Climate-Vegetation-Feedbacks as a Mechanism for Accelerated Climate Change: The onset of the African Humid Period

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Introduction:

Paleo-environmental records and models indicate that the African Humid Period (AHP) abruptly ended about 5000-4000 years before present (BP). Some proxies indicate also an abrupt onset of the AHP between 14,000 and 11,000 BP. How important are local orbital forcing, ice-sheet forcing, greenhouse gas forcing, and the reorganization of the Atlantic Meridional Overturning Circulation (AMOC) for changes in the African Monsoon/vegetation system? Here we use transient simulations with climate-vegetation models of different complexity to identify the factors that control the onset of the African Monsoon/Vegetation. We test the following hypothesis:

(1) There is no indication for insolation-thresholds for the onset/break of the AHP.

(2) Forcing from CO_2/ice-sheets significantly controls the climate of North Africa.

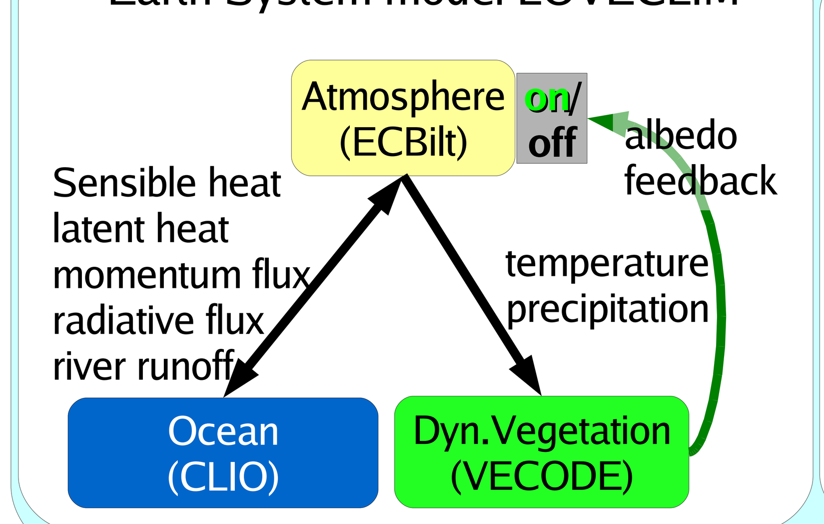
(3) CO_2 fertilization contributes to the vegetation changes over North Africa.

(4) A shutdown of the AMOC is as important as orbital insolation for the African Monsoon.

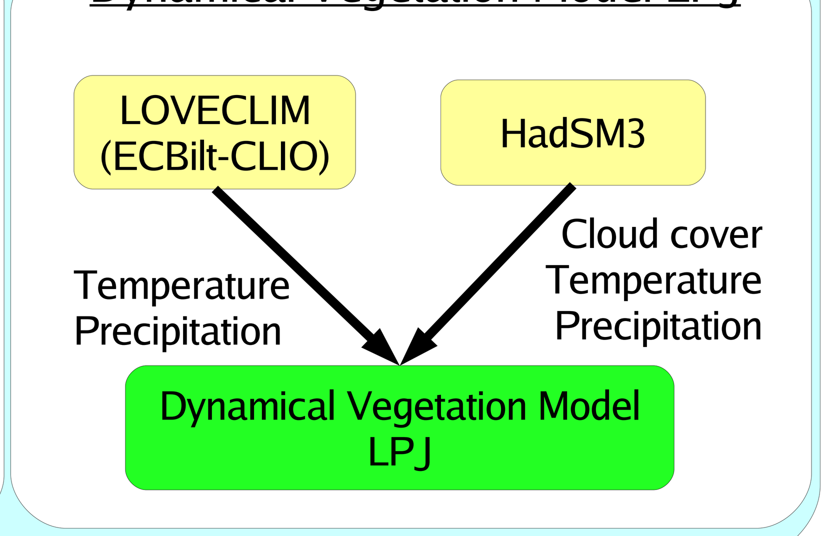
Model Simulations from LGM to Present (21,000BP – 0 BP)

- Dynamical vegetation model LPJ forced with 2m air temperatures, precipitation, and cloud cover from time slice experiments with the HadSM3 model and a transient simulation with ECBilt-CLIO.
- Earth System model of intermediate complexity, LOVECLIM in two versions: ECBilt-CLIO with VECODE active/inactive vegetation-albedo feedback.

