An Improved Plant Nitrogen Cycle in the Community Land Model

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Motivation

- The role of nutrient availability in regulating net ecosystem production and ecosystem C use efficiency
- Accurate predictions of the land C sink and nutrient constraints captured by CLM
- Plant NPP allocation for N acquisition: up to 20% of NPP to both symbiotic and free-living microbes at the root surface to increase their access to N (Brzostek et al., 2015; Hobbie, 2006)
- BUT, CLM assumes that N is acquired at no C cost to plants!

Scientific Questions

1) How much N is taken up and what is the global distribution?

2) How does N acquisition from soil (directly through roots or from mycorrhizal symbionts), senescing leaves, and biological N fixation vary across seasonal transitions?

3) How does the C cost of N acquisition vary spatially and temporally?

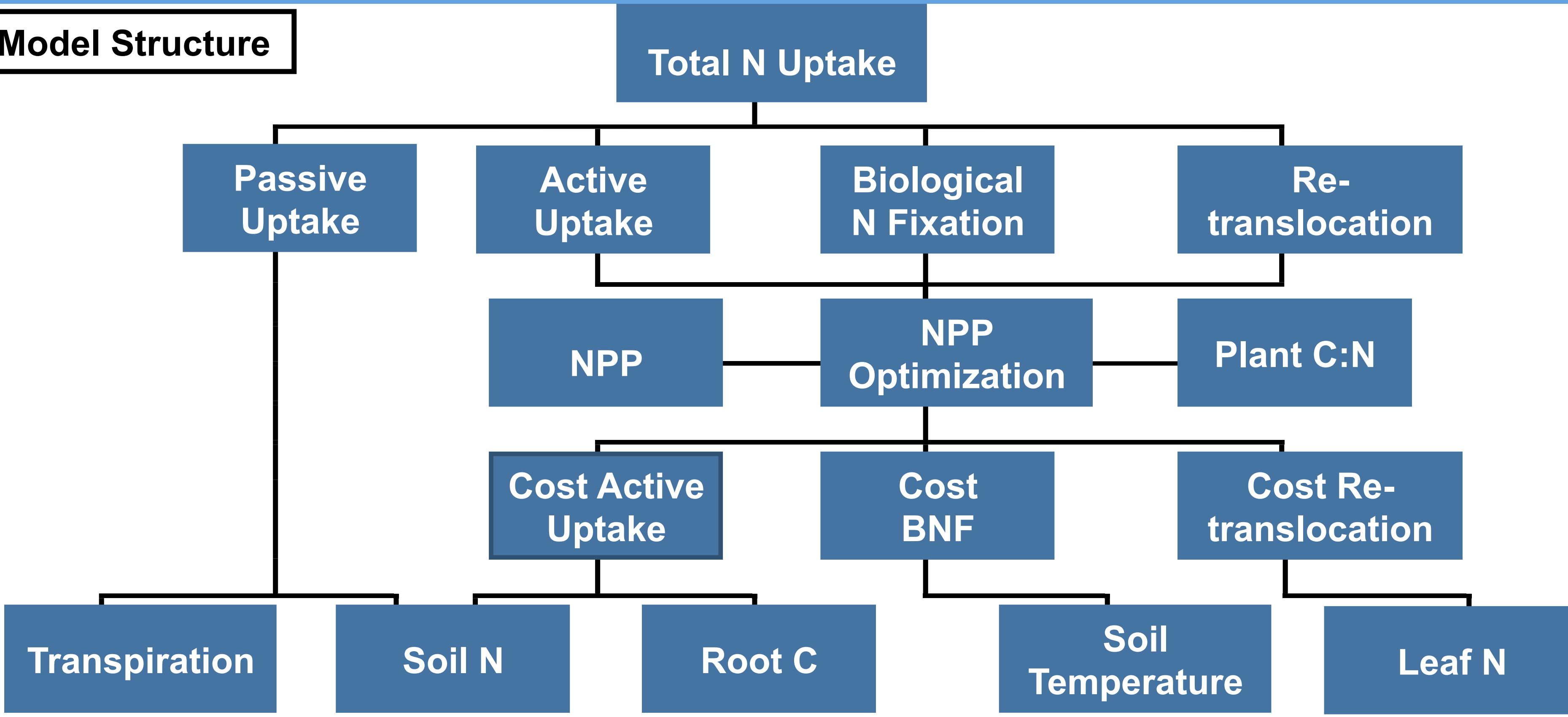
4) How sensitive is the land C sink to a dynamic prediction of the C cost of N acquisition?

Methods

- The Fixation and Uptake of Nitrogen (FUN) model (Fisher et al., 2010; Brzostek et al., 2014) explicitly includes the C cost for N acquisition.
- FUN is grounded in optimal allocation theory whereby plants optimize the allocation of C used to acquire N from the soil (directly through roots or from mycorrhizal symbionts), senescing leaves, and biological N fixation.
  - Different C costs with different N returns are associated with each pathway, and those costs dynamically vary.
- FUN has been coupled into the Joint U.K. Land Environment Simulator (JULES) and to Noah-MP.

Methods

Model Structure

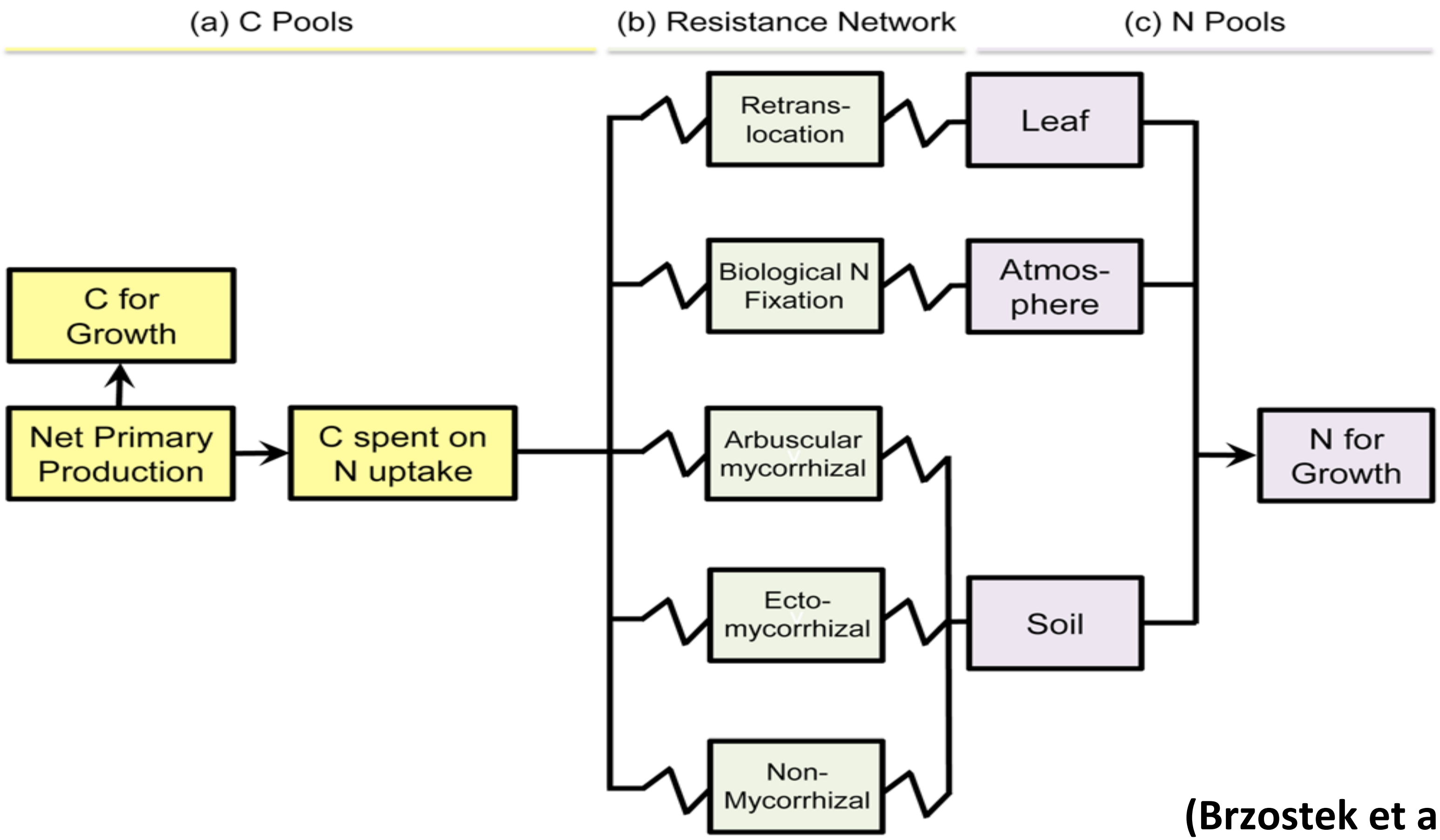


(Fisher et al., 2010)

CLM provides FUN:

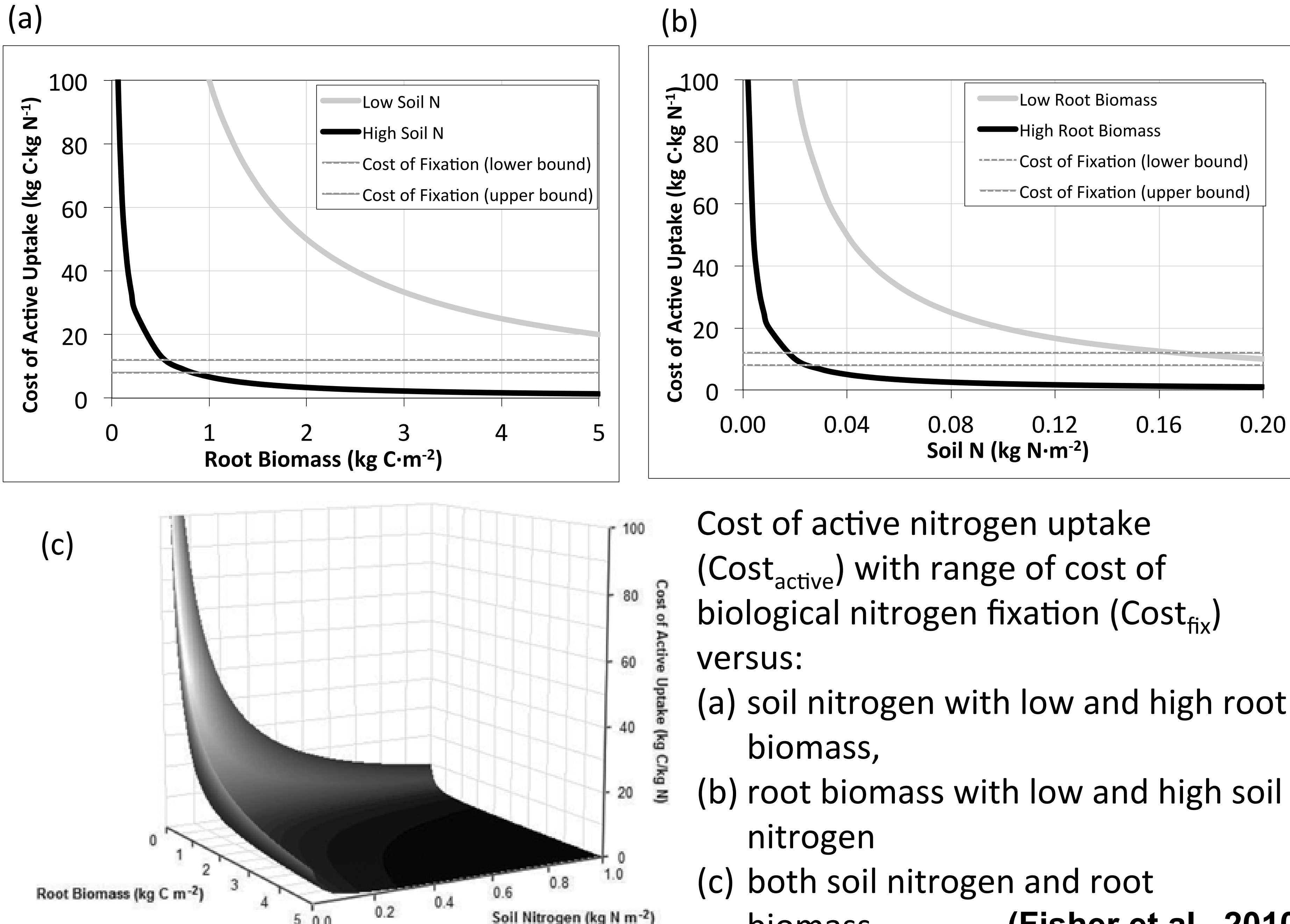
1) Available C 2) Soil mineral N 3) Root Biomass
4) Leaf N 5) Plant C:N ratio 6) Soil layer depth
7) Soil temperature 8) Transpiration

Methods



(Brzostek et al., 2014)

FUN optimally allocates C to growth and to N uptake as a function of the N needed to support NPP and the integrated C costs across all of the pathways in the resistor network.

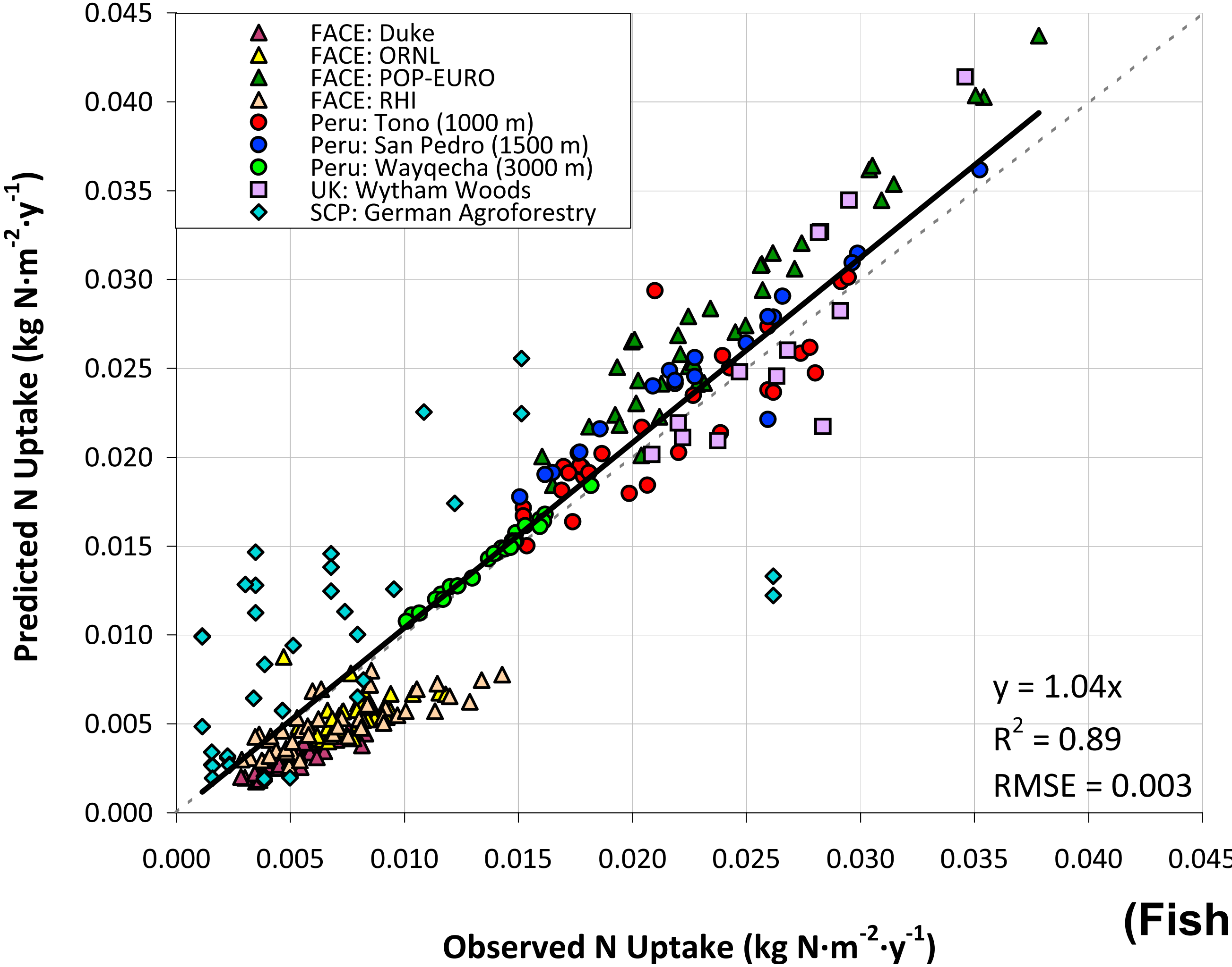


Cost of active nitrogen uptake ($Cost_{active}$) with range of cost of biological nitrogen fixation ($Cost_{fix}$) versus:

(a) soil nitrogen with low and high root biomass,

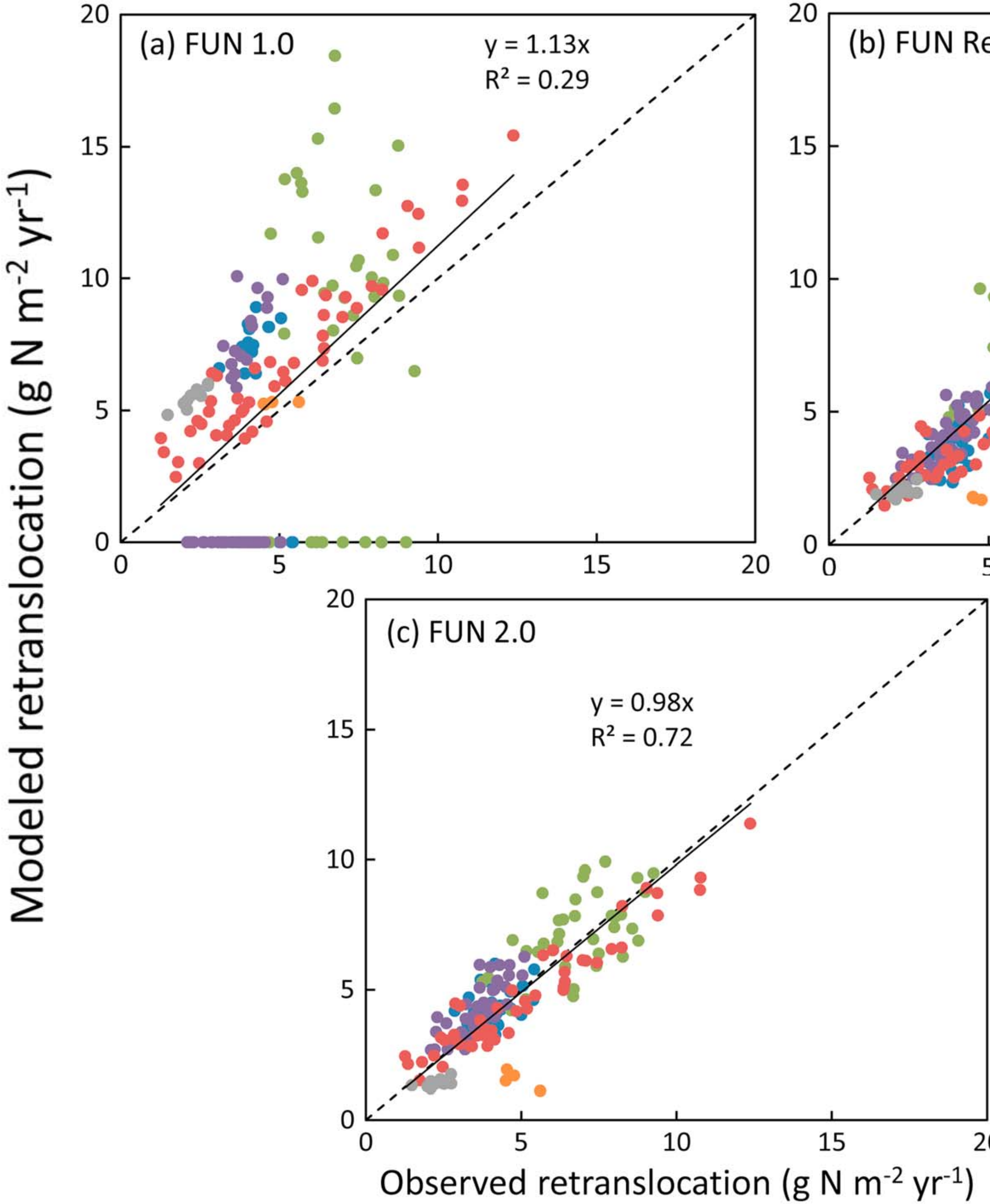
(b) root biomass with low and high soil nitrogen

(c) both soil nitrogen and root biomass. **(Fisher et al., 2010)**



(Fisher et al., 2010)

Scatterplot of observed versus predicted N uptake FUN from the Free Air CO_2 Enrichment (FACE) experiments (Finzi *et al*., 2007), three agroecosystem sites from the Special Collaborative Project 179 (SCP179) international workshop data set (McVoy *et al*., 1995), three tropical montane sites in the Peruvian Andes (Tan, 2008), and an ancient woodland in the United Kingdom (Tan, 2008).



Stepwise improvement in model predictions of retranslocation that vary in mycorrhizal association from
(a) FUN 1.0 to
(b) FUN Resistors
(c) FUN 2.0.
The dashed line indicates the 1:1 relationship.

(Brzostek et al., 2014)

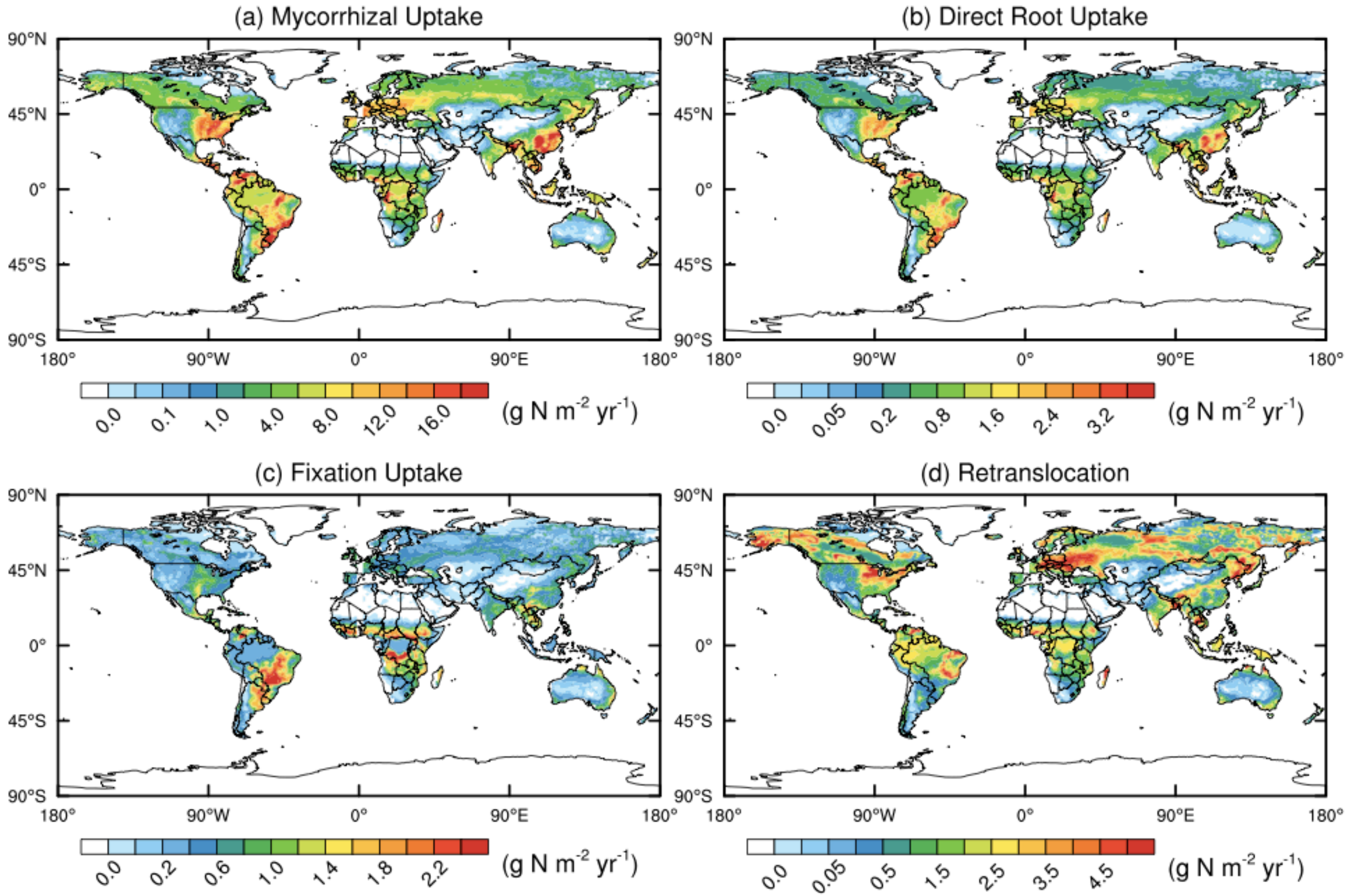
CLM-FUN Coupling

- FUN was coupled with CLM4.5-BGC:

CNEcosystemDynMod.F90	CNAllocationMod.F90
CNFUNMod.F90	CNNUptakeFixationMod.F90
CNPhenologyMod.F90	CNNStateUpdate1Mod.F90
CNDecompMod.F90	CNSummaryMod.F90

