Accounting for N &P limitations in tropical forests using the land component of an earth system model: an Amazon basin case study

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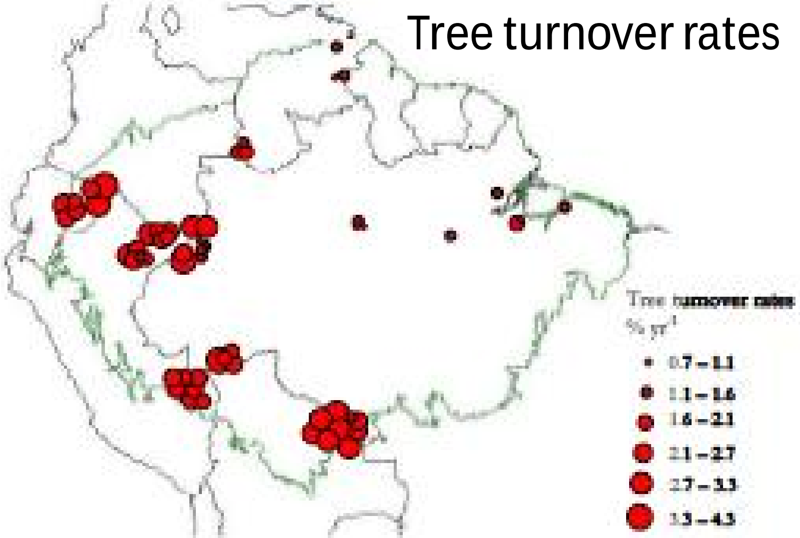
Observed gradients on Amazon forest

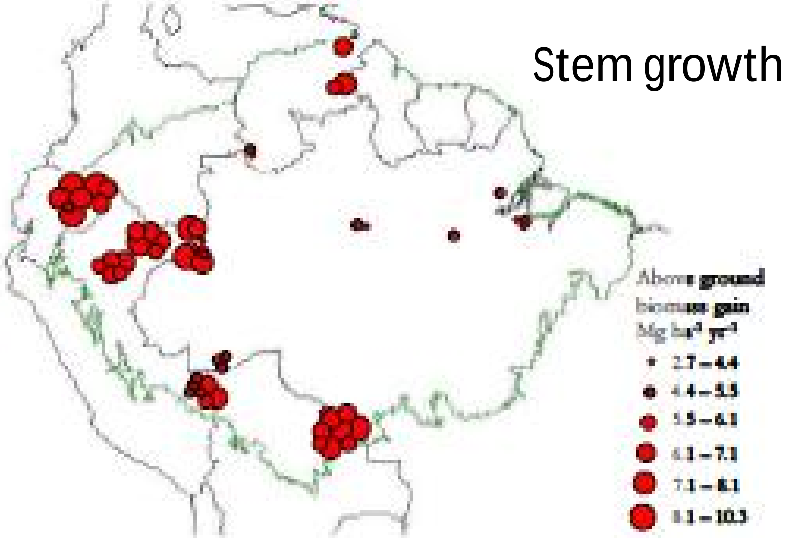
Background on observed gradients on Amazon forest

