Climate Dynamics of Tropical Africa: Capturing Paleoclimate Changes

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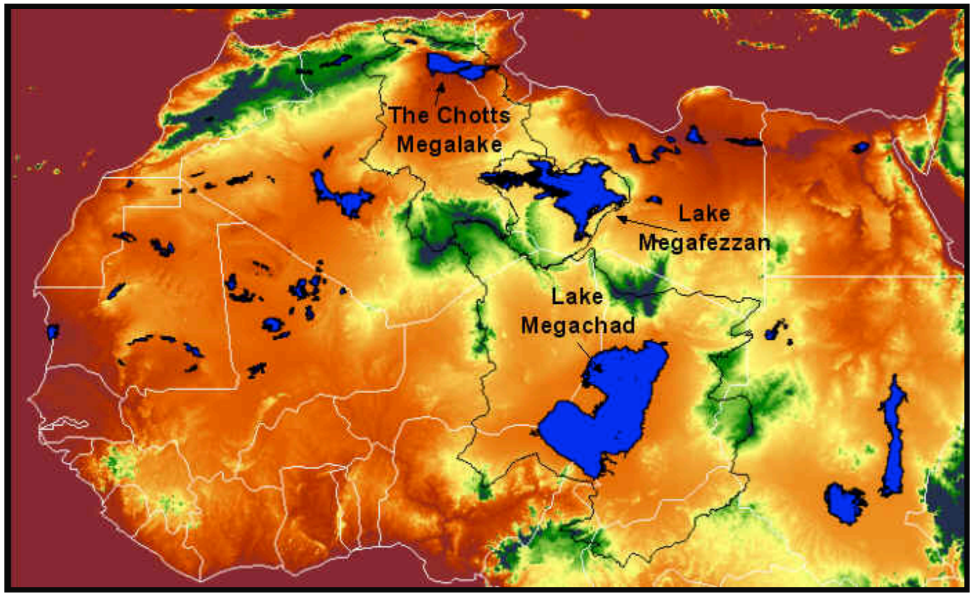
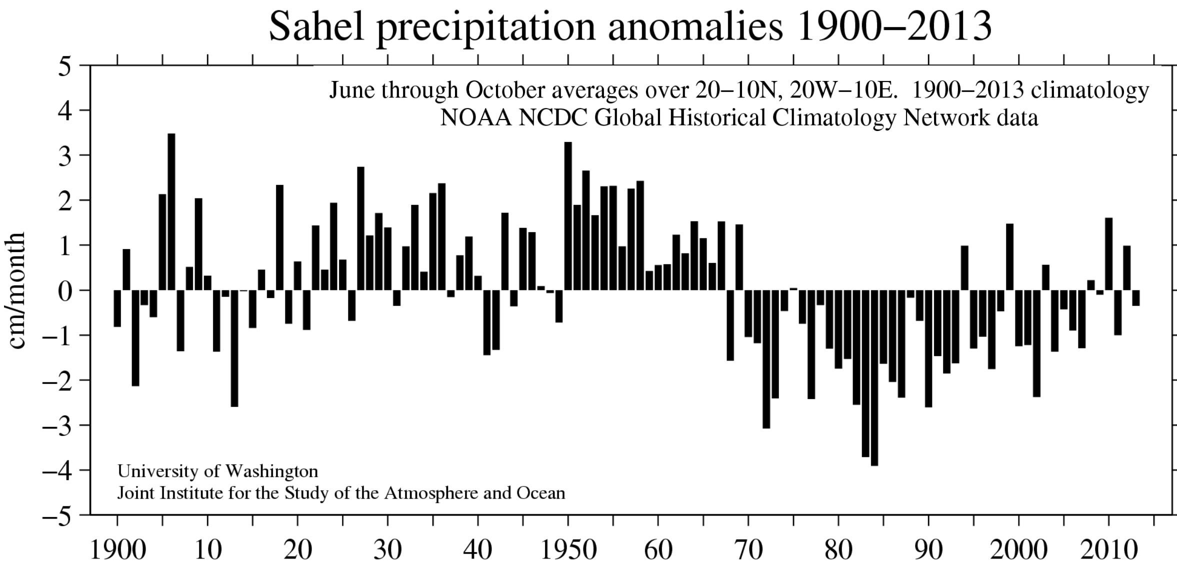


The Sahel



Since 1950, the Sahel has seen persistent anomalies of precipitation:

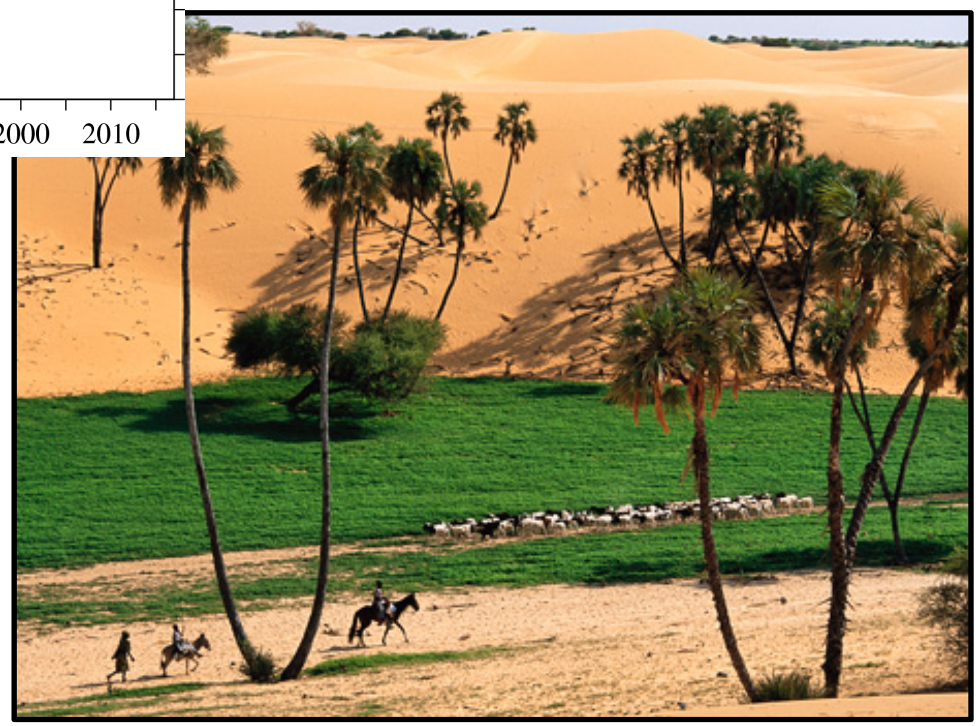
- 1950s – 1960s, persistent excessive rainfall
- 1970s – 1980s, excessive drought

Partial recovery, rise in extreme events

Satellite observations indicate a strong increase in seasonal greenness since the early 1980s.

Proposed cause are numerous, including:

- Improved agricultural practices
- Increasing GHGs, direct and indirect (SST) effects on Sahel rainfall.



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Past and Future – Data and Models

How will precipitation change in the future in the Sahel – all of Africa?

How can the past provide us a perspective to answer this question?

- When was the tropical Africa much wetter/greener and drier than today over the last *glacial-interglacial* period? What processes influenced this change?
- How abruptly did these humid and dry periods in tropical Africa start and end? And why?

