CLM5: Model structure recap

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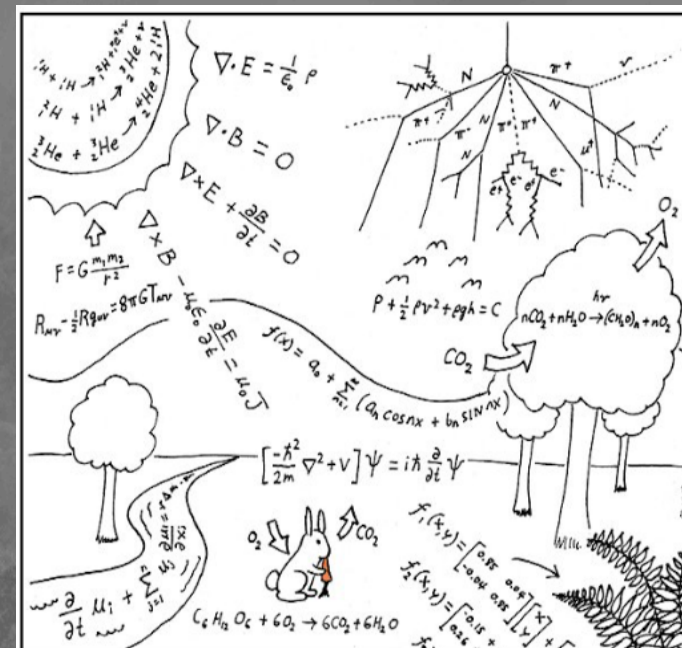


NCAR: Rosie Fisher, Dave Lawrence, Keith Oleson, Ben Sanderson, Sean Swenson, Will Wieder, Gordon Bonan, Peter Lawrence, Danica Lombardozzi, Justin Perket, Ahmed Tawfik, Liz Burakowski, Yaqiong Lu.

Software: Erik Kluzek, Ben Andre, Bill Sacks, Mariana Vertenstein.

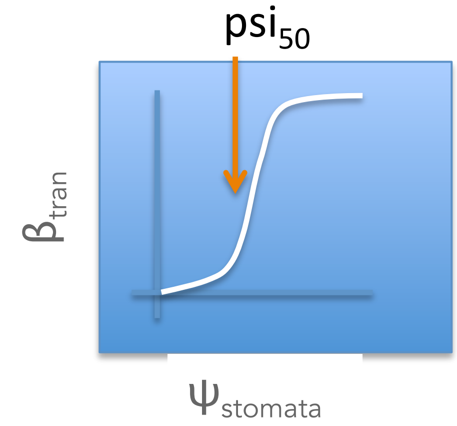
External: Charlie Koven, Bill Riley, Chonggang Xu, Daniel Kennedy, Pierre Gentine, Mingjie Shi, Josh Fisher, Andrew Slater, Andrew Fox, Quinn Thomas, Hongyi Li, Ashehad Ali, Kyla Dahlin, Mathew Williams, Marysa Laguë, Jingyung Tang, Bardan Ghmire, Zack Subin.

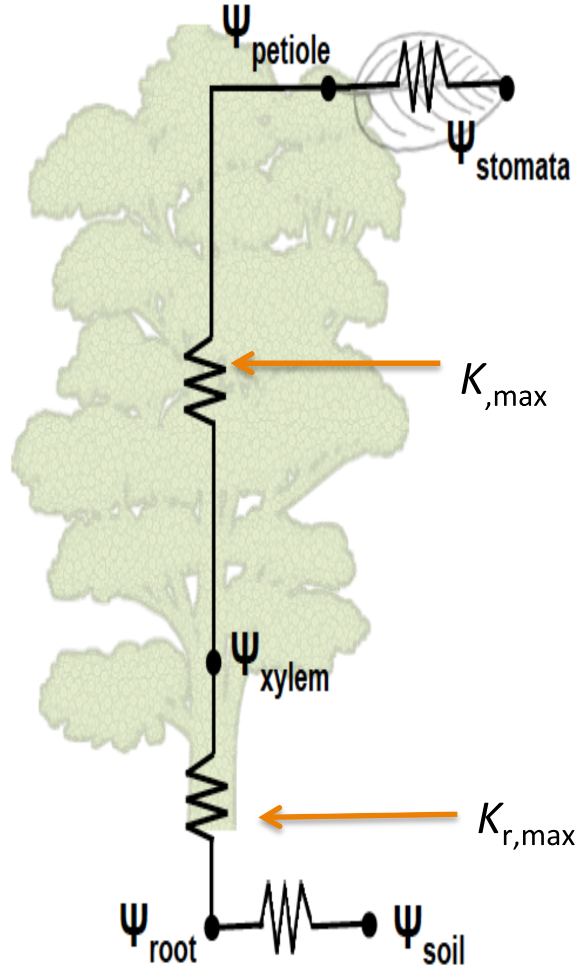
RECAP of (SOME) DEVELOPMENTS

MOST STRUCTURAL DEVELOPMENTS WERE FINALIZED LAST YEAR

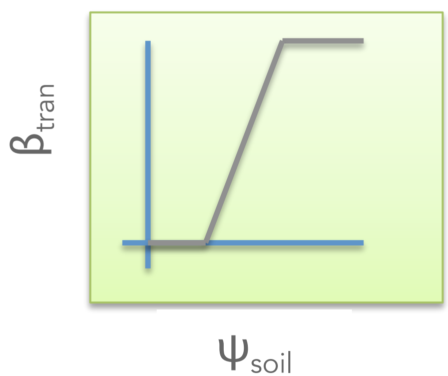
Plant Hydrodynamics

- Stomatal conductance is a function of prognostic (predicted) leaf Water Potential
- LWP is the result of atmospheric demand and supply from soil via resistance network.
- Based on Sperry and Love, 2015



