Abrupt Change of Northern African Climate-Ecosystem in the Holocene: ----Modeling, Mechanism and Implications

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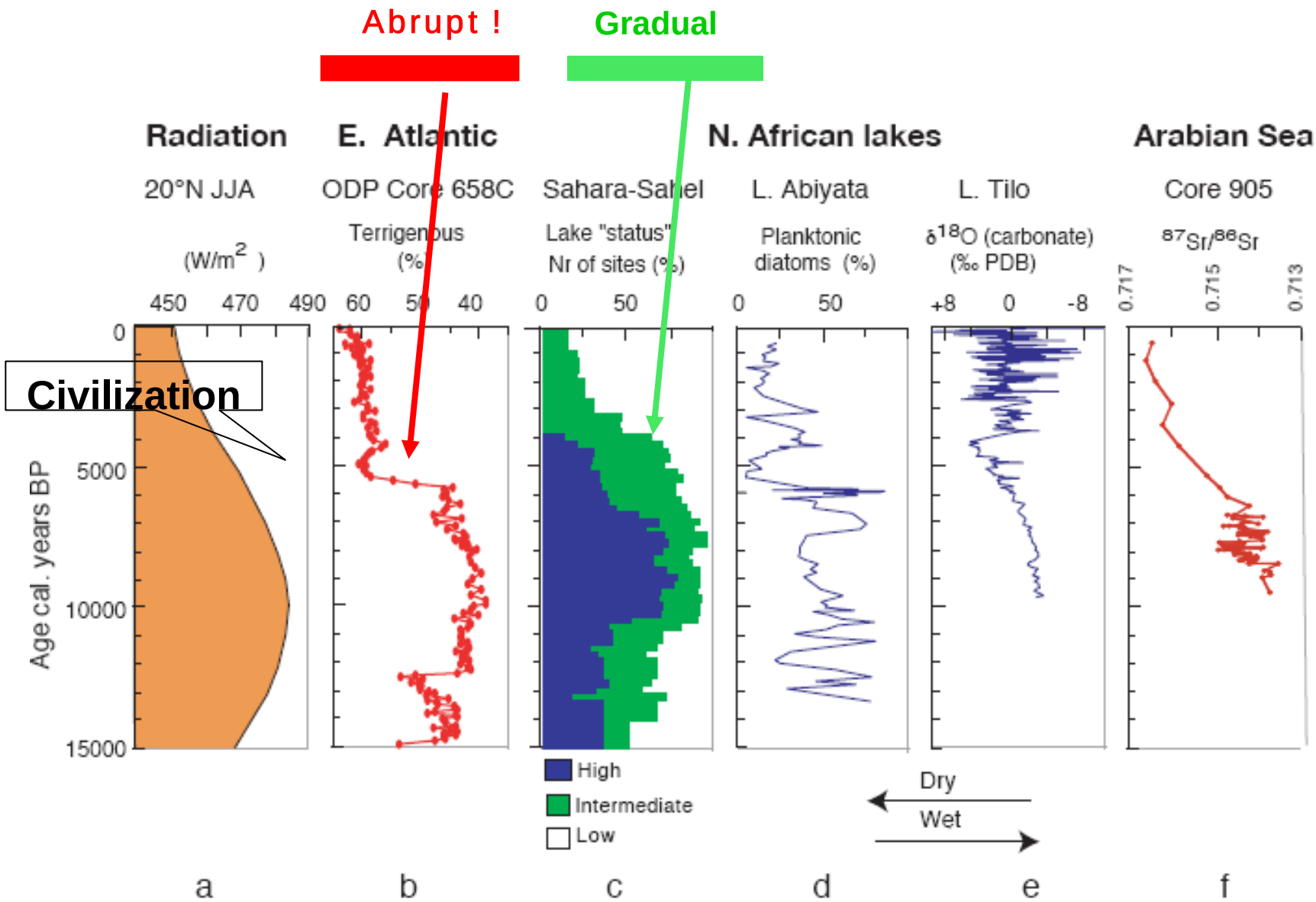
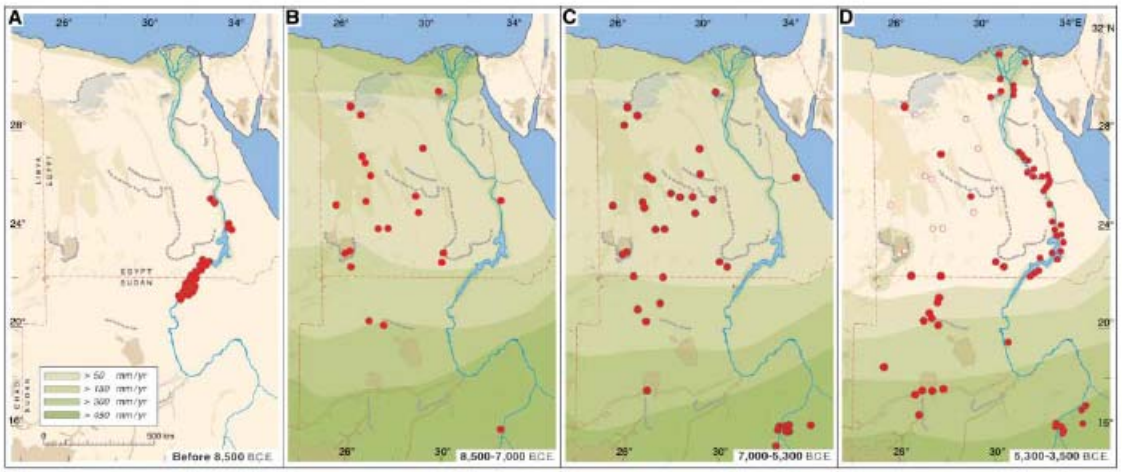

Abrupt !
Gradual
Radiation
E. Atlantic
N. African lakes
Arabian Sea
20°N JJA
ODP Core 658C
Sahara-Sahel
L. Abiyata
L. Tilo
Core 905
(W/m2)
Terrigenous (%)
Lake "status" Nr of sites (%)
Planktonic diatoms (%)
δ18O (carbonate) (‰ PDB)
87Sr/86Sr
450 470 490
60 50 40
0 50
0 50
+8 0 -8
0.717 0.715 0.713
Civilization
Age cal. years BP
0
5000
10000
15000
High
Intermediate
Low
Dry
Wet
a
b
c
d
e
f

Climate: Motor of Africa's Evolution



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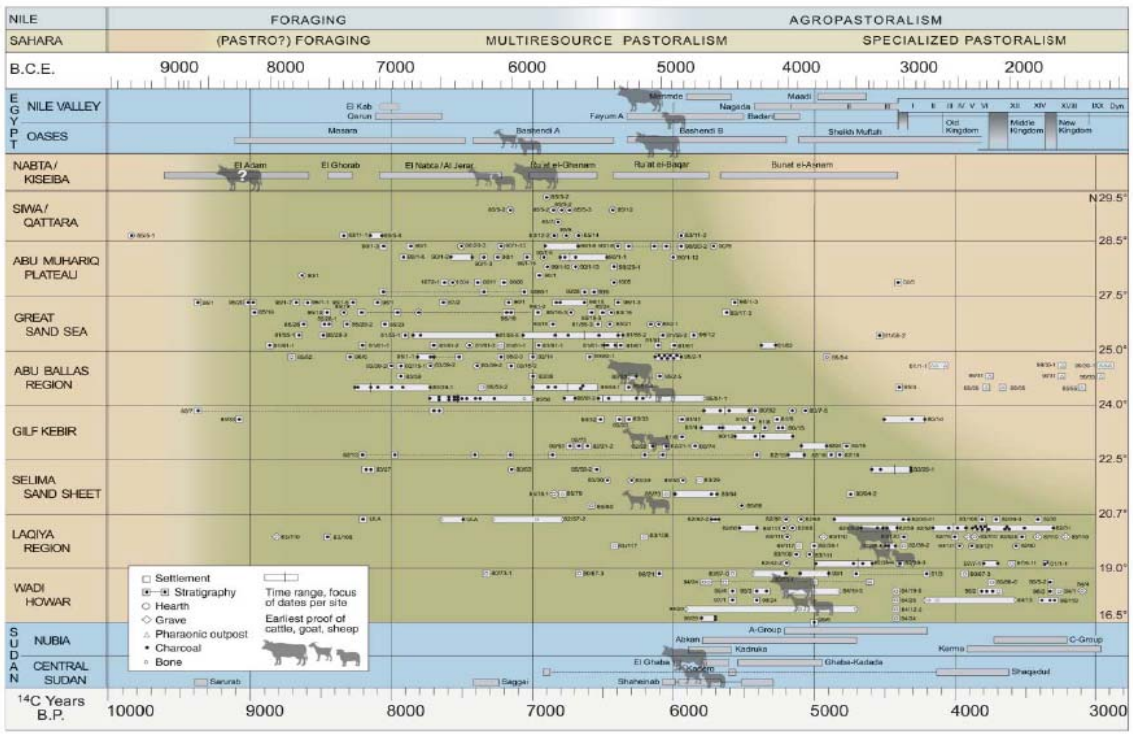


Lat

Time

Kuper and Kropelln, 2006, Science

A Model of Intermediate Complexity (CLIMBER2)

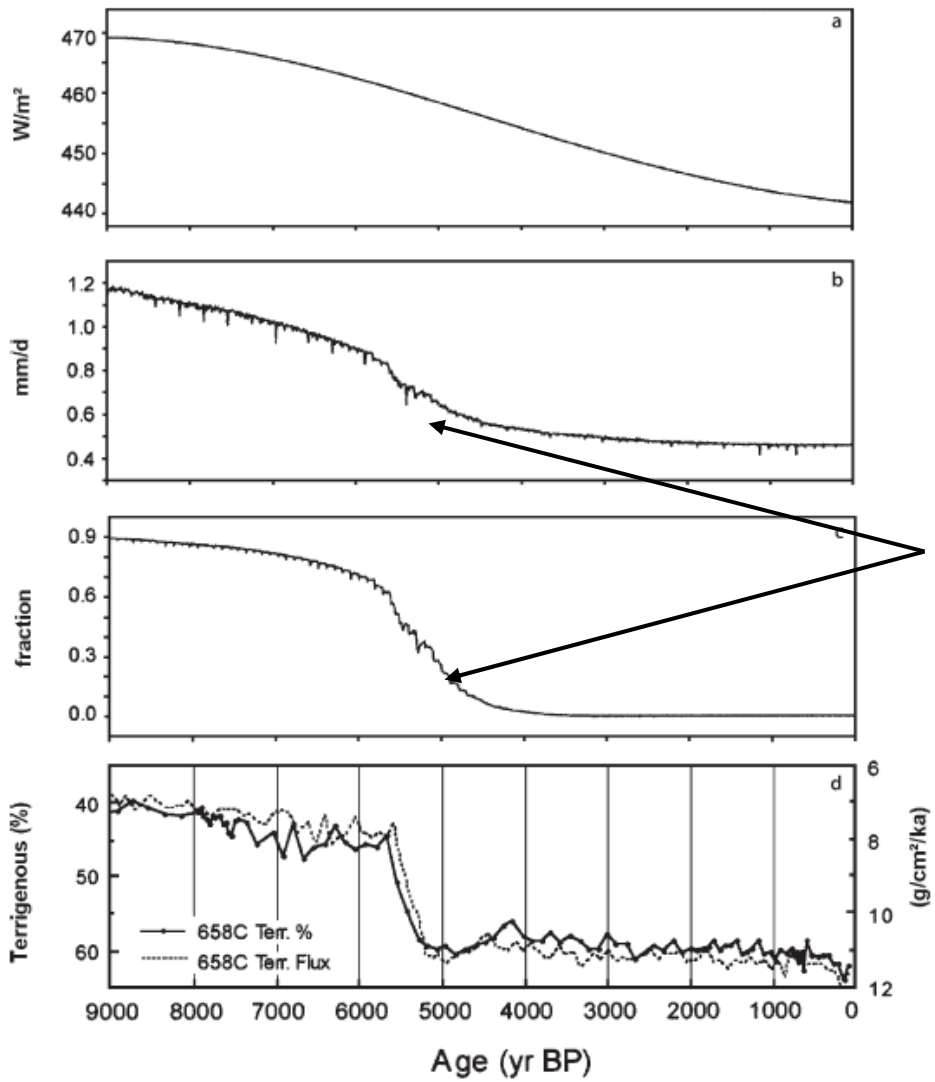
Insolation

Precipitation

Vegetation

Obs (dust)