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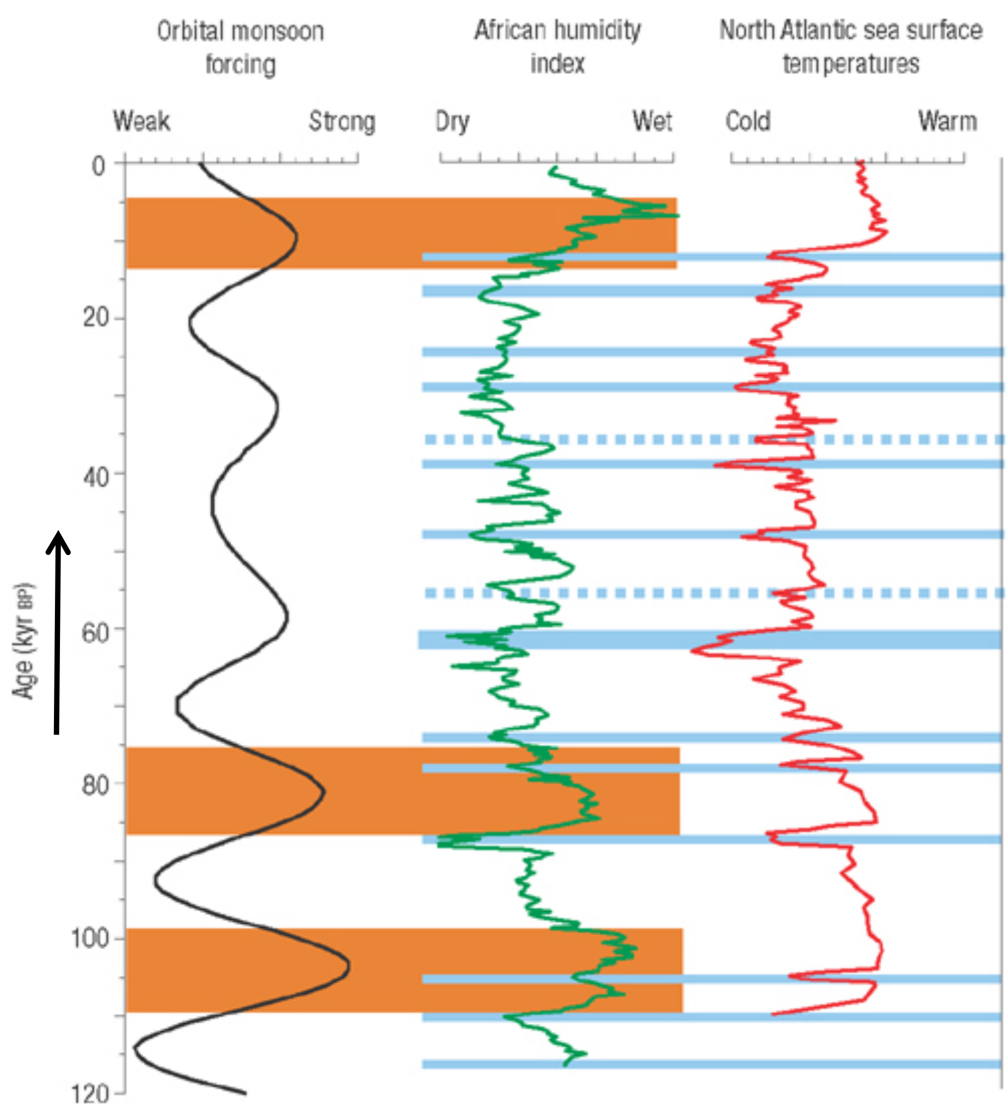
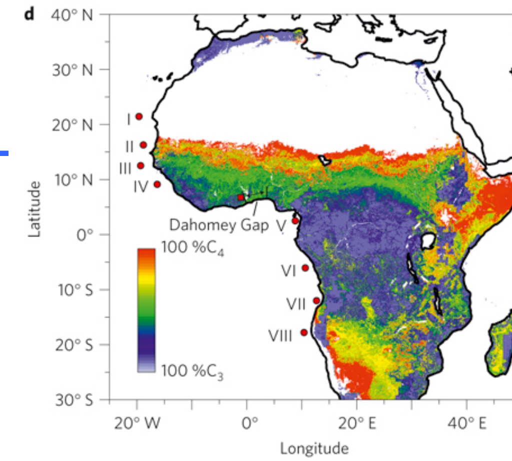
Data – Glacial-Interglacial





Measurements: siliciclastic grain size variations in a deep-sea core off western Africa and alkenone measurements from two sediment cores near Portuguese margin

Interpretation:

African "humidity index" displays eccentricity-modulated precessional cycles (~20 kyr), with millennial variations correlated with North Atlantic SSTs

deMenocal, Science, 2008

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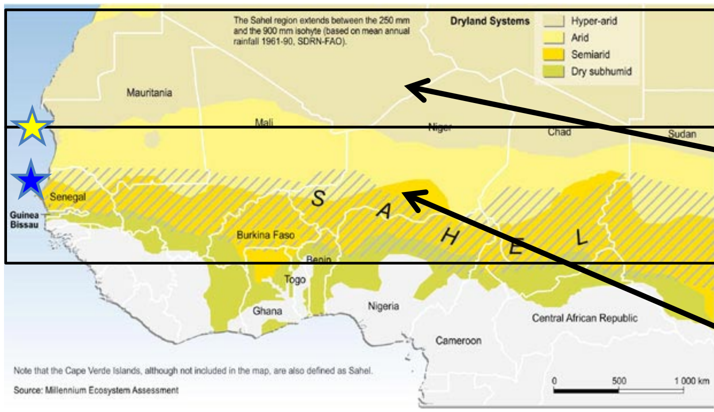
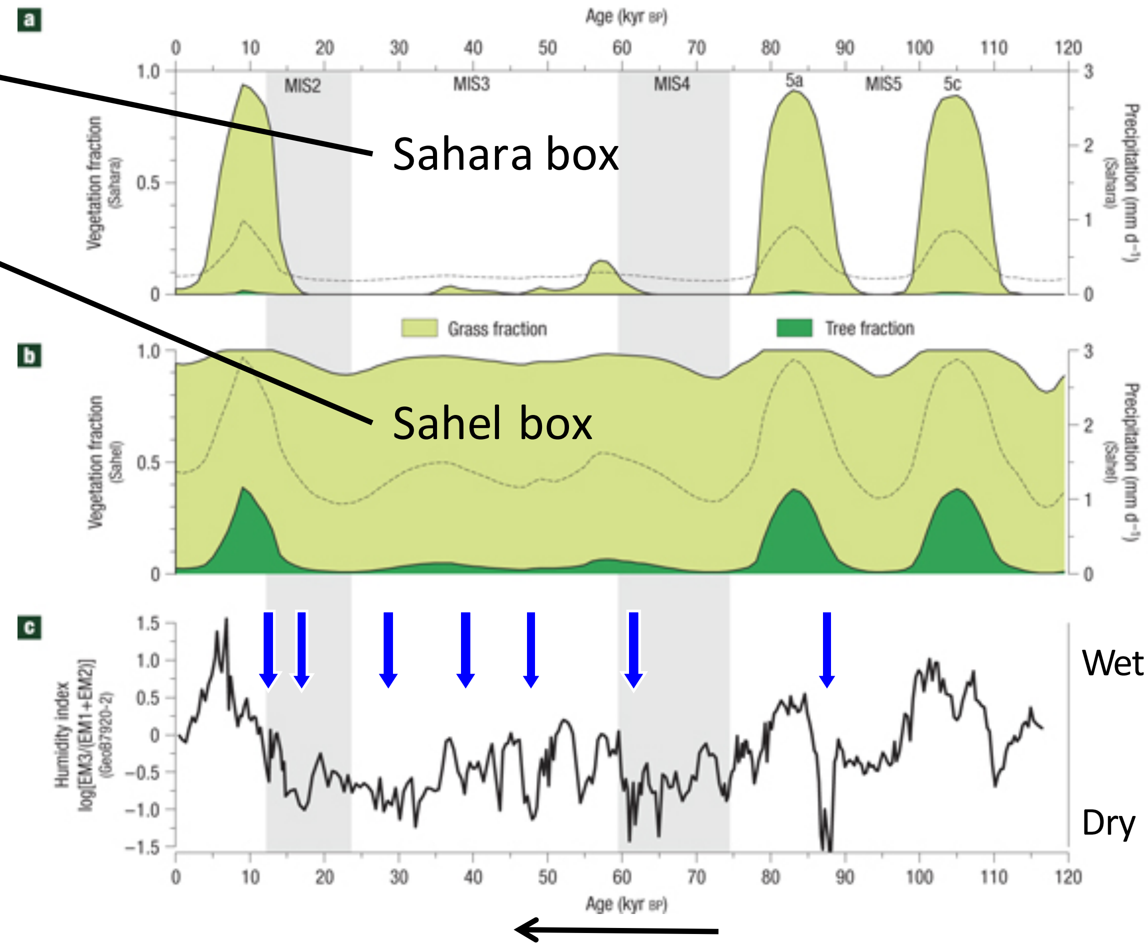
Models – Glacial-Interglacial: Orbital Forcing