Earth System model LOVECLIM



Dynamical Vegetation Model LPJ



Summary and conclusion:

1) Role of the local insolation for the rapid onset of the AHP:

- The initial northward shift of the ITCZ rainfall is triggered by the increased incoming solar radiation during boreal summer (June-September).
- The vegetation feedback leads to a 'rapid' climate response.
- An 'insolation threshold' is unlikely to exist for the North African Monsoon/vegetation, based on the proxy/model evidence.

2) For a given insolation, the North African climate-vegetation system has two different states, indicating the significance of CO_2/ice-sheet forcing for this region.

3) Atmospheric CO_2 changes directly affect the vegetation growth over North Africa through the fertilization effect. The fertilization effect contributes a (weak) negative climate-vegetation feedback.

4) A shutdown of the Atlantic meridional overturning circulation is equally important as the local orbital forcing. The YD event therefore masks potential insolation-driven rapid onsets in paleoclimate proxies.

Simulated Temperature, Rainfall, and Vegetation in North Africa

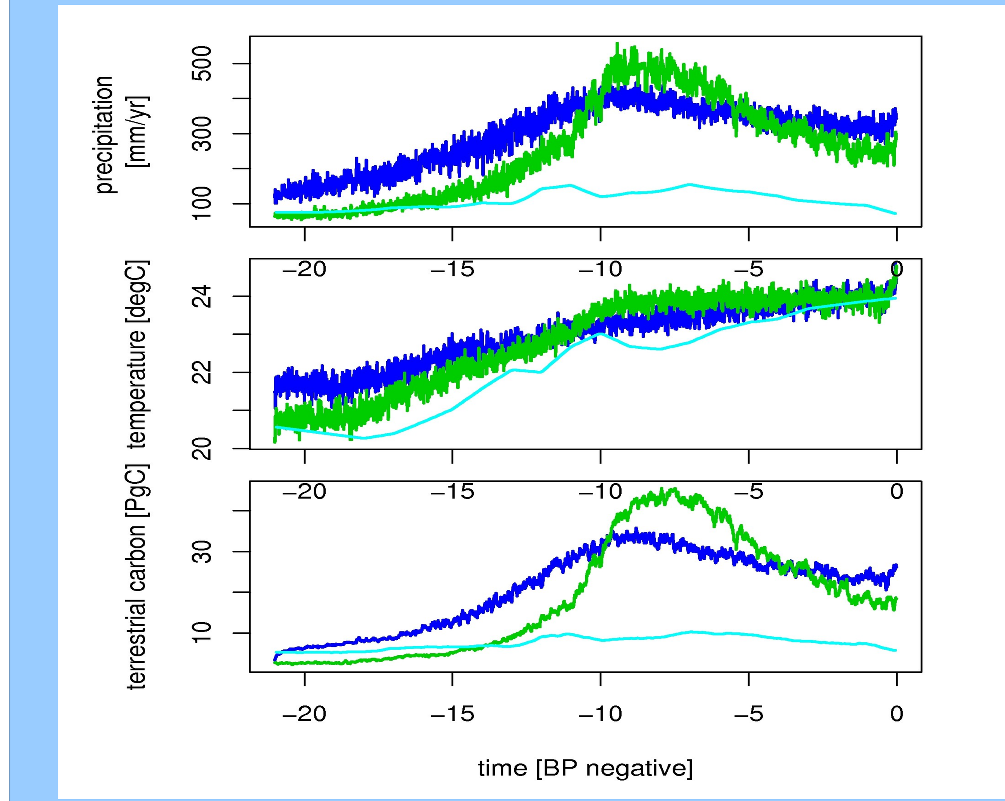


Fig 1: Time series of temperature, precipitation and carbon stock over North Africa (15°N -30°N/15°W-35°E) in the LOVECLIM simulations with (without) vegetation feedback in green (blue). The simulation with LPJ HadSM3 is shown in light blue.

