Mid-latitude Afforestation:
Consequences for General Circulation and Tropical Precipitation

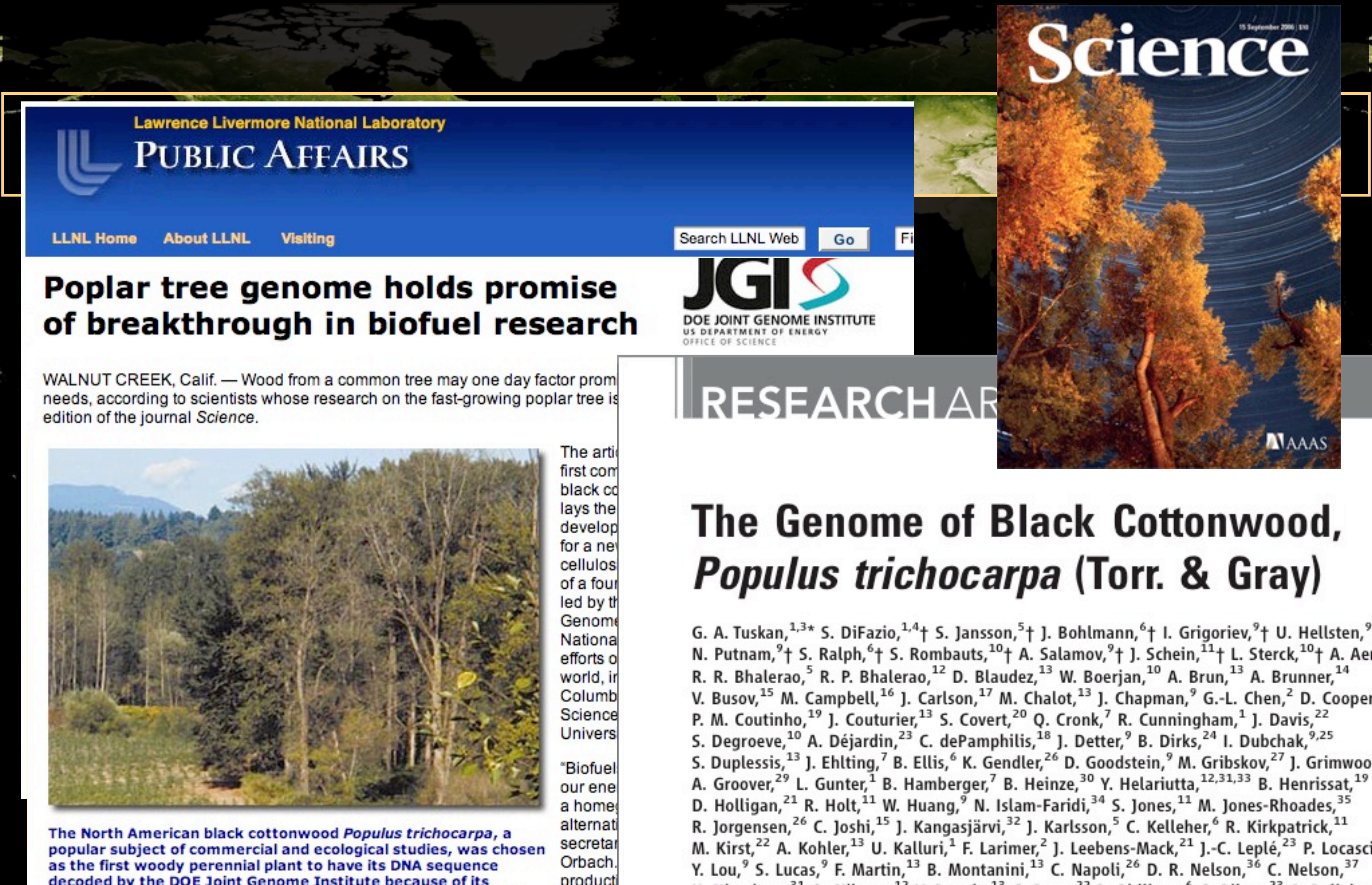
Abigail Swann[1], Inez Fung[2], John Chiang[3]

Land Model Working Group Meeting,
March15th, 2011

[1]Harvard University, Organismic and Evolutionary Biology Dept. &
Sustainability Science Prgm., Harvard Kennedy School
[2] University of California Berkeley, Dept. Earth & Planetary Science
[3] University of California Berkeley, Dept. of Geography

NDVI June, 2009

Mid Latitude Ecosystems



Lawrence Livermore National Laboratory

PUBLIC AFFAIRS

Poplar tree genome holds promise of breakthrough in biofuel research

WALNUT CREEK, Calif. — Wood from a common tree may one day factor prom
needs, according to scientists whose research on the fast-growing poplar tree is
edition of the journal *Science*.

The North American black cottonwood *Populus trichocarpa*, a popular subject of commercial and ecological studies, was chosen as the first woody perennial plant to have its DNA sequence decoded by the DOE Joint Genome Institute because of its

The arti
first com
black co
lays the
develop
for a ne
cellulos
of a four
led by th
Genome
Nationa
efforts o
world, in
Columb
Science
Univers

"Biofuel
our ene
a home
alternati
secretar
Orbach.
producti

Science

15 September 2006 | $10

AAAS

RESEARCH AR

The Genome of Black Cottonwood, *Populus trichocarpa* (Torr. & Gray)

G. A. Tuskan,[1,3]* S. DiFazio,[1,4]† S. Jansson,[5]† J. Bohlmann,[6]† I. Grigoriev,[9]† U. Hellsten,[9]
N. Putnam,[9]† S. Ralph,[6]† S. Rombauts,[10]† A. Salamov,[9]† J. Schein,[11]† L. Sterck,[10]† A. Ae
R. R. Bhalerao,[5] R. P. Bhalerao,[12] D. Blaudez,[13] W. Boerjan,[10] A. Brun,[13] A. Brunner,[14]
V. Busov,[15] M. Campbell,[16] J. Carlson,[17] M. Chalot,[13] J. Chapman,[9] G.-L. Chen,[2] D. Cooper
P. M. Coutinho,[19] J. Couturier,[13] S. Covert,[20] Q. Cronk,[7] R. Cunningham,[1] J. Davis,[22]
S. Degroeve,[10] A. Déjardin,[23] C. dePamphilis,[18] J. Detter,[9] B. Dirks,[24] I. Dubchak,[9,25]
S. Duplessis,[13] J. Ehlting,[7] B. Ellis,[6] K. Gendler,[26] D. Goodstein,[9] M. Gribskov,[27] J. Grimwoo
A. Groover,[29] L. Gunter,[1] B. Hamberger,[7] B. Heinze,[30] Y. Helariutta,[12,31,33] B. Henrissat,[19]
D. Holligan,[21] R. Holt,[11] W. Huang,[9] N. Islam-Faridi,[34] S. Jones,[11] M. Jones-Rhoades,[35]
R. Jorgensen,[26] C. Joshi,[15] J. Kangasjärvi,[32] J. Karlsson,[5] C. Kelleher,[6] R. Kirkpatrick,[11]
M. Kirst,[22] A. Kohler,[13] U. Kalluri,[1] F. Larimer,[2] J. Leebens-Mack,[21] J.-C. Leplé,[23] P. Locasc
Y. Lou,[9] S. Lucas,[9] F. Martin,[13] B. Montanini,[13] C. Napoli,[26] D. R. Nelson,[36] C. Nelson,[37]

Global Climate Model Details

model:

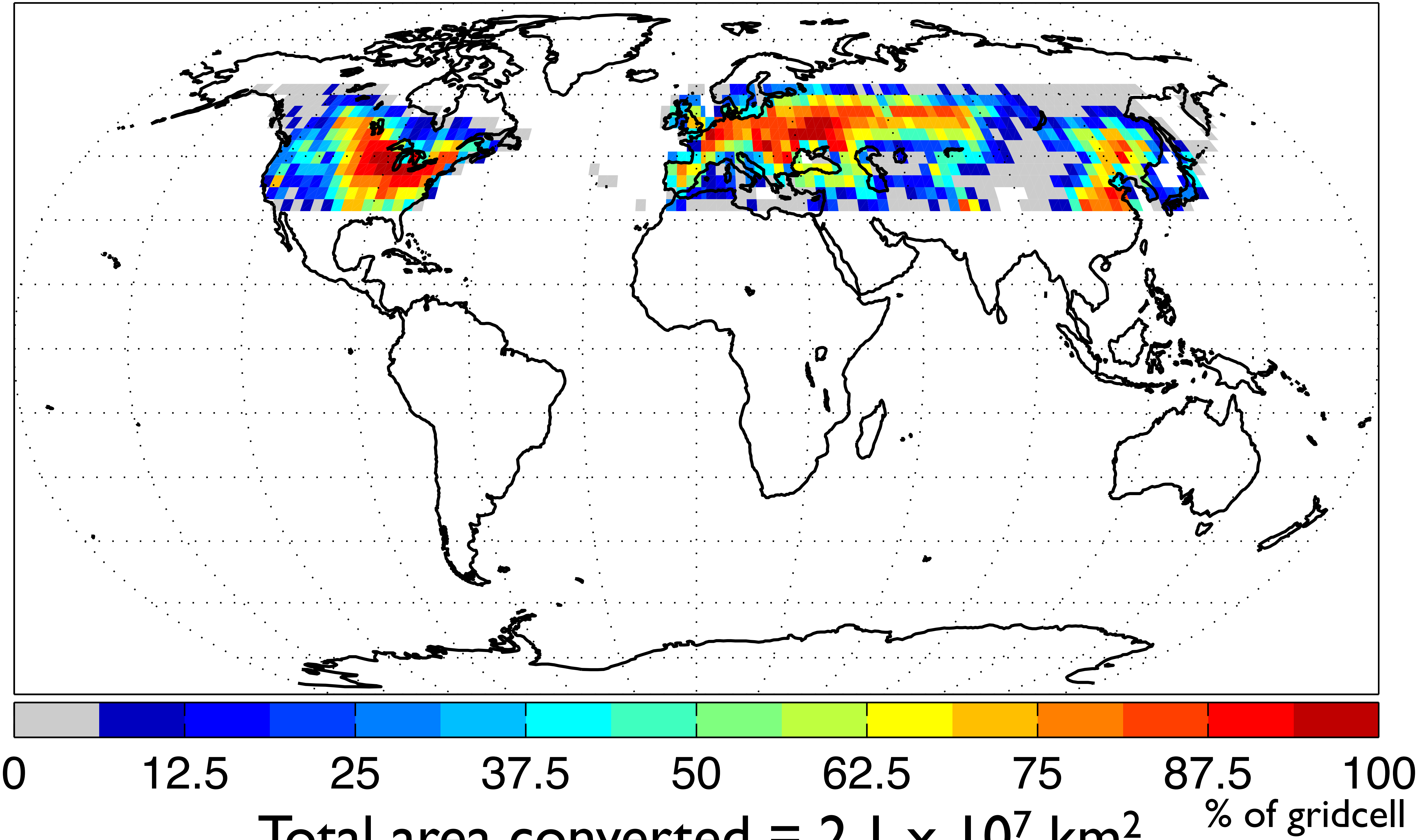
National Center for Atmospheric Research Community Climate Model
Atmosphere: CAM 3.0, Land:CLM 3.5, run w/ CASA' (biogeochemistry)
Resolution: T42 L26
Ocean: Slab Ocean Model

model spin-up: Land and carbon pools are set to equilibrium values from a long control run with fixed observed SST.

CO_2 held fixed at 355ppm for all present day runs

equilibrium experiments: runs are 120 years, results averaged over 100 years.

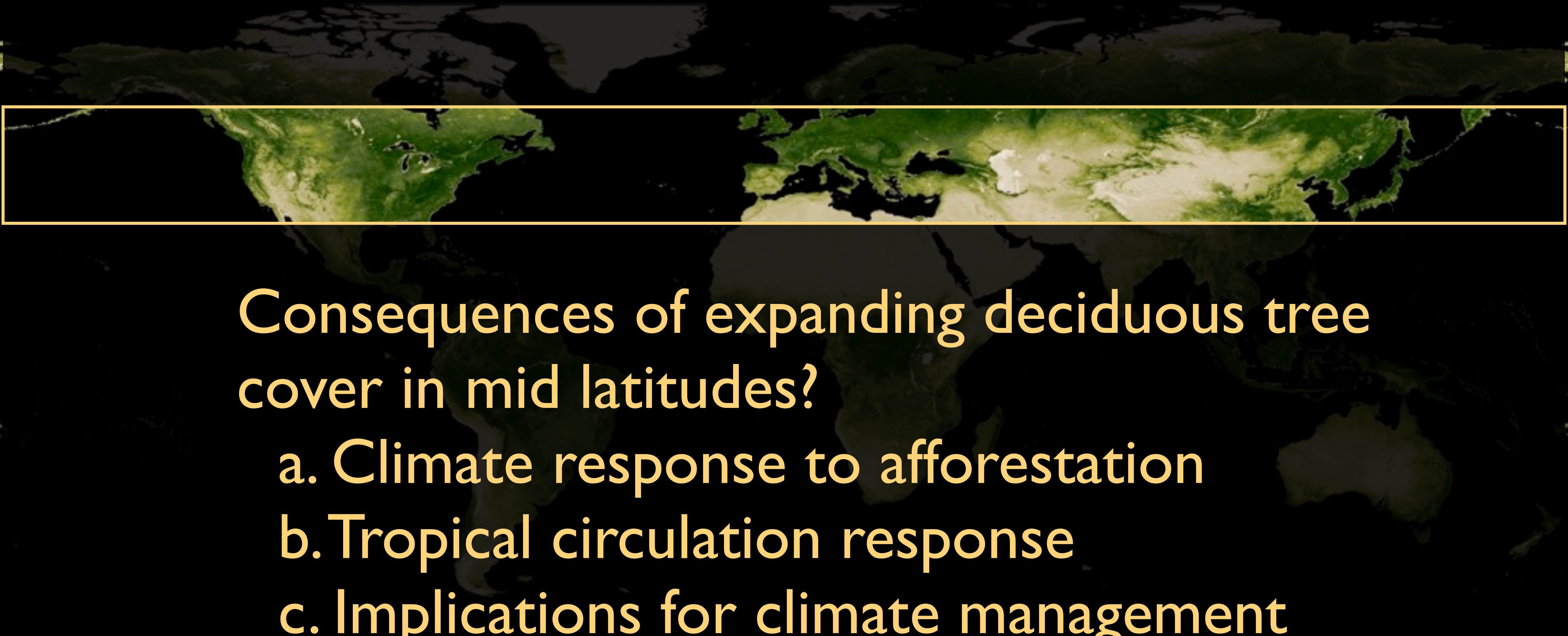
Crops and C3 grass ⇒ Broadleaf Decid. Trees



