NATURAL ENVIRONMENT RESEARCH COUNCIL

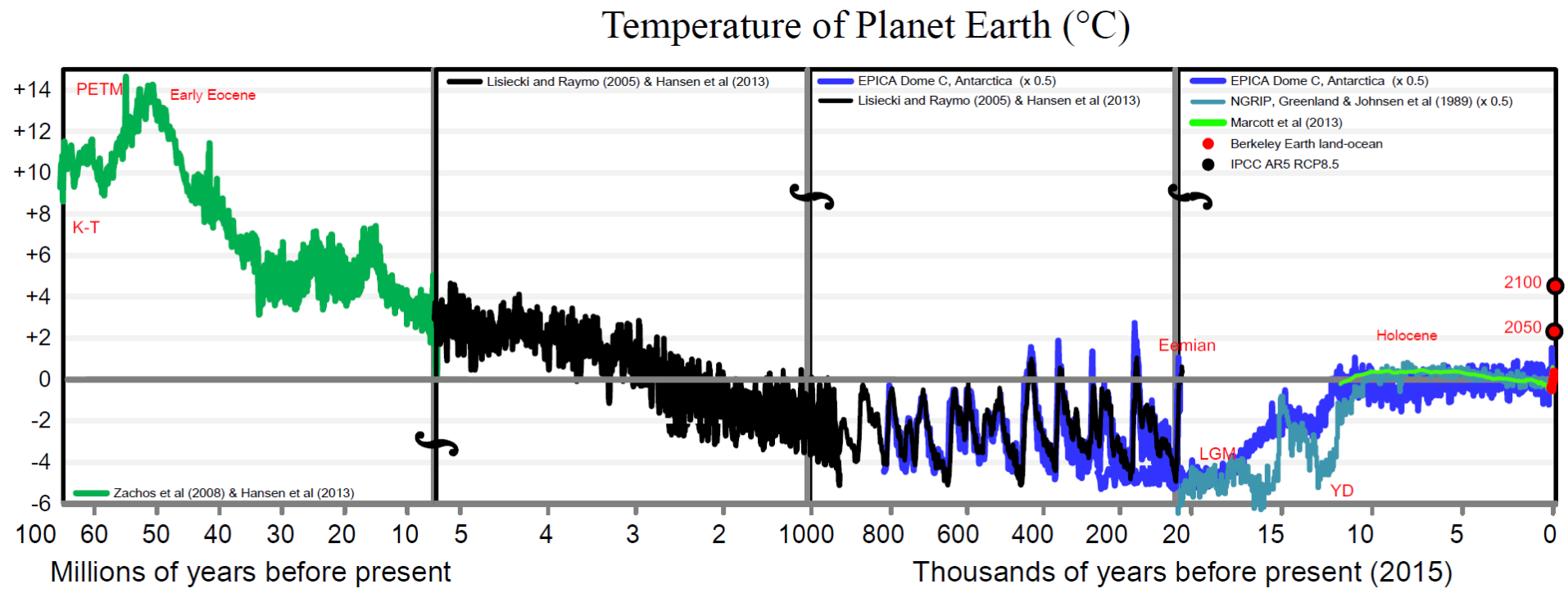
University of BRISTOL

What can we learn from simulations of the last ice-age with JULES?

Peter Hopcroft[1], Paul Valdes[1], Anna Harper[2] and Ron Kahana[3]

[1] School of Geographical Sciences, University of Bristol. [2] College of Engineering, Mathematics and Physical Sciences , University of Exeter. [3] Met Office, Exeter

The last ice-age in context



Wikipedia

Last Glacial Maximum (LGM): 21kyr

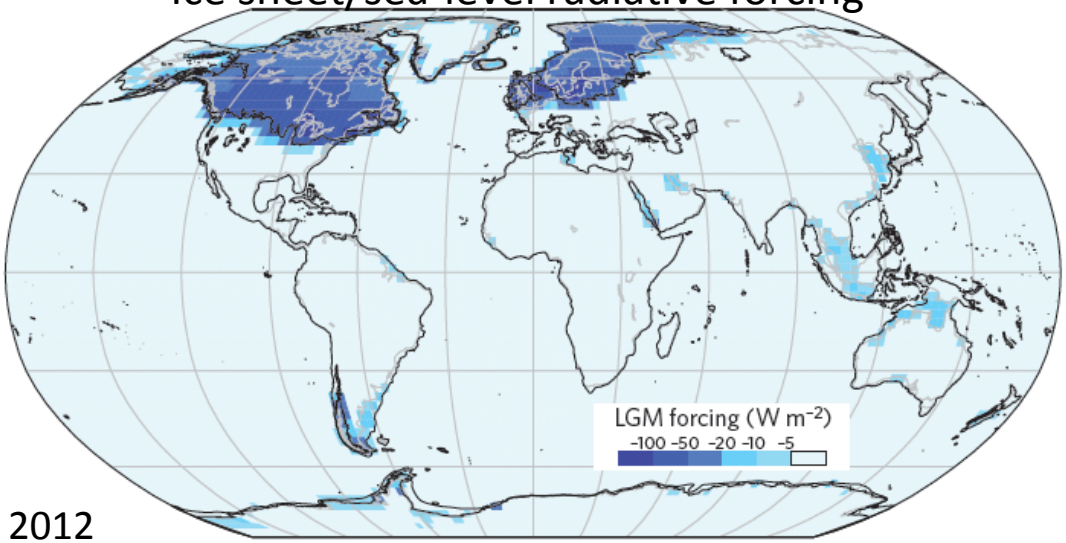
Greenhouse gases:

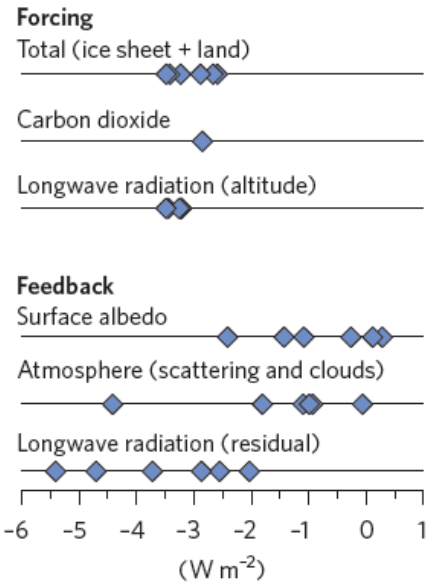
CO_2 = 185 ppm

CH_4 = 370 ppb

N_2O = 200 ppb

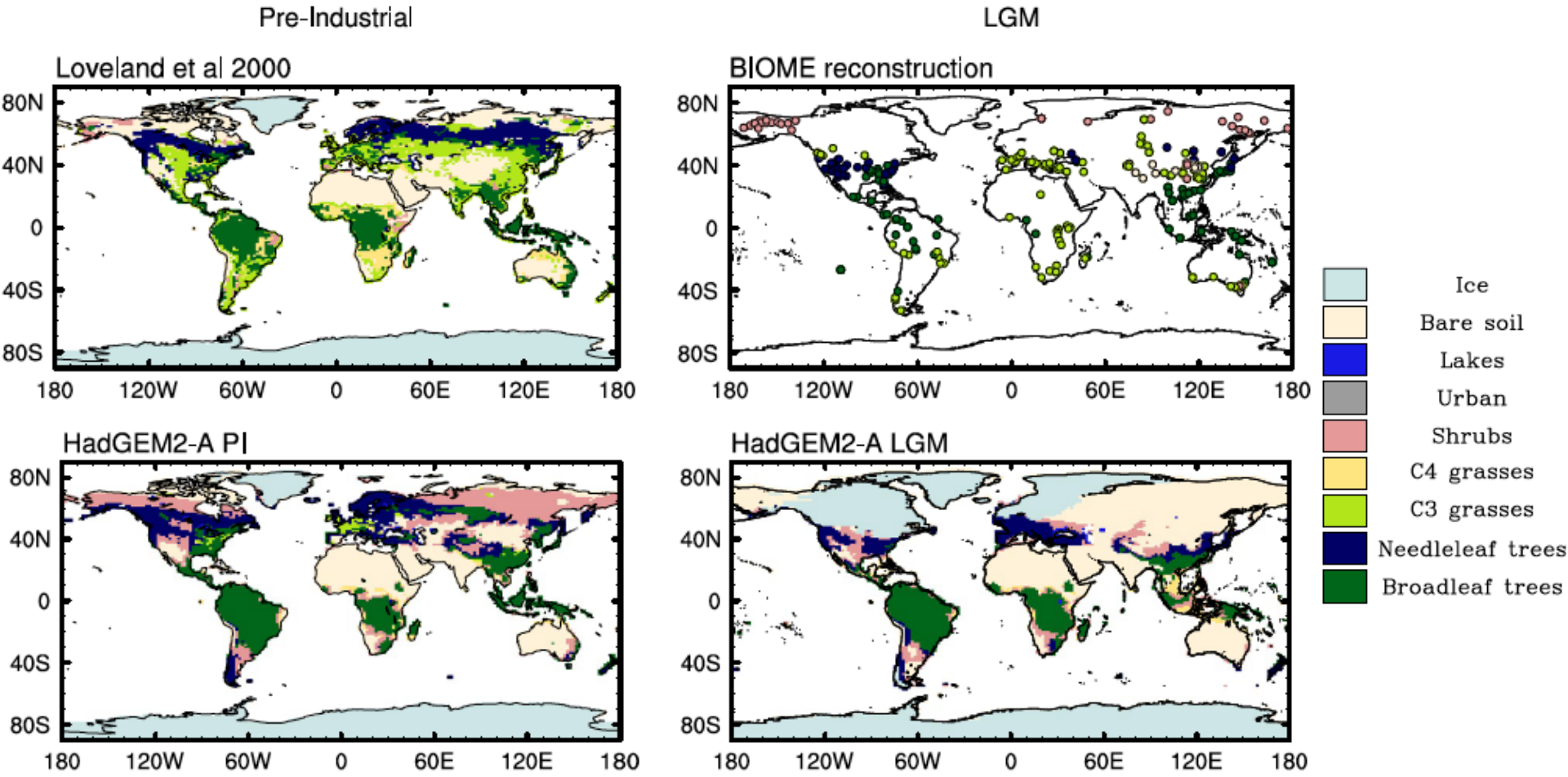
Ice sheet/sea-level radiative forcing





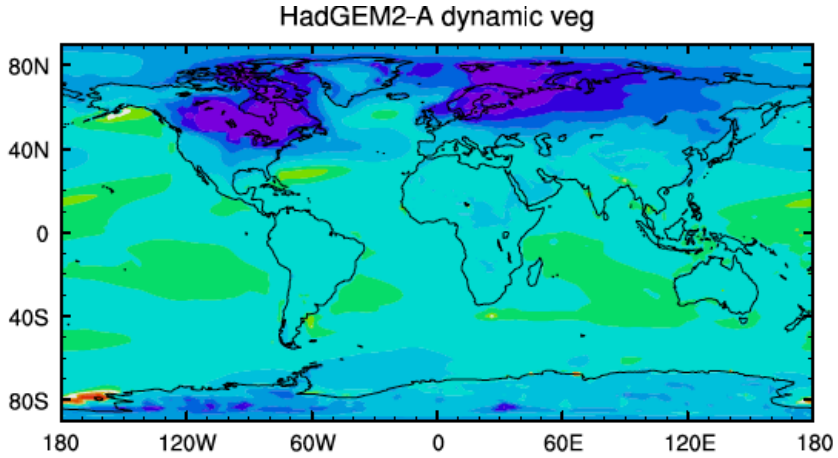
Braconnot et al 2012

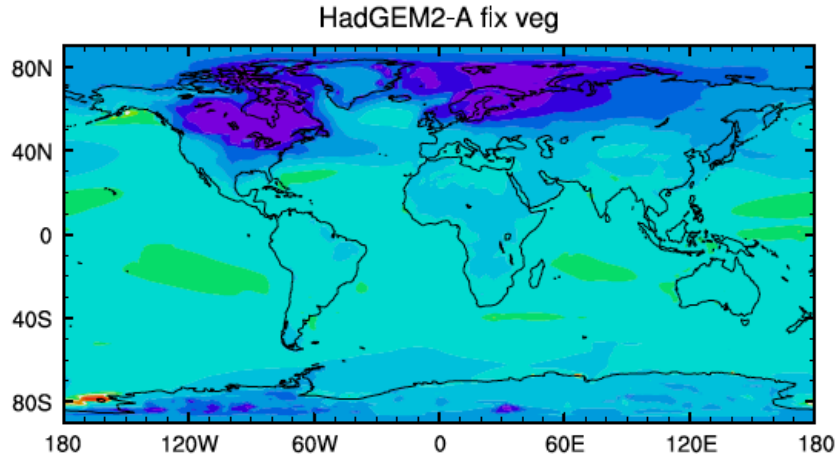
HadGEM2-A
Pre-industrial and LGM simulations