Vegetation Changes 9000-8000 BP

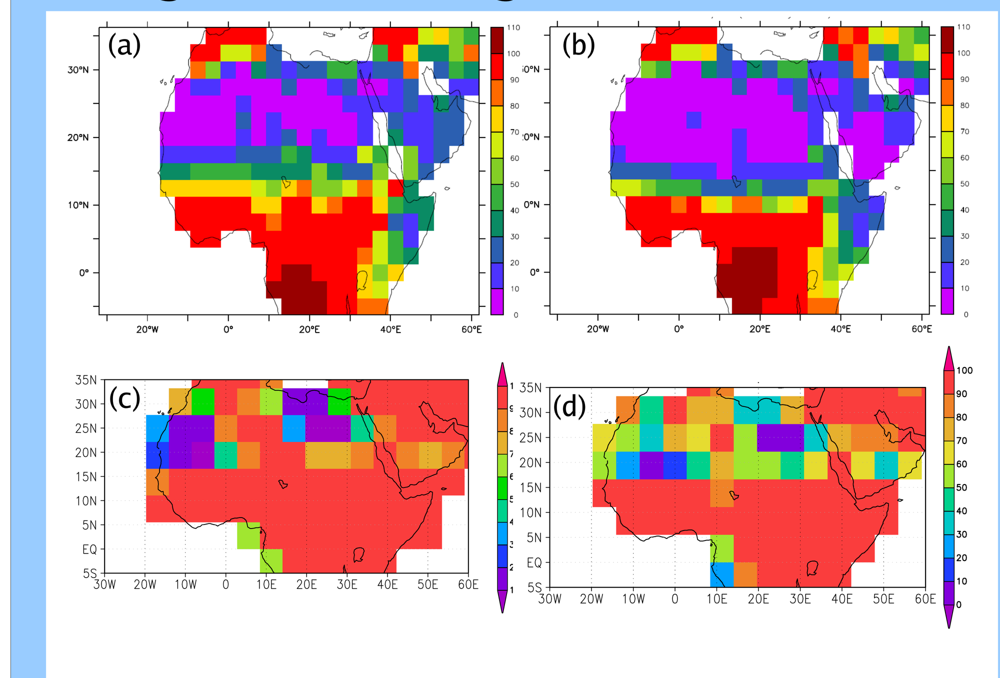


Fig 2: Simulated plant fraction coverage [%] during the maximum of the African humid period 9000-8000 BP: (a) LPJ with HadSM3 forcing , (b) LPJ with ECBILT forcing, (c) LOVECLIM with vegetation-albedo feedback, (d) LOVECLIM without vegetation-albedo feedback.

