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Toward a consistent approach for diagnosing phosphorus limitations in carbon cycle models

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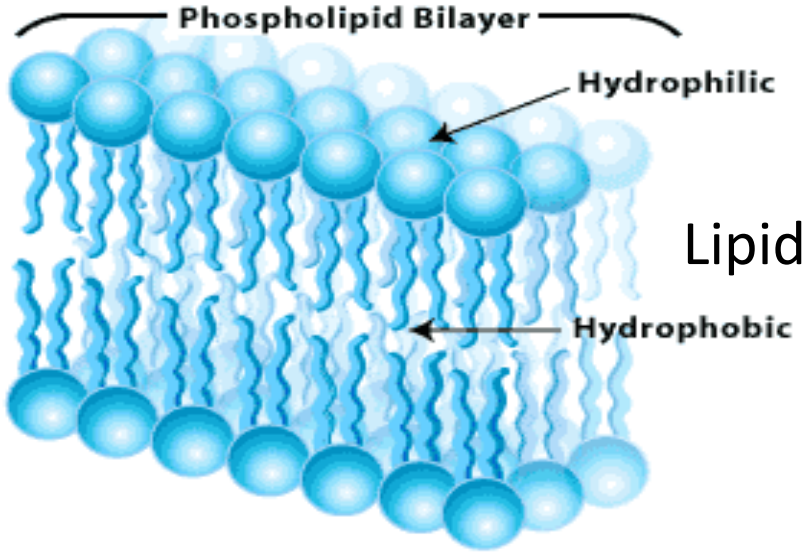
LSCE (UMR 8212)

Phosphorus (P) is a fundamental component of all organisms.