Plant carbon dynamics

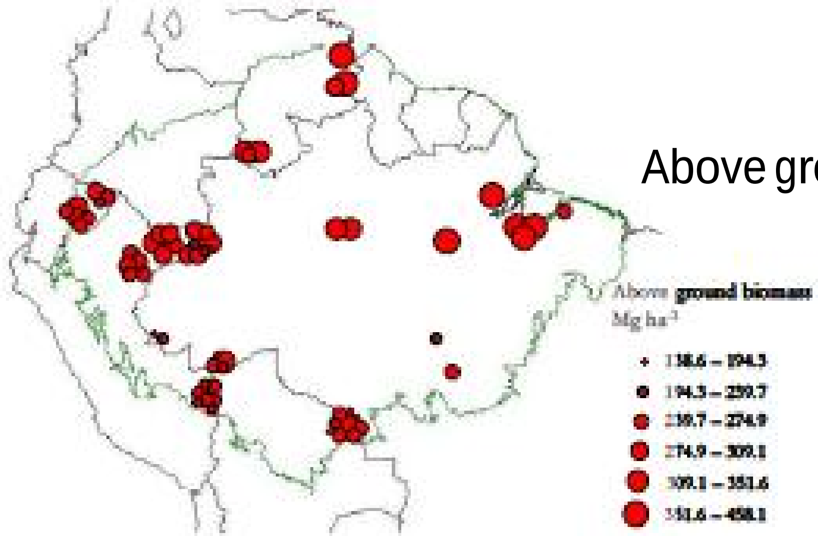
Tree turnover rates



Stem growth rates



Philips et al. 2004

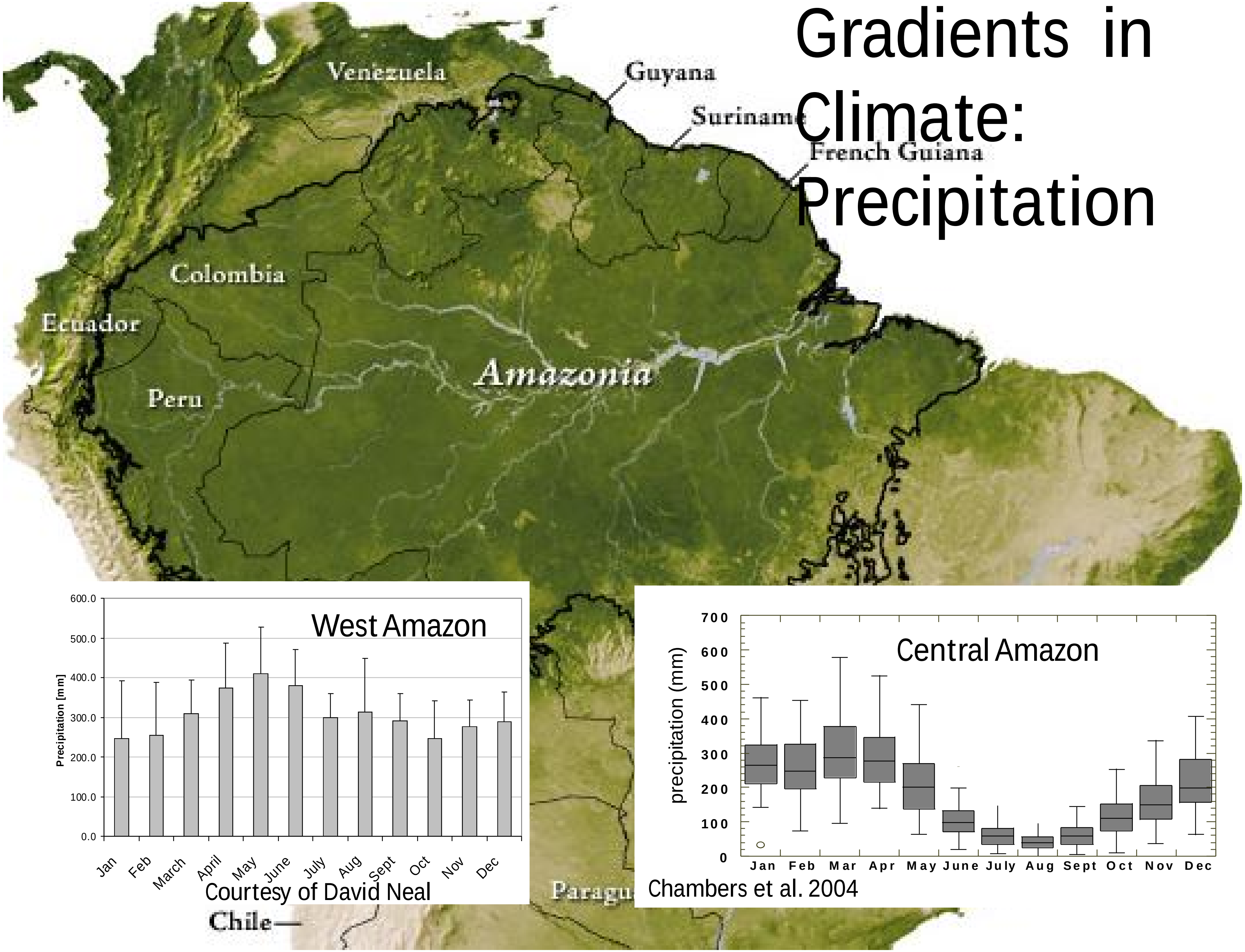


Above ground biomass

Quesada et al. 2009

Baker et al. 2004

Gradients in Climate: Precipitation

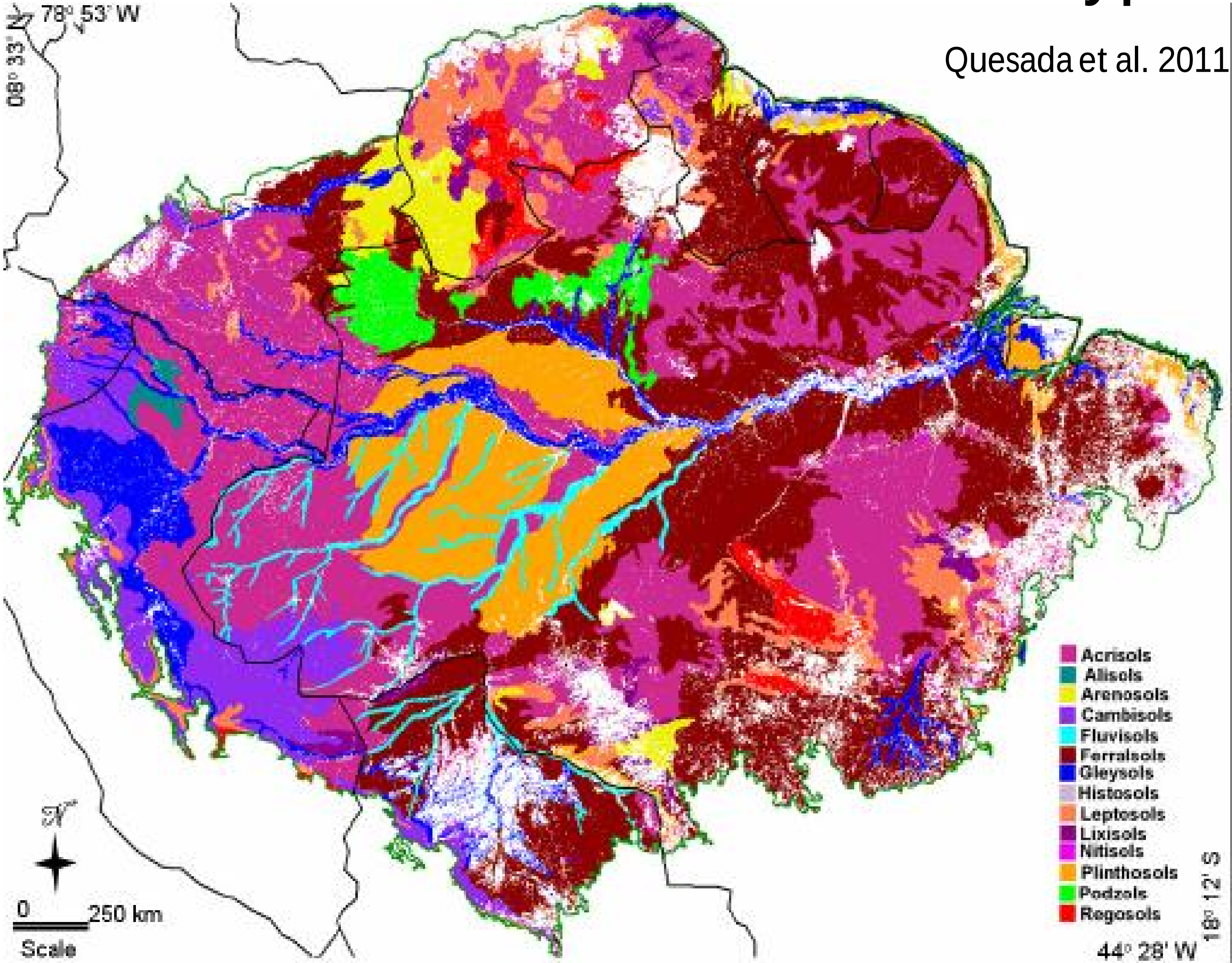


Courtesy of David Neal

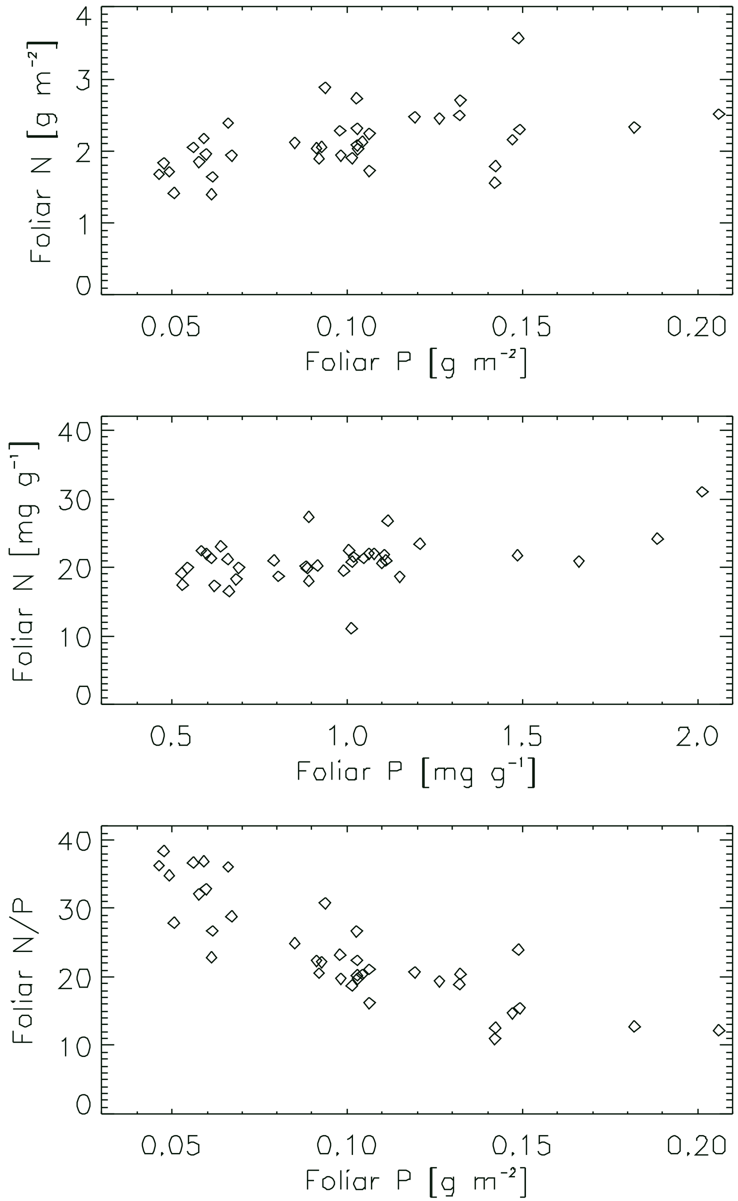
Chambers et al. 2004

Gradient in soil types

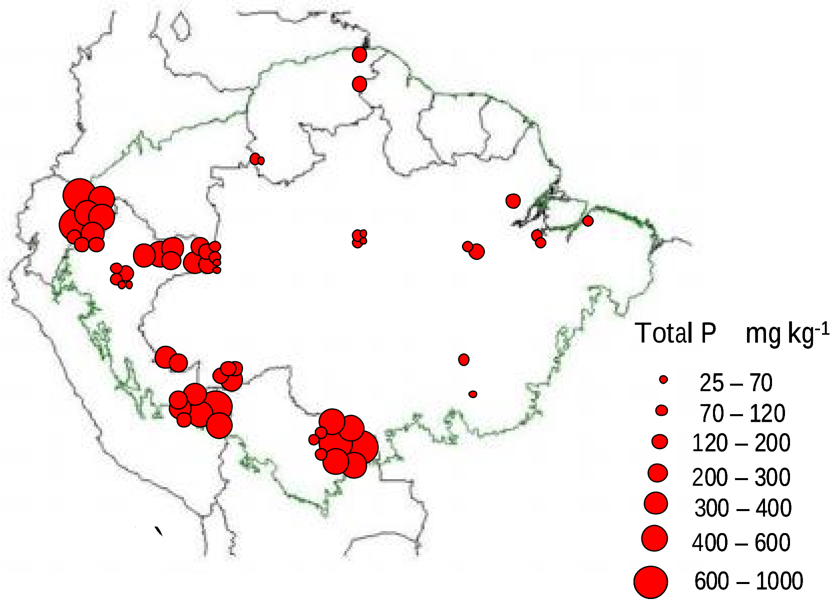
Quesada et al. 2011



Gradient in soil and foliar nutrient concentrations



Total soil P [mg kg^{-1}]