CLIMBER2 AOV Model Simulation



Interpretation:

Recurrence of humid periods when precession-forced orbital monsoon forcing is strong.

Greening of Sahel and Sahara associated with precipitation increases.

Tjallingii et al., Science, 2008

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Models – Glacial-Interglacial: Millennial Events

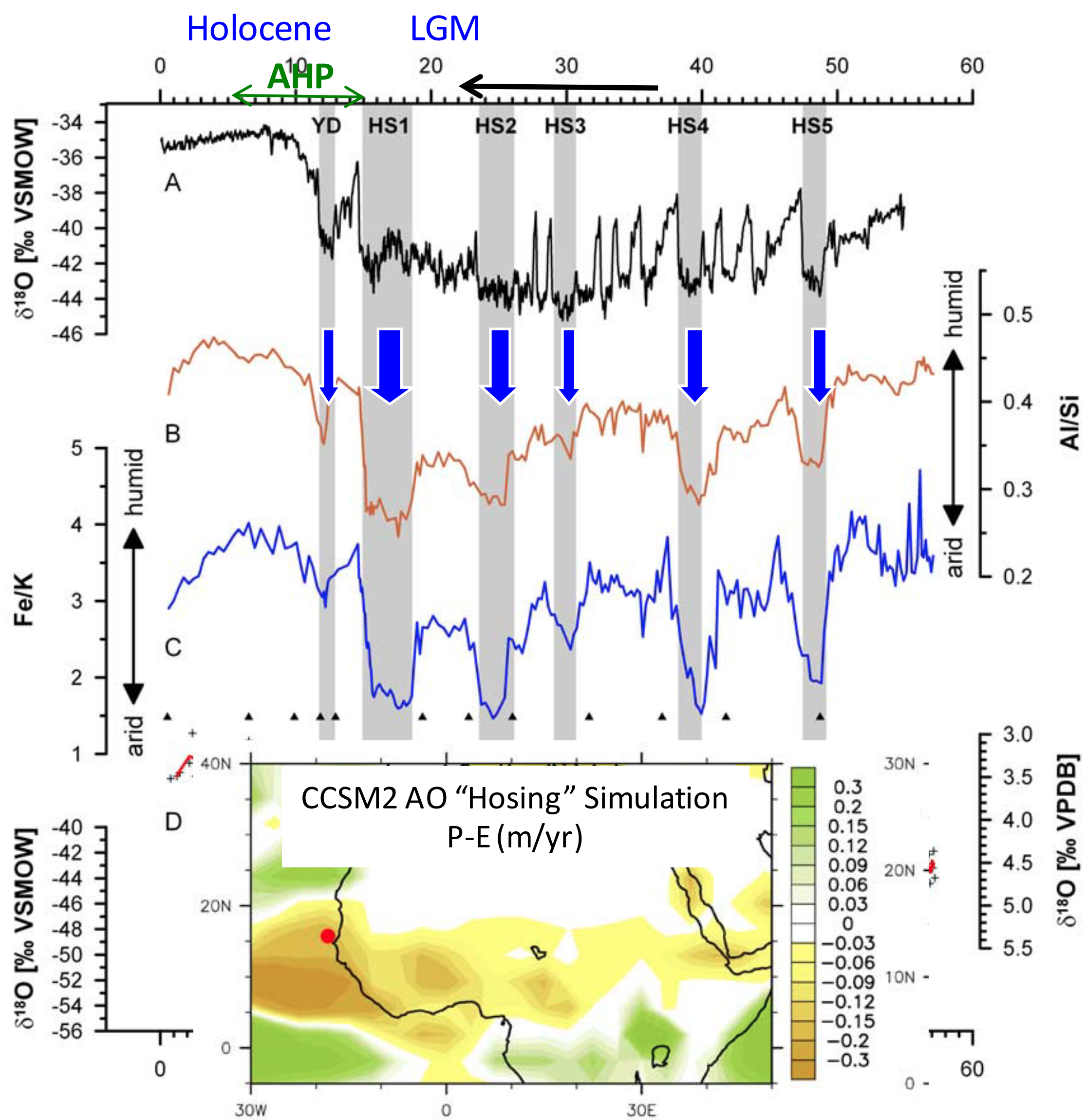
Measurements: grain size and elemental ratios in marine core GeoB9508-5, on continental slope just west of Senegal River mouth.

<u>Interpretation</u>:

Data: Strong decreases in Al/Si and Fe/K ratios during Heinrich stadials are associated with much lower sediment discharge from Senegal River ➔ arid West African Sahel.

Climate model: Cold North Atlantic during meltwater events induces a southward shift of West African monsoon trough and mid-tropospheric African Easterly Jet.