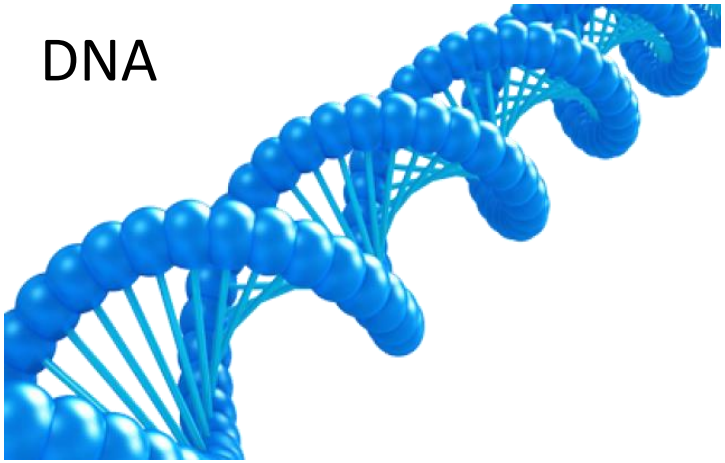
✓DNA and RNA

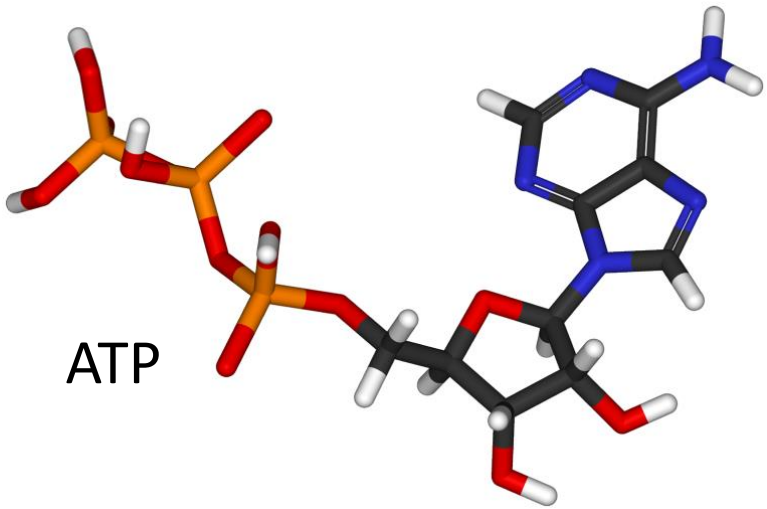
✓Transport cellular energy： ATP

✓Biological membranes: lipid

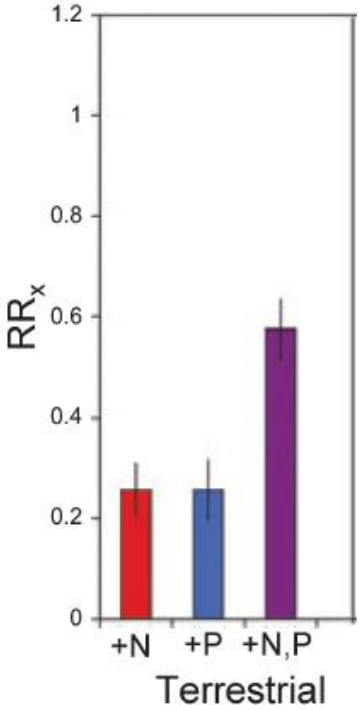


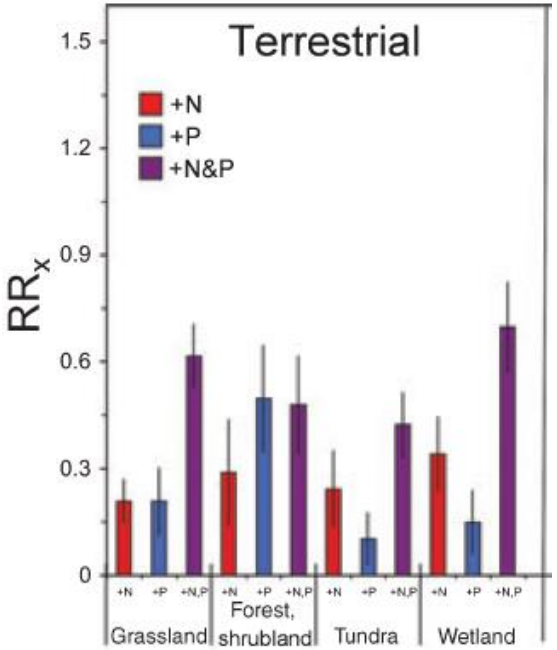
DNA





Evidences for P limitation: fertilization experiments

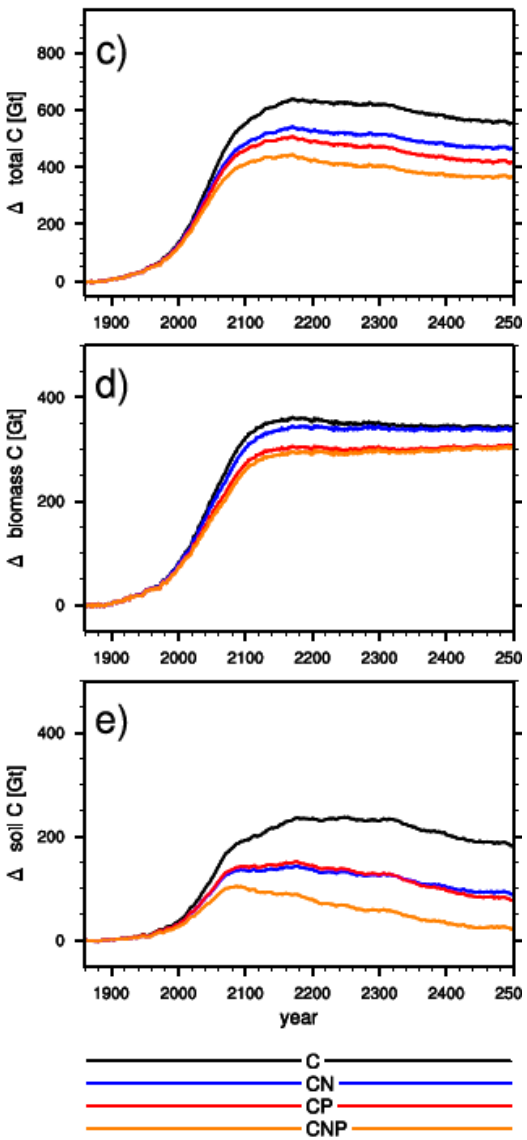


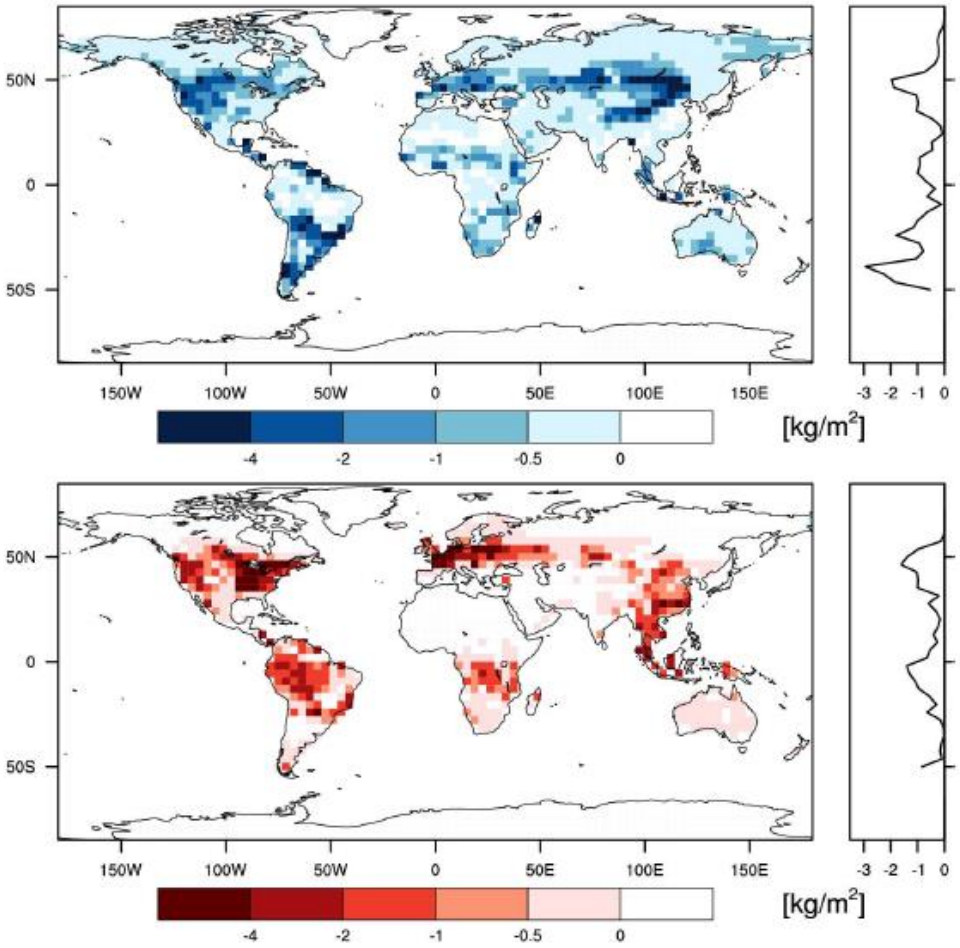


$RR_X = \ln (E/C)$

Elser et al., 2007, Ecology Letters

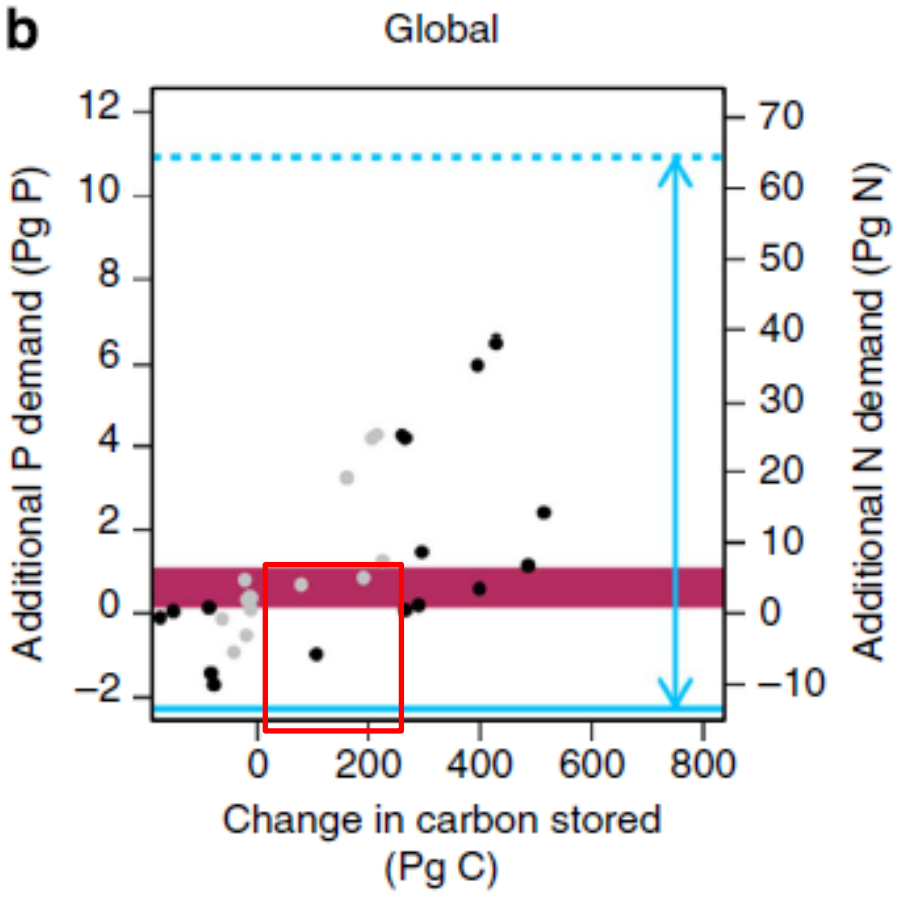
Evidences for P limitation: models incorporating C-P interactions





Goll et al., 2011, Biogeosciences

Previous study: P demand and deficit derived from carbon stock



Additional P demand

(carbon stock-based additional P demand)

The extra-amount nutrient necessary to achieve the increase of carbon pools predicted by each Earth system model.

From 2000 to 2099:

RCP2.6: -0.9~4.3 Pg P

RCP8.5: -1.7~6.5 Pg P

Carbon sink or at least carbon neutral !

C:P for active tissues : 407

C:P for wood: 6502

C:P for soil: 50

Peñuelas et al., 2013
Nature Communications

Previous study: project the carbon storage considering P limitation

Table 2 | Global terrestrial C storage for individual CMIP5 models and the ensemble mean.

Model	Global Terrestrial C Storage (PgC)						
	Initial	Historical			Projected		
	CMIP5	CMIP5	N limit	NP limit	CMIP5	N limit	NP limit
BCC-CSM1.1(m)	1,139	1,245	1,244	1,243	1,666	1,375	1,326
BNU-ESM	1,497	1,599	1,583	1,582	1,716	1,503	1,466
CanESM2	1,775	1,800	1,800	1,799	1,872	1,694	1,637
CESM1(BGC)	999	957	956	956	884	855	828
GFDL-ESM2G	2,160	2,059	2,048	2,048	2,116	1,910	1,879
HadGEM2-ES	1,569	1,581	1,578	1,578	1,899	1,498	1,469
INM-CM4	2,023	2,135	2,135	2,134	2,291	2,190	2,128
IPSL-CM5A-MR	1,957	1,983	1,981	1,981	2,277	1,942	1,910
MIROC-ESM	2,900	2,840	2,833	2,833	2,784	2,492	2,447
MPI-ESM-MR	3,327	3,347	3,334	3,334	3,614	3,035	2,985
NorESM1-M	1,106	1,061	1,061	1,060	862	832	810
Mean	1,859	1,873	1,868	1,868	1,998	1,757	1,717
s.d.	736	727	724	724	784	661	653