Results

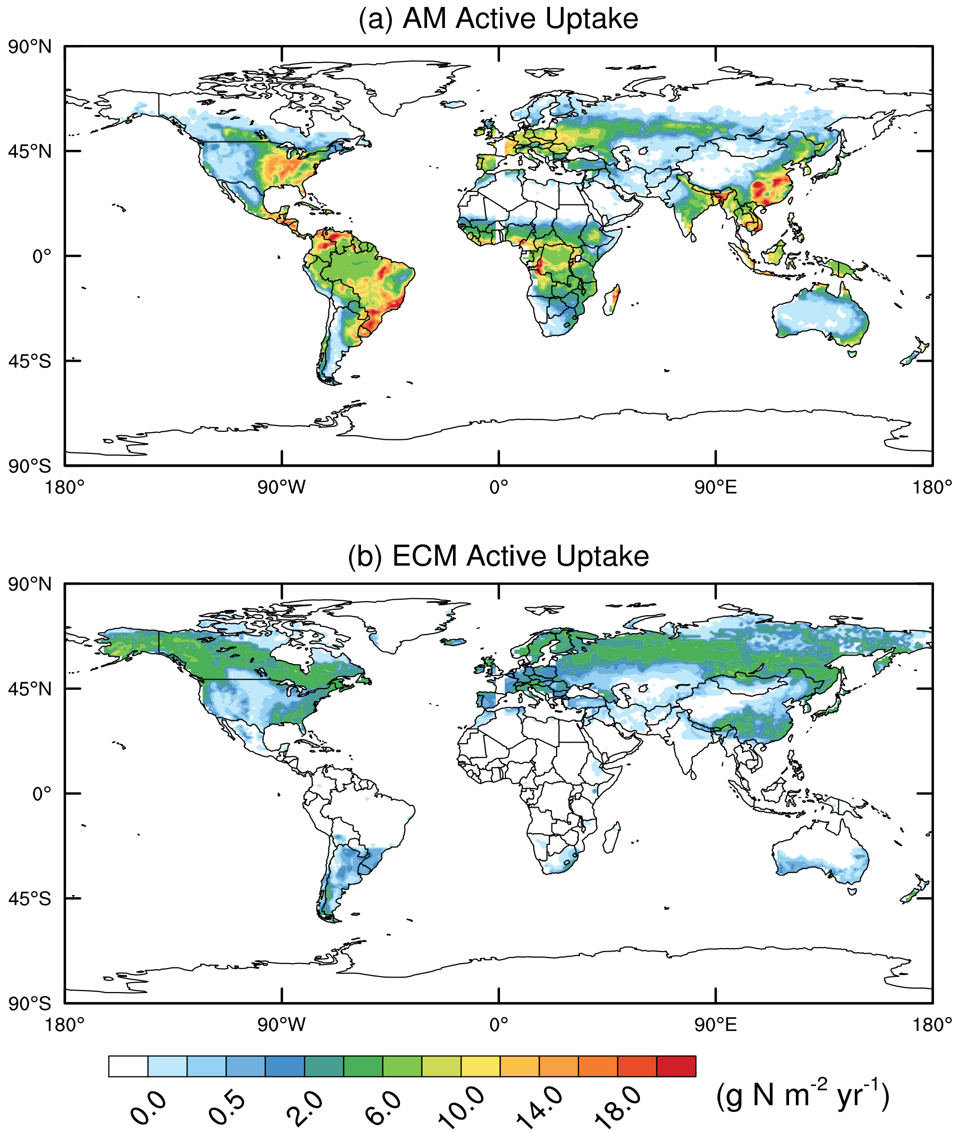
How much N is taken up and what is the global distribution?



- The global total uptake is 1.2 Pg N yr^{-1}. Mycorrhizal uptake is the largest uptake pathway, followed by retranslocation, direct root uptake, and fixation.

Results

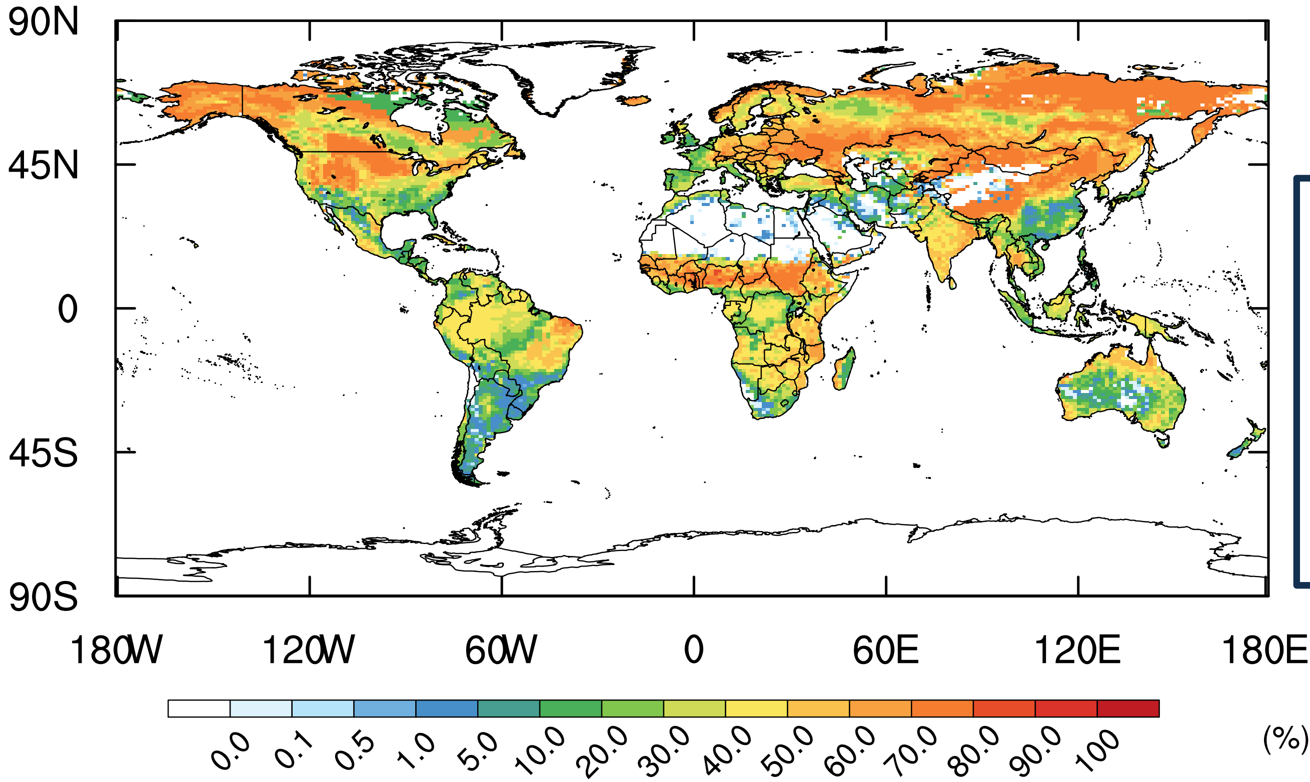
How much N is taken up and what is the global distribution?



- AM fungal uptake exceeds ECM fungal uptake globally.
- The AM and ECM uptake amounts are 80% and 20% of the total mycorrhizal uptake amount, respectively.

Results

How much N is taken up and what is the global distribution?



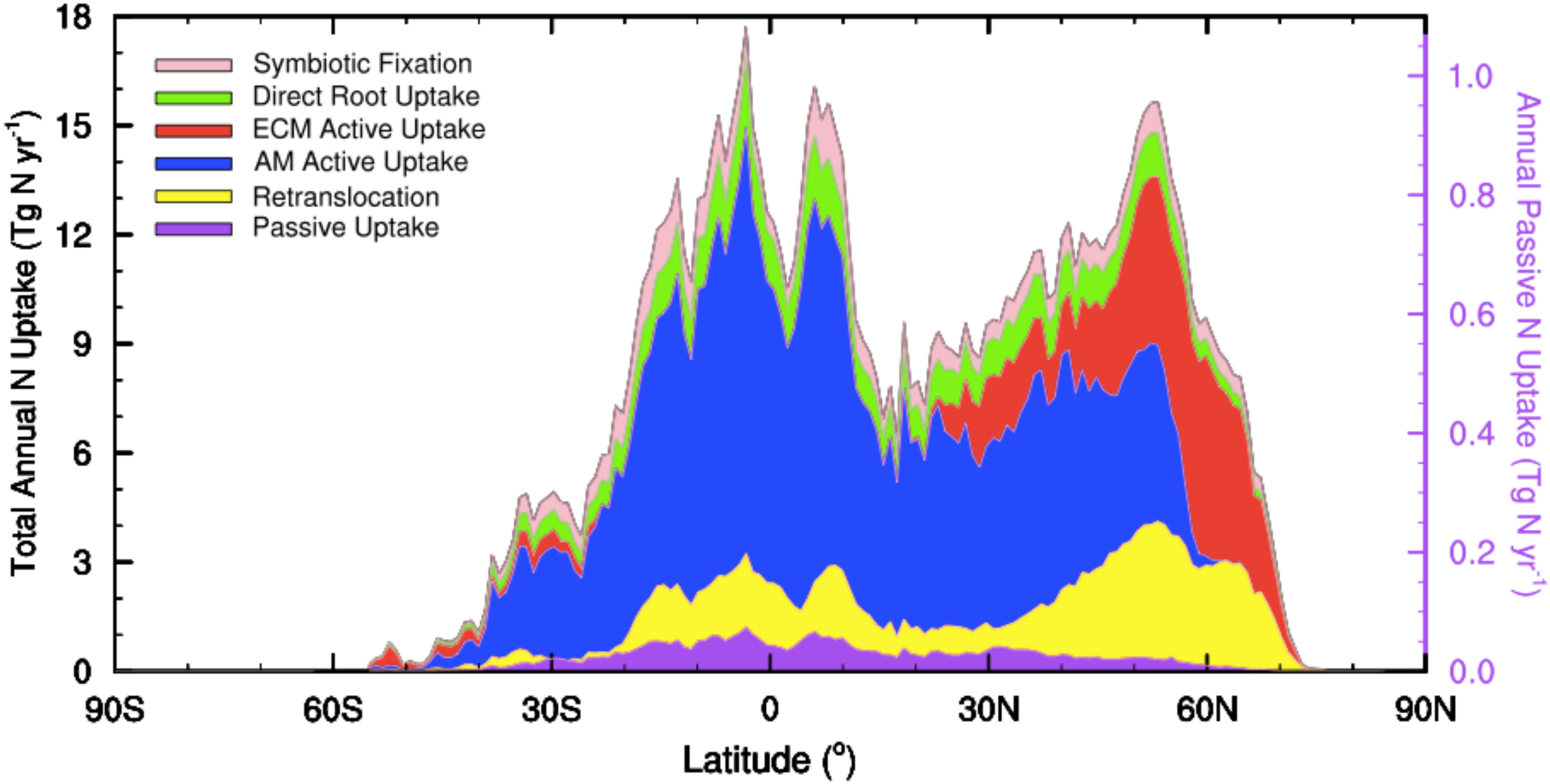
$$R_{Nretrans} = \frac{N_{retrans}}{N_{dead,leafn}}$$