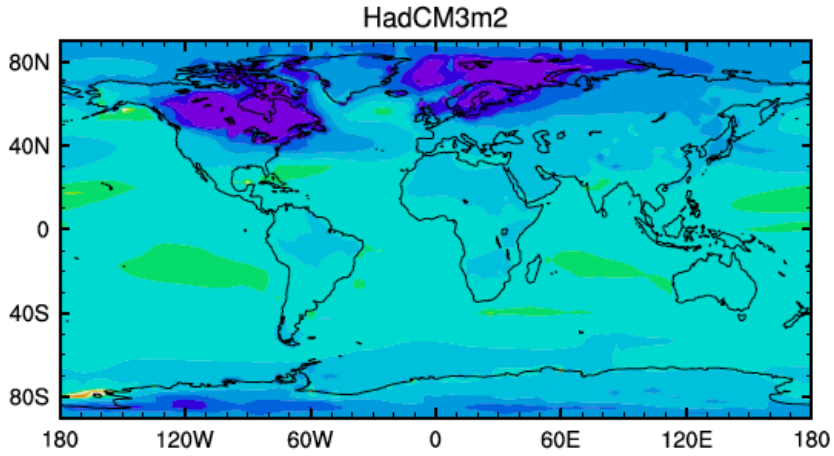


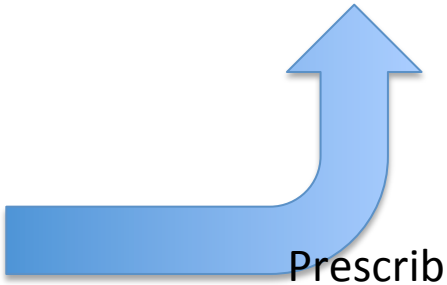
Hopcroft & Valdes 2014

Surface temperature anomalies







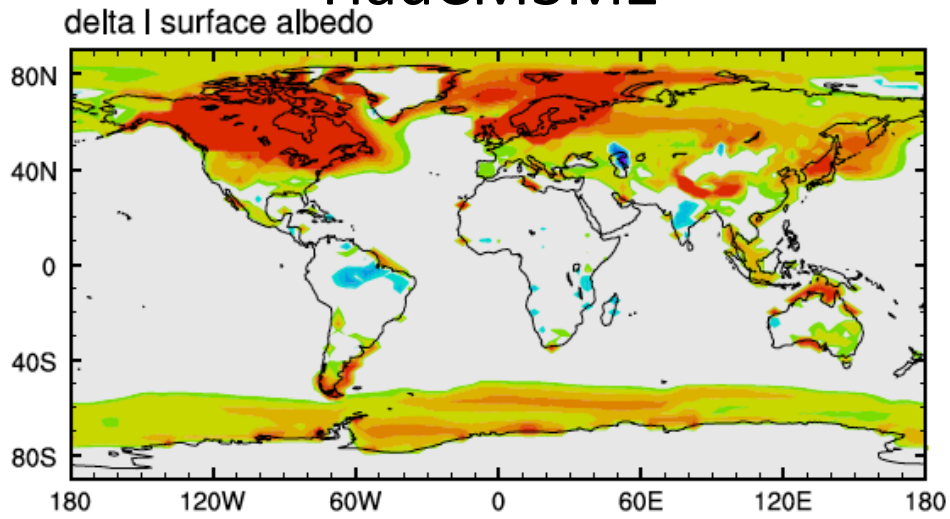


Prescribing HadCM3m2 vegetation cover

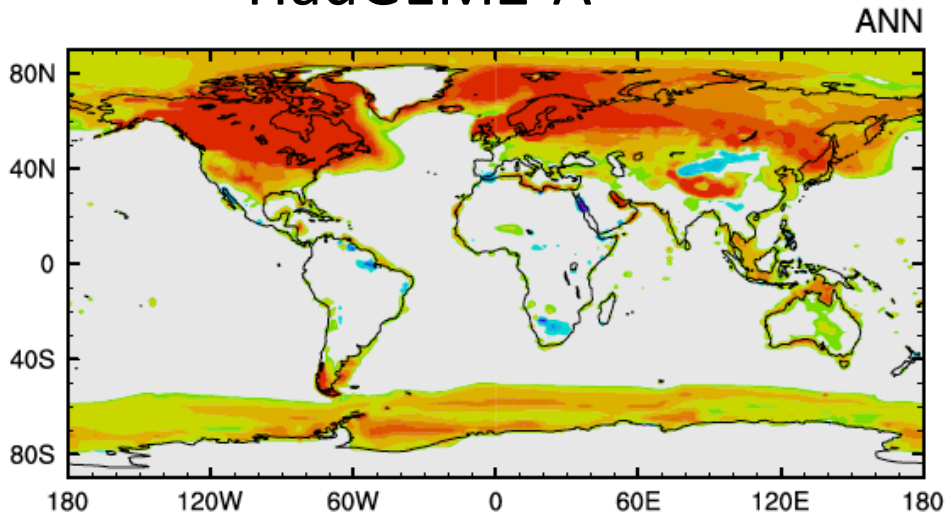
Hopcroft & Valdes 2014

Surface albedo forcing

HadCM3M2



HadGEM2-A



Leaf mortality, temperature dependence:

$$\lambda_{lm} = \lambda_0 \left[1 + d_T \left(T_{off} - T_c\right)\right]$$

In HadGEM2 and JULES grasses begin to die off <5°C

Snow-covered albedo:

$$\alpha_{ds} = (1 - f_r)\alpha_s^0 + f_r \alpha_s^{inf}$$

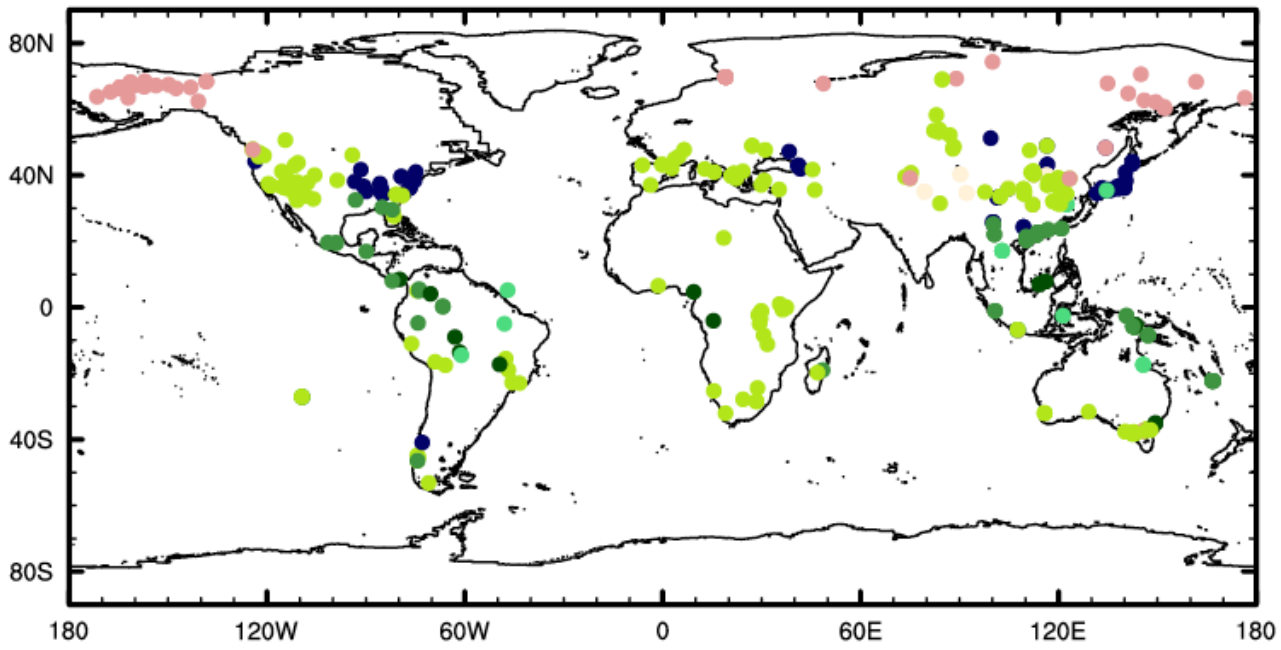
where

$$f_r = 1 - e^{-\Lambda/2}$$

Λ = leaf area index

Hopcroft & Valdes 2014

LGM pollen reconstruction



Fractional type

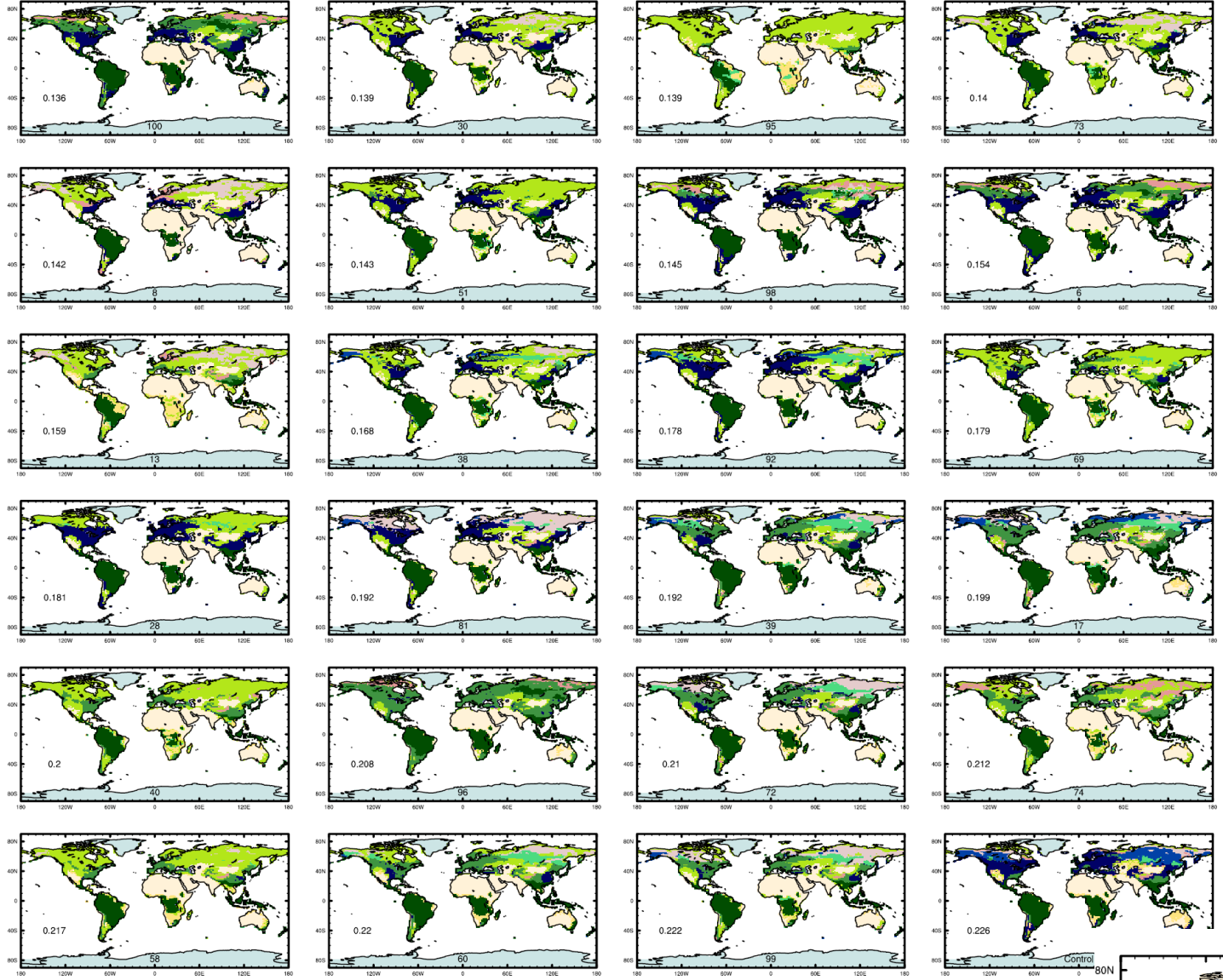
- Ice
- Bare soil
- Lakes
- Urban
- Deciduous shrubs
- Evergreen shrubs
- C4 grasses
- C3 grasses
- Needleleaf deciduous trees
- Needleleaf evergreen trees
- Broadleaf deciduous trees
- Temperate broadleaf evergreen trees
- Tropical broadleaf evergreen trees

Data from: Prentice et al 2000, Bigelow et al 2003, Pickett et al 2004, Marchant et al 2009.
Available from: http://www.bridge.bris.ac.uk/projects/BIOME_6000

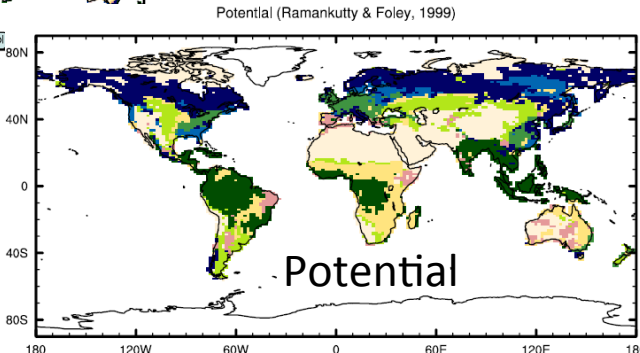
LGM JULESv4.1 perturbed parameter ensemble

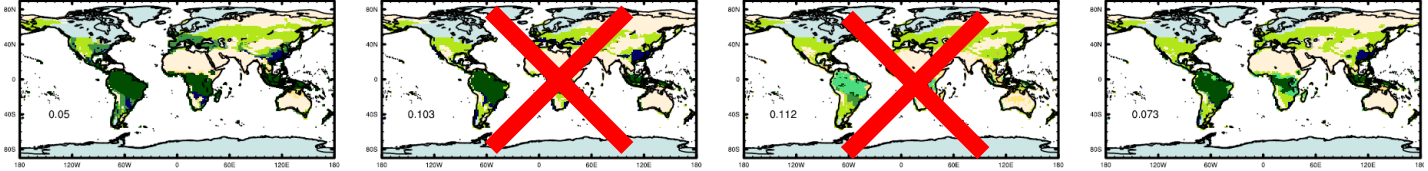
- 100 Pre-industrial + 100 LGM ensemble members
- Parameters from latin hypercube sampling
- Driven with 3hr HadGEM2 climate fields (Pre-Ind or LGM)

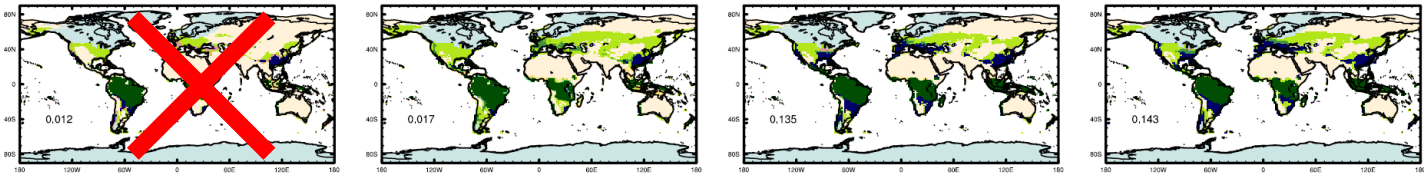
Variable	Description	Units
g_leaf_0	Minimum turnover rate for leaves	/360 days
tleaf_of	Temperature below which leaves are dropped	(K)
lai_min	Minimum leaf area index	m^2/m^2
Topt	Optimal temperature for photosynthesis (Topt=Tupp-4.0)*	°C
f0	Maximum ratio of internal to external CO_2	-
nmass	Leaf nitrogen content per unit mass	kgN/kgLeaf
g_area	Disturbance rate	/360 days
v_crit_alpha	Critical soil moisture parameter	[0-1]

