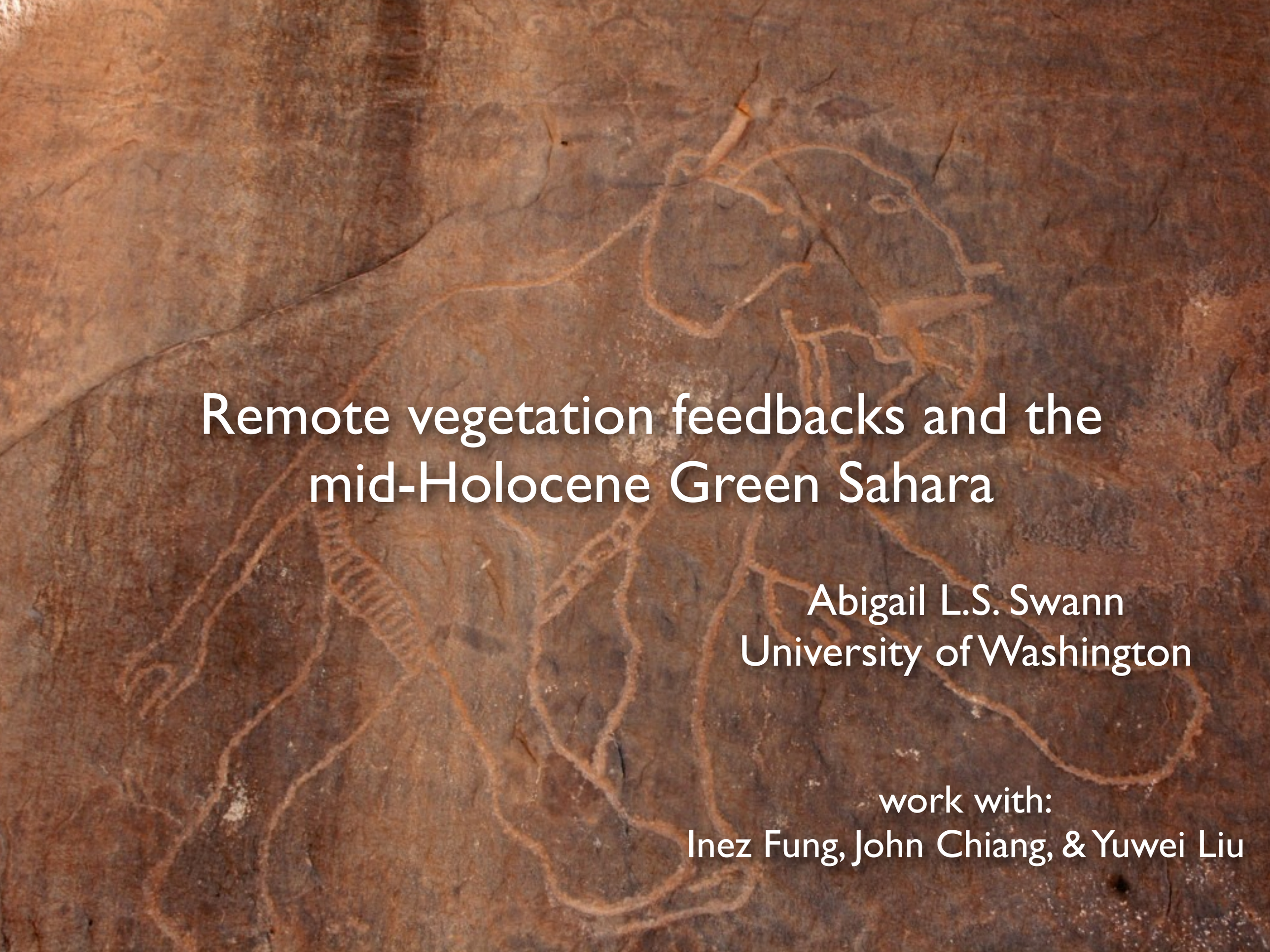


Remote vegetation feedbacks and the mid-Holocene Green Sahara

Abigail L.S. Swann
University of Washington

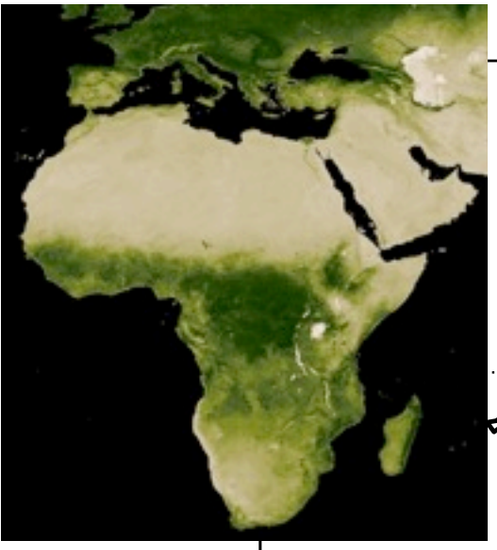
work with:
Inez Fung, John Chiang, & Yuwei Liu

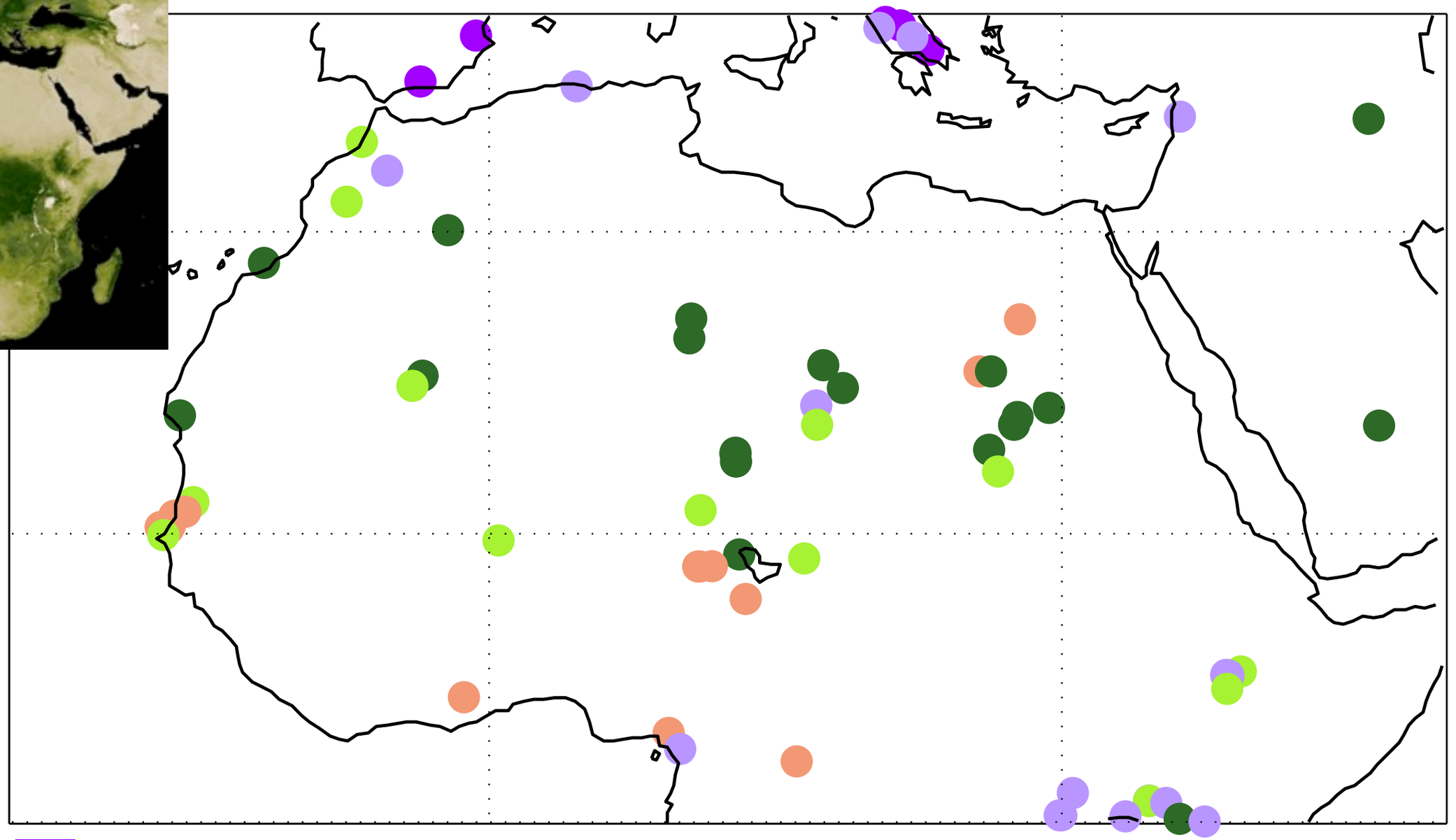
~6000 years ago, the Sahara more like the Sahel

Mike Hettwer

from 10btravelling

Sahara more like the Sahel 6Kya





temperate deciduous broadleaf forest

warm-temperate evergreen broadleaf and mixed forest

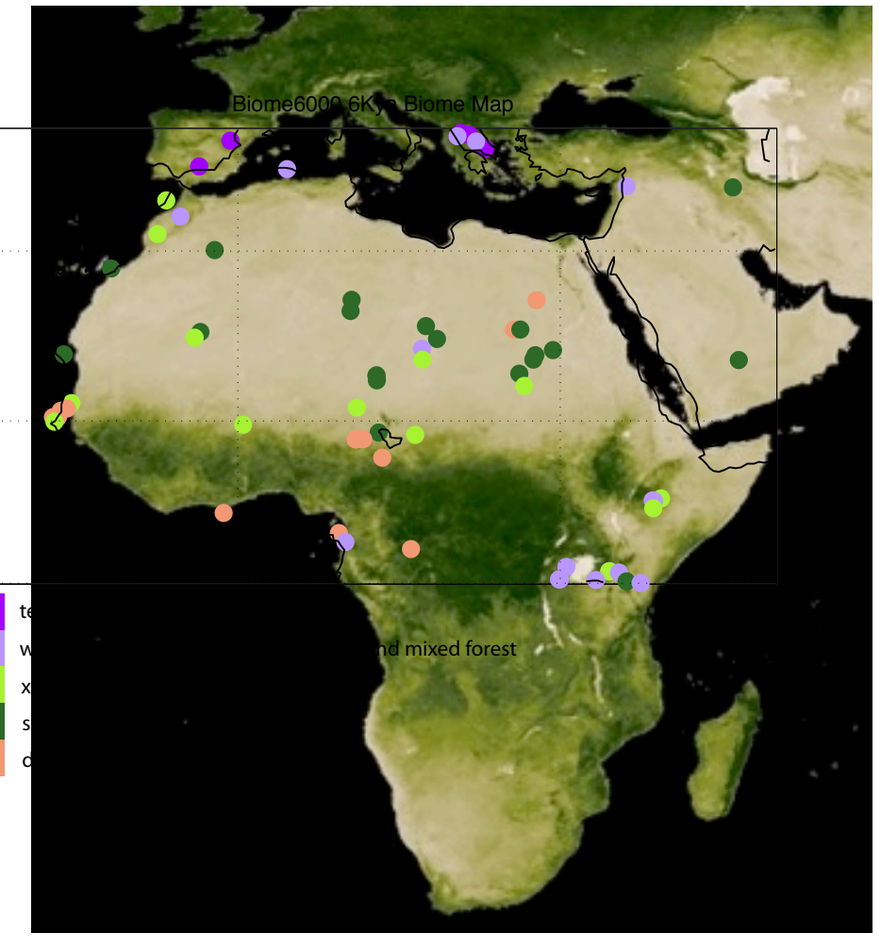
xerophytic woods/scrub

steppe

desert

Biome6000 dataset, Prentice and Webb 1998

Precip. over Africa higher in mid-Holocene



NDVI July, 2009

Why?

orbital forcing: e.g. Kutzbach and Street-Perrott, 1985

local vegetation albedo: Charney et al., 1975

previous modeling studies:
Joussaume et al. (1995); Kutzbach et al. (1996); Claussen and Gayler (1997); Brovkin et al. (1998); Claussen et al. (1999); Zeng et al. (1999); Braconnot et al. (2000); Bonfils et al. (2001); Levis et al. (2004); etc.

Previous modeling work has been unable to simulate enough precipitation over the Sahara with orbital forcing and local vegetation feedbacks

Mid-Holocene Green Sahara?