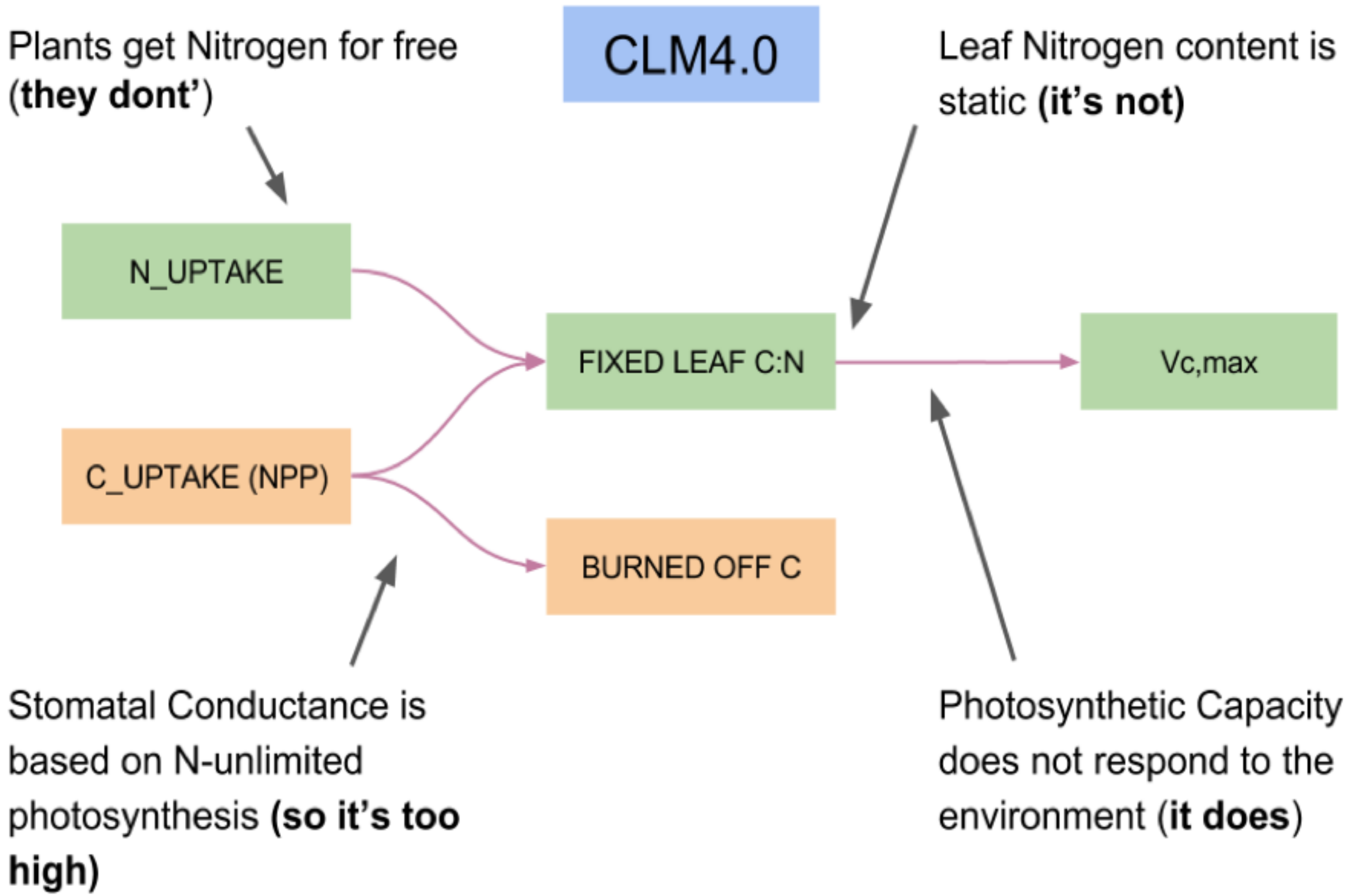


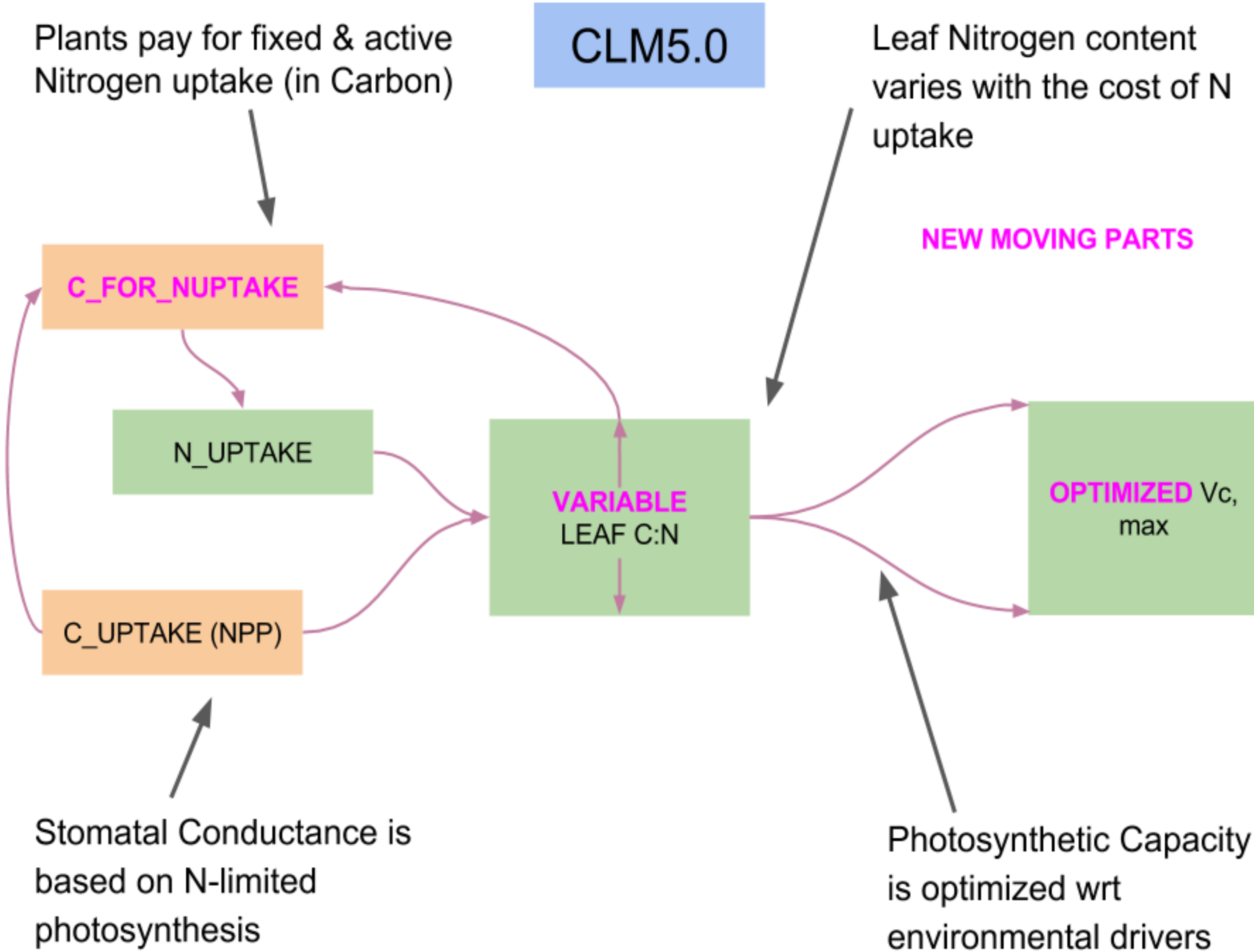
STATUS QUO DROUGHT STRESS MODEL

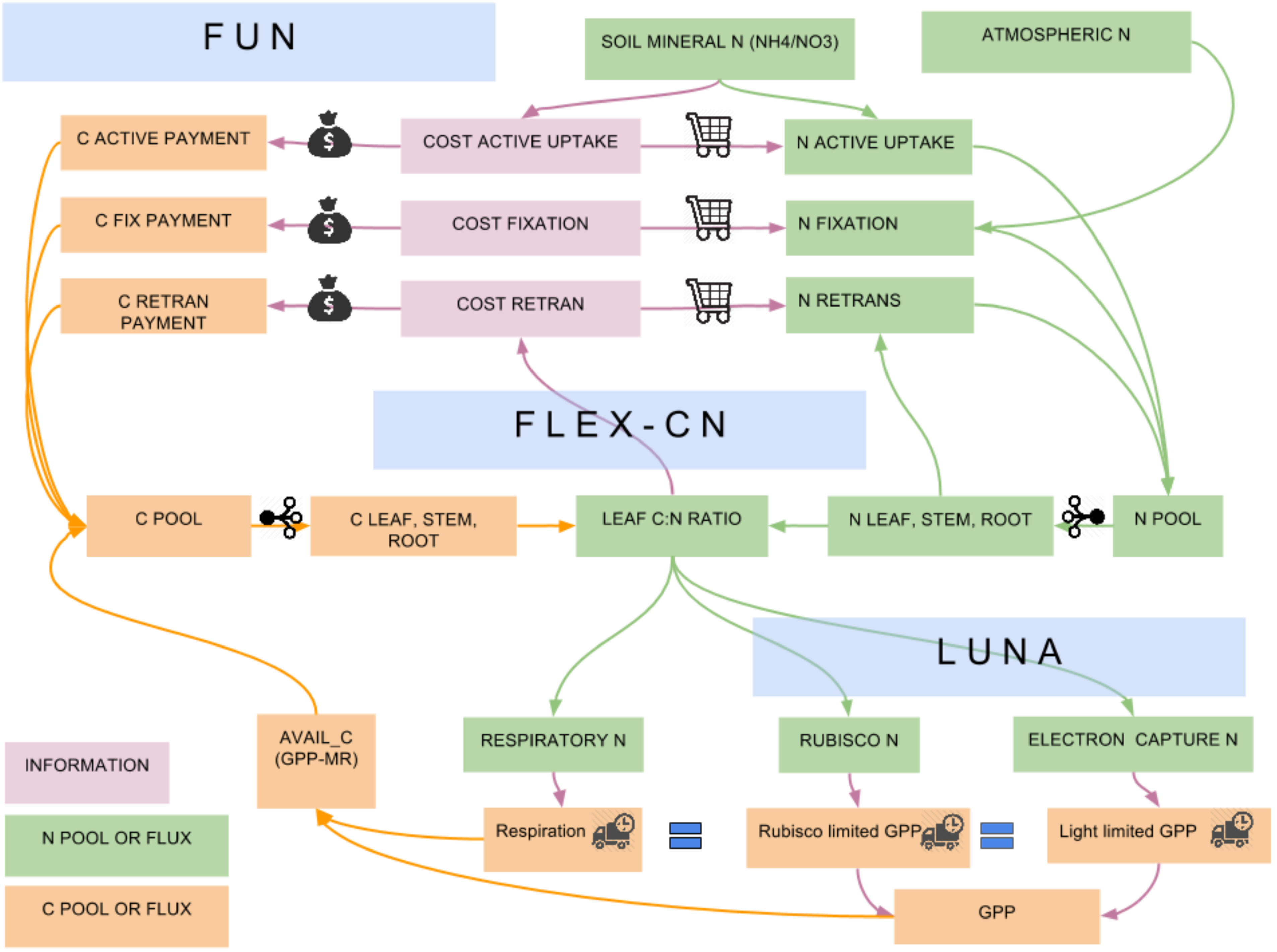


Kennedy, Gentine, Oleson, Sweson, Fisher, Lawrence et al. in prep

NEW NITROGEN MODEL


CLM4.0
Plants get Nitrogen for free (they dont')
Leaf Nitrogen content is static (it's not)
N_UPTAKE
FIXED LEAF C:N
Vc,max
C_UPTAKE (NPP)
BURNED OFF C
Stomatal Conductance is based on N-unlimited photosynthesis (so it's too high)
Photosynthetic Capacity does not respond to the environment (it does)

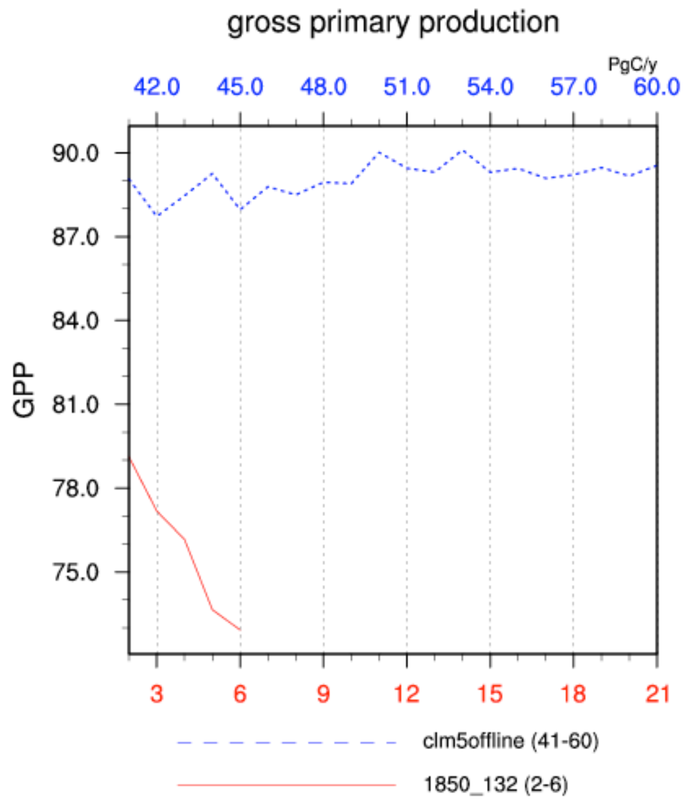

CLM5.0
Plants pay for fixed & active Nitrogen uptake (in Carbon)
Leaf Nitrogen content varies with the cost of N uptake
NEW MOVING PARTS
C_FOR_NUPTAKE
N_UPTAKE
VARIABLE LEAF C:N
OPTIMIZED Vc, max
C_UPTAKE (NPP)
Stomatal Conductance is based on N-limited photosynthesis
Photosynthetic Capacity is optimized wrt environmental drivers

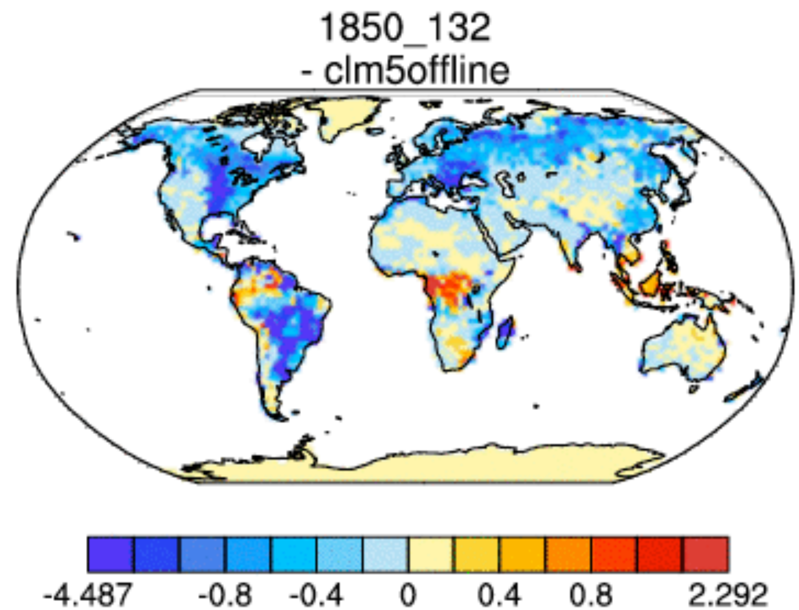


FUN
SOIL MINERAL N (NH4/NO3)
ATMOSPHERIC N
C ACTIVE PAYMENT
COST ACTIVE UPTAKE
N ACTIVE UPTAKE
C FIX PAYMENT
COST FIXATION
N FIXATION
C RETRAN PAYMENT
COST RETRAN
N RETRANS
FLEX-CN
C POOL
C LEAF, STEM, ROOT
LEAF C:N RATIO
N LEAF, STEM, ROOT
N POOL
LUNA
AVAIL_C (GPP-MR)
RESPIRATORY N
RUBISCO N
ELECTRON CAPTURE N
Respiration
Rubisco limited GPP
Light limited GPP
GPP
INFORMATION
N POOL OR FLUX
C POOL OR FLUX

NEW STOMATAL CONDUCTANCE

GPP in coupled run



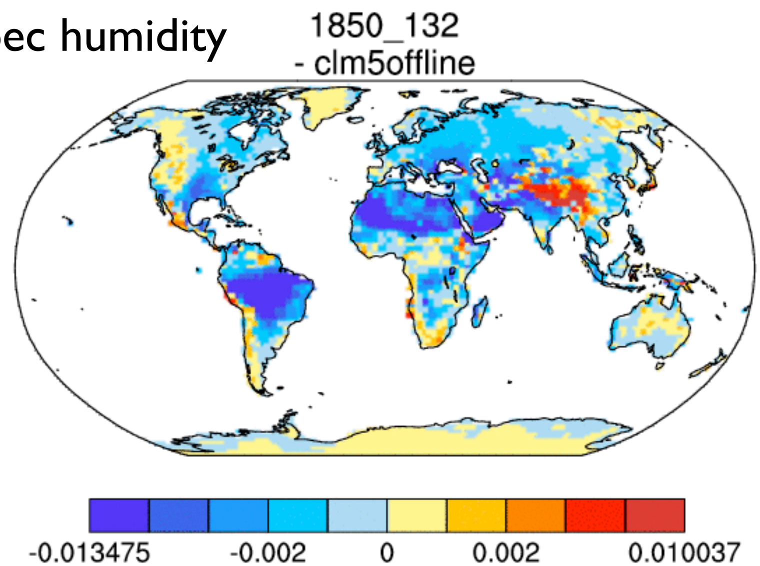


Why the systematic drop?

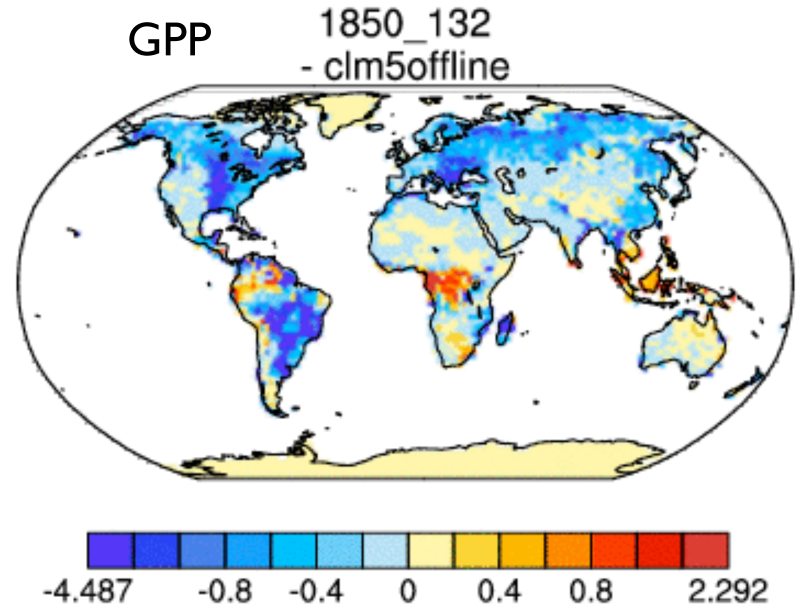
- Always a drop, larger in this run
- Climate differences not uniform
- Possibly a correlation with VPD bias in CESM

GPP in coupled run

Spec humidity



GPP

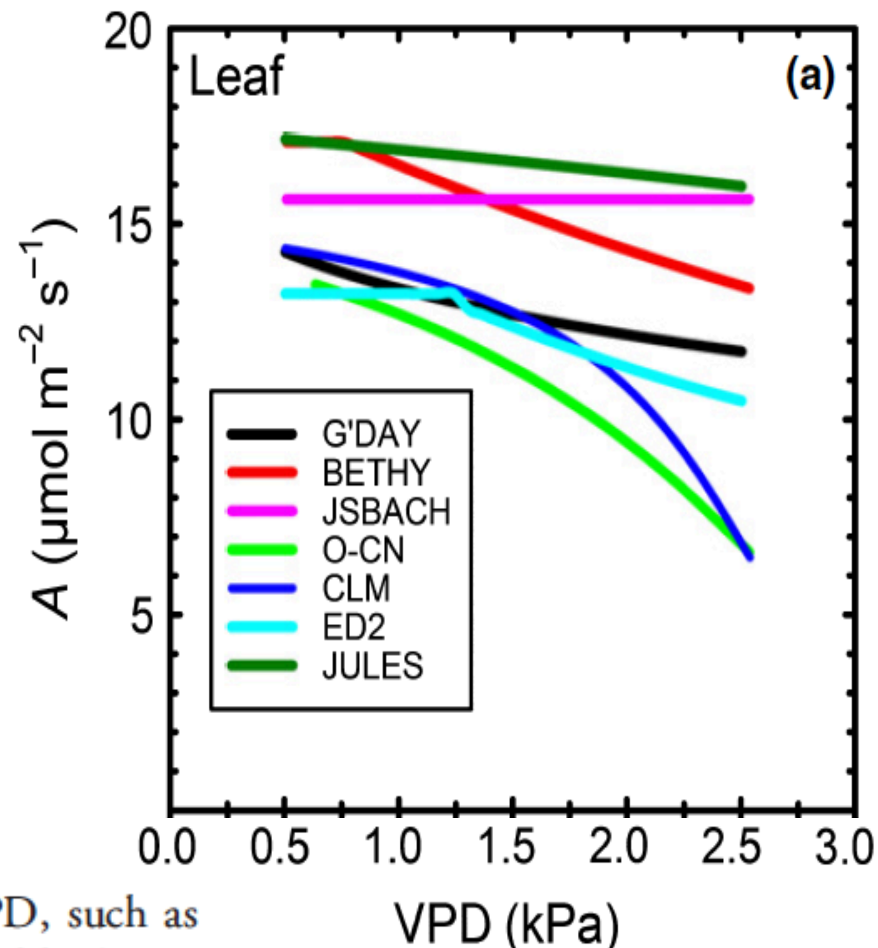


Why the systematic drop?