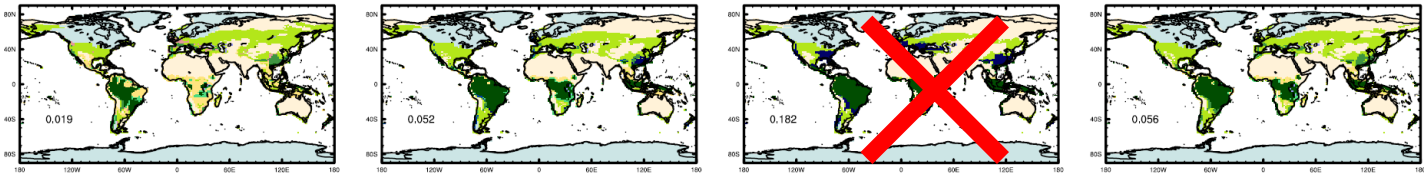


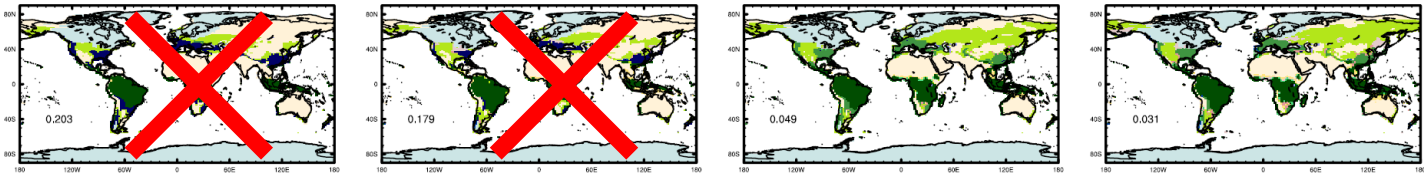
Pre-Ind
Ensemble 1

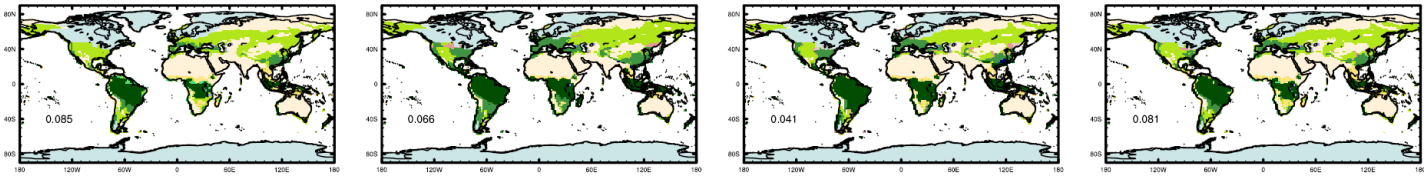


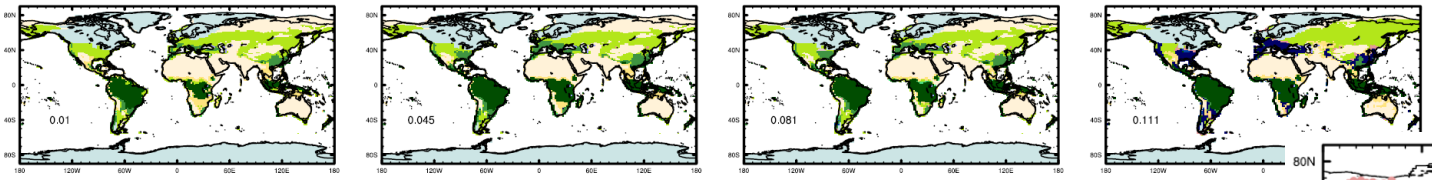


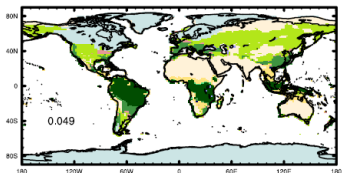




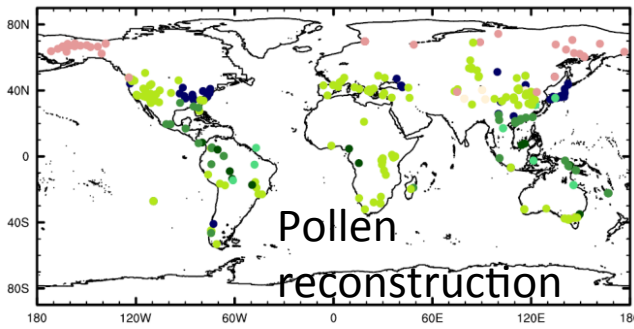




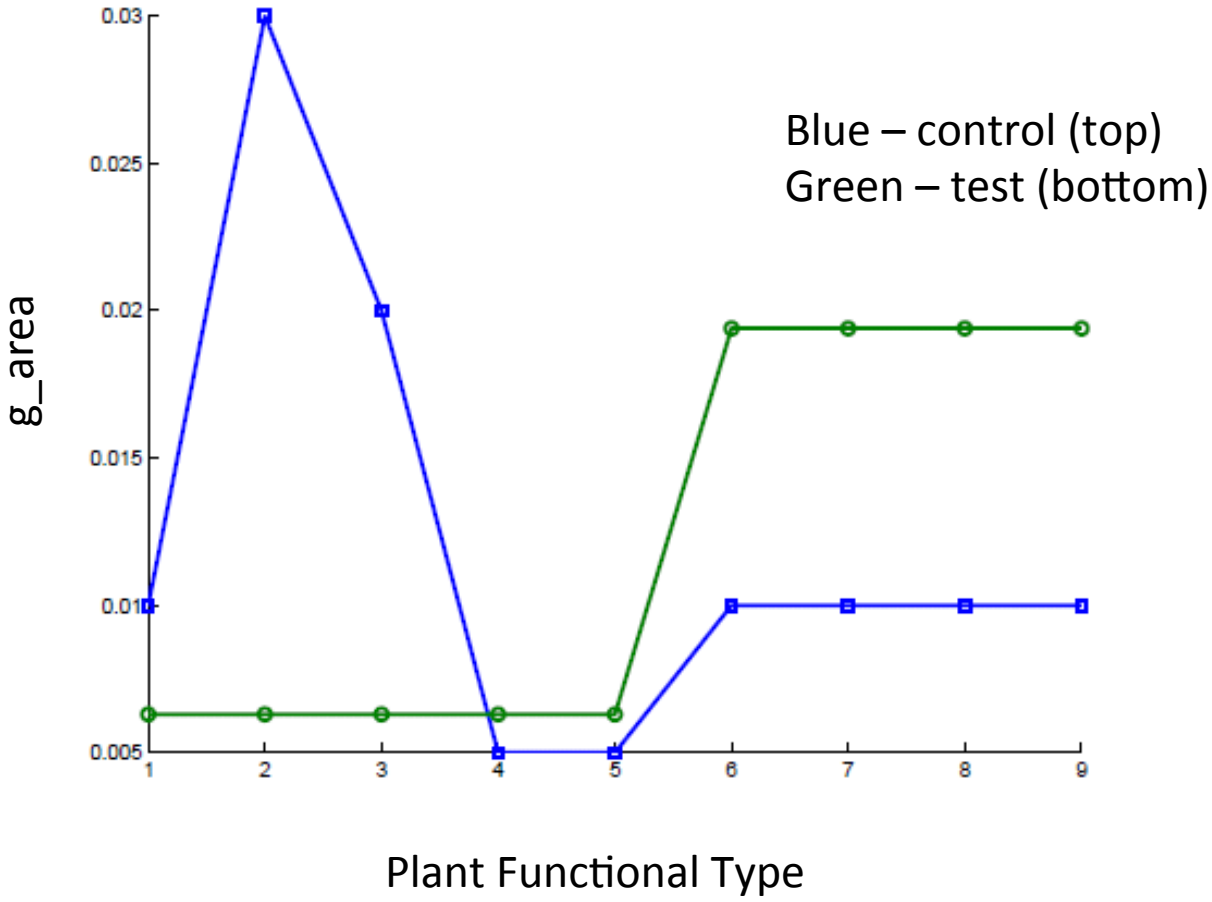


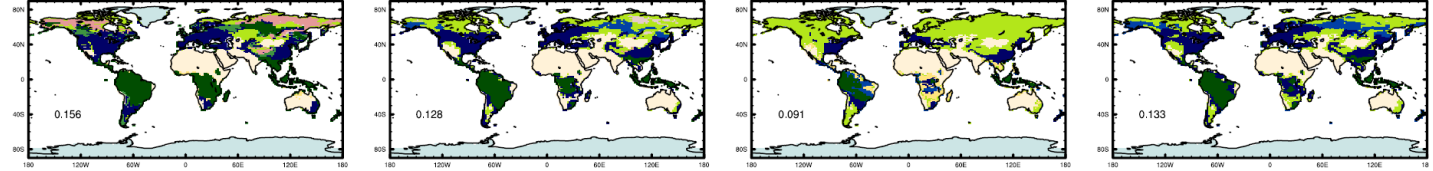


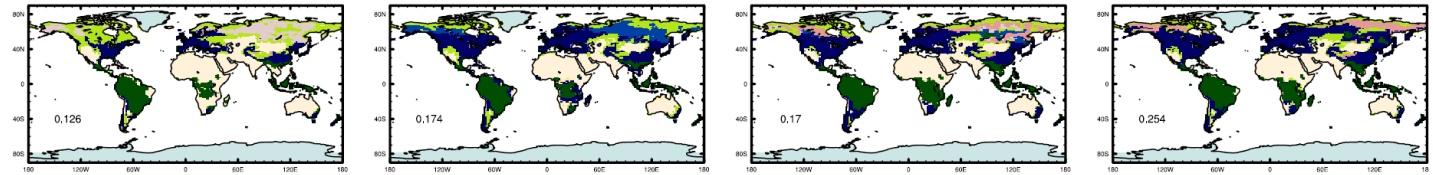
LGM
Ensemble 1

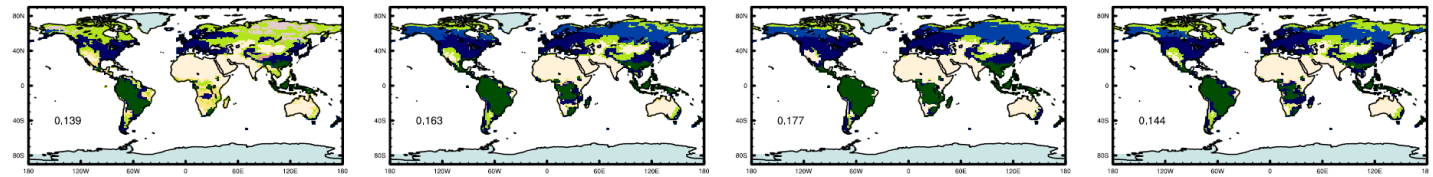


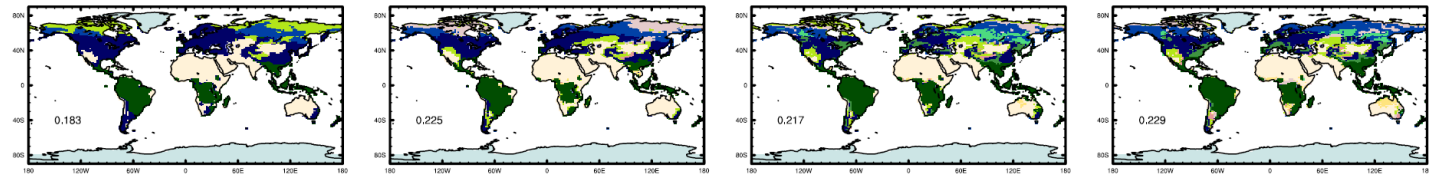
g_area

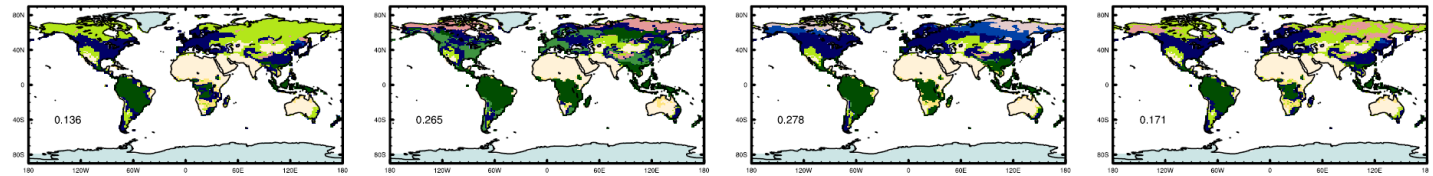

g_area
0.03
0.025
0.02
0.015
0.01
0.005
1
2
3
4
5
6
7
8
9
Blue – control (top)
Green – test (bottom)
Plant Functional Type