Total area converted = 2.1 x 10^7 km^2

Swann et al., in review

Mid Latitude Afforestation



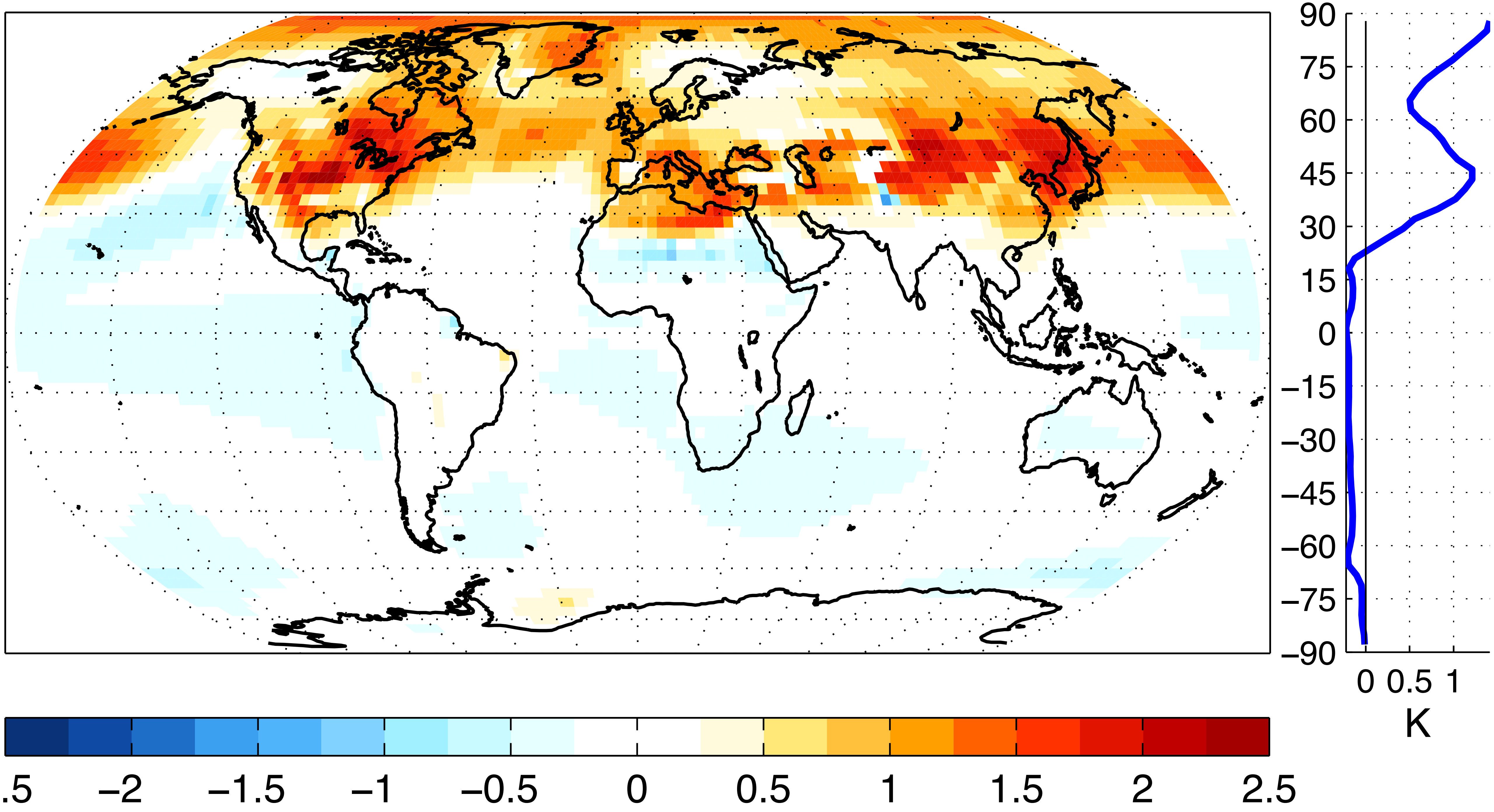
Consequences of expanding deciduous tree cover in mid latitudes?

- a. Climate response to afforestation
- b. Tropical circulation response
- c. Implications for climate management