- Always a drop, but larger after parameter calibration
- Climate differences (T, P) generally not uniform, spec humidity more systematic lower

Stomatal Conductance

- CLM Ball-Berry model has extreme response to humidity.
- Tried replacement of Ball Berry with Medlyn model (in G'Day)
- Doesn't have enormous impact.
- Theoretically better
- Does improve dry condition performance.



However, we believe that formulations involving VPD, such as those adopted by ED2, G'DAY and JULES (Table 1) are theoretically preferable because, unlike RH, VPD is directly proportional to water loss, more closely reflects stomatal mechanics (e.g. Aphalo & Jarvis, 1991; De Beeck *et al.*, 2010), and is strongly linked to productivity (Lobell *et al.*, 2014; Ort & Long, 2014). In addition, formulations involving VPD, rather than RH, will likely be better able to project the response of vegetation to future climate

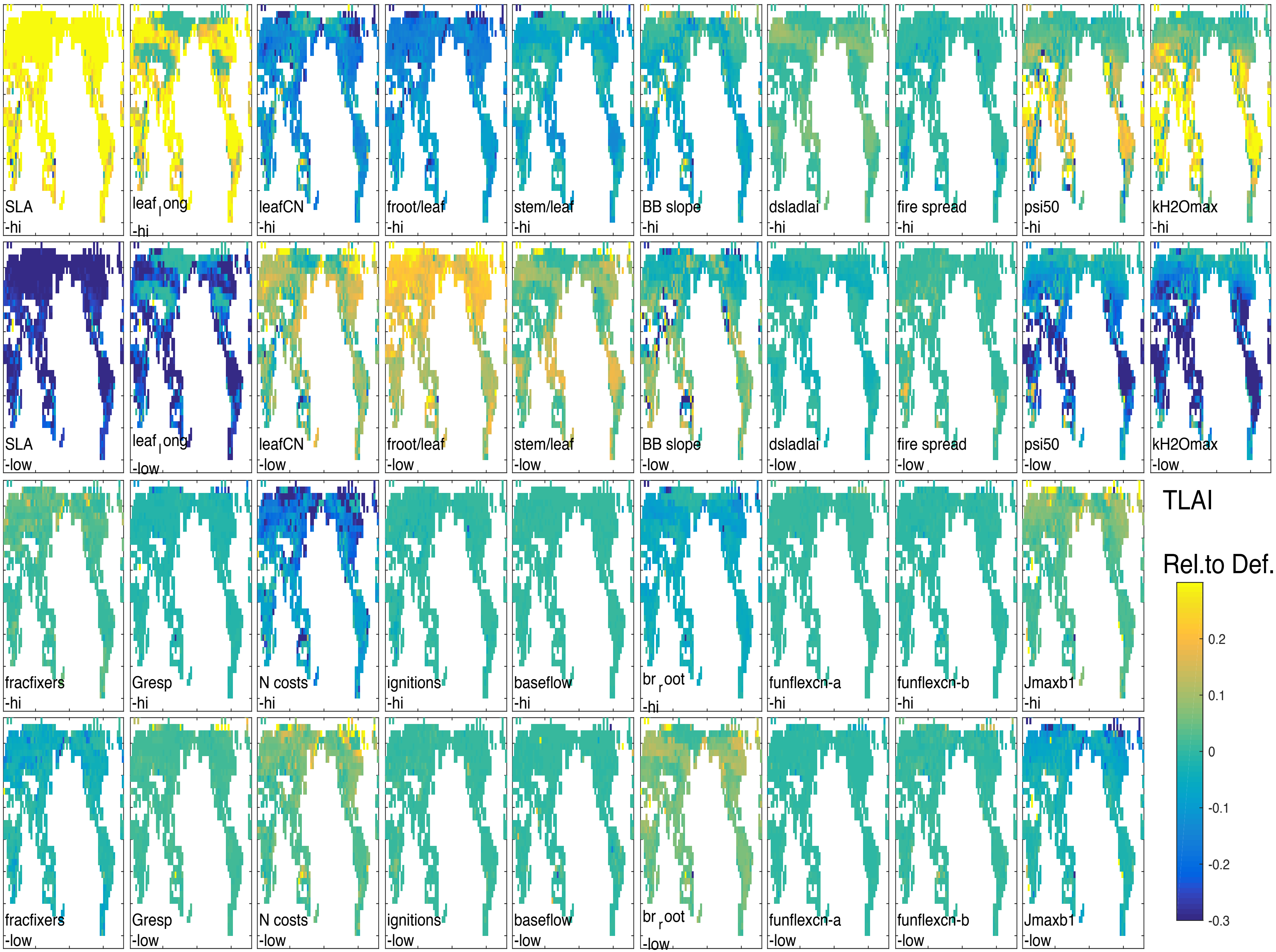
(Some) New CLM5 Parameters

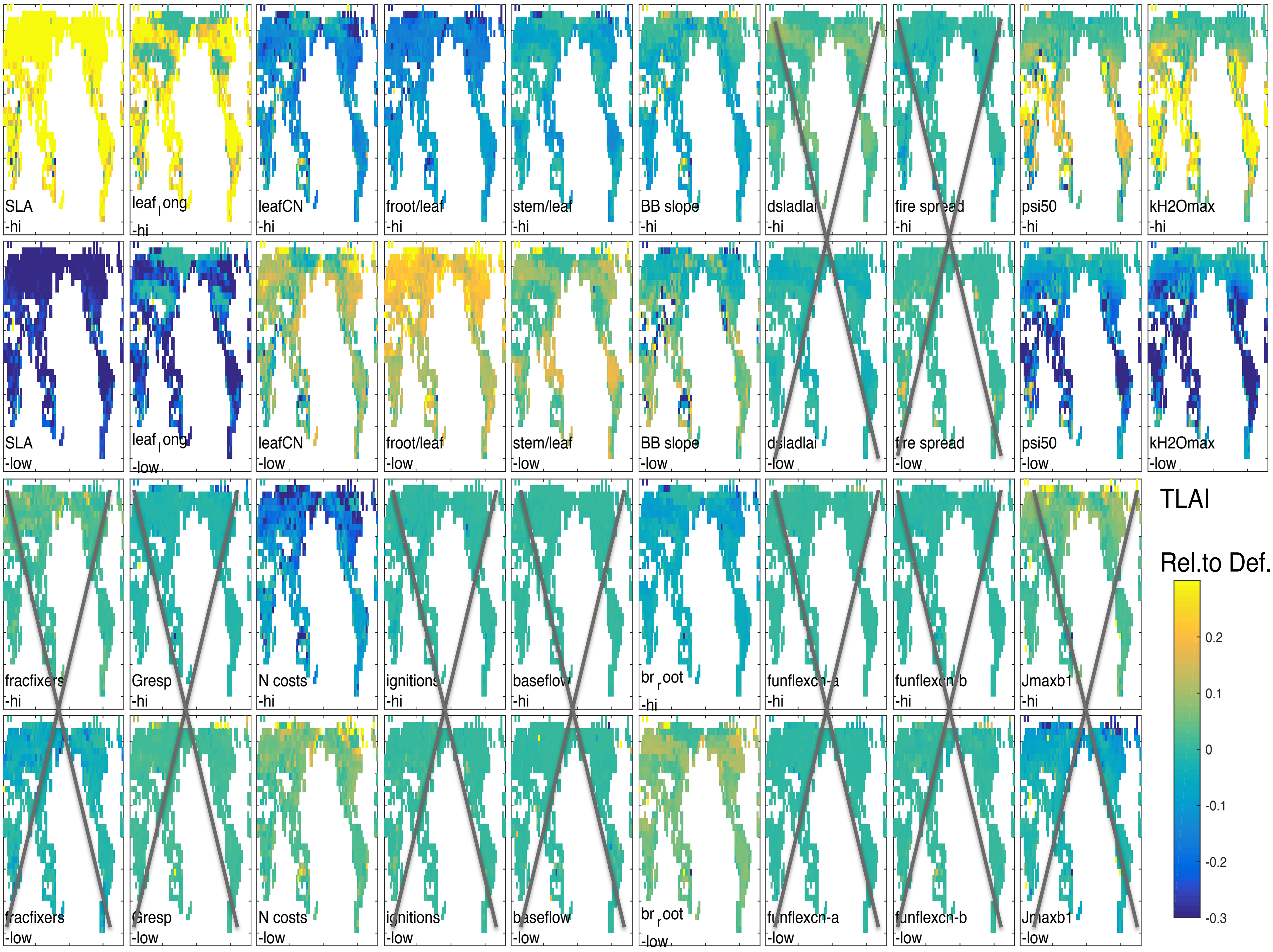
- Plant Hydrodynamics
  - ψ50
  - K_{MAX}
  - K_{RMAX}

- Medlyn Photosynthesis
  - G1 stomatal slope

- Nitrogen Model
  - leafCN target
  - N costs
  - Fraction N fixers

Initial sensitivity search


SLA -hi
leaf long -hi
leafCN -hi
froot/leaf -hi
stem/leaf -hi
BB slope -hi
dsladlai -hi
fire spread -hi
psi50 -hi
kH2Omax -hi
SLA -low
leaf long -low
leafCN -low
froot/leaf -low
stem/leaf -low
BB slope -low
dsladlai -low
fire spread -low
psi50 -low
kH2Omax -low
fracfixers -hi
Gresp -hi
N costs -hi
ignitions -hi
baseflow -hi
br root -hi
funflexcn-a -hi
funflexcn-b -hi
Jmaxb1 -hi
TLAI
Rel.to Def.
0.2
0.1
0
-0.1
-0.2
-0.3
fracfixers -low
Gresp -low
N costs -low
ignitions -low
baseflow -low
br root -low
funflexcn-a -low
funflexcn-b -low
Jmaxb1 -low


SLA -hi
leaf long -hi
leafCN -hi
froot/leaf -hi
stem/leaf -hi
BB slope -hi
dsladlai -hi
fire spread -hi
psi50 -hi
kH2Omax -hi
SLA -low
leaf long -low
leafCN -low
froot/leaf -low
stem/leaf -low
BB slope -low
dsladlai -low
fire spread -low
psi50 -low
kH2Omax -low
fracfixers -hi
Gresp -hi
N costs -hi
ignitions -hi
baseflow -hi
br root -hi
funflexcn-a -hi
funflexcn-b -hi
Jmaxb1 -hi
fracfixers -low
Gresp -low
N costs -low
ignitions -low
baseflow -low
br root -low
funflexcn-a -low
funflexcn-b -low
Jmaxb1 -low
TLAI
Rel.to Def.
0.2
0.1
0
-0.1
-0.2
-0.3

2-PHASE CALIBRATION

- Whole 10D parameter space has too many dimensions

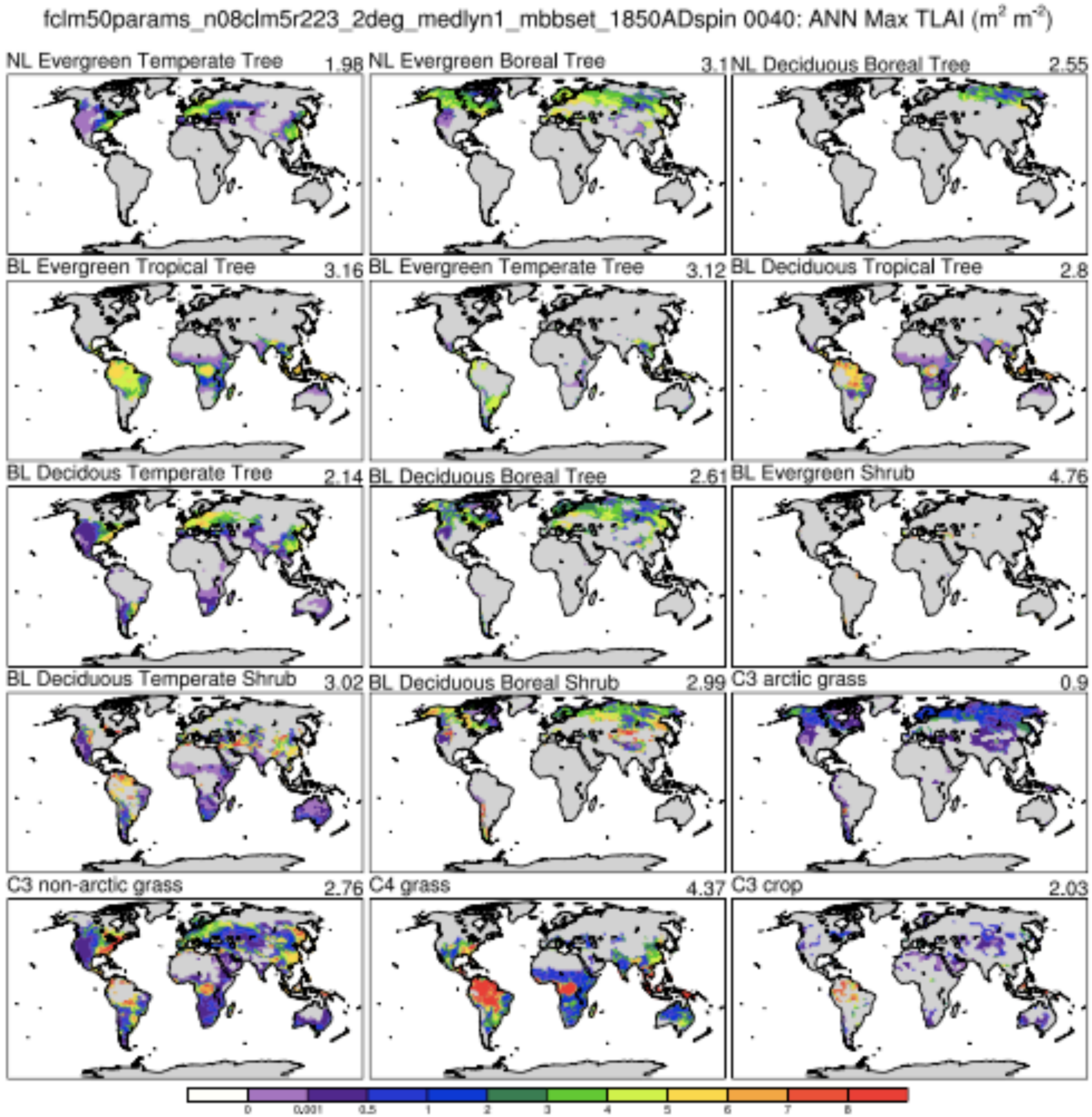
- **SP calibration** (driven with satellite Leaf Area Index). Parameters that operate '**upstream**' of GPP
  - Psi50 (water potential at 50% conductance loss)
  - KRMAX (maximum root condutance)
  - Ball Berry slope (stomatal conductance)
  - Leaf C:N ratio