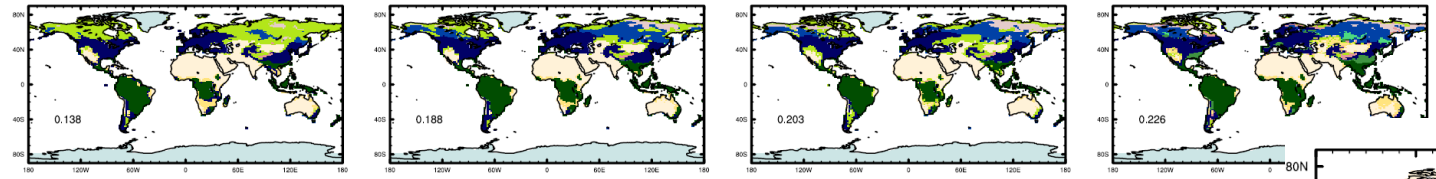


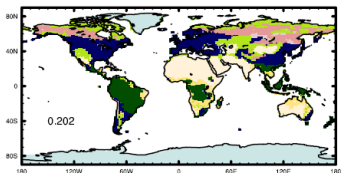




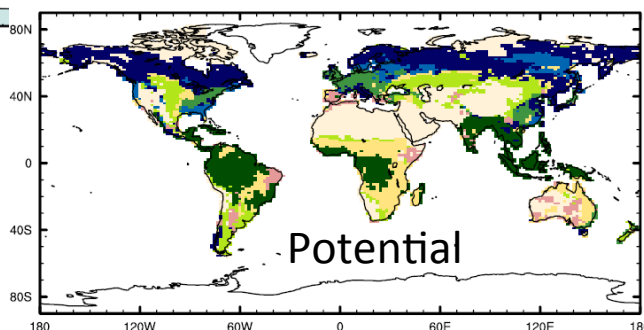


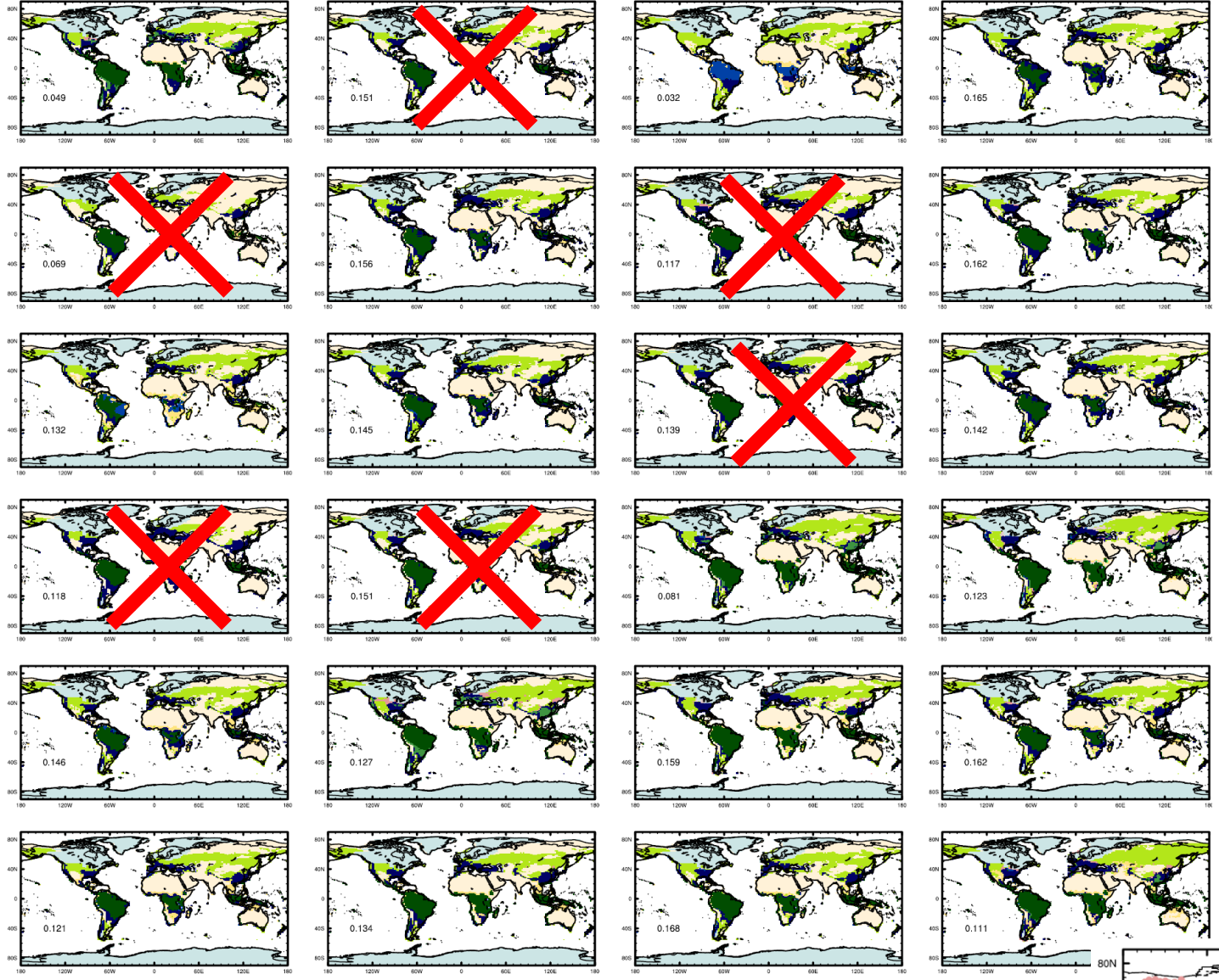




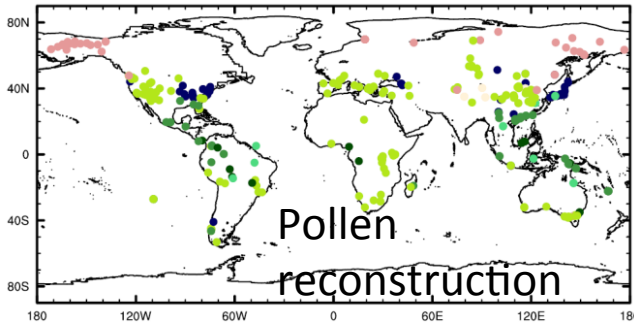


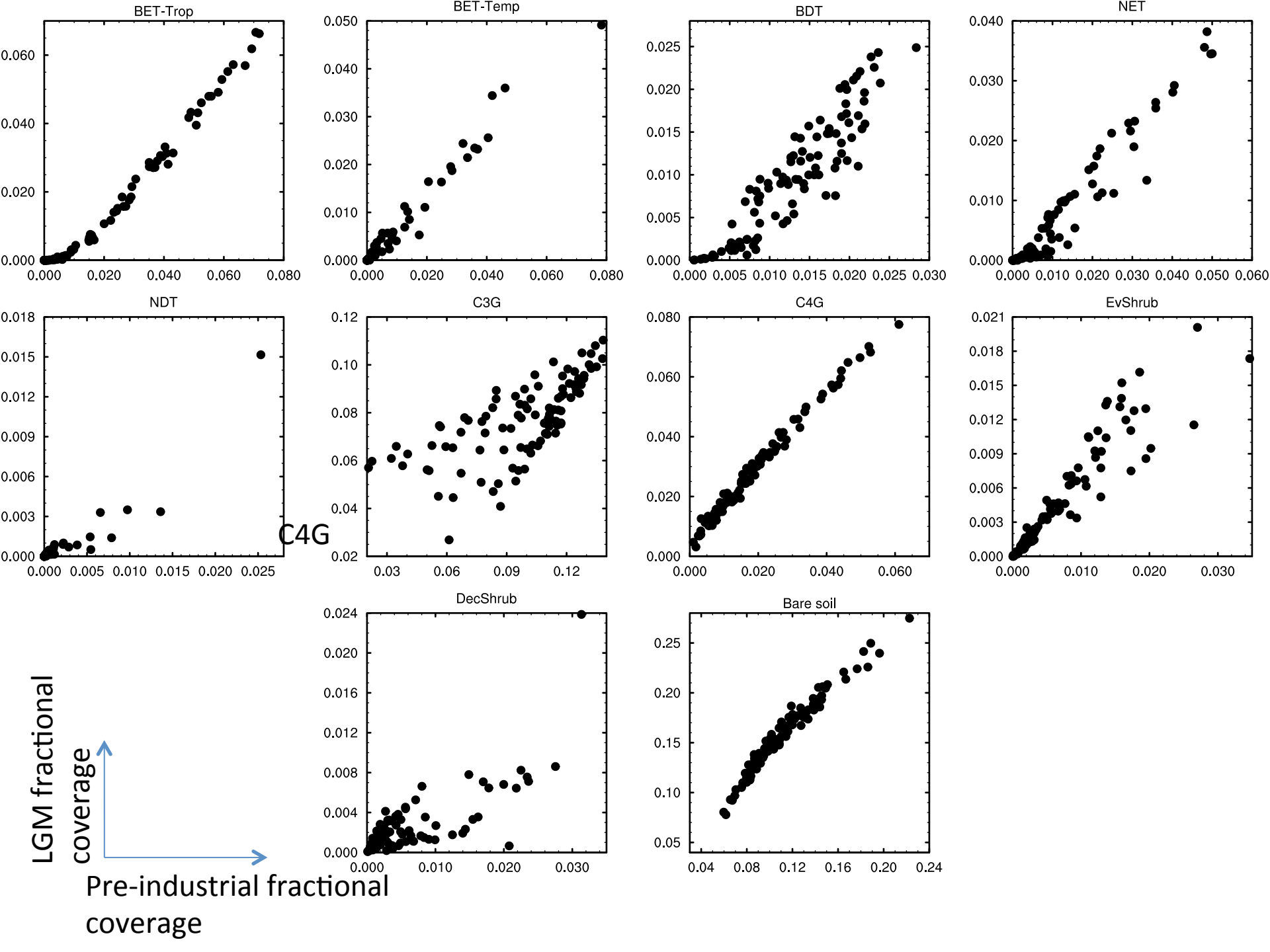
Pre-Ind
Ensemble 2





LGM
Ensemble 2

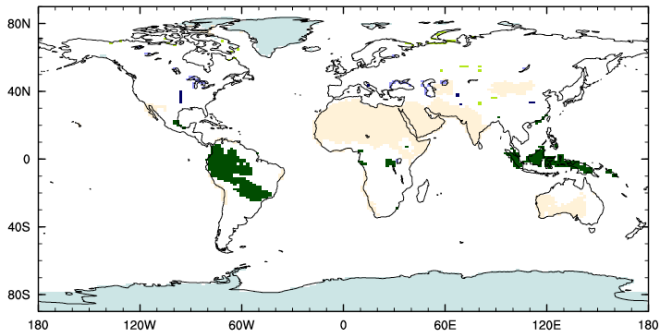


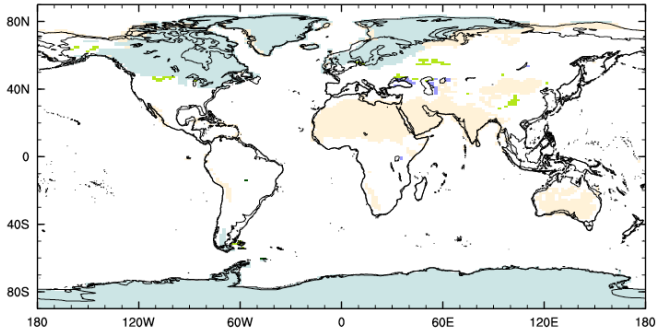

BET-Trop
BET-Temp
BDT
NET
NDT
C3G
C4G
EvShrub
DecShrub
Bare soil
C4G
LGM fractional coverage
Pre-industrial fractional coverage

Pre-Industrial

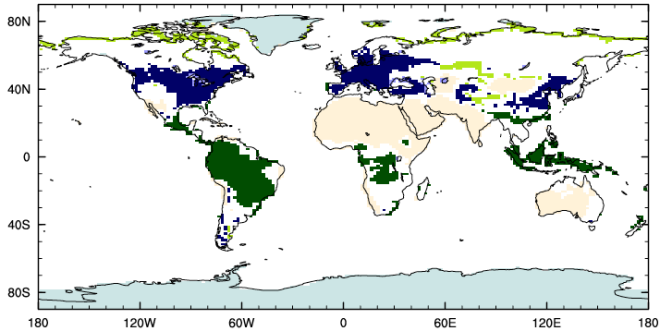
LGM

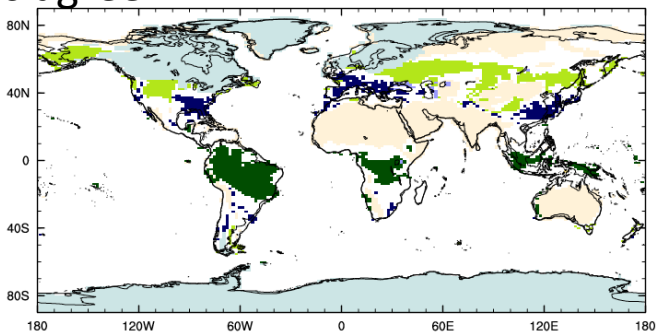
All 25 best models agree



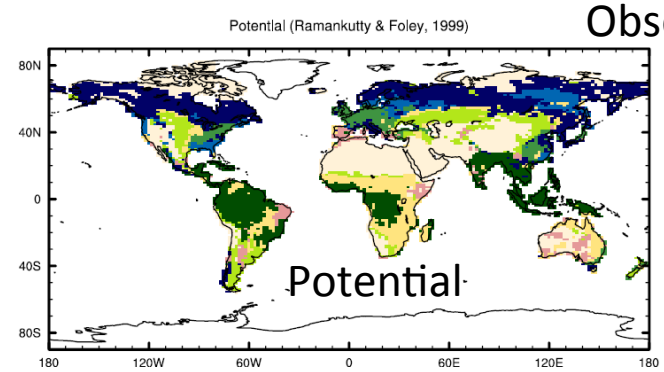


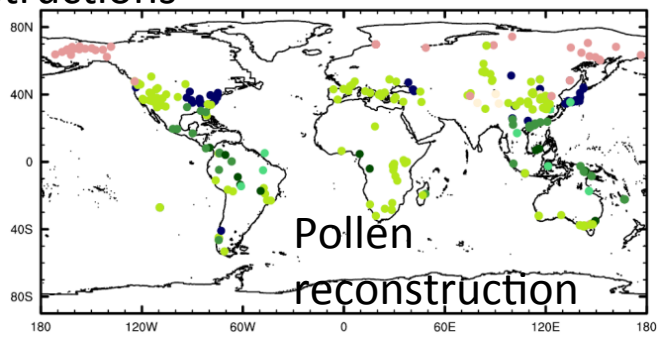
75% of best 25 models agree





Observations/Reconstructions





Preliminary Conclusions

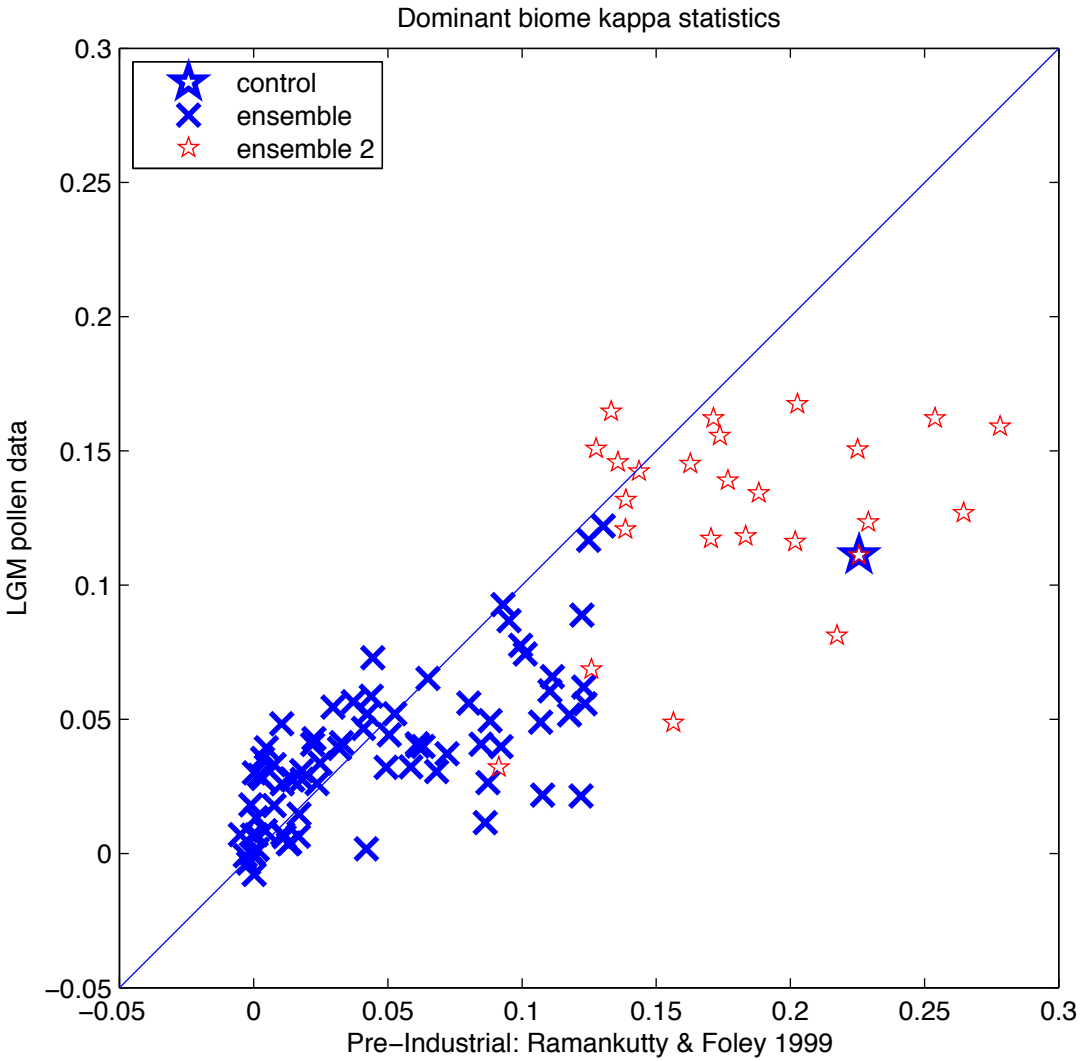
- Amazon forest area overestimated in both times?
- Needle-leaf - broadleaf tree competition heavily influenced by g_area (disturbance rate).
- Atmospheric feedbacks quantified in HadGEM2 rule out ice-age models with dominant bare-soil in Asia: ~6 of best 25 models.

What did the ice-age simulations tell us?