DeMenocal et al., 2000, QSR



Positive vegatation feedback

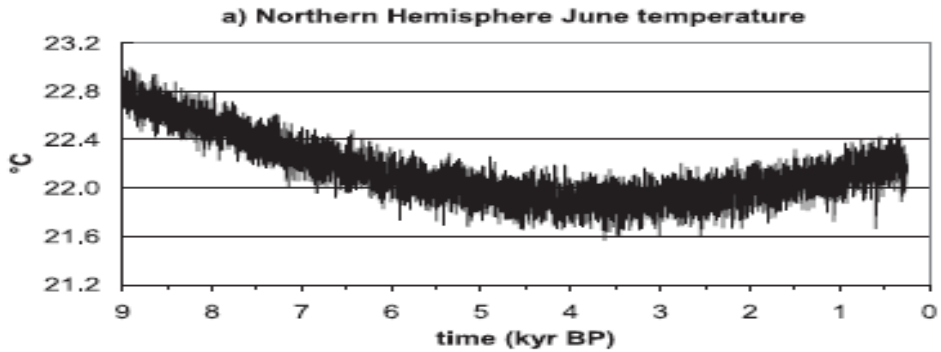
Multiple equilibrium

Abrupt Change (Unstable Collapse)

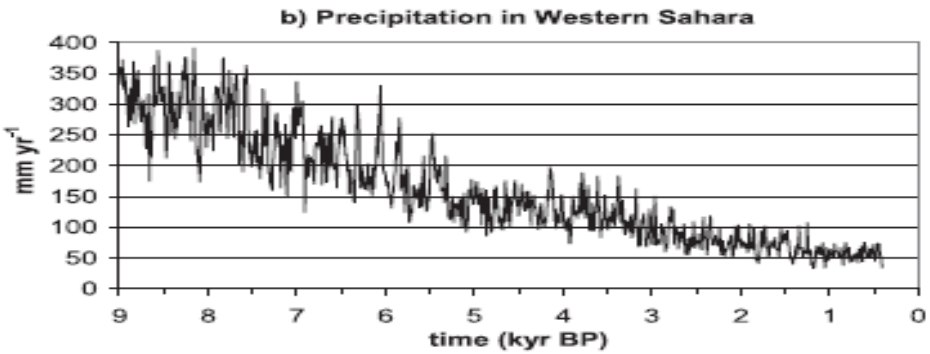
Claussen et al., 1999, GRL

ECBilt: QG Atm+Veg

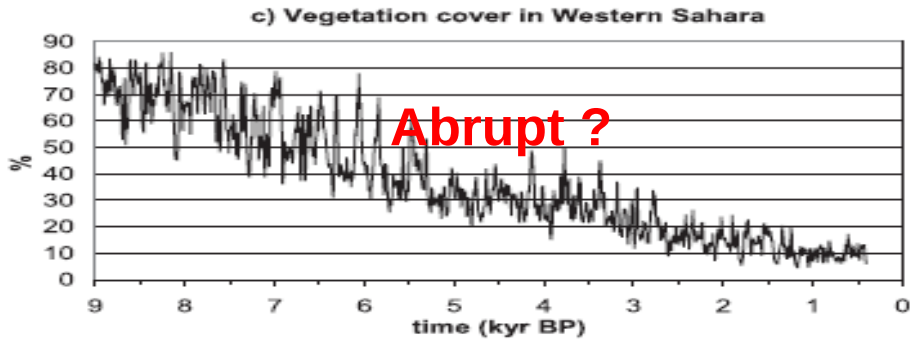
June Temp



Precipitation



Vegetation

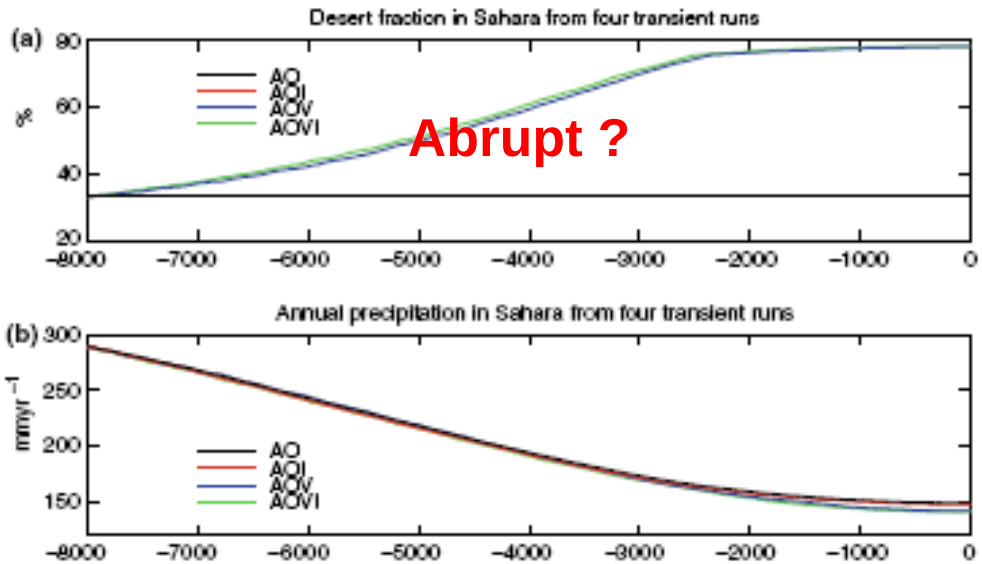


Renssen et al., 2003, GRL

McGill Model: EB Atm + Veg

Desert fraction

Precipitation



Wang et al., 2005, Clim. Dyn

- FOAM-LPJ Transient Holocene Simulation

  - Mechanism of Abrupt Change
  - Climate-Vegetation Feedback
  - Rethinking of Paleo-observation

FOAM-LPJ

- **FOAM (Fast Ocean Atmosphere Model): (Jacob, 1997)**
  CCSM2 Atm. Dyn + CCSM3 Physics (R15, 18-level)
  OM3 (POP-like) Ocean (2.8^{o}*1.4^{o}*32-level)

- **LPJ: (Sitch et al., 2003)**
  Global dynamic vegetation model

Transient Holocene Simulation (1st GCM simulation)

- **Initial condition: 6,500 years BP**

- **Forcing: Orbital forcing (only)**

Liu et al., 2006, Geophys. Res. Lett; **Liu et al., 2007, Quat. Sci. Res;** a long shot, a single shot, a puzzling sho