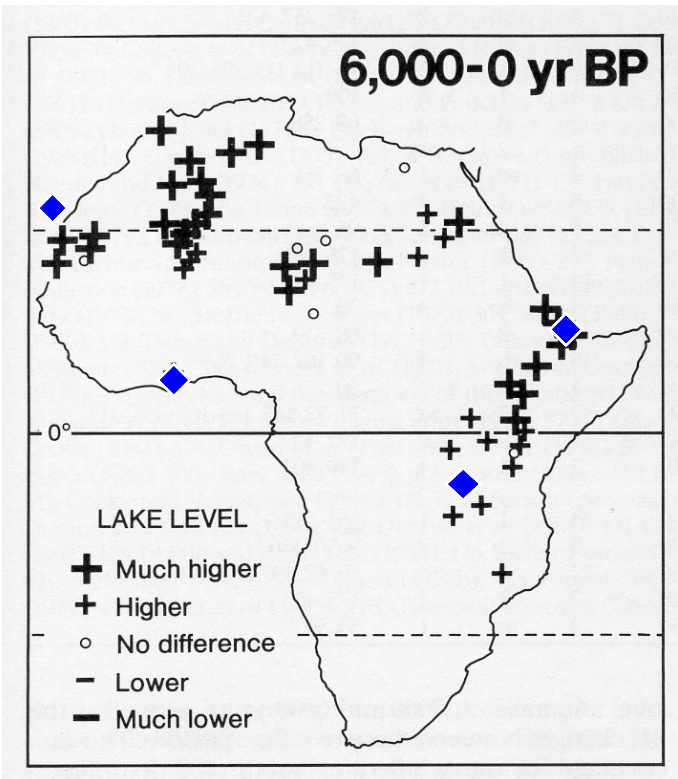
Mulitza et al., Paleoceanography, 2008



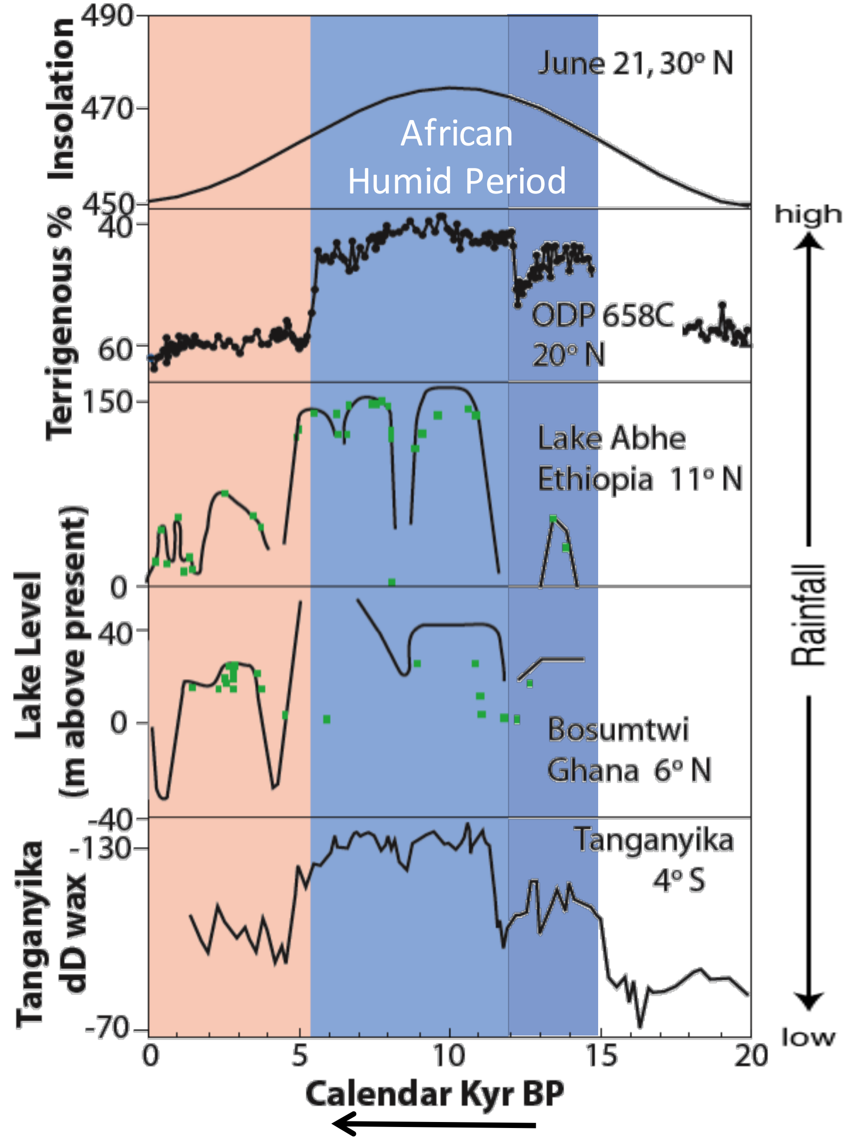
Last 21ka – Deglaciation and Holocene

Abrupt, synchronous initiation of the African Humid Period across Africa?

The DATA



Street-Perrott & Perrott, 1993



deMenocal et al., 2000; Gasse, 2000; Tierney et al. 2008

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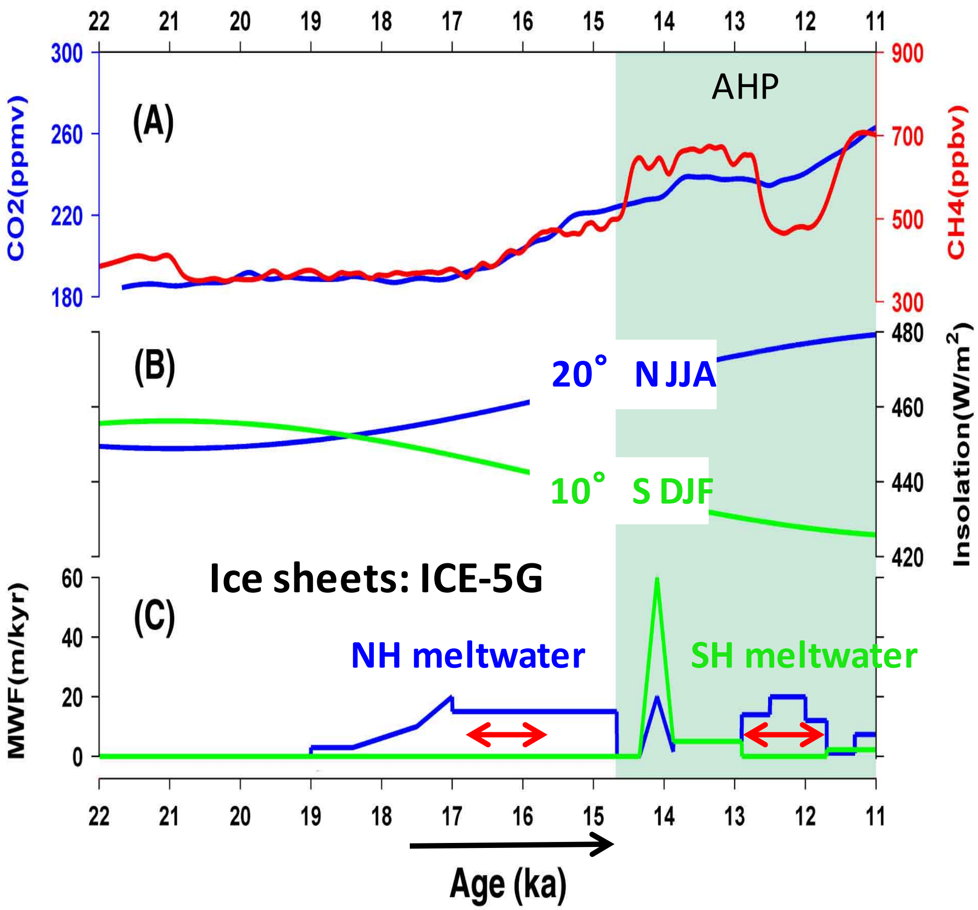
Role of Climate Forcings

TraCE (Transient Climate Evolution) Project to simulate 21ka to present



Community Climate System Model 3

- Atmosphere model, 3.75° lat-lon
- *Land model with predicted vegetation*
- Ocean model, ~3° , 25 levels
- Sea ice model, dynamic & thermodynamic

Three simulations

- TraCE – all forcings: GHG, orbital, ice sheets, and meltwater
- *TraCE – orbital-only**
- *TraCE – GHG-only**