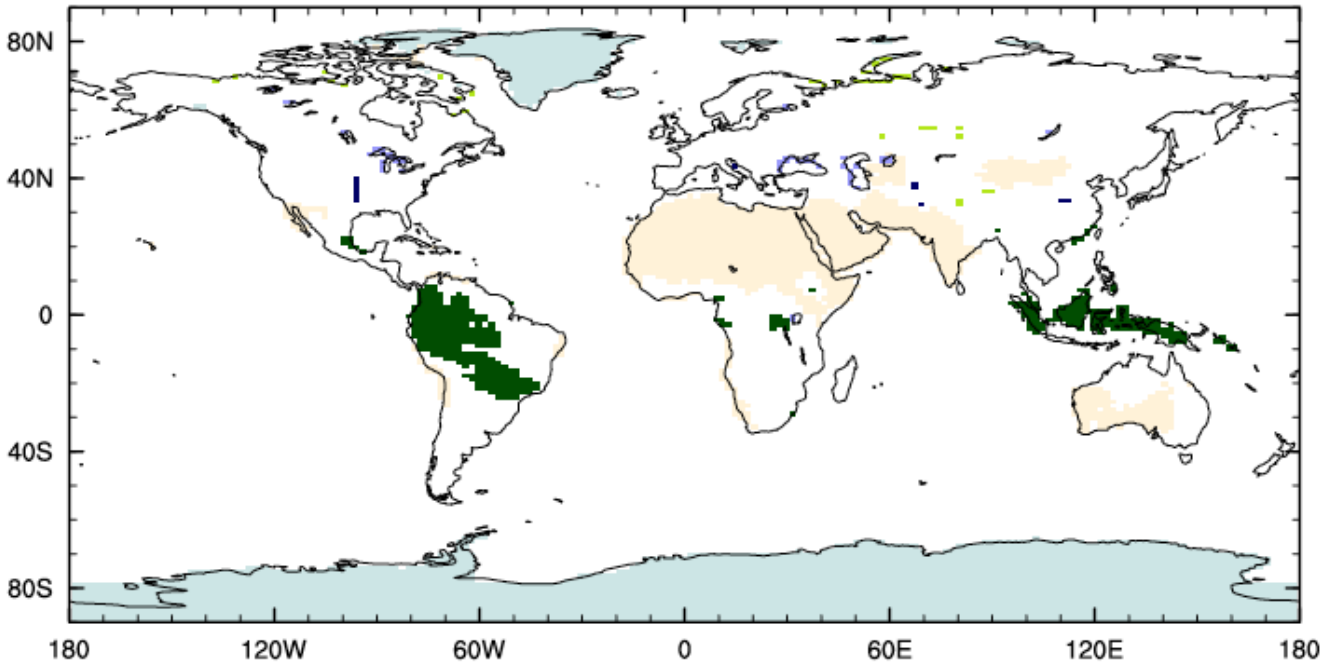
- Some models that are deemed functional for the modern (e.g. HadGEM2-ES) are very poor for the LGM, when snow-albedo feedbacks are very important. LGM can therefore improve the model.
- Sparse coverage of LGM pollen data difficult to compare with models, but northern Eurasia a key area of discrepancy or disagreement.

Further work

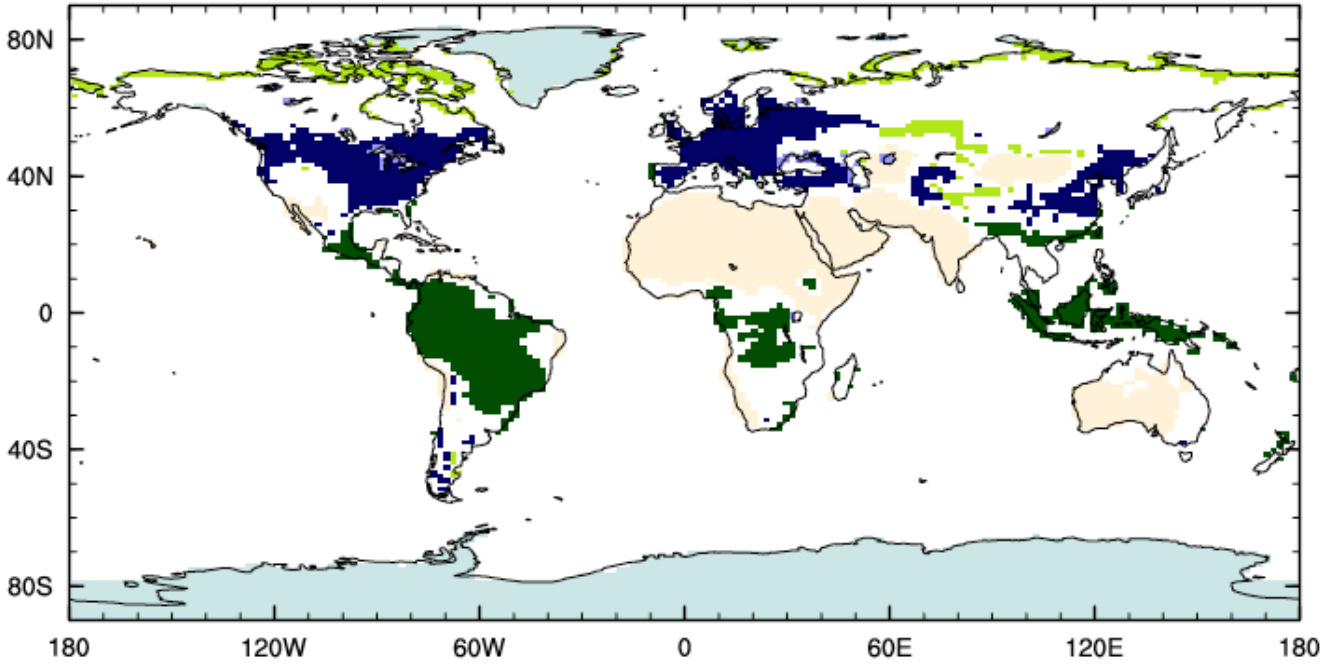
- Ensemble iterations
  – improve on current ensemble by further exploring parameter space as a function of model skill.
- Use feedbacks in HadGEM2 to quantify which JULES ensemble members are reasonable
- Fire – global charcoal database for the LGM. Fire could be used to parameterise disturbance (g_area) to some extent?


Dominant biome kappa statistics
control
ensemble
ensemble 2
LGM pollen data
Pre−Industrial: Ramankutty & Foley 1999
0.3
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.05
0
0.05
0.1
0.15
0.2
0.25
0.3

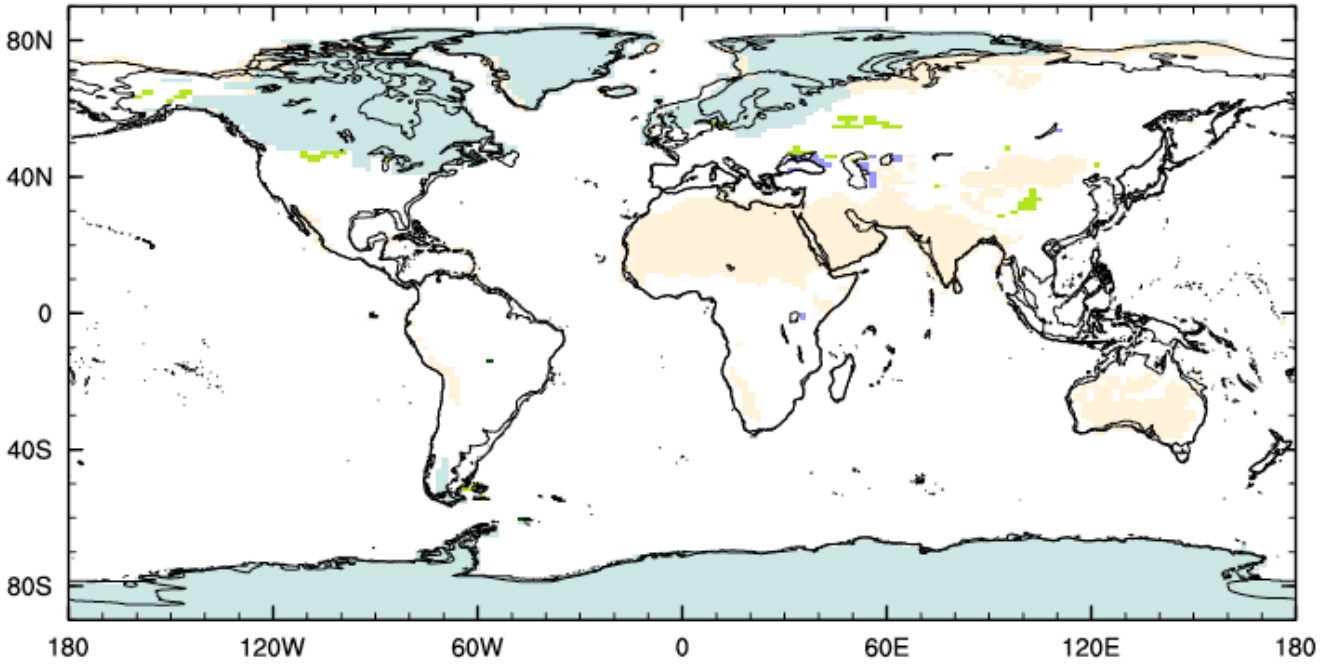
All 25 best models agree



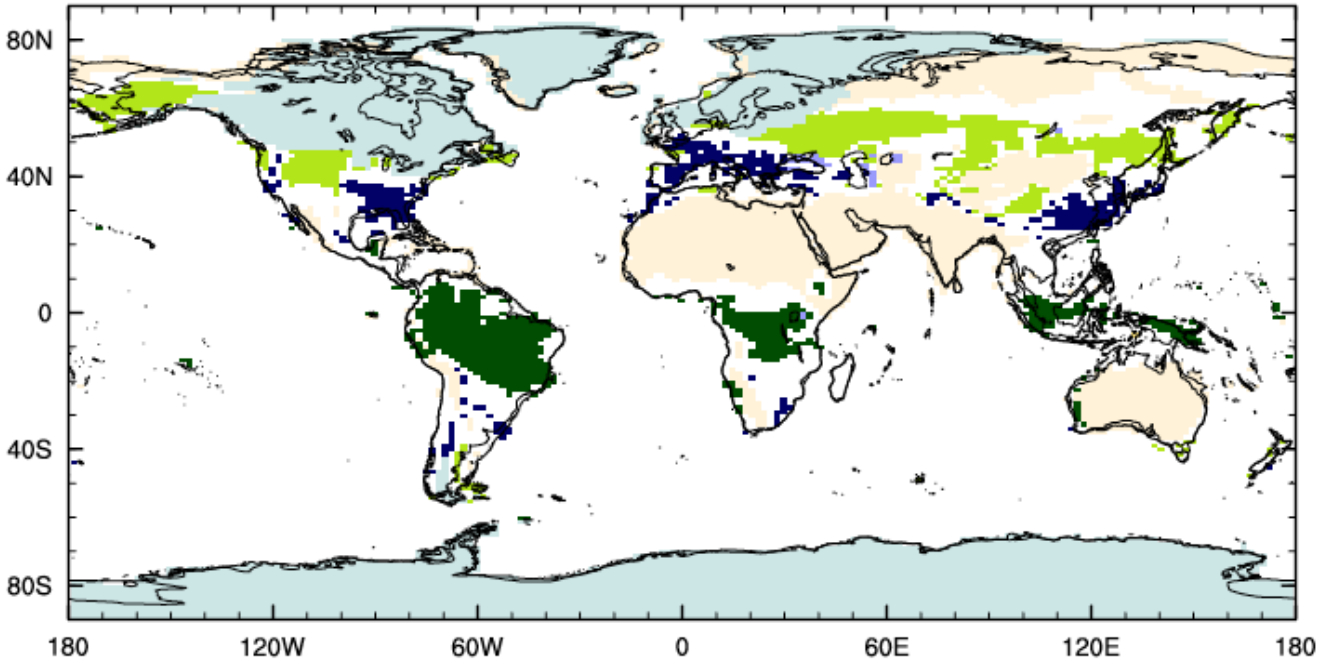
75% of best 25 models agree



All 25 best models agree

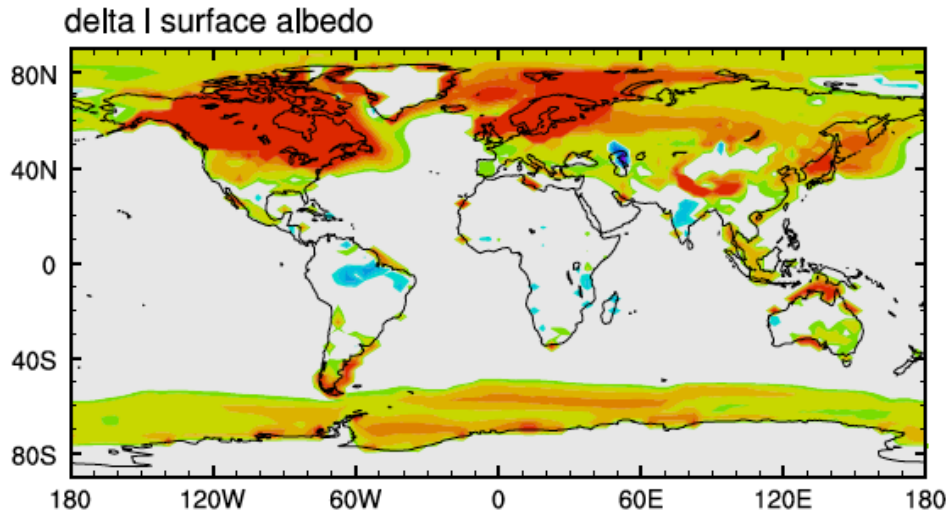


75% of best 25 models agree

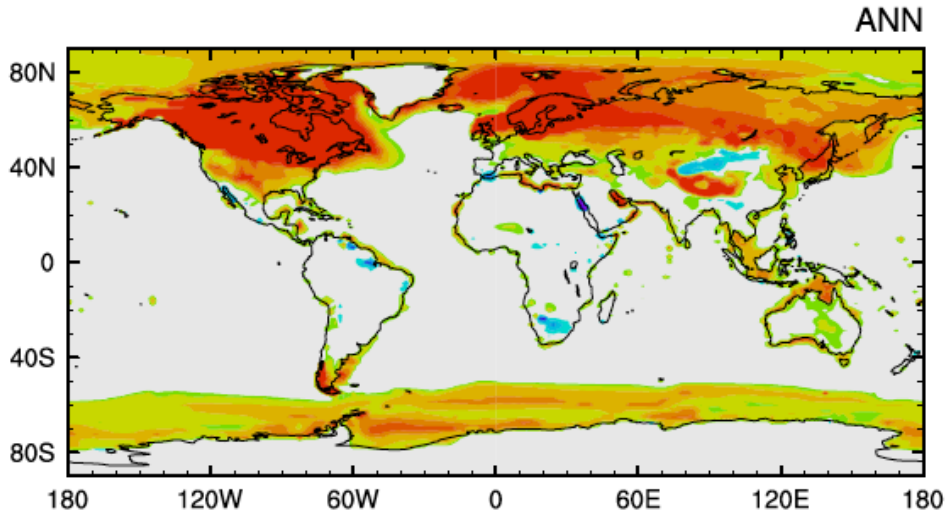


Variable	Range	Source
g_leaf_0	25th - 75th centiles TRY database (Kattge et al., 2011)	This work
tleaf_of	±5K	This work
lai_min	1-4 for trees, other PFTs no change	Booth et al. (2012)
Topt	±5K	Booth et al. (2012)
f0	0.7-0.95for trees, 0.65-0.8 for grasses	Booth et al. (2012)
nmass	25th - 75th centiles TRY database (Kattge et al., 2011)	This work
g_area	±50%	This work
v_crit_alpha	0.01 to 0.99	Booth et al. (2012)