Carbon sink

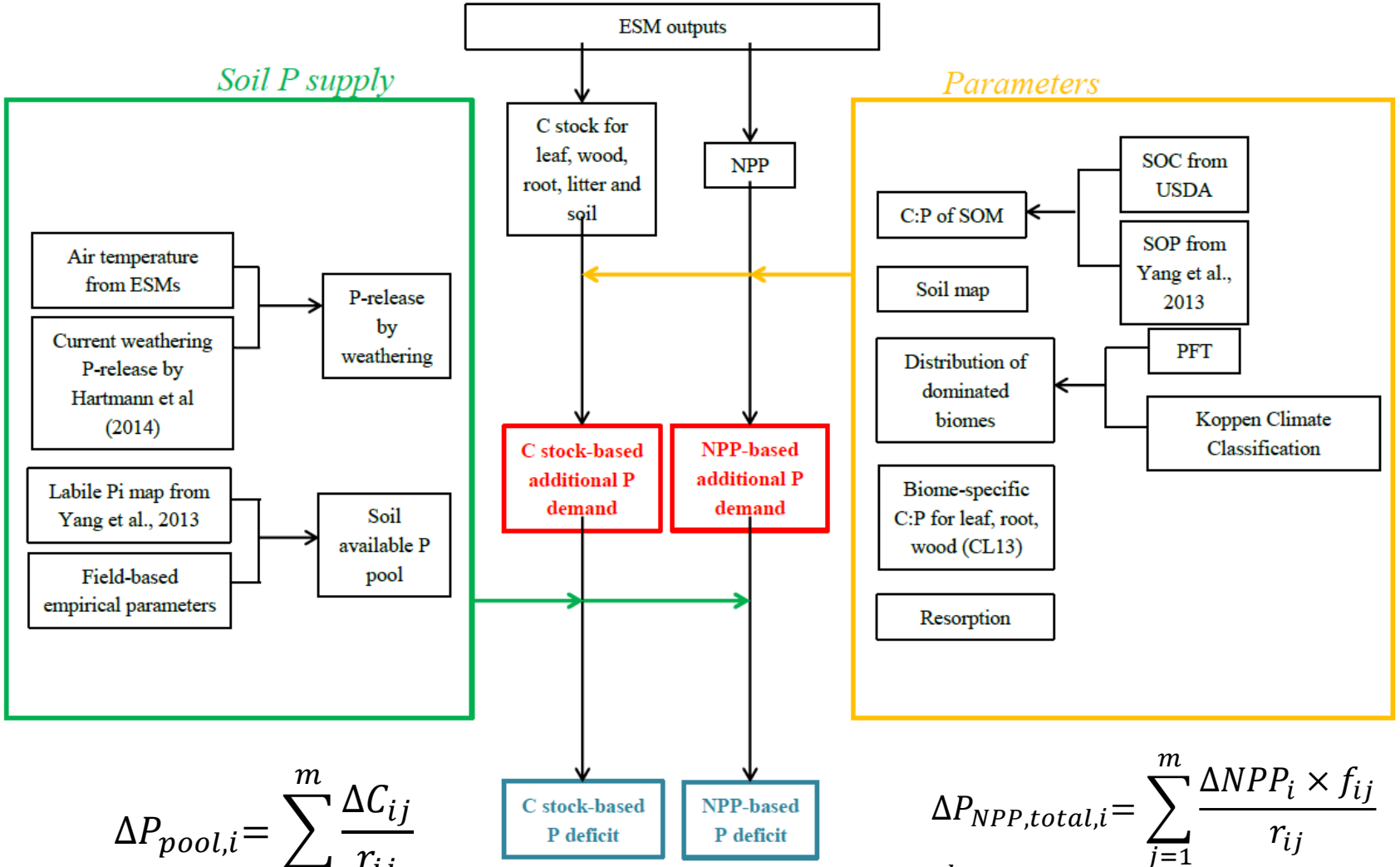
Carbon source

Wieder et al., 2015
Nature Geoscience

Objectives

- To quantify the P demand implied by CMIP5 projections by carbon stock-based and NPP-based methods.
- To investigate whether current soil P pools can support the P demand.
- To investigate where, when and how soil P deficit may occur during the 21st century.
- To identify the uncertainties in P demand and P deficit.

Data, material & methods



$$\Delta P_{pool,i} = \sum_{j=1}^{m} \frac{\Delta C_{ij}}{r_{ij}}$$

$$\Delta P_{NPP,total,i} = \sum_{j=1}^{m} \frac{\Delta NPP_i \times f_{ij}}{r_{ij}}$$

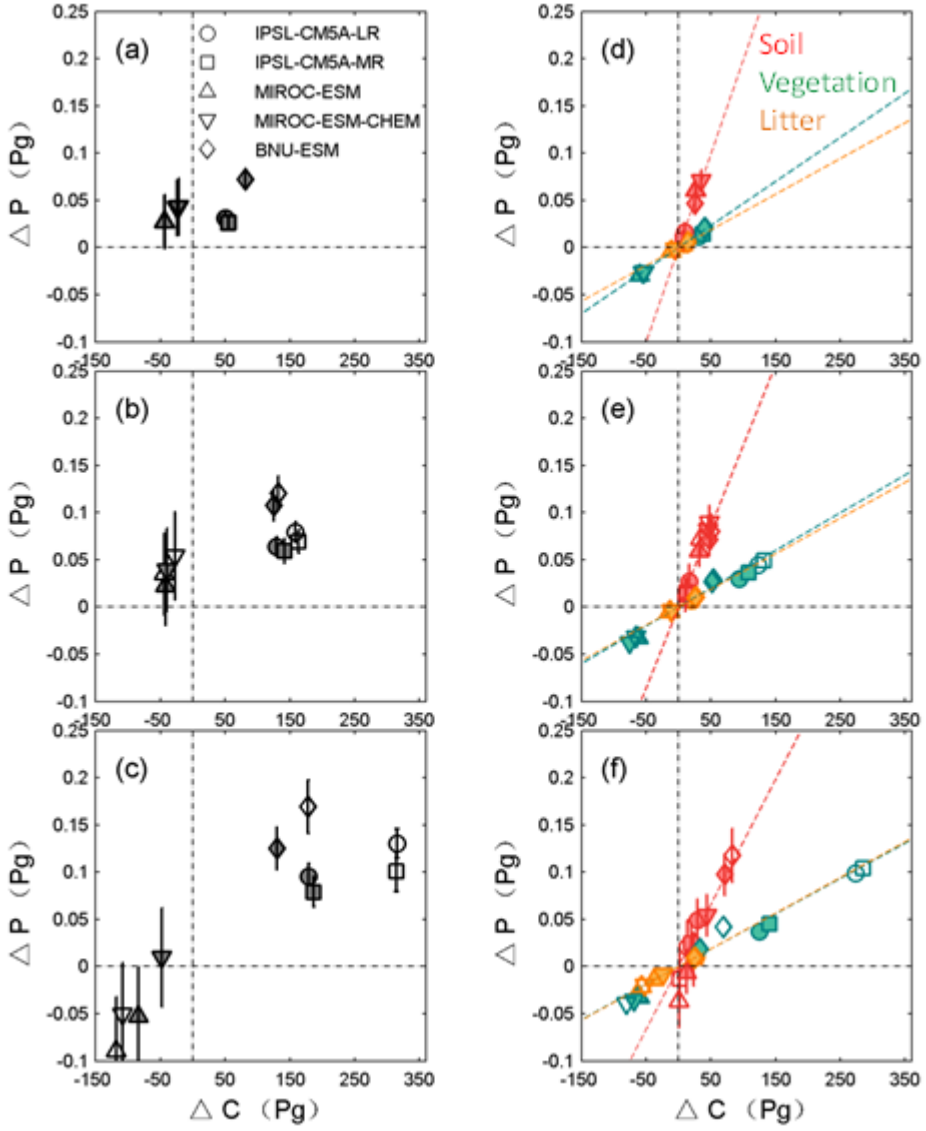
$$\Delta P_{NPP,i} = \sum_{t=a}^{b} \left(\Delta P_{NPP,total,i} - \Delta P_{RSB,i} - \Delta P_{MR,i}\right)$$