where $N_{retrans}$ is the total retranslocated N, and $N_{dead,leafn}$ is the amount of N in dead leaves prior to senescence.

- CLM4.5-FUN2.0 produces dynamically varying retranslocation amounts (previously CLM gave a constant 50% retranslocation across all pixels).
- The global mean retranslocation ratio is 44%.

Results

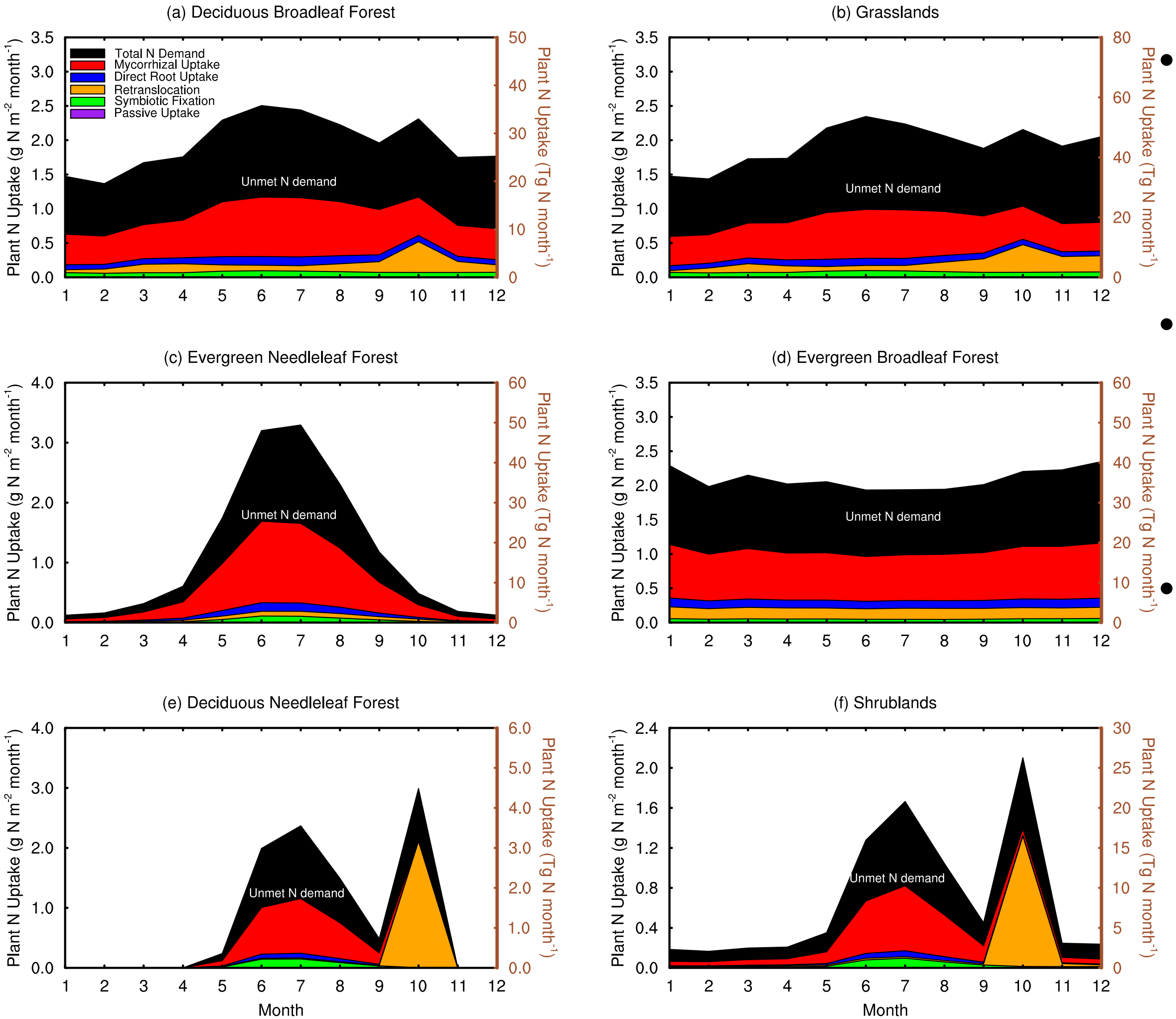
How much N is taken up and what is the global distribution?



- The high N uptake regions are tropics and mid-latitudes in the north hemisphere.
- The fractions of the mycorrhizal uptake, direct root uptake, retranslocation, fixation, and passive uptake amounts are 63.8%, 9.6%, 19.3%, 7.2%, and 0.1% of the total N uptake amount, respectively.

Results

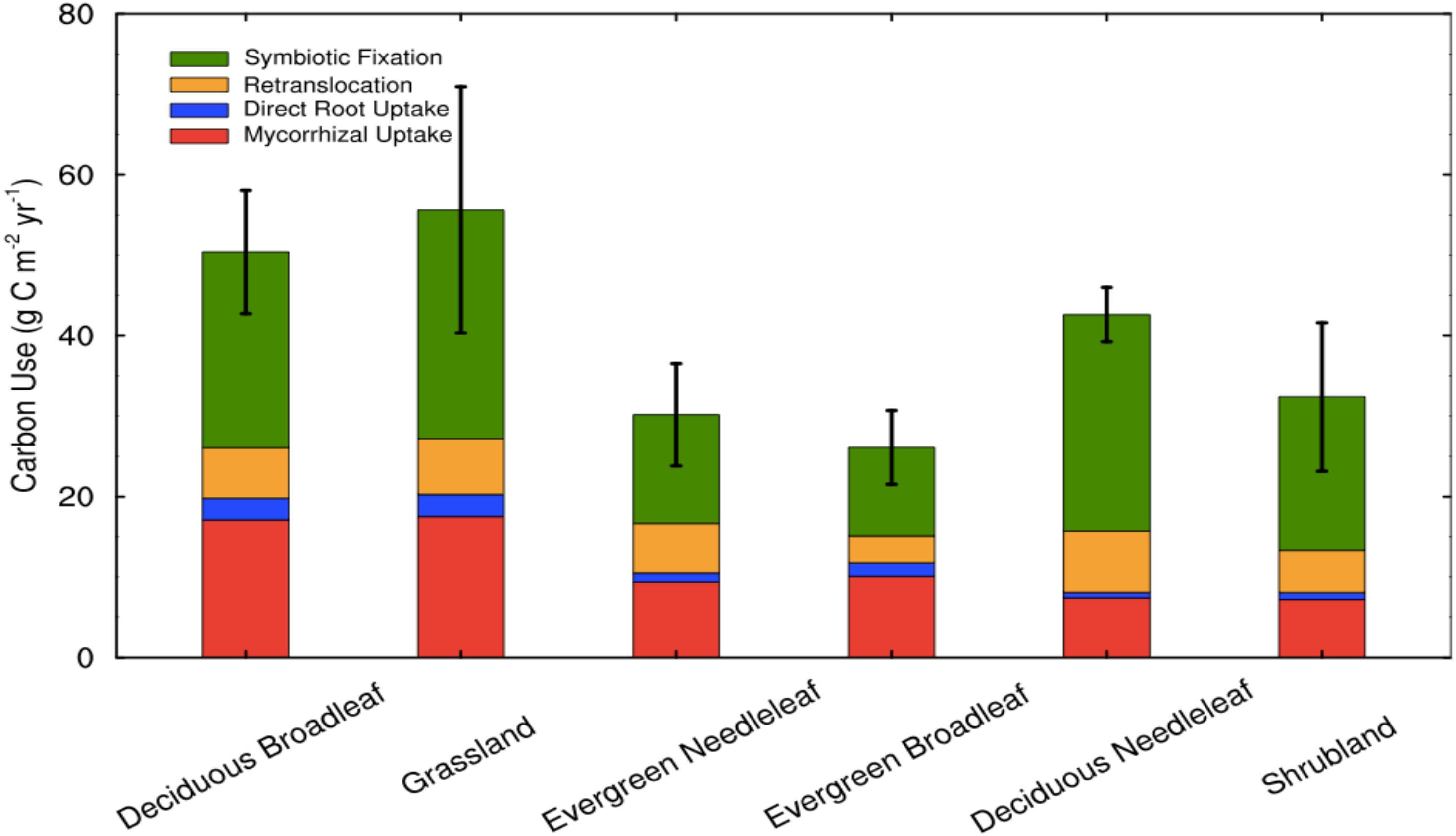
How does N acquisition from leaves, soil and air vary across seasonal transitions?