HadCM3M2



HadGEM2-A



$$\alpha_{ds} = (1 - f_r)\alpha_s^0 + f_r\alpha_s^{inf}$$

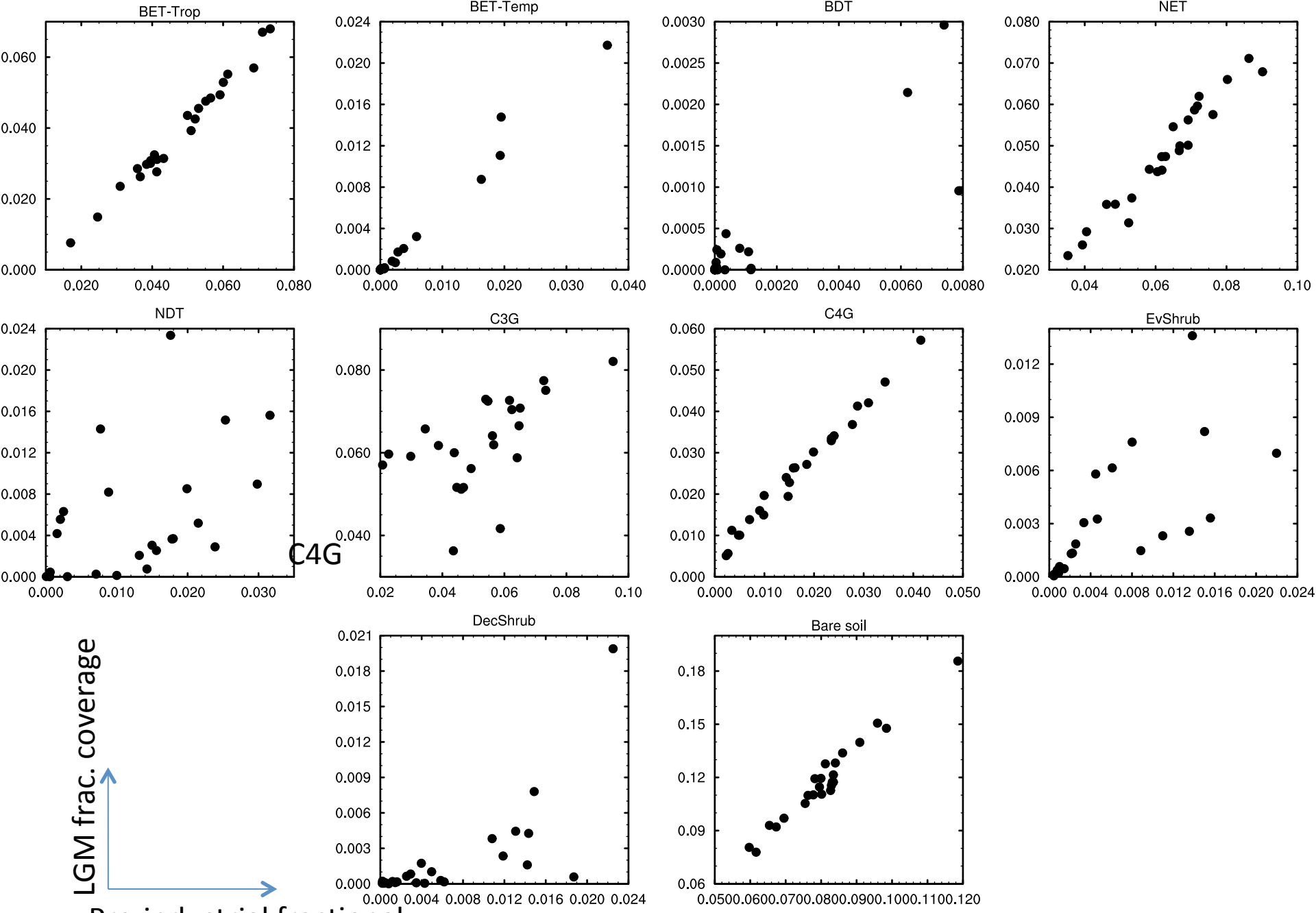
$$\lambda_{lm} = \lambda_0\left[1 + d_T\left(T_{off} - T_c\right)\right]$$

where

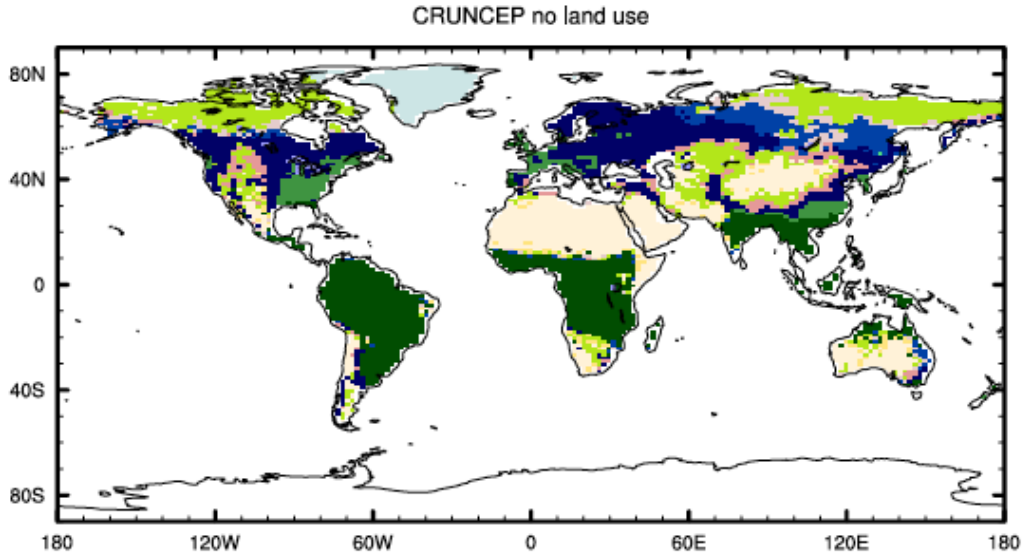
$$f_r = 1 - e^{-\Lambda/2}$$

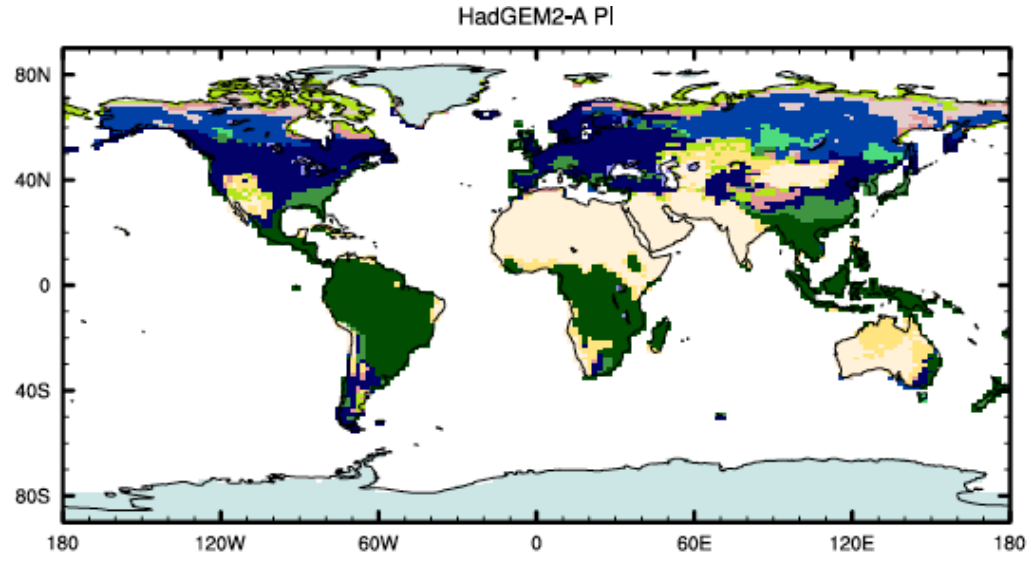
Parameter	Model	Plant Functional type				
		Trees		Grasses		Shrubs
		Broadleaf	Needleleaf	C3	C4	
T_{off} (°C)	HadCM3M2	0	−30	–	–	−30
	HadGEM2	5	−40	5	5	−40

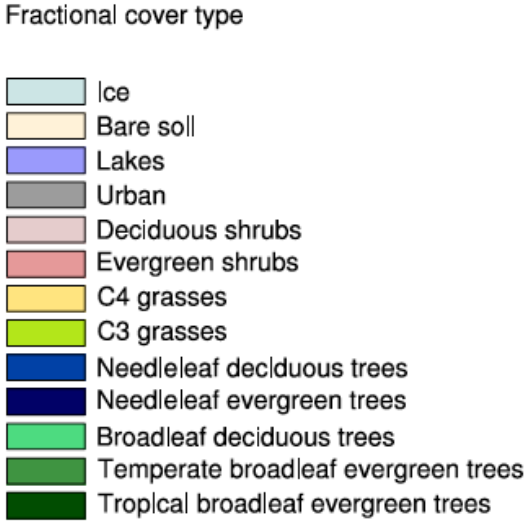
Hopcroft & Valdes 2014


BET-Trop
BET-Temp
BDT
NET
NDT
C3G
C4G
EvShrub
DecShrub
Bare soil
C4G
LGM frac. coverage
Pre-industrial fractional coverage

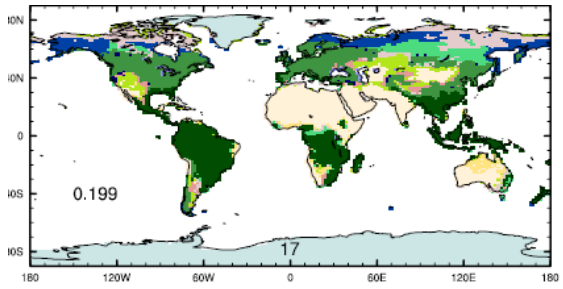
Pre-industrial/modern simulation

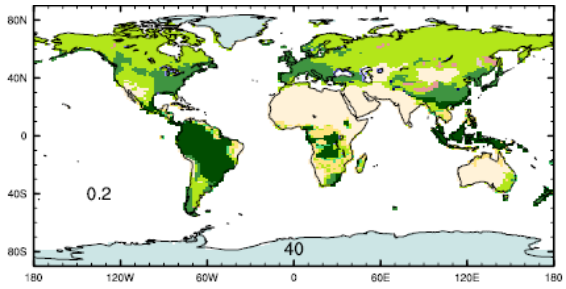


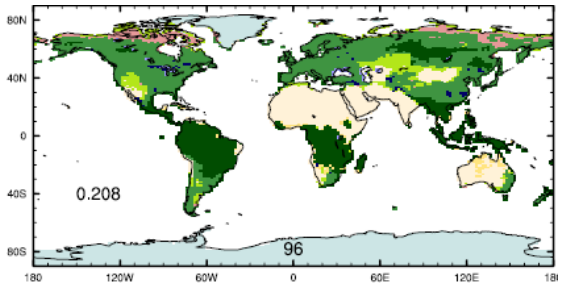


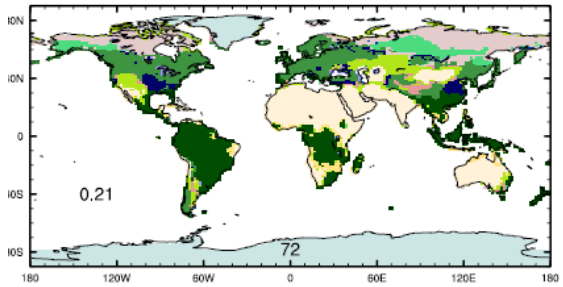


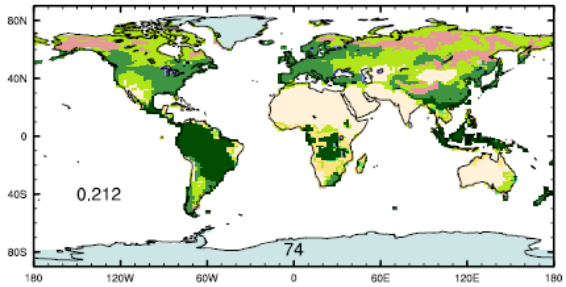
Dominant type 10 best models
Cohen kappa score and ensemble member number