* All else held at 17ka

Otto-Bliesner et al., Science, 2014

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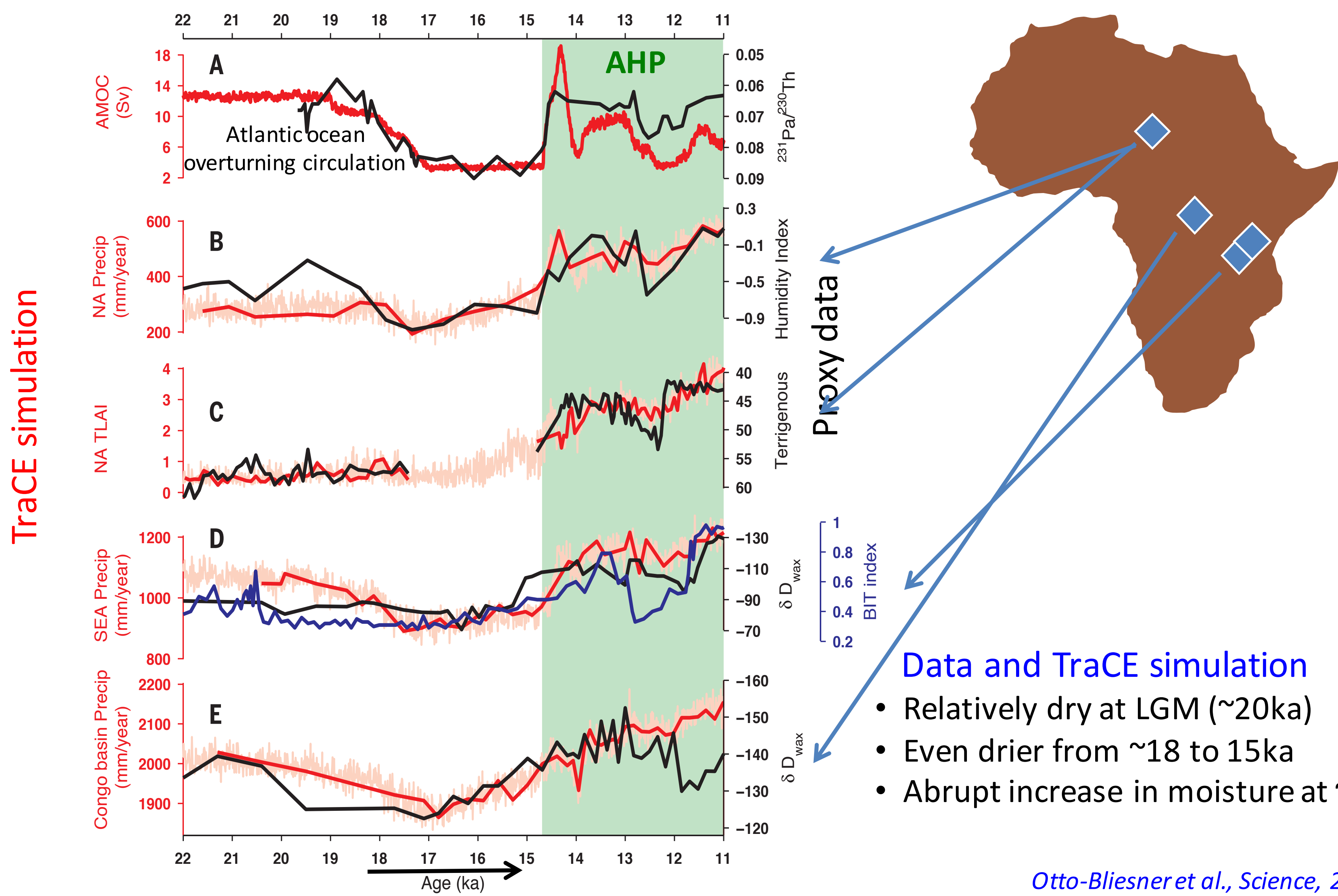
TraCE simulation versus Proxy Data



Data and TraCE simulation

- Relatively dry at LGM (~20ka)
- Even drier from ~18 to 15ka
- Abrupt increase in moisture at ~14.7ka

Otto-Bliesner et al., Science, 2014

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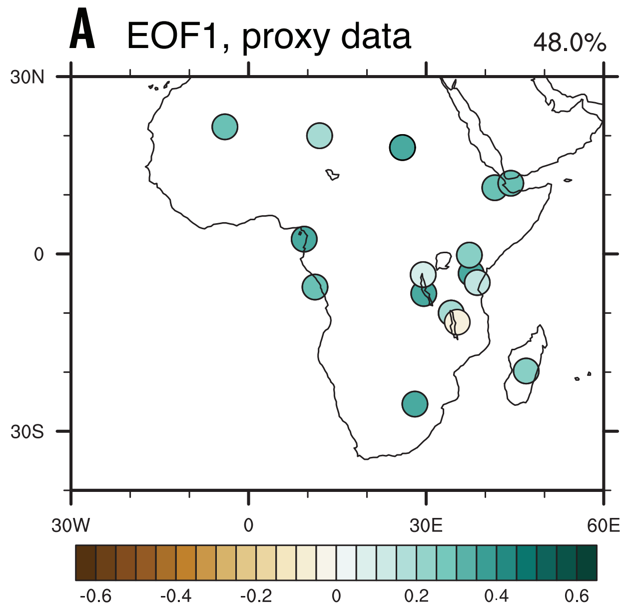
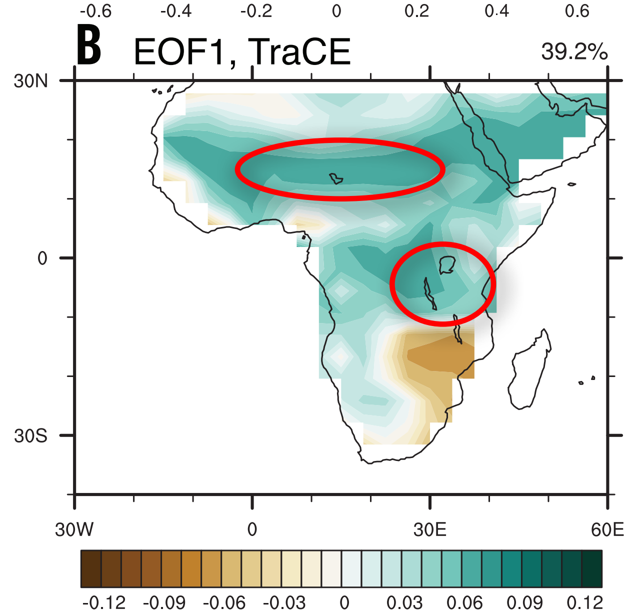
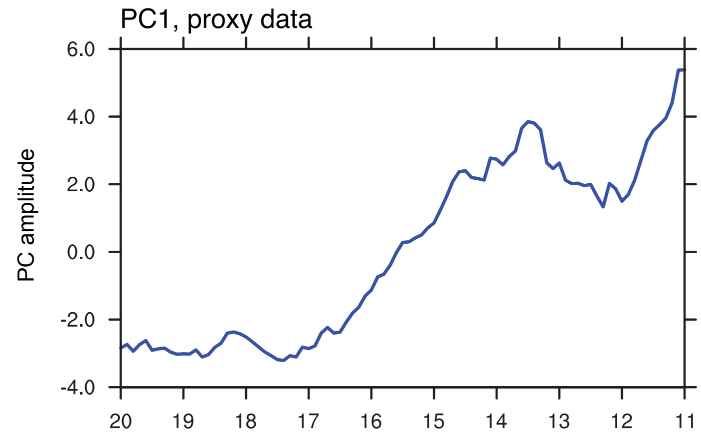
Dominant Pattern of Hydroclimate Variability

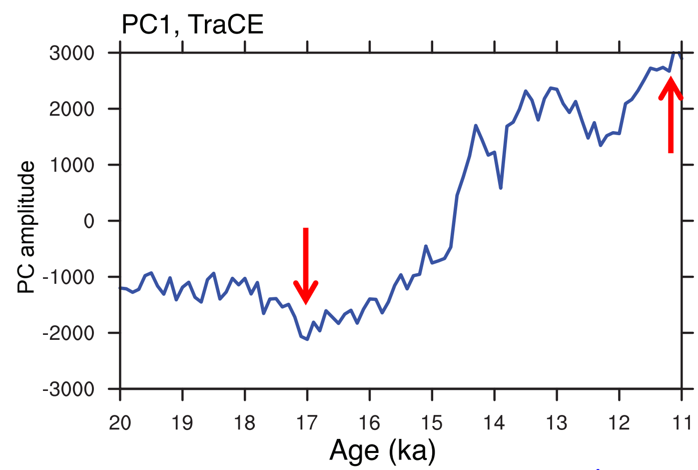






Pan-African coherent changes

- Dry from LGM (20ka) to 17ka
- Increase in moisture from 17ka to 11ka
- Some drying at Younger Dryas period (~12ka)