Forcing factors for the Climate 21,000-0 BP

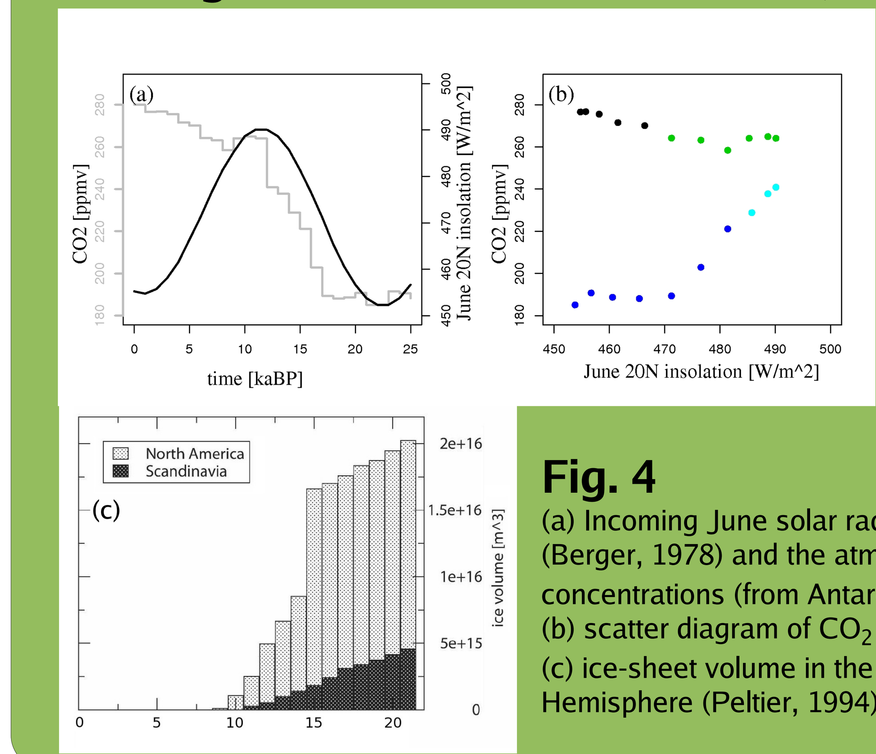


Fig. 4
(a) Incoming June solar radiation at 20N (Berger, 1978) and the atmospheric CO_2 concentrations (from Antarctic ice cores), (b) scatter diagram of CO_2 over insolation, (c) ice-sheet volume in the Northern Hemisphere (Peltier, 1994)