NDVI June, 2009

Surface Temp. Increases with Mid Latitude Trees

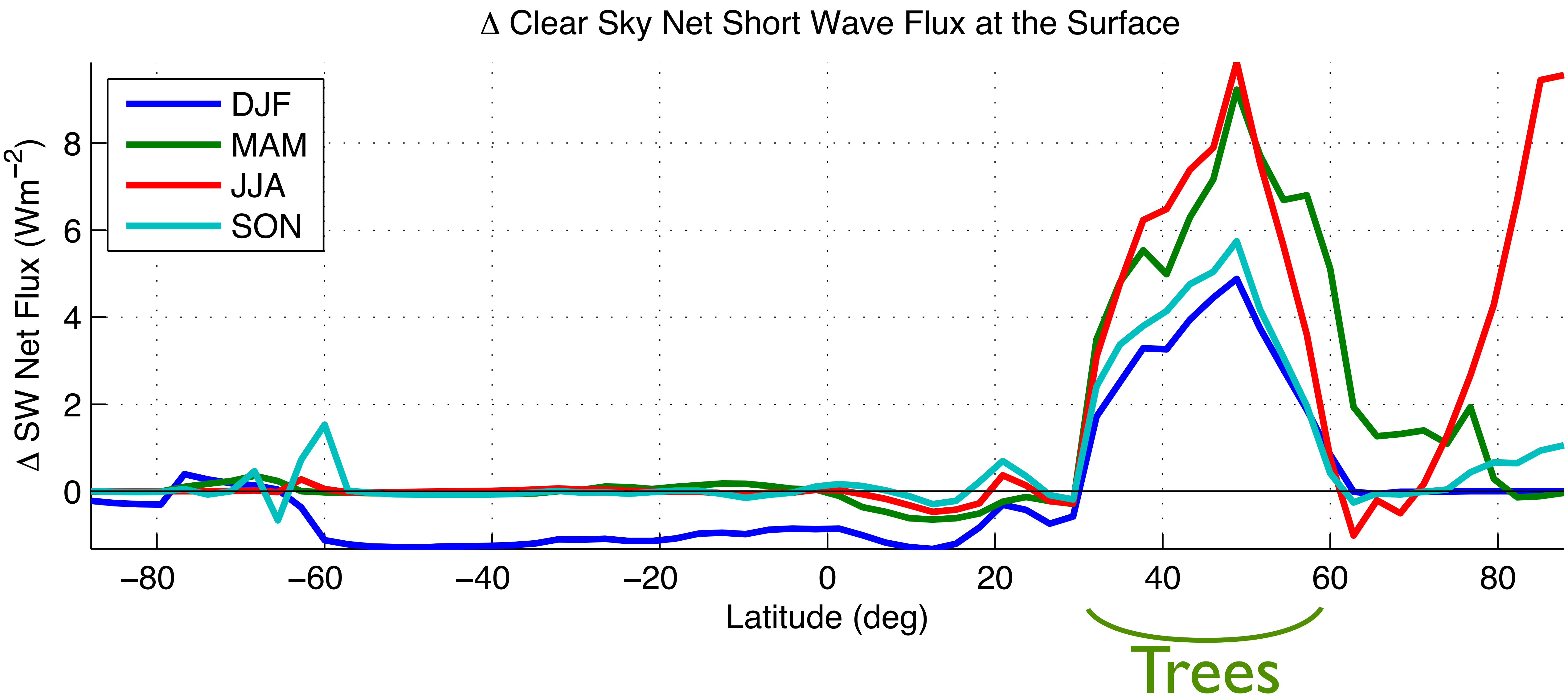
annual mean



Kelvin

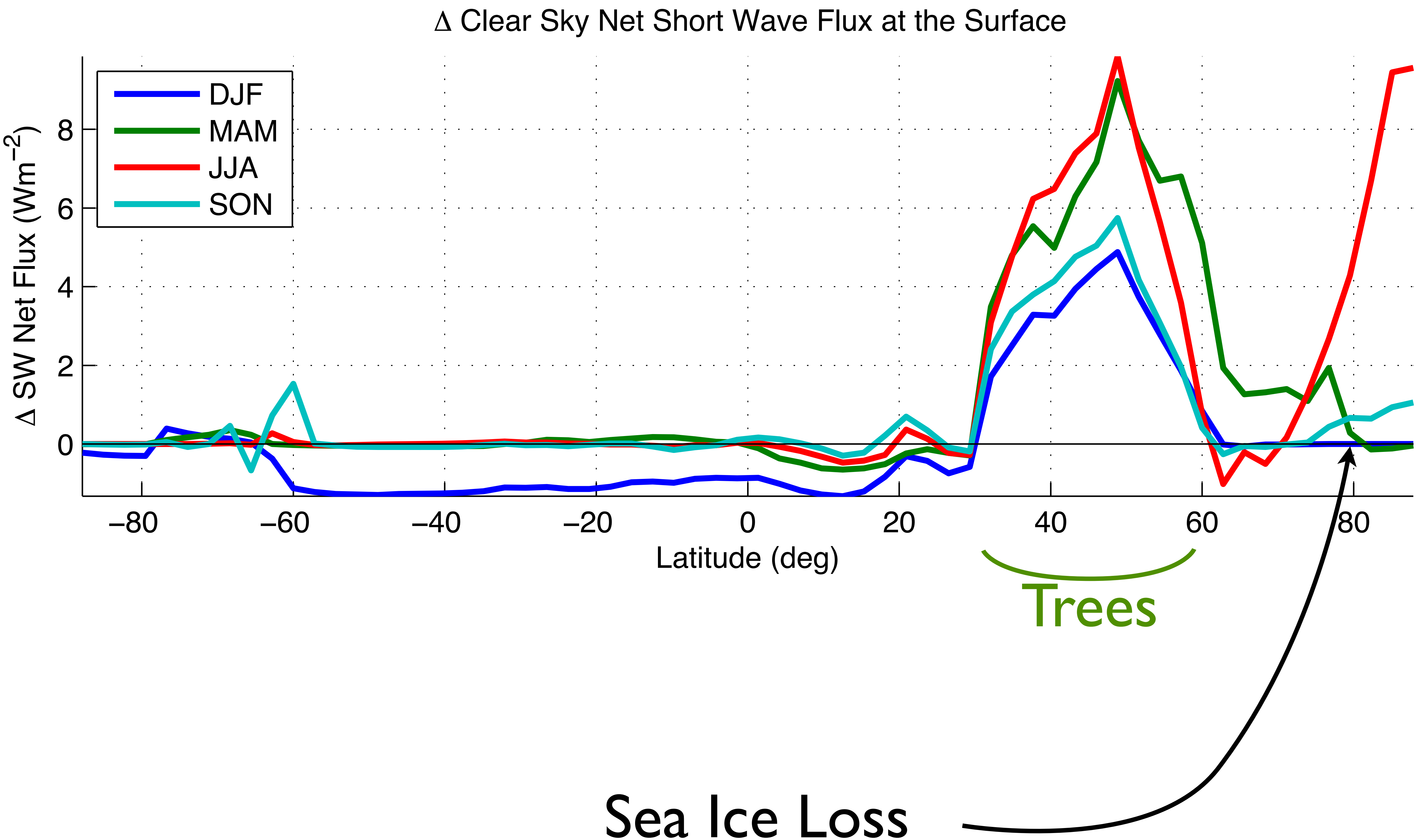
Swann et al., in review

Trees Lower Albedo ⇒ More Absorbed Solar



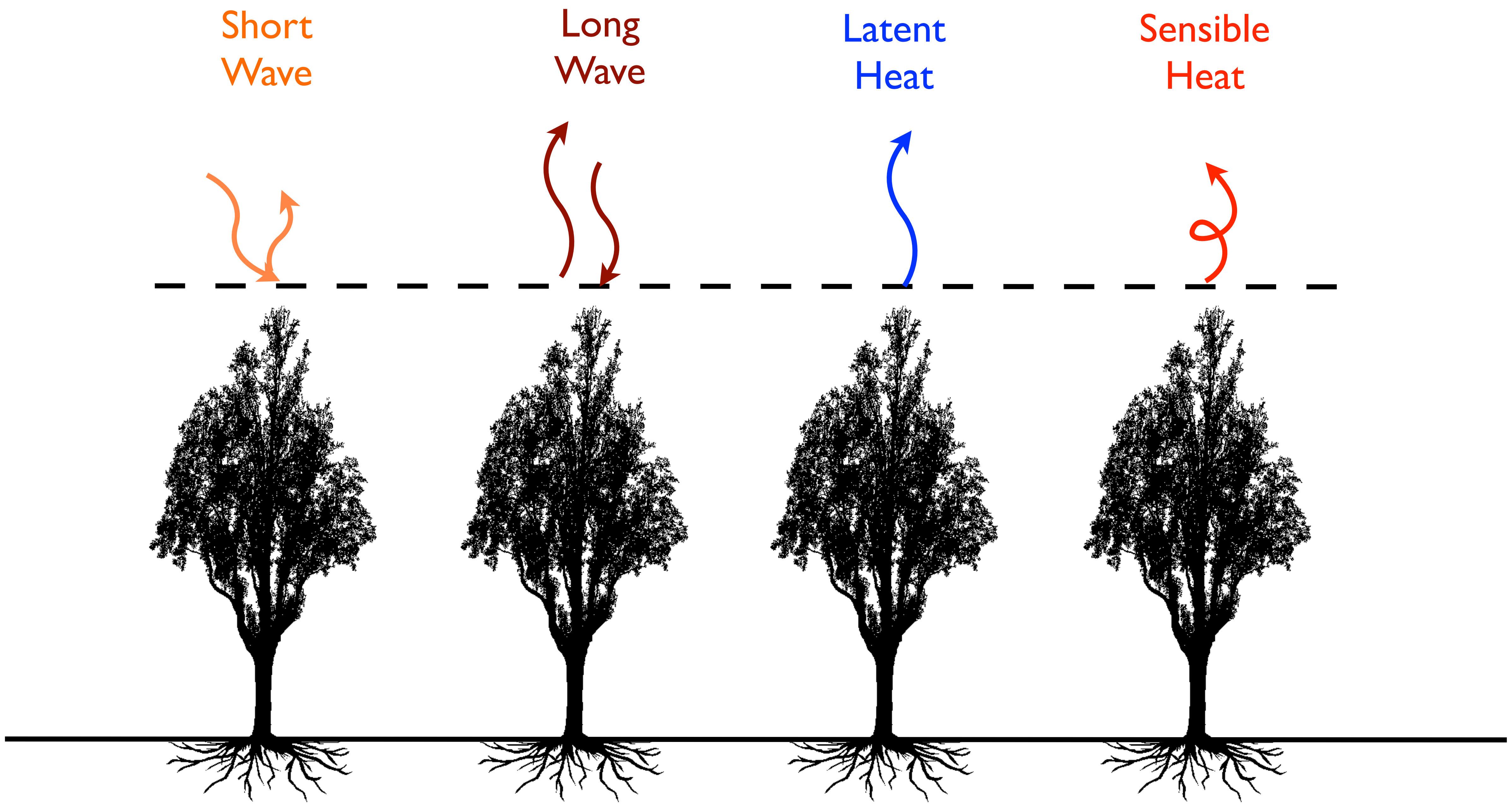
Swann et al., in review

Trees Lower Albedo ⇒ More Absorbed Solar



Swann et al., in review

Terrestrial Surface Energy Budget



Atmospheric Water Supply Gap

$$1 - \frac{ET}{PET}$$

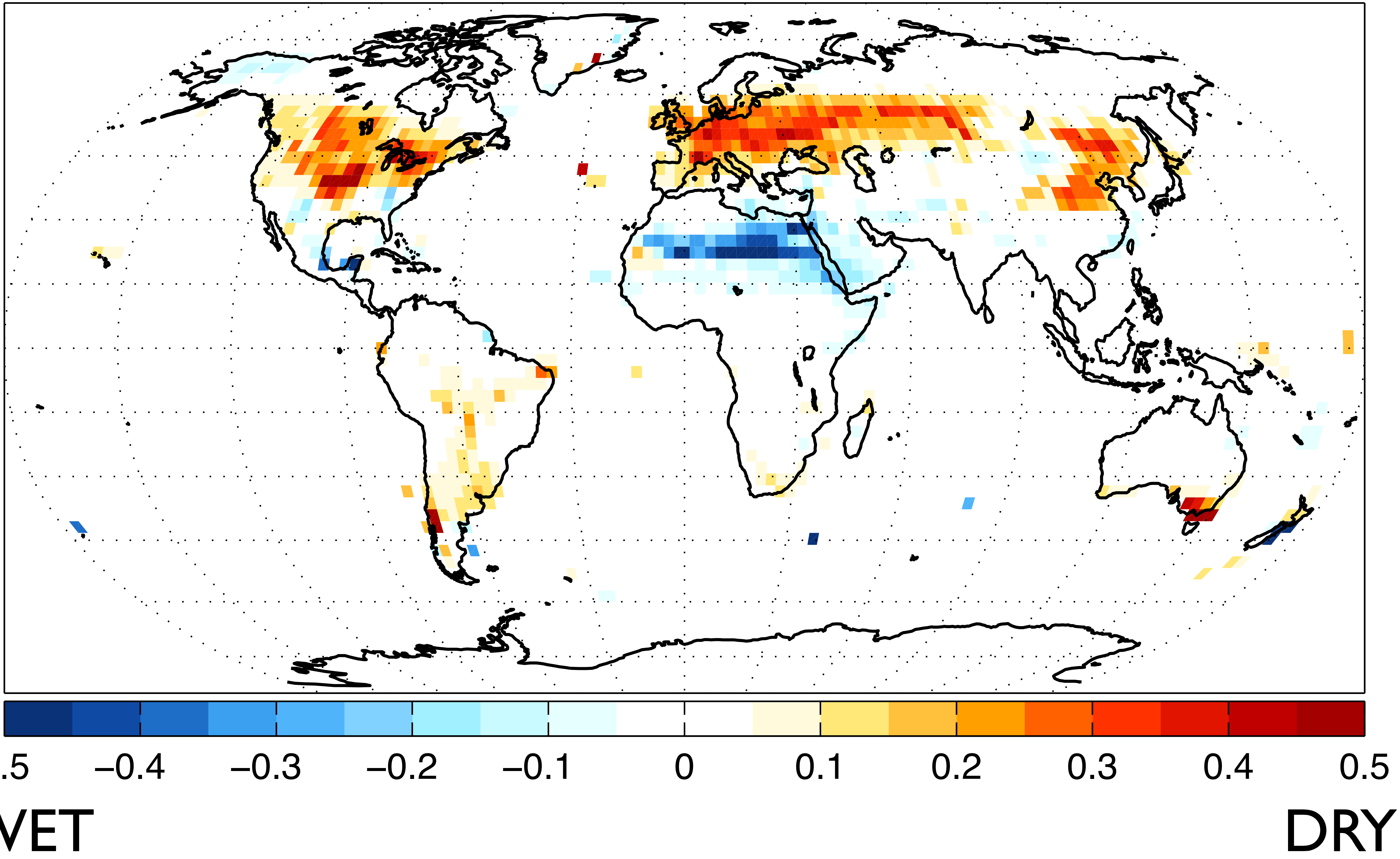
Measures the inability of the surface to meet the water demands of the atmosphere.