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Sensitivity to GHG and Orbital Forcings

Deglacial change (11ka minus 17ka) of <u>model</u> precipitation

Monsoon nature of rainfall:

- North Africa – NH summer months
- SE equatorial Africa – SH summer months

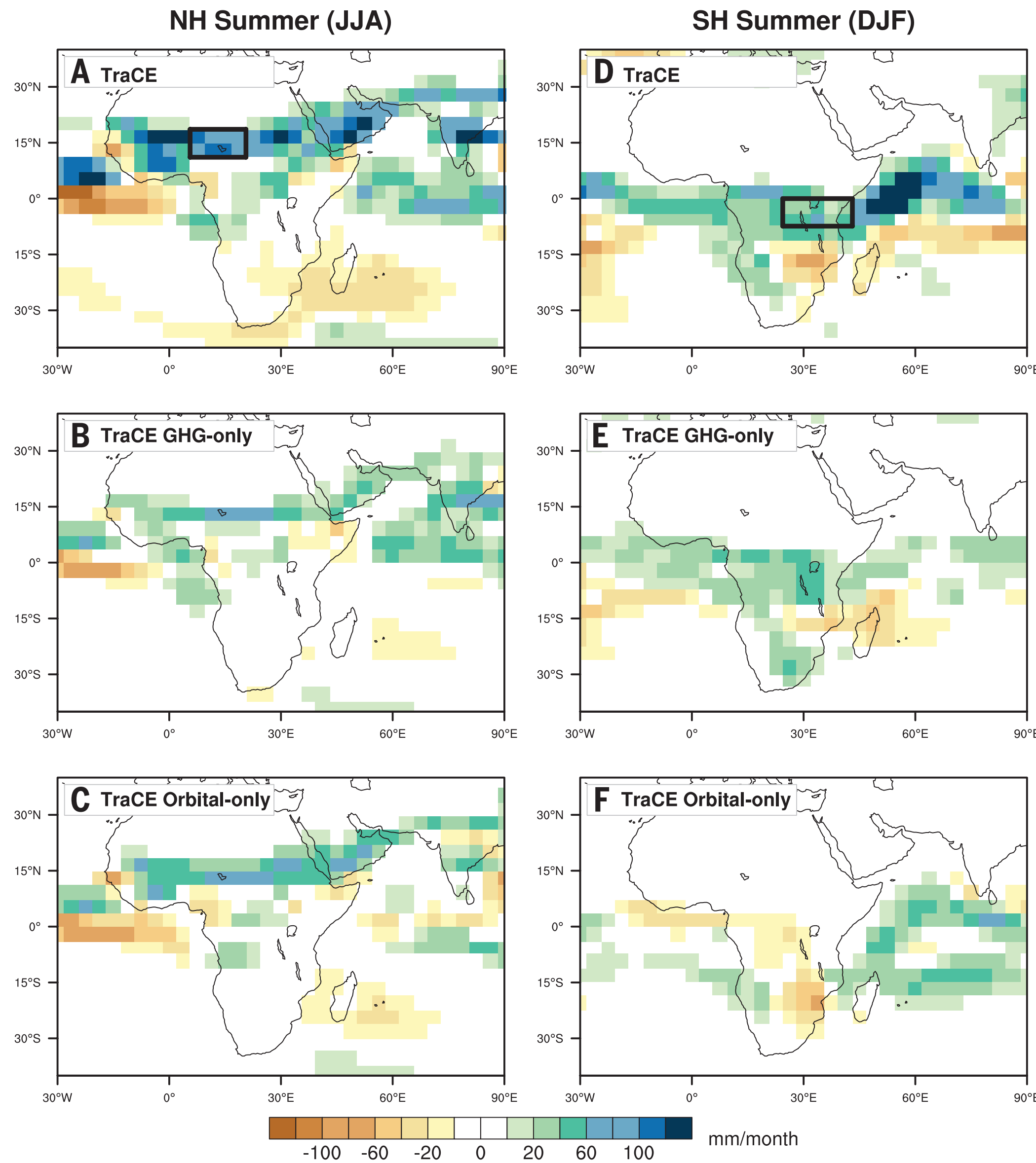
<u>TraCE simulation with all forcings</u> shows summer rainfall increases from 17ka to 11ka in both regions.

<u>Only orbital forcing</u>:

- **Sahel**: Increased summer rainfall plus northward expansion.
- **SE equatorial Africa**: Decreased summer rainfall.

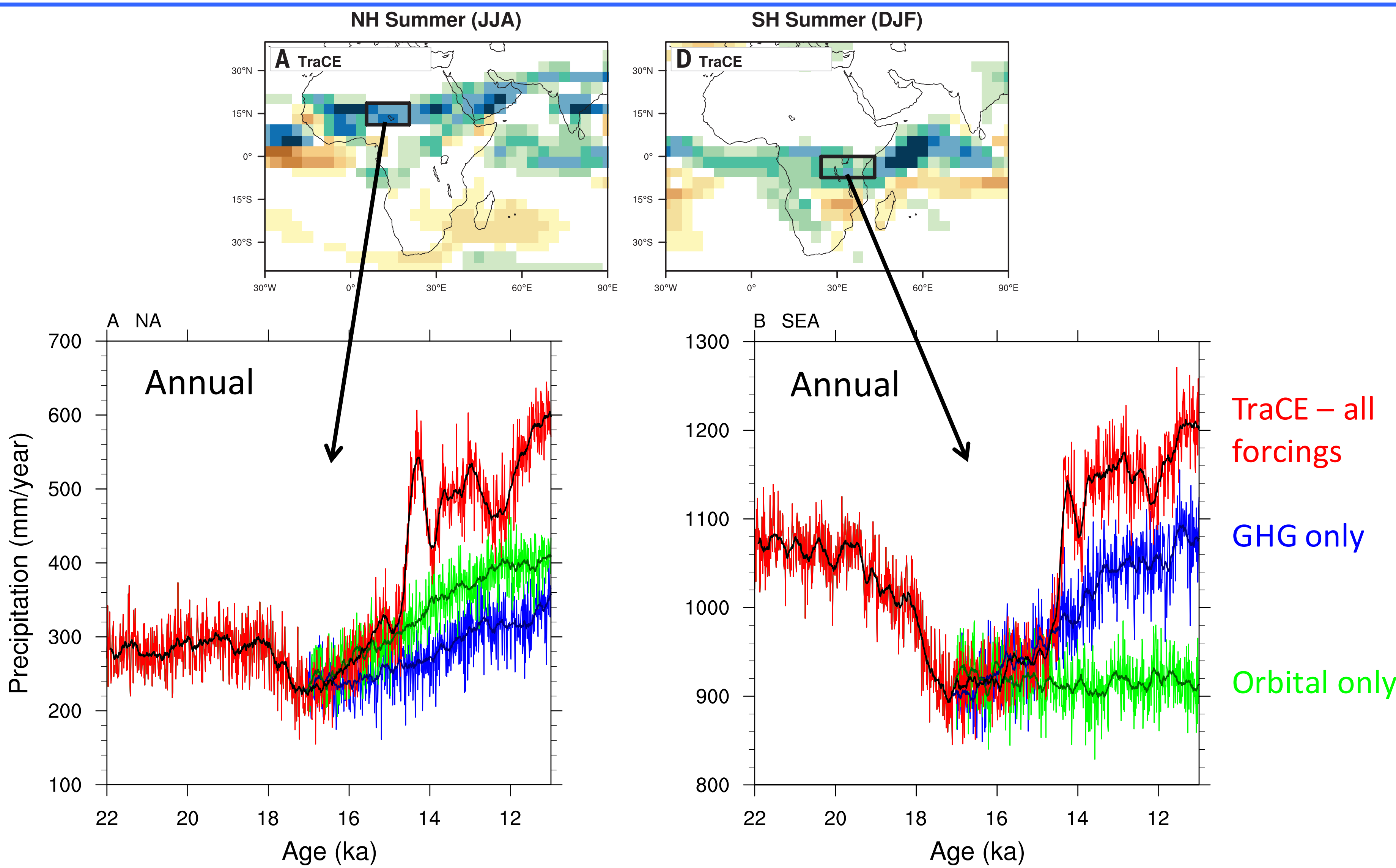
<u>Only GHG forcing</u>:

- **Sahel**: Increased summer rainfall.
- **SE equatorial Africa**: Increased summer rainfall.