Traditional view:

Regional vegetation supports regional precipitation, orbital forcing shifts circulation

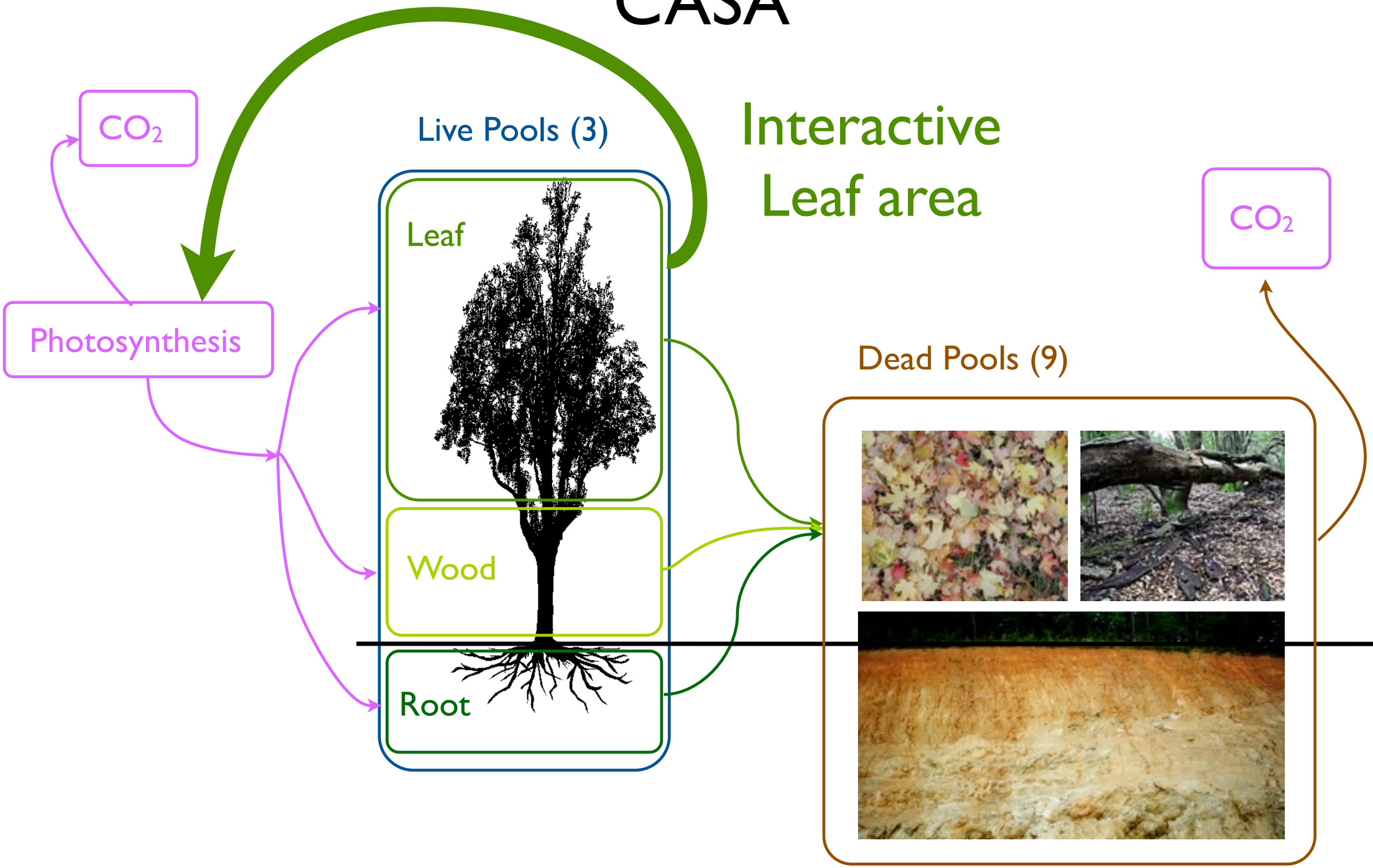
New Hypothesis:

Mid latitude forests remotely forced circulation to increase precipitation over Africa.

Model setup

- CAM 3.5 - CLM 3.5 - CASA'
- Atmospheric CO_2 is fixed at 280ppm
- run with slab ocean (fixed ocean heat flux)
- T42 resolution
- orbital forcing at either -6000 yrs or 1950
- Also tried all runs with CAM 3 - CLM 3.5 - CASA' with the same qualitative results

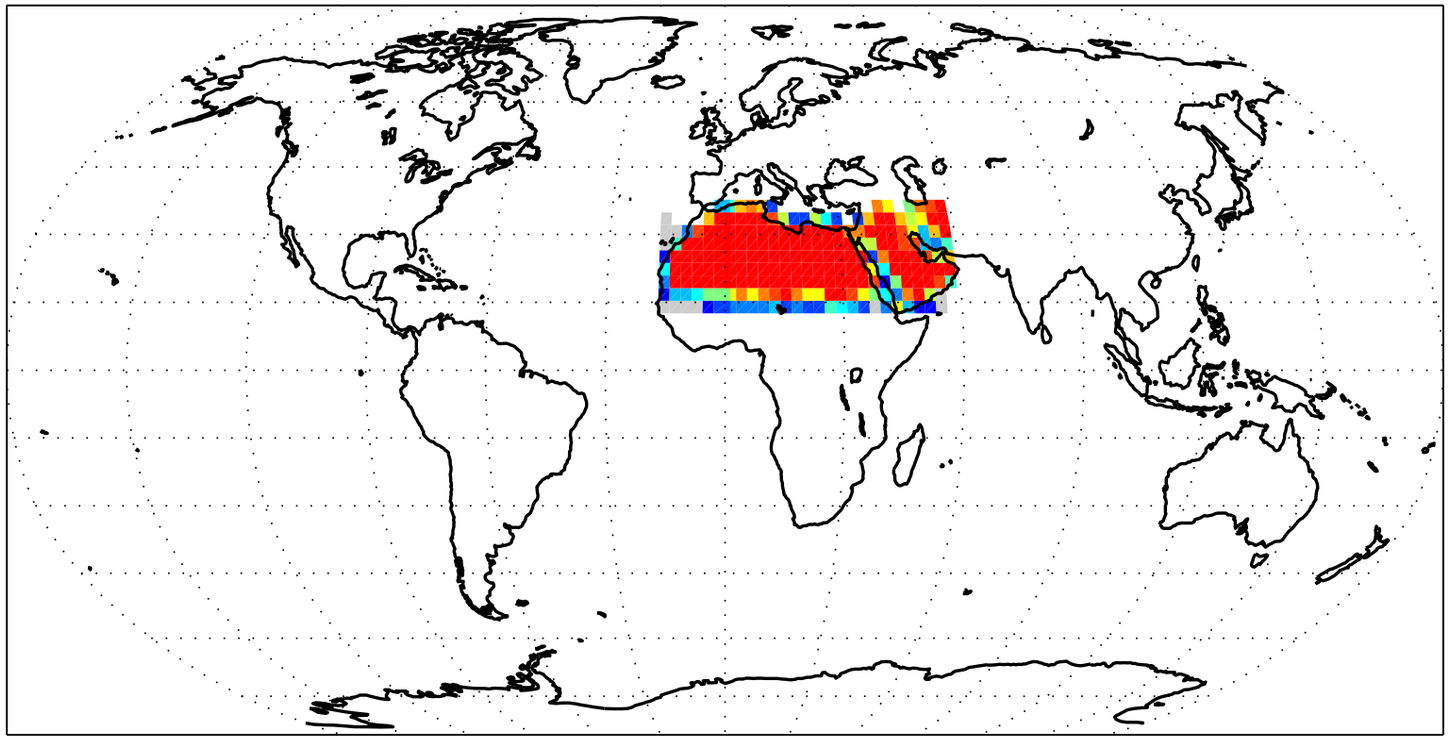
CASA'


CO_2
Photosynthesis
Live Pools (3)
Leaf
Wood
Root
Interactive
Leaf area
Dead Pools (9)
CO_2

Adding grass and trees in CLM

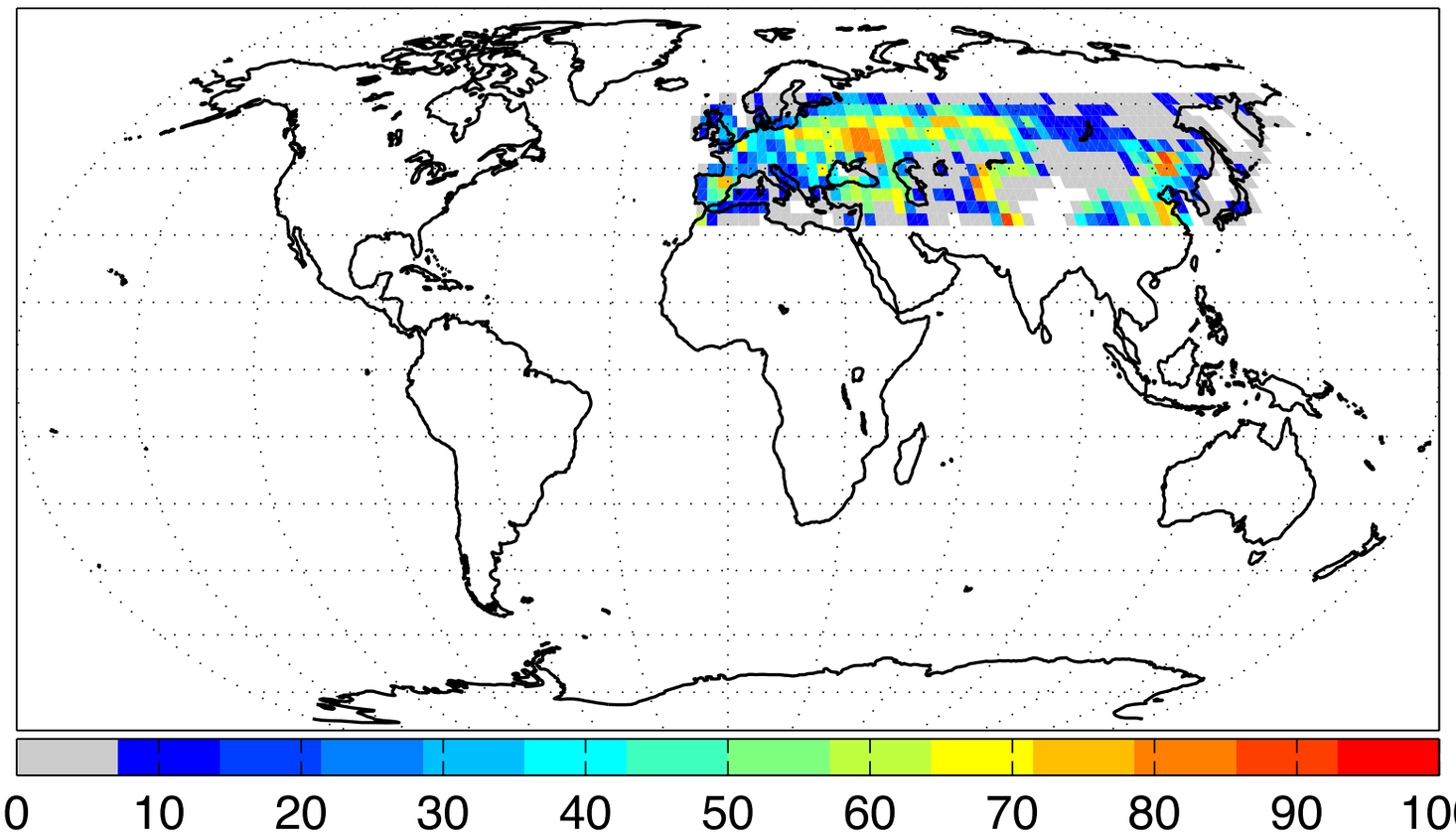
Grasslands added

All bare ground in Sahara and Saudi Arabia turned to grass



Forests added

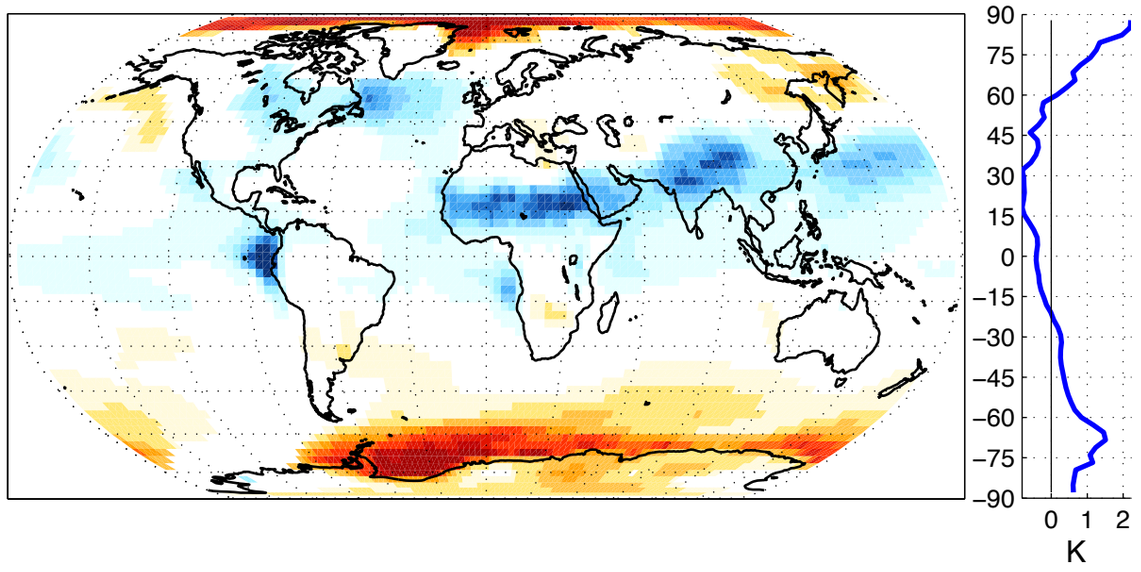
All C3 grass and agriculture in Eurasia turned to deciduous broadleaf trees



Temperature Change

Effect of Orbital forcing

[Mid-Holocene control] -
[Present Day control]



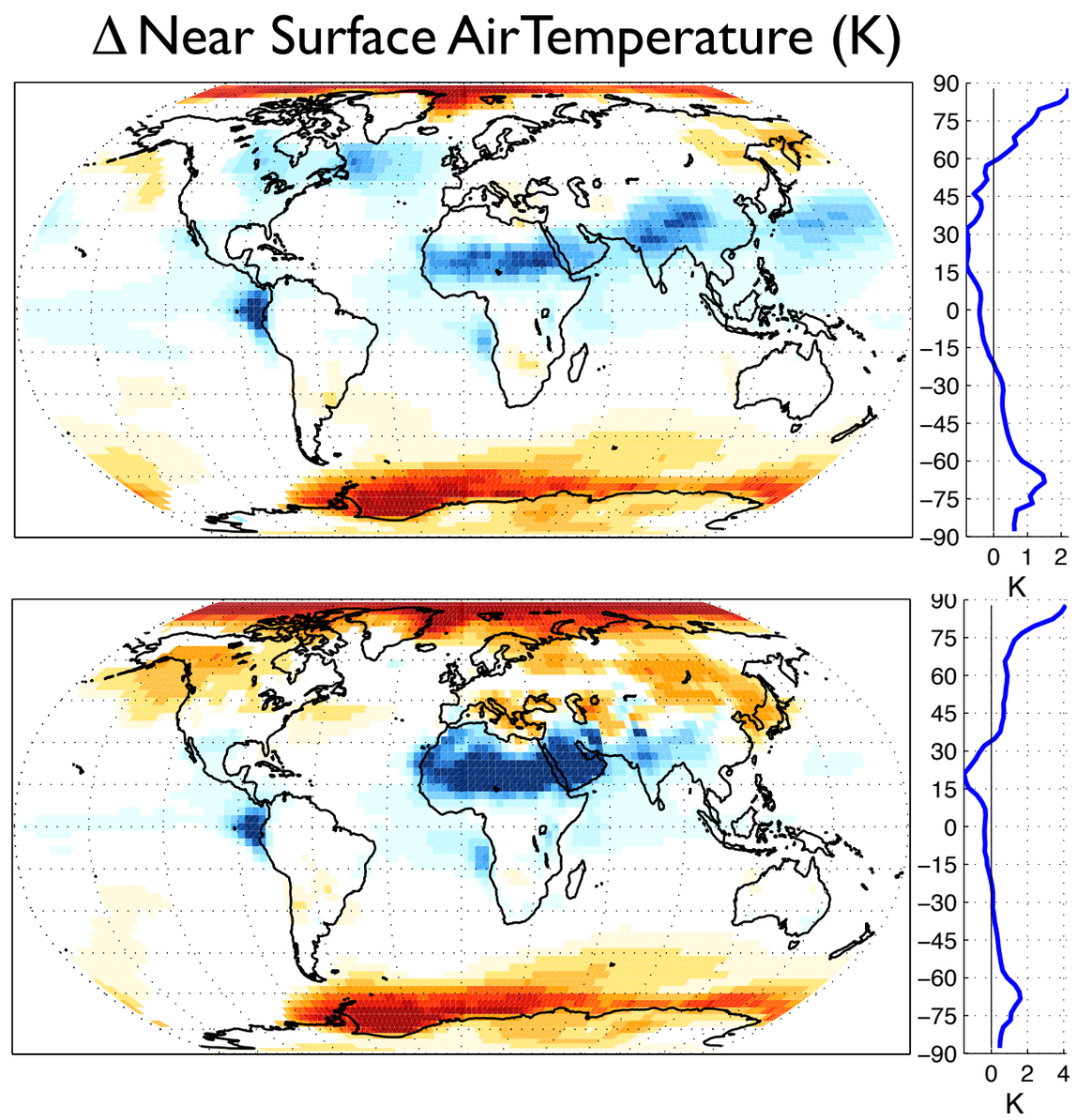
Temperature Change

Effect of Orbital forcing

[Mid-Holocene control] -
[Present Day control]