Quesada et al. (2010)

Leaf N:P ratios
used to estimate N –P limitations to growth

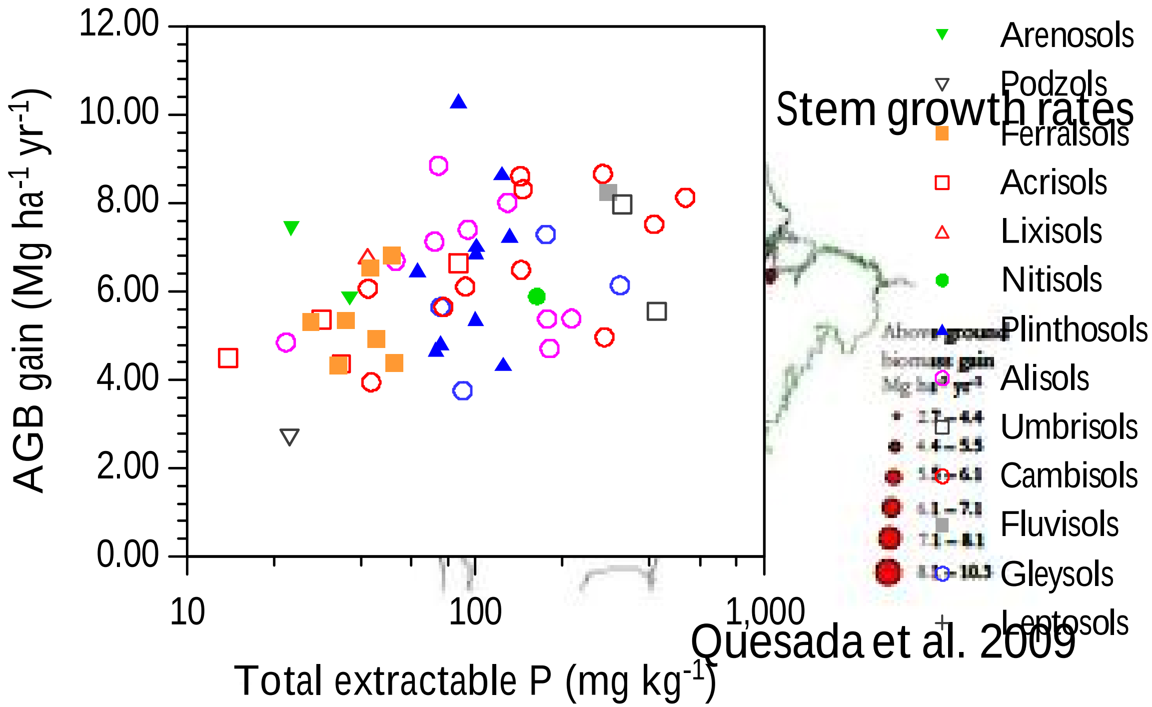
N:P ratios above 16 :1 are used (Aerts and Chapin, 2000) to define P limitation

Foliar data from Fyllas et al. (2009)

What can explain observed patterns of stem growth rates in Amazon basin?

Variability of climate, soil types and soil fertility (nutrients)

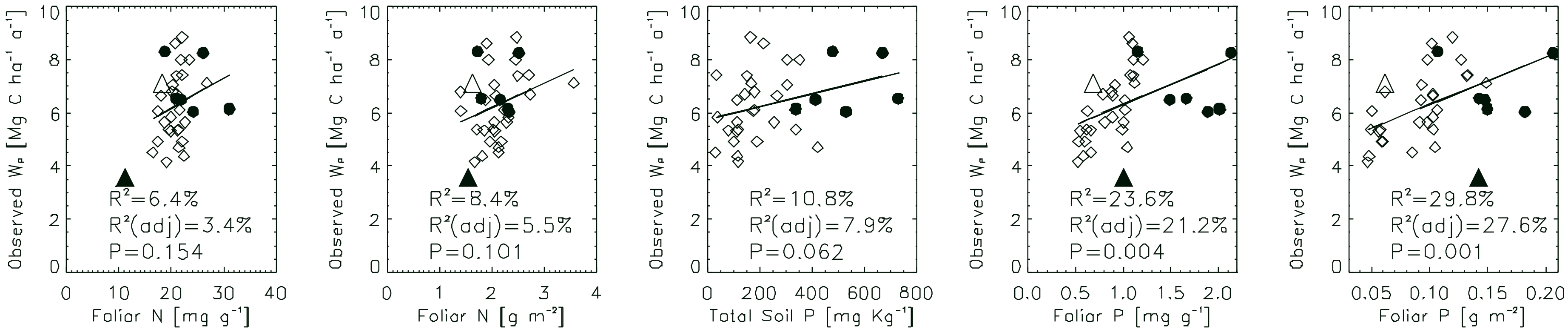
Nutrients appear to be one of best suspects
-Quesada et al. (2010) found forest stem growth rates to be related to total soil P.