Otto-Bliesner et al., Science, 2014

Sensitivity to GHG and Orbital Forcings



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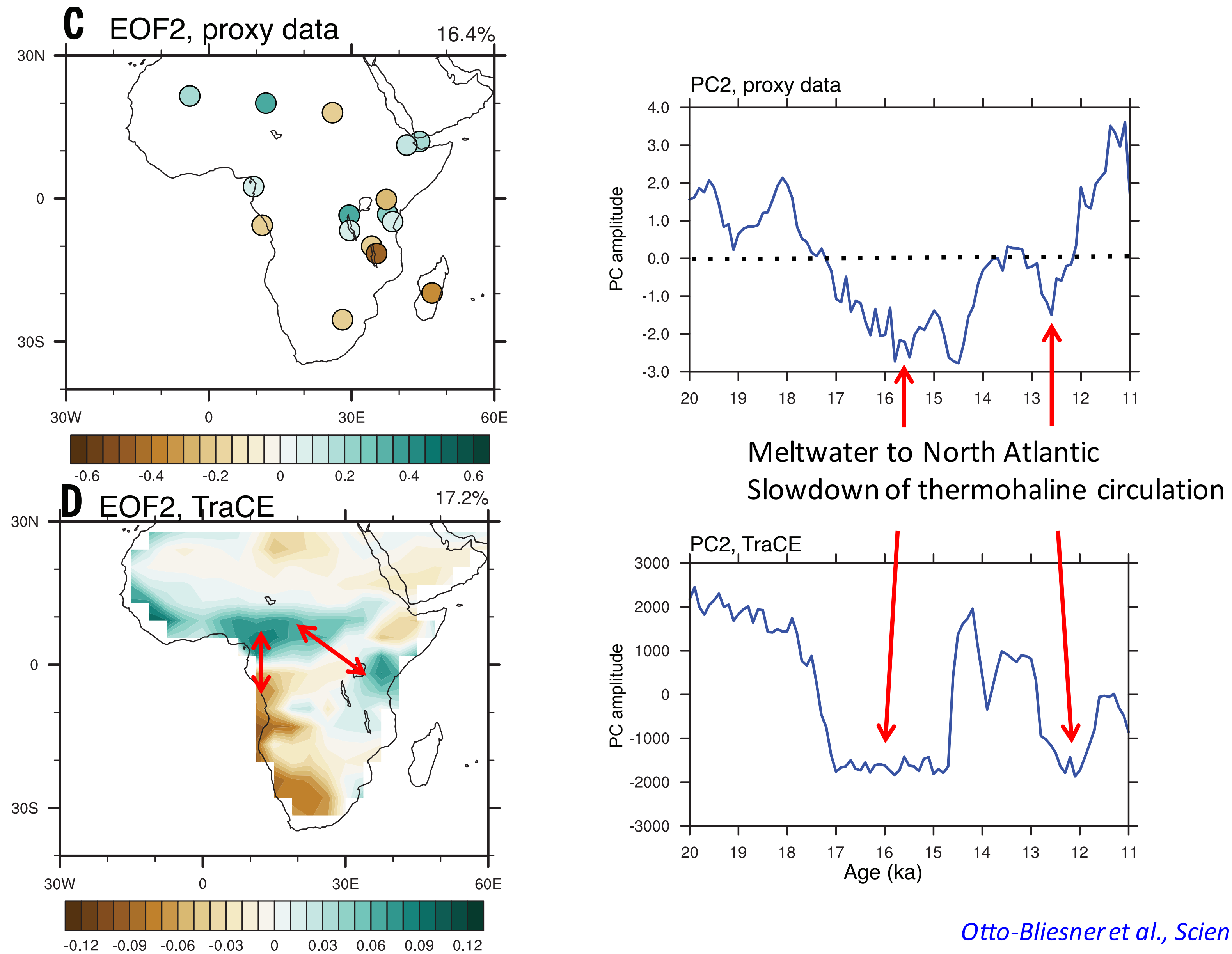
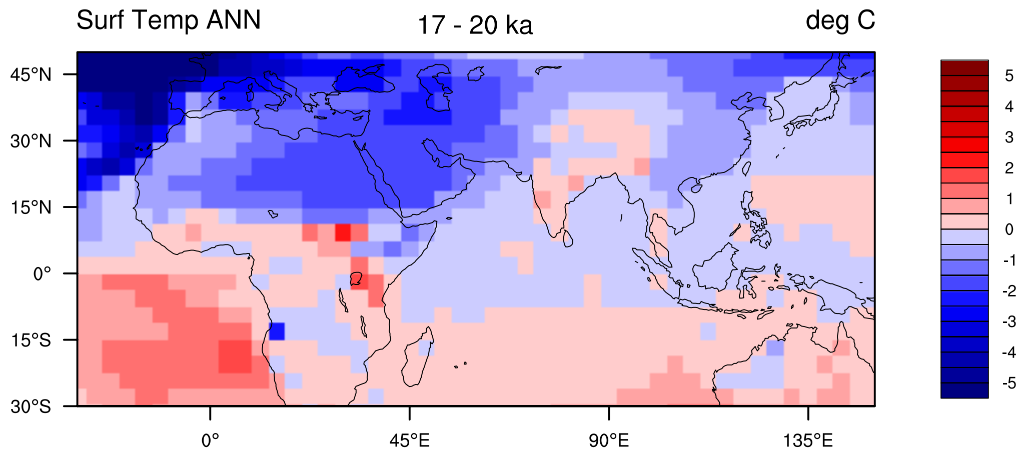
Meltwater and North Atlantic Influence



Otto-Bliesner et al., Science, 2014

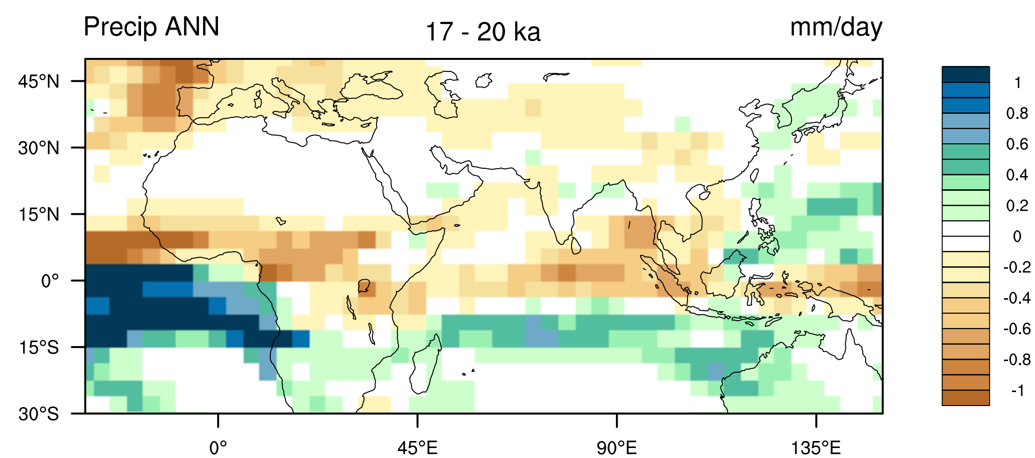
Meltwater and North Atlantic Influence

LGM to Heinrich 1 change (17ka minus 20ka)



- Adding meltwater to the North Atlantic, cooling the SSTs, and slowing the ocean conveyor circulation,
- With the ocean transporting less heat northward, the South Atlantic warms,
- Shifting rainfall south, drying North Africa.