Effect of all forcing (orbital + grass + trees)

[orbital + sahara grass + eurasian trees] -
[Present Day Control]



Temperature Change

Effect of Orbital forcing

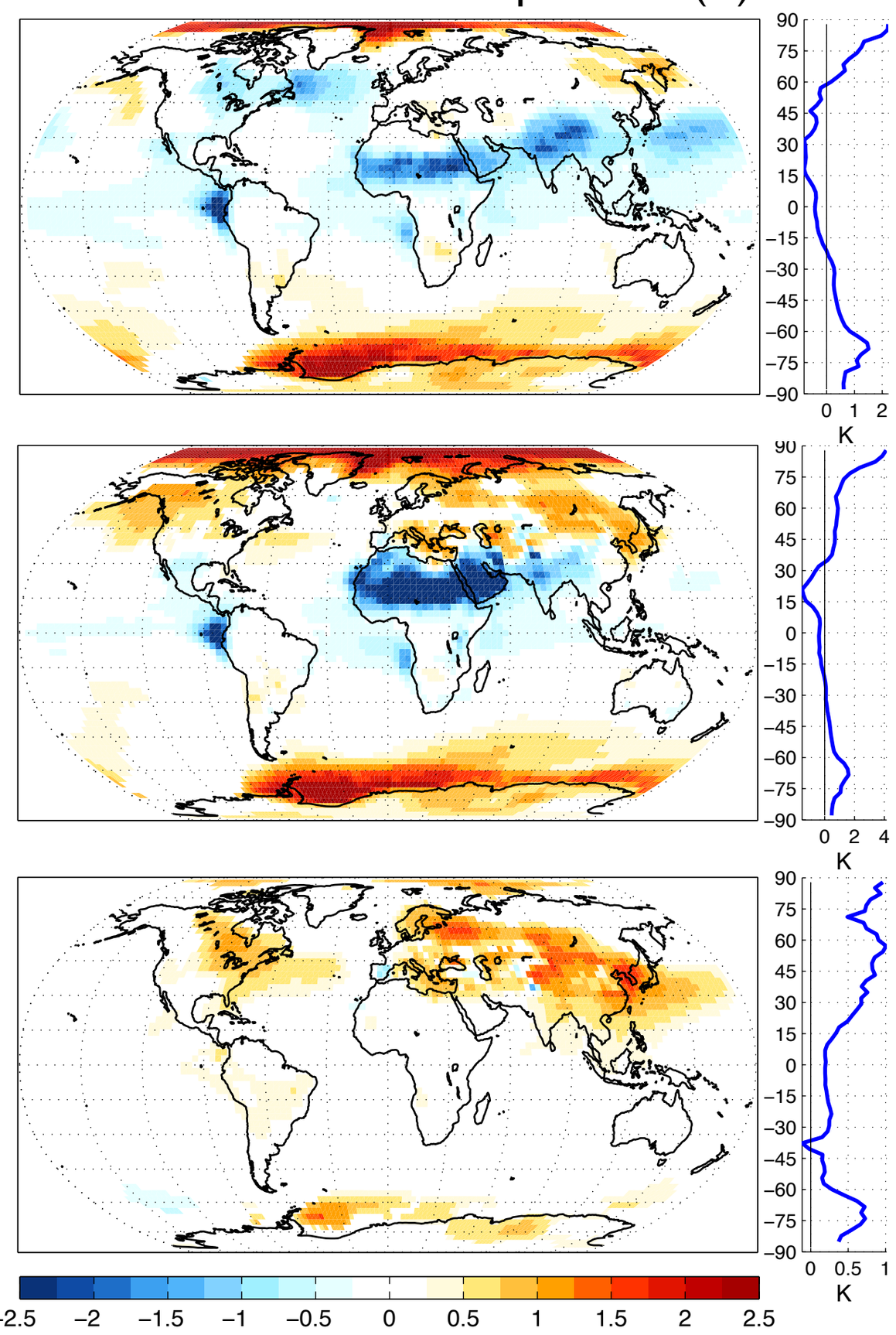
[Mid-Holocene control] -
[Present Day control]

Effect of all forcing (orbital + grass + trees)

[orbital + sahara grass + eurasian trees] -
[Present Day Control]

Additive effect of Eurasian Trees

[orbital + sahara grass + eurasian trees] -
[orbital + sahara grass]



Precipitation Change

Effect of Orbital forcing

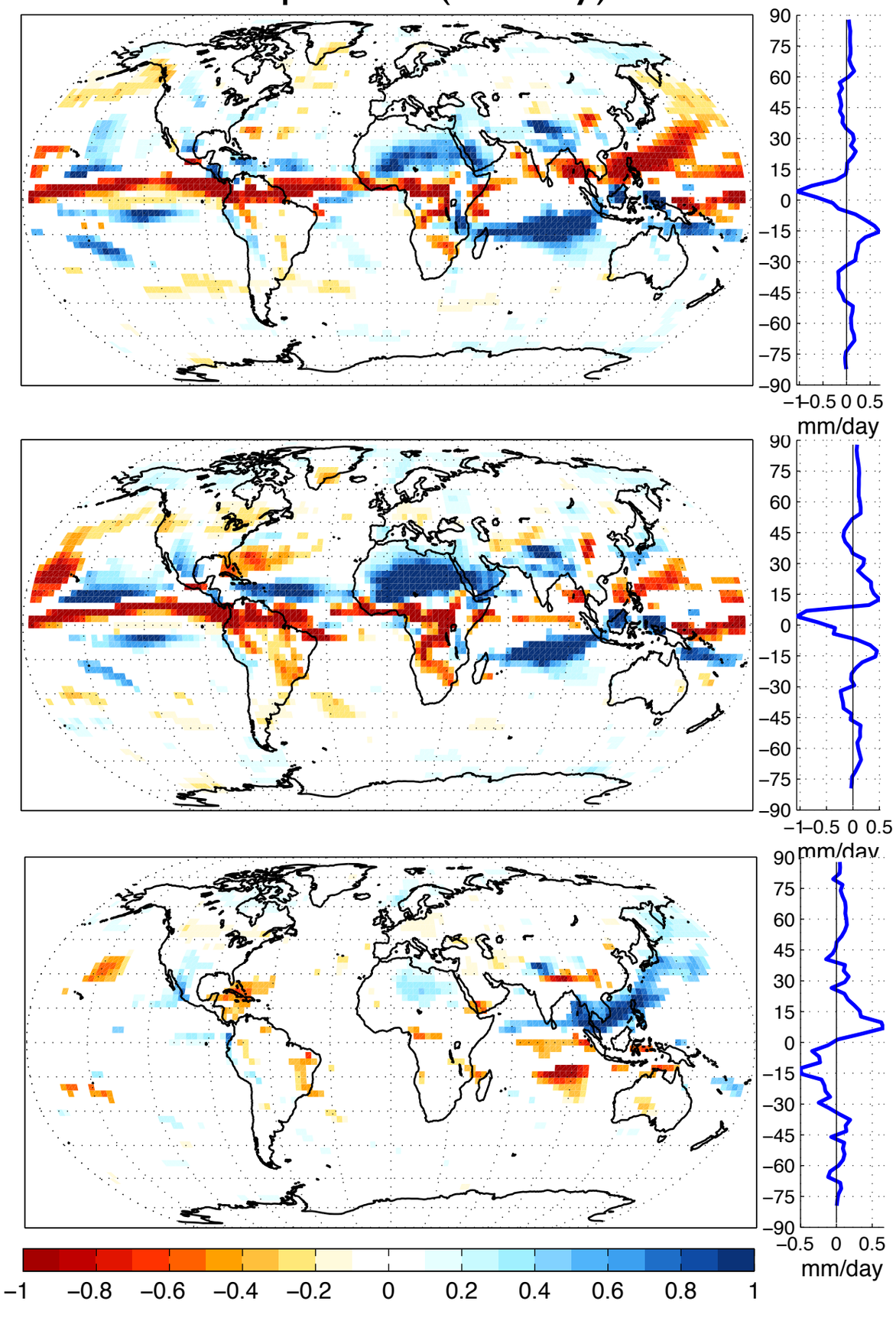
[Mid-Holocene control] -
[Present Day control]

Effect of all forcing (orbital + grass + trees)

[orbital + sahara grass + eurasian trees] -
[Present Day Control]

Additive effect of Eurasian Trees

[orbital + sahara grass + eurasian trees] -
[orbital + sahara grass]



Trees cause more rain over Africa

Effect of Orbital forcing

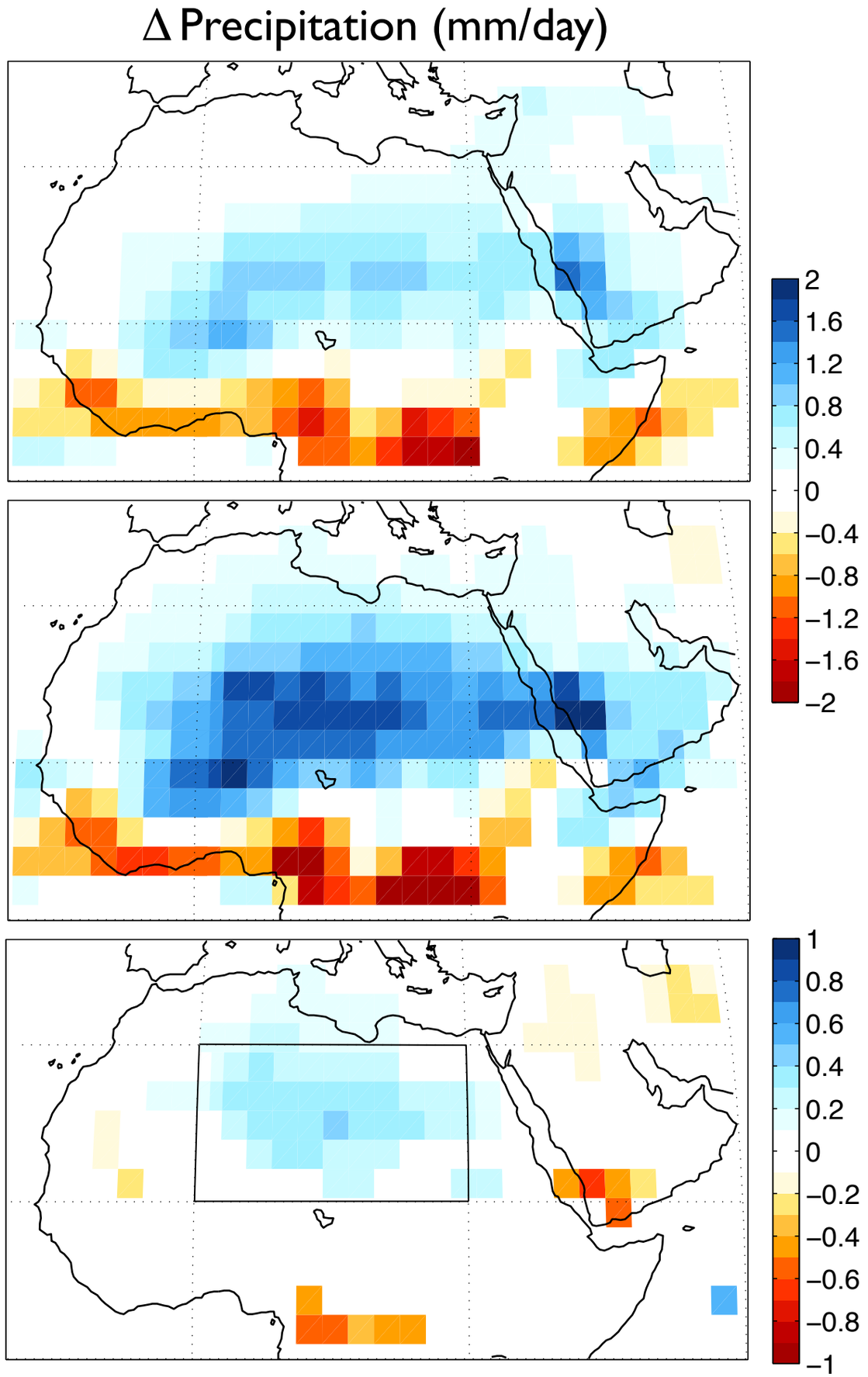
[Mid-Holocene control] -
[Present Day control]

Effect of all forcing (orbital + grass + trees)