- Total N uptake does not meet total N demand for most of the year in all biomes.
- Evergreen broadleaf forest has the largest N uptake rate, which is 12.6 g N m^{-2} y^{-1}.
- Deciduous needleleaf forest has the most met demand.

Results

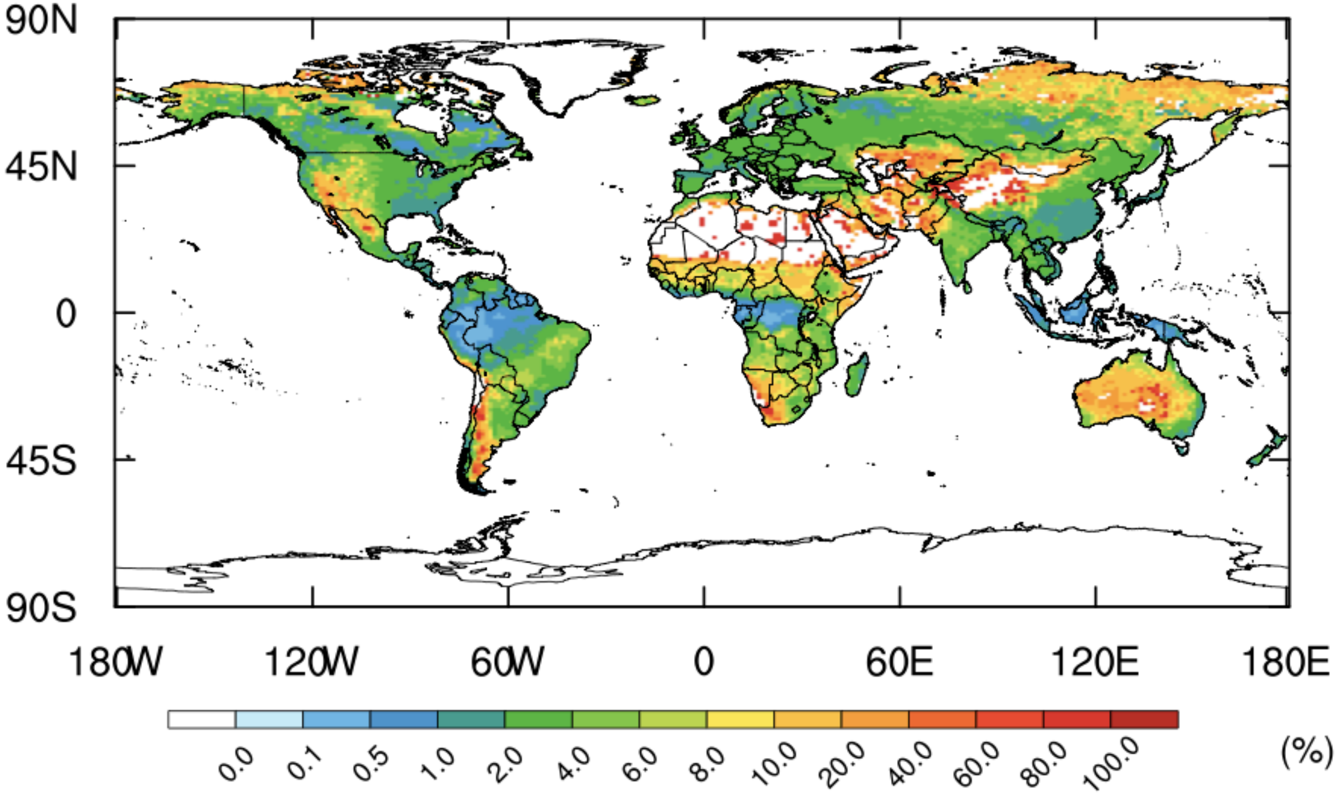
How does the C cost of acquisition vary spatially and temporally?



- C spent on N acquisition is 5.1 Pg C yr^{-1} globally.
- The mycorrhizal and fixation used C amounts are 1.6 Pg C yr^{-1} and 2.5 Pg C yr^{-1}, respectively; they are 31% and 50% of the global total used C amount, respectively.
- Grassland spends the most C on N acquisition per unit area; evergreen broadleaf forest spends the least C on N acquisition per unit area.

Results

How does the C cost of acquisition vary spatially and temporally?



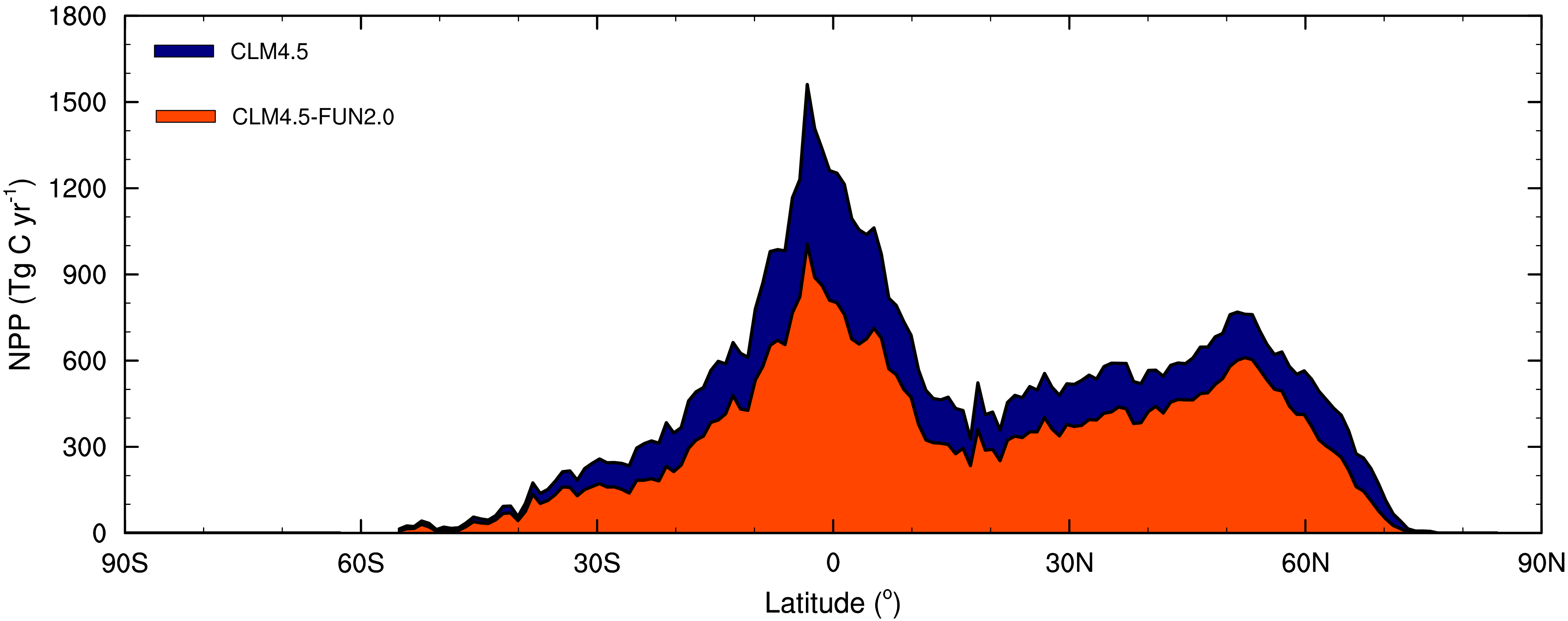
$$C_{use.ratio} = \frac{C_{use,\ acquisition}}{C_{available}}$$

where $C_{use,\ acquisition}$ is the total C used by the four N uptake pathways, and $C_{available}$ is the difference between GPP and maintenance respiration.

- Tropical forests have the lowest C use ratio.
- High-latitude shrubland and arid and semi-arid regions have the highest C use ratio.

