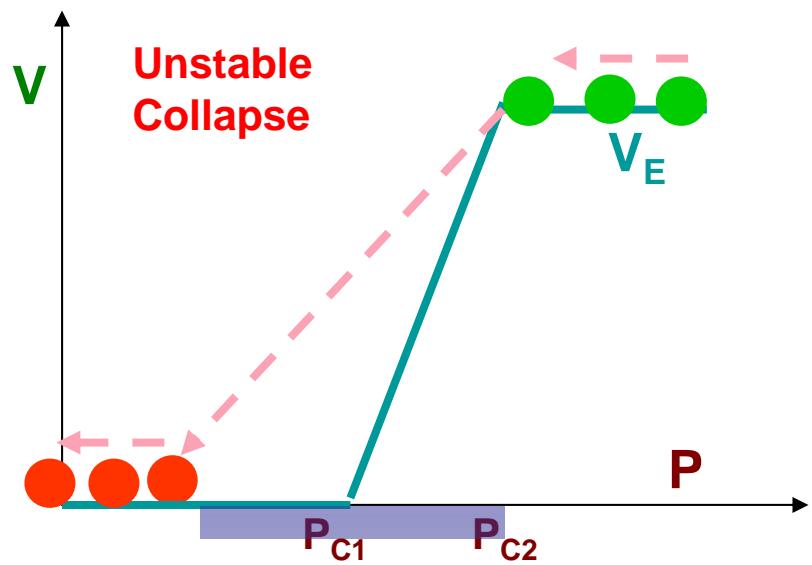
a

b

Steady Forcing

Unstable Collapse and Stable Decline

# FOAM-LPJ JJA Precipitation

0 ka

P, V

6ka

P, V

0ka --- 6 ka

P, V

0ka --- 6 ka

T

JJASON SAT Prec vs Surface Wind (500 yr ave)
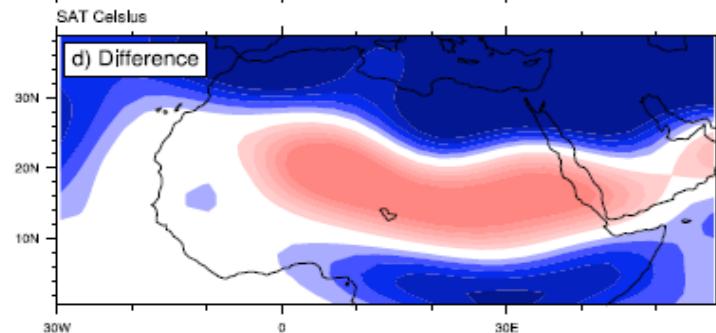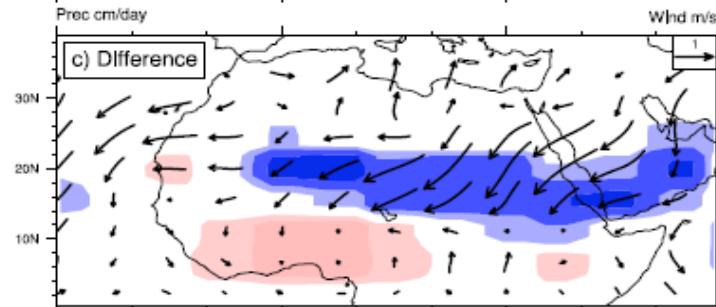