$$\Delta(1 - \frac{ET}{PET}) > 0$$ Widening Gap

$$\Delta(1 - \frac{ET}{PET}) < 0$$ Narrowing Gap

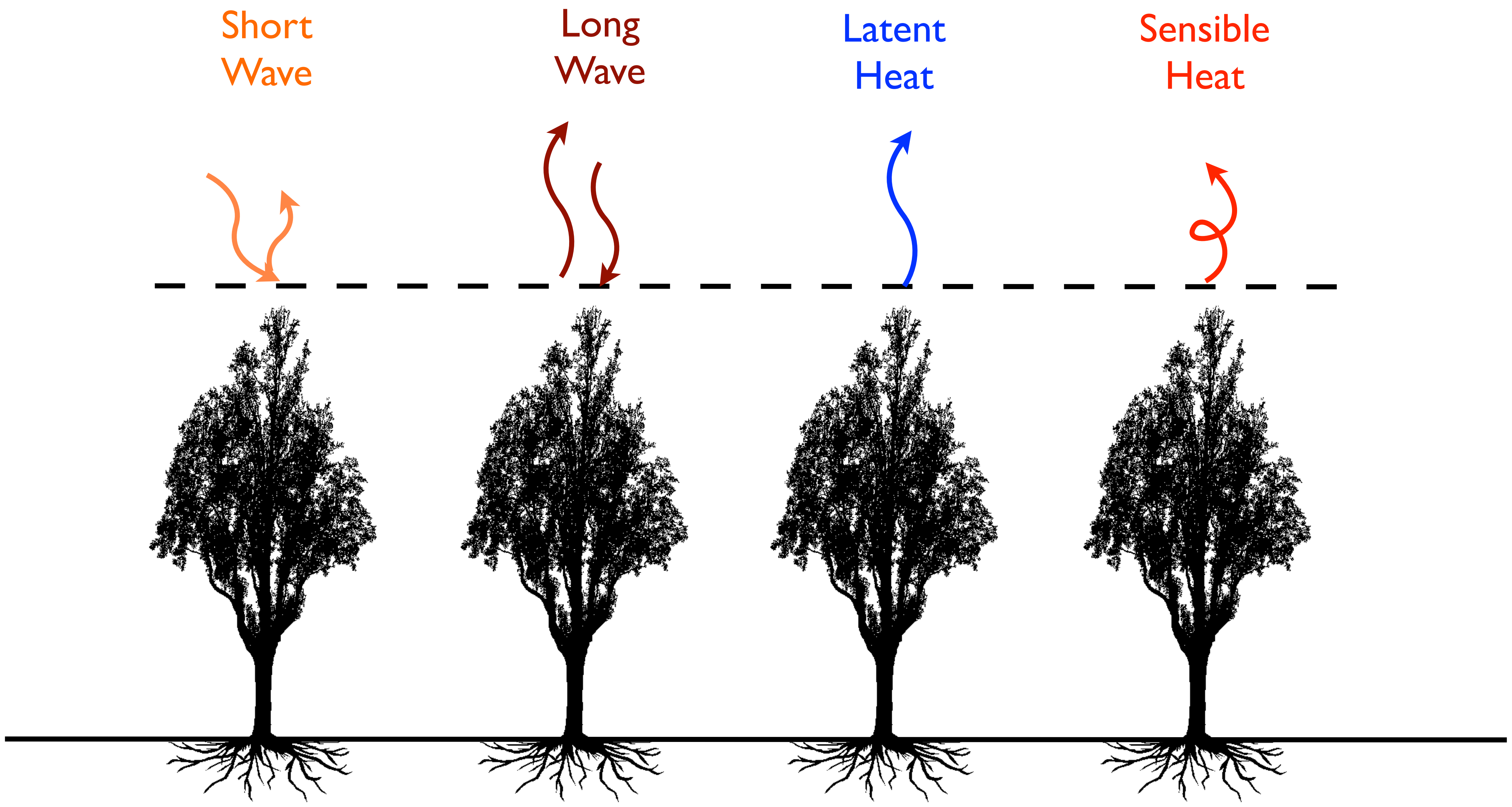
JJA

Water Supply Gap

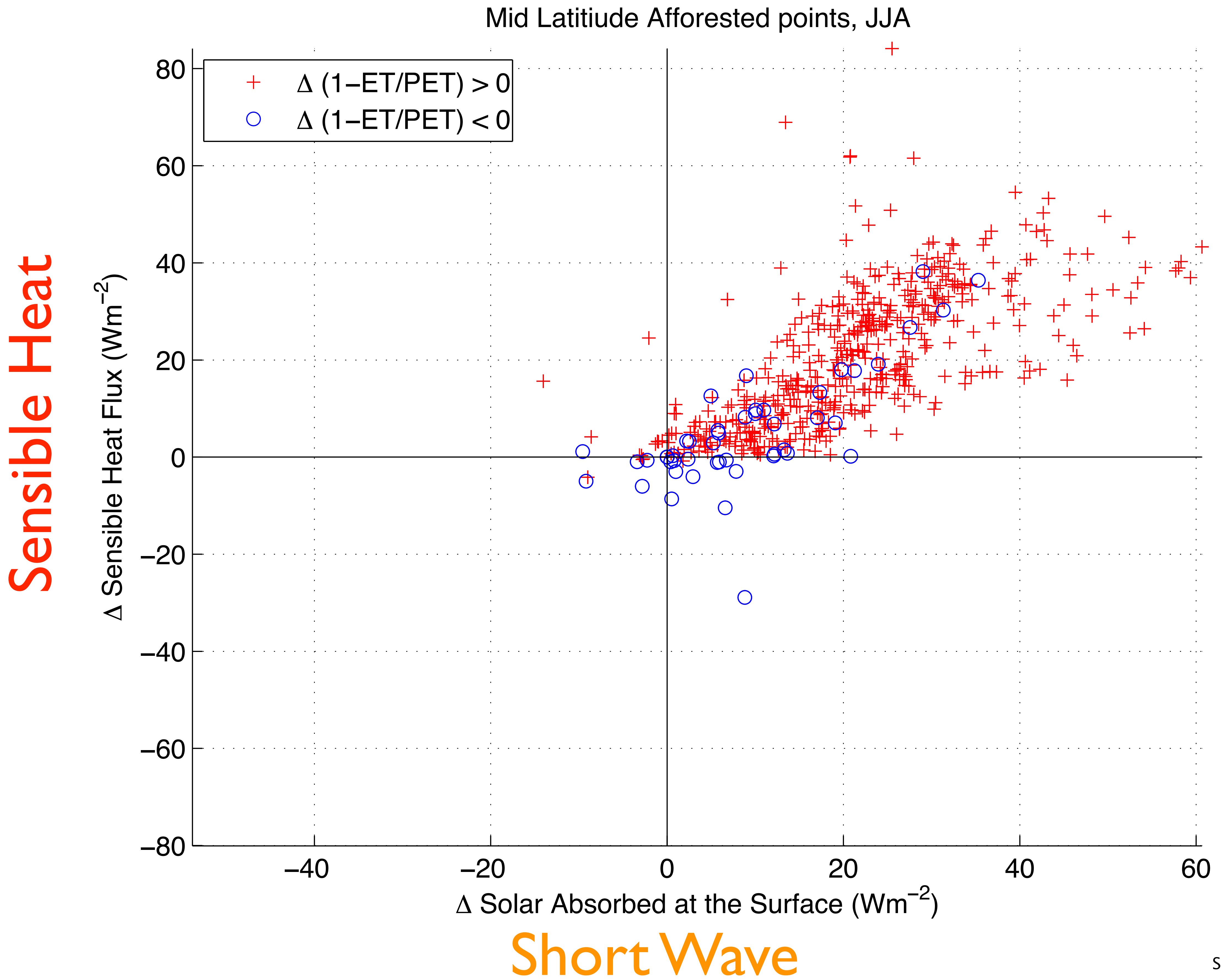


Swann et al., in review

Terrestrial Surface Energy Budget

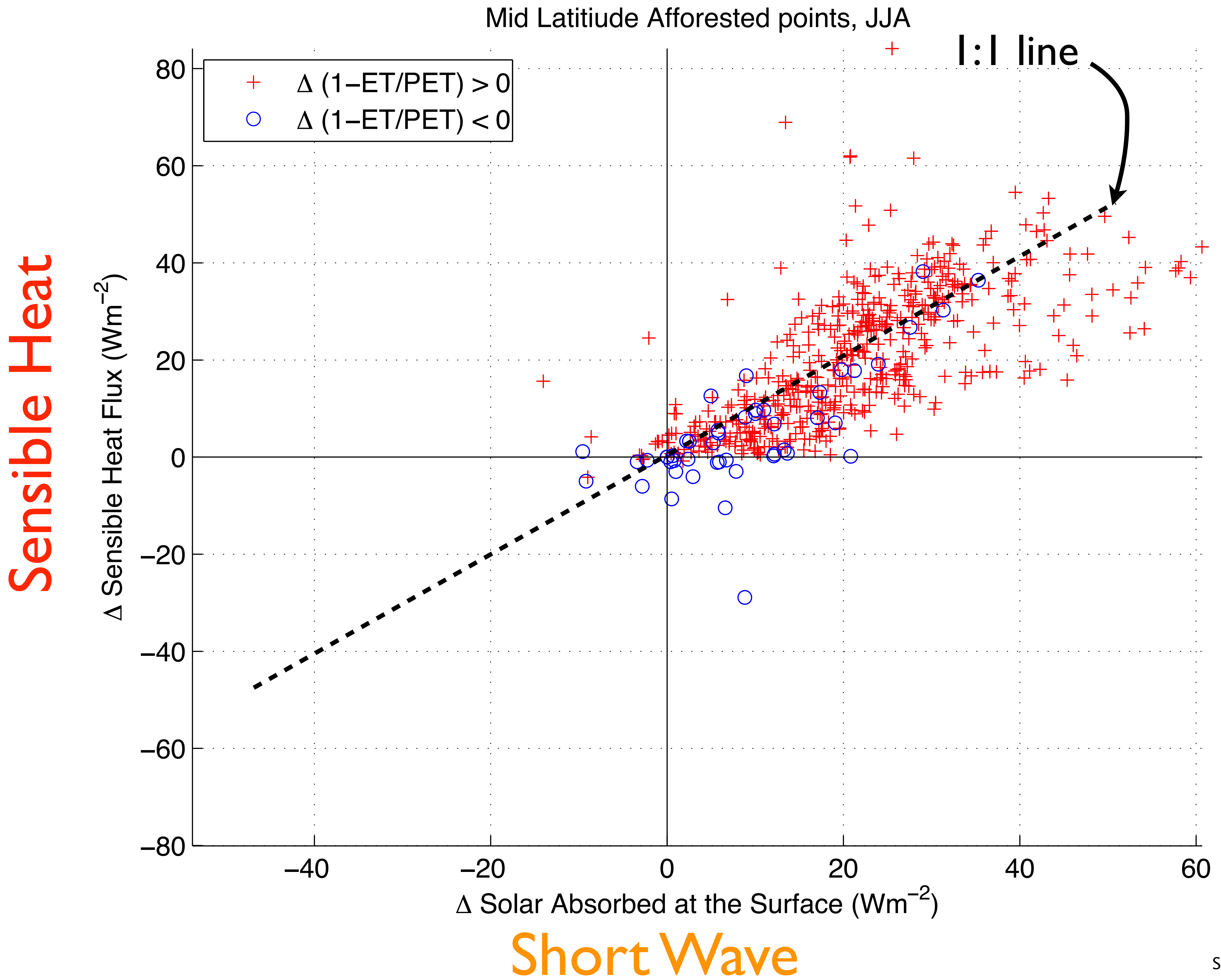


Sensible Heat removes absorbed Short Wave



Swann et al., in review

Sensible Heat removes absorbed Short Wave



Swann et al., in review

Mid Latitude Afforestation

dry ⇒ hot

Latent heat is curtailed by water limitation

Sensible heat removes most of the extra energy

Temperature increases most where water is limited

Mid Latitude Afforestation

dry ⇒ hot

Latent heat is curtailed by water limitation

Sensible heat removes most of the extra energy