Additional P demand diagnosed from carbon stock changes

1900-2010

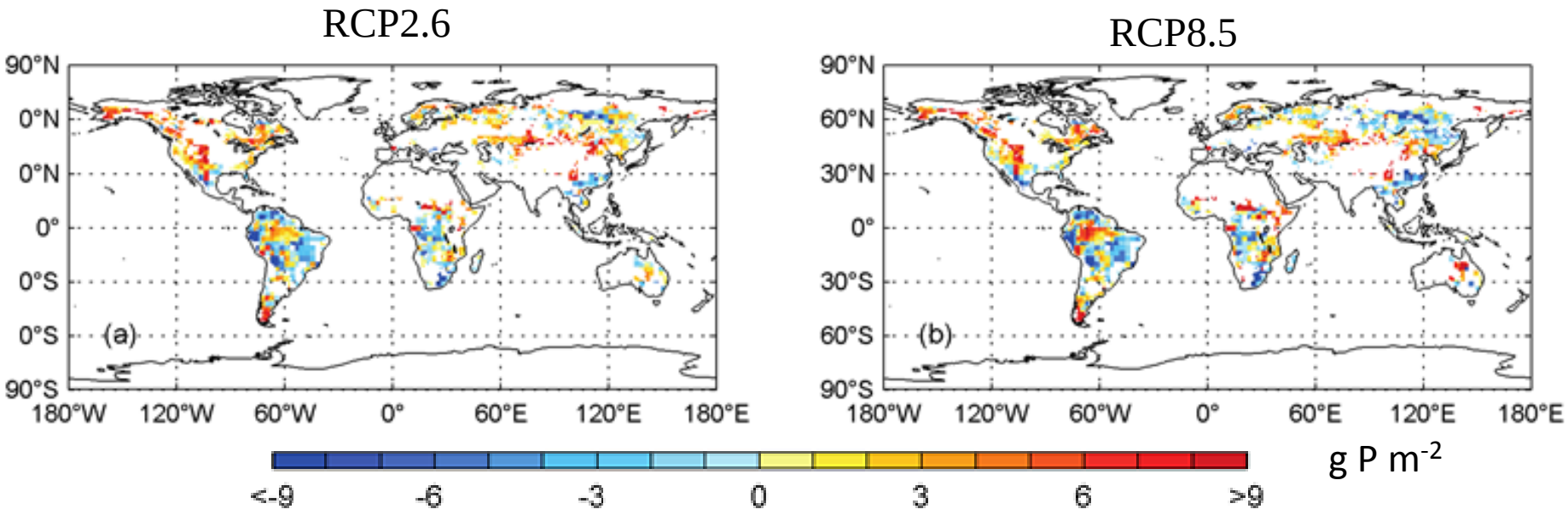
1900-2050

1900-2100

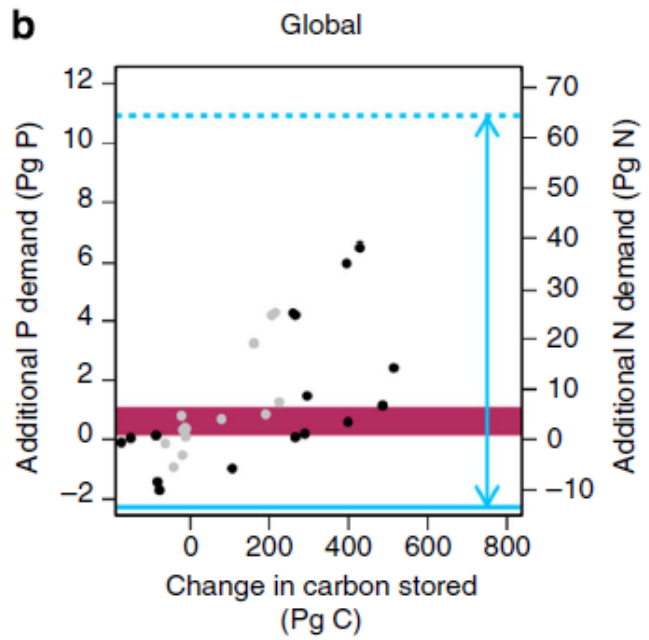


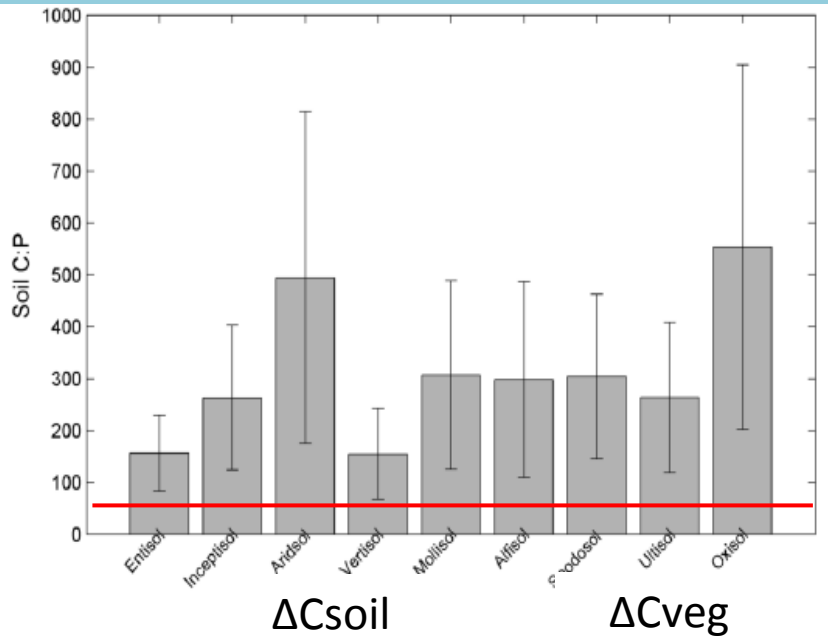
Additional P demand diagnosed from carbon stock changes

Spatial patterns of additional P demand based on the changes of terrestrial pools from 1900 to 2100

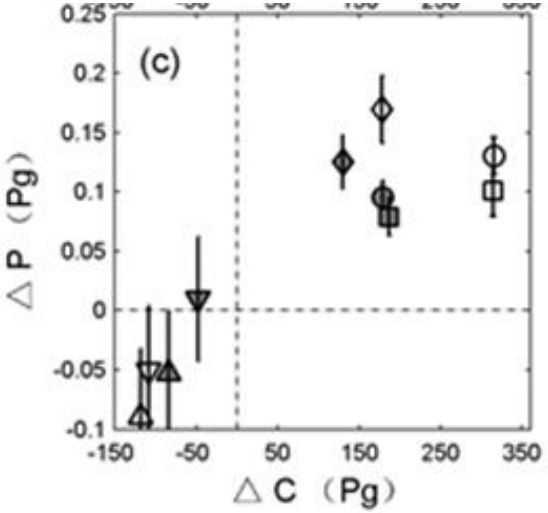


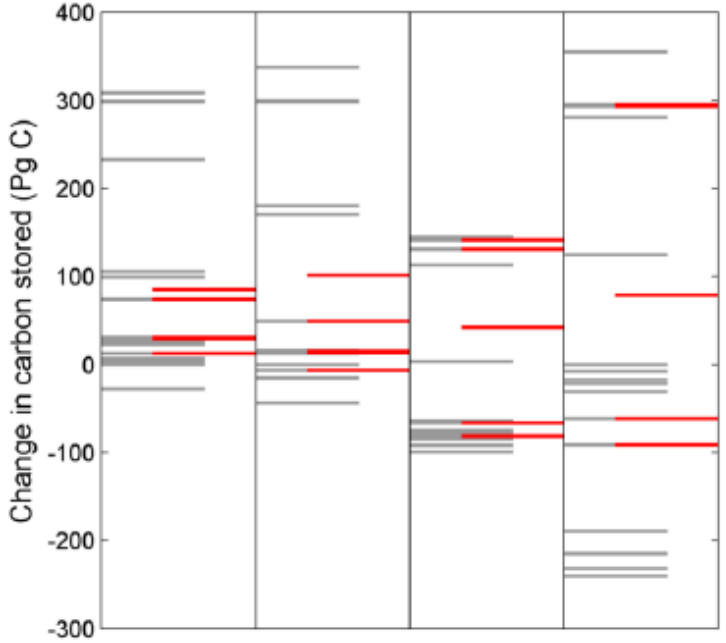
Comparison of carbon stock–based P demand with other studies