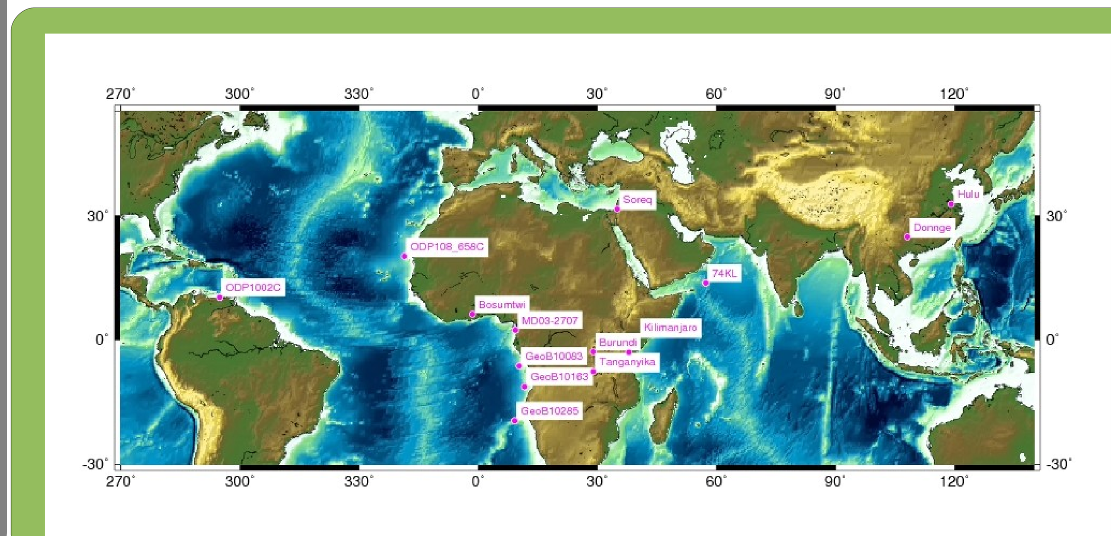


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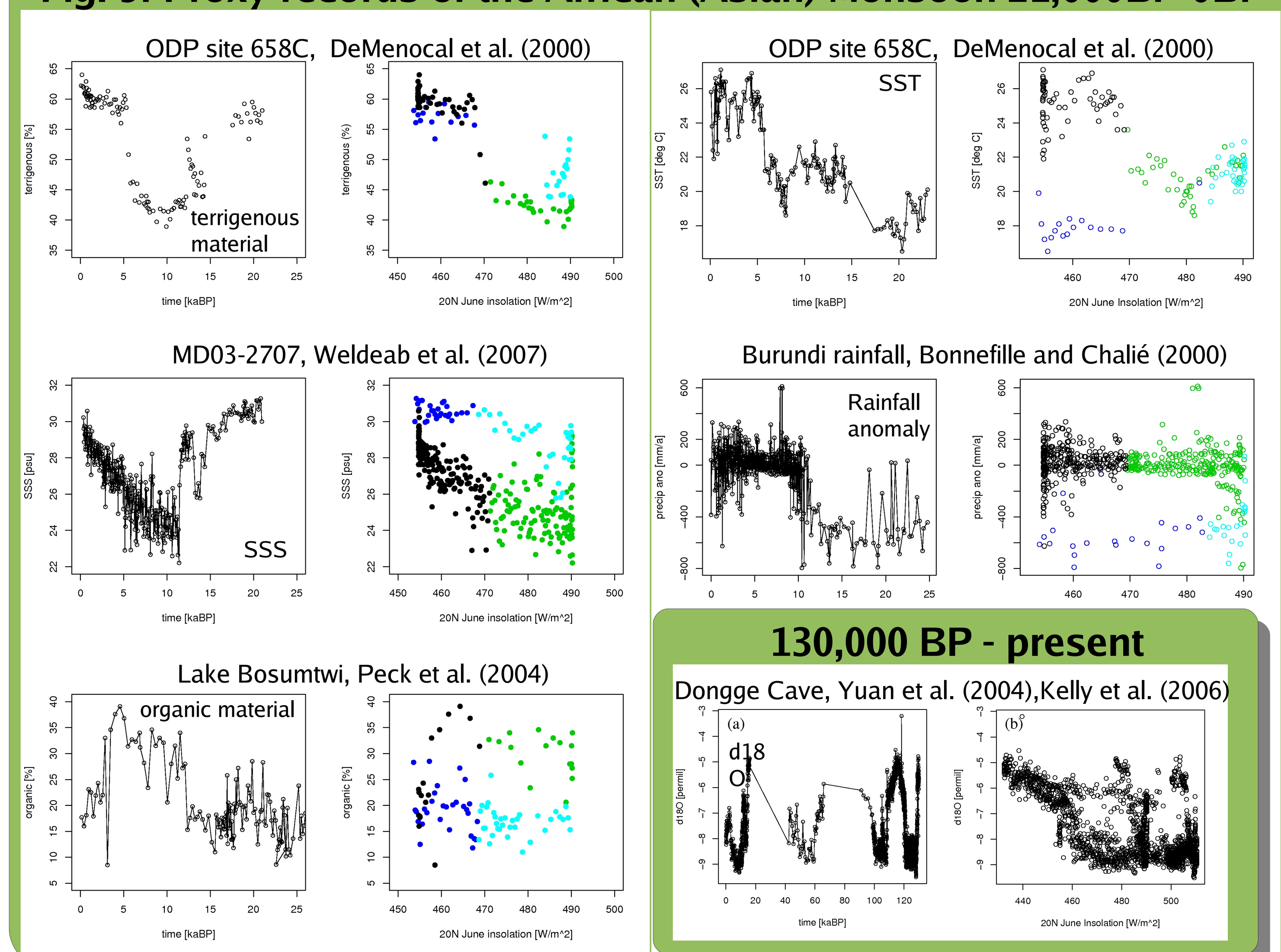
Fig. 5: Proxy records of the African (Asian) Monsoon 21,000BP-0BP