Results

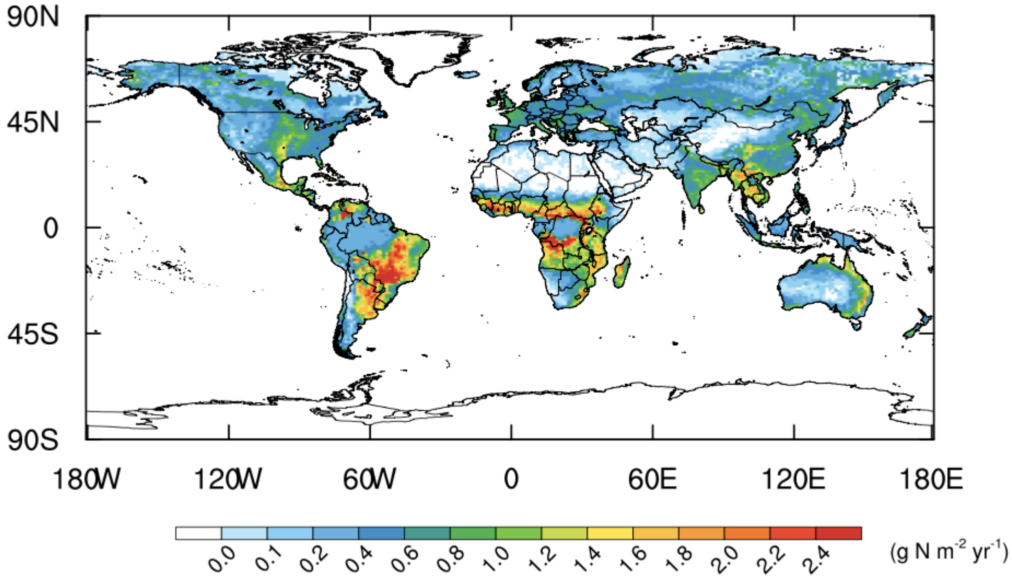
How sensitive is the land C sink to a dynamic prediction of the C cost of N acquisition?



- Global total NPP is down-regulated by 30%.
- The reduced NPP amount peaks at 2°S, and decreases towards the Poles.
- CLM4.5-FUN2.0 results in NPP decrease in all biomes.

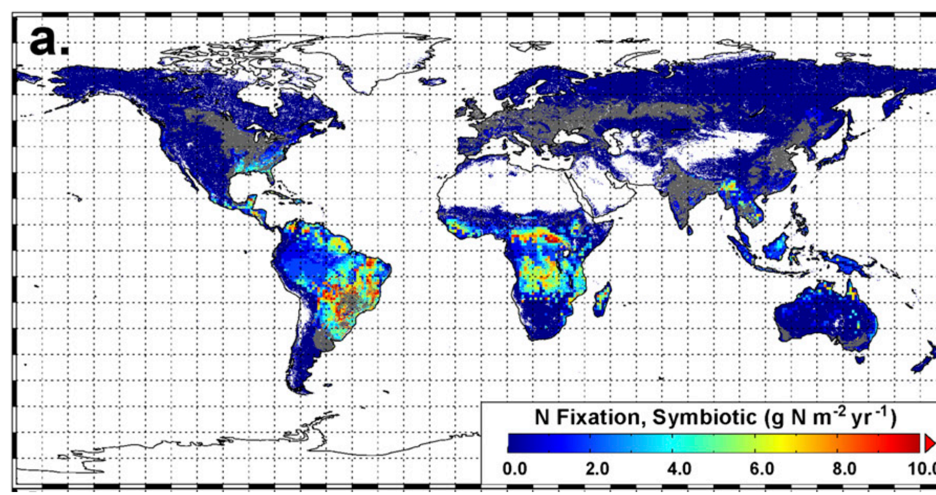
Discussion

CLM4.5-FUN2.0 simulated symbiotic BNF



- CLM4.5-FUN2.0 predicted symbiotic BNF is 83.9 Tg N yr^{-1} and 0.62 g N m^{-2} yr^{-1}.

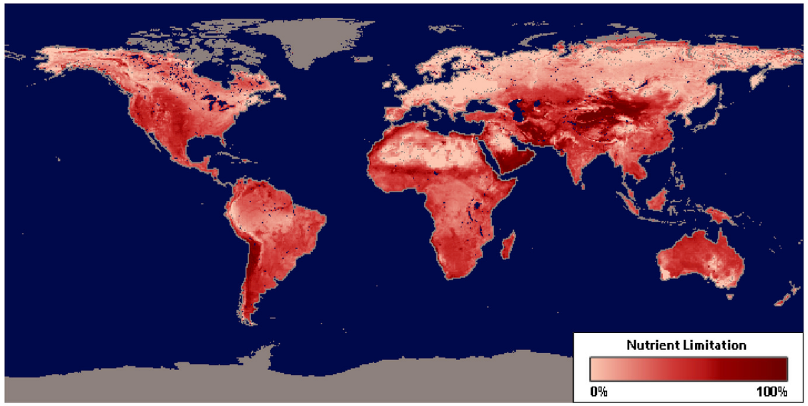
- Symbiotic BNF is 105.1 Tg N yr^{-1} (Cleveland et al., 2013) and 0.85 g N m^{-2} yr^{-1} on an per unit area basis (Sullivan et al., 2014).

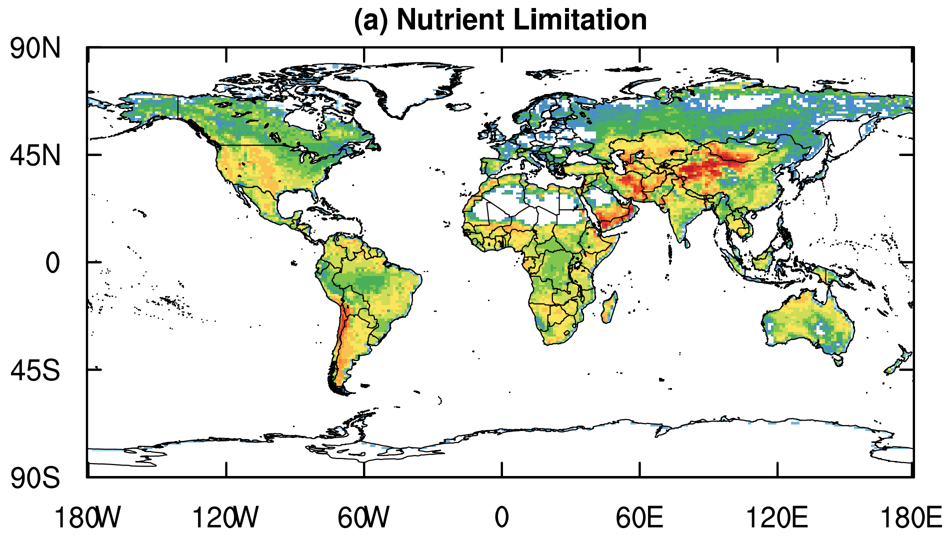


Symbiotic N fixation, Cleveland et al. (2013)

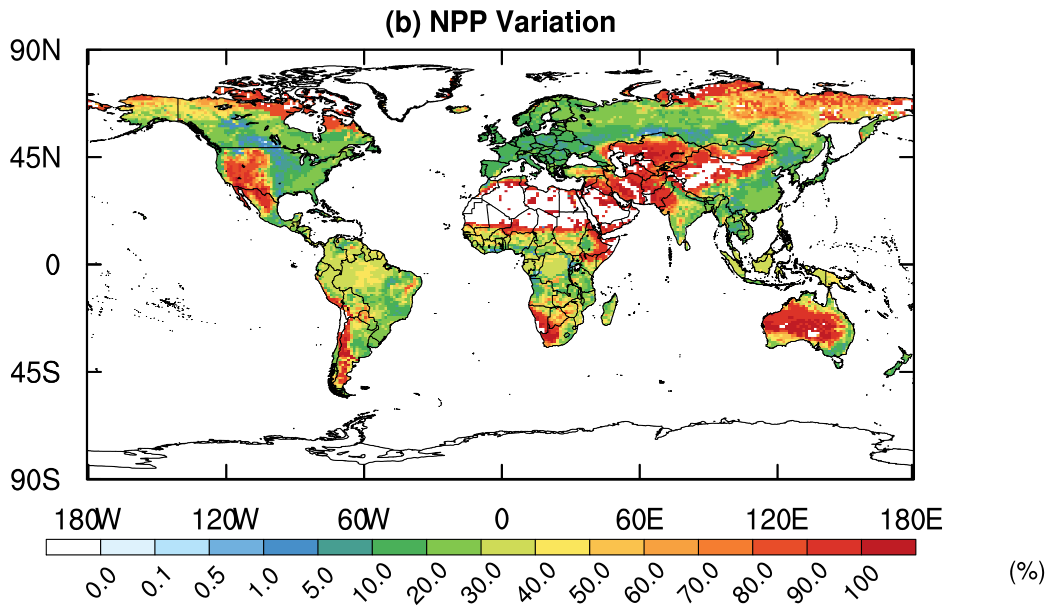
Discussion

Benchmarking CLM4.5-FUN2.0





- We used a new global nutrient limitation product developed from remote sensing (Fisher et al., 2012).
- The nutrient limitation and NPP variation patterns at the global scale.