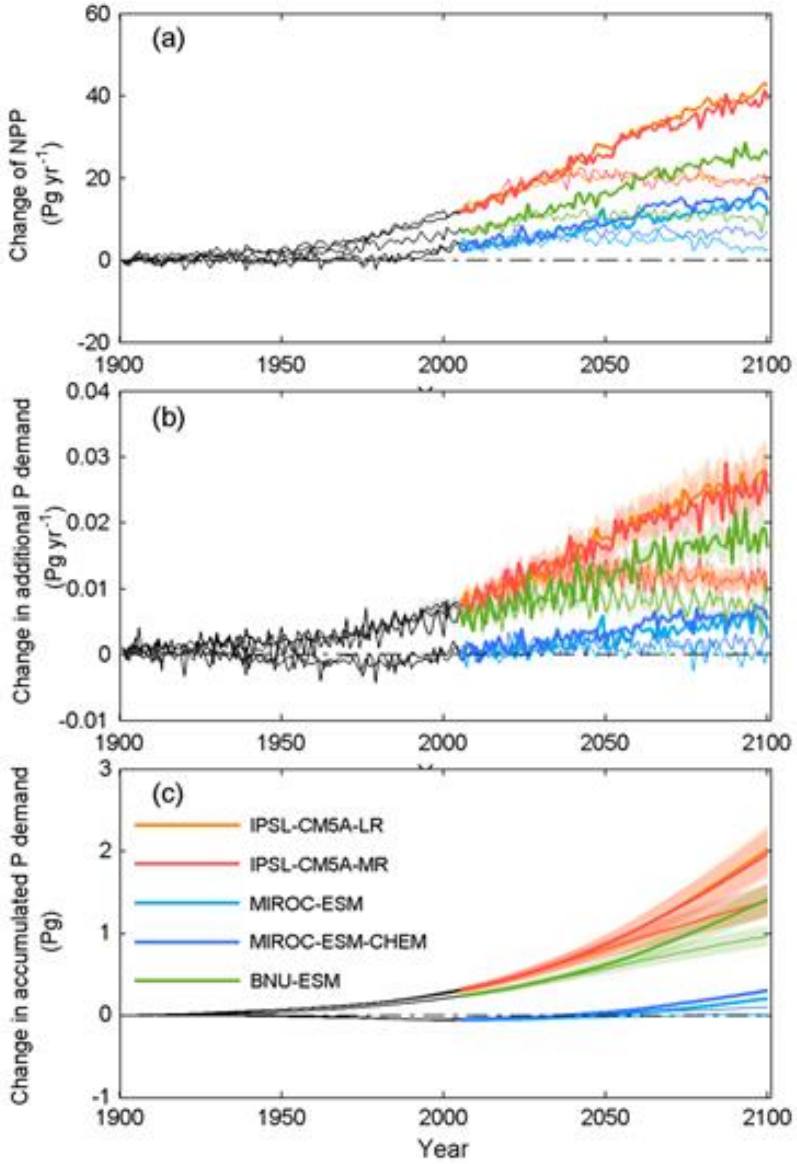
ΔCsoil ΔCveg





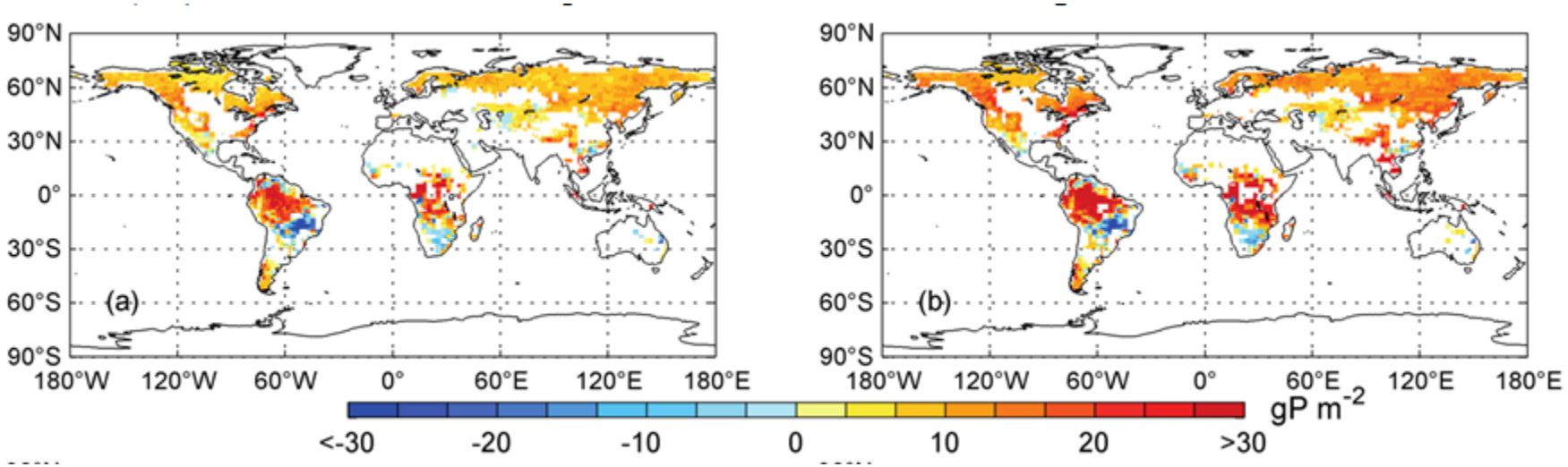
RCP2.6 RCP8.5 RCP2.6 RCP8.5

Additional P demand diagnosed from NPP



Additional P demand diagnosed from NPP

Spatial patterns of additional P demand based on NPP



P supply by mineralization

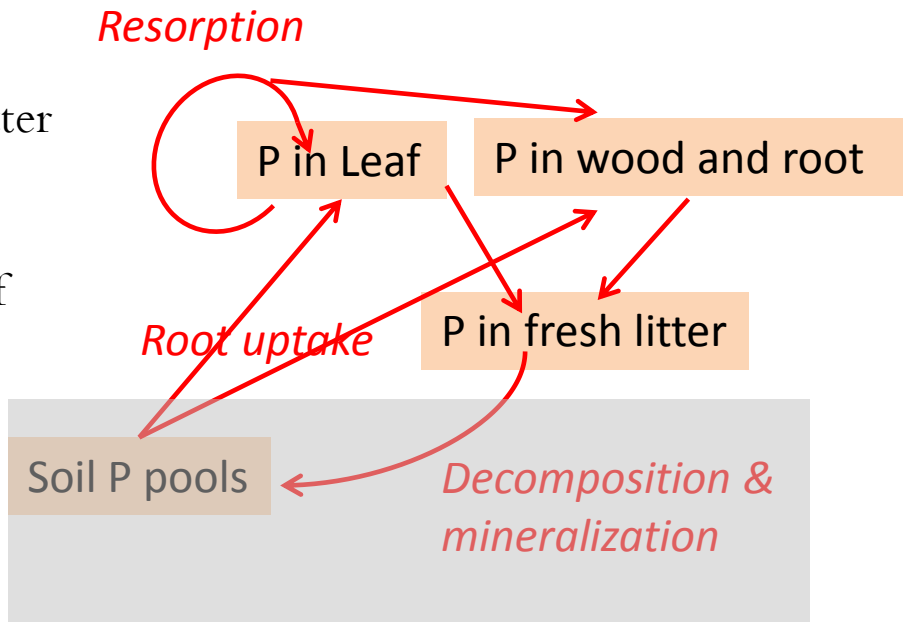
Two assumptions

L1: 100% P in increasing fallen leaves can be mineralized and support the plant growth in the following year, while P in wood and root components of litter cannot be used by ecosystem at the time scale of 200 year.

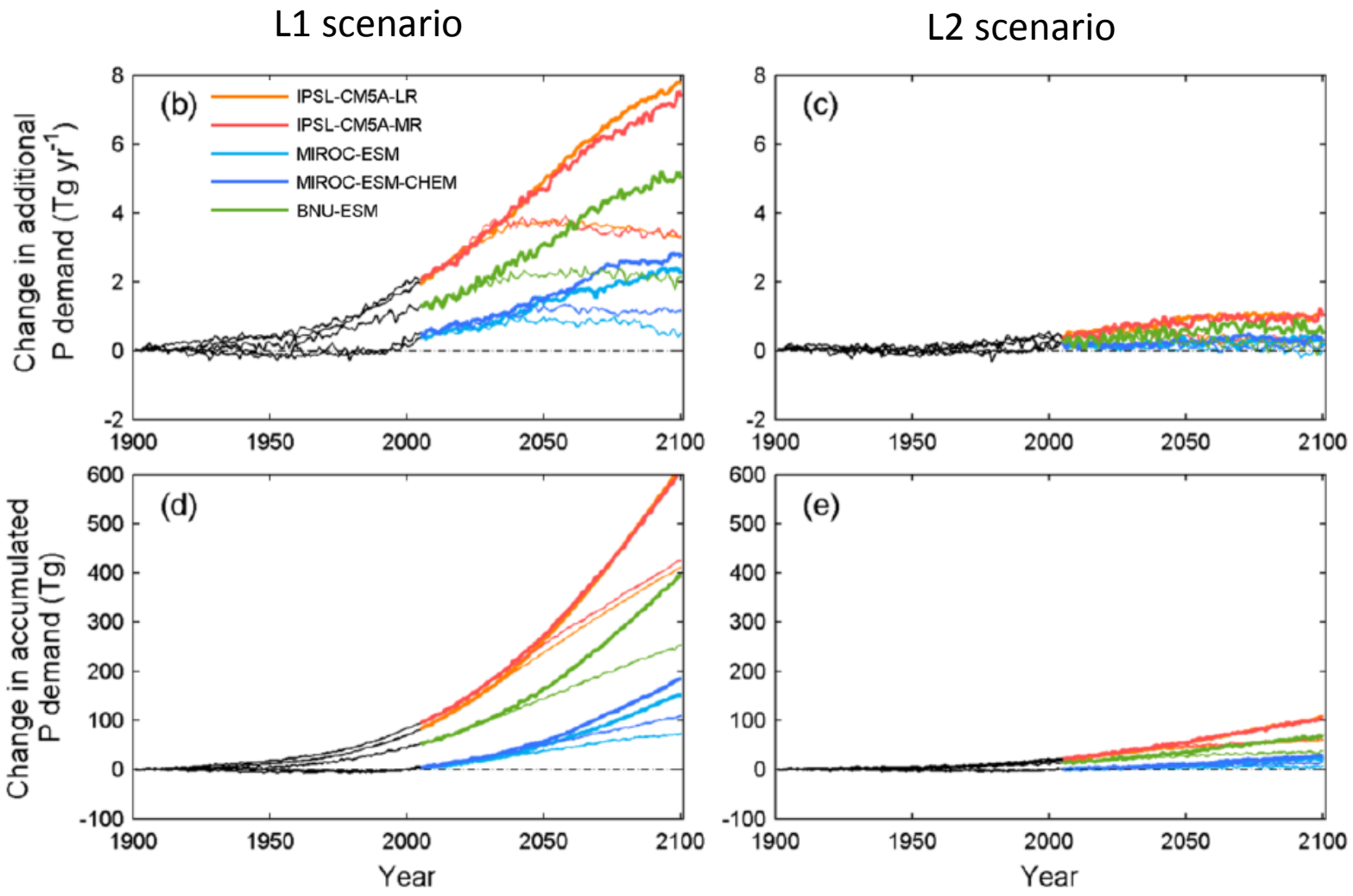
$$\Delta P_{NPP,total,i} = \sum_{j=1}^{m} \frac{\Delta NPP_i \times f_{ij}}{r_{ij}}$$

$$\Delta P_{NPP,i} = \sum_{t=a}^{b} \left(\Delta P_{NPP,total,i} - \Delta P_{RSB,i} - \Delta P_{MR,i}\right)$$

L2: 90% P in wood and root component of litter can be recycled in addition to the 100% P in fallen leaves, which provide a upper-bound of recycled P.