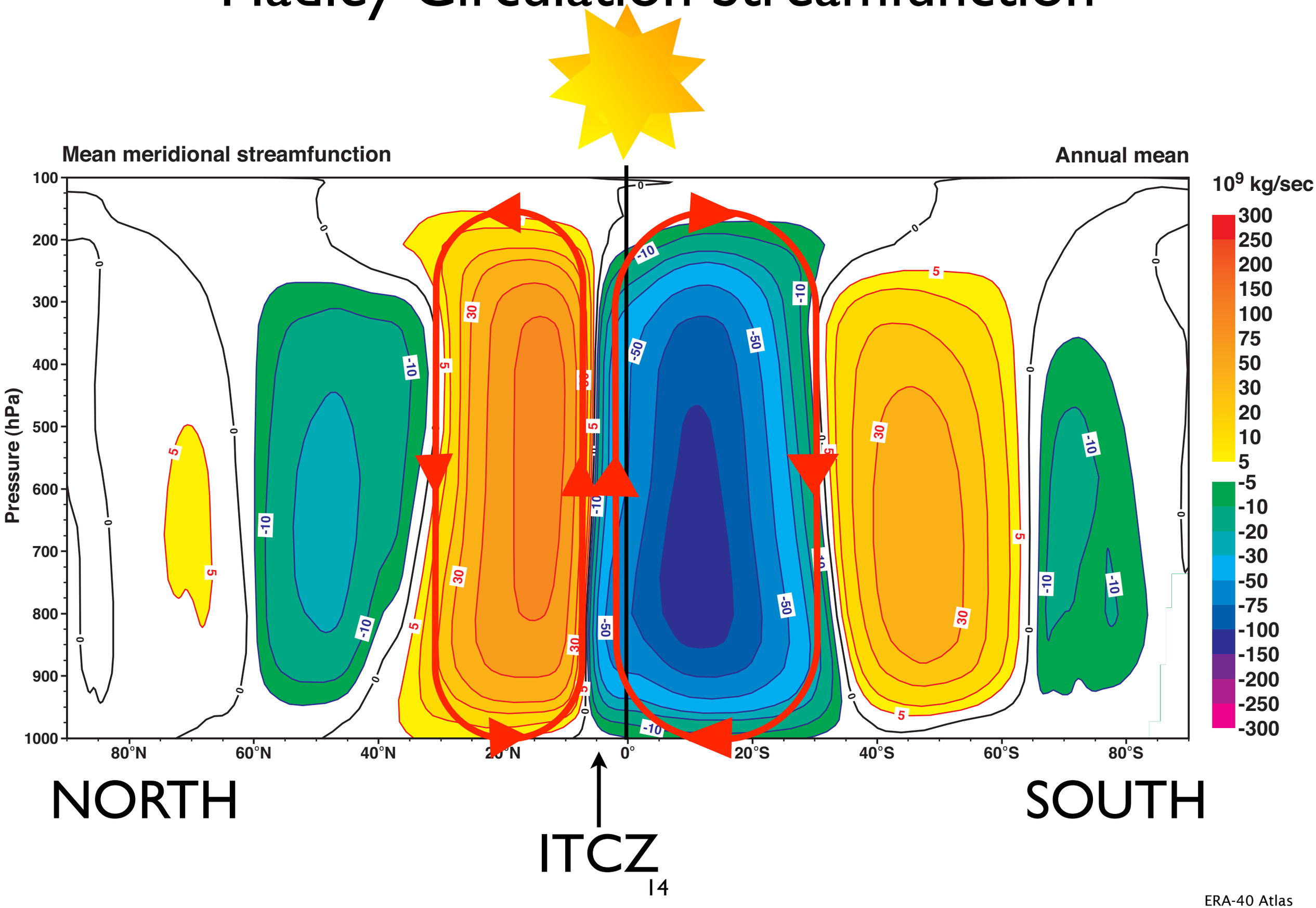
[orbital + sahara grass + eurasian trees] -
[Present Day Control]

Additive effect of Eurasian Trees

[orbital + sahara grass + eurasian trees] -
[orbital + sahara grass]