Conclusion

- Total N uptake does not meet the total N demand, though this varies by biome and season, which reduces NPP globally by 30%.
- Global total N uptake amount is 1.2 Pg N yr^{-1}.
- N acquisition uses 5.1 Pg C yr^{-1} globally.
- Mycorrhizal N uptake is the dominant N uptake pathway and BNF is the most expensive N uptake pathway.
- The global mean retranslocation ratio is 44%.

Acknowledgments

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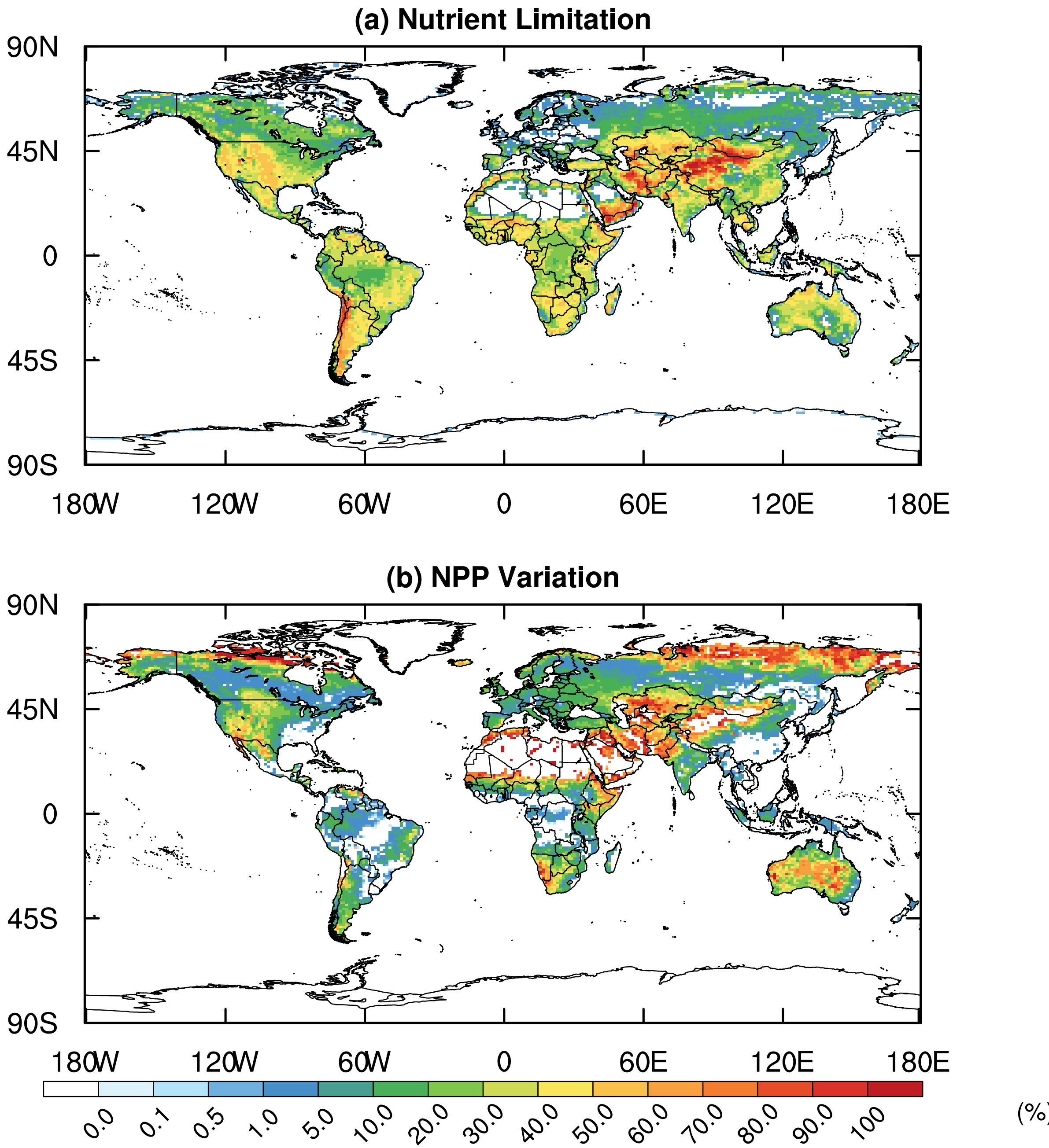
- The US National Science Foundation Ecosystem Science Program

Thank you for your attention!


(a) Nutrient Limitation
90N
45N
0
45S
90S
180W
120W
60W
0
60E
120E
180E
(b) NPP Variation
90N
45N
0
45S
90S
180W
120W
60W
0
60E
120E
180E
0.0
0.1
0.5
1.0
5.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100
(%)

Name of the PFTs	**AM (%)**	**ECM (%)**
Bare soil (not vegetated)	0	100
Needleleaf evergreen temperate tree	0	100
Needleleaf evergreen boreal tree	0	100
Needleleaf deciduous boreal tree	0	100
Broadleaf evergreen tropical tree	100	0
Broadleaf evergreen temperate tree	100	0
Broadleaf deciduous tropical tree	100	0
Broadleaf deciduous temperate tree	50	50
Broadleaf deciduous boreal tree	0	100
Broadleaf evergreen shrub	0	100
Broadleaf deciduous temperate shrub	0	100
Broadleaf deciduous boreal shrub	0	100
C3 arctic grass	0	100
C3 non-arctic grass	100	0
C4 grass	100	0

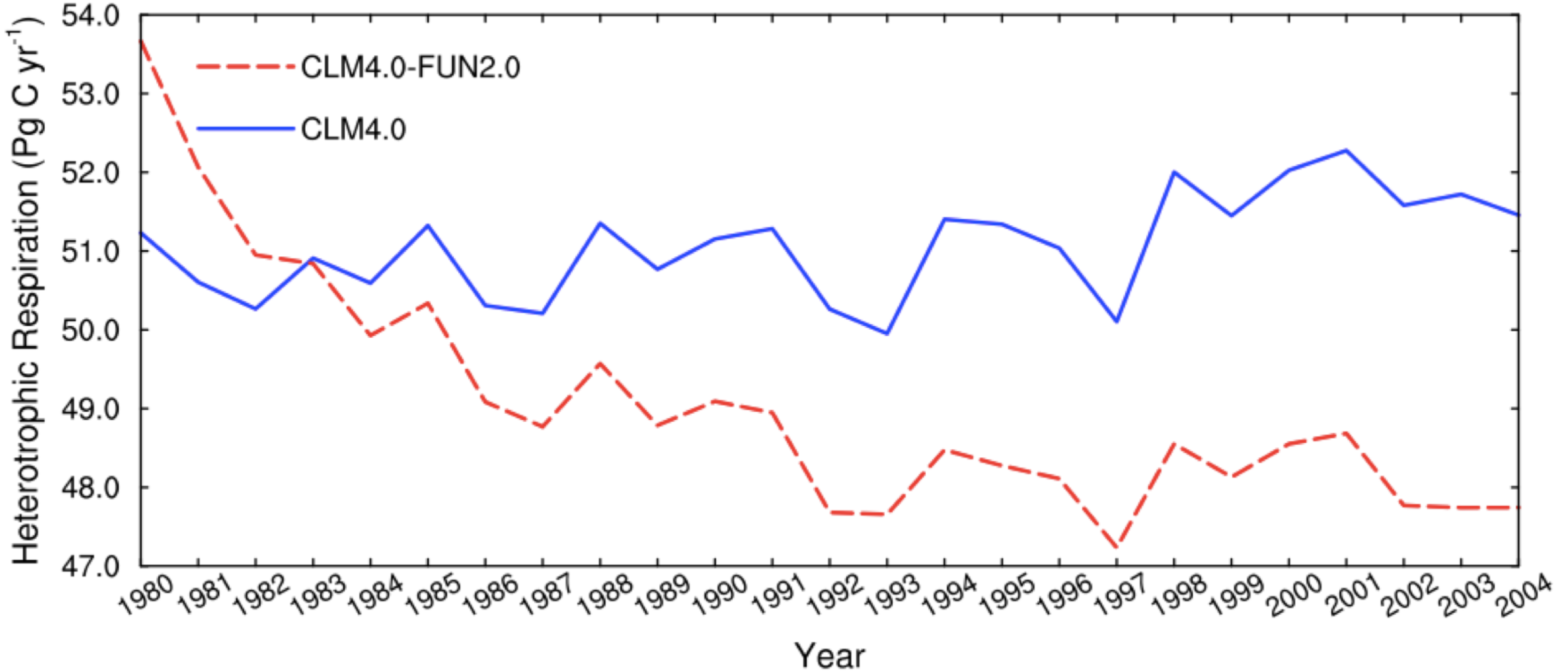


Fig. 9. The global annual total (1980–2004) heterotrophic respiration (Pg C yr^{-1}) simulated by CLM4.0 and CLM4.0-FUN2.0.