Temperature increases most where water is limited

⇒ soil moisture controls

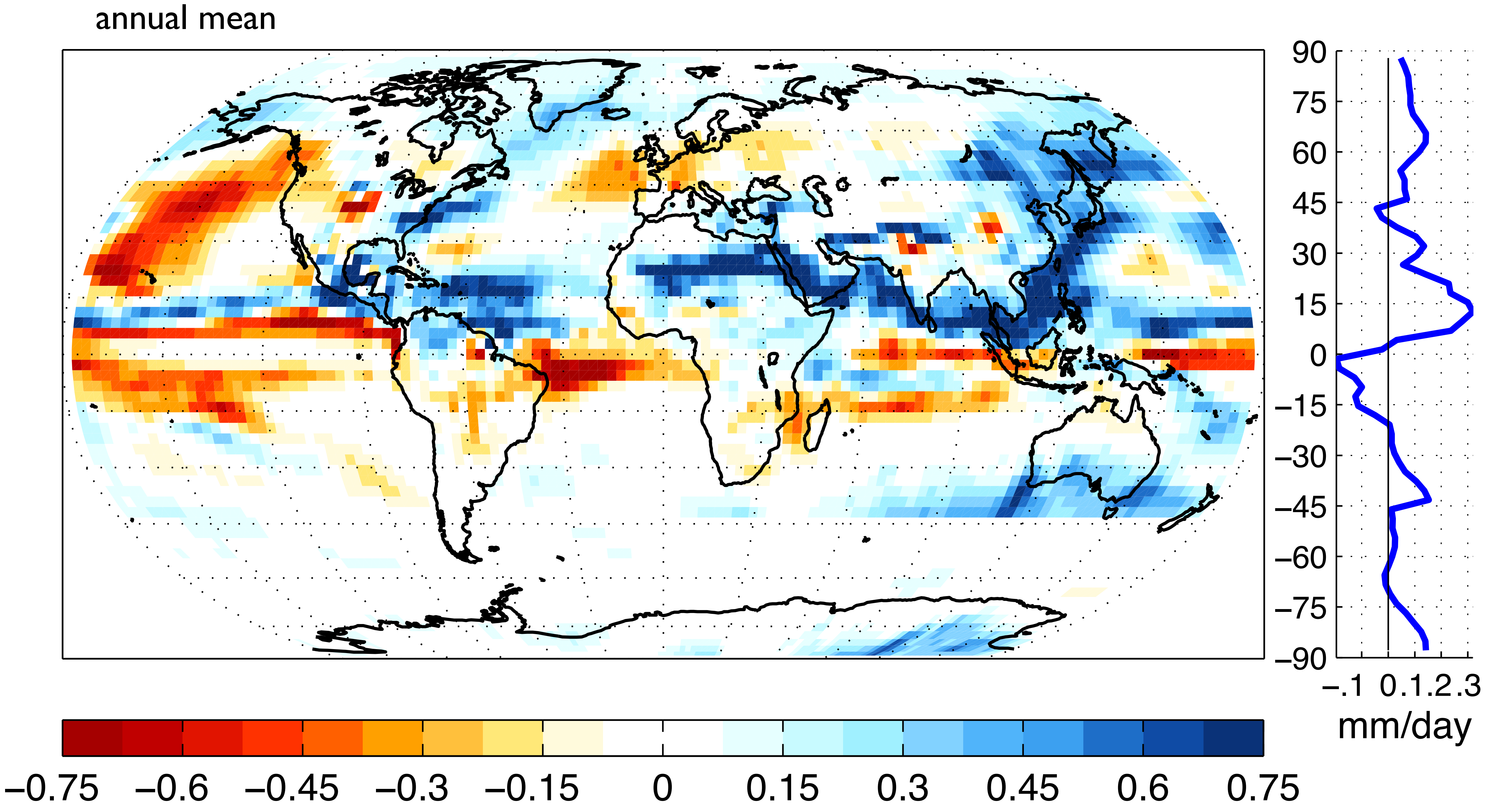
the surface temperature response

Mid Latitude Afforestation

1. Climate response to Forests
2. Tropical Circulation and Precipitation
3. Implications for climate management

NDVI June, 2009

Mid Latitude Trees modify *Tropical* Precipitation



DRY

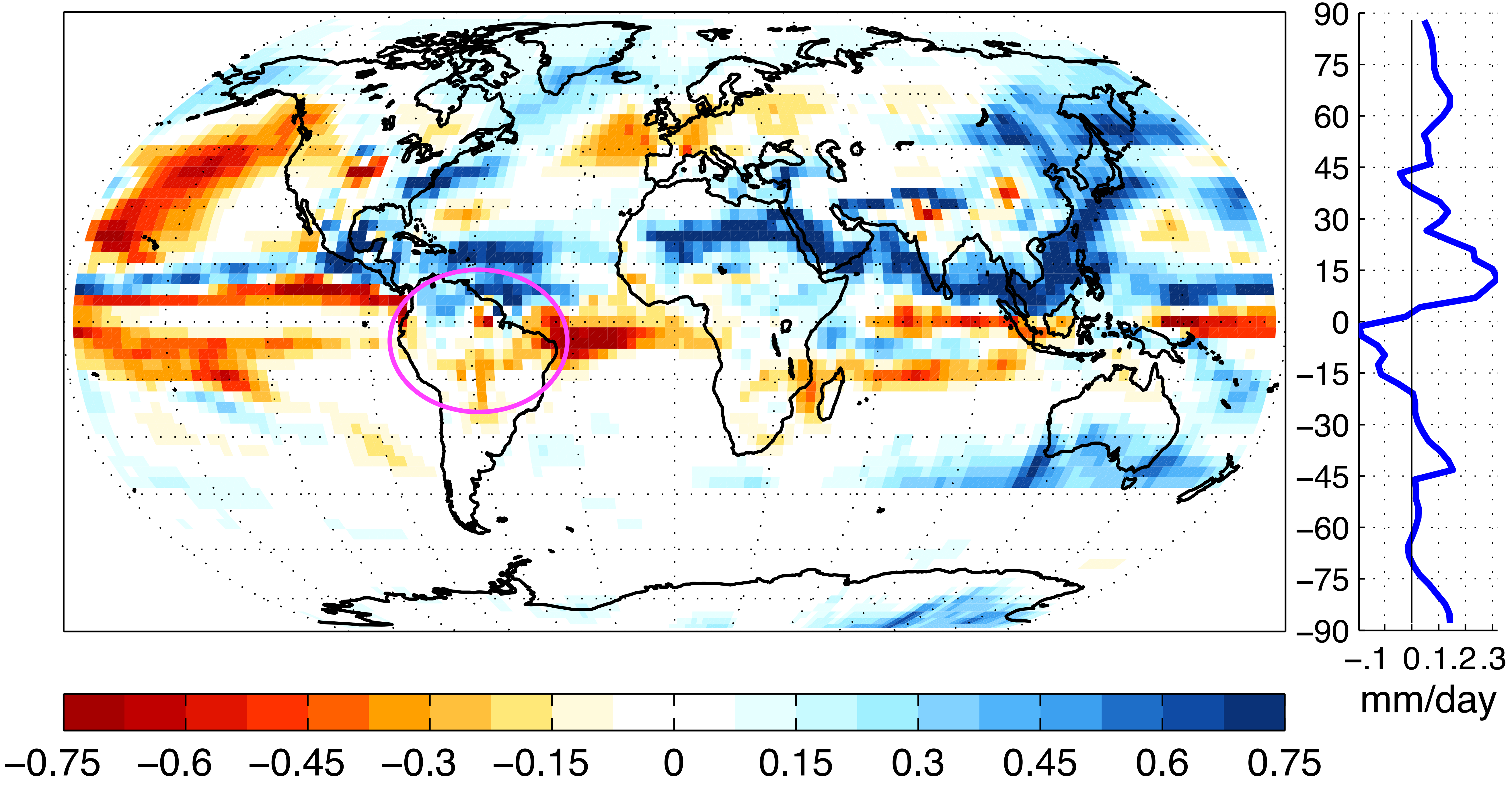
WET

mm/day

Swann et al., in review

Mid Latitude Trees modify *Tropical* Precipitation

annual mean



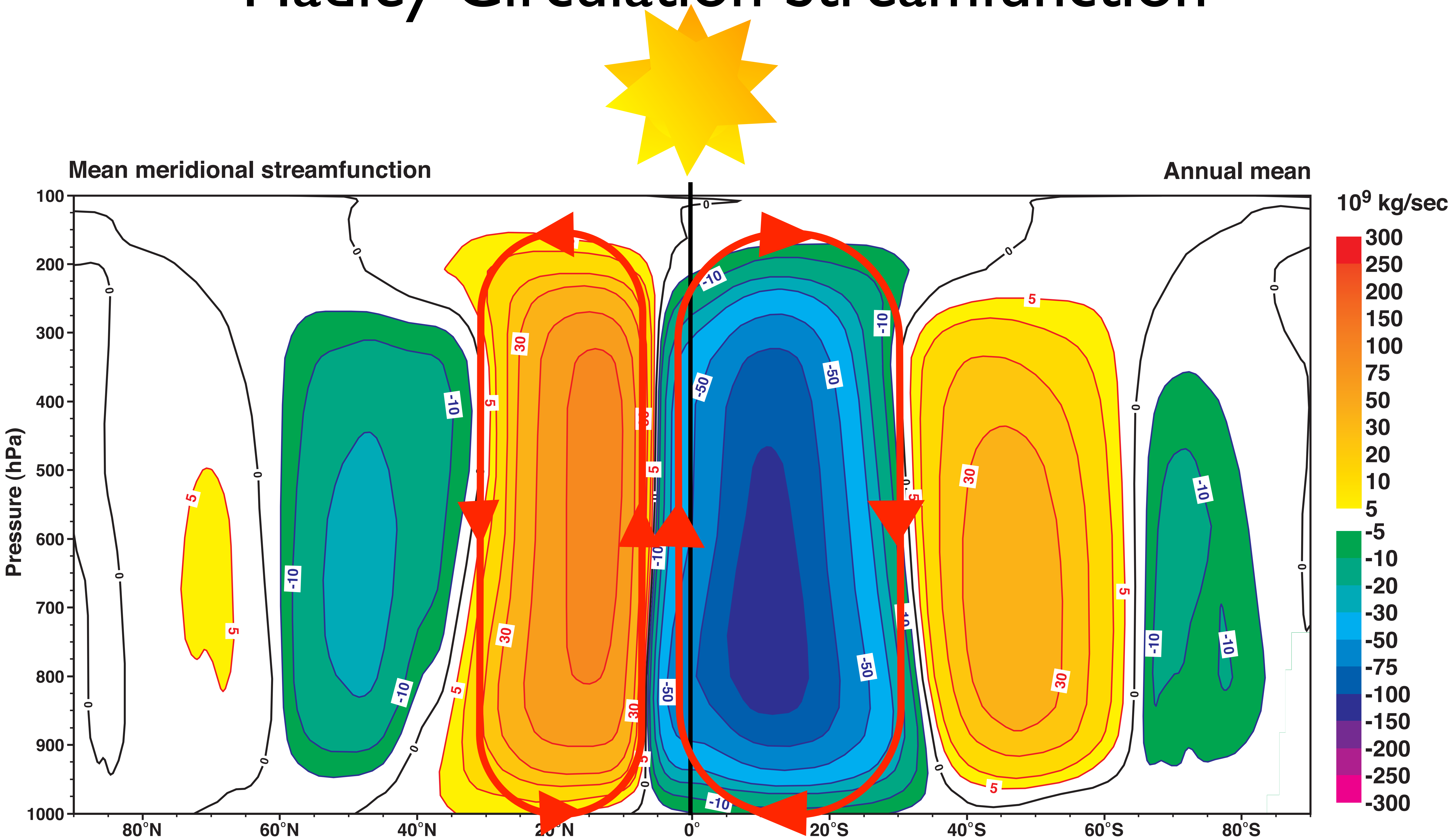
DRY

WET

mm/day

Swann et al., in review

Hadley Circulation Streamfunction



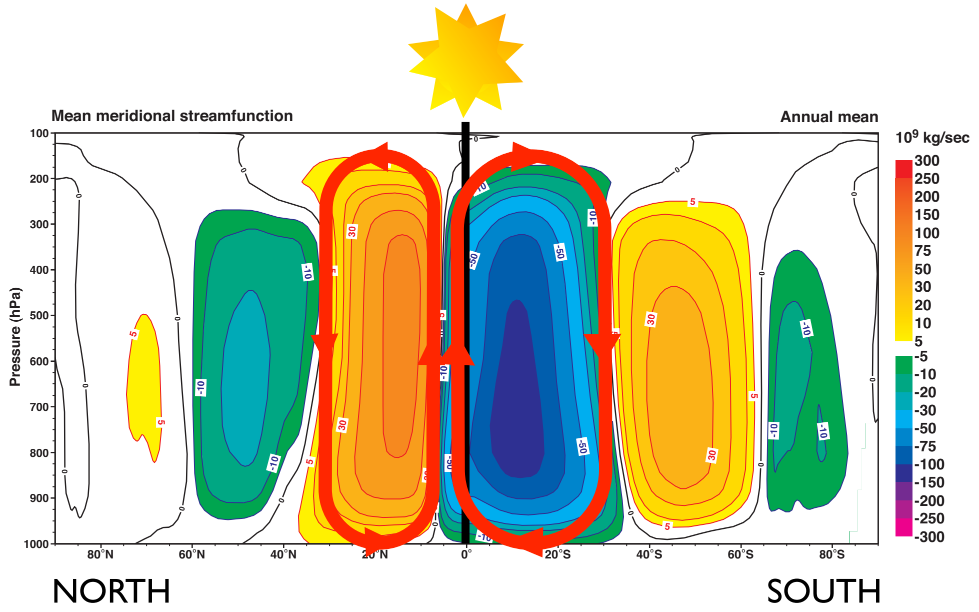
NORTH

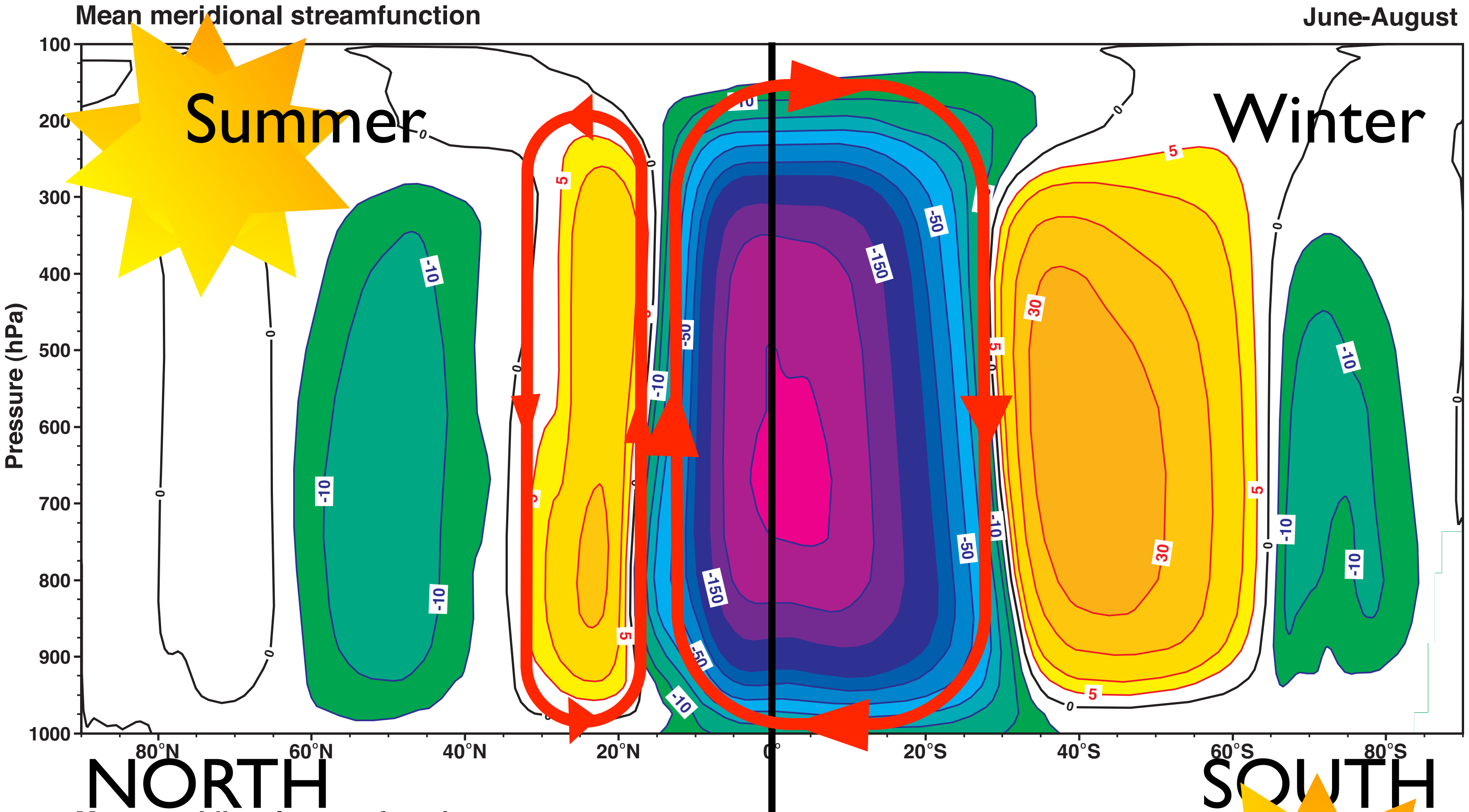
SOUTH