FOAM-LPJ, JJA Climate

0 ka

Prep, Wind

6ka

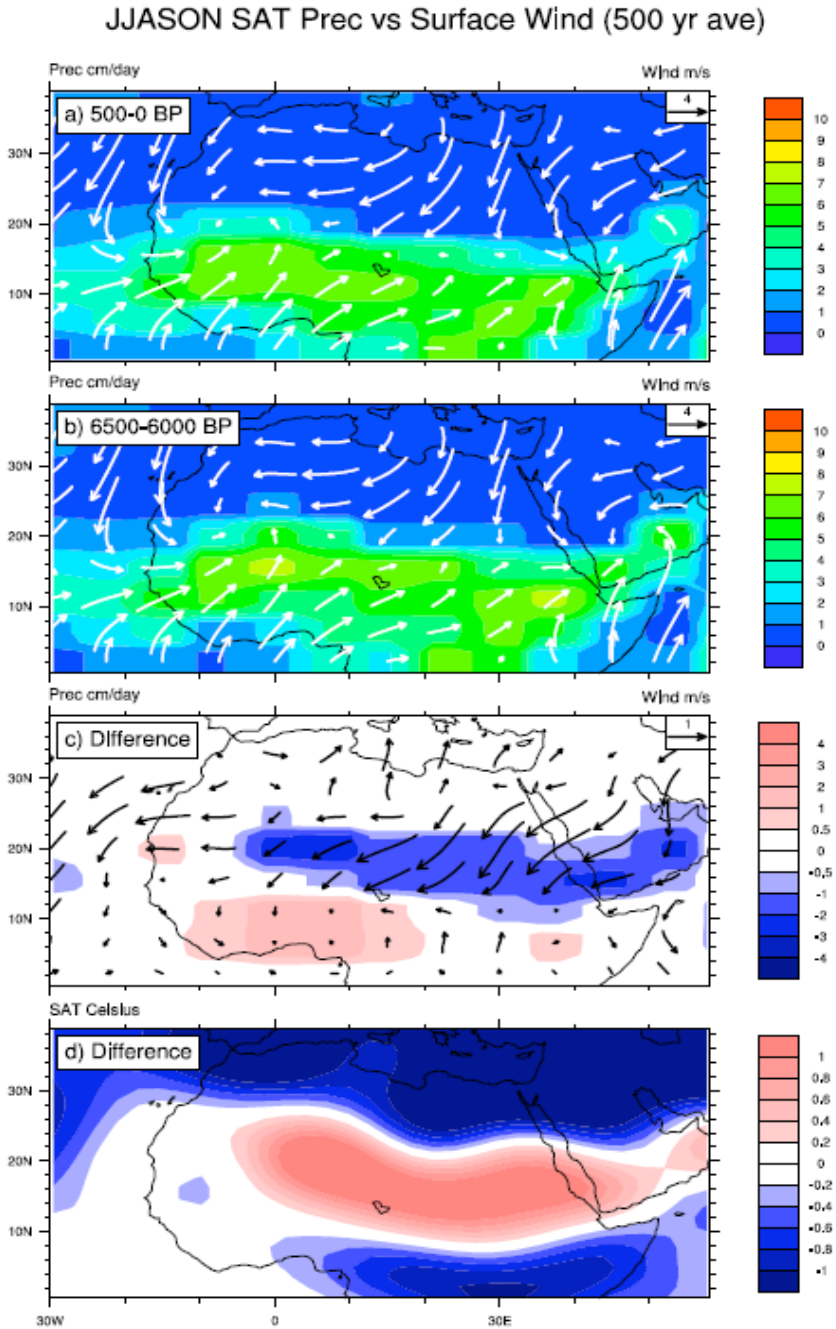
Prep, Wind

0ka --- 6 ka

Prep, Wind

0ka --- 6 ka

Tair



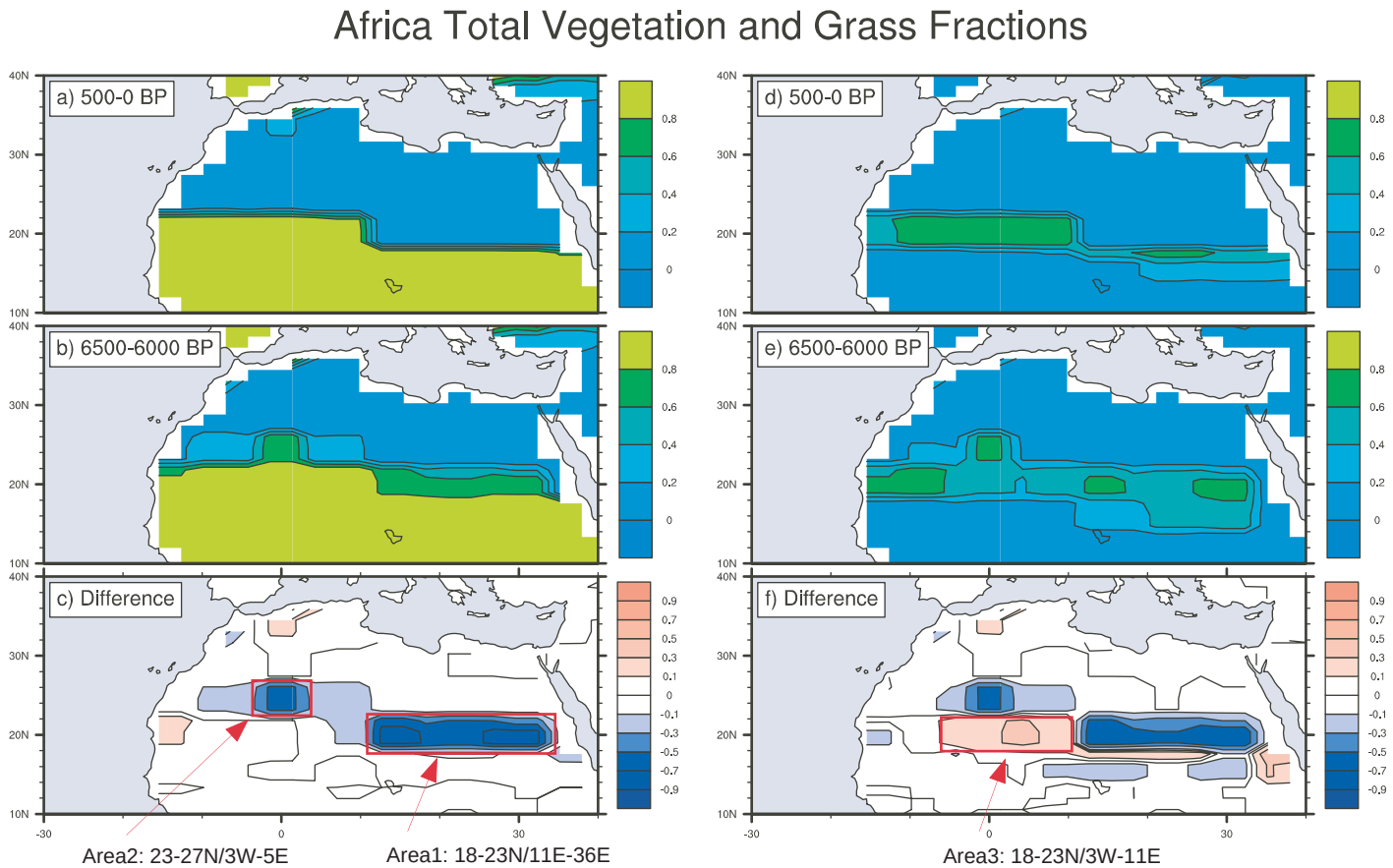
FOAM-LPJ Vegetation

Total Veg **Grass**

0ka

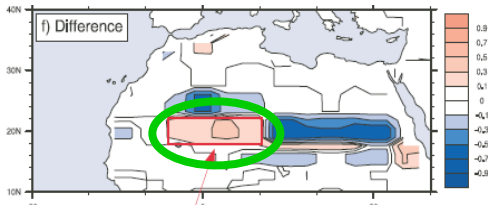
6ka

0ka – 6ka

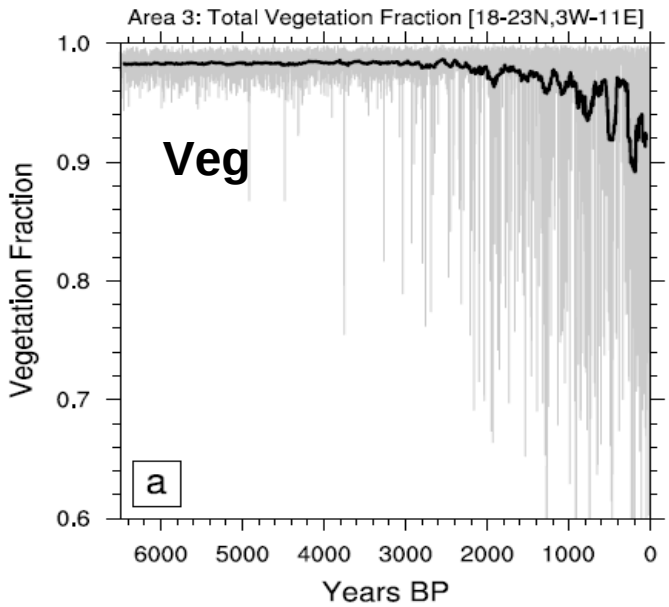


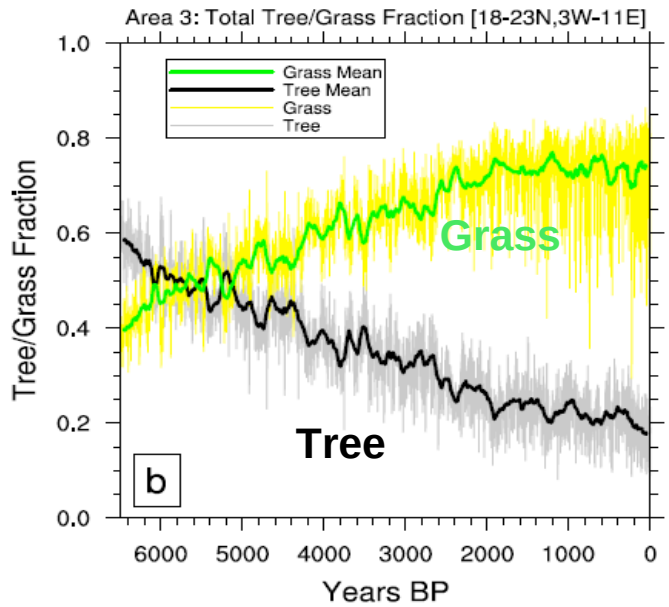
Evolution of Climate-Vegetation System

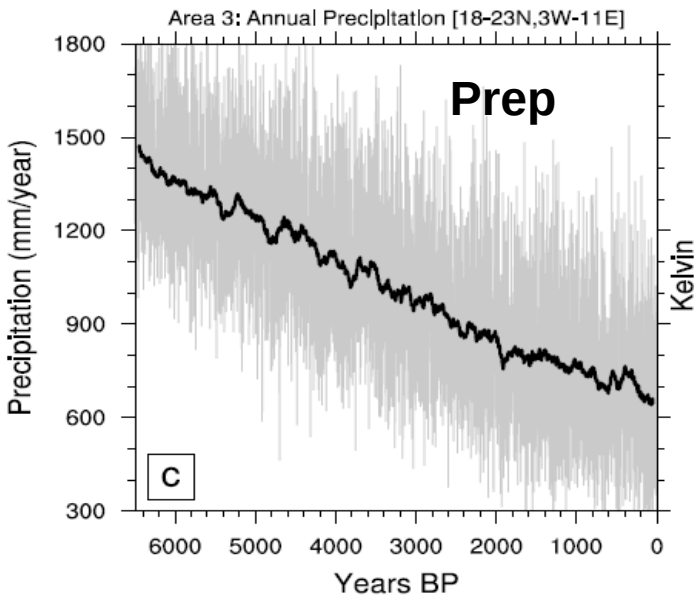
(Southern Central Africa)

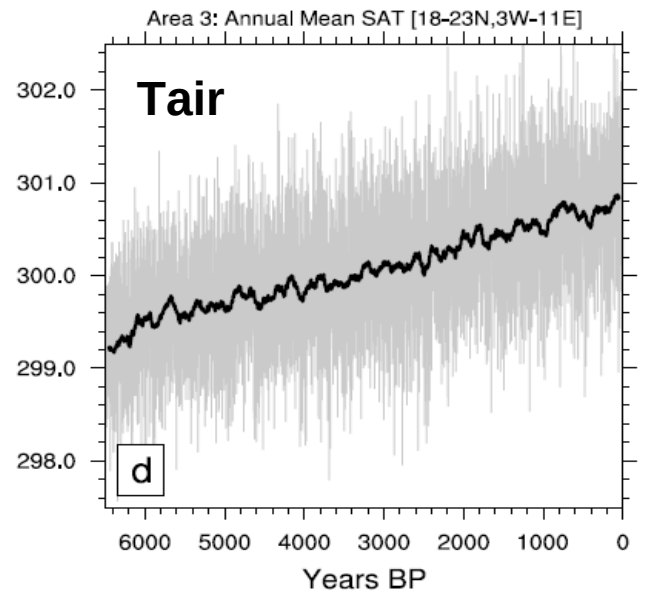


Gradual



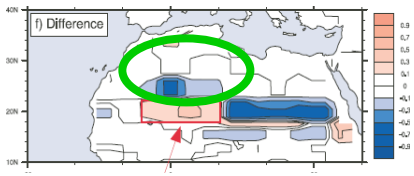




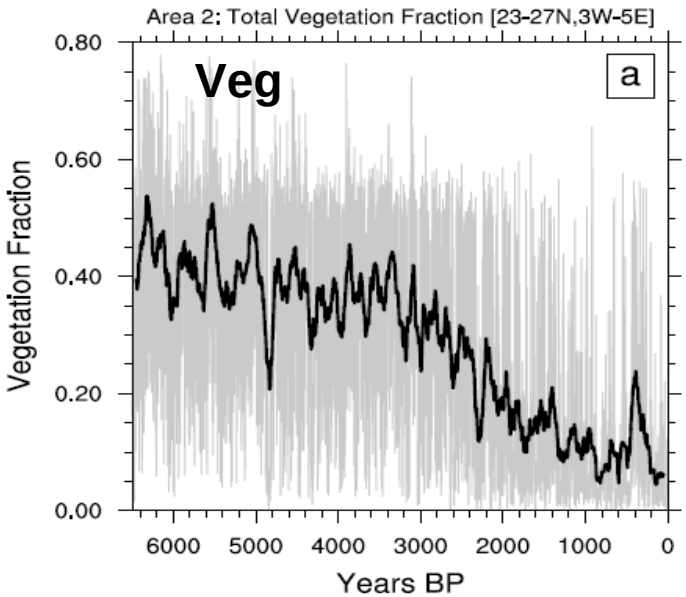


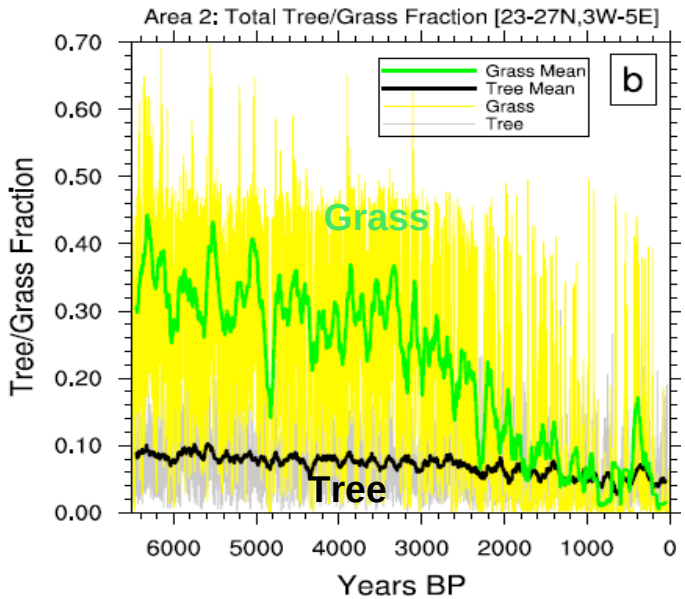
Evolution of Climate-Vegetation System

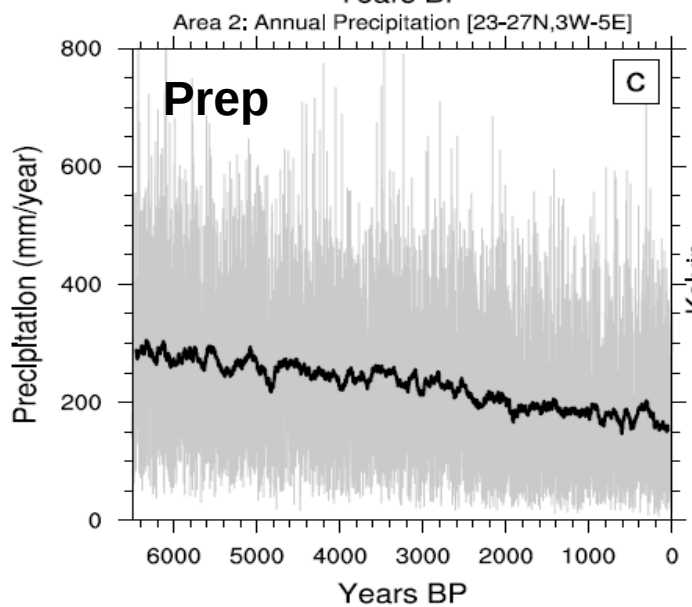
(Central-West Africa)