- **BGC calibration** (with prognostic Leaf Area Index)
  - Specific Leaf Area
  - Leaf Longevity
  - Root: leaf ratio
  - Stem: leaf ratio
  - Nitrogen uptake costs

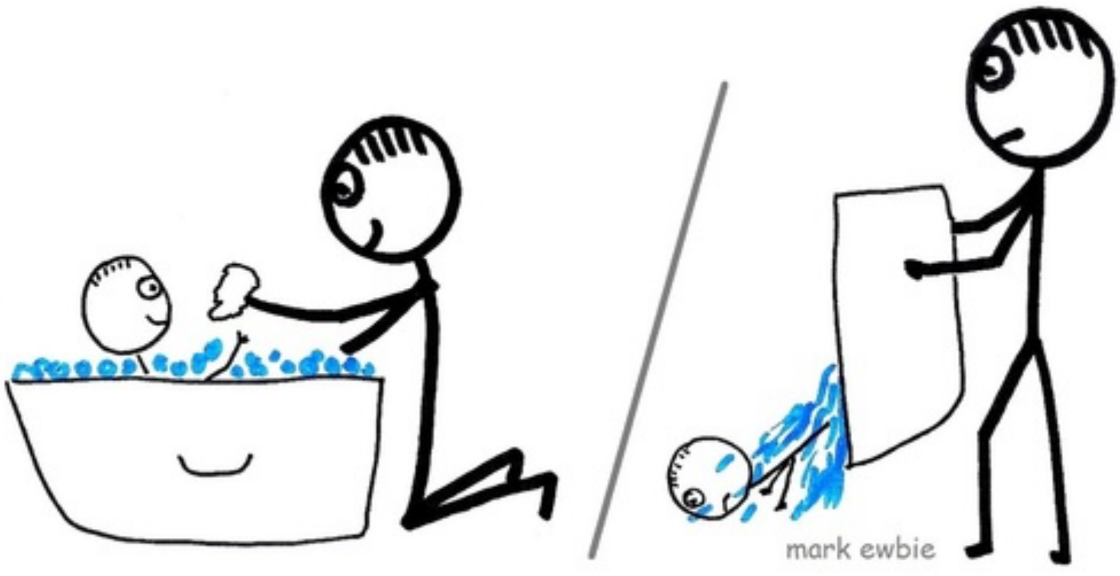
BEN…

Chimera-like parameter file

- Calibrated Values
- Some PFTs hand-tuned
- Model structure modified (Medlyn gs)
- Works OK, but mostly indefensible


fclm50params_n08clm5r223_2deg_medlyn1_mbbset_1850ADspin 0040: ANN Max TLAI (m² m⁻²)
NL Evergreen Temperate Tree
1.98
NL Evergreen Boreal Tree
3.1
NL Deciduous Boreal Tree
2.55
BL Evergreen Tropical Tree
3.16
BL Evergreen Temperate Tree
3.12
BL Deciduous Tropical Tree
2.8
BL Decidous Temperate Tree
2.14
BL Deciduous Boreal Tree
2.61
BL Evergreen Shrub
4.76
BL Deciduous Temperate Shrub
3.02
BL Deciduous Boreal Shrub
2.99
C3 arctic grass
0.9
C3 non-arctic grass
2.76
C4 grass
4.37
C3 crop
2.03
0
0.001
0.5
1
2
3
4
5
6
7
8

Throwing the baby out with the bath water



Throwing the baby out with the bath water

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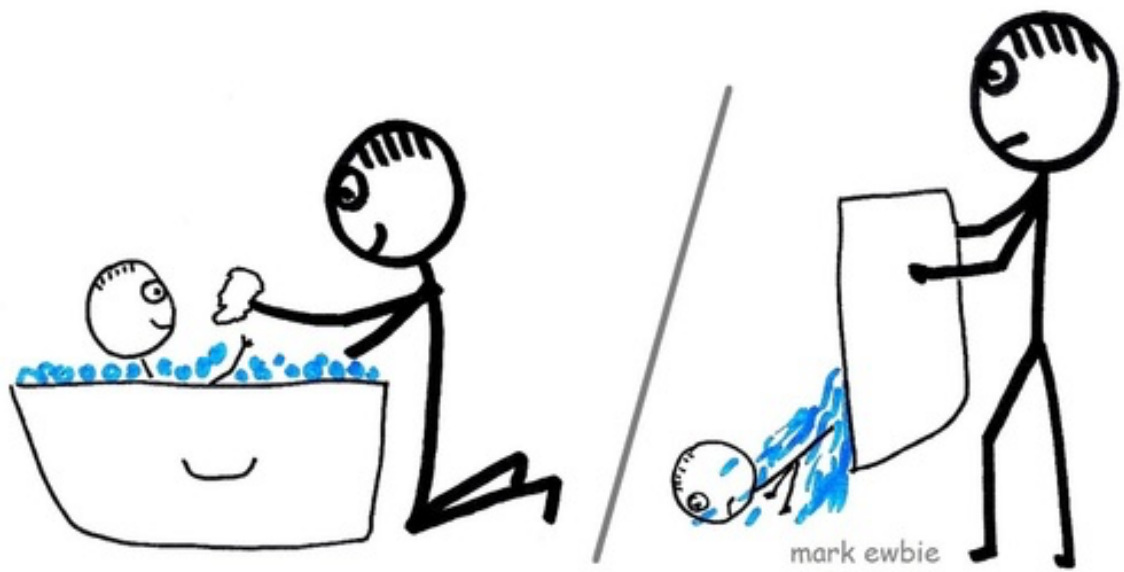
a Pragmatic Approach to parameterization



Sensitive Parameter Space

- Psi_{50} (Choat paper)
- K_{RMAX} (function of psi50)
- Medlyn Stomatal Slope (Medlyn paper)
- Leaf C:N ratio (TRY)

- Specific Leaf Area (TRY)
- Leaf Longevity (TRY)
- Root: leaf ratio
- Stem: leaf ratio
- Nitrogen uptake costs

Sensitive Parameter Space

New Philosophy

- Keep well constrained parameters at default values
- Introduce minimal variation in less constrained parameters
- Allows better traceability of PFT variation

Global Change Biology

Global Change Biology (2011) 17, 2905–2935, doi: 10.1111/j.1365-2486.2011.02451.x

TRY – a global database of plant traits

J. KATTGE*, S. DÍAZ†, S. LAVOREL‡, I. C. PRENTICE§, P. LEADLEY¶, G. BÖNISCH*, E. GARNIER‖, M. WESTOBY§, P. B. REICH**, ††, I. J. WRIGHT§, J. H. C. CORNELISSEN‡‡, C. VIOLLE‖, S. P. HARRISON§, P. M. VAN BODEGOM‡‡, M. REICHSTEIN*,

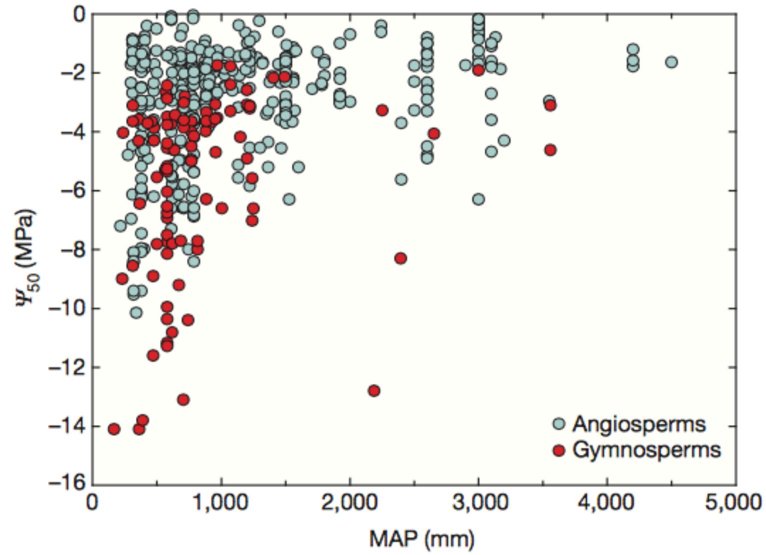
types (PFT)

	Seed mass			Plant height			LL			SLA			N_m			P_m			N_a		
	n	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD	*n*	Mean	SD
All data	49837	2.38	1.08	26624	1.84	0.78	1540	9.40	0.41	45733	16.60	0.26	33880	17.40	0.18	17056	1.23	0.24	12860	1.59	0.19
PFT summary																					
Mean		5.27	0.79		2.67	0.43		11.42	0.25		15.08	0.20		17.46	0.16		1.24	0.21		1.53	0.17
SD between		0.90			0.69			0.40			0.18			0.10			0.14			0.11	
n/PFT	2623			1401			91			2407			1783			898			677		
Sign. *P*	***			***			***			***			***			***			***		
Species summary																					
Mean		2.12	0.13		3.06	0.18		9.09	0.03		18.84	0.09		18.37	0.08		1.22	0.11		1.48	0.10
SD between		1.03			0.81			0.40			0.22			0.16			0.23			0.16	
nsp	2707			882			363			2423			1250			649			519		
n/sp	11			10			3			16			18			16			15		
Sign. *P*	***			***			***			***			***			***			***		
Plant functional types																					
Fern (218)	3	0.08	0.83	329	0.75	0.47	13	28.48	0.25	647	18.86	0.22	143	14.77	0.19	91	0.72	0.21	50	1.14	0.20
Grass C3 (594)	3935	0.61	0.70	1242	0.44	0.31	81	3.85	0.22	5033	20.12	0.20	2669	17.84	0.16	1435	1.43	0.23	1075	1.14	0.17
Grass C4 (248)	635	0.58	0.60	383	0.64	0.33	6	1.68	0.18	583	19.23	0.22	1128	14.14	0.15	150	1.36	0.23	232	0.93	0.16
Herb C3 (3129)	15506	0.77	0.82	3404	0.38	0.38	215	3.49	0.25	18830	22.83	0.19	4893	23.31	0.16	1870	2.02	0.21	2798	1.29	0.18
Herb C4 (63)	183	0.49	0.53	36	0.25	0.55		1.00	0.00	212	20.20	0.25	87	18.78	0.24	47	1.86	0.25	127	1.31	0.14
Climber nonwoody (233)	751	15.25	0.57	268	1.05	0.48	17	8.99	0.35	949	23.40	0.20	295	25.34	0.17	143	1.38	0.26	154	1.33	0.19
Climber woody (73)	102	15.16	0.43	76	3.74	0.51	7	16.68	0.35	443	14.73	0.19	157	21.34	0.14	101	1.62	0.23	42	1.32	0.20
Shrub broadleaved deciduous (596)	1573	6.67	0.99	1221	3.59	0.49	167	4.68	0.19	3838	15.36	0.18	2223	21.50	0.14	1209	1.56	0.20	748	1.45	0.18
Shrub broadleaved evergreen (1162)	1911	4.02	0.98	1694	1.61	0.55	284	15.88	0.26	3216	8.99	0.21	2623	13.73	0.18	1504	0.84	0.25	1033	1.90	0.19
Shrub needleleaved (83)	256	2.55	1.28	121	3.53	0.58	17	36.66	0.25	303	7.43	0.15	223	10.11	0.15	123	0.74	0.26	89	1.83	0.17
Tree broadleaved deciduous (699)	1606	33.80	1.09	1471	20.82	0.28	240	5.83	0.17	3963	15.40	0.17	4343	21.32	0.13	2225	1.44	0.20	1723	1.57	0.16
Tree broadleaved evergreen (2136)	1487	27.64	1.07	1973	16.56	0.36	360	16.83	0.29	3859	9.46	0.19	5921	16.89	0.16	3177	0.86	0.20	2723	1.87	0.15
Tree needleleaved deciduous (16)	64	6.88	0.57	88	32.98	0.20	12	6.08	0.01	129	10.09	0.09	248	19.37	0.10	155	1.83	0.15	37	1.80	0.13
Tree needleleaved evergreen (134)	889	13.77	0.63	882	27.20	0.30	63	39.71	0.21	1517	5.00	0.13	5558	12.09	0.10	3622	1.23	0.16	984	2.62	0.14

doi:10.1038/nature1168

Global convergence in the vulnerability of forests to drought

Brendan Choat[1]*, Steven Jansen[2]*, Tim J. Brodribb[3], Hervé Cochard[4,5], Sylvain Delzon[6], Radika Bhaskar[7], Sandra J. Bucci[8], Taylor S. Feild[9], Sean M. Gleason[10], Uwe G. Hacke[11], Anna L. Jacobsen[12], Frederic Lens[13], Hafiz Maherali[14], Jordi Martínez-Vilalta[15,16], Stefan Mayr[17], Maurizio Mencuccini[18,19], Patrick J. Mitchell[20], Andrea Nardini[21], Jarmila Pittermann[2 R. Brandon Pratt[12], John S. Sperry[23], Mark Westoby[10], Ian J. Wright[10] & Amy E. Zanne[24,25]