ERA-40 Atlas

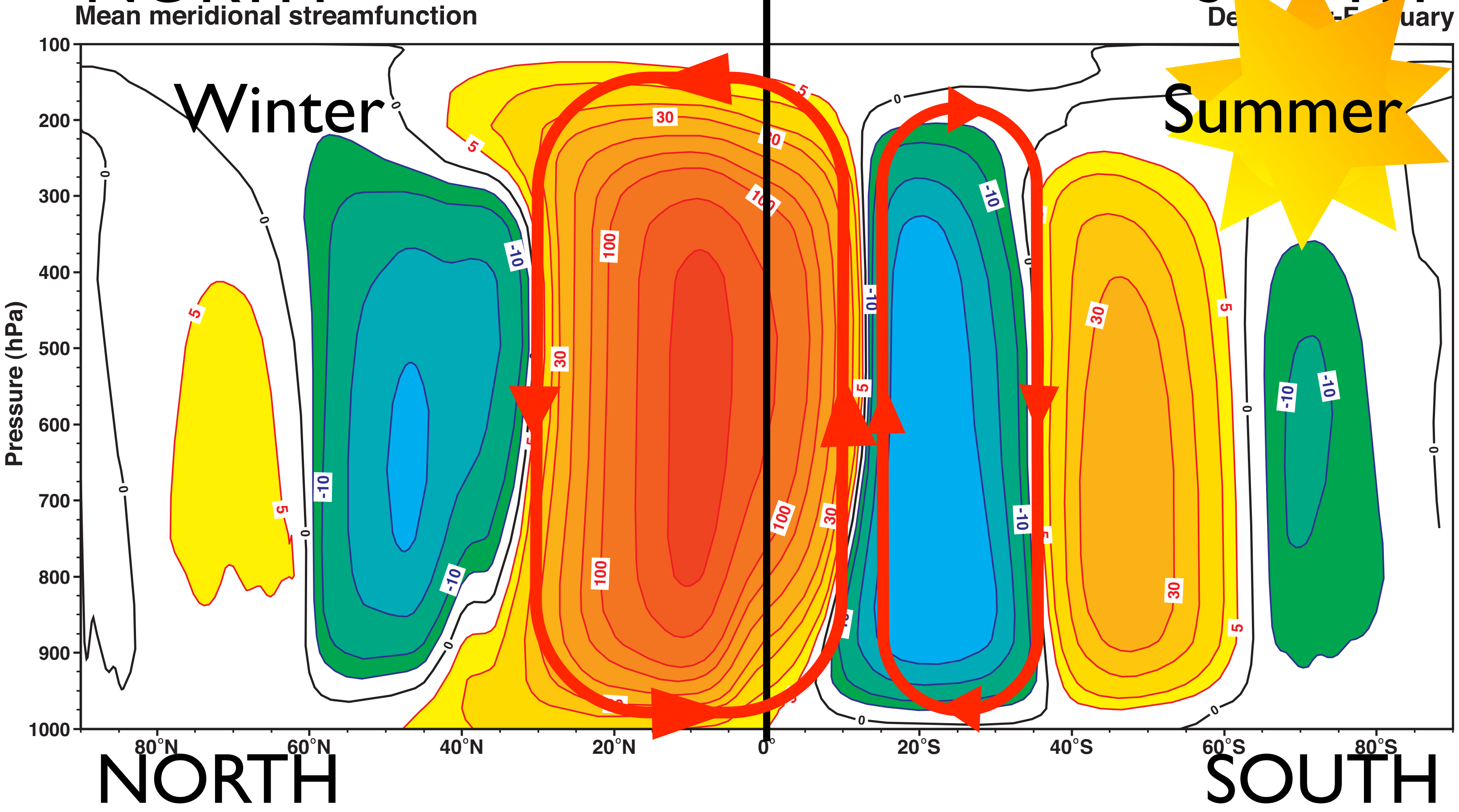
Winter Cell Does the Transport

NH Summer





NH Winter

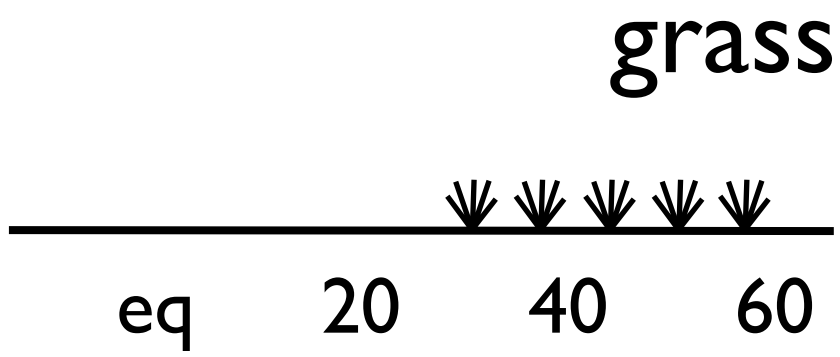


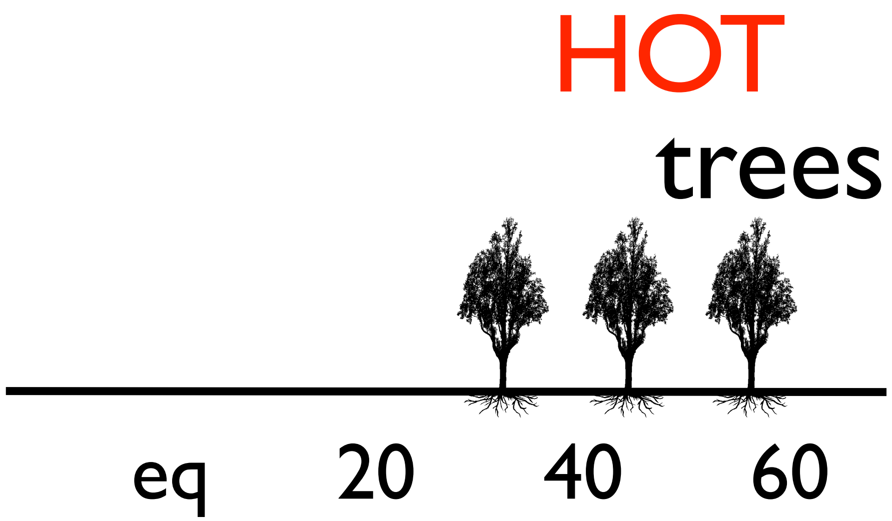
ERA-40 Atlas

Hypothesized Mechanism

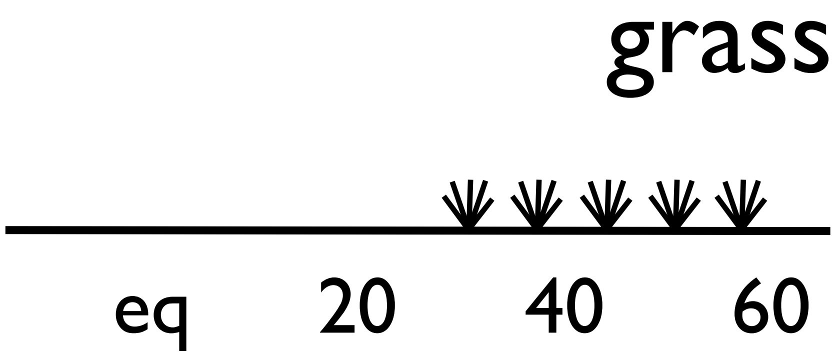
1. dark trees = NH warm

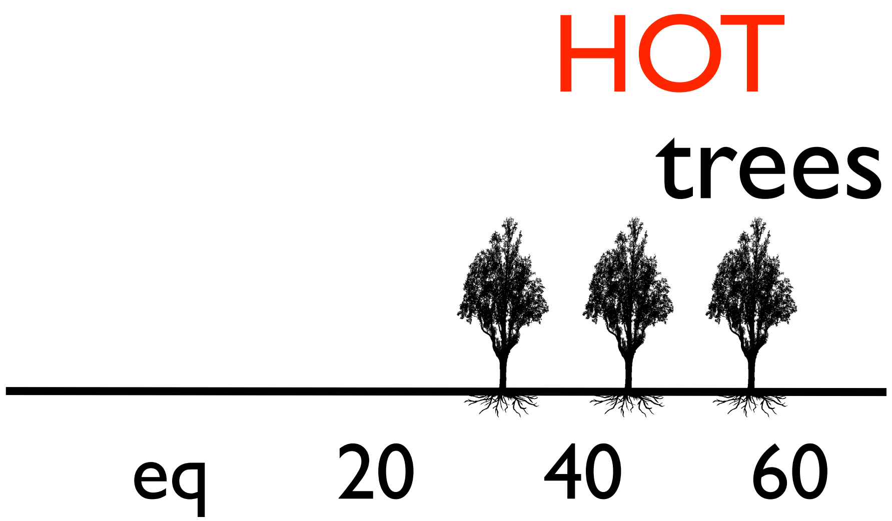
*because the surface is water limited*





Hypothesized Mechanism

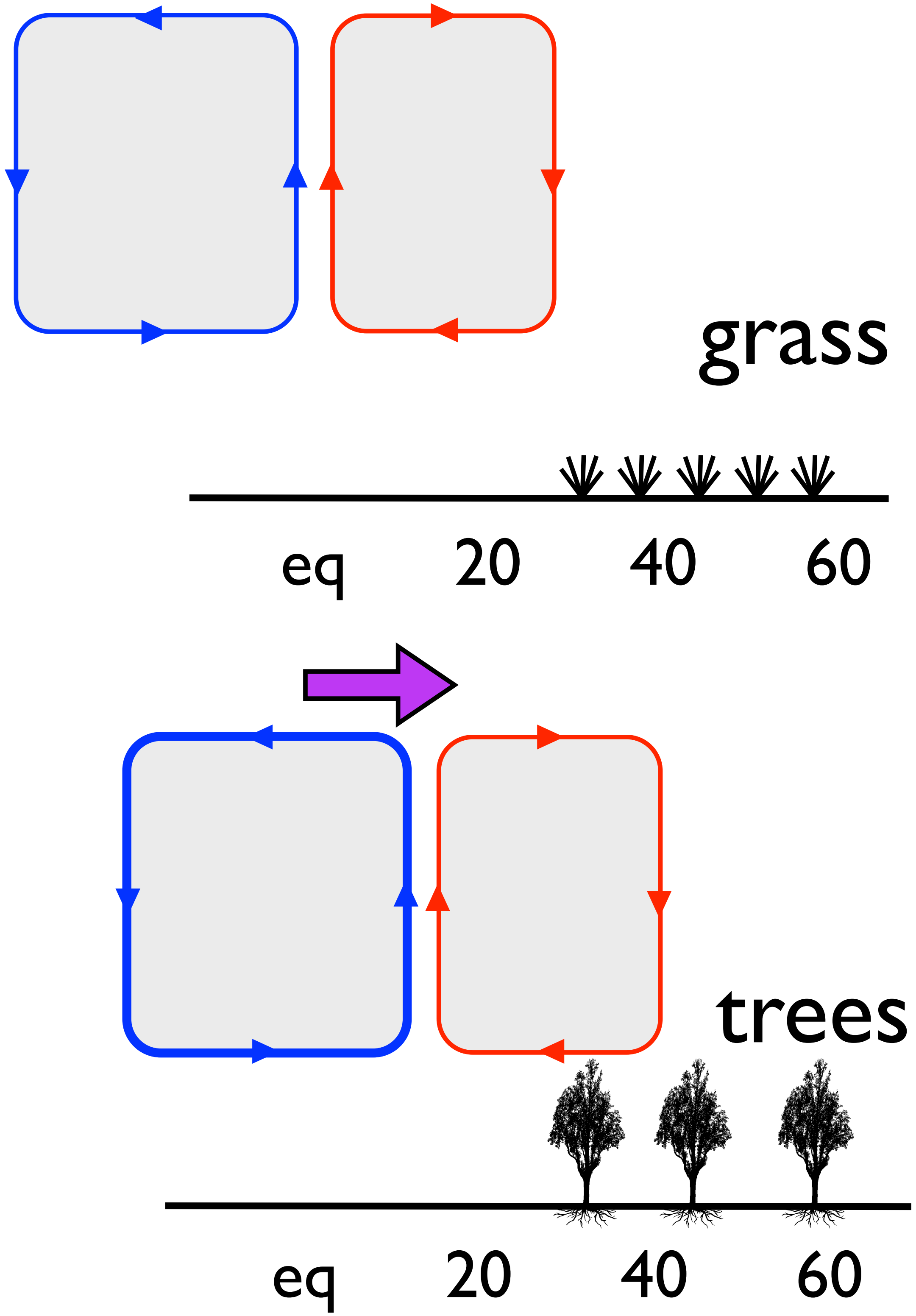




1. dark trees = NH warm

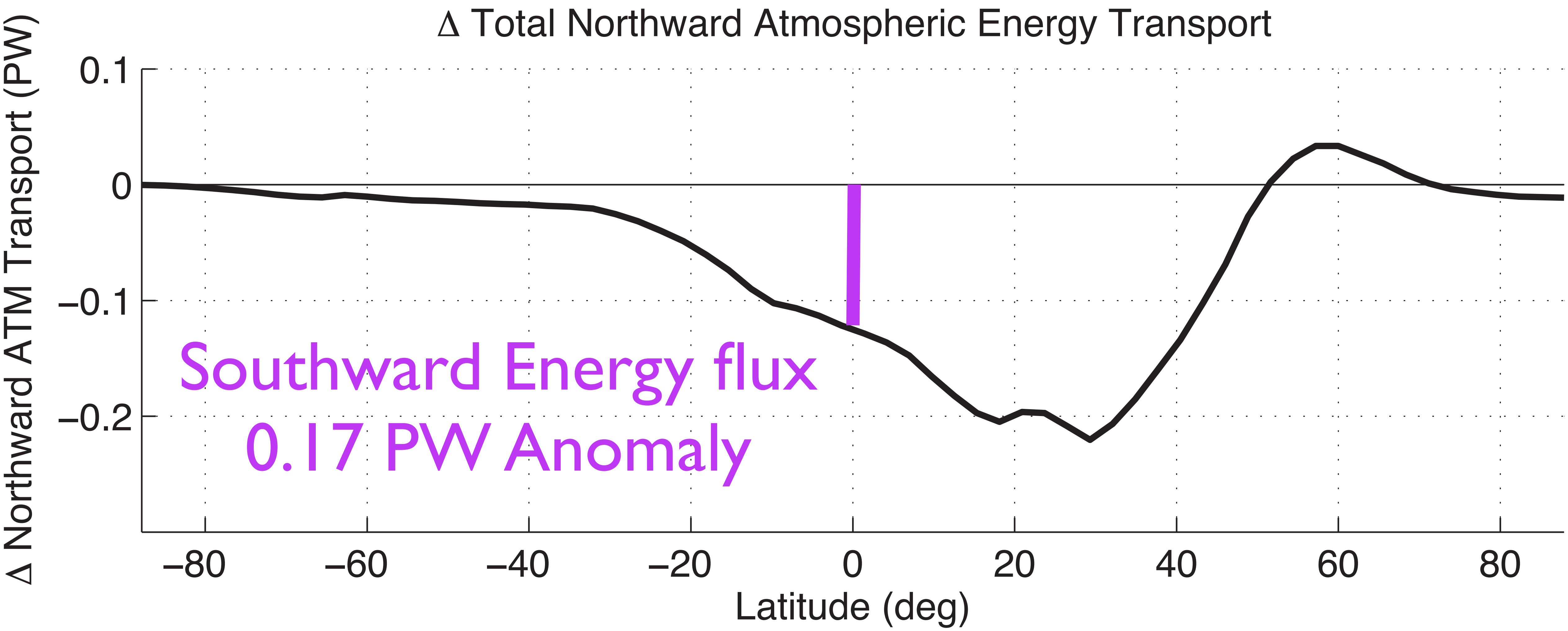
2. Energy gradient (N-S) between the Hemispheres increases

Hypothesized Mechanism



1. dark trees = NH warm
2. Energy gradient (N-S) between the Hemispheres increases
3. Hadley Cell moves north to increase southward heat transport