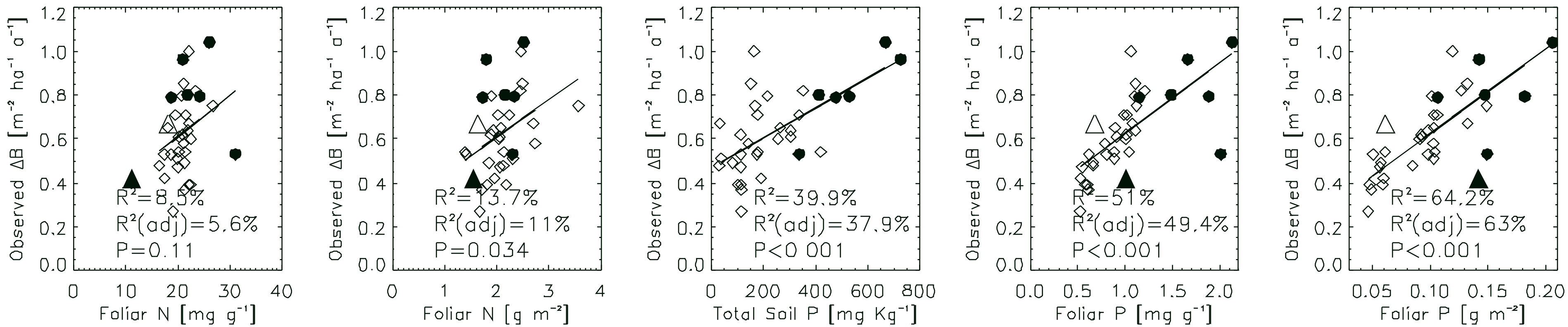
Quesada et al. (2010)

What can explain observed patterns of stem growth rates in Amazon basin?

Stem growth rates



Basal area growth



Foliar nutrients explain some % of observed spatial heterogeneity of stem growth rates and Ba growth

Mercado et al. 2011, Quesada et al. 2009, Fyllas et al.2009

What can explain observed patterns of stem growth rates in Amazon basin?

Photosynthesis –respiration = Net primary productivity (NPP)
= Above ground productivity, ANPP (leaves, stems)
+ Below ground productivity, BNPP

- Variability of Plant respiration

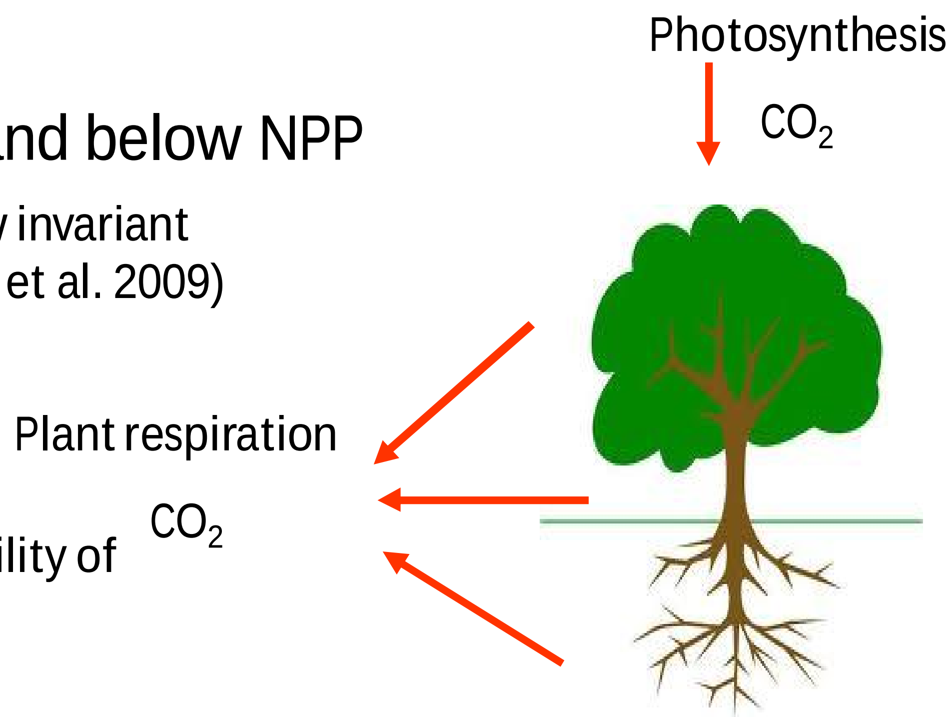
- Variability of allocation to above and below NPP

However, measurements from 10 plots show invariant allocation (64 % ANPP & 36% BNPP) (Aragao et al. 2009)

- Variability of photosynthesis

Can variability of photosynthetic uptake (including N and P constraints) explain variability of stem growth rates?

Use a model to help answer this question



Introducing a leaf P & N limitations to photosynthesis modelling in the tropics:

Parameterisation of photosynthesis including N & P

V_{cmax} and J_{max} – two main parameters in photosynthesis modelling

– usually estimated as a linear dependency of leaf N

Domingues et al (2010) parameterisation:

based on leaf level measurements of photosynthesis and nutrient contents

Need leaf P, N, and leaf mass per area LMA [g/m^2]

$$\left.\begin{array}{l} V_{cmax} = \min [\, f(N, LMA), f(P, LMA) \,] \\ J_{max} = \min [\, f(N, LMA), f(P, LMA) \,] \end{array}\right\}$$

Both V_{cmax} and J_{max} can either be
P limited,
N limited or
co-limited by N and P

Methodology

1-Can simulated photosynthesis explain observed patterns of stem growth rates in Amazon basin ?

Site level application – canopy gas exchange model

2-What are the implications for C fluxes across Amazonia using global models ?

Regional level application – global Land surface model (JULES)

Site level exercise : method

-Run canopy photosynthesis model at 38 sites (Colombia, Venezuela, Peru, Ecuador & Brazil)

-Use observed foliar N, P and LMA (for V_{cmax} and J_{max}) , LAI at each site.

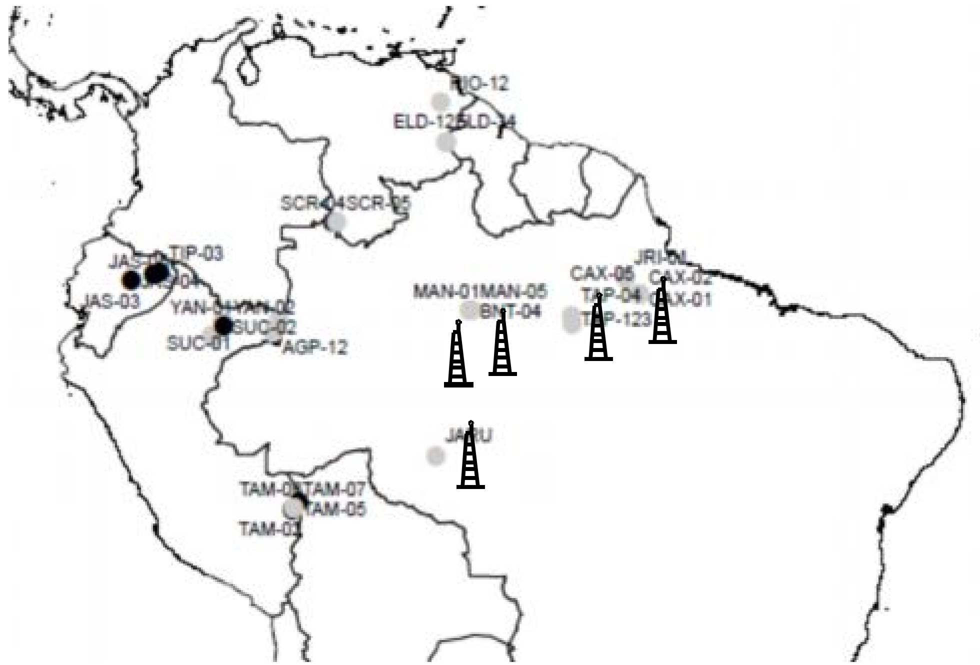
-ERA -40 climatology 1982-2001

-Model was evaluated against
observed GPP and leaf respiration (annual values) from few available sites
eddy correlation data at 5 sites in the Amazon hourly observations
(not shown here , Mercado et al. 2009)

Aim:

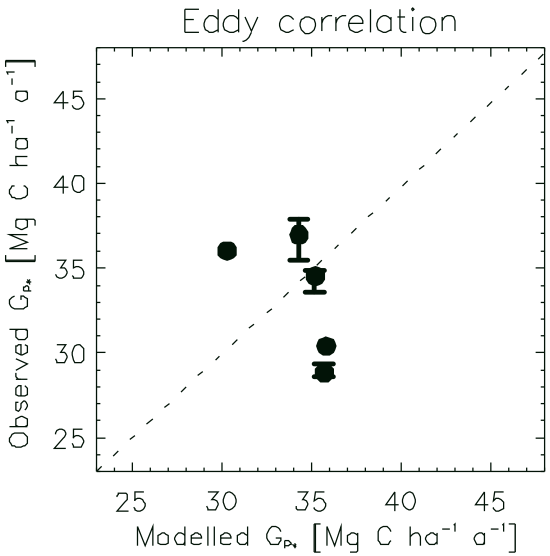
-Relate observed stem growth rates to simulated canopy photosynthesis

-Climate effect
-N effect (assume N limiting)
-P effect (assume P limiting)
-N & P effect (N and P limiting)

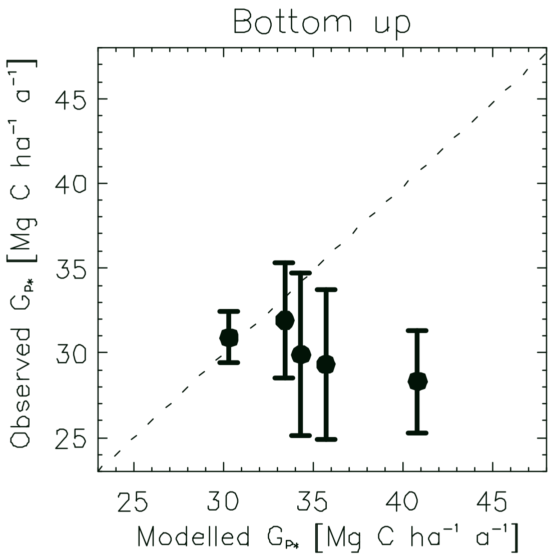


Site level exercise : model evaluation

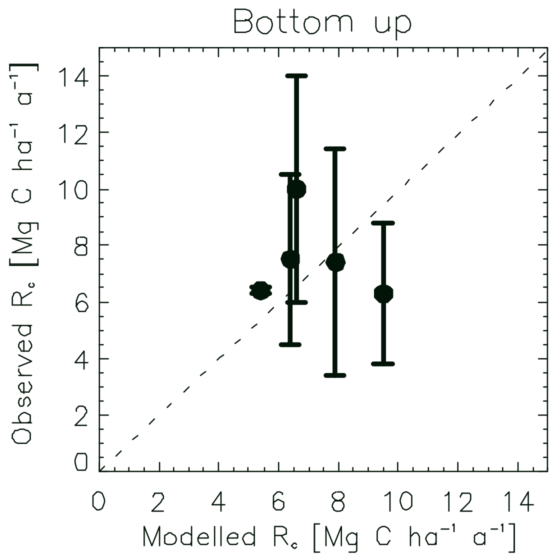
Photosynthesis



Photosynthesis



Leaf respiration



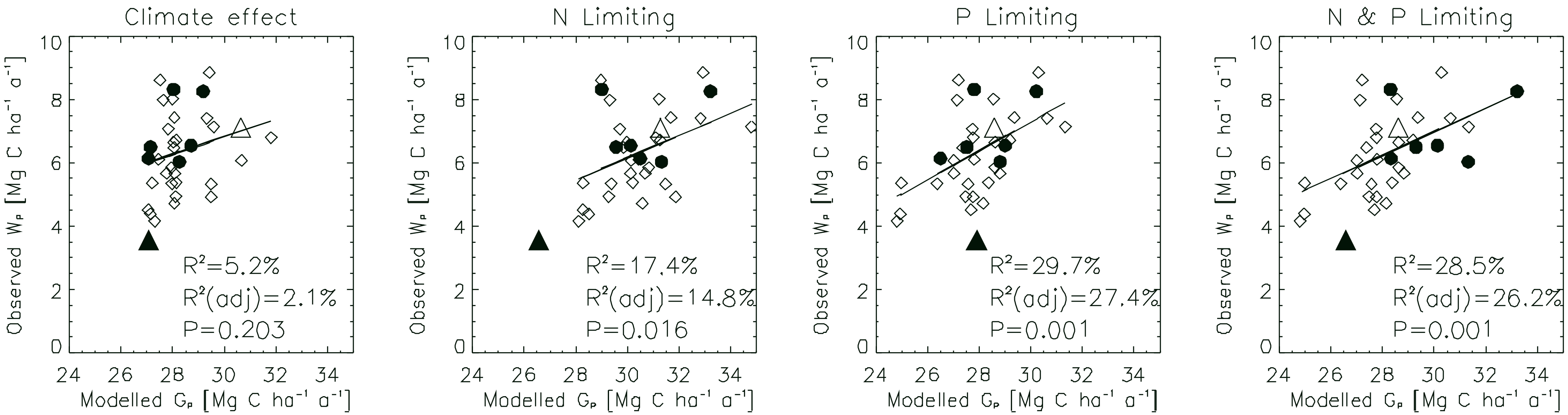
Eddy correlation data provided by N. Restrepo-coupe (U. Arizona)

Bottom up estimates of GPP and leaf respiration Courtesy of Yadvinder Malhi and (Oxford U.) Luiz Aragao (Exeter U)

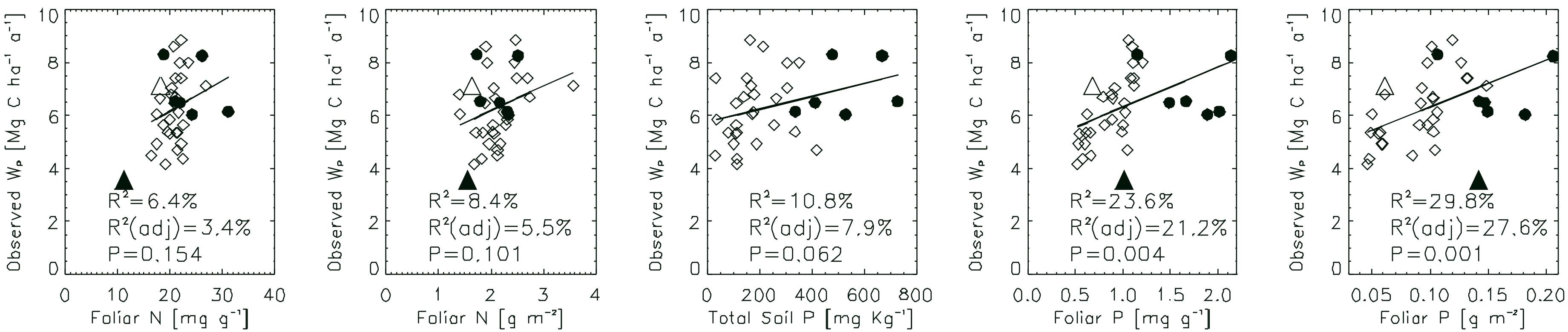
Mercado et al. (in press)

Site level exercise -results

Simulated photosynthesis vs Observed stem growth rates (35 sites , av. Observations)



Foliar and soil Nutrients vs Stem growth



Simulated photosynthesis constrained by both N & P explains up to ~29% of variability in observed stem growth rates