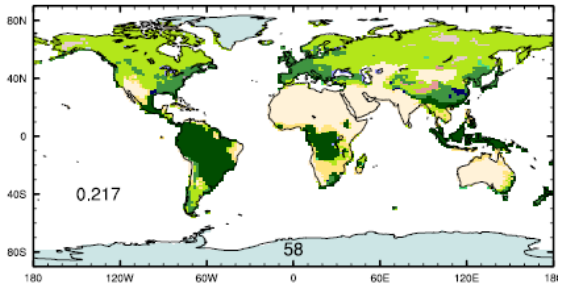


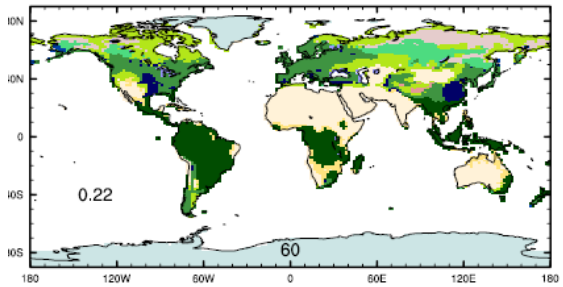


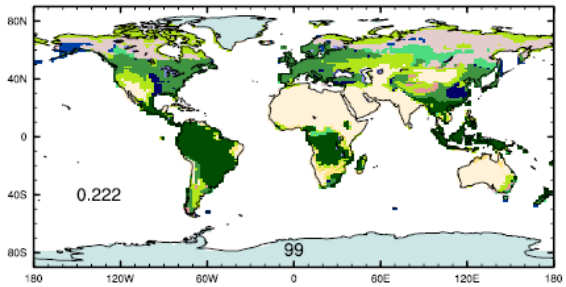


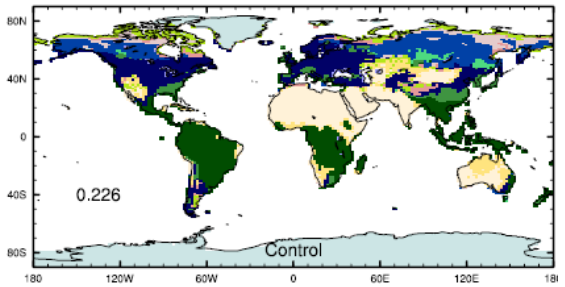




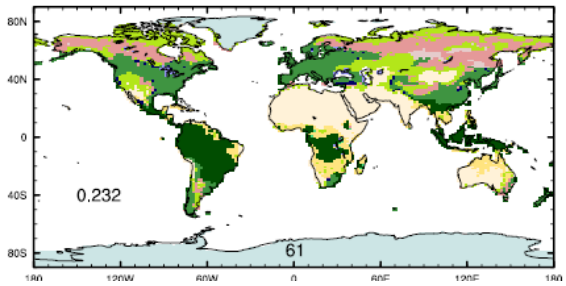


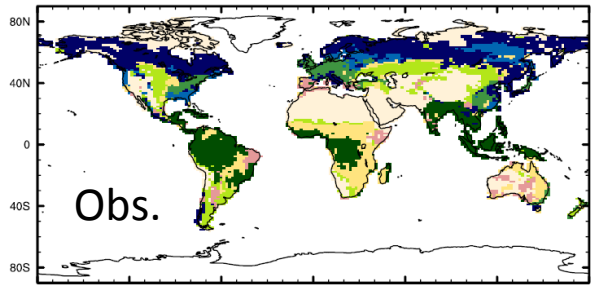




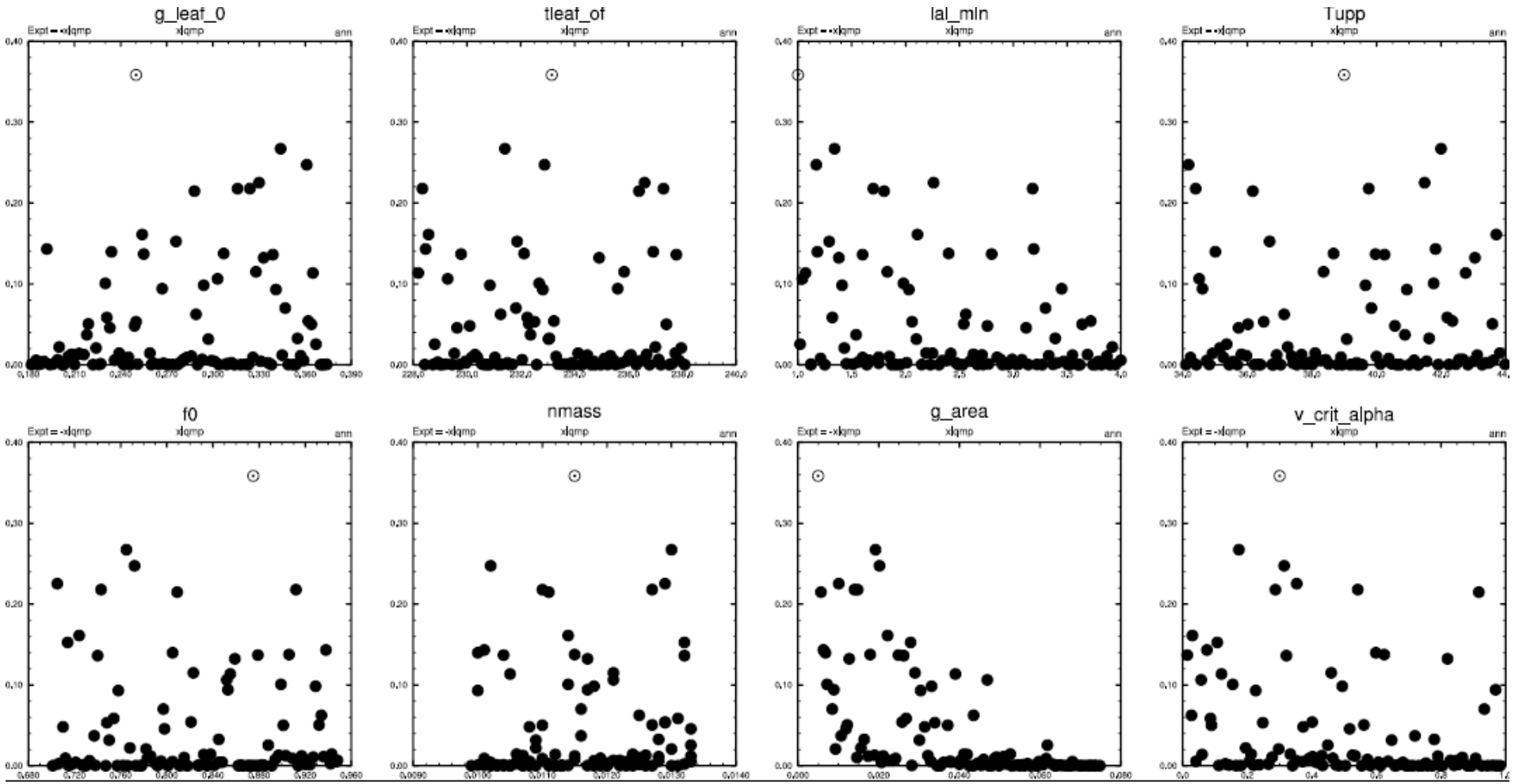


Potential (Ramankutty & Foley, 1999)

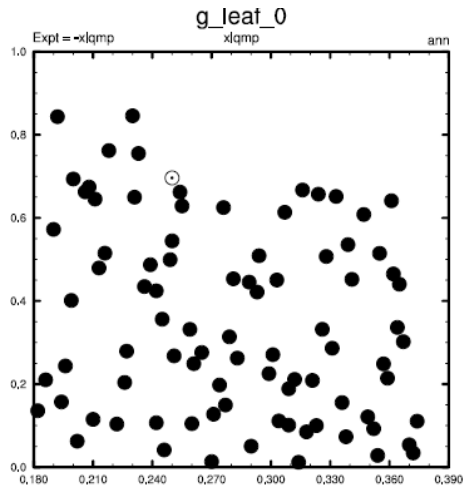


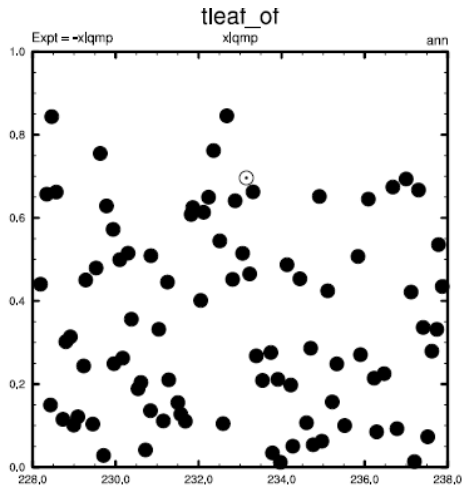


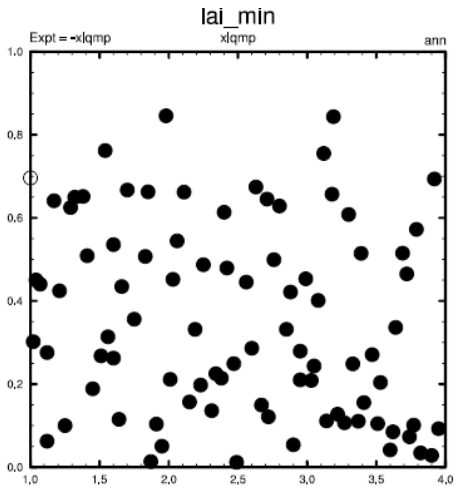
NH extra-tropical Needle-leaf tree coverage versus parameters

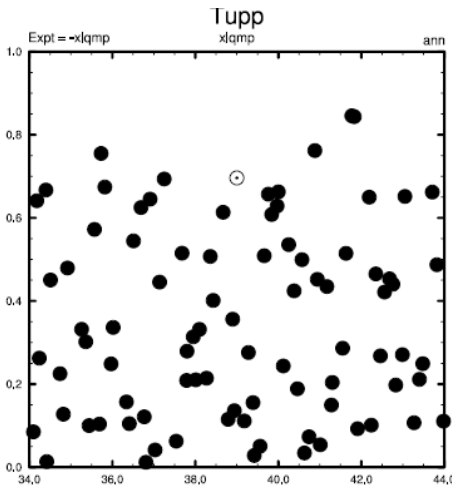


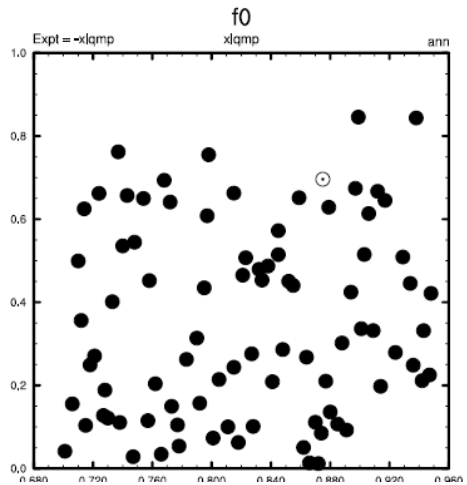
Amazon broad-leaf tree coverage versus parameters