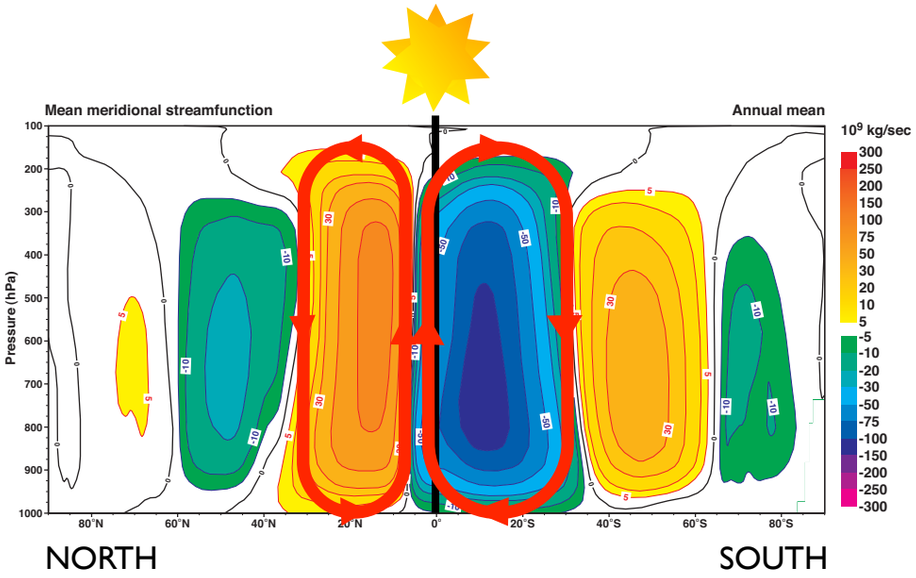
Hadley Circulation Streamfunction



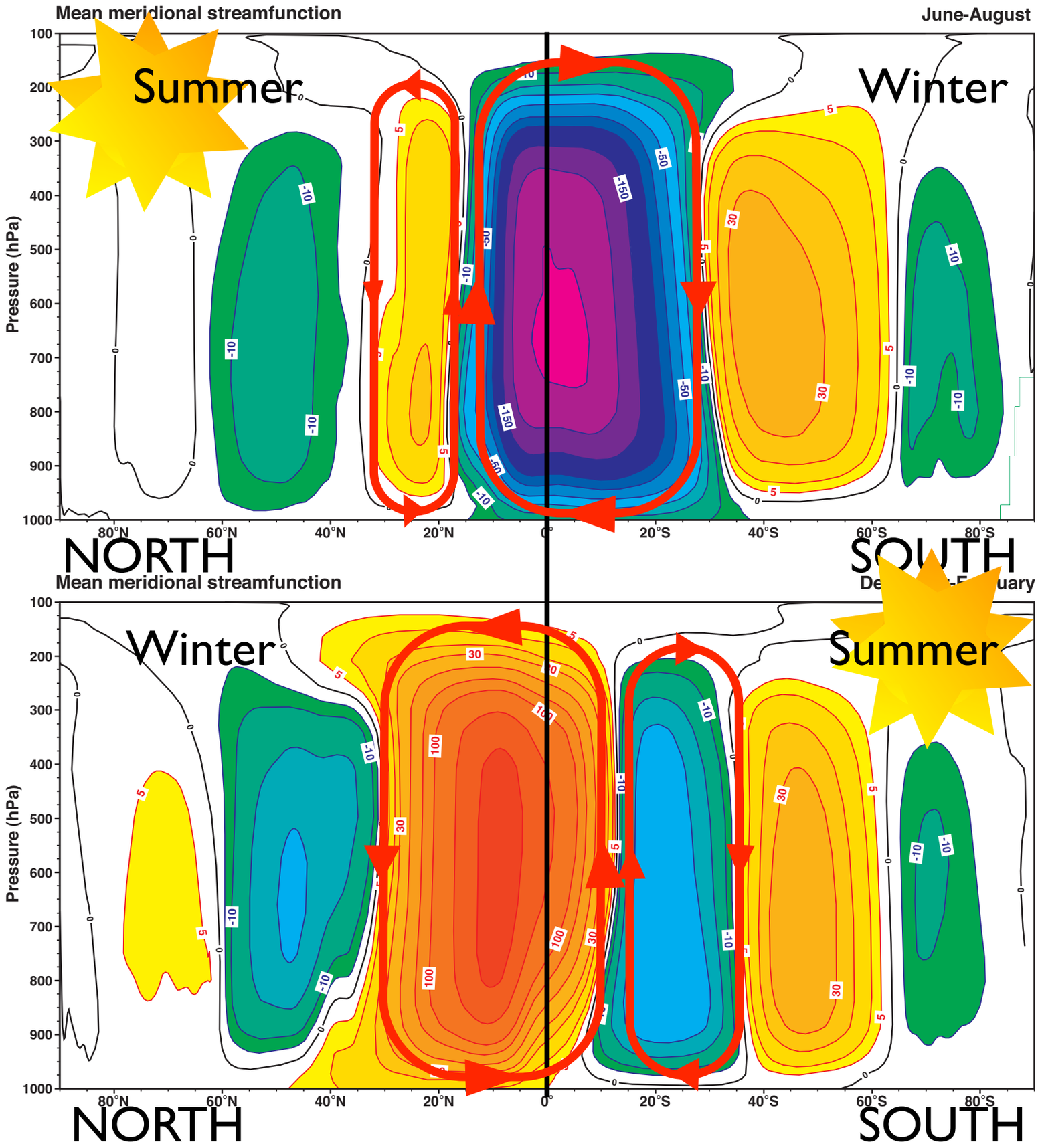
ERA-40 Atlas

Winter Cell Does the Transport

NH Summer

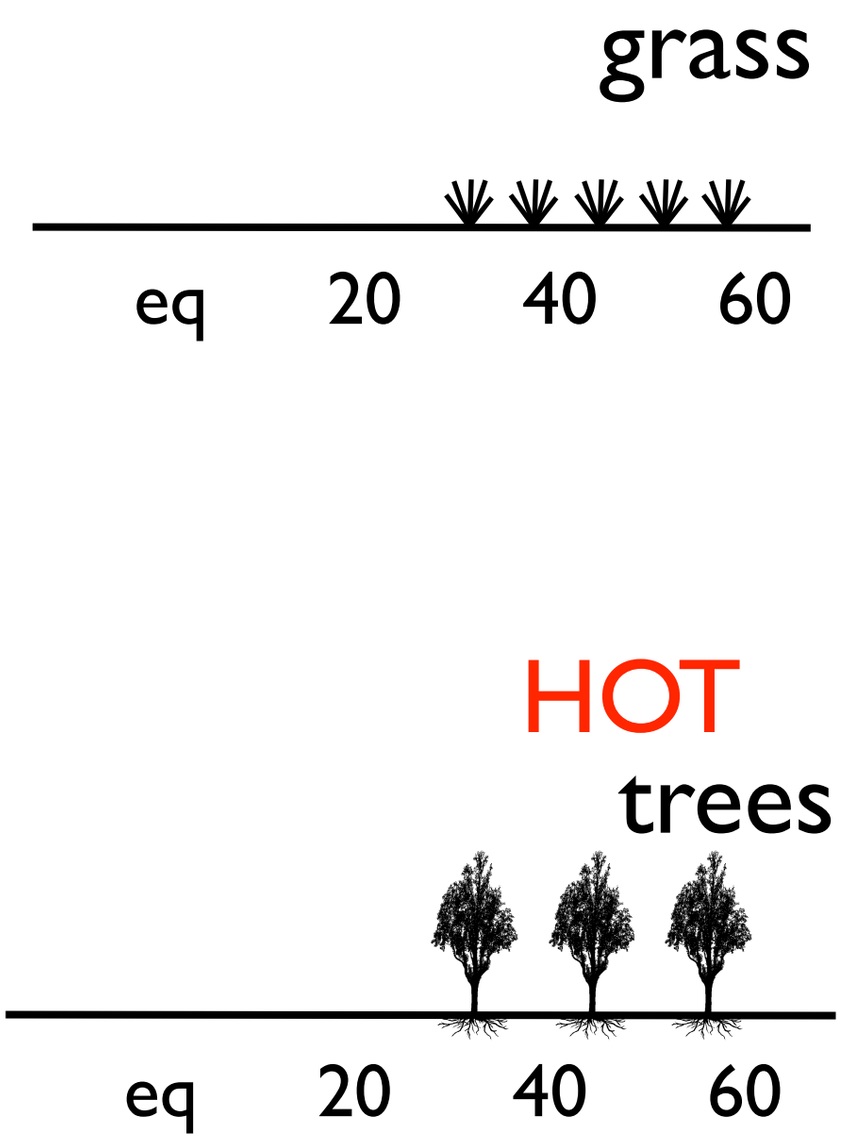


NH Winter



Hypothesized Mechanism

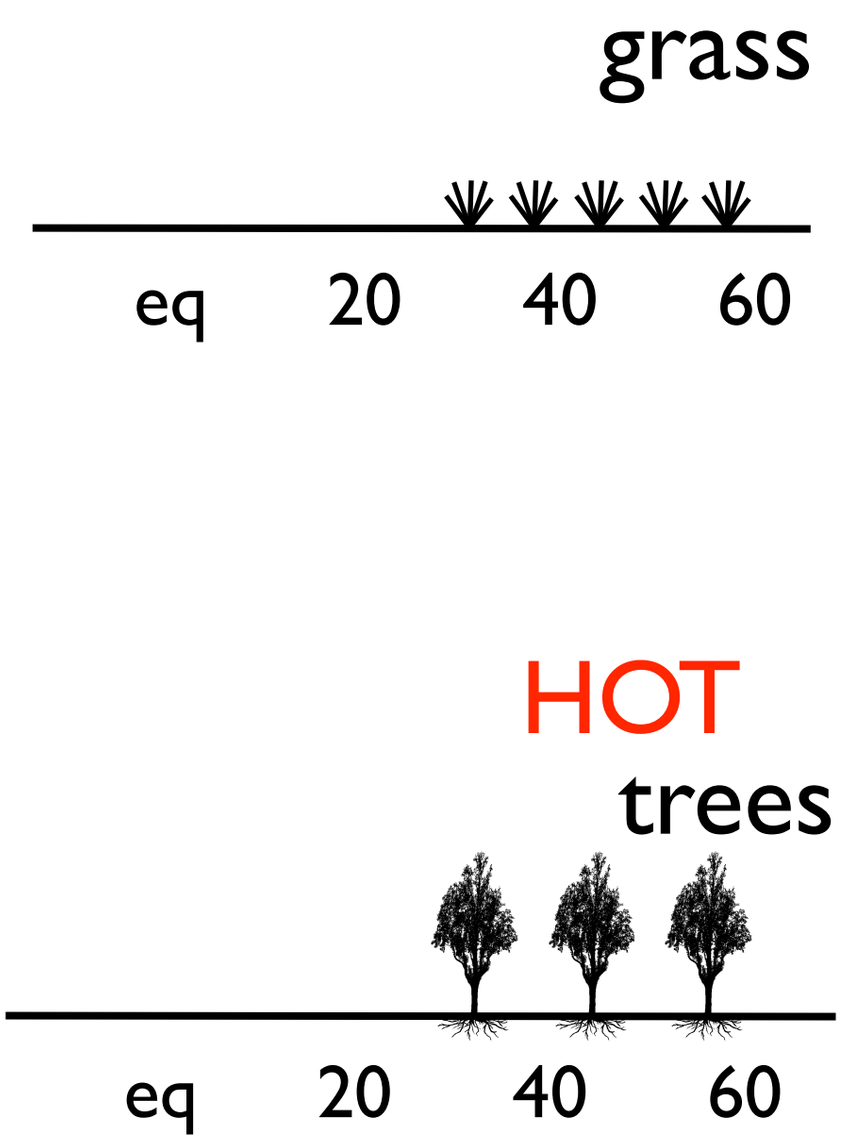
1. dark trees = NH warm



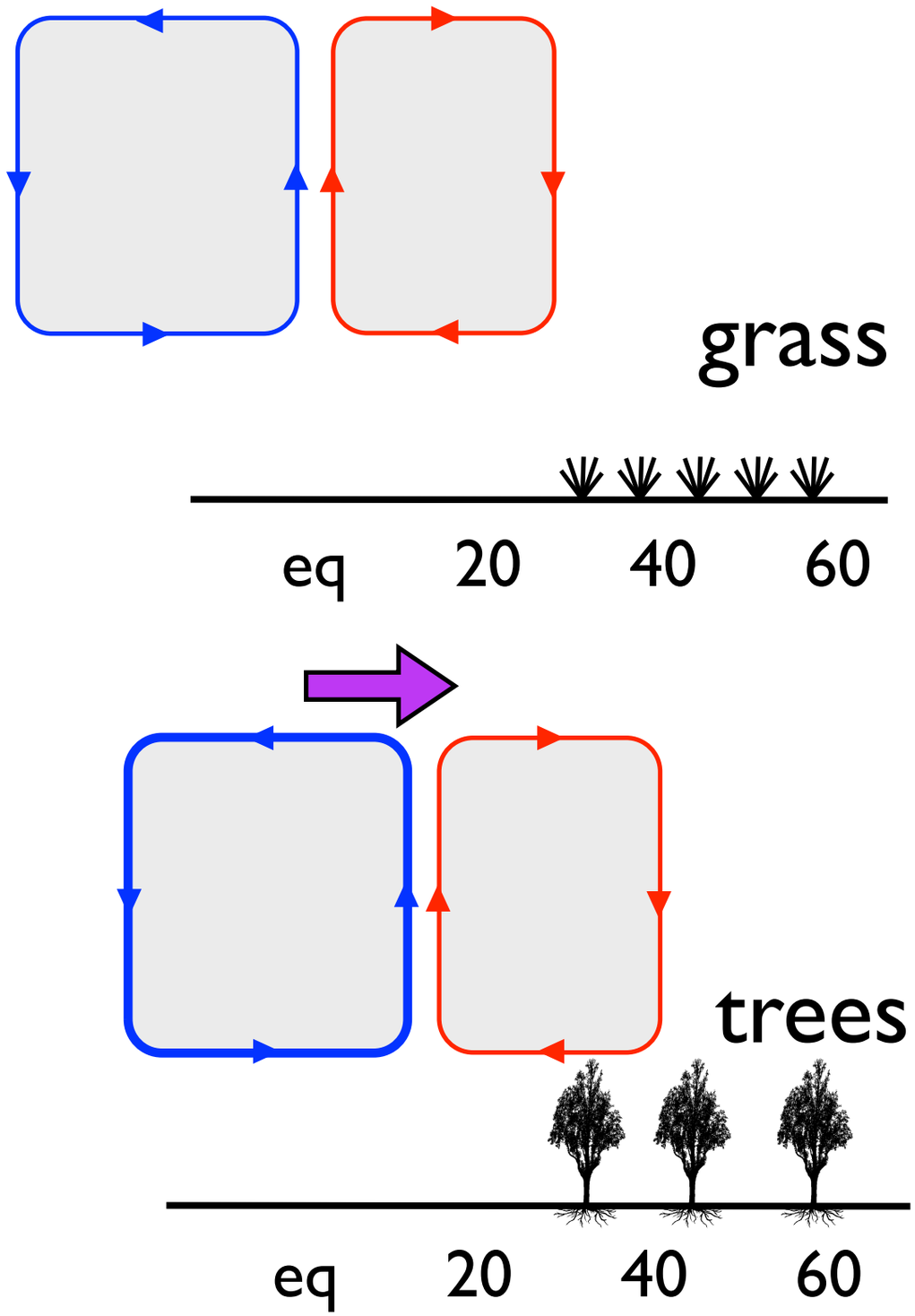
Hypothesized Mechanism

1. dark trees = NH warm

2. Energy gradient (N-S) between the Hemispheres increases



Hypothesized Mechanism



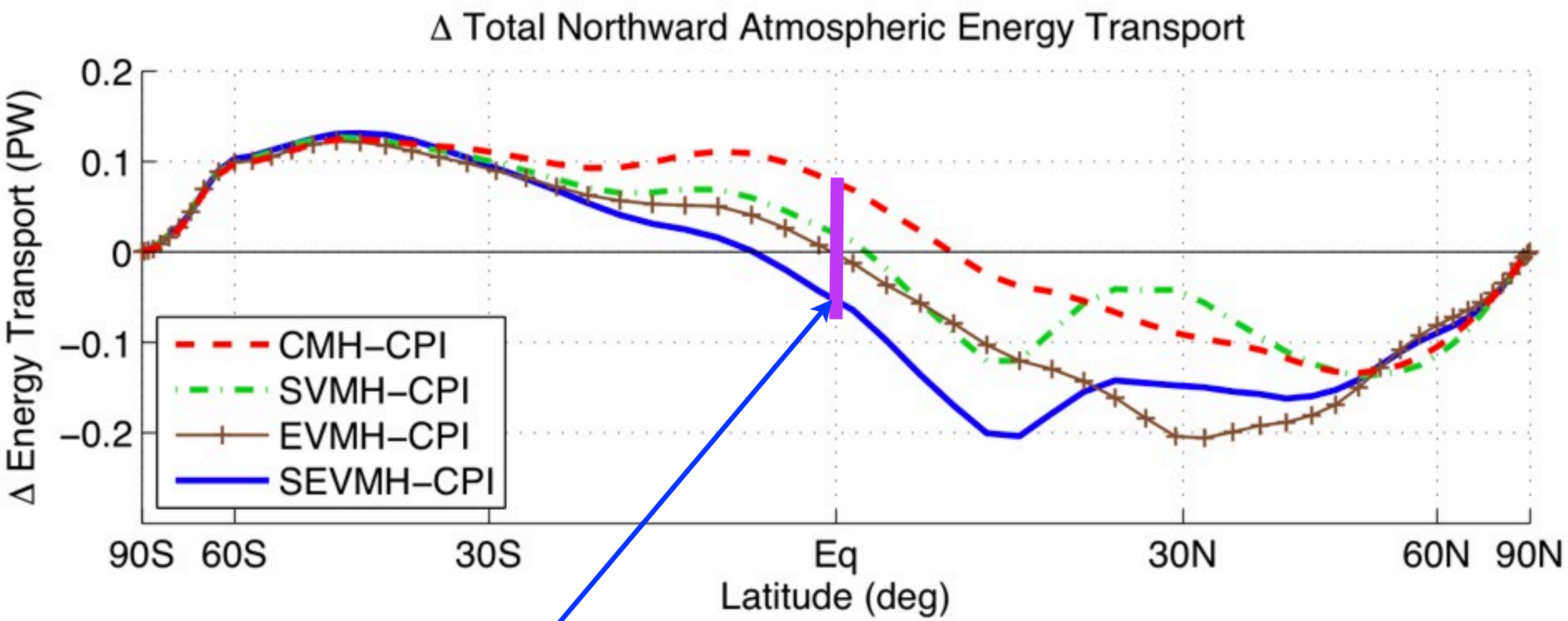
1. dark trees = NH warm

2. Energy gradient (N-S) between the Hemispheres increases

nice review on this: Chiang et al. 2012

3. Hadley Cell moves north to increase southward heat transport

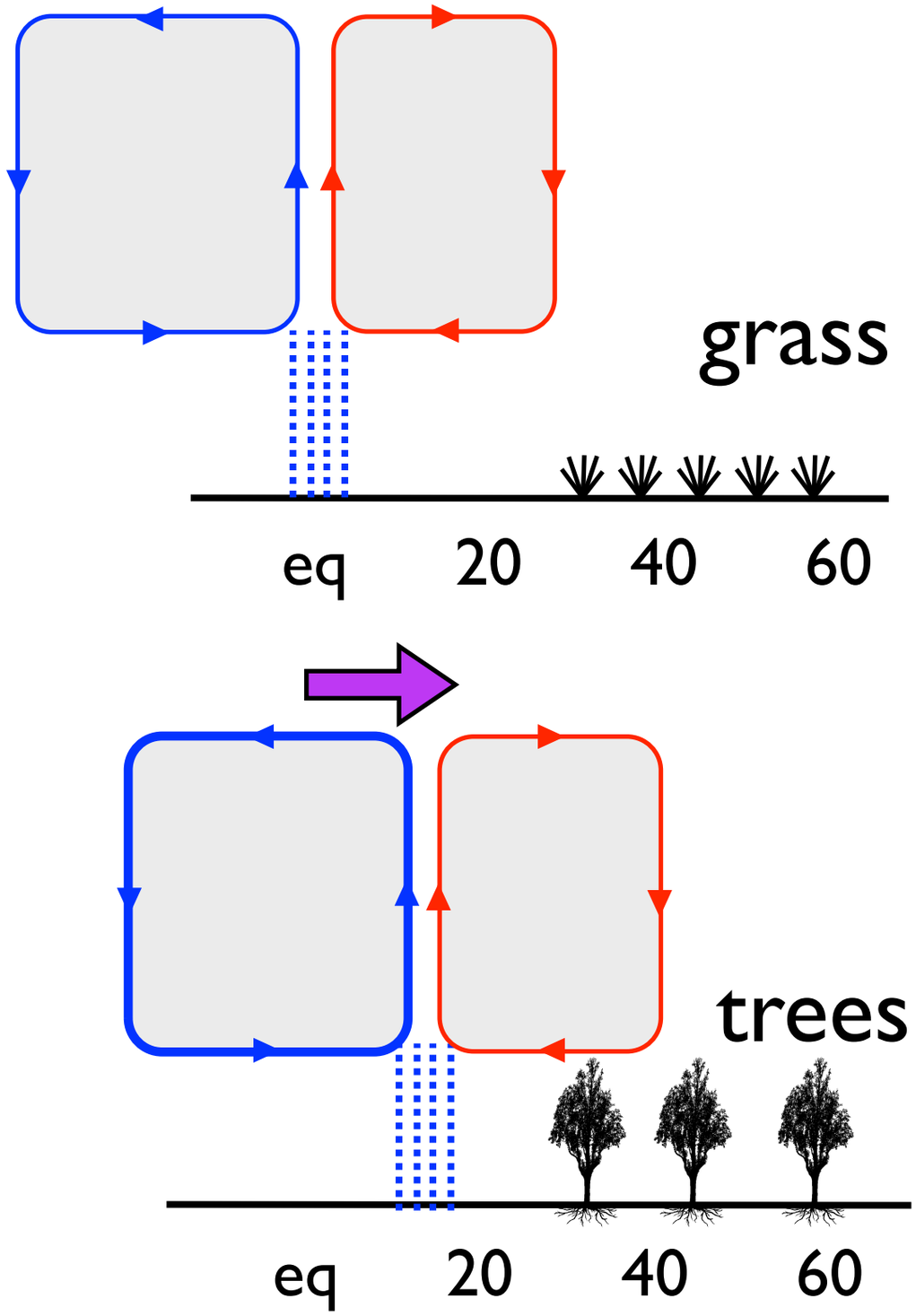
Circulation shift driven by trees moves energy Southward



3% change at the Equator (pval = 0.0008)