Waterhosing experiments: North African Climate during AMOC shutdown

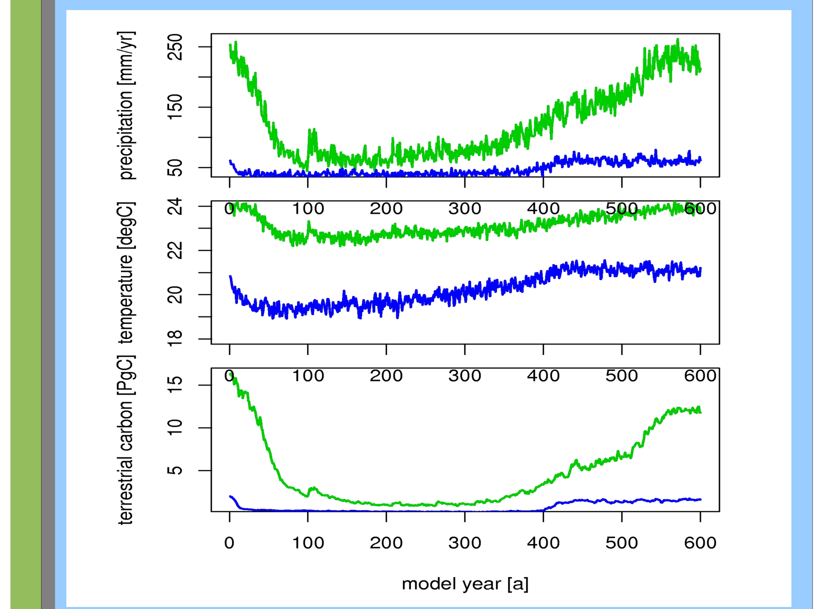


Fig 6: Time series of temperature, precipitation and carbon stock averaged over North Africa (15°N -30° N/15°W-35°E) in the waterhosing experiments (Menviel et al, 2008): simulation during the LGM climate (blue) and during the preindustrial climate (green).

Vegetation-Atmosphere feedback dynamics

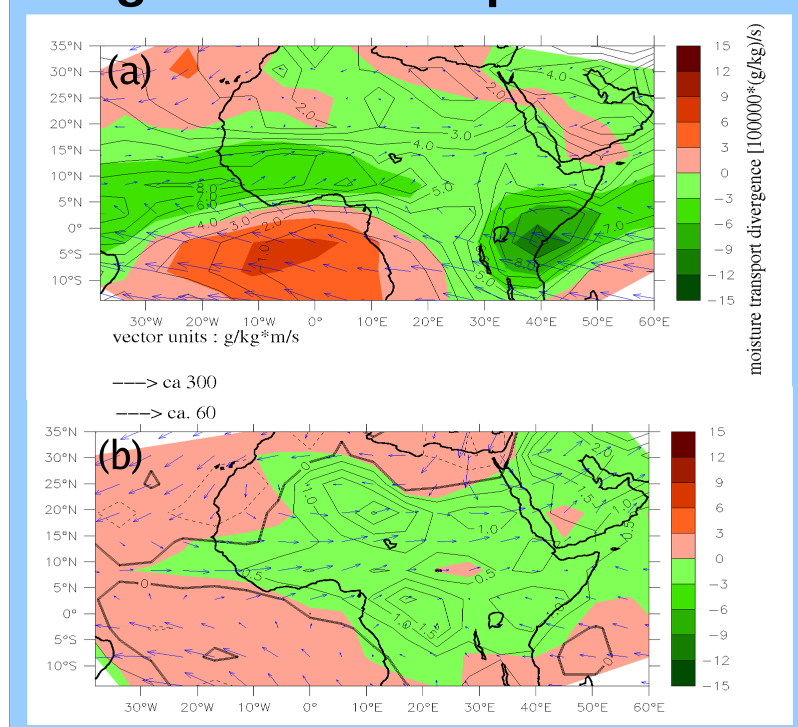


Fig 3: **(a)** Moisture flux (vectors) and moisture flux convergence (divergence) in green (red) colors for June-September during the peak African Monsoon 9,000-8,000 BP. Black contours depict the precipitation [mm/day]. **(a)** LOVECLIM without vegetation-albedo feedback, **(b)** difference between LOVECLIM with and without vegetation-albedo feedback. Green colors mark regions of more moisture convergence and increased precipitation (contours) with vegetation-albedo feedback.