Group	Species	ψ50	ψ88	ψmin midday	ψmin	ψ50 safety	ψ88 safety	MAT (me	MAP (me	MPDQ (me	PET (pote	AI (aridity	Growth f	Developr	Biome	Latitude	Longitude	Elevation
		MPa	MPa	MPa	Leaf or stem	MPa	MPa	°C	mm	mm	mm							m
Angiosperm	*Acacia cyclops*	-0.91						15.20	875.00	38	1333	0.6564	Tree	Adult	woodland/shruland	-32.9000	115.6900	20
Angiosperm	*Acacia greggii*	-0.88	-4.06	-3.74	Xylem water p	-2.86	0.32	15.98	310.00	21	1620	0.1914	Tree	Adult	woodland/shruland	32.0127	-110.6291	1036
Angiosperm	*Acer campestre*	-2.00						11.71	937.00	217	928	1.0097	Tree	Adult	temperate seasonal forest	45.3333	5.5000	200
Angiosperm	*Acer glabrum*	-2.30						6.18	713.00	104	965	0.7389	Tree	Adult	woodland/shruland	40.7000	-111.6833	2134
Angiosperm	*Acer grandidentatum*	-3.66	-7.14	-4.15	Xylem water p	-0.49	2.99	6.18	713.00	104	965	0.7389	Tree	Adult	woodland/shruland	40.7000	-111.6833	2134
Angiosperm	*Acer monspessulanum*	-3.31	-4.60	-5.50	Leaf water pot	-2.19	-0.90	10.90	709.00	129	938	0.7559	Tree	Adult	woodland/shruland	41.2167	0.9167	1000
Angiosperm	*Acer negundo*	-1.34	-2.74	-1.12	Xylem water p	0.22	1.62	6.58	683.10	91	1103	0.6193	Tree	Adult	temperate seasonal forest	40.2500	-111.6167	2000
Angiosperm	*Acer opalus*	-2.45						8.70	1026.00	195	933	1.0997	Shrub	Adult	temperate seasonal forest	45.2000	5.7333	800
Angiosperm	*Acer platanoides*	-1.80						11.71	937.00	217	928	1.0097	Tree	Adult	temperate seasonal forest	45.3333	5.5000	200
Angiosperm	*Acer pseudoplatanus*	-1.60						11.71	937.00	217	928	1.0097	Tree	Adult	temperate seasonal forest	45.3333	5.5000	200
Angiosperm	*Acer rubrum*	-1.97	-4.50	-1.30	Xylem water p	0.67	3.20	15.00	1220.00	259	1273	0.9584	Tree	Adult	temperate seasonal forest	36.0167	-78.9833	150
Angiosperm	*Acer saccharum*	-3.87						7.18	891.00	151	881	1.0114	Tree	Adult	temperate seasonal forest	44.5000	-73.1167	110
Angiosperm	*Adansonia rubrostipa*	-1.10	-2.82	-0.95	Xylem water p	0.15	1.87	21.81	770.00	5	1923	0.4004	Tree	Adult	tropical seasonal forest	-20.4500	44.8167	150
Angiosperm	*Adansonia za*	-1.70	-3.49	-0.97	Xylem water p	0.73	2.52	21.81	770.00	5	1923	0.4004	Tree	Adult	tropical seasonal forest	-20.4500	44.8167	150
Angiosperm	*Adenostoma fasciculatum*	-7.98	-12.02	-6.53	Xylem water p	1.45	5.49	14.56	399.60	5	1218	0.3281	Shrub	Adult	woodland/shruland	34.0833	-118.8416	480
Angiosperm	*Adenostoma sparsifolium*	-4.89	-8.00	-4.06	Xylem water p	0.83	3.94	14.56	399.60	5	1218	0.3281	Shrub	Adult	woodland/shruland	34.0833	-118.8416	480
Angiosperm	*Aglaia glabrata*	-0.71						27.21	3000.00	587	1471	2.0394	Tree	Adult	tropical rainforest	4.5594	114.4213	13
Angiosperm	*Agonis flexuosa*	-2.36						15.20	875.00	38	1333	0.6564	Tree	Adult	woodland/shruland	-32.9000	115.6900	20
Angiosperm	*Albizia julibrissin*	-0.09						9.45	610.00	86	1145	0.5328	Tree	Adult	woodland/shruland	40.7667	-111.8333	1460
Angiosperm	*Aleurites moluccana*	-2.17						21.70	1560.00	72	1468	1.0627	Shrub	Adult	tropical seasonal forest	21.6833	101.4167	570
Angiosperm	*Allocasuarina campestris*	-2.96	-8.50	-7.00	Leaf water pot	-4.04	1.50	17.15	375.00	41	1434	0.2615	Shrub	Adult	woodland/shruland	-32.3167	117.8667	300
Angiosperm	*Alnus cordata*	-1.40						14.40	900.00	146	1027	0.8763	Tree	Adult	temperate seasonal forest	43.8000	11.2000	40

Reconciling the optimal and empirical approaches to modelling stomatal conductance

BELINDA E. MEDLYN*, REMKO A. DUURSMA†, DEREK EAMUS‡, DAVID S. ELLSWORTH†, I. COLIN PRENTICE*, CRAIG V. M. BARTON§, KRISTINE Y. CROUS¶, PAOLO DE ANGELIS‖, MICHAEL FREEMAN** and LISA WINGATE††

Table 2 Statistics of fits of the three alternative models to example datasets

		Eqn (2) (Ball *et al.* 1987)			Eqn (3) (Leuning, 1995)				Eqn (11) (this paper)		
Dataset	n	g_0	g_1	R^2	g_0	g_1	D_0	R^2	g_0	g_1	R^2
Sitka A	77	0.039 (0.004)	4.55 (0.38)	0.651	0.038 (0.003)	7.35 (0.92)	0.35 (0.08)	0.724	**0.033 (0.003)**	**1.66 (0.14)**	**0.759**
Sitka B	27	0.027 (0.008)	5.17 (0.67)	0.704	0.024 (0.01)	5.36 (2.24)	1.89 (2.22)*	0.729	**0.022 (0.008)**	**2.57 (0.43)**	**0.732**
Duke Pine	136	0.057 (0.019)	7.14 (1.36)	0.170	0.007 (0.02)*	10.96 (2.67)	1.15 (0.58)	0.522	**-0.007 (0.013)***	**5.08 (0.49)**	**0.527**
Alpine Ash	60	0.016 (0.016)*	11.98 (1.0)	0.716	0.001 (0.01)*	14.43 (2.37)	0.95 (0.33)	0.801	**-0.004 (0.014)***	**6.06 (0.46)**	**0.797**
Macchia	47	**0.038 (0.008)***	**9.09 (0.92)**	**0.684**	0.03 (0.01)	14.7 (10.1)*	1.22 (1.25)*	0.631	0.028 (0.01)	5.95 (0.89)	0.613
Fagus	24	**−0.002 (0.015)***	**11.24 (0.88)**	**0.881**	-0.06 (0.04)*	8.17 (1.94)	7.28 (10.0)*	0.782	-0.044 (0.025)*	6.99 (0.93)	0.778
Savanna	77	0.048 (0.015)	13.62 (0.89)	0.756	**0.023 (0.02)***	**141.3 (524)***	**0.125 (0.5)***	**0.77**	-0.004 (0.02)*	11.23 (0.97)	0.685
Red Gum	96	0.016 (0.007)	15.27 (1.03)	0.702	**0.014 (0.007)**	**68.7 (103)***	**0.43 (0.72)***	**0.739**	0.009 (0.007)*	12.13 (0.96)	0.690

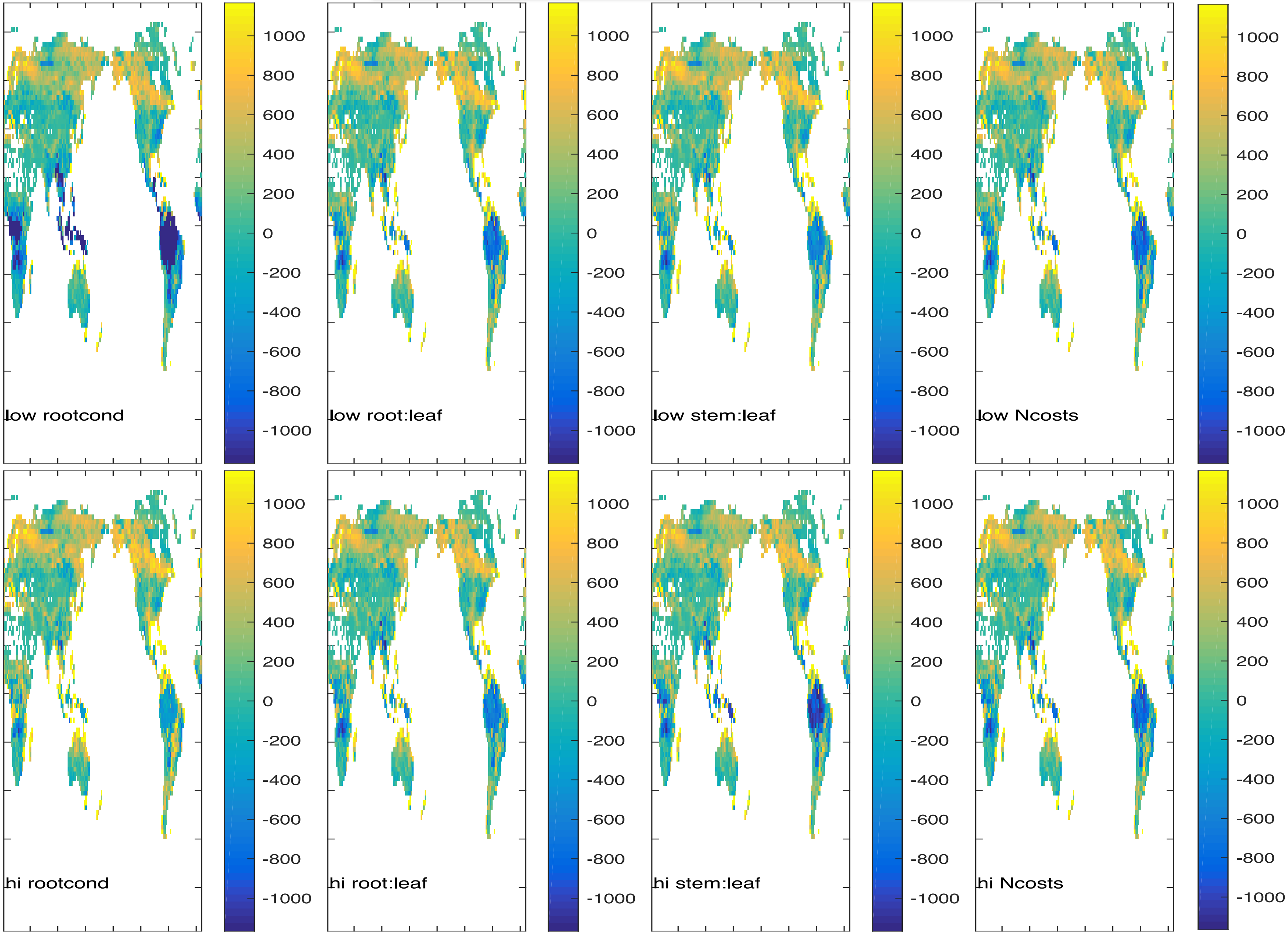
Reduced Parameter Space

- Psi50 (Choat paper)
- KRMAX (function of psi50)
- Medlyn Stomatal Slope (Medlyn paper)
- Leaf C:N ratio (TRY)

- Specific Leaf Area (TRY)
- Leaf Longevity (TRY)
- Root: leaf ratio
- Stem: leaf ratio
- Nitrogen uptake costs