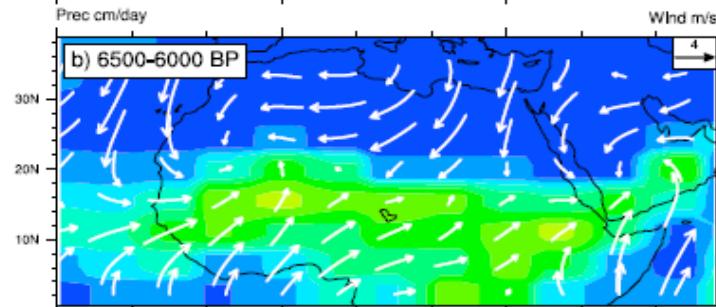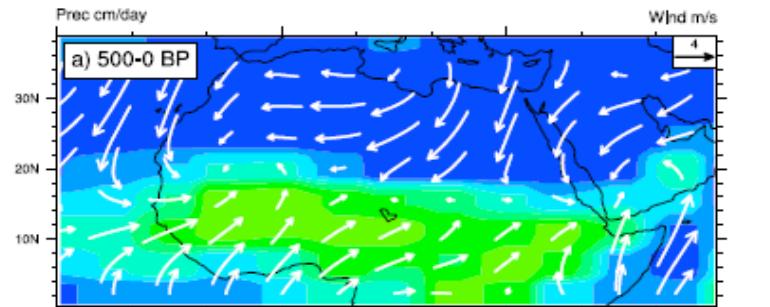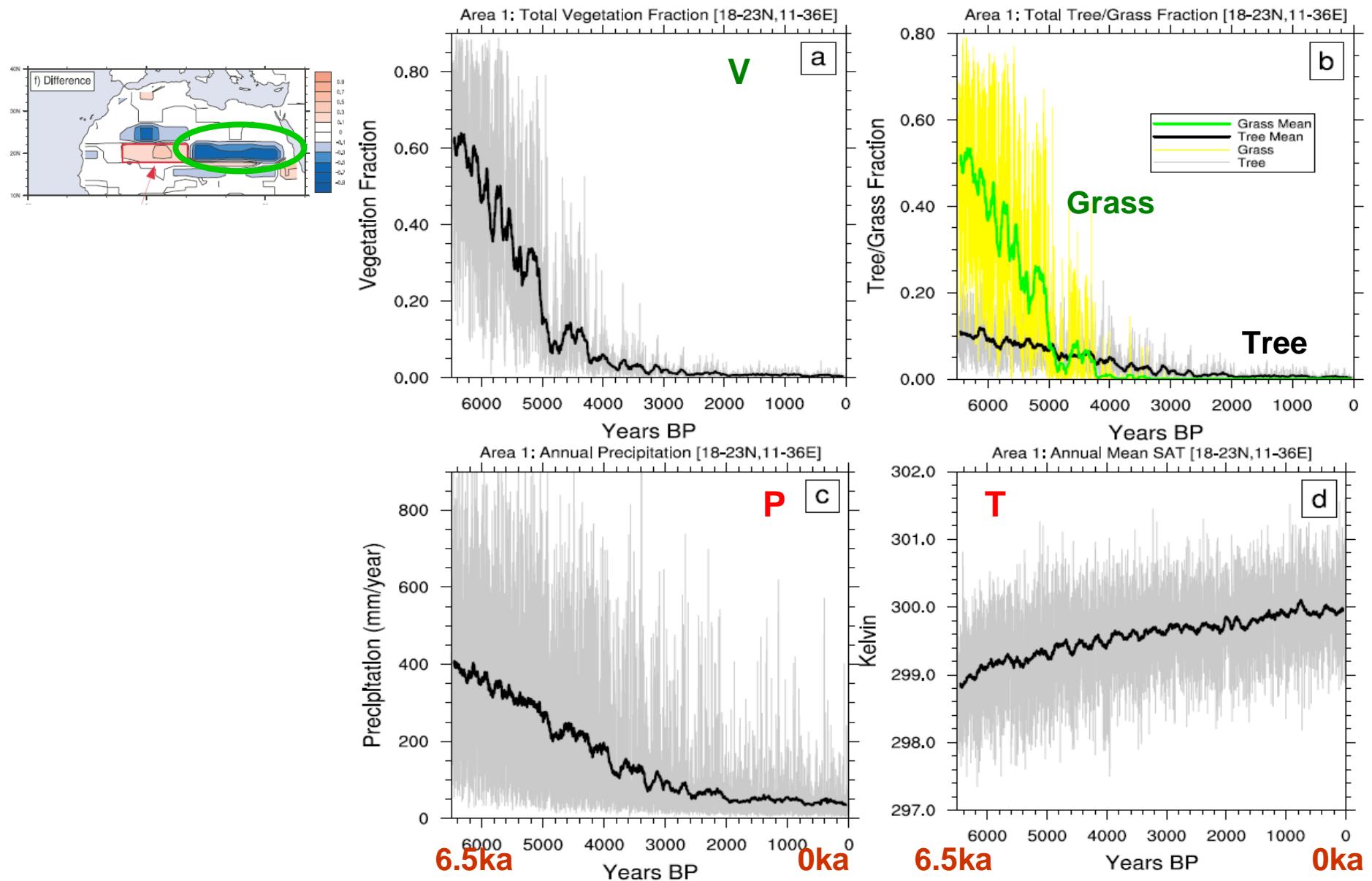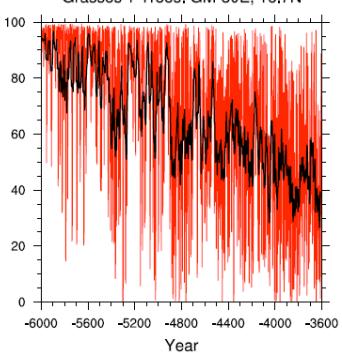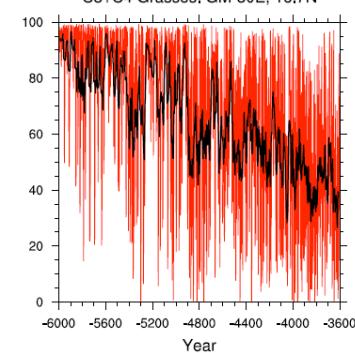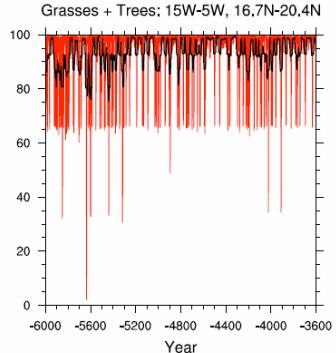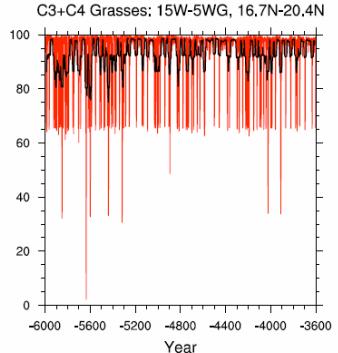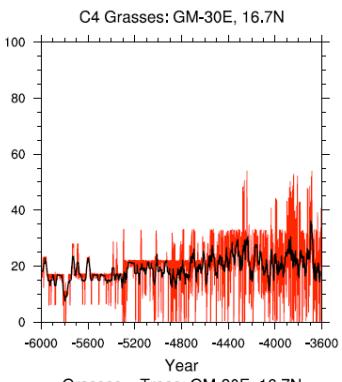