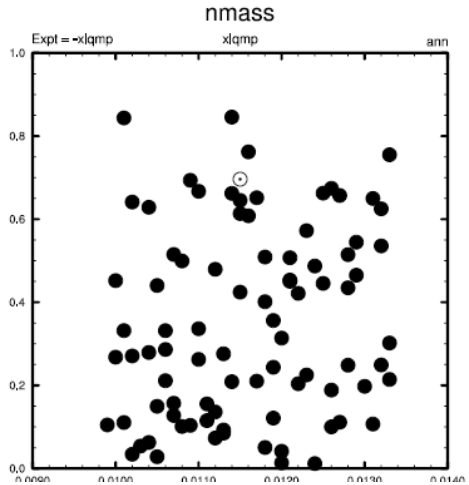


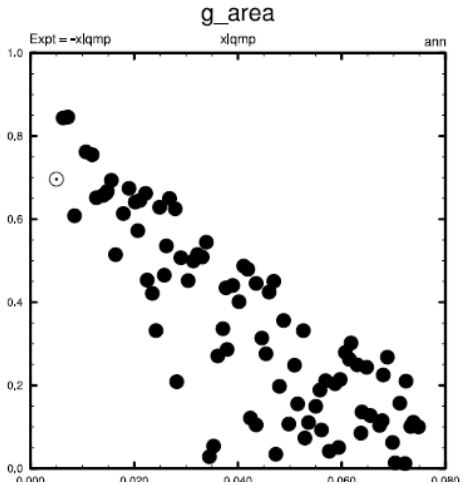


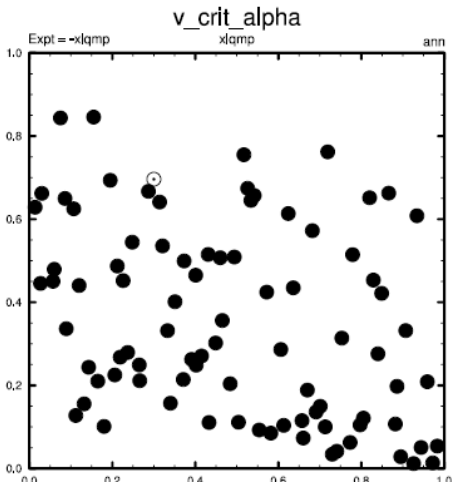




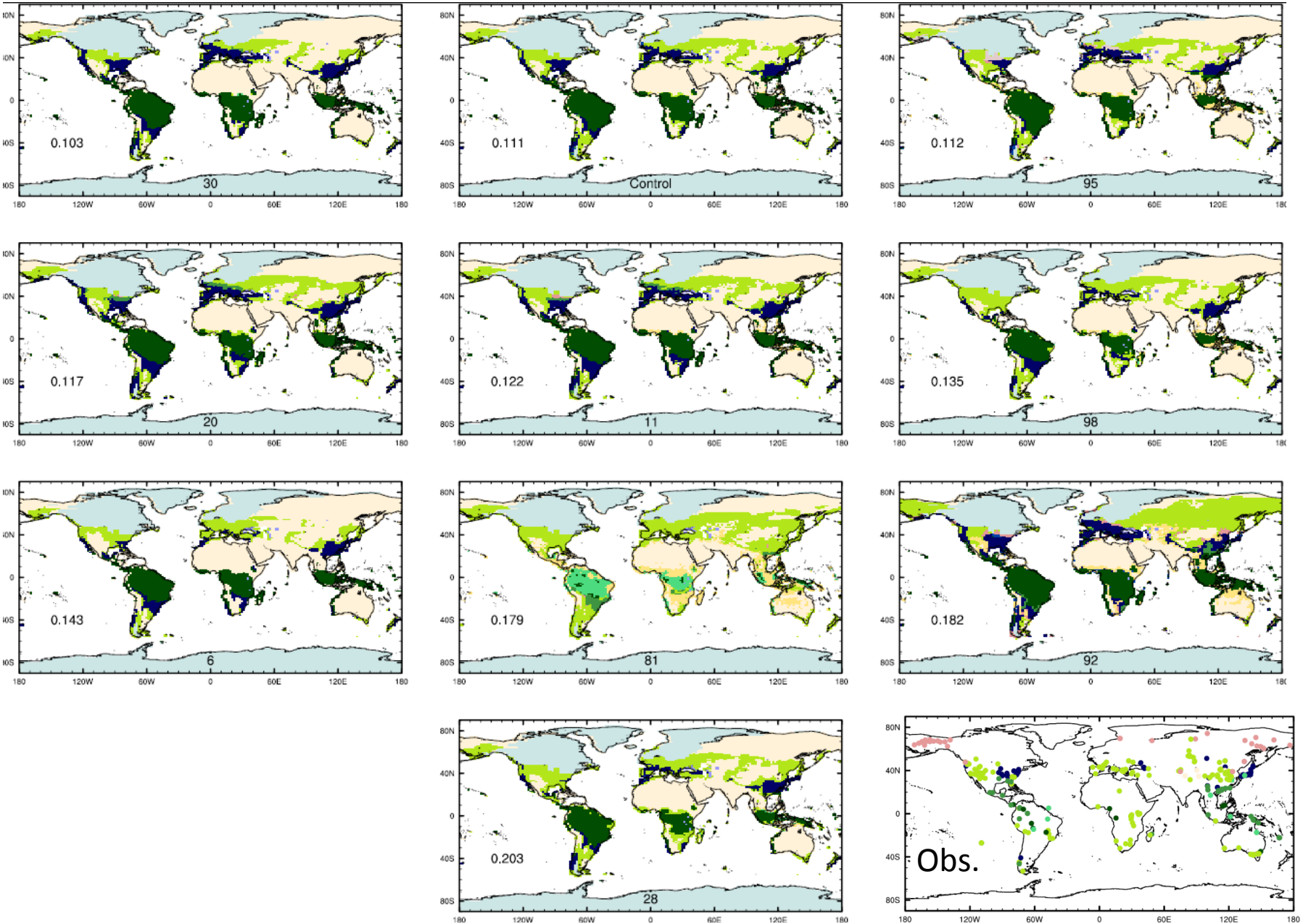


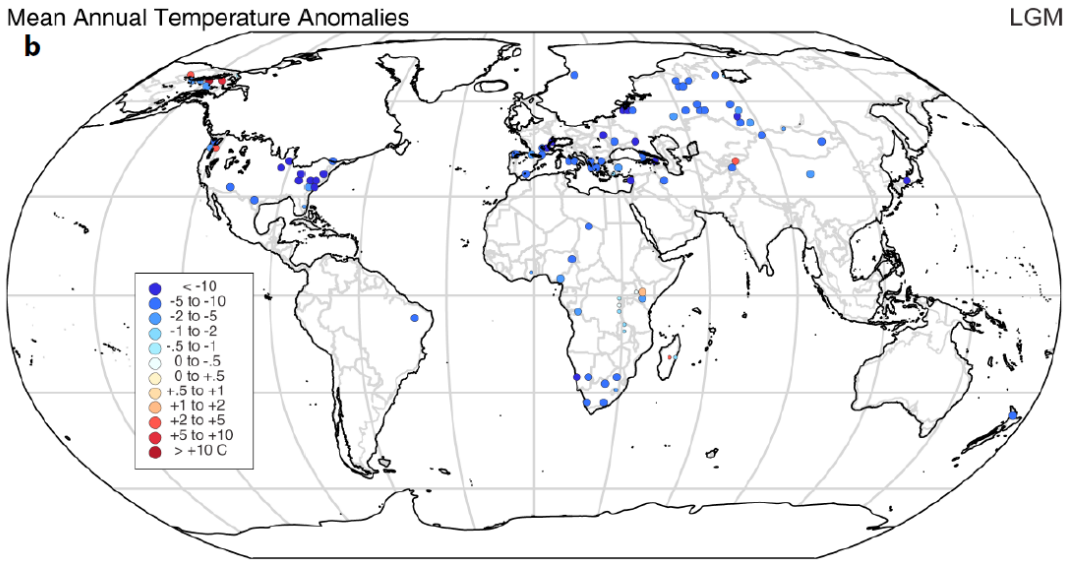


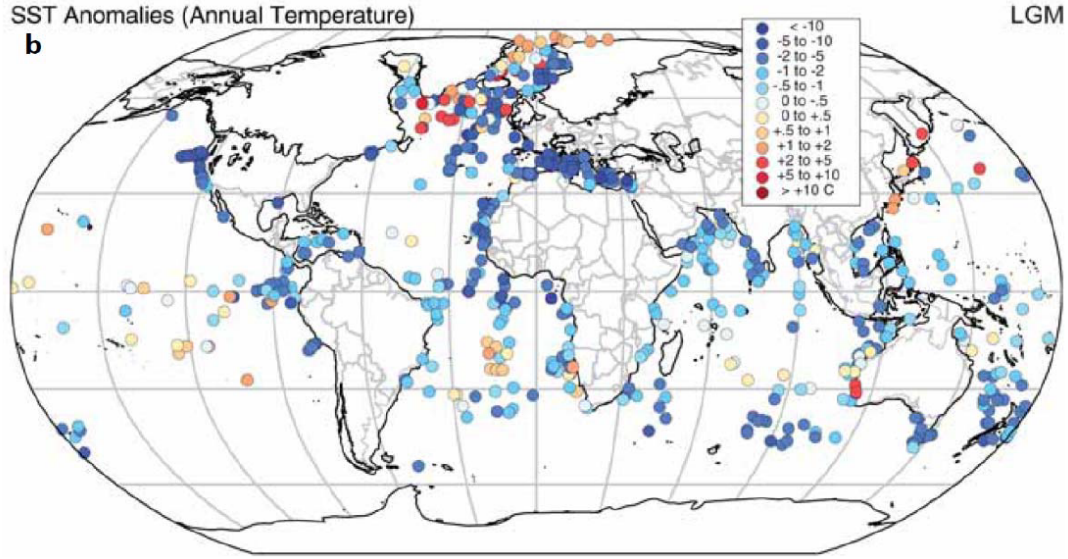


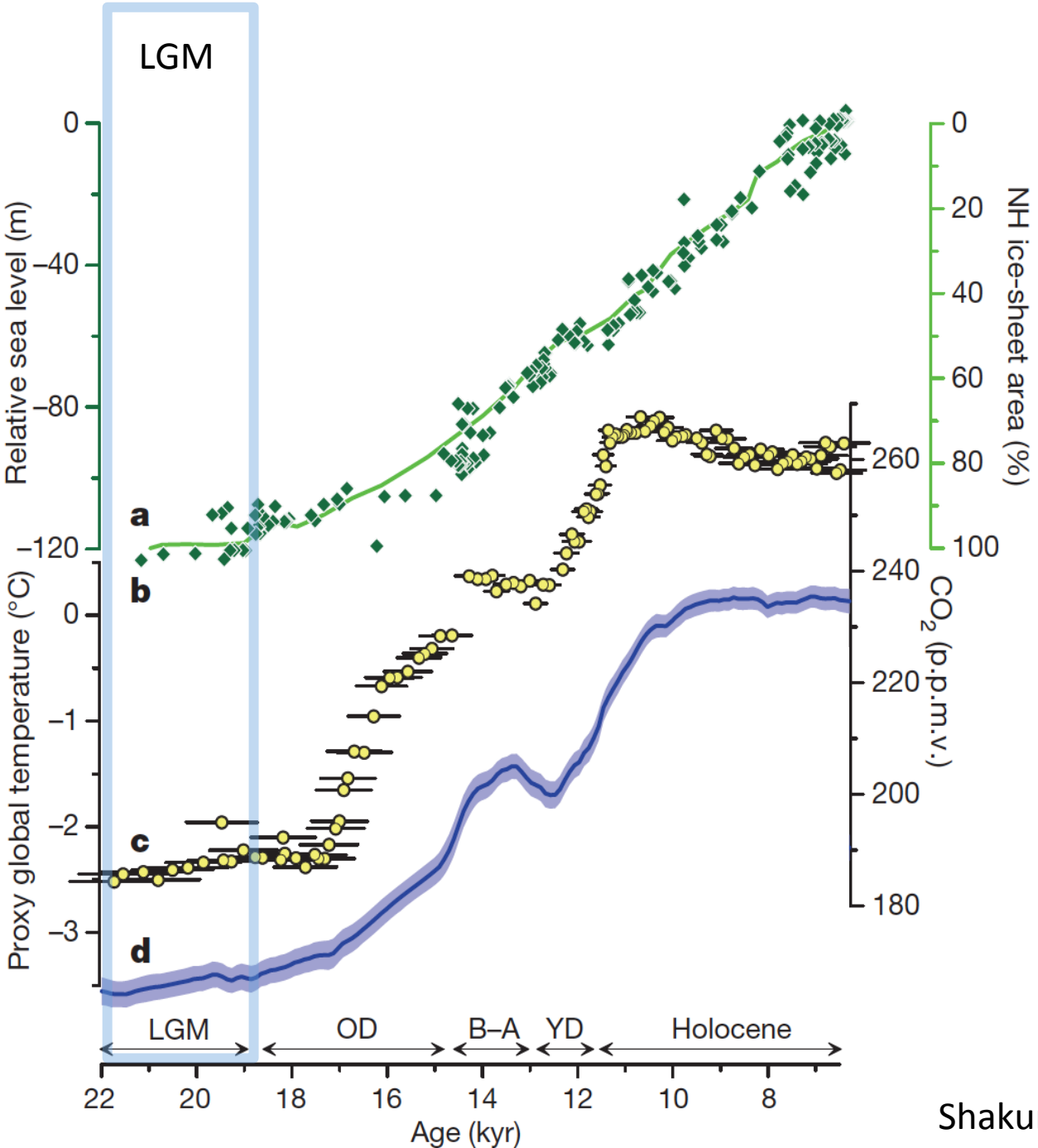


Dominant type 10 best models
Cohen kappa score and ensemble number

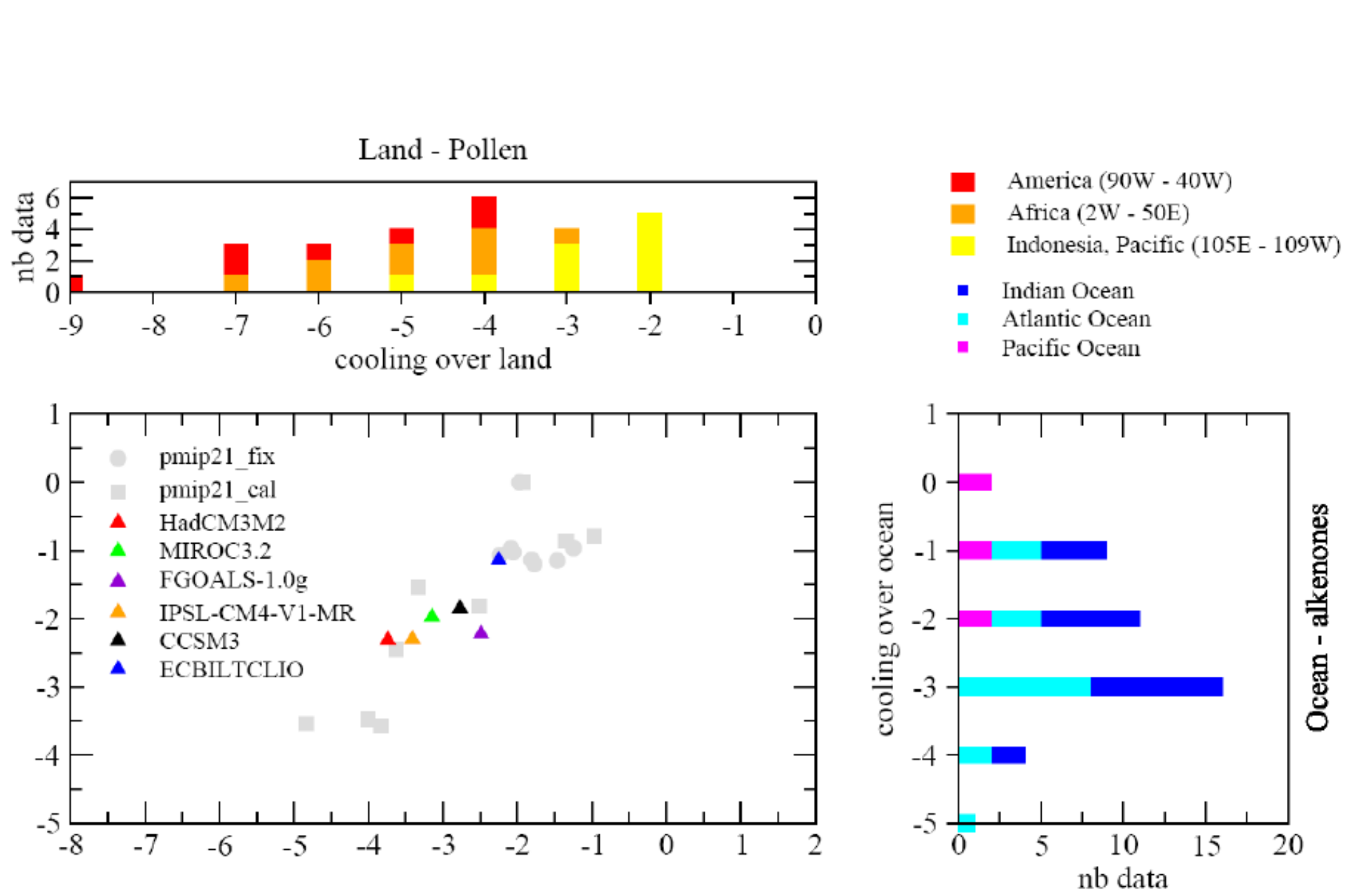


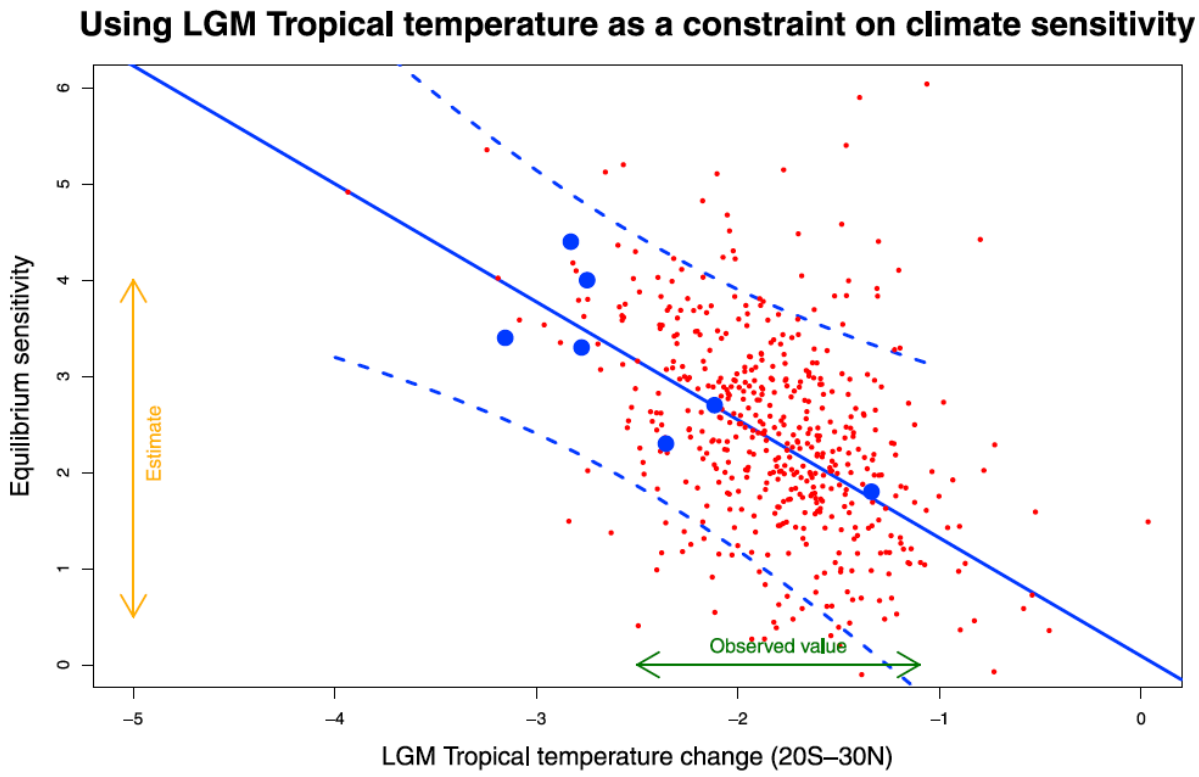

Mean Annual Temperature Anomalies
LGM
b
< -10
-5 to -10
-2 to -5
-1 to -2
-.5 to -1
0 to -.5
0 to +.5
+.5 to +1
+1 to +2
+2 to +5
+5 to +10
> +10 C


SST Anomalies (Annual Temperature)
LGM
b
< -10
-5 to -10
-2 to -5
-1 to -2
-.5 to -1
0 to -.5
0 to +.5
+.5 to +1
+1 to +2
+2 to +5
+5 to +10
> +10 C



Shakun et al 2012


Land - Pollen
nb data
cooling over land
America (90W - 40W)
Africa (2W - 50E)
Indonesia, Pacific (105E - 109W)
Indian Ocean
Atlantic Ocean
Pacific Ocean
pmip21_fix
pmip21_cal
HadCM3M2
MIROC3.2
FGOALS-1.0g
IPSL-CM4-V1-MR
CCSM3
ECBILTCLIO
cooling over ocean
nb data
Ocean - alkenones



Hargreaves et al 2012