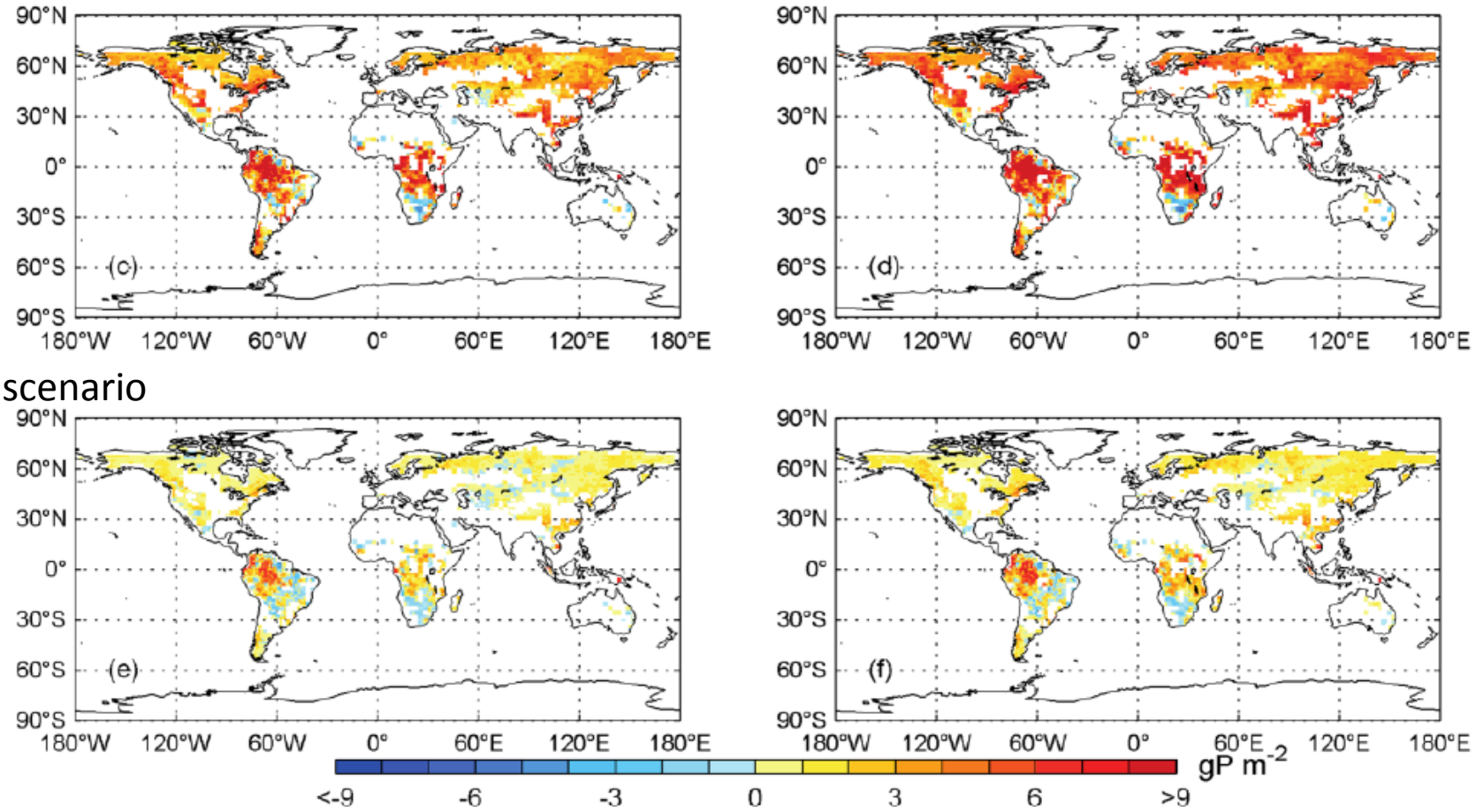
Additional P demand diagnosed from NPP



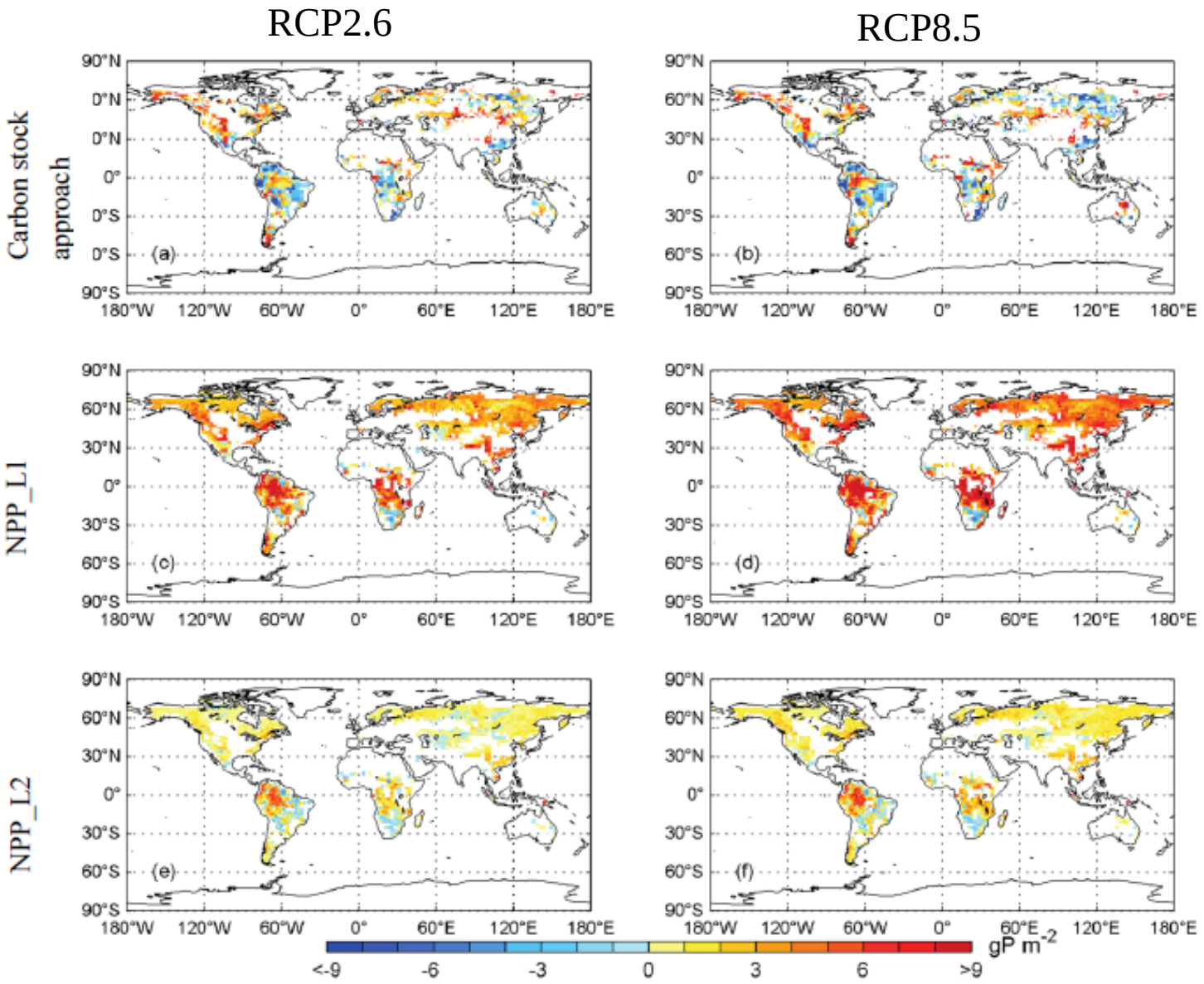
Additional P demand diagnosed from NPP

Spatial patterns of additional P demand based on NPP

L1 scenario RCP2.6 RCP8.5



Reconciling of additional P demand derived from carbon stock and NPP



Four scenarios of soil available P for plants (SAP)

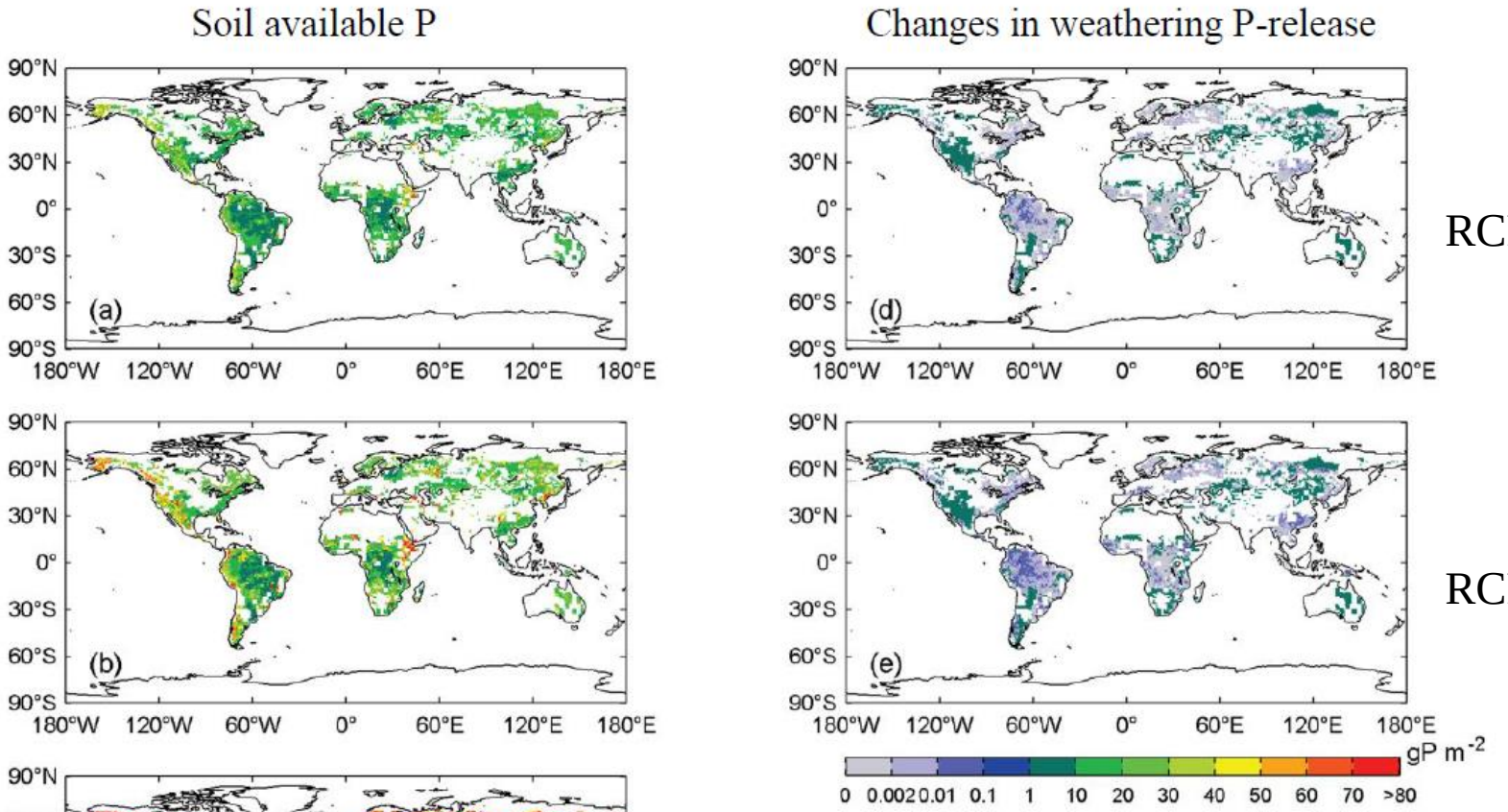
Current knowledge of SAP quantity remains elusive!