Swann et al., 2011

Hypothesized Mechanism



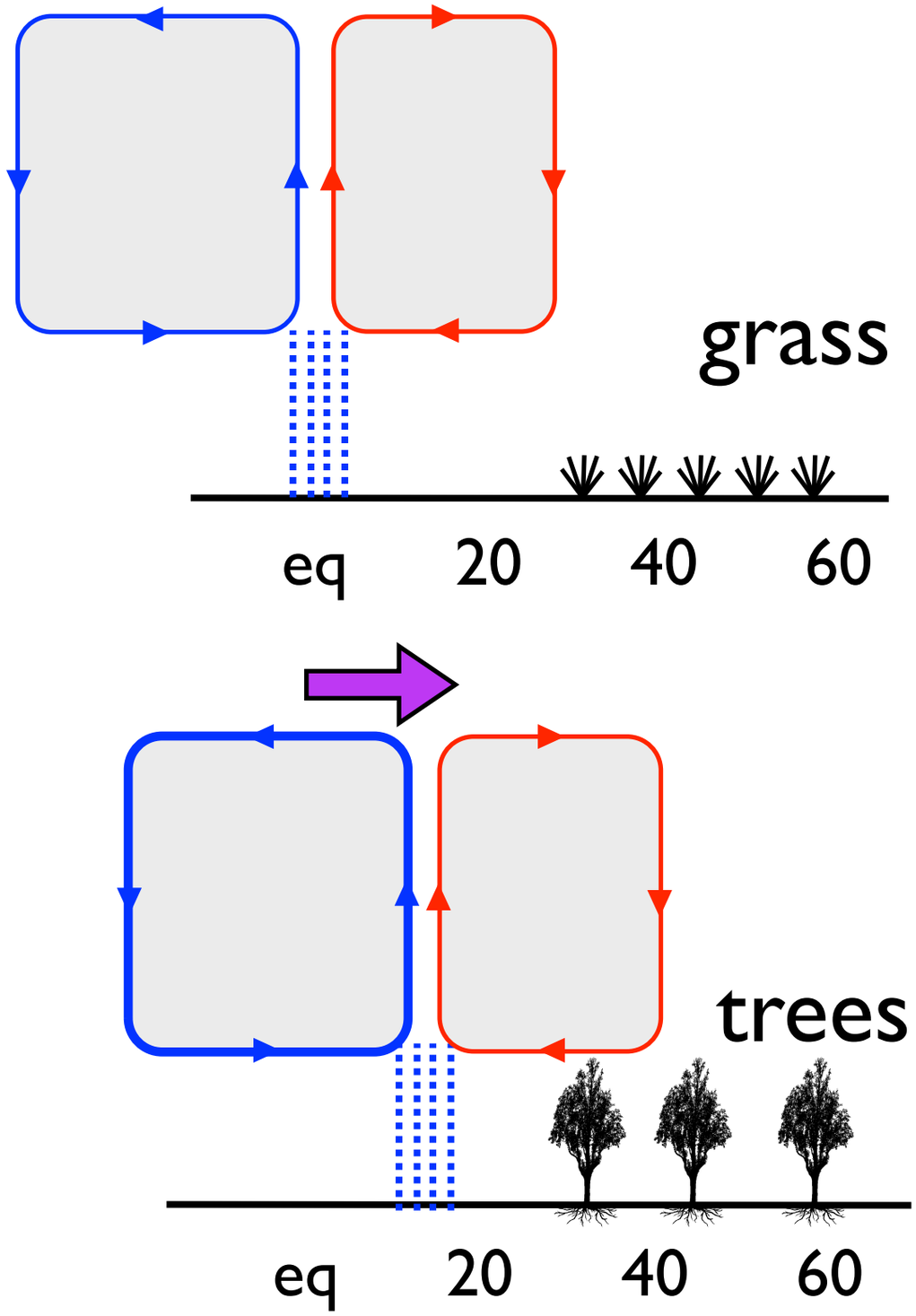
1. dark trees = NH warm

2. Energy gradient (N-S) between the Hemispheres increases

3. Hadley Cell moves north to increase southward heat transport

4. ITCZ shifts North

Hypothesized Mechanism



1. dark trees = NH warm

2. Energy gradient (N-S) between the Hemispheres increases

3. Hadley Cell moves north to increase southward heat transport

4. ITCZ shifts North

⇒ Tropical productivity follows changes in precipitation

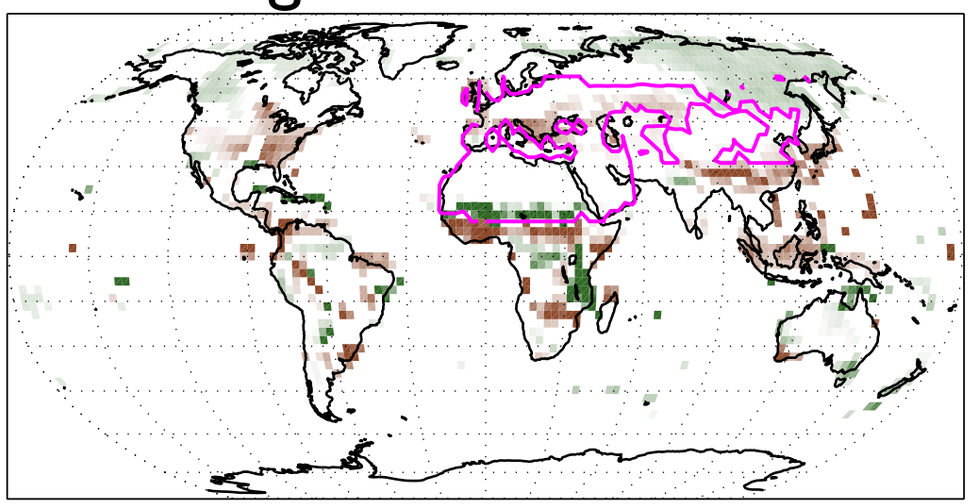
Productivity changes locally *and* remotely

Effect of
Orbital forcing

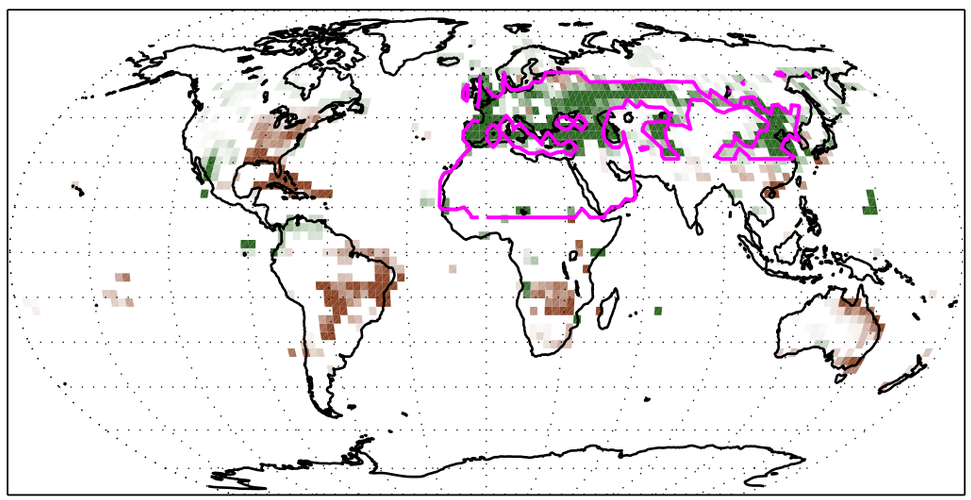
Δ Net Primary Production (gC/m²/yr)