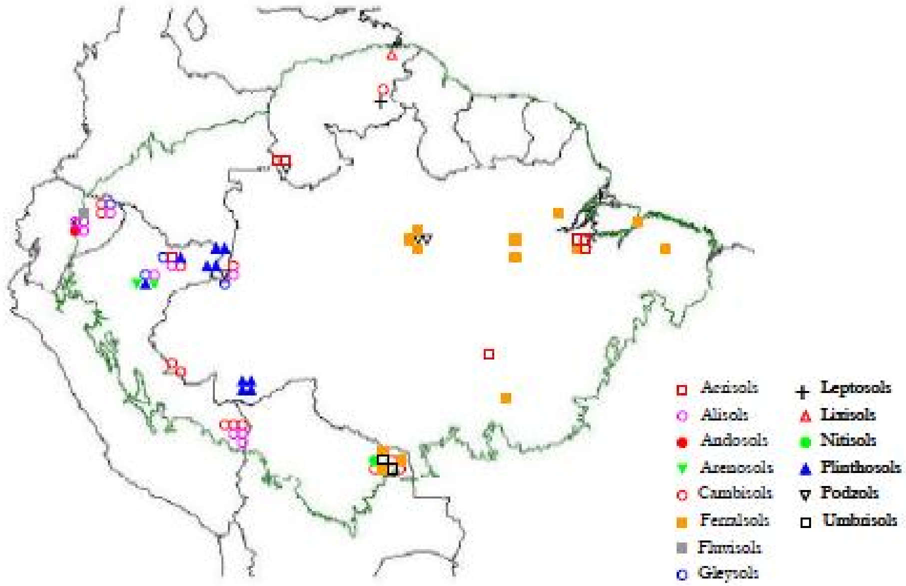
Mercado et al. (in press)

Regional level application

JULES –UK land surface model of met office GCM

1) Implement N & P parameterisation into photosynthesis model:
 Need gridded values of N, P & LMA !
 Use pedontransfer functions that predict N, P and LMA from soil types.

Rainfor consortium (nutrients, soils, diameters, LAI, height, biomass, etc)



Soils in Quesada et al. (2011)
Foliar nutrients in Fyllas et al. (2009)

Soil types and leaf traits (P, N, LMA) relationships

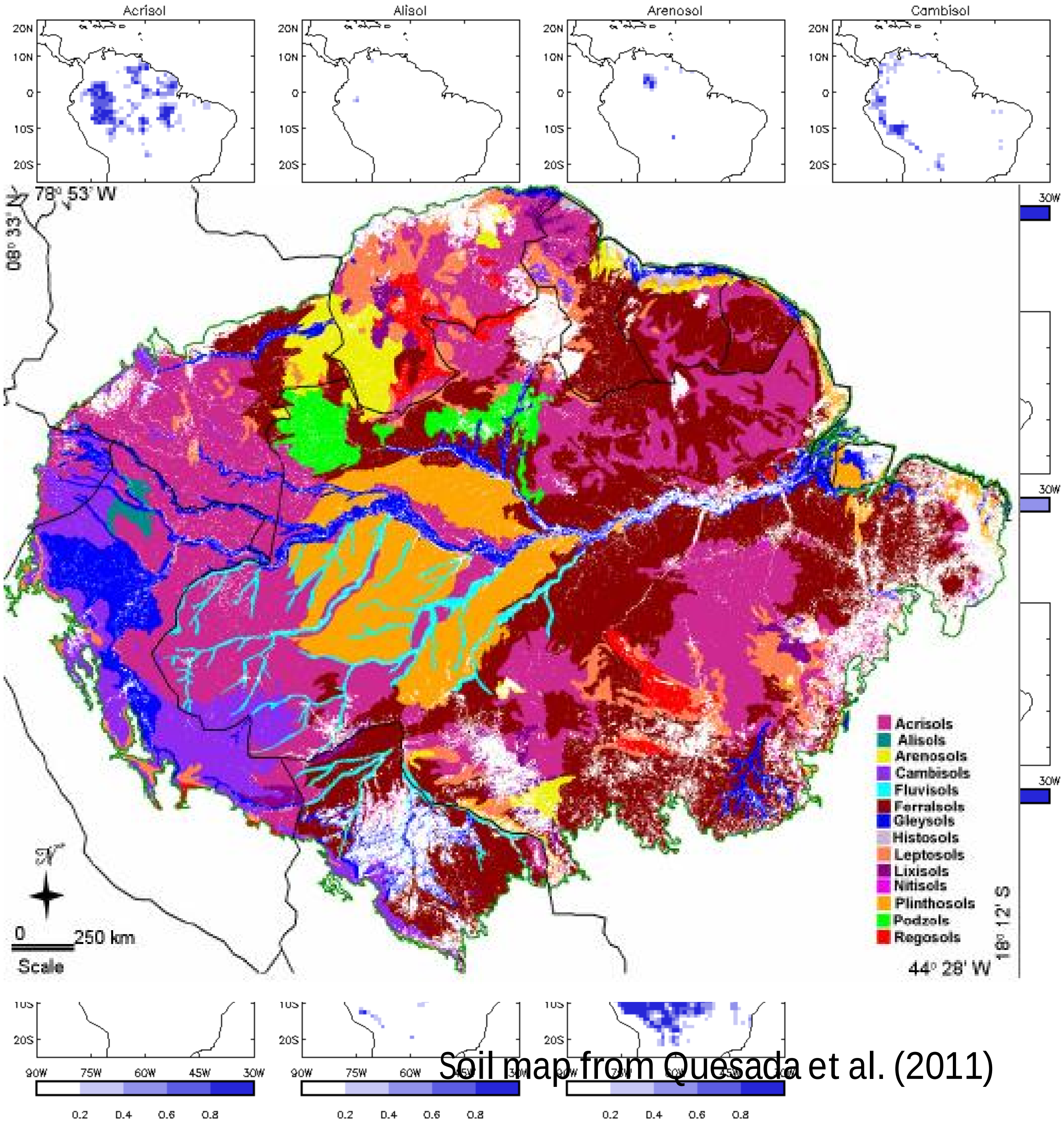
	Soil Type	N	P	LMA
2	Acrisols	19.24	0.74	95.29
3	Alisols	21.74	1.12	98.73
4	Arenosols	18.96	0.92	112.54
5	Cambisols	22.94	1.24	87.53
6	Fluvisols	27.06	2.22	86.29
7	Ferrasols	20.49	0.67	95.53
8	Gleysols	21.82	1.16	99.56
9	Histosols	21.76	1.10	75.80
10	Leptosols	20.07	0.75	74.89
11	Lixisols	16.93	0.65	85.49
12	Nitisols	28.08	1.27	81.24
13	Plinthosols	20.96	0.99	89.17
14	Podzols	11.93	0.90	141.96
15	Regosols	22.94	1.24	87.53

LMA=Leaf mass per area [g m^{-2}]

Nikos Fyllas & Jon Lloyd
(unpublished work)