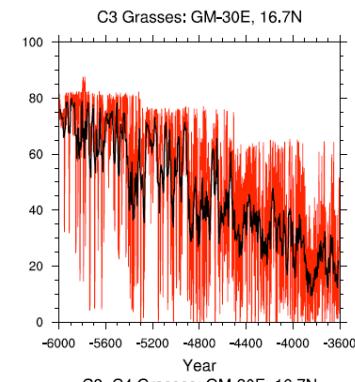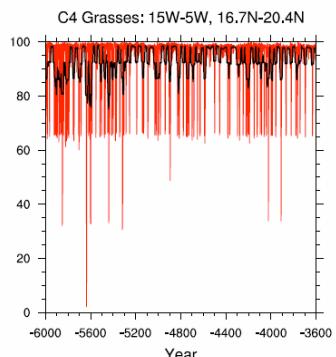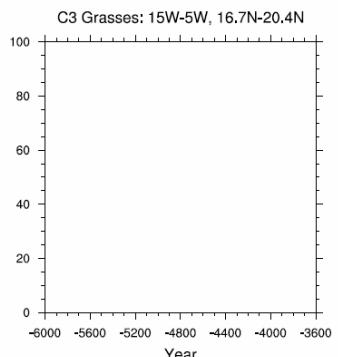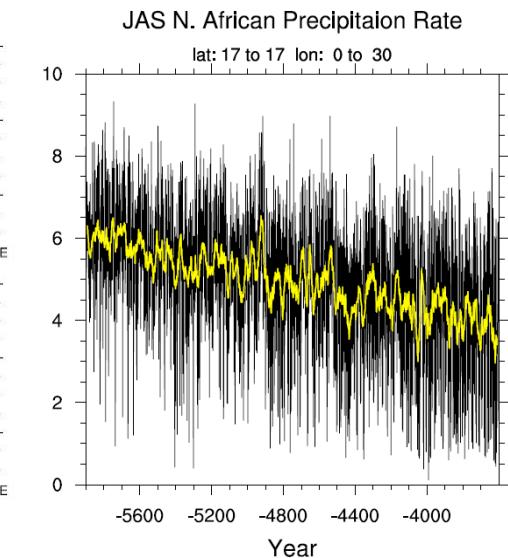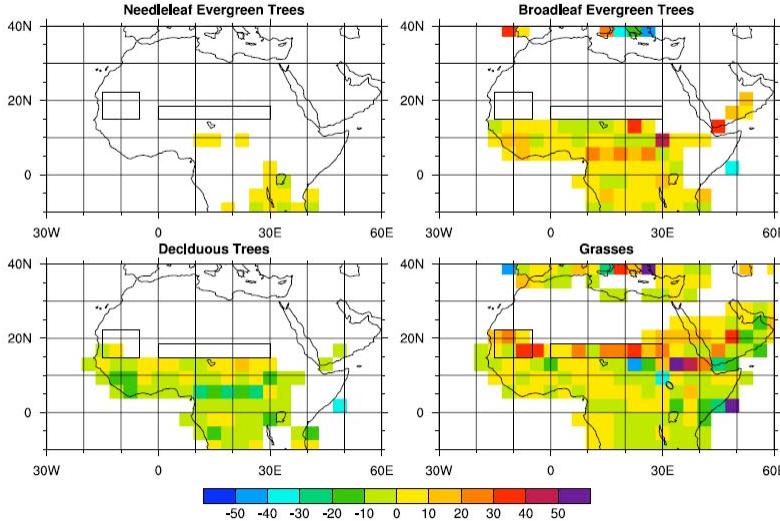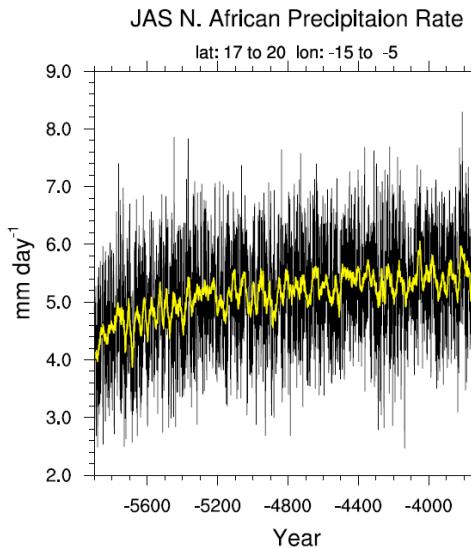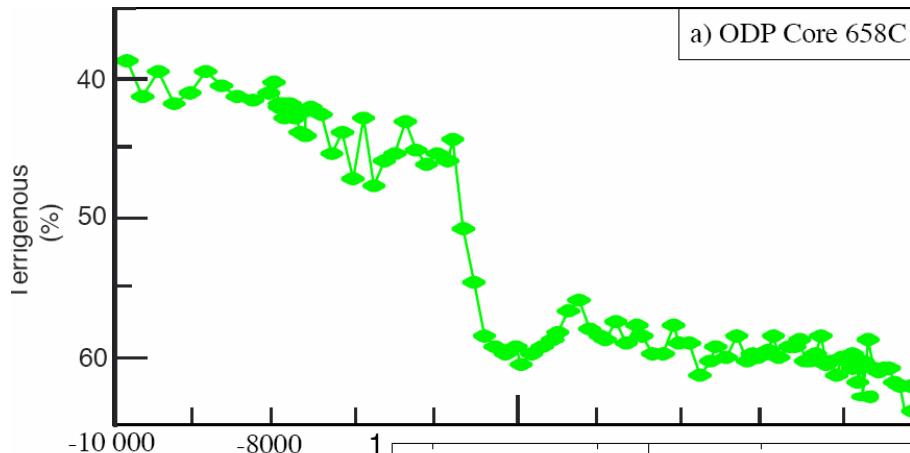
Evolution of Climate-Vegetation System (Central-East Africa)