Circulation shift moves energy Southward

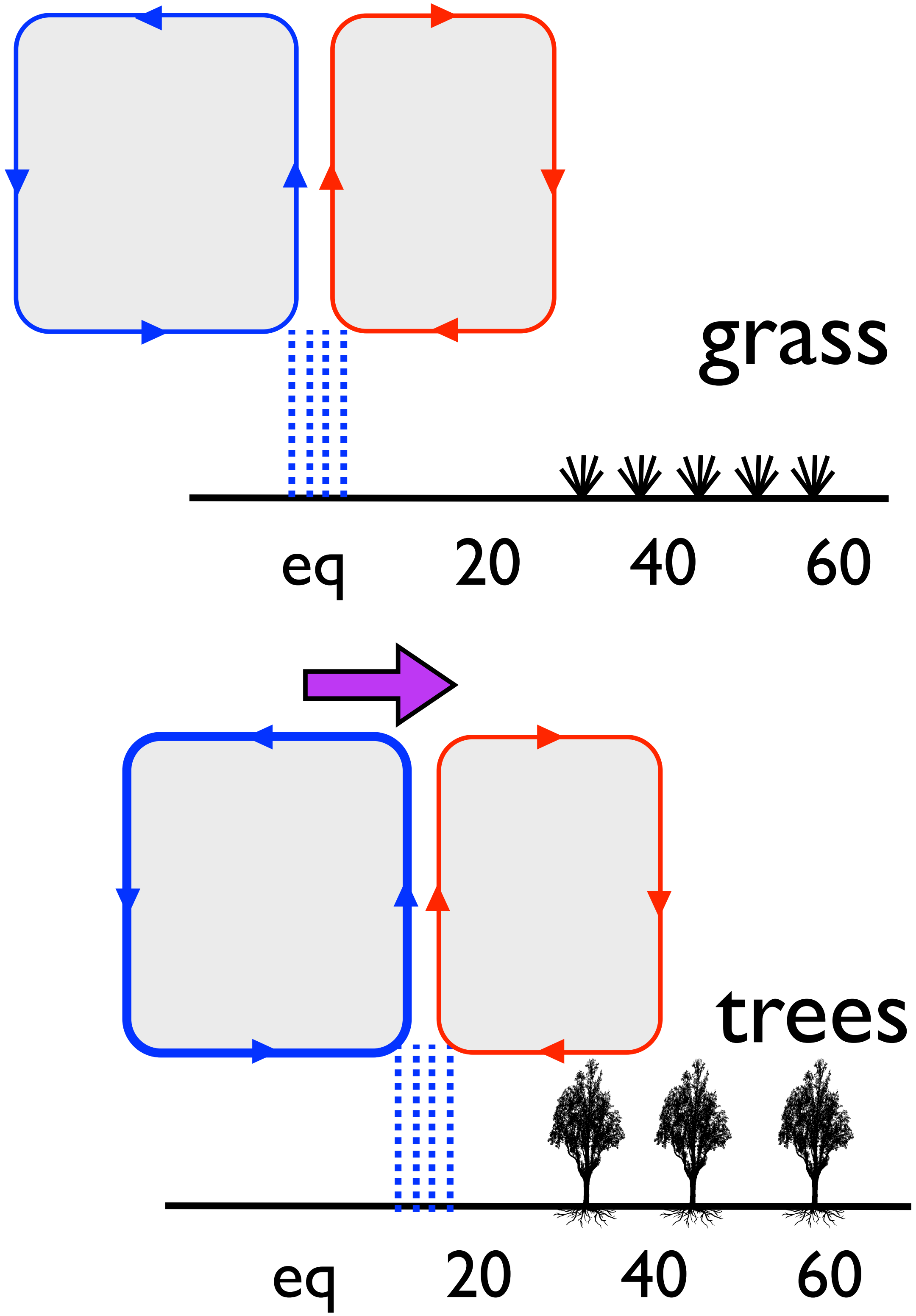


Southward Energy flux
0.17 PW Anomaly

13% change at the Equator

Swann et al., in review

Hypothesized Mechanism



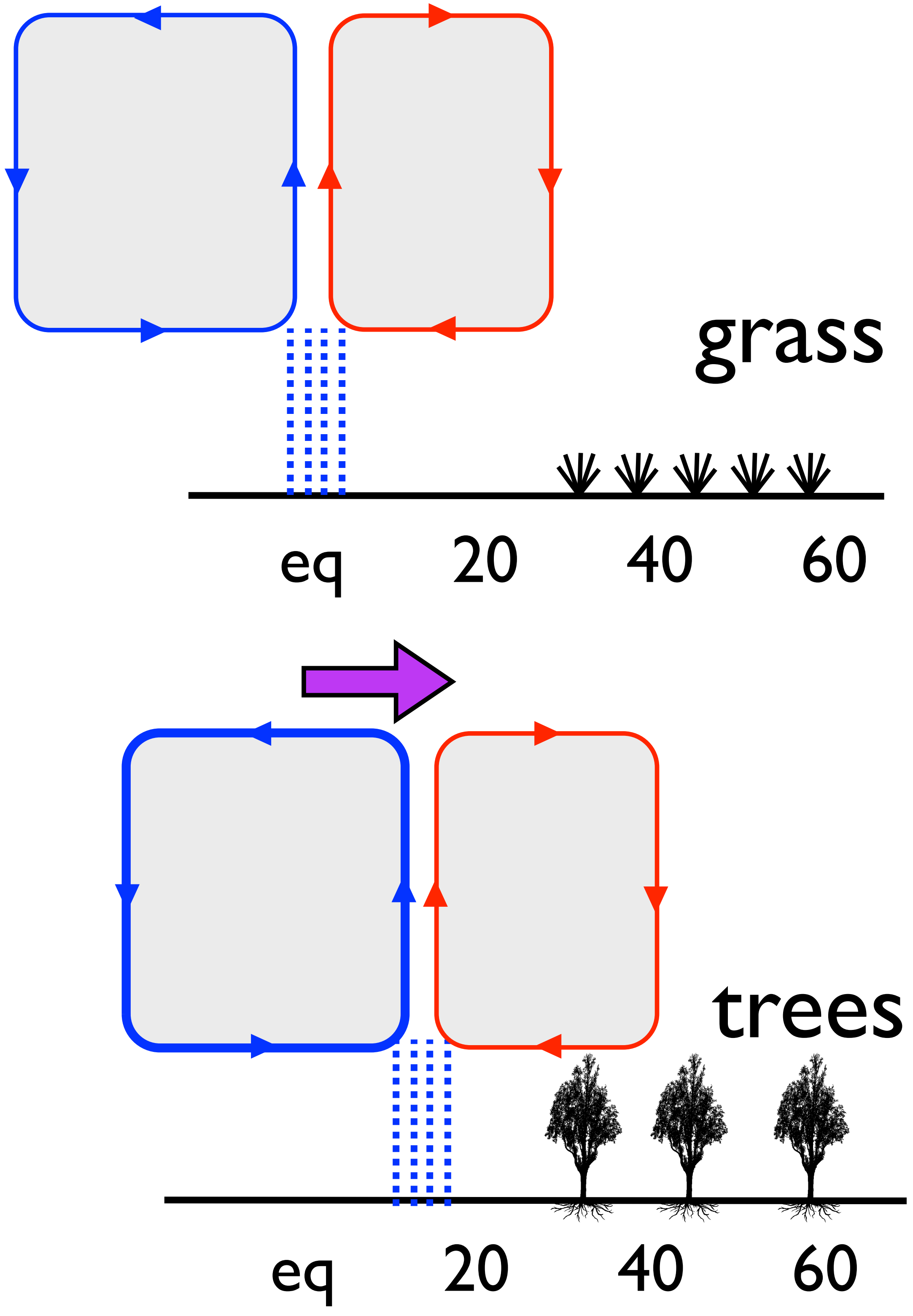
1. dark trees = NH warm

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

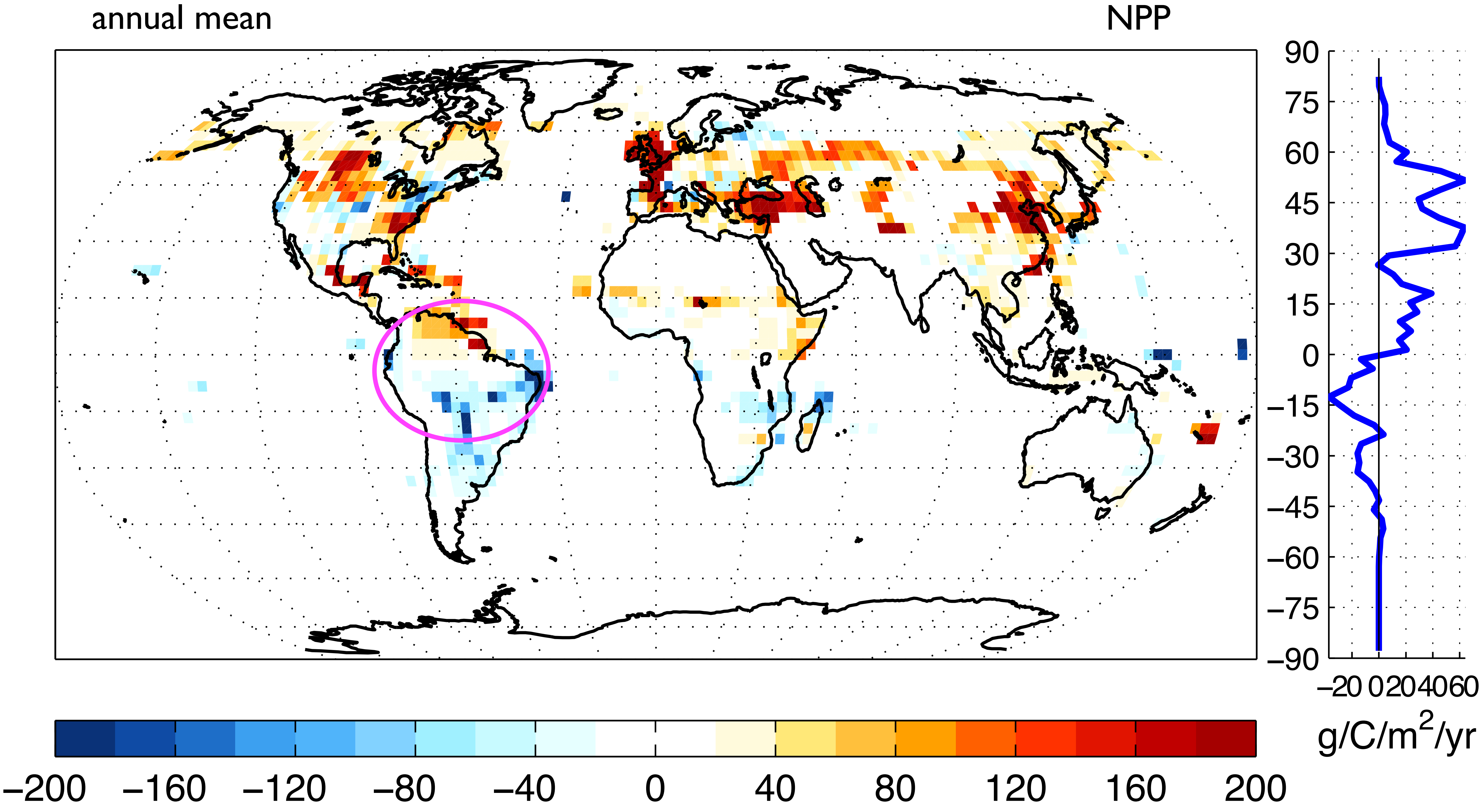
2. Energy gradient (N-S) between the Hemispheres increases

3. Hadley Cell moves north to increase southward heat transport

4. ITCZ shifts North

⇒ Tropical productivity follows changes in precipitation

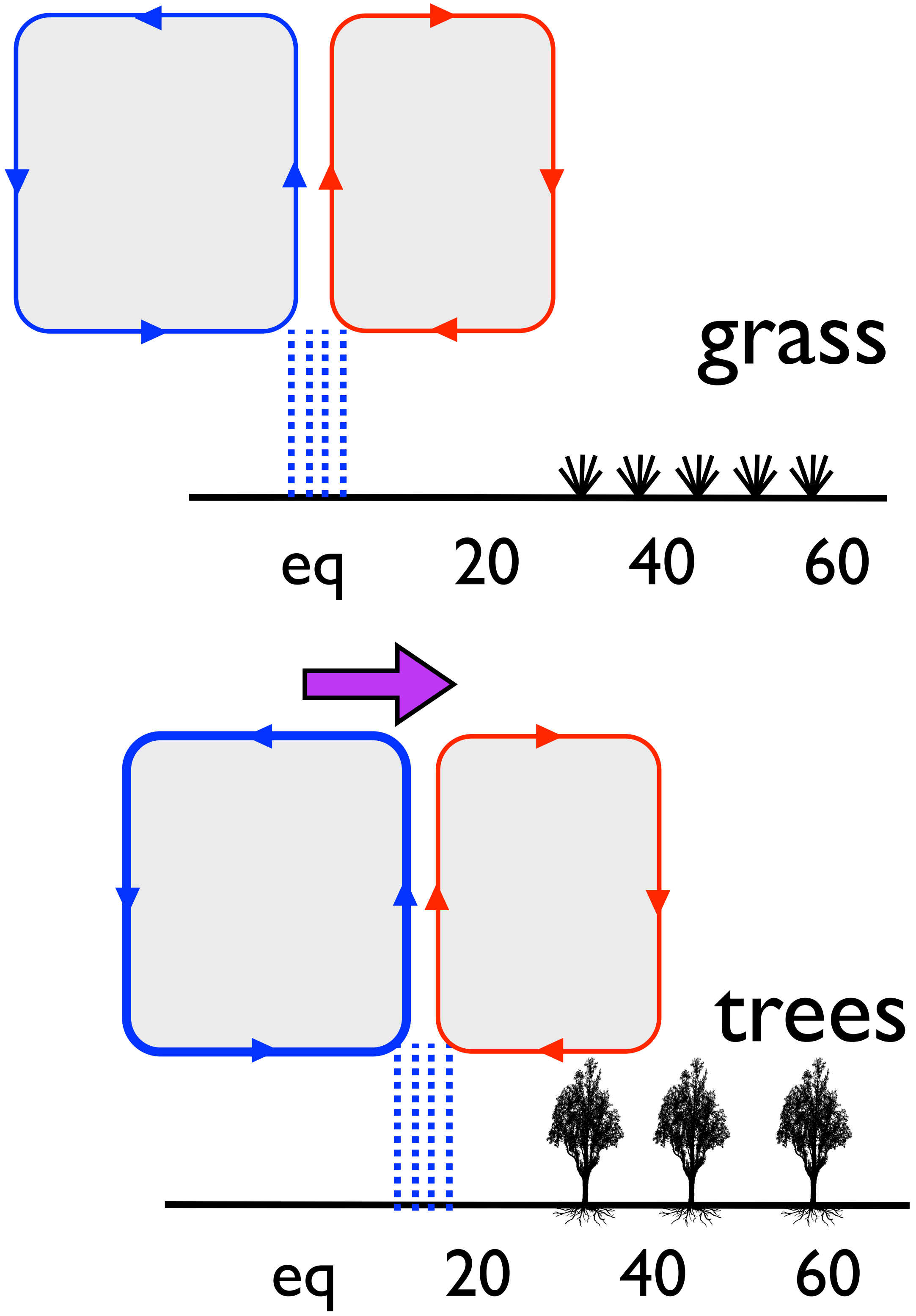
Mid Lat. Afforestation modifies *Tropical* Productivity



gC/m^2/yr

Swann et al., in review

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 Latitude Afforestation

1. Climate response to Forests
2. Tropical Circulation and Precipitation
3. Implications for climate management

NDVI June, 2009

Afforestation Carbon Budget

2 PgC => 1ppm

Change in Carbon Pools:

ΔM Afforested:	270 PgC
ΔM Mid-lat:	-3 PgC
ΔM High-lat:	-28 PgC
ΔM Tropics:	-9 PgC
Total ΔM:	**228 PgC**

Carbon is taken up by switching from grass to trees, 1/2 above ground 1/2 below ground

Climate Response to ΔCarbon

ΔCarbon ~ 228 PgC

2 PgC => 1ppm

ΔCO_2: -114 ppm

Δclimate forcing: -2.23-2.1 Wm^{-2}

Climate Response to ΔCarbon

ΔCarbon ~ 228 PgC

2 PgC => 1ppm

ΔCO_2: -114 ppm → Δclimate forcing: -2.2 Wm^{-2}

assume climate feedback:

	ΔT:
0.5 degrees/Wm^{-2} (2 °C for 2xCO_2)	-1.10 °C
0.75 degrees/Wm^{-2} (3 °C for 2xCO_2)	-1.65 °C
1 degrees/Wm^{-2} (4 °C for 2xCO_2)	-2.20 °C

Climate Response to ΔCarbon

ΔCarbon ~ 228 PgC

2 PgC => 1ppm

ΔCO_2: -114 ppm → Δclimate forcing: -2.2 Wm^{-2}

assume climate feedback:

0.5 degrees/Wm^{-2} (2 °C for $2xCO_2$)

0.75 degrees/Wm^{-2} (3 °C for $2xCO_2$)

1 degrees/Wm^{-2} (4 °C for $2xCO_2$)

ΔT:

-1.10 °C

-1.65 °C

-2.20 °C

Equilibrium Experiment:

if we account for ocean response, the net drawdown of atmospheric CO_2 is only 14%-40% =>~16-46ppm.