Four scenarios of SAP

- ✓ *S0:* ecosystem cannot utilize various forms of P in present soil (except for annual weathering P)
- ✓ *S1:* resin Pi
- ✓ *S2*: labile Pi (defined as resin-Pi + bicarbonate Pi)
- ✓ *S3*: labile P (defined as resin Pi + bicarbonate inorganic and organic P)

Hedley et al., 1982
Soil Science Society of America Journal

Additional P available for plants



S1: 1.18 Pg P

S2: 2.15 Pg P

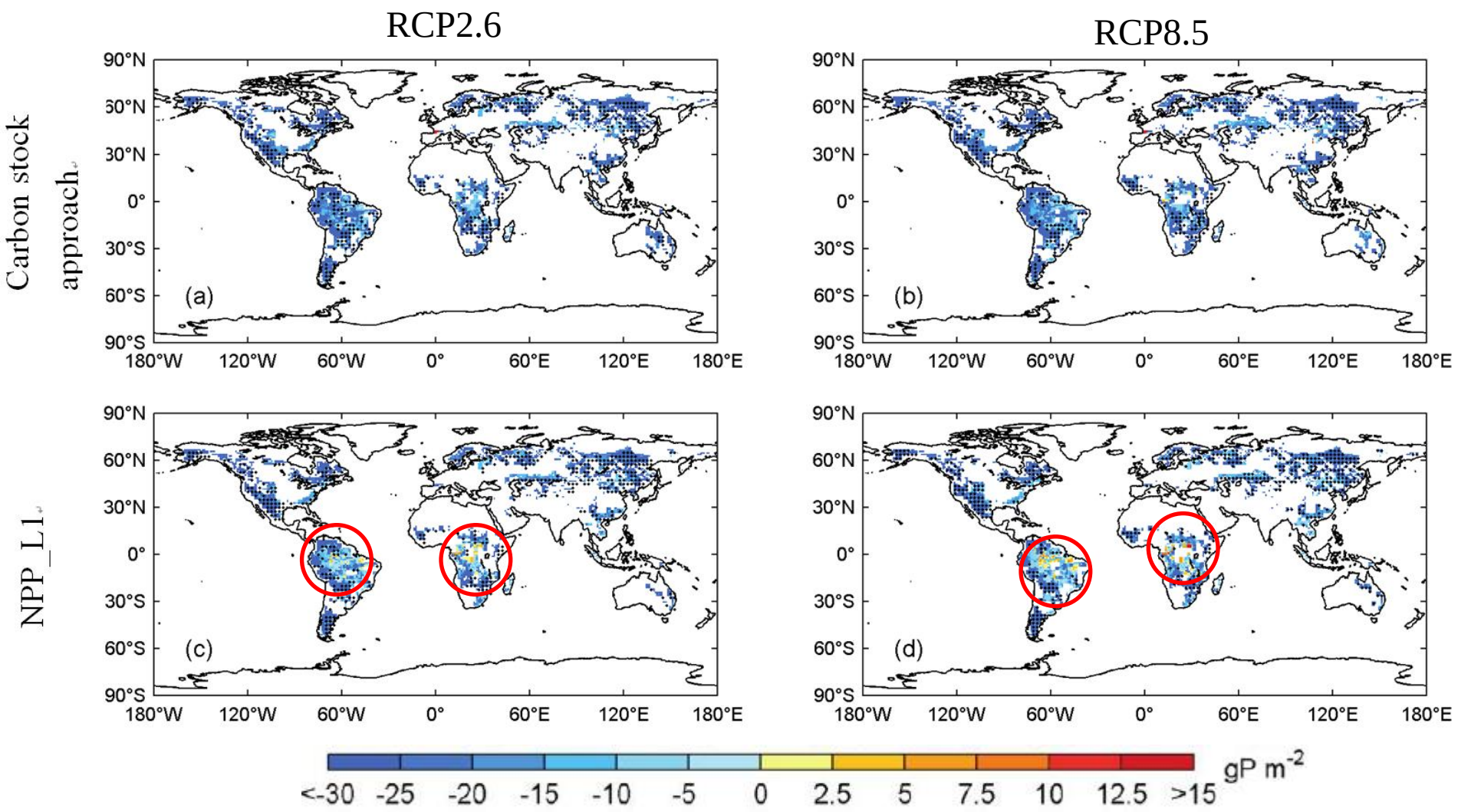
S3: 3.81 Pg P

ΔP_{WTR} : 0.13~0.14 Tg P (RCP 2.6),

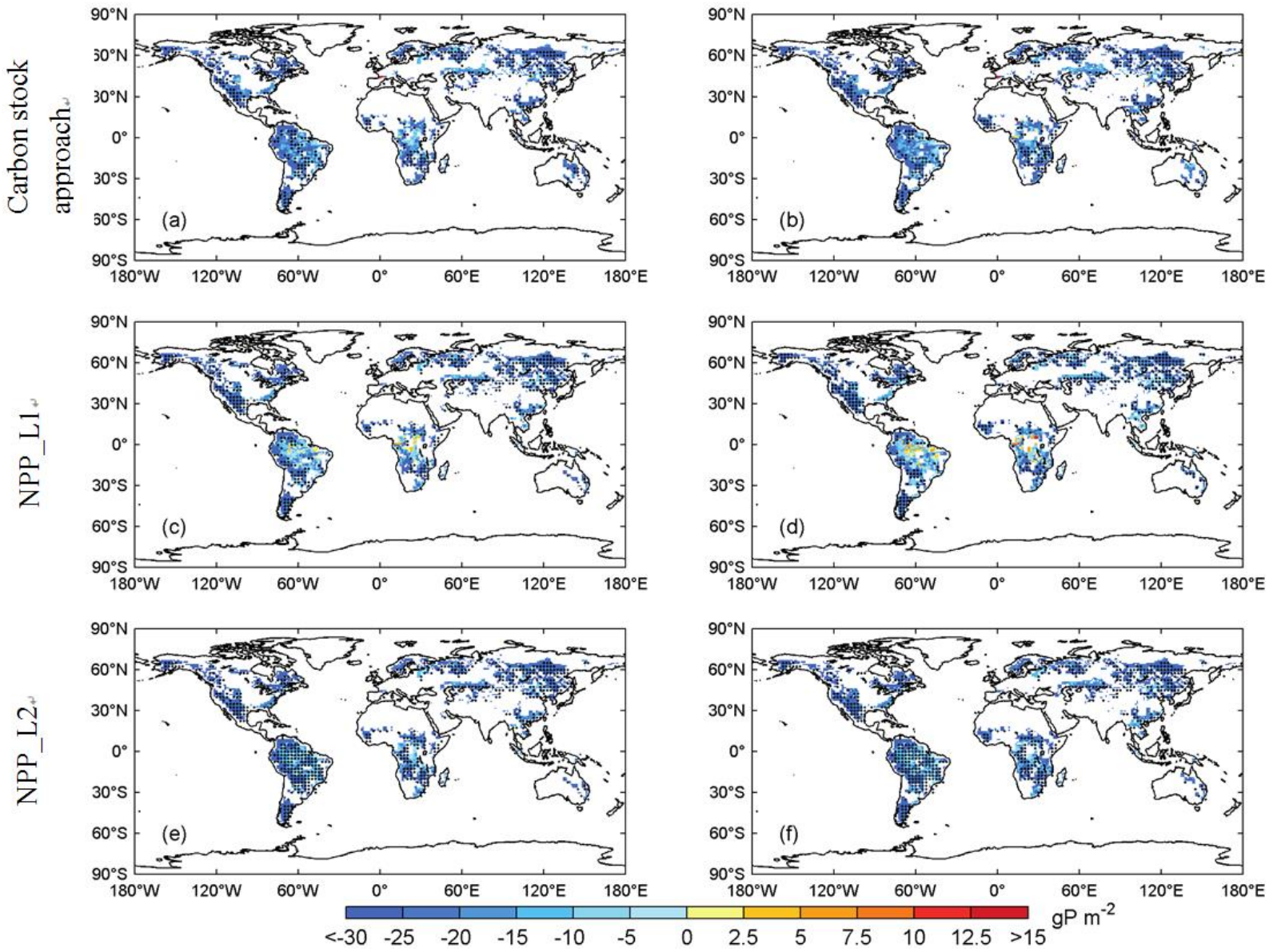
0.33~0.40 Tg P (RCP 8.5)