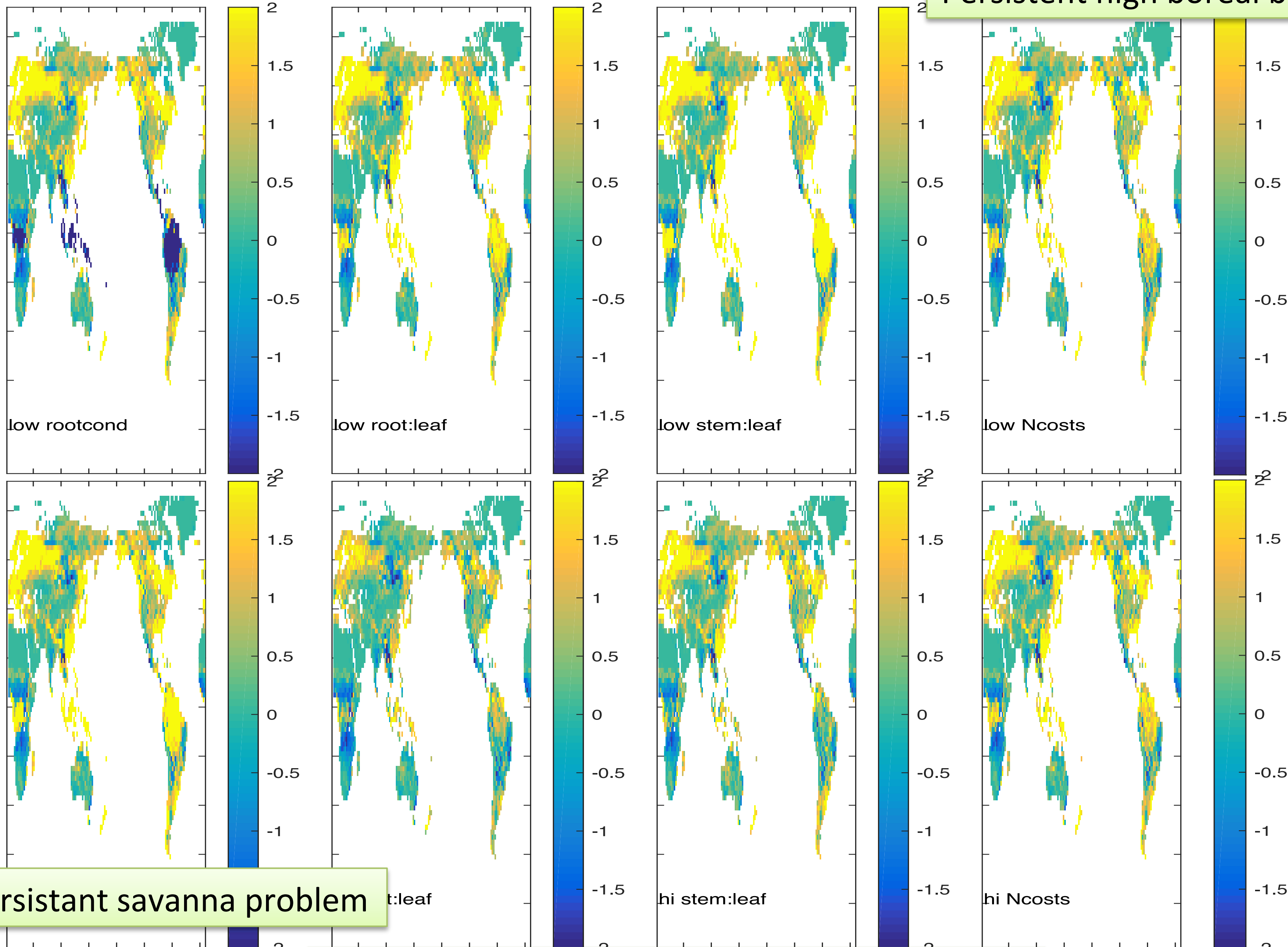
GPP bias (gC/m2/y)

Nothing improves boreal forest high bias



Amazon bias improved w/ krmax

LAI bias (m2/m2)



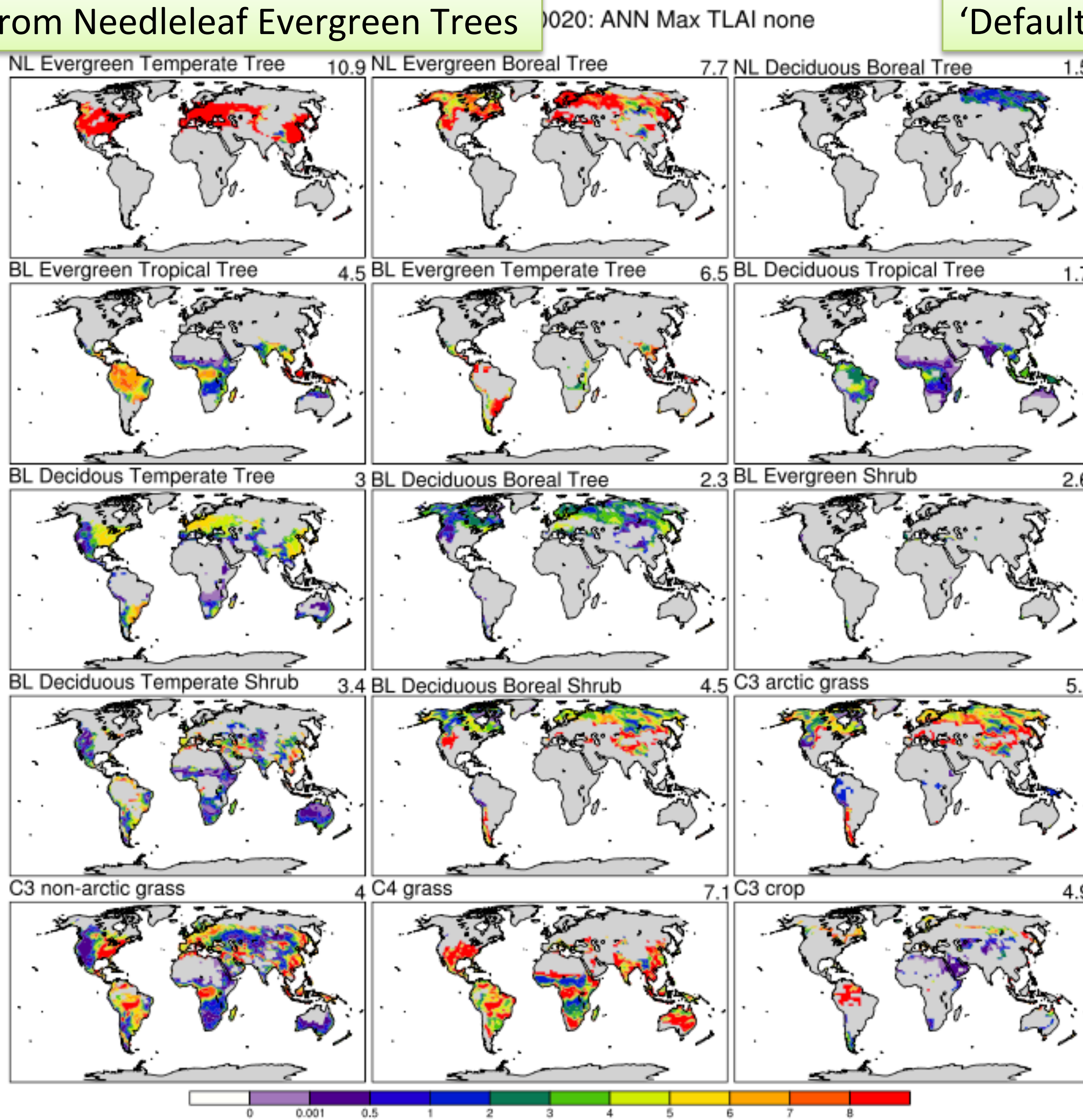
Persistent high boreal bias

Persistant savanna problem

LAI improved by more root and stem allocation

Boreal bias from Needleleaf Evergreen Trees

'Default' PFT level LAI



Reduced Parameter Space

Nothing improves boreal forest high GPP bias

Need to increase leafCN for NET

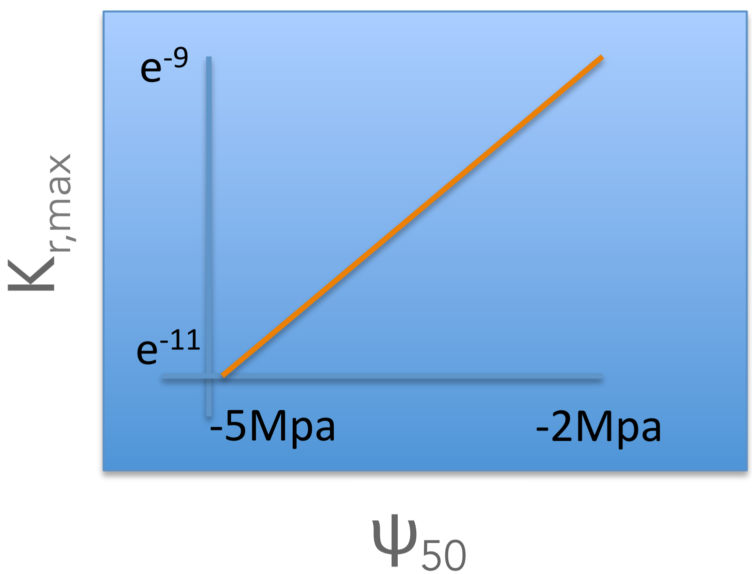
LAI improved by more root and stem allocation

Increase root & stem frac. for all PFTs

Amazon bias improved w/ krmax

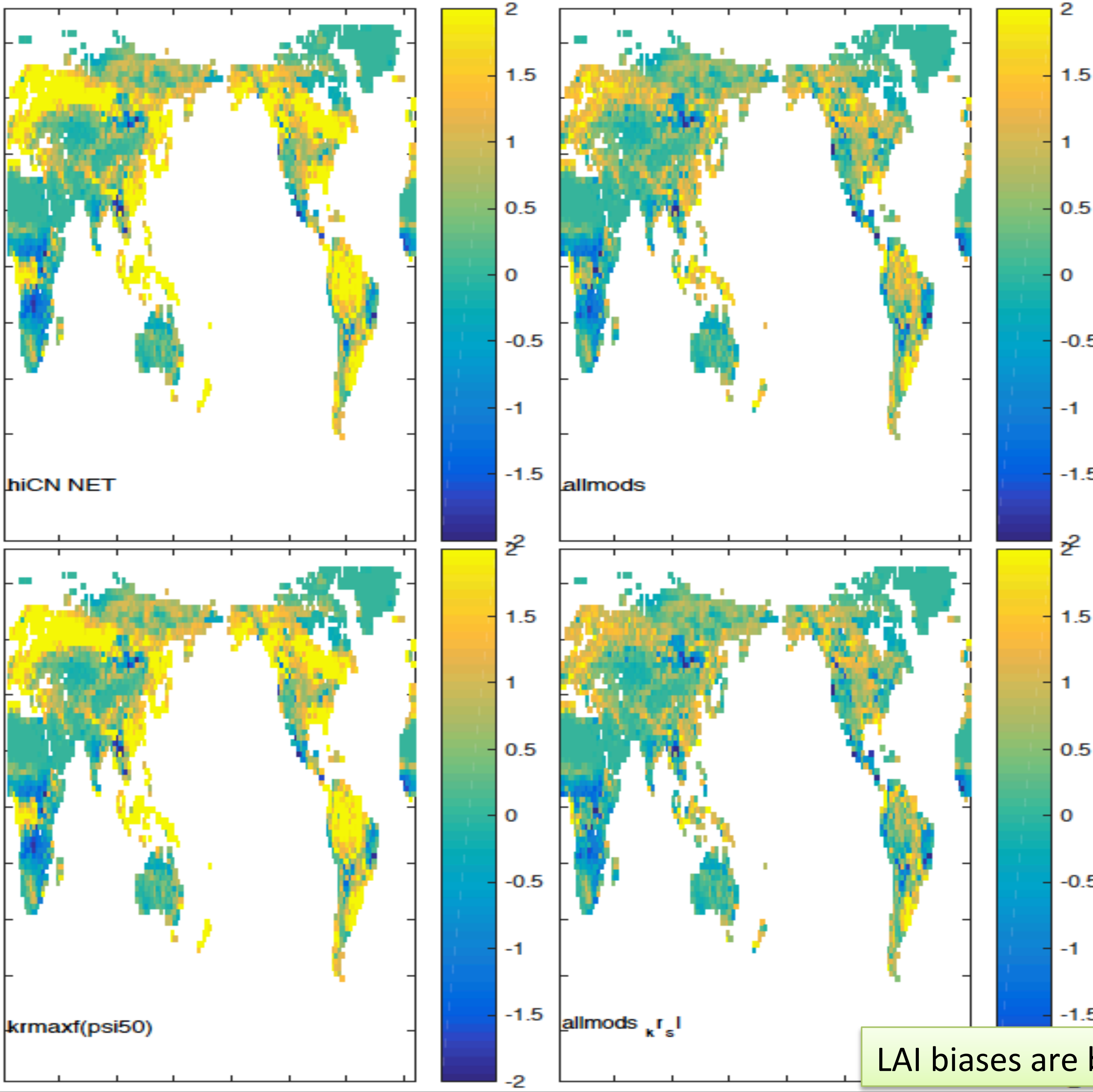
How to boost tropical productivity but not boreal?