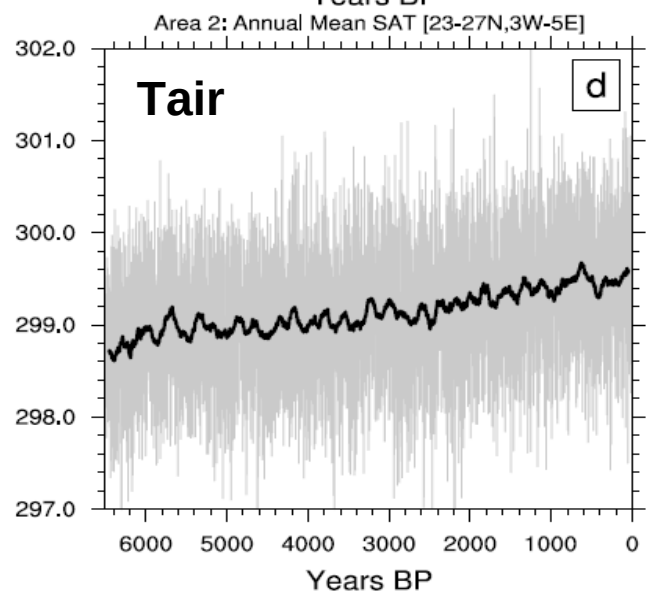


Gradual/ abrupt



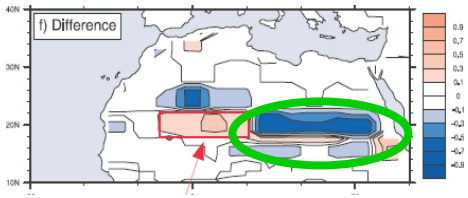




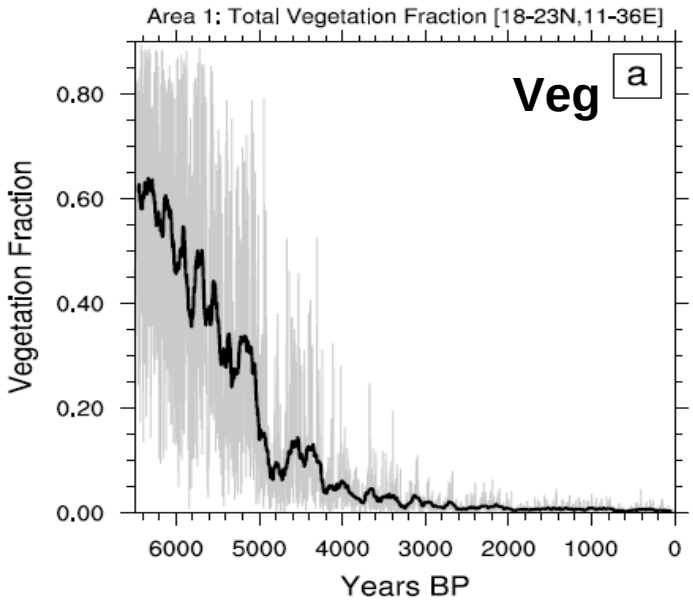


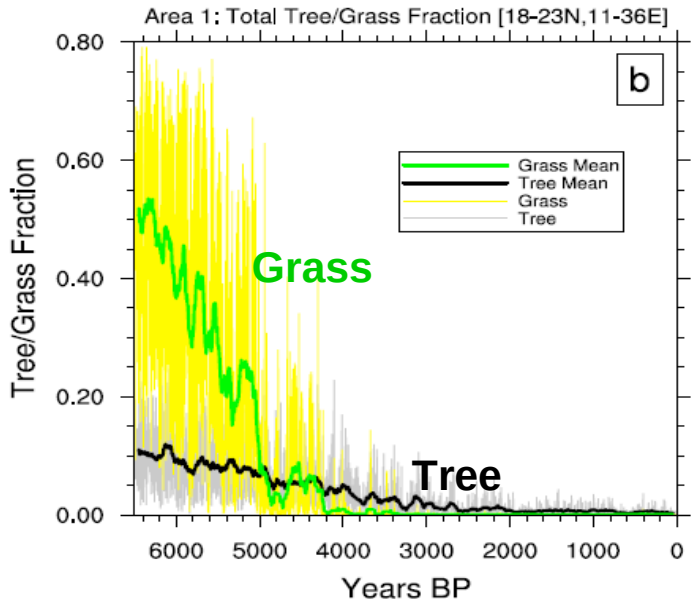
Evolution of Climate-Vegetation System

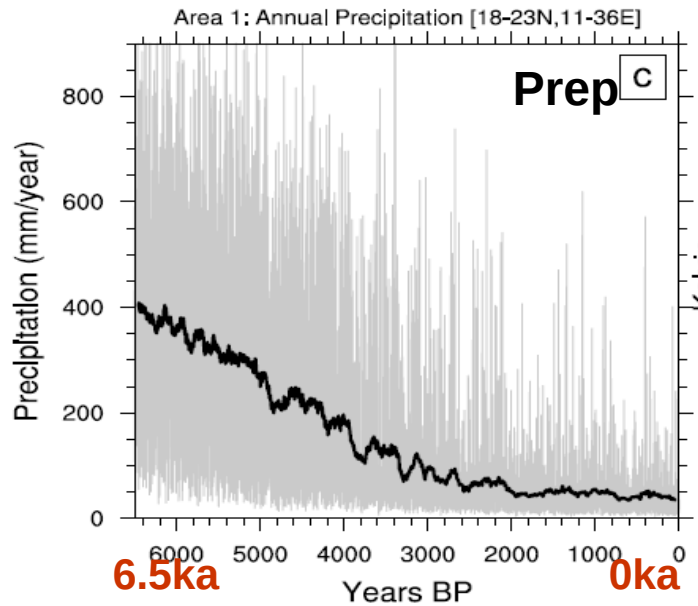
(Central-East Africa)

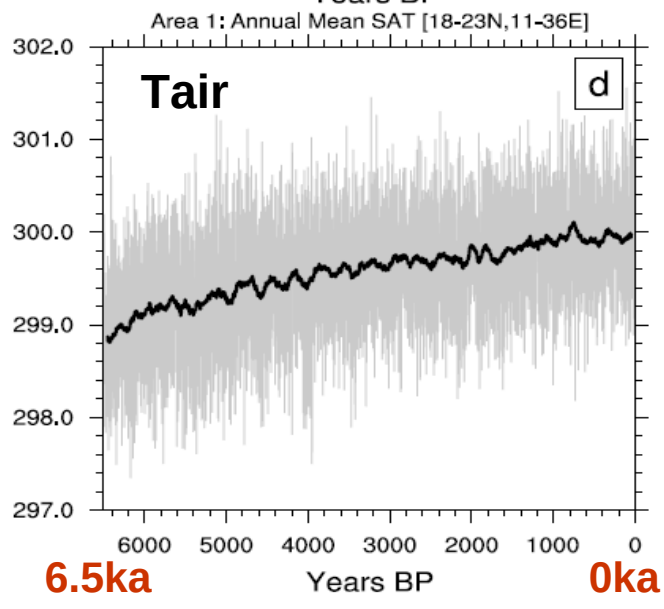


Abrupt

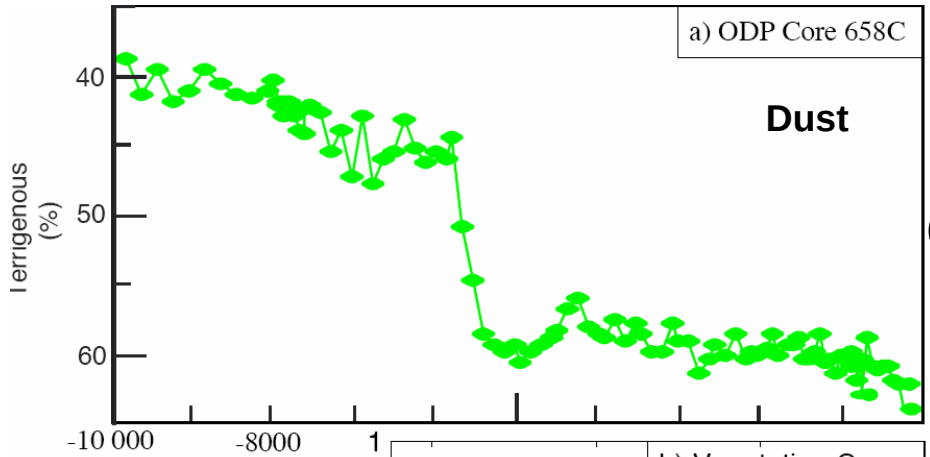






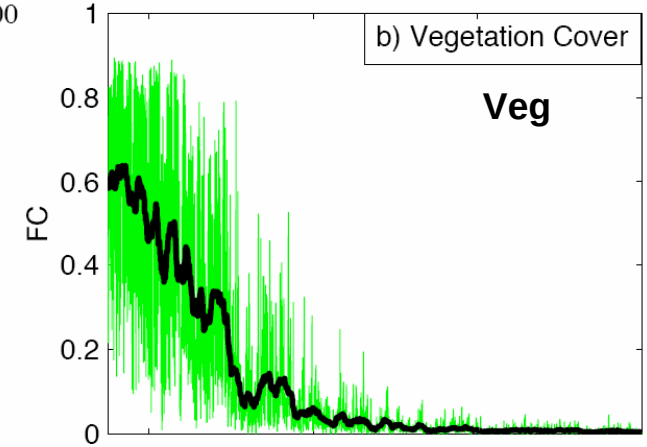


The Abrupt Change

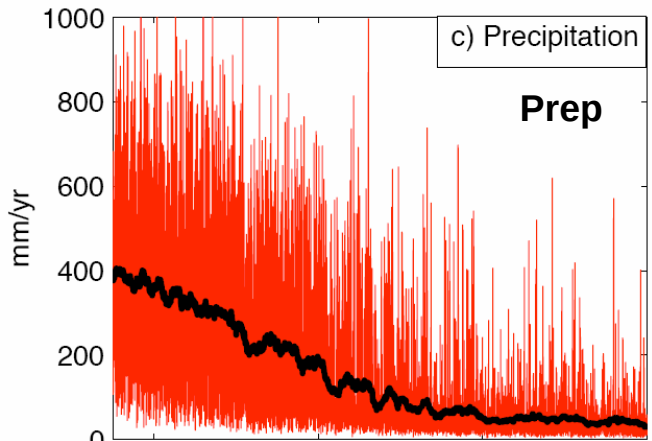


Observation

Abrupt

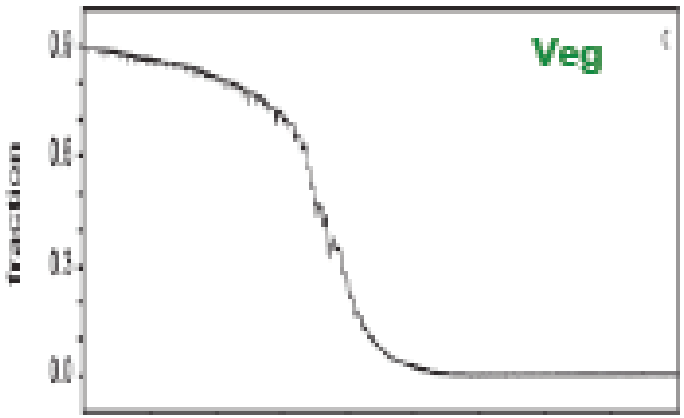


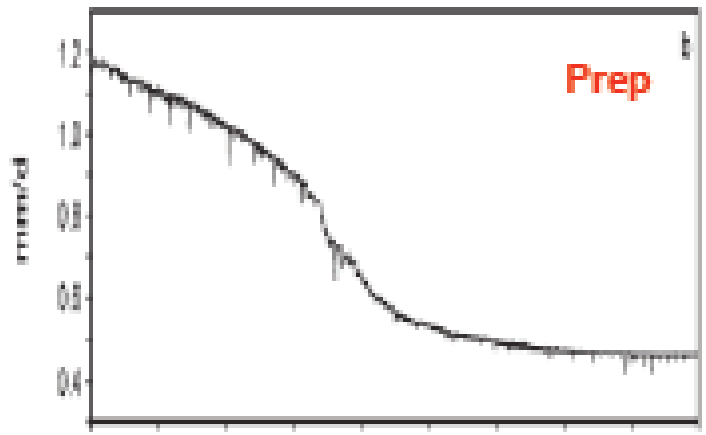
Model



Gradual

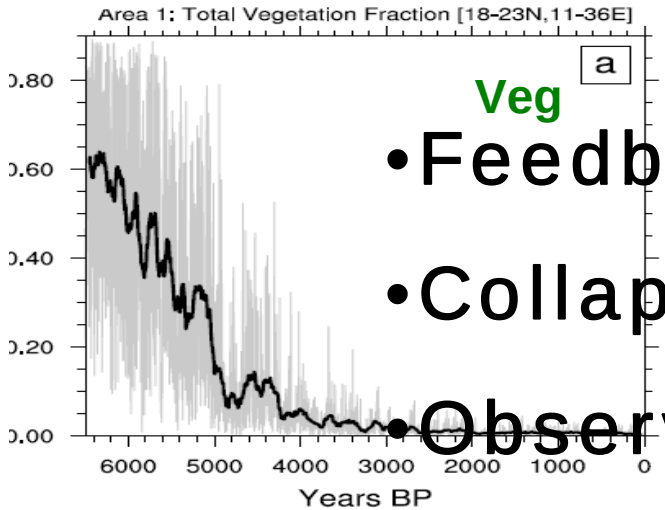
CLIMBER-2

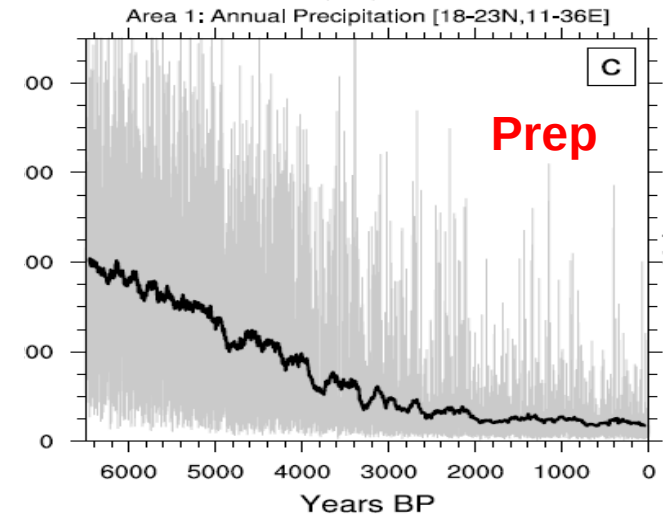




Strong veg feedback

FOAM-LPJ





- Feedback ?
- Collapse?
- Observation?