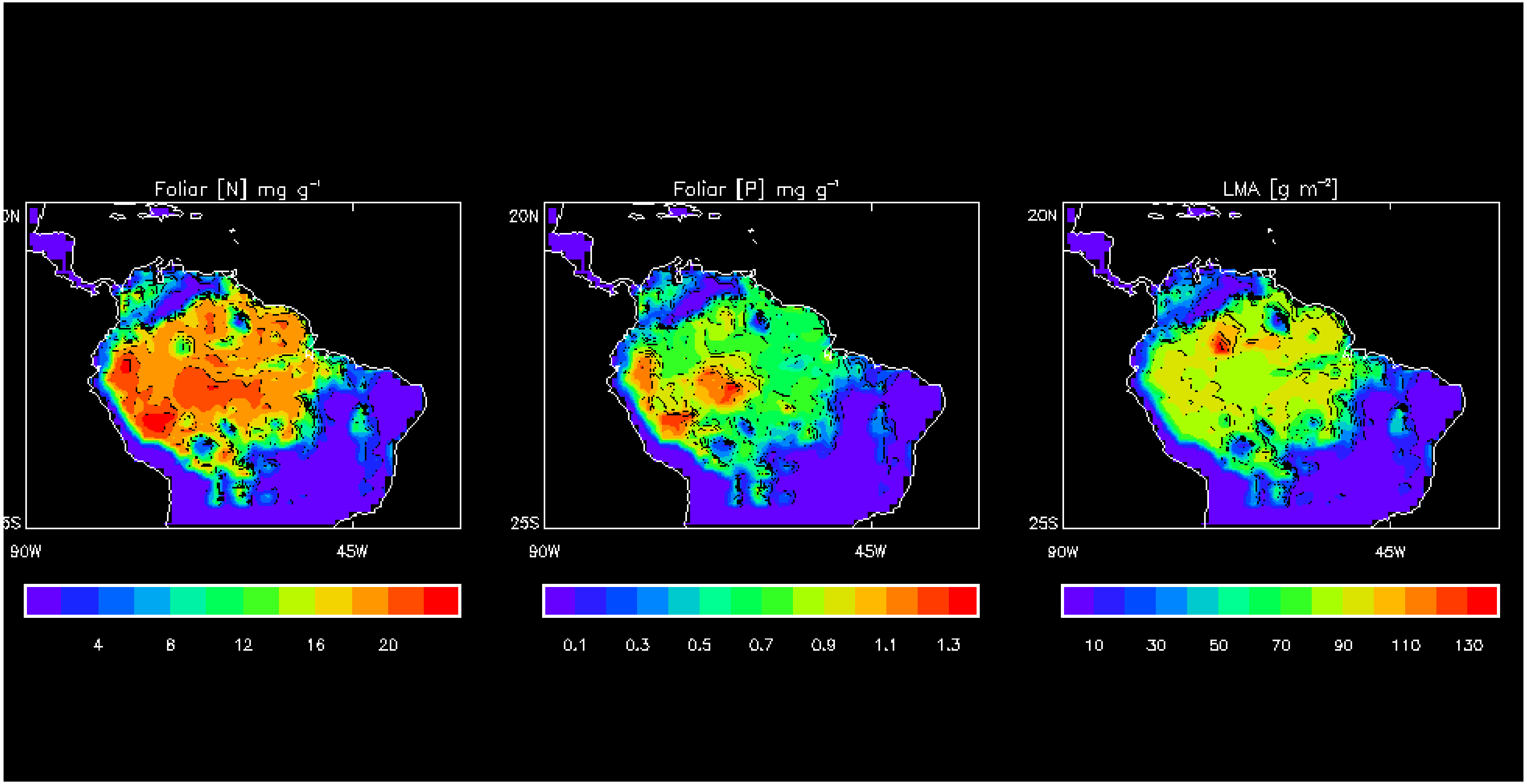
Soil types

Percentage of each soil type on each grid box (1 degree)



Soil map from Quesada et al. (2011)

Mapping of leaf traits based on soil types (soil pft)



V_{cmax} and J_{max} for the 14 soil plant functional types (SPFTS)

V_{cmax} = min [f (N, LMA) , f (P, LMA)]

J_{max} = min [f (N, LMA) , f (P, LMA)]

Both V_{cmax} and J_{max} can be P and/or N limited

According to Domingues et al. (2010) model:

	V_{cmax-n}	V_{cmax-p}	J_{max-n}	J_{max-p}	N	P
Acrisol	52	42	81	67	19.24	0.74
Alisol	56	52	87	82	21.74	1.12
Arenosol	57	53	88	82	18.96	0.92
Cambisol	53	50	83	79	22.94	1.24
Fluvisol	56	65	88	100	27.06	2.22
Ferrasol	53	41	83	64	20.49	0.67
Gleysol	56	54	87	83	21.82	1.16
Histosols	47	43	75	68	21.76	1.10
Leptosols	45	36	72	57	20.07	0.75
Lixisols	46	37	72	58	16.93	0.65
Nitisols	55	48	86	76	28.08	1.27
Plinthosols	52	46	80	72	20.96	0.99
Podzols	54	62	83	95	11.93	0.90
Regoosol	53	50	83	79	22.94	1.24

N limited

P limited

N-P co-limited

Running JULES for the Amazon Basin

-Sheffield et al. Climatology (3 hourly values) , 1 degree, 2003-2008 period
-Land cover map, is map of soils with rainforest (Quesada et al. 2010)
-Modified parameterisation of photosynthesis to include P and N limitations

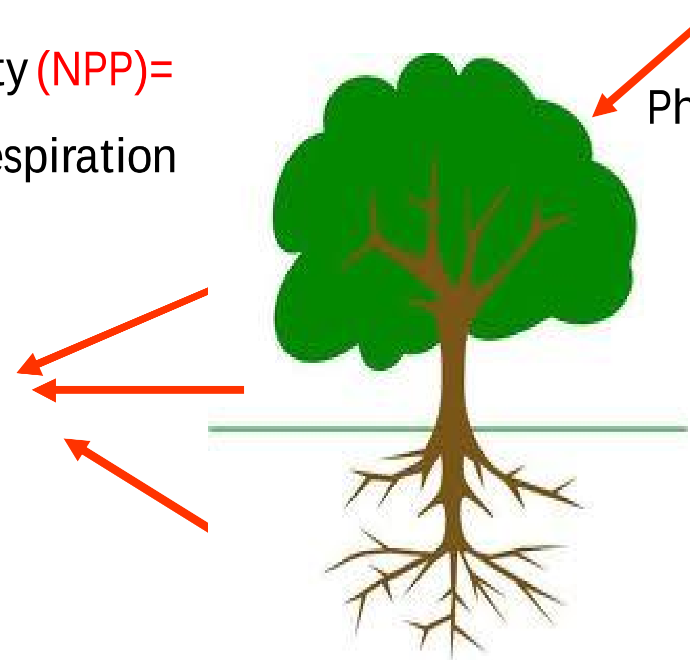
Aim :
-Look at spatial variability of GPP, NPP and ratio of Plant respiration to GPP and compare to control JULES (only 1 type of broad leaf trees)

TERMINOLOGY

Gross Primary productivity (GPP)