$K_{rmax} = f(\psi_{50})$



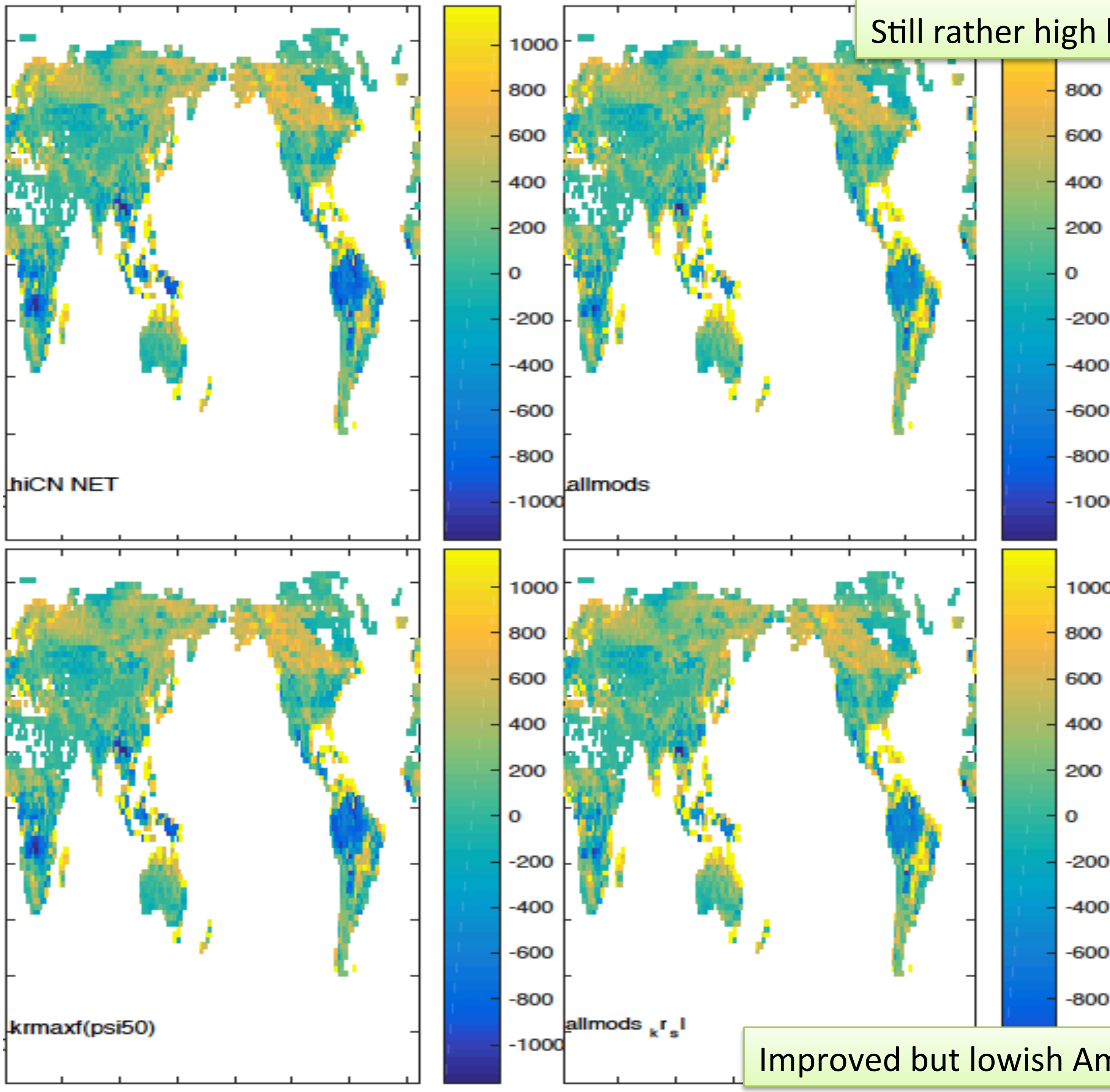
- $K_{r,max}$ is the conductivity of the whole root system
- Hence its value is hard to determine from observations of root sections
- Hydraulic literature generally finds a safety/efficiency trade-off in xylem performance
- Tropical PFTs have wetter ψ_{50} than boreal PFTs (-2.7 vs -4.6)

LAI bias
(m2/m2)



LAI biases are better…

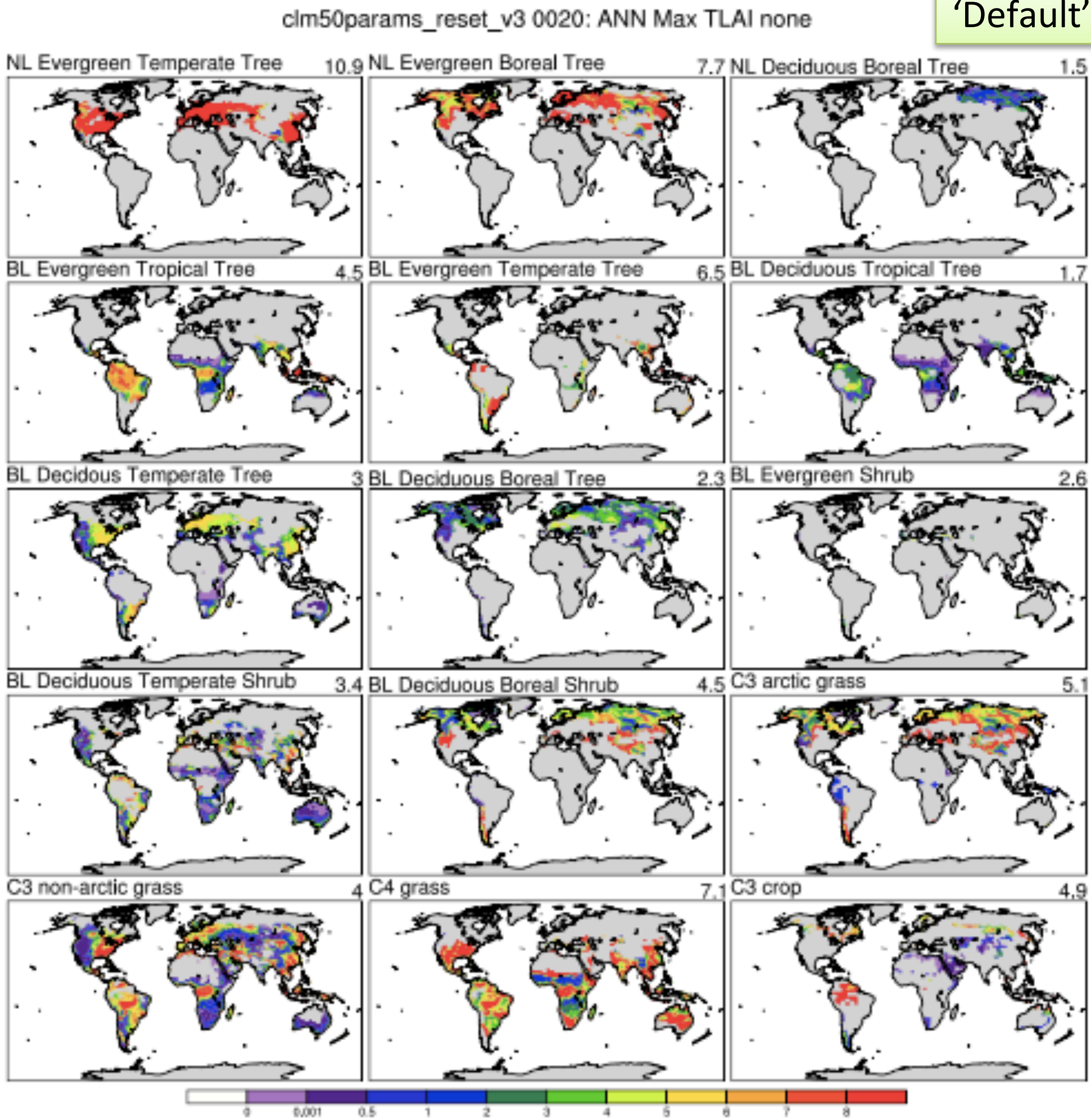
GPP bias (gC/m2/y)