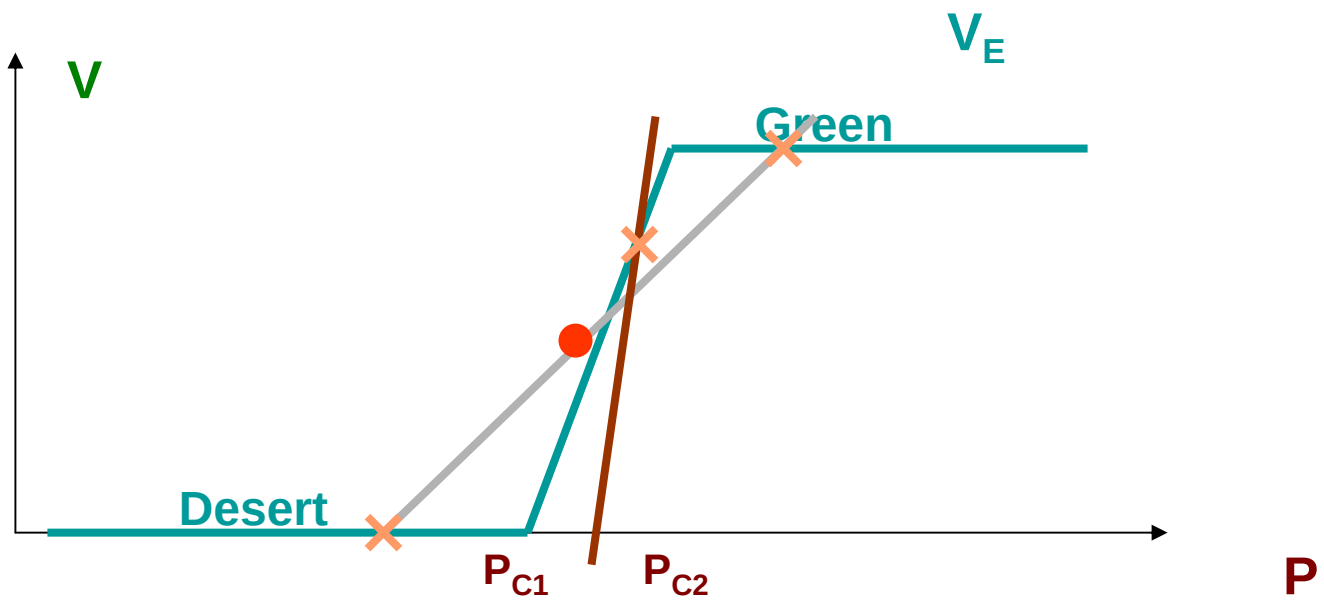
Strong climate variability

- FOAM-LPJ Transient Holocene Simulation

  - Mechanism of Abrupt Change
  - Climate-Vegetation Feedback
  - Rethinking of Paleo-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.	$P_E(V,t) = P_d(t) + D_B V$	$P(V,t) = P_E(V,t) + P_N(t)$