JAS N. African Precipitaion Rate

lat: 17 to 20 lon: -15 to -5

mm day^{-1}
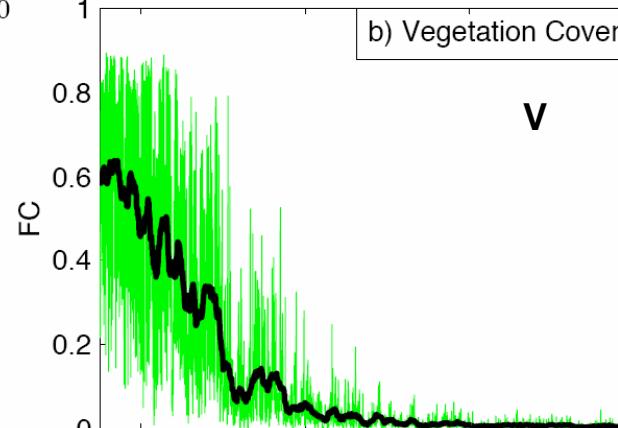
b30.108 years: 2380-2399 - b30.105.dv5 years: 280-299

Needleleaf Evergreen Trees

Broadleaf Evergreen Trees

Deciduous Trees

Grasses

-50 -40 -30 -20 -10 0 10 20 30 40 50

JAS N. African Precipitaion Rate

lat: 17 to 17 lon: 0 to 30

C3 Grasses: 15W-5W, 16.7N-20.4N

C4 Grasses: 15W-5W, 16.7N-20.4N

C3+C4 Grasses: 15W-5WG, 16.7N-20.4N

Grasses + Trees: 15W-5W, 16.7N-20.4N

C3 Grasses: GM-30E, 16.7N

C4 Grasses: GM-30E, 16.7N

C3+C4 Grasses: GM-30E, 16.7N

Grasses + Trees: GM-30E, 16.7N

a) ODP Core 658C

Ierrigenous (%)

40

50

60

-10 000   -8000

Observation

b) Vegetation Cover

FC

V

1
0.8
0.6
0.4
0.2
0

Model

c) Precipitation

P

mm/y

1000
800
600
400
200
0

Precipitation variability