Climate Response to ΔCarbon

ΔCarbon ~ 228 PgC

ΔCO

Climate Response from ΔCO_2 ~ -0.2 to -0.7 °C

Climate Response from albedo and transpiration = + 0.3 °C

assu

0.5 degrees/Wm^{-2} (2 °C for $2xCO_2$) ΔT: -1.10 °C

0.75 degrees/Wm^{-2} (3 °C for $2xCO_2$) -1.65 °C

1 de

Afforestation leads to little temperature change, but gradients in temperature can still drive changes in circulation and precipitation

if we account for ocean response, the drawdown of atmospheric CO_2 is only 30Pg/15ppm.

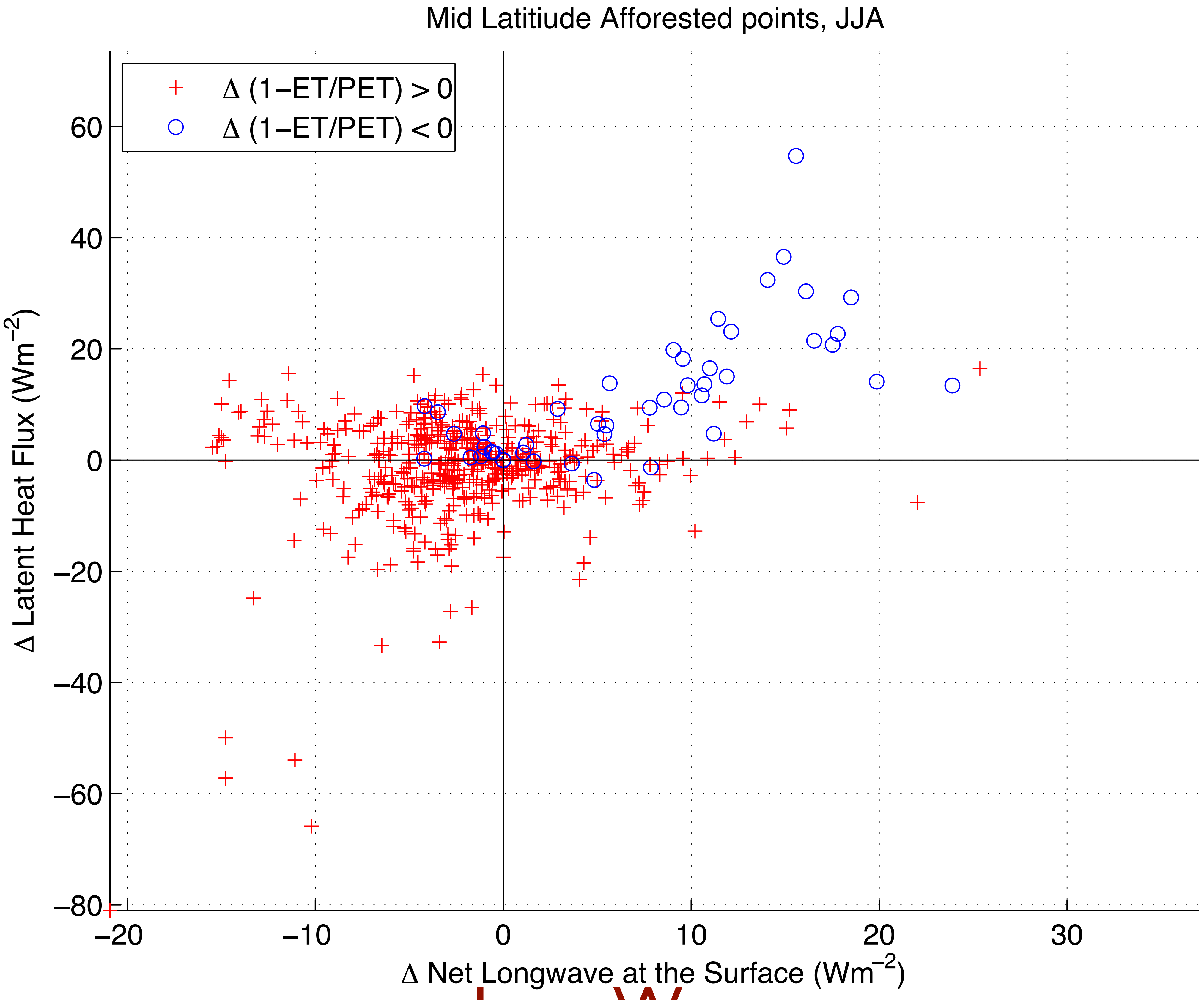
Mid Latitude Afforestation

1. Climate response to mid latitude Afforestation
    - Soil moisture status controls climate response (dry = hot)
2. Tropical Circulation and Precipitation
    - Circulation shifts northward to transport more energy to the south
3. Implications for Future Climate
    - Circulation could still change despite global ΔT

NDVI June, 2009

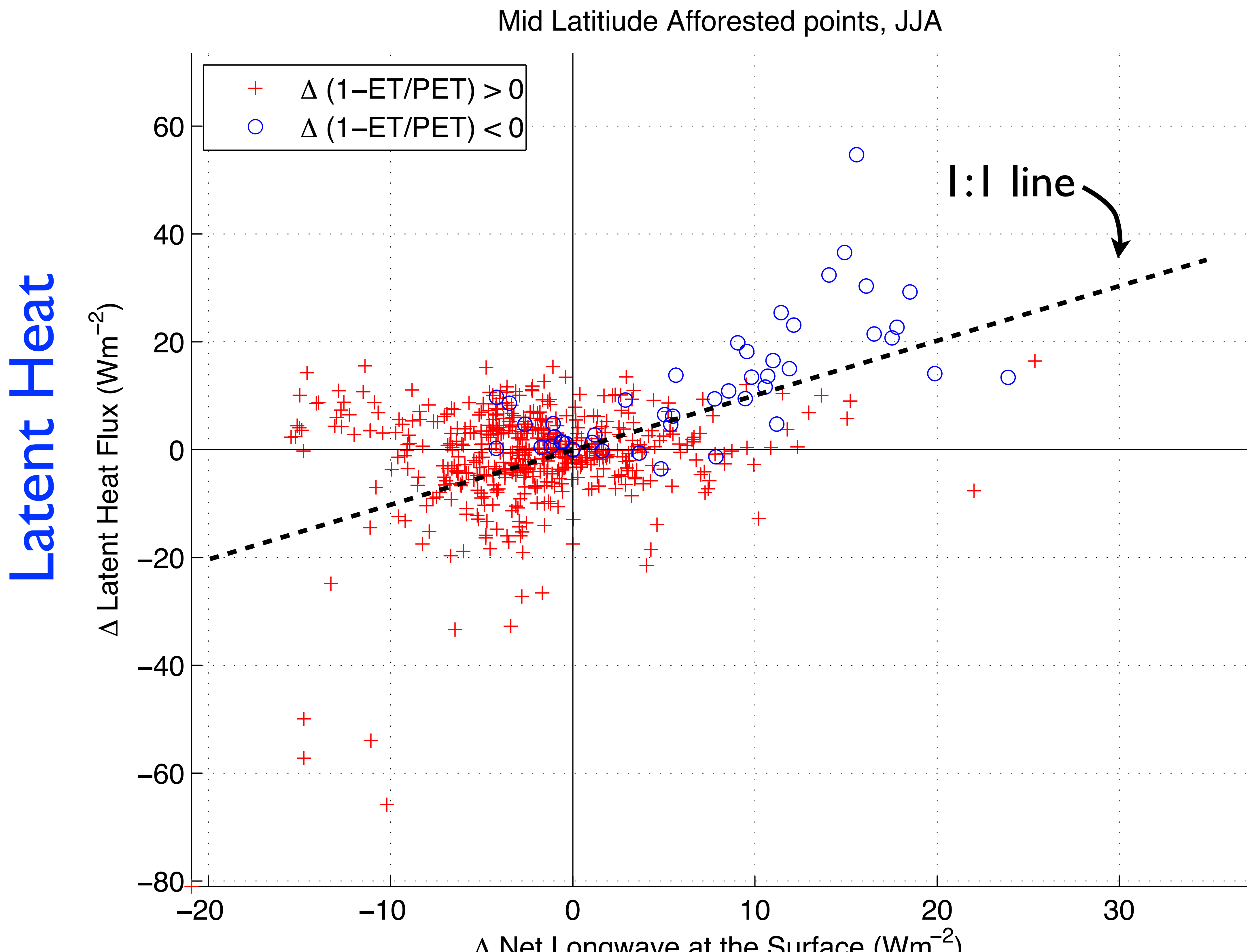
Latent Heat fluxes occur where water is not limited

Latent Heat



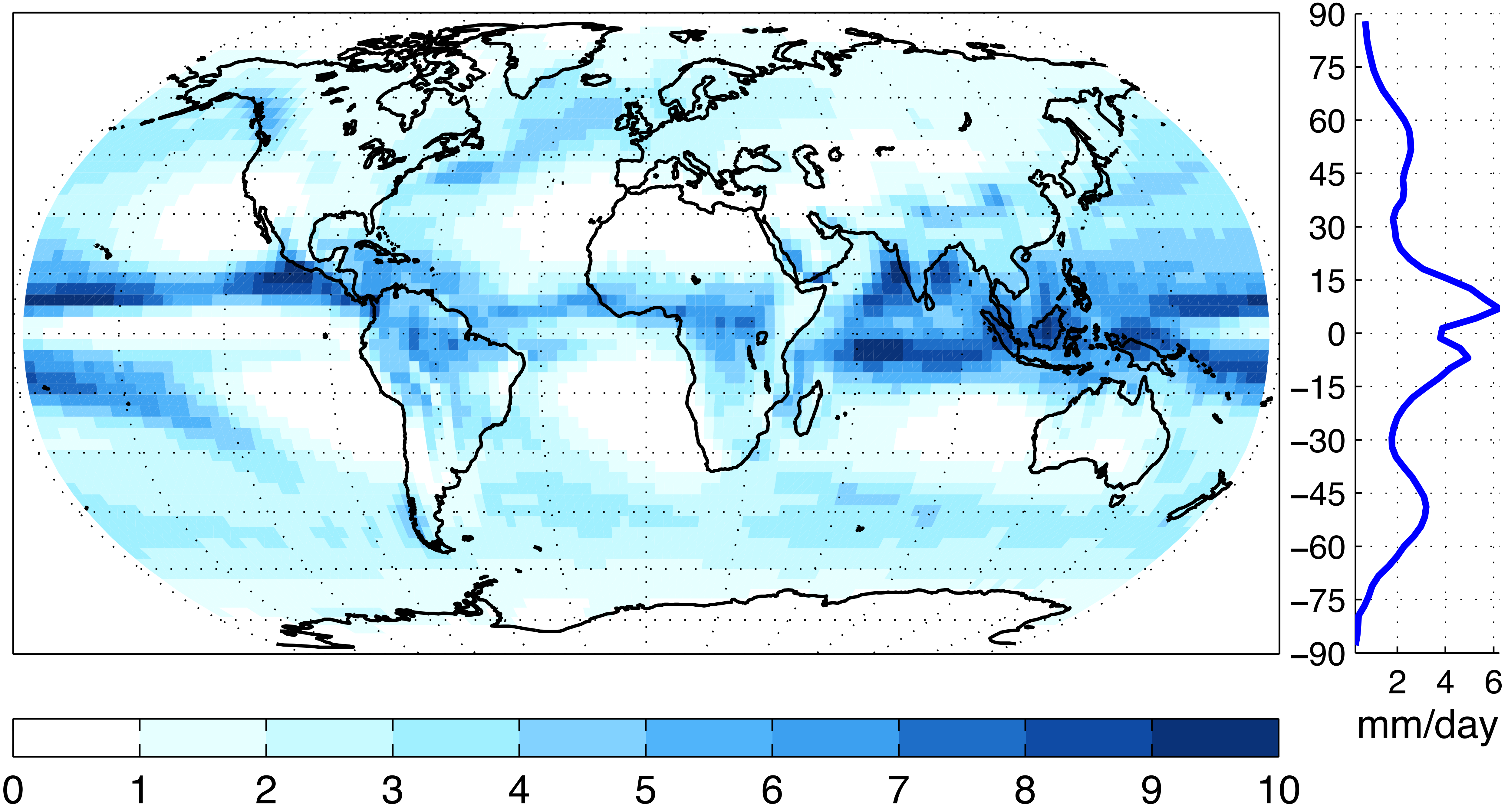
Long Wave

Latent Heat fluxes occur where water is not limited



Long Wave

Annual Mean Precipitation



mm/day