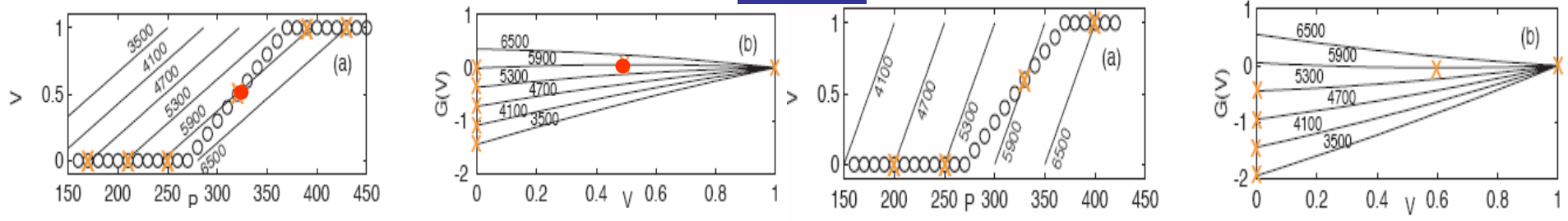


Unstable Collapse and Stable Collapse

Unstable Case

Forcing

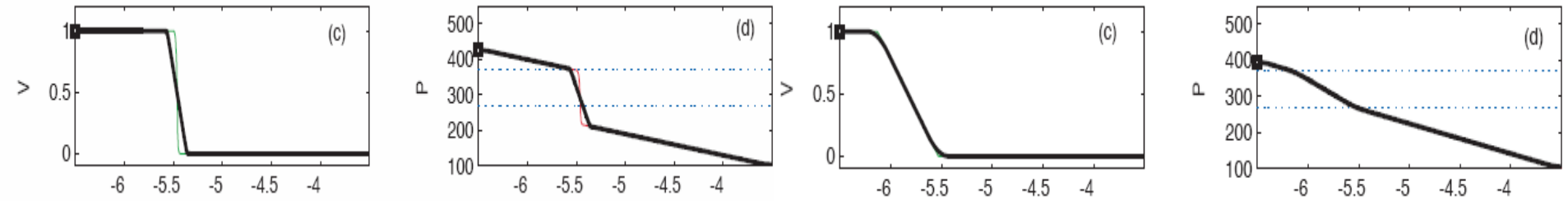
Stable Case



V **Unstable Collapse** P

Steady

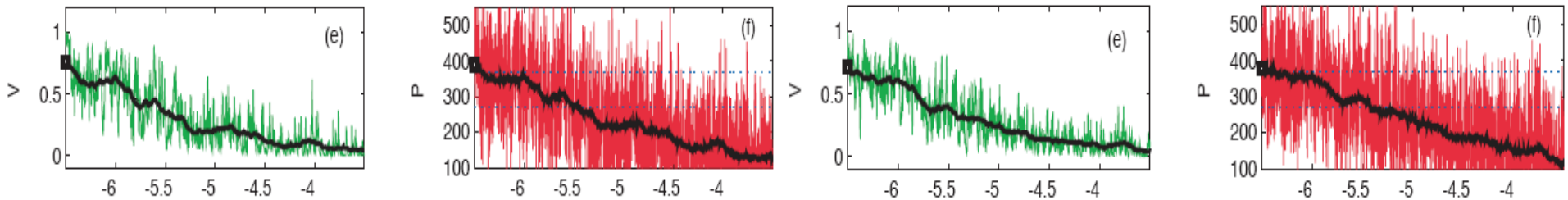
V **Stable Decline** P



Stochastic suppression

Annual Stochastic

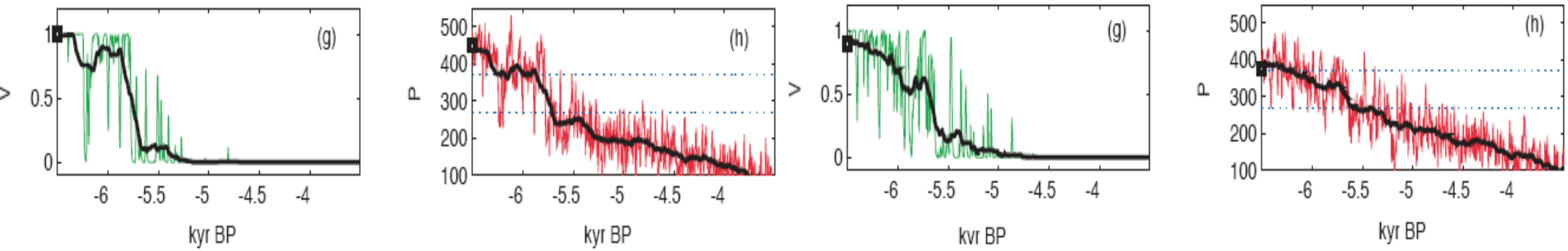
Stochastic suppression



Unstable Collapse

Decadal Stochastic

Stable Collapse



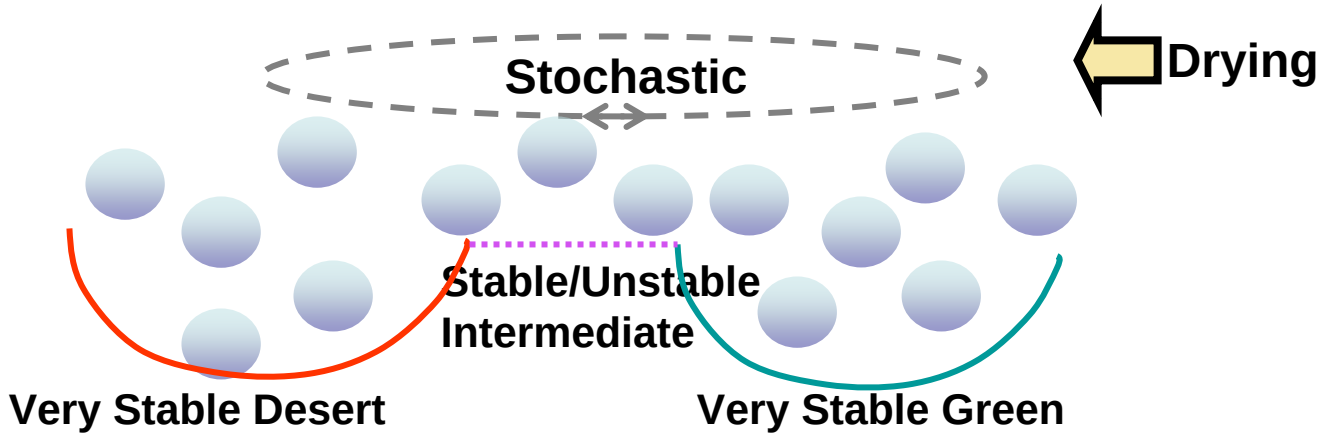
The Role of Stochastic Forcing

Fast Forcing

=>

Stochastic

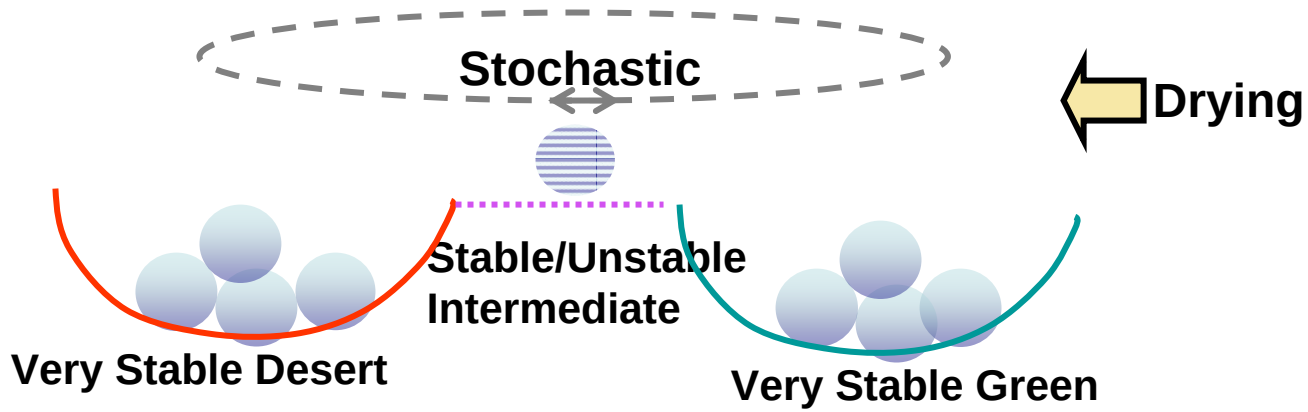
Suppression



Slow Forcing

=>

Stable
Collapse

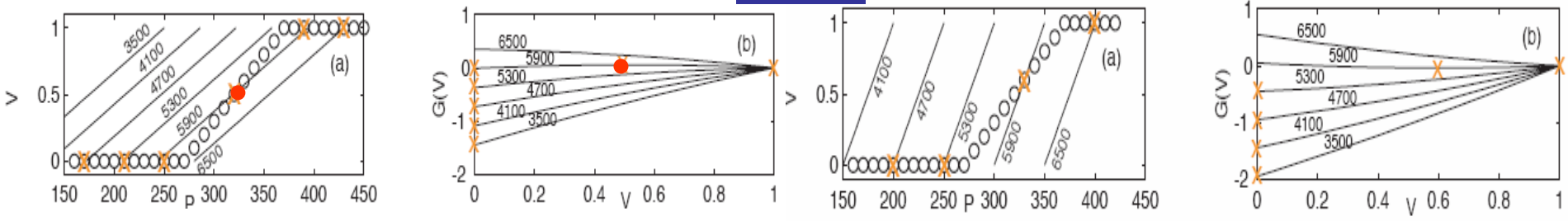


A Unified View of Abrupt Changes

Unstable Case

Forcing

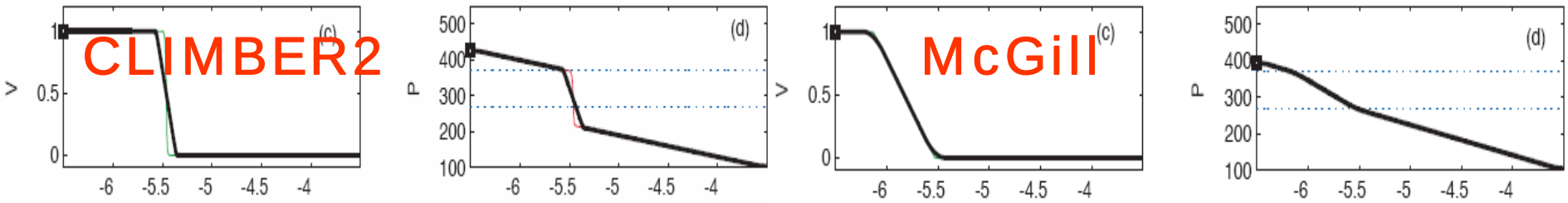
Stable Case



V Unstable Collapse P

Steady

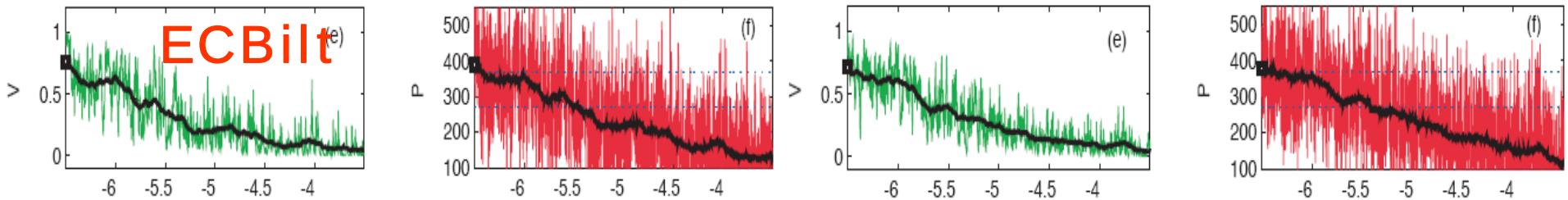
V Stable Decline P



Stochastic suppression

Annual Stochastic

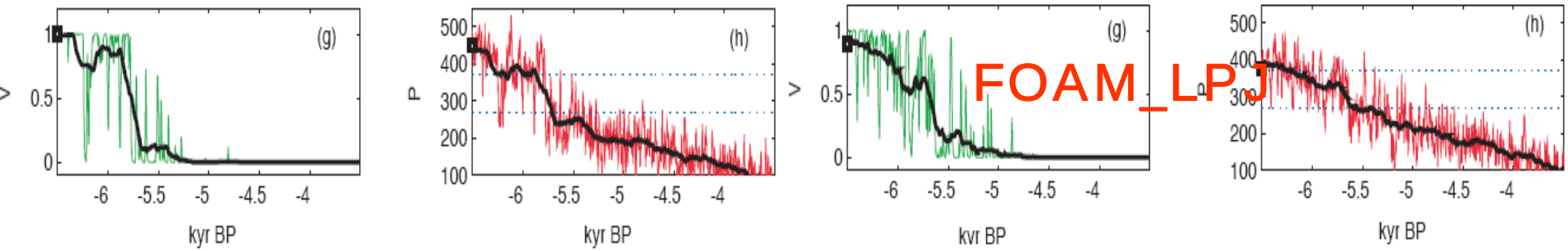
Stochastic suppression



Unstable Collapse

Decadal Stochastic

Stable Collapse



Mechanism of Abrupt Change

The Classical Paradigm: Unstable Collapse **(multiple equilibrium)**

Positive vegetation feedback
=> multiple equilibrium
=> collapse of both vegetation and climate

A New Paradigm: Stable Collapse (monostable)

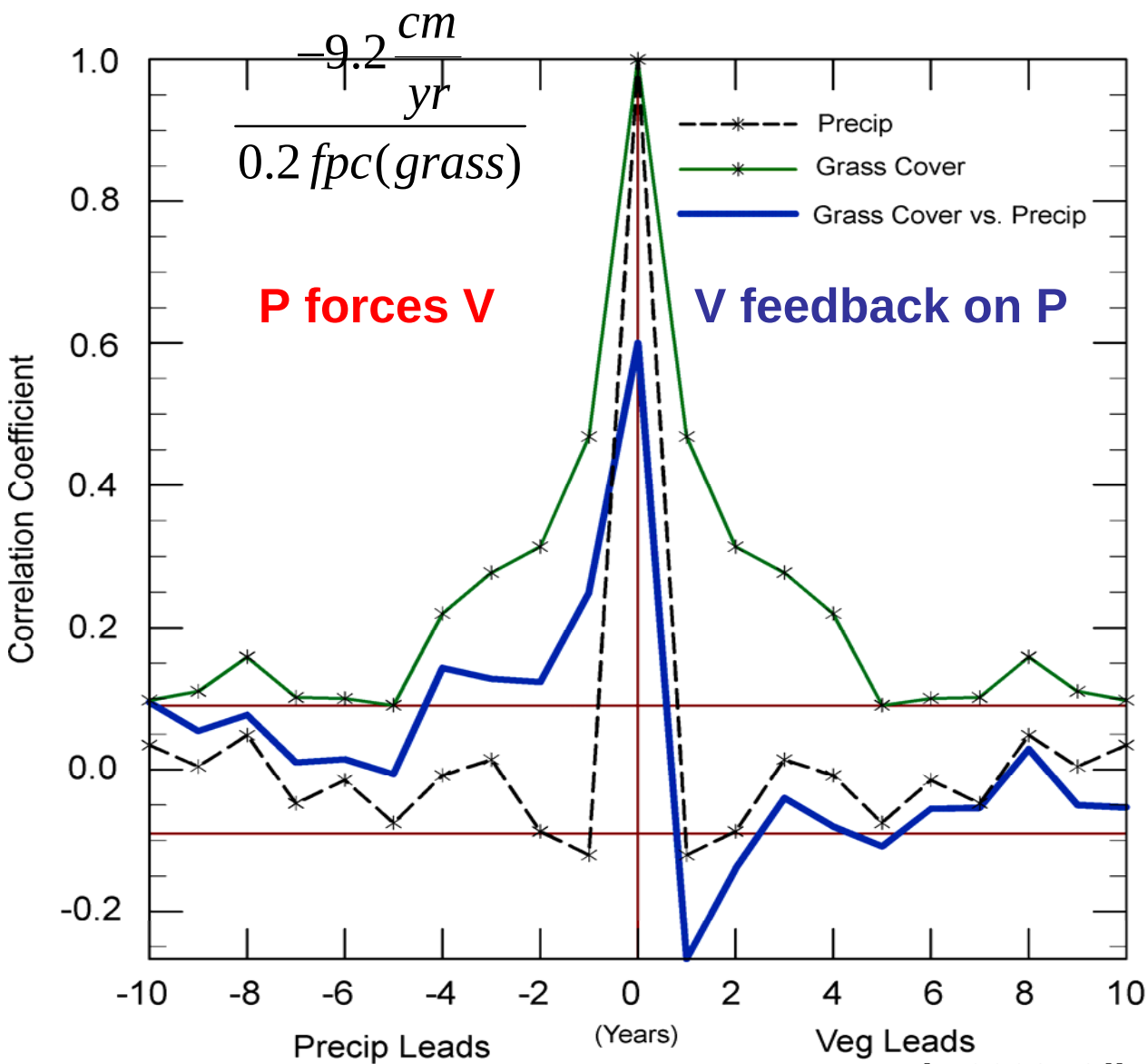
Low frequency climate variability
+ nonlinear bioclimatic threshold
=>Abrupt vegetation collapse,
but gradual precipitation decline

- FOAM-LPJ Transient Holocene Simulation

  - Mechanism of Abrupt Change
  - Climate-Vegetation Feedback
  - Rethinking of Paleo-observation

Forcing and Feedback

Corr<grass cover, annual rainfall> (6K FOAM-LPJ)



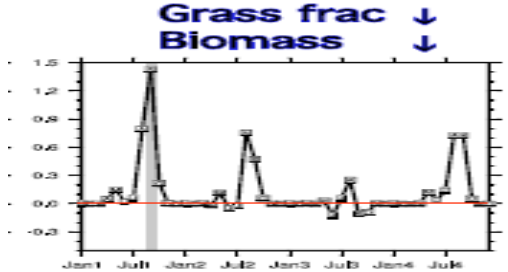
Notaro et al., 2008, Glb Change Biology

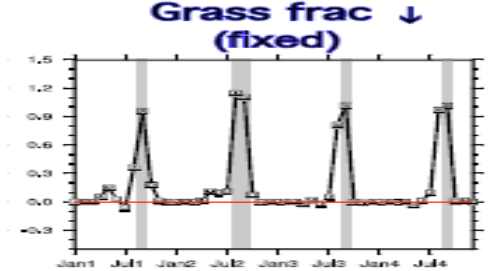
Dynamic Assessment:

Ensemble

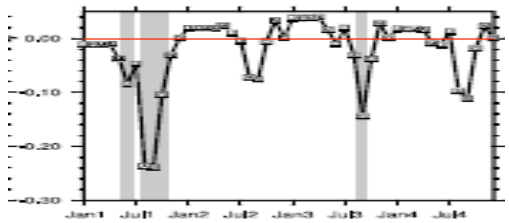
Sensitivity

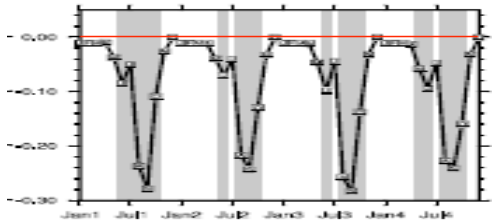
Experiments



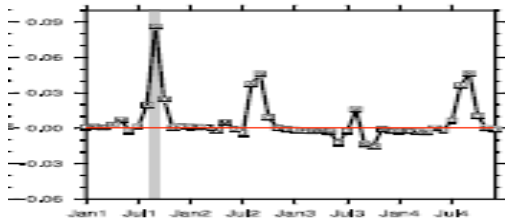


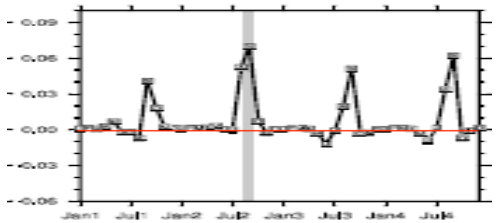
Prep



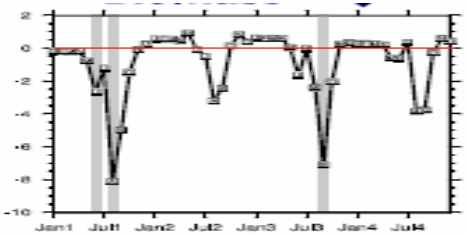


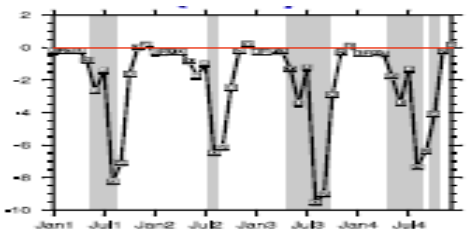
Leaf Area Index





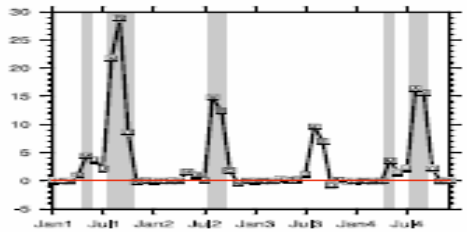
Top Soil Moisture

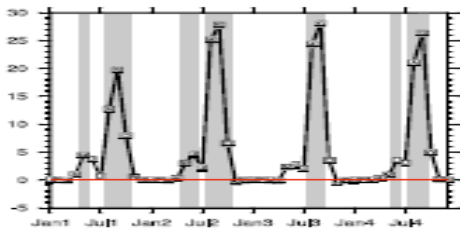




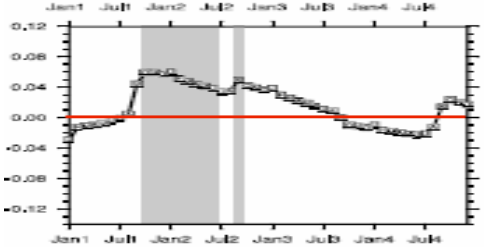
Transpiration

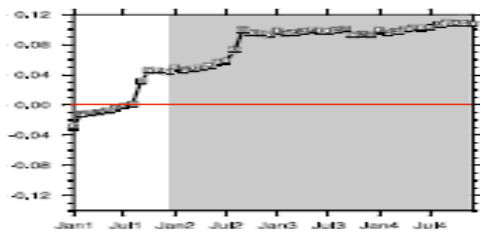
-10
+30





BareGround Evap





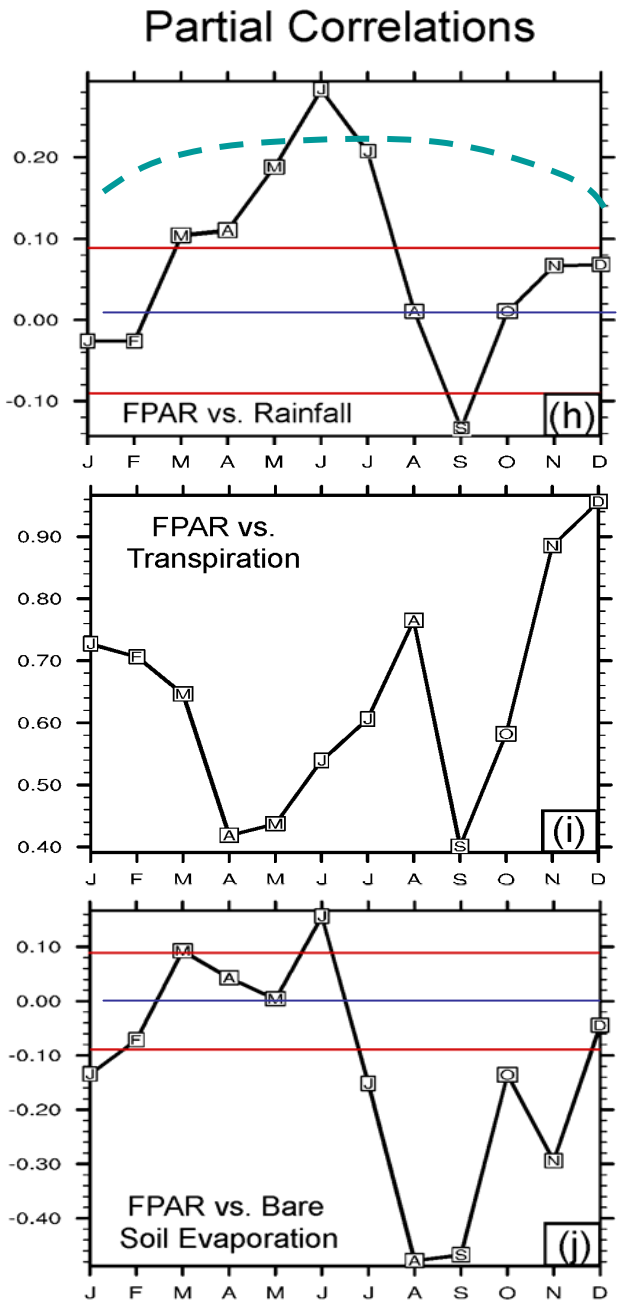
Lower Soil Moisture

Separating Vegetation and Soil Moisture Feedback

PCor<FPAR(0), Prep(+1)>

PCor<FPAR(0), Trans(+1)>

PCor<FPAR(0), BSoilEvp(+1)>



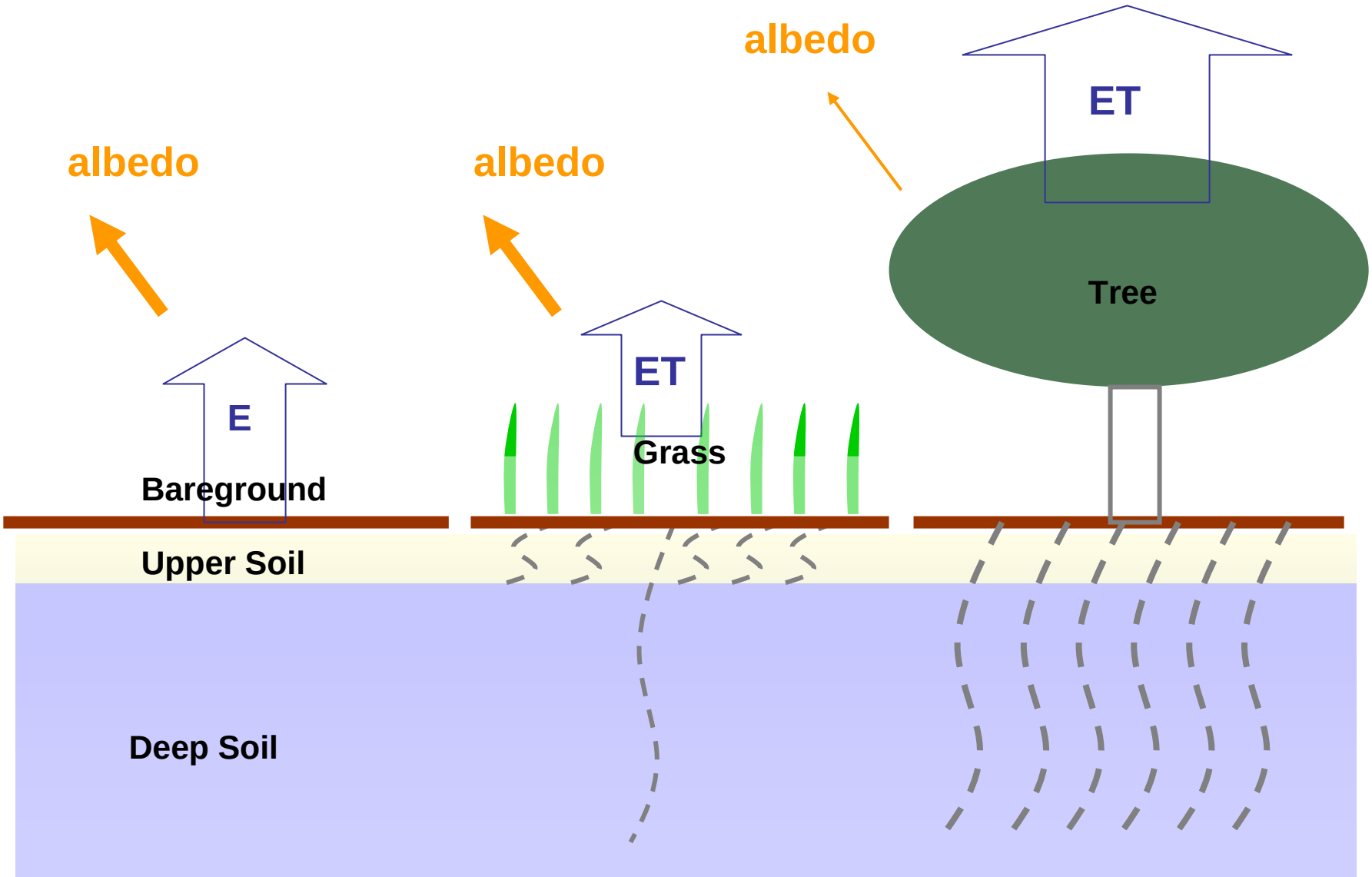
Partial Correlation with fixed upper layer soil moisture!

Dependence on:

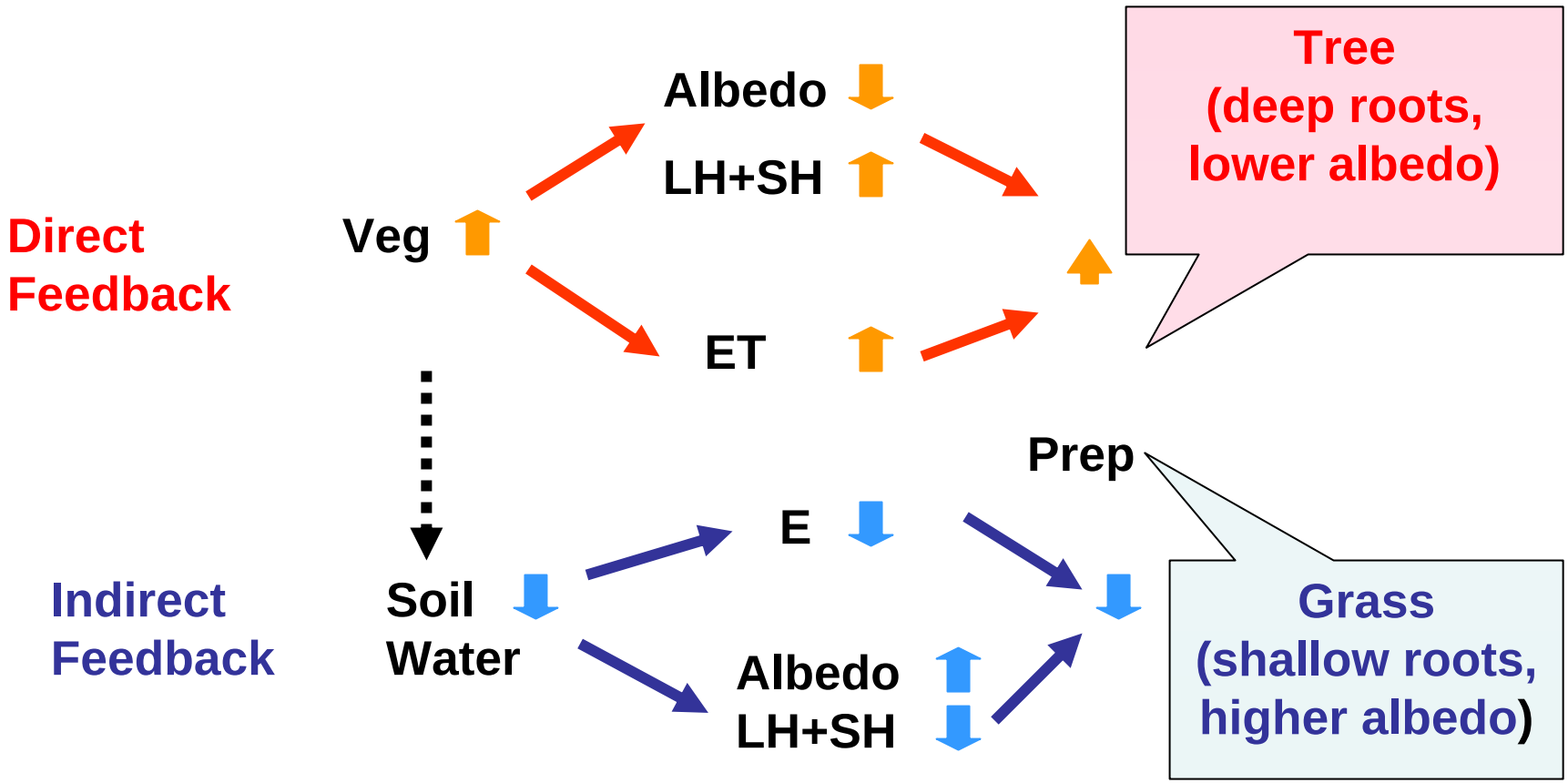
- Time scale
- Seasonality
- Background climate
- Soil, grass, tree.