CO2 Fertilization effect on the climate-vegetation state

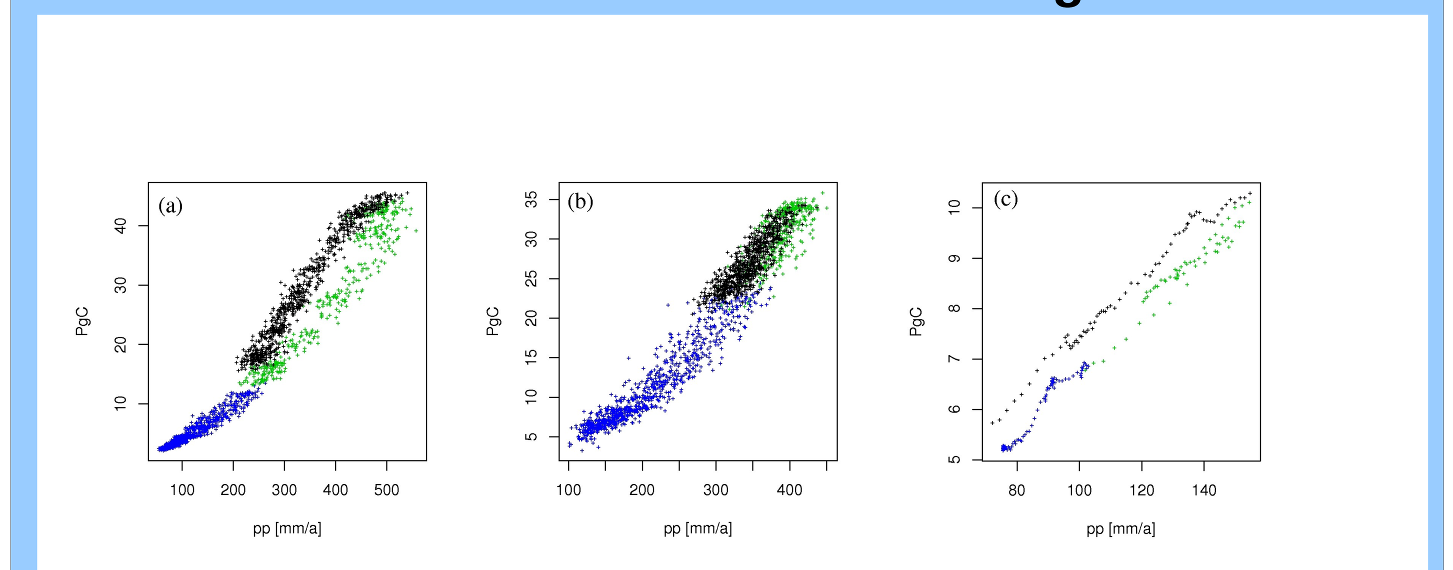


Fig 7: Time series of precipitation and carbon stock over North Africa (15°N -30°N/15°W-35°E) as a scatter diagram: (a) LOVECLIM with vegetation feedback, (b) LOVECLIM without vegetation-albedo feedback, (c) LPJ with HadSM3. Colors denote the intervals LGM-deglaciation (blue), the African Humid Period (green) and the late Holocene (black).

CO2 Fertilization effect: LPJ sensitivity runs

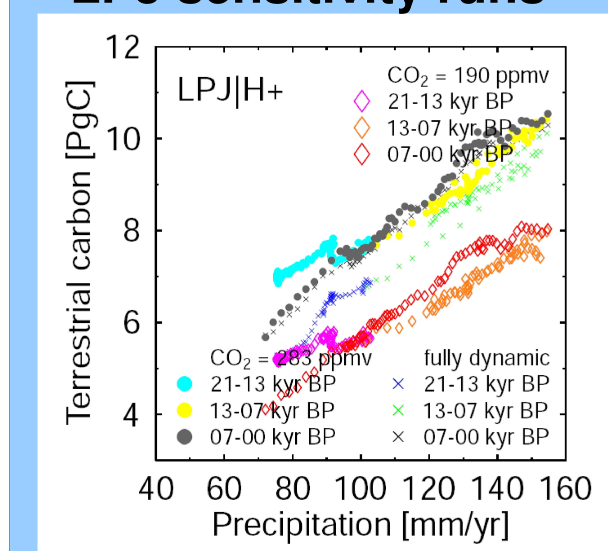


Fig 8: Sensitivity experiments with LPJ using prescribed CO_2 values (190ppmv, 283ppmv) for the net primary production.