Net Primary productivity (NPP)=

Photosynthesis-Plant respiration



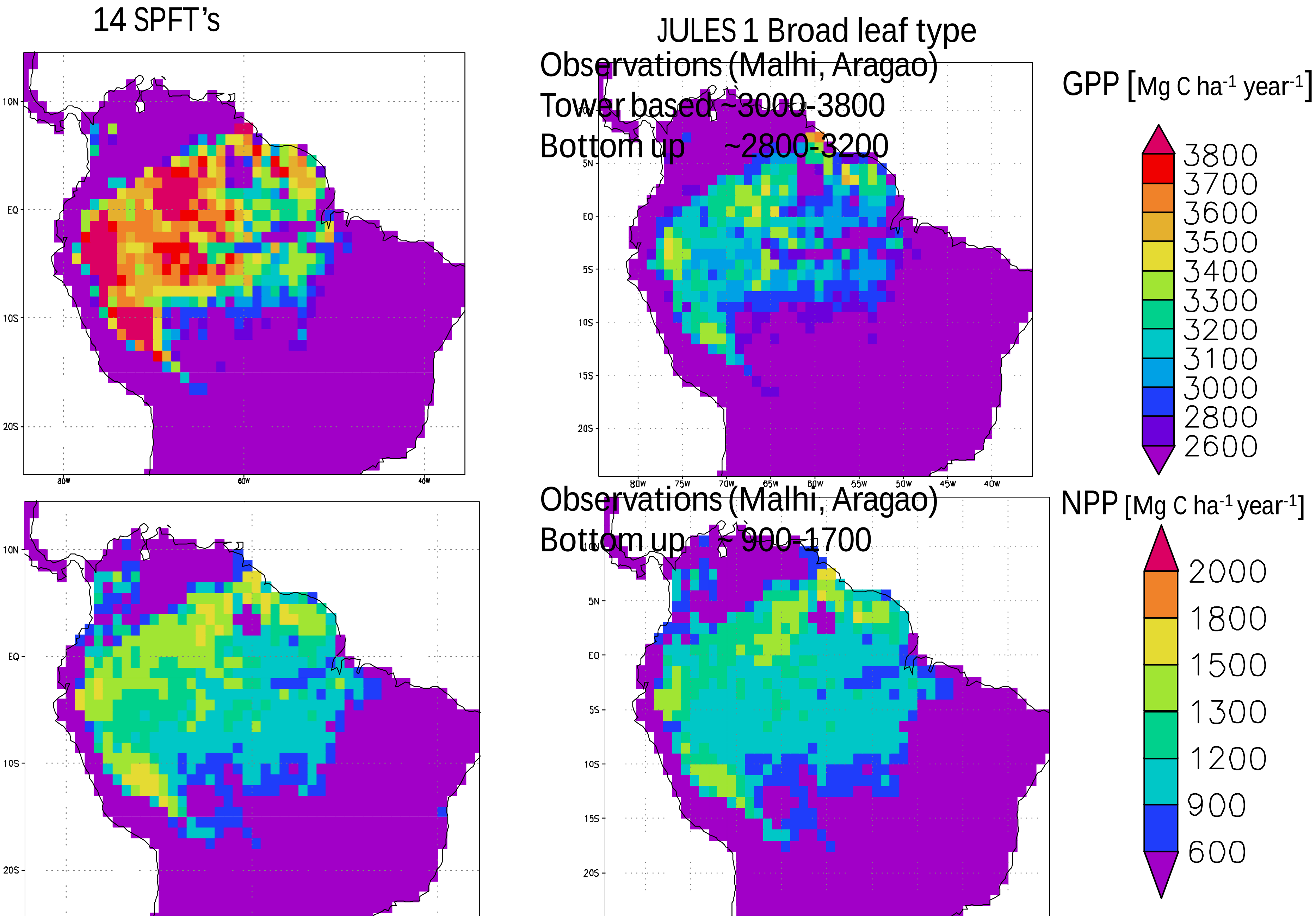
Photosynthesis

CO_2

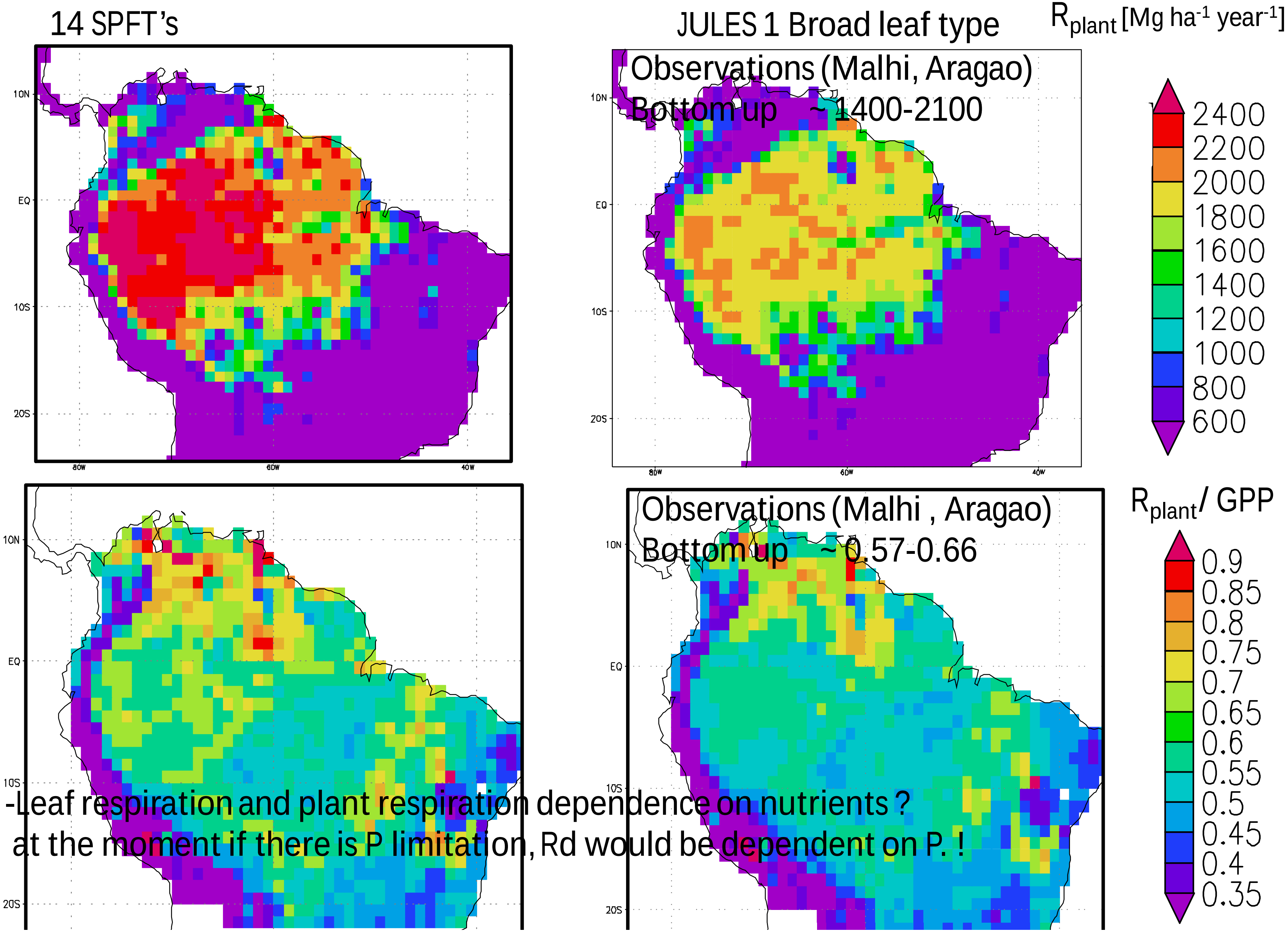
Plant respiration

CO_2

Mean annual simulated fluxes for the period 2003-2008



Mean annual simulated values for the period 2003-2008



-Leaf respiration and plant respiration dependence on nutrients ?
at the moment if there is P limitation, Rd would be dependent on P. !

Summary and final remarks

There are gradient in stem growth rates, tree turnover and above ground biomass across Amazonia

Simulated photosynthesis constrained by both N & P explains up to ~29% of variability in observed stem growth rates

Using N& P constraints within a land surface model, shows heterogeneity of simulated GPP & NPP across the Amazon region, relative to the standard version of the model.

Outlook

-Does this translate into changes in simulated growth ?

-Use of available observations of single components of NPP to evaluate JULES

-We are still waiting for the observations to confirm our results (spatial variability of GPP).

-Help to inform need of inclusion of P cycle in global models