Africa Savanna

Vegetation Feedback: Soil, Grass and Tree



Synergistic Vegetation-Soil Feedback:



Vegetation Feedback

FOAM-LPJ (and CCSM2) simulated a negative vegetation feedback on subsequent annual rainfall over North Africa during mid-Holocene

An initial decrease in North African grass results in reduced plant evapotranspiration but greater bare-ground evaporation in the rainy season, leading to a net increase in total evapotranspiration. This supports greater rainfall, producing a negative vegetation feedback.

- FOAM-LPJ Transient Holocene Simulation

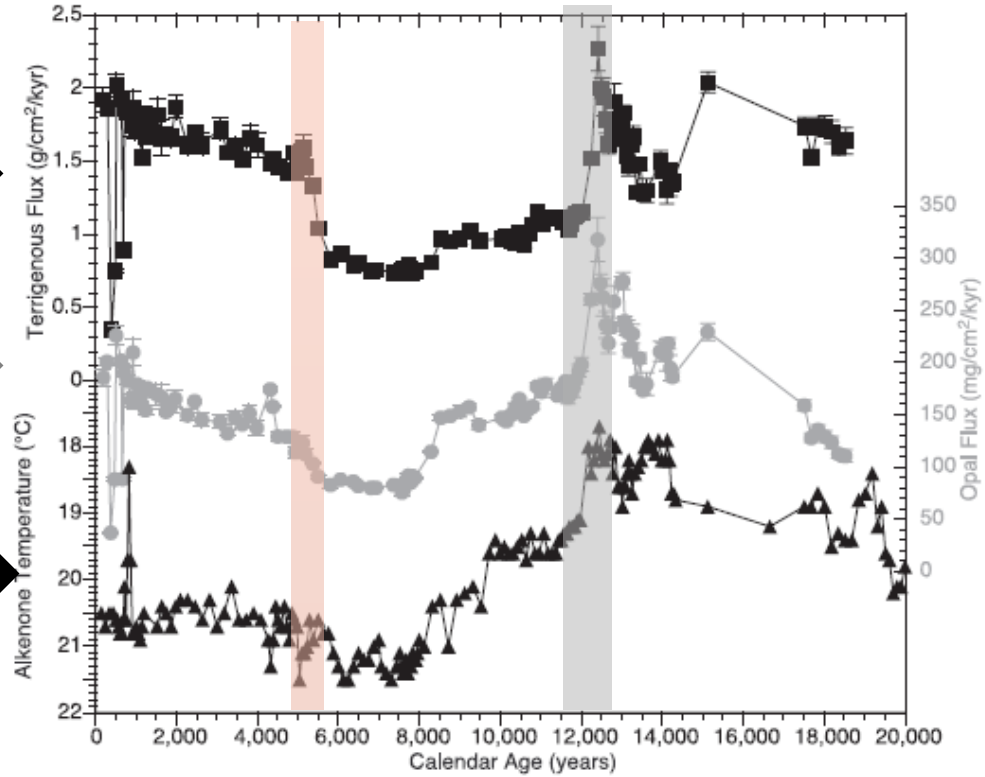
  - Mechanism of Abrupt Change
  - Climate-Vegetation Feedback
  - Rethinking of Paleo-observation

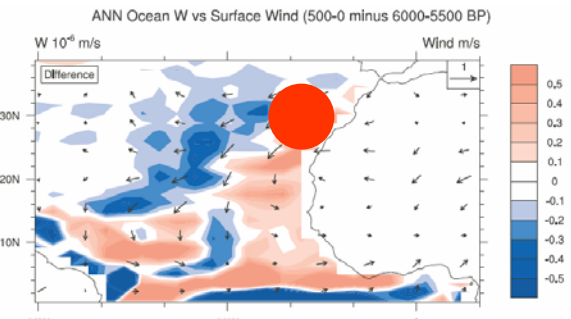
Tropical North Atlantic (ODP 658C)

Dust flux: Abrupt Increase

Upwelling: Gradual Increase

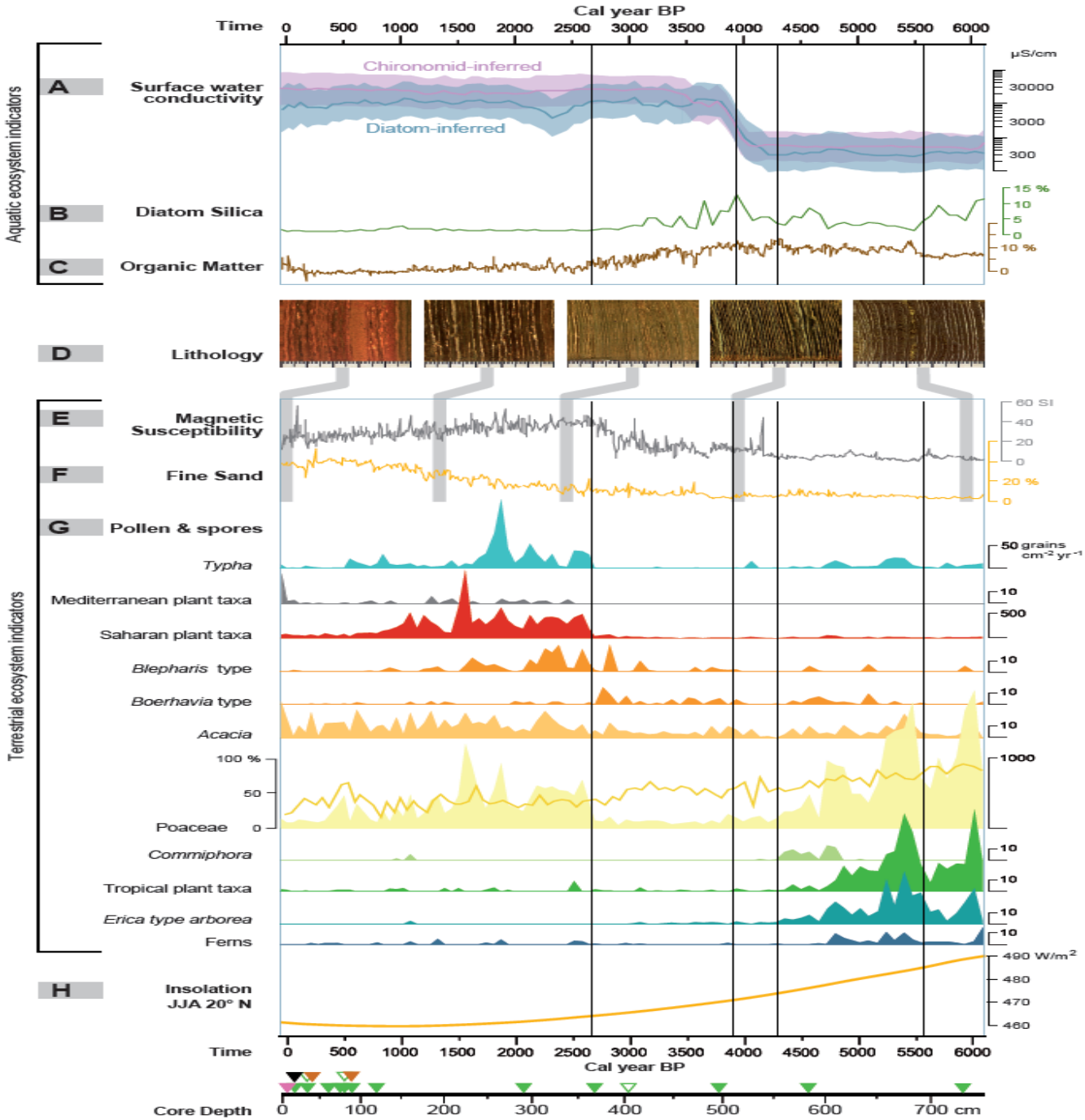
SST: even more gradual cooling

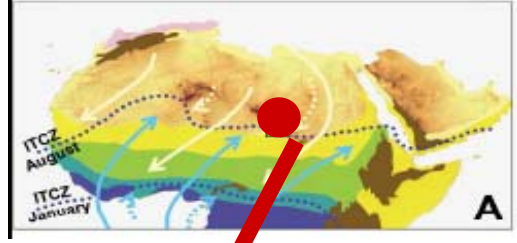




	5 ka	YD
Veg collapse	**Yes!**	**Yes!**
Clim collapse	**?**	**Yes!**

Adkins et al., 2006



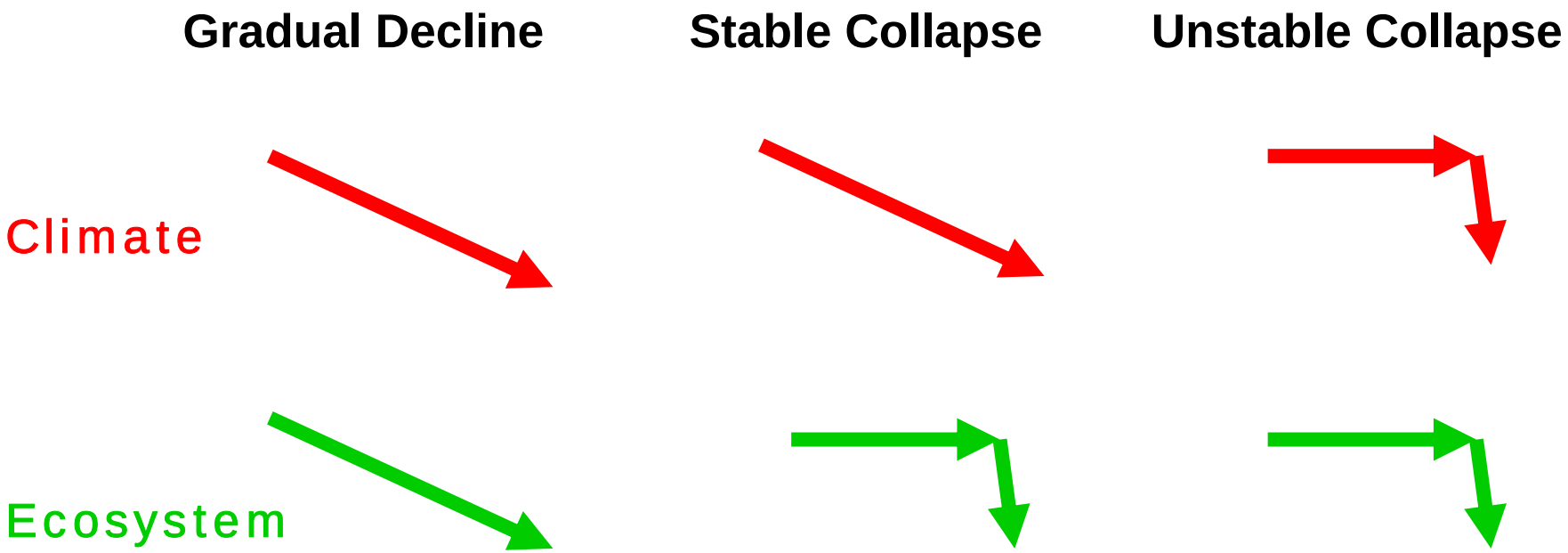


Kroepelin et al., 2008, Science

Paleo-observation

High resolution, separate hydrological/ecological proxies are needed to understand abrupt climate changes

Abrupt Change in Climate and/or Ecosystem?



Conclusions

Evolution of Climate-Ecosystem in the Holocene

A variety of transient evolution behaviors, including gradual and abrupt changes, dominated by a collapse at 5ka

Vegetation Feedback in Northern Africa

Negative grass feedback on annual rainfall in the mid-Holocene.

Implication: vegetation feedback in the real world?

Vegetation Collapse

Due to nonlinear ecosystem response, strong decadal variability, instead of strong positive vegetation feedback (in FORM-LPJ).

Implication: “stable collapse”, abrupt change in monostable system!

Paleo-observations

Strong desertification/ecosystem response could be accompanied by a gradual climate change

Implication: Large scale, high resolution, hydrology/ecology proxies?

Collaborators

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