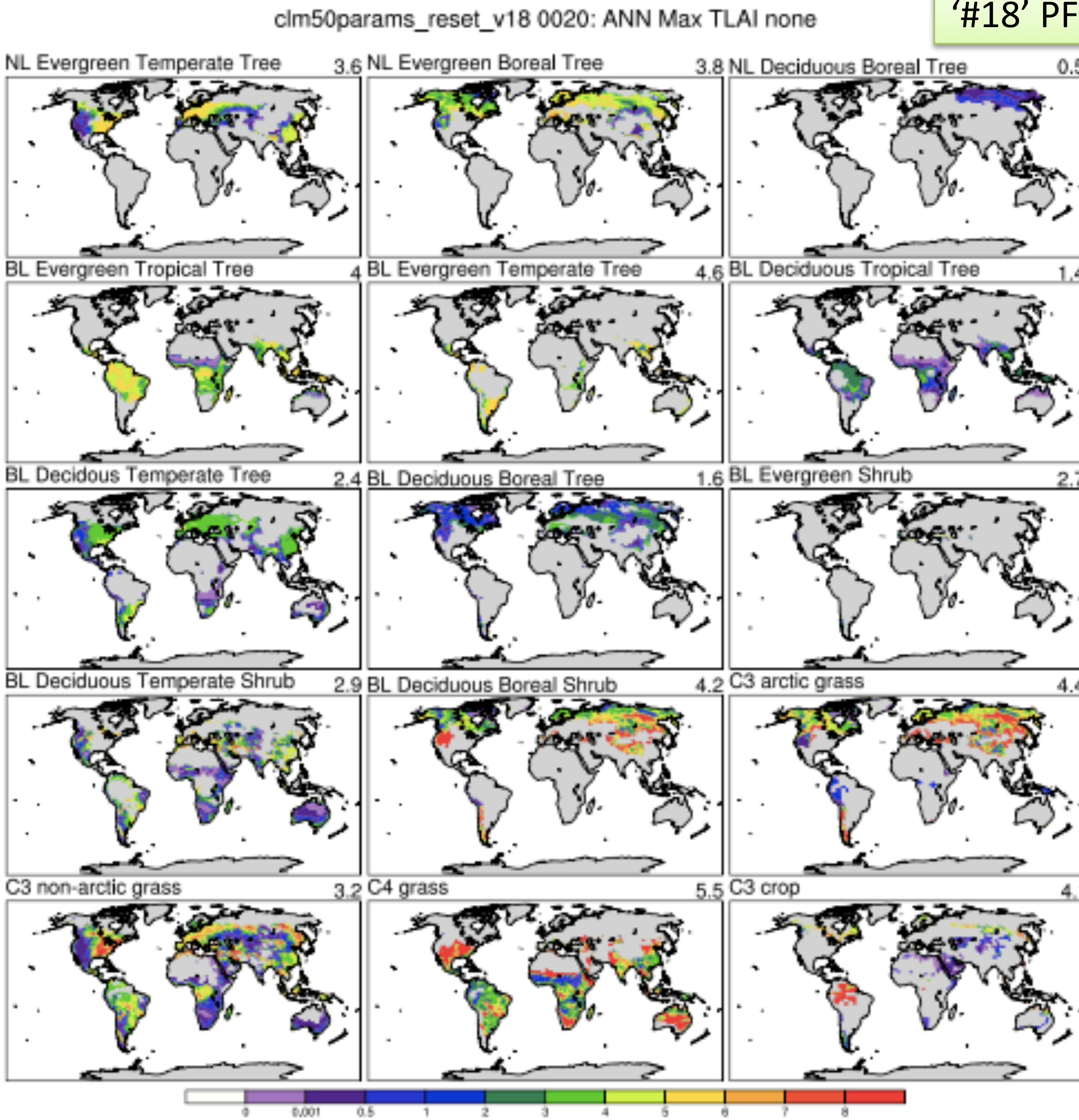
Still rather high boreal GPP

Improved but lowish Amazon GPP

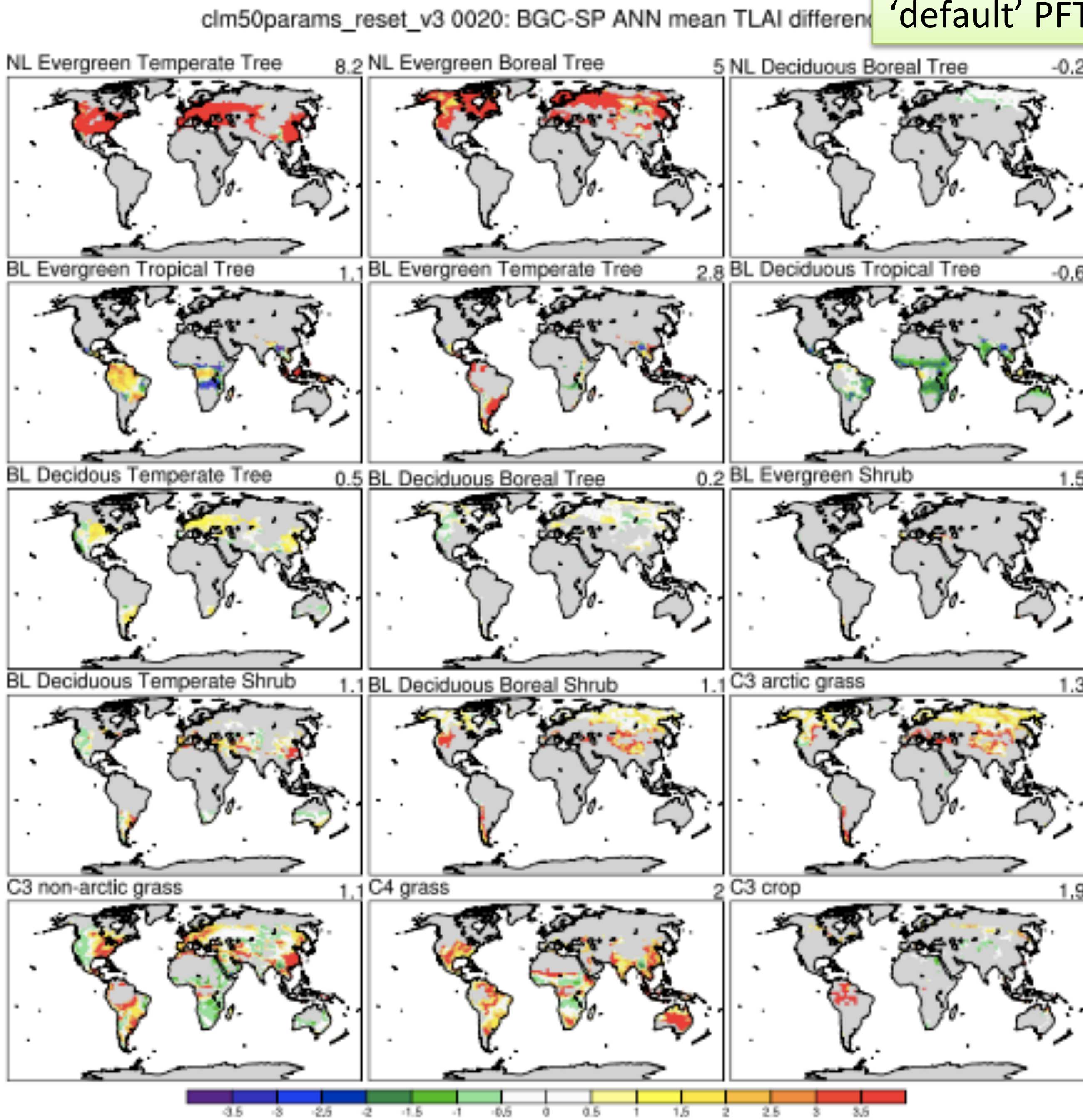
‘Default’ PFT level LAI



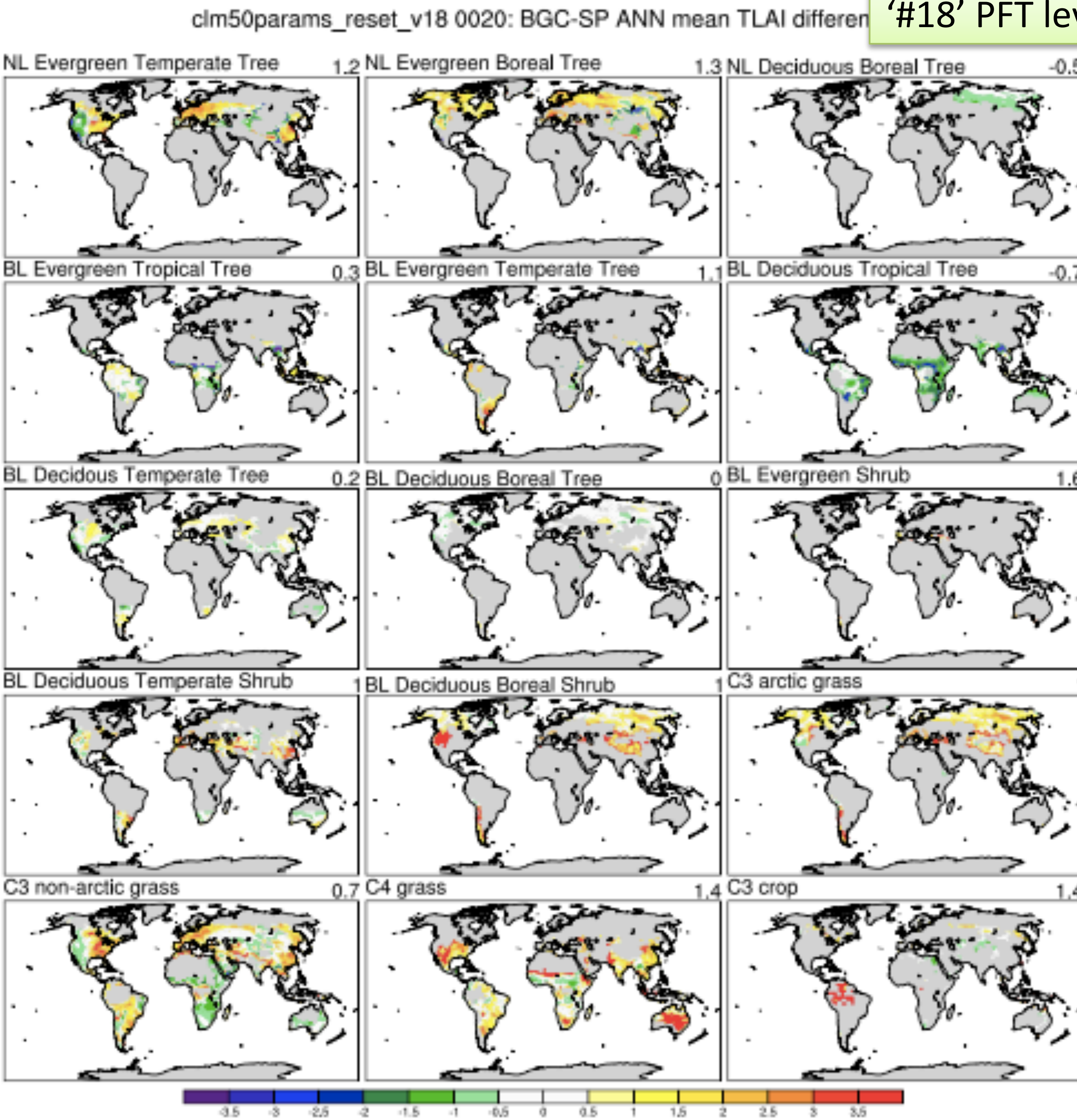
‘#18’ PFT level LAI



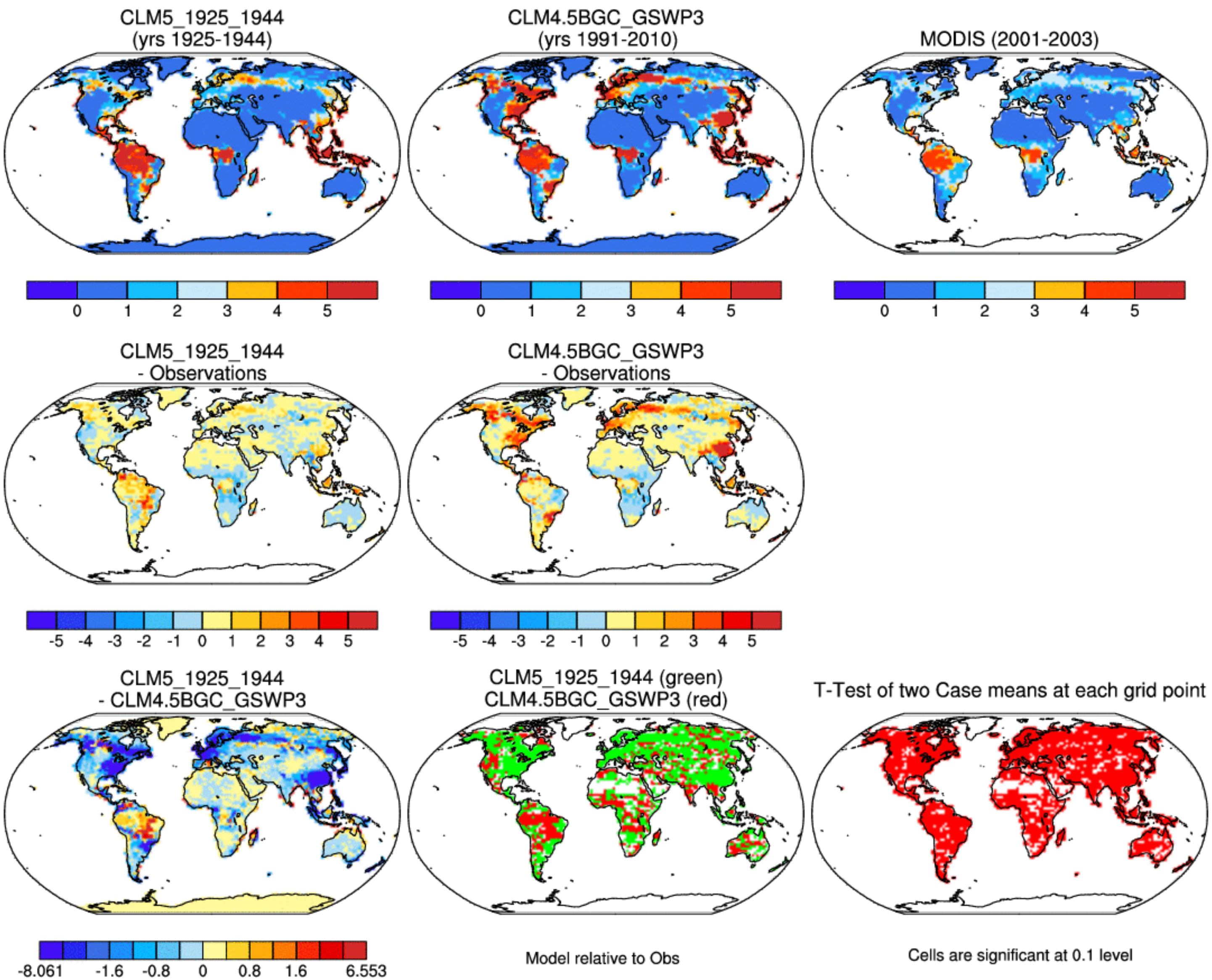
'default' PFT level LAI bias

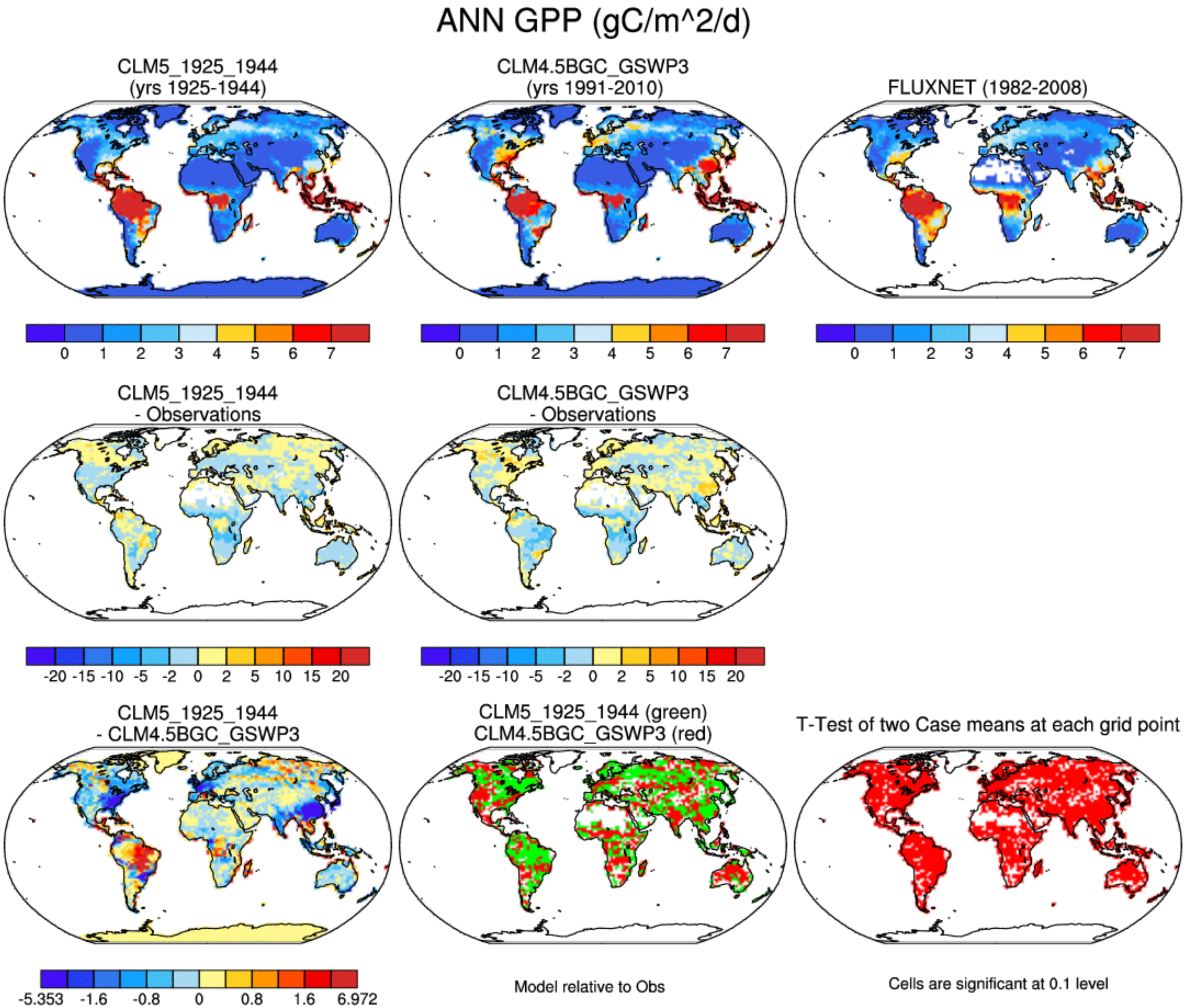


‘#18’ PFT level LAI bias



ANN TLAI (m2/m2)




ANN GPP (gC/m^2/d)
CLM5_1925_1944
(yrs 1925-1944)
CLM4.5BGC_GSWP3
(yrs 1991-2010)
FLUXNET (1982-2008)
0 1 2 3 4 5 6 7
0 1 2 3 4 5 6 7
0 1 2 3 4 5 6 7
CLM5_1925_1944
- Observations
CLM4.5BGC_GSWP3
- Observations
-20 -15 -10 -5 -2 0 2 5 10 15 20
-20 -15 -10 -5 -2 0 2 5 10 15 20
CLM5_1925_1944
- CLM4.5BGC_GSWP3
CLM5_1925_1944 (green)
CLM4.5BGC_GSWP3 (red)
T-Test of two Case means at each grid point
-5.353 -1.6 -0.8 0 0.8 1.6 6.972
Model relative to Obs
Cells are significant at 0.1 level

Conclusions

- The model has some persistent biases that we don't understand
  - High boreal productivity
  - Low savanna productivity
  - Massive C4 grass production in absence of strong limitations

- Parameter choice in a massive dimensional space is hard(!)

- Finding the optimal approach will be an ongoing research topic