Effect of
Eurasian trees

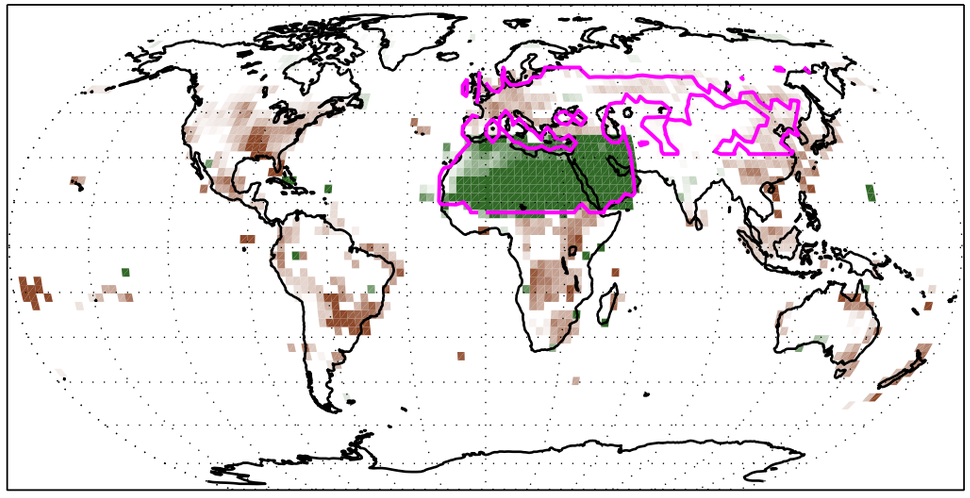
CMH - CPI



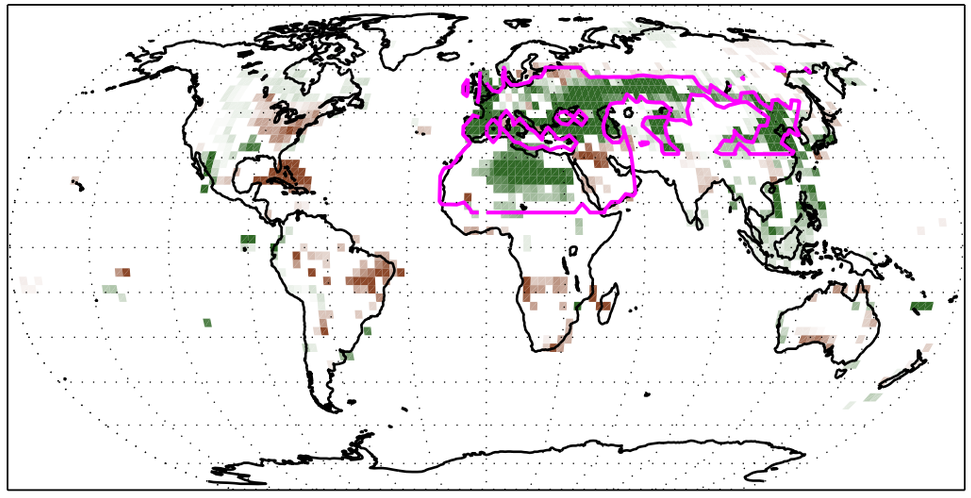
EVMH - CMH



SVMH - CMH

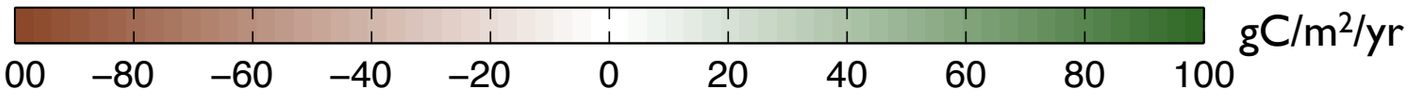


SEVMH - SVMH

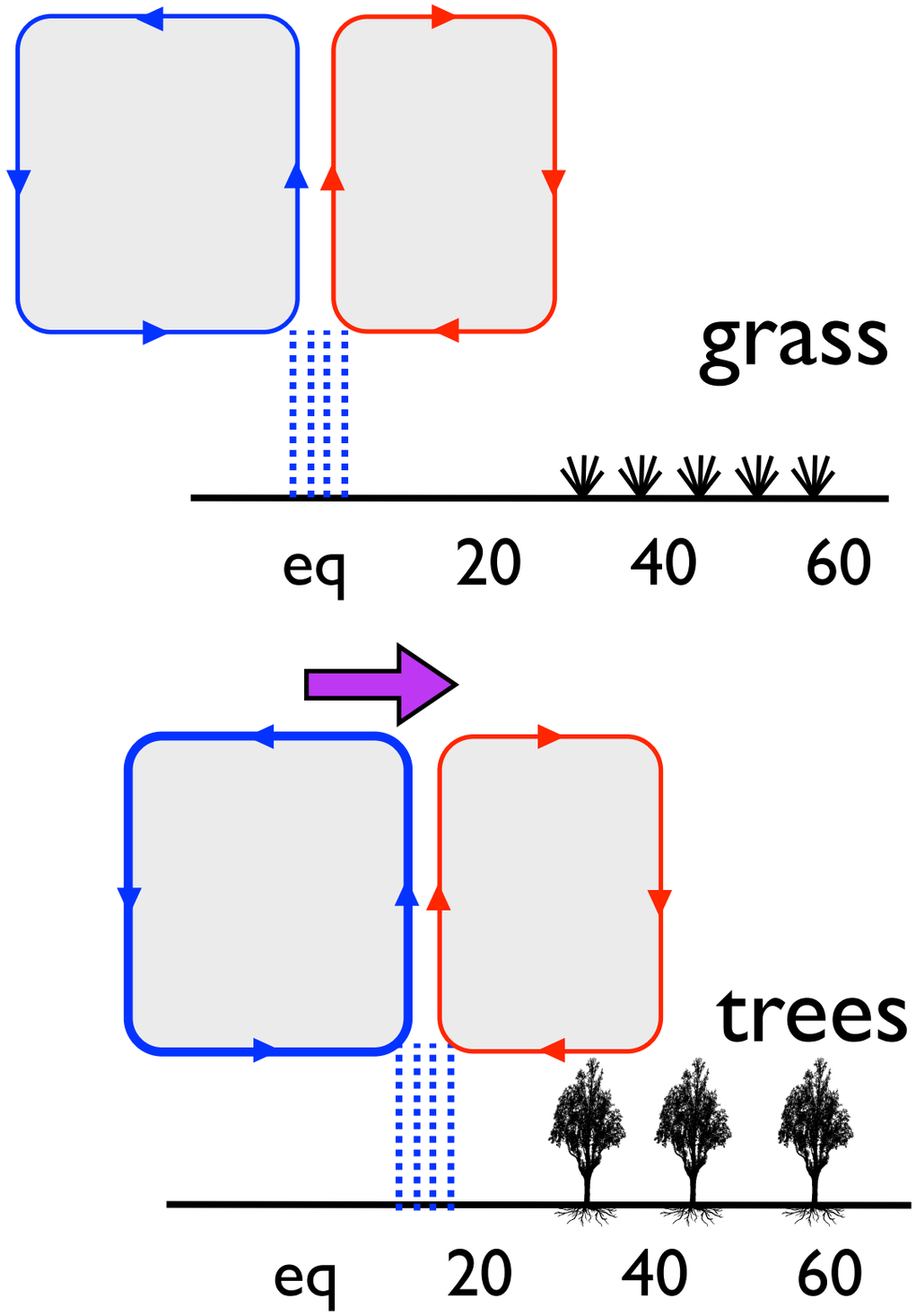


Effect of
Orbital forcing + grass + trees

Additive effect of
trees



Hypothesized Mechanism



1. dark trees = NH warm

2. Energy gradient (N-S) between the Hemispheres increases

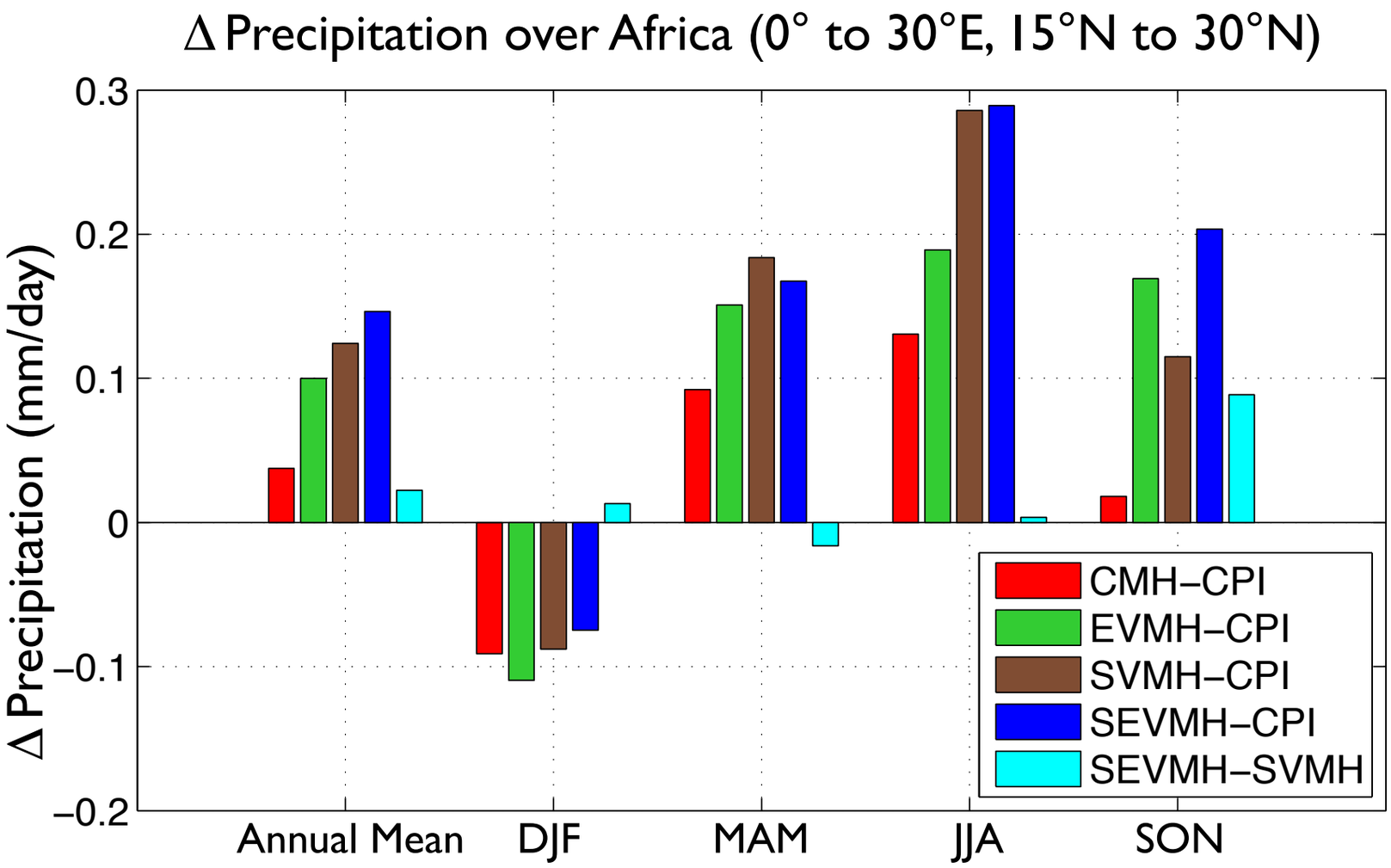
3. Hadley Cell moves north to increase southward heat transport

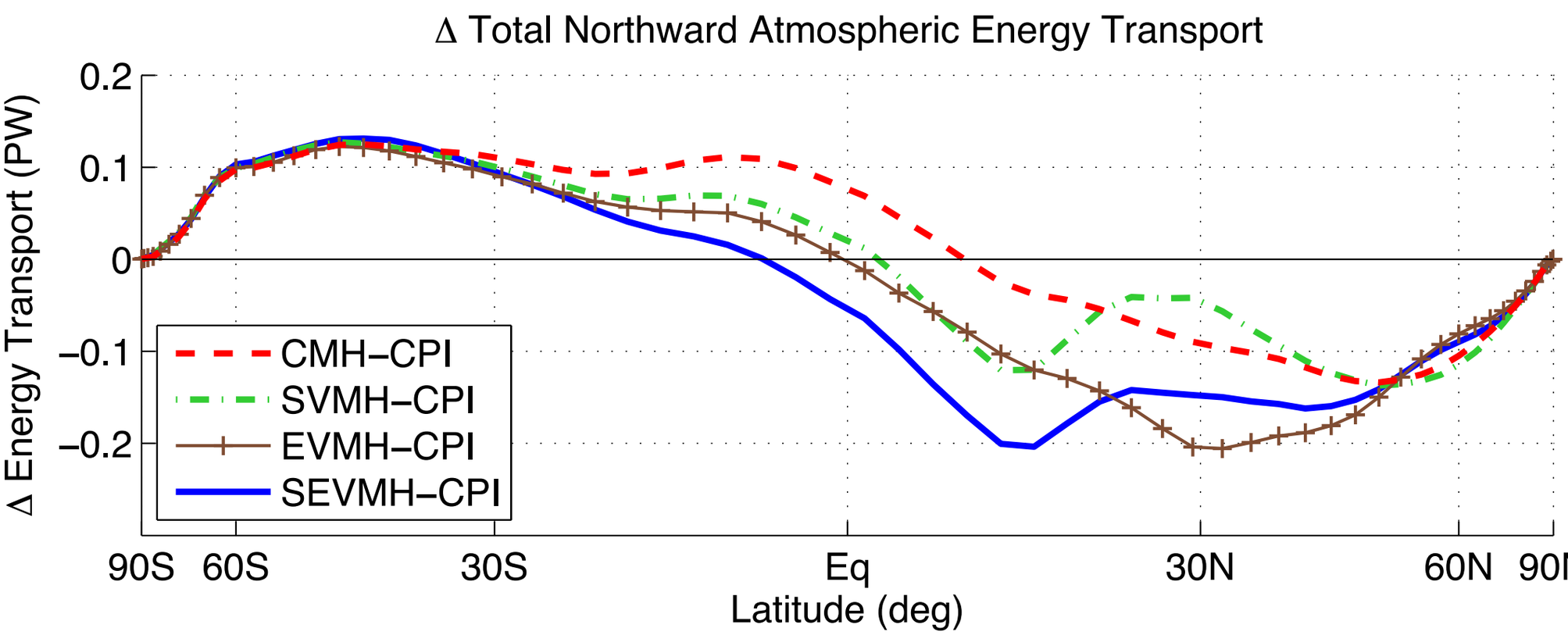
4. ITCZ shifts North

⇒ Tropical productivity follows changes in precipitation

mid-Holocene green Sahara

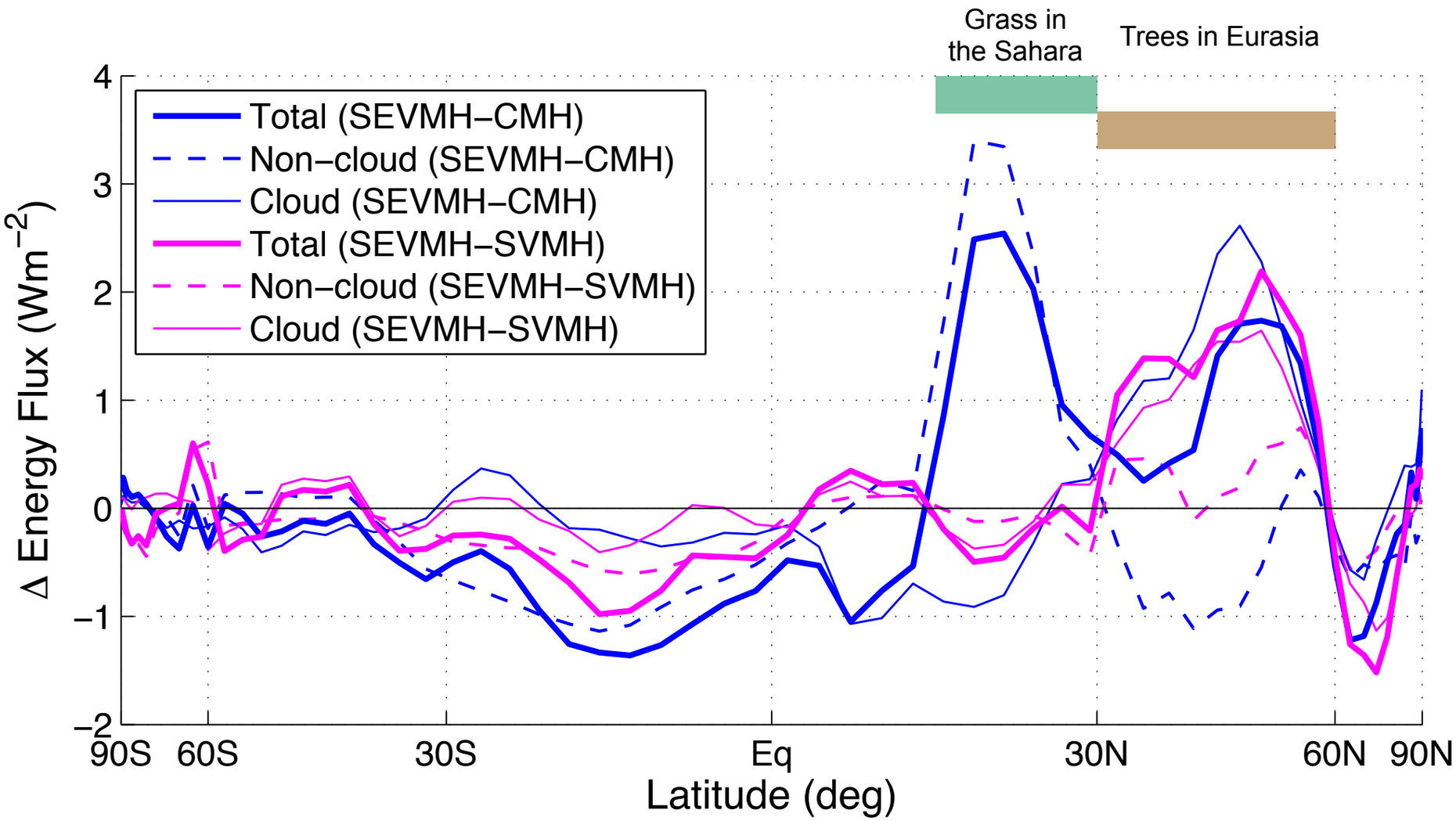
- mid-latitude trees in Eurasia can shift the ITCZ and increase rainfall over Africa in the mid-Holocene
- paleo-proxy records based on plants may have information about climate forcing in addition to local climate conditions


Δ Precipitation over Africa (0° to 30°E, 15°N to 30°N)
Δ Precipitation (mm/day)
0.3
0.2
0.1
0
−0.1
−0.2
Annual Mean
DJF
MAM
JJA
SON
CMH−CPI
EVMH−CPI
SVMH−CPI
SEVMH−CPI
SEVMH−SVMH



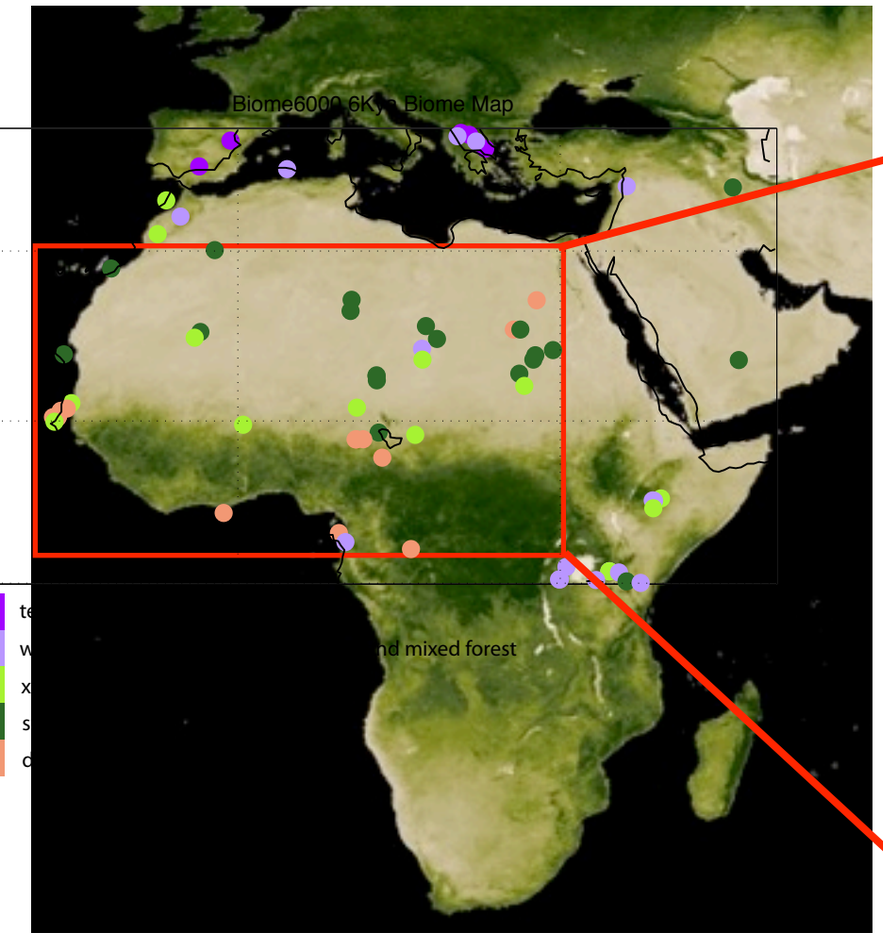
Experiment	Δ EFlux (PW)	Δ EFlux (%)	pval
CPD - CPI	0.042	2.3	0.0303*
CMH - CPI	0.076	4.2	0.0003**
SVMH - CPI	0.020	1.1	0.2786
EVMH - CPI	-0.003	-0.1	0.8680
SEVMH - CPI	-0.054	-3.0	0.0080**
SEVMH - SVMH	-0.091		0.0008**