- Ocean circulation takes too long to transmit to SE equatorial Africa,
- Instead the cooling is transmitted westward over Europe, then southward over the Indian Ocean by the atmosphere,
- Shifting rainfall south, drying SE equatorial Africa.



When meltwater to North Atlantic ceases, rainfall pattern abruptly flips back

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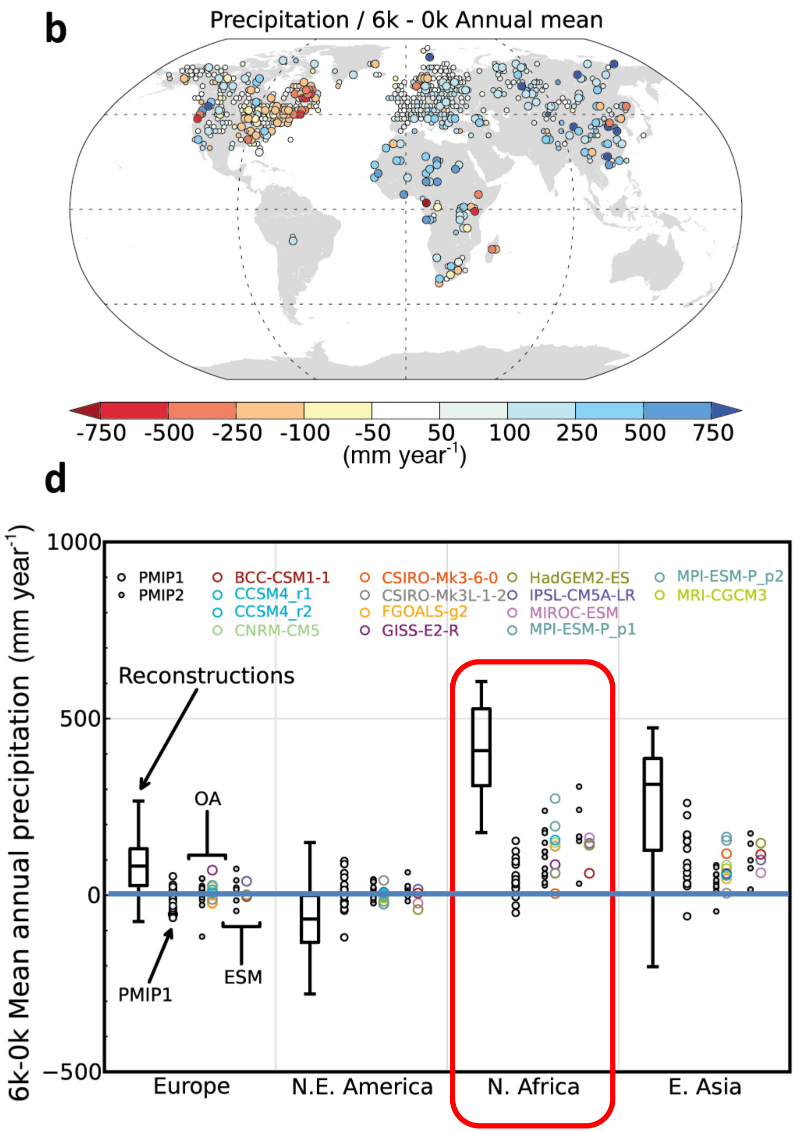
A Challenge: Green Sahara during the AHP



IPCC AR5 WG1 report, Chapter 9, 2013

Poorly-represented positive land-atmosphere feedbacks?

- Vegetation
  - (As opposed to desert) influences surface albedo, evapotranspiration.
- Soil
  - Composition and color affect soil albedo and soil water retention.
- Groundwater hydrology
  - Groundwater for recharging large lakes in mid-Holocene accumulated during Early Holocene.
- Dust
  - More vegetated land surface with greater soil moisture and enlarged lakes –> decreased dust production.

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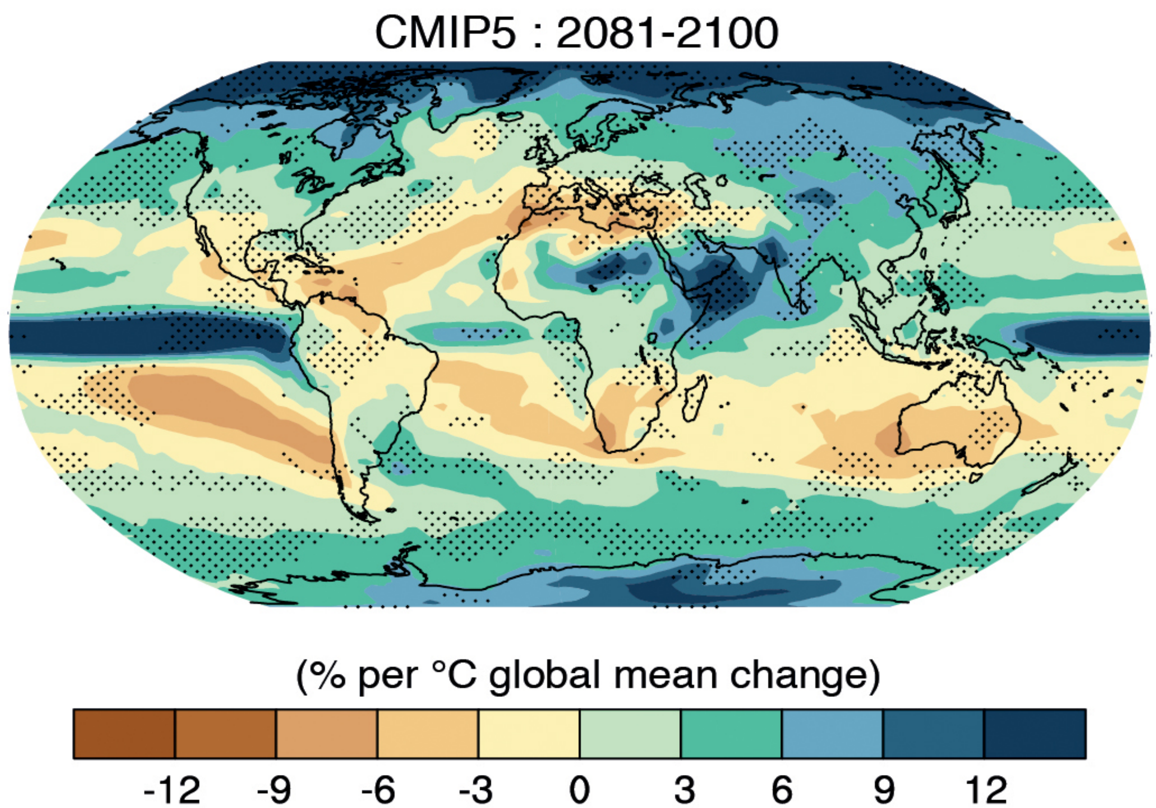
Concluding Remarks

- *GHG changes, particularly atmospheric CO_2, played an important role in the pan-African rainfall response during the deglaciation,*
- *Onset of African Humid Period synchronized by state of Atlantic Meridional Overturning Circulation.*

Precipitation scaled by global temperature (% per ° C)



IPCC AR5 WGI, 2013

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