P deficit under S2

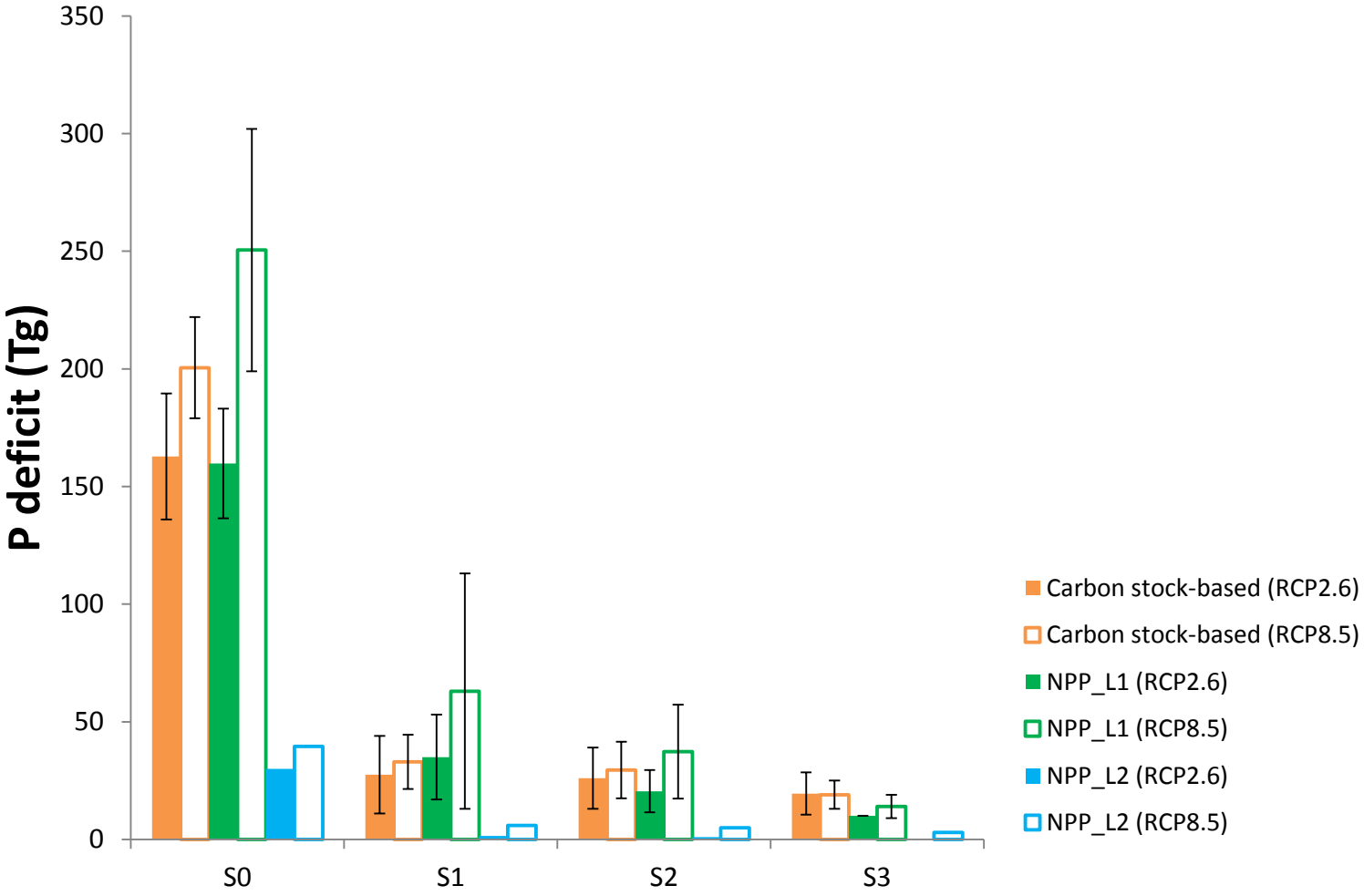
$$P_{deficit,i} = \Delta P_{pool,i} - SAP - \Delta P_{WTR}$$



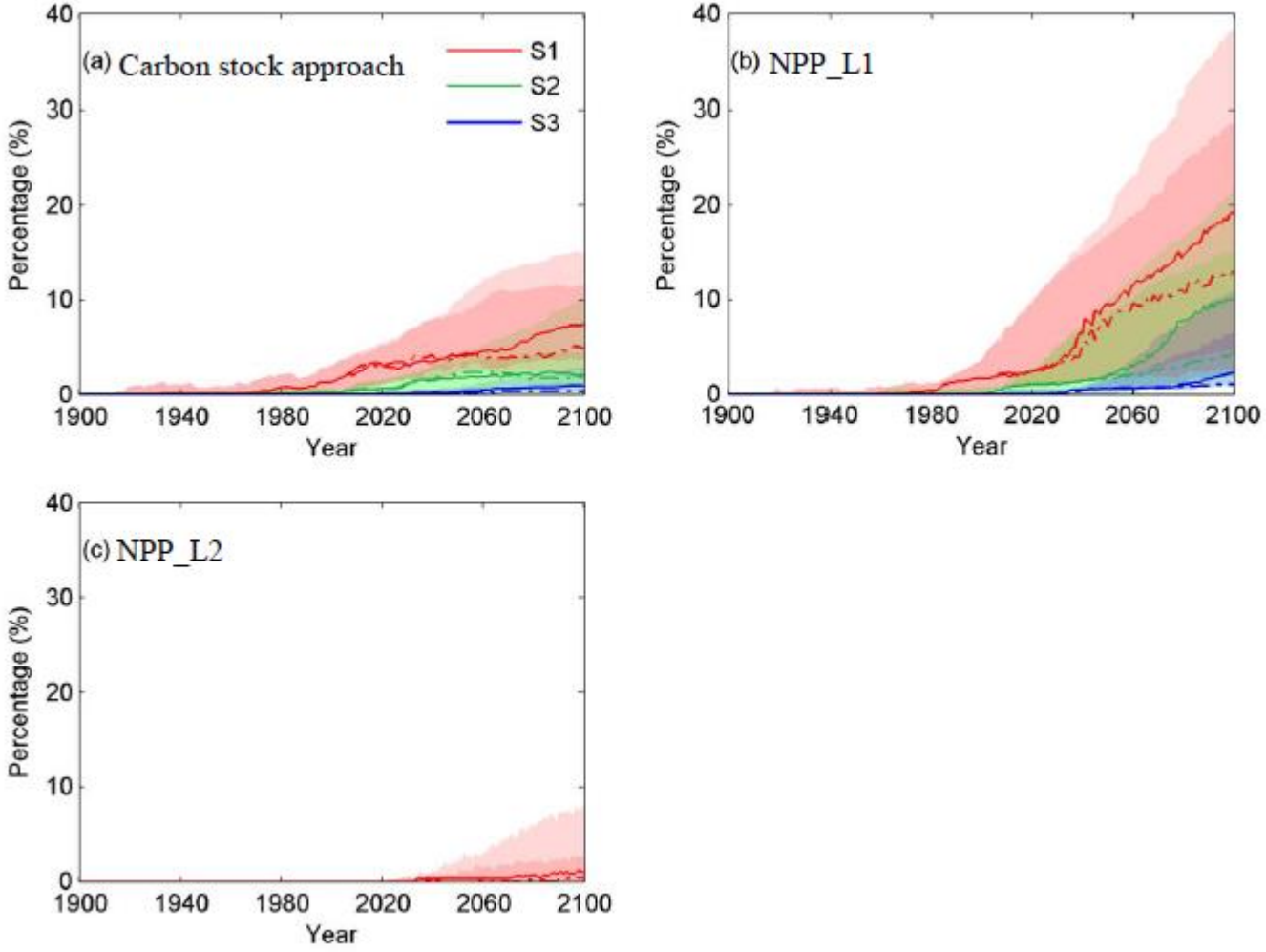
P deficit under S2



Global P deficit under four scenarios of SAP



The occurrence of P deficit



Compatible carbon stock by 2100

ESM		RCP 2.6	RCP 8.5
IPSL_CM5A_LR	**Initial**	**1970**	**2130**
	S0	1743	1791
	S1	1952	2070
	S2	1965	2103
	S3	1969	2124
IPSL_CM5A_MR	**Initial**	**2038**	**2182**
	S0	1803	1832
	S1	2011	2104
	S2	2027	2142
	S3	2035	2169
MIROC_ESM	**Initial**	**2150**	**2109**
	S0	1979	1916
	S1	2101	2051
	S2	2117	2071
	S3	2127	2085
MIROC_ESM_CHEM	**Initial**	**2189**	**2120**
	S0	1970	1899
	S1	2138	2062
	S2	2160	2087
	S3	2174	2103
BNU_ESM	**Initial**	**1742**	**1805**
	S0	1515	1468
	S1	1736	1783
	S2	1741	1799
	S3	1742	1804