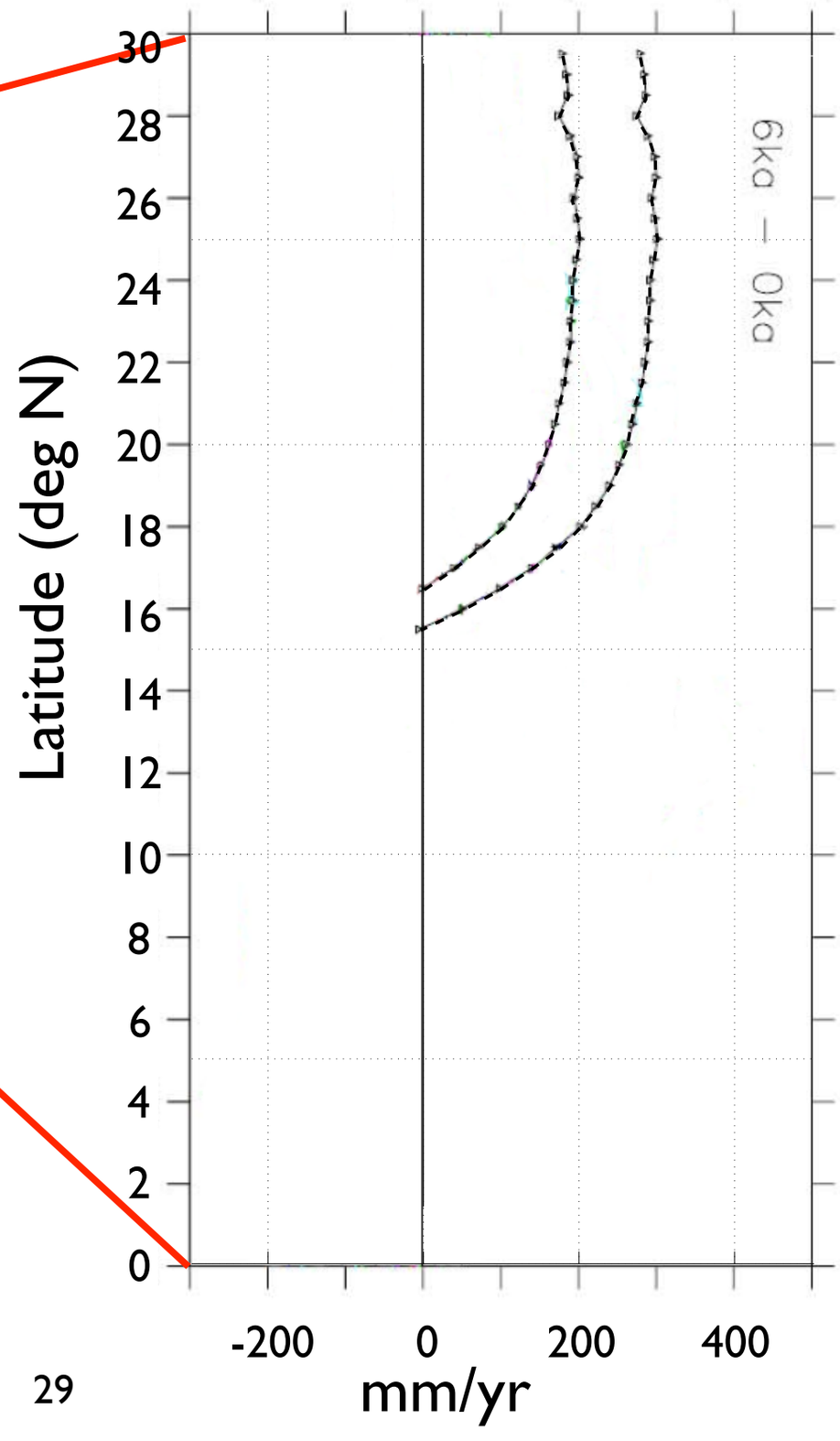
TABLE 1. **Δ Atmospheric Energy Transport:** Change in northward energy flux by the


Grass in
the Sahara
Trees in Eurasia
Total (SEVMH–CMH)
Non–cloud (SEVMH–CMH)
Cloud (SEVMH–CMH)
Total (SEVMH–SVMH)
Non–cloud (SEVMH–SVMH)
Cloud (SEVMH–SVMH)
Δ Energy Flux (Wm^{-2})
4
3
2
1
0
−1
−2
90S
60S
30S
Eq
30N
60N
90N
Latitude (deg)

11–3–2013

Excess Precipitation estimated from pollen record

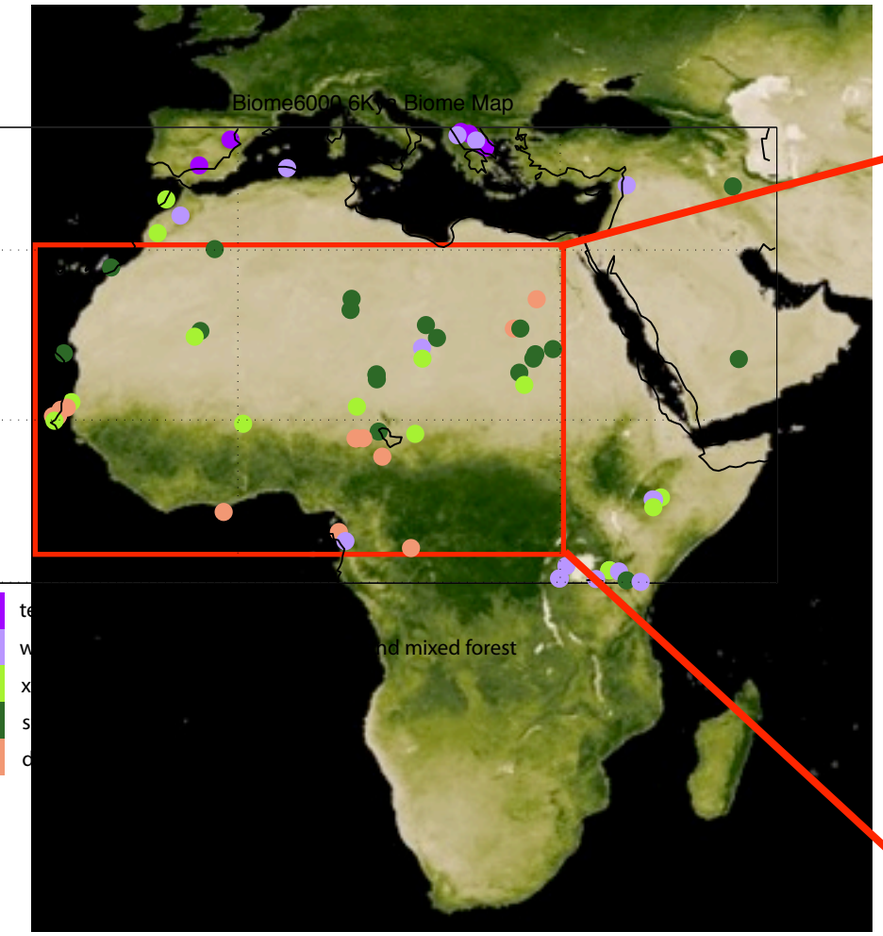


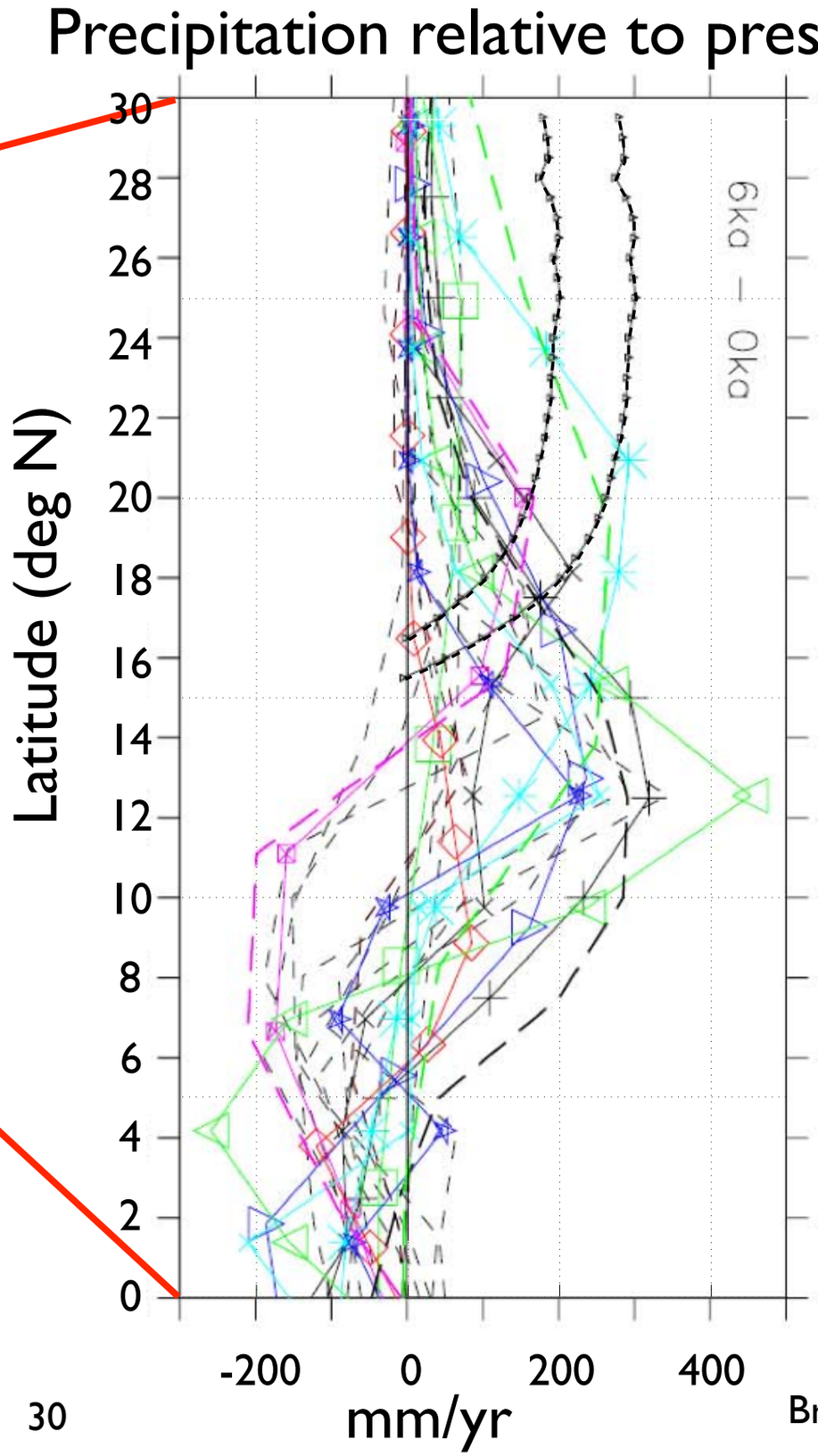


– – – Excess Precip.

Jolly & Prentice, unpublished

Orbital and Dynamic Veg don't get enough precip



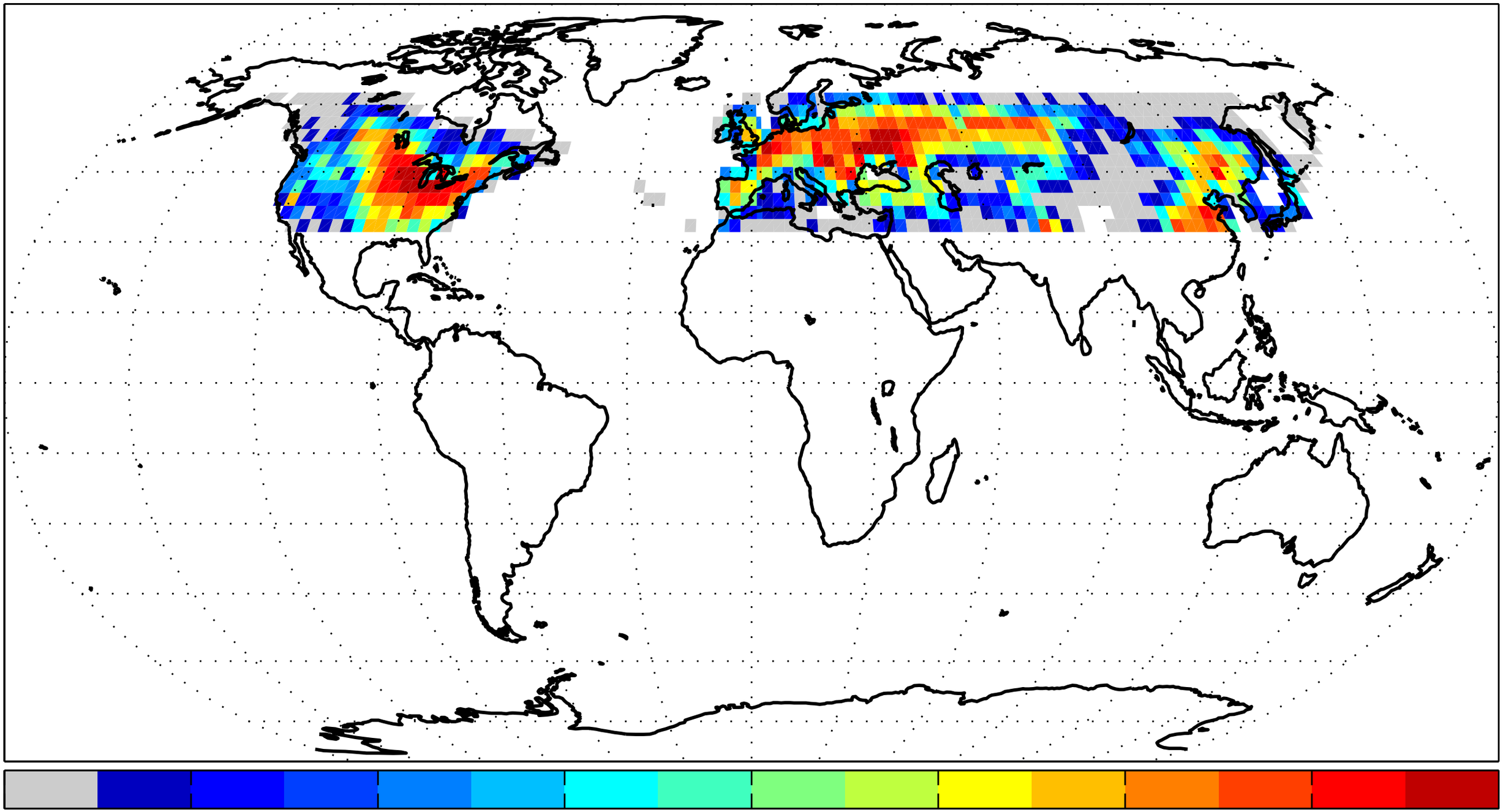


– – – Excess Precip.

colored lines: PMIP2 model results

Braconnot et al. 2007

Expand Mid-Latitude Forests



0 12.5 25 37.5 50 62.5 75 87.5 100

% of gridcell