Distribution of phosphorus in agricultural soils at global scale : drivers and uncertainty

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Grignon, 13/06/2014

INRA SCIENCE & IMPACT

UMR ISPA, Bordeaux

Phosphorus (P) in agricultural soils : + (yield) vs. - (water)

High P (P4)

Low P (P0)

Heterogeneous distribution =f(geology, farming management, land-use change, climate, soil erosion, soil dynamic processes)
Vitousek et al. 2010 ; MacDonald et al. 2011

Current picture of its distribution at global scale

Large sources of uncertainty

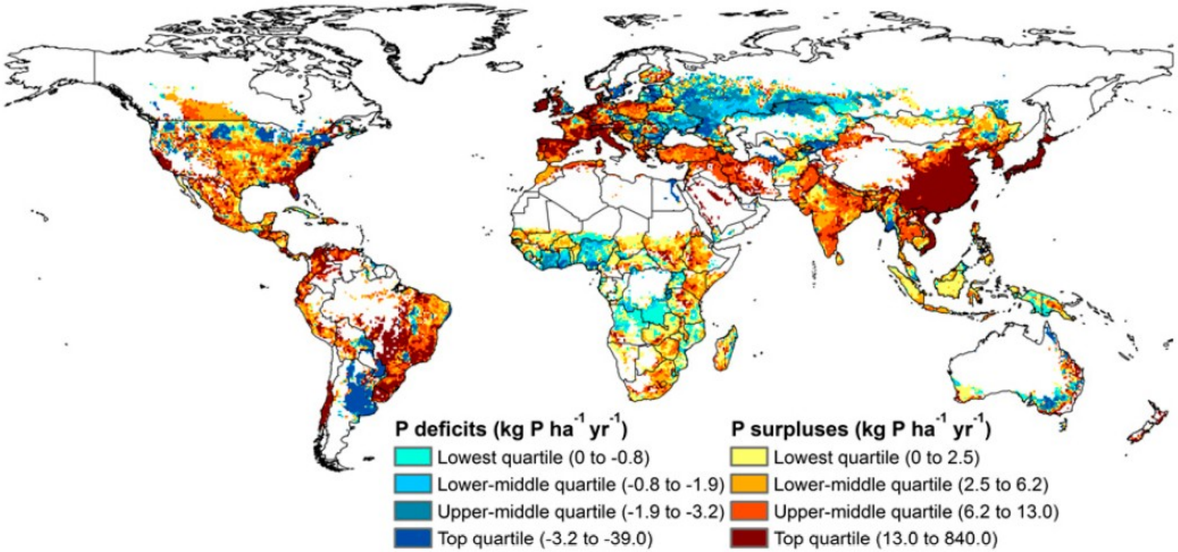
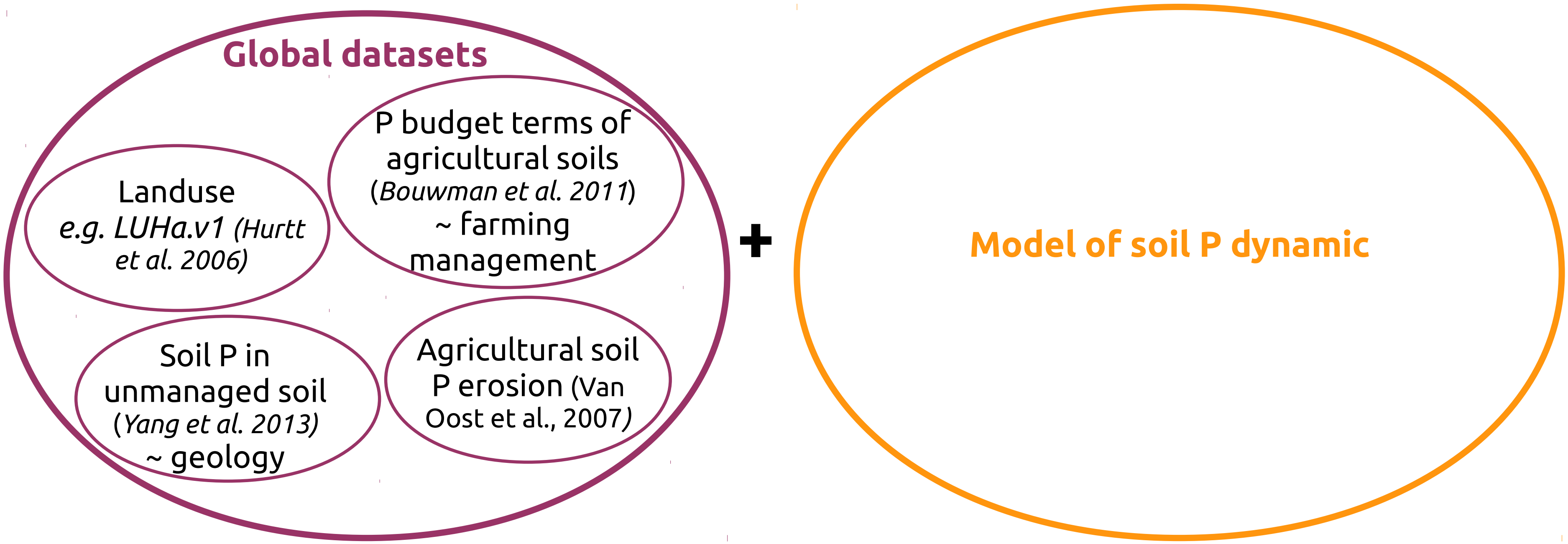


Fig. : 2000 soil P budget (soil input – soil output)
MacDonald et al. 2011

Q1 : what are the drivers of the current global distribution of P in agricultural soils ?
Q2 : what are the main sources of uncertainty in the estimates of this distribution ?

Method overview

Historical evolution of soil P in cropland/grassland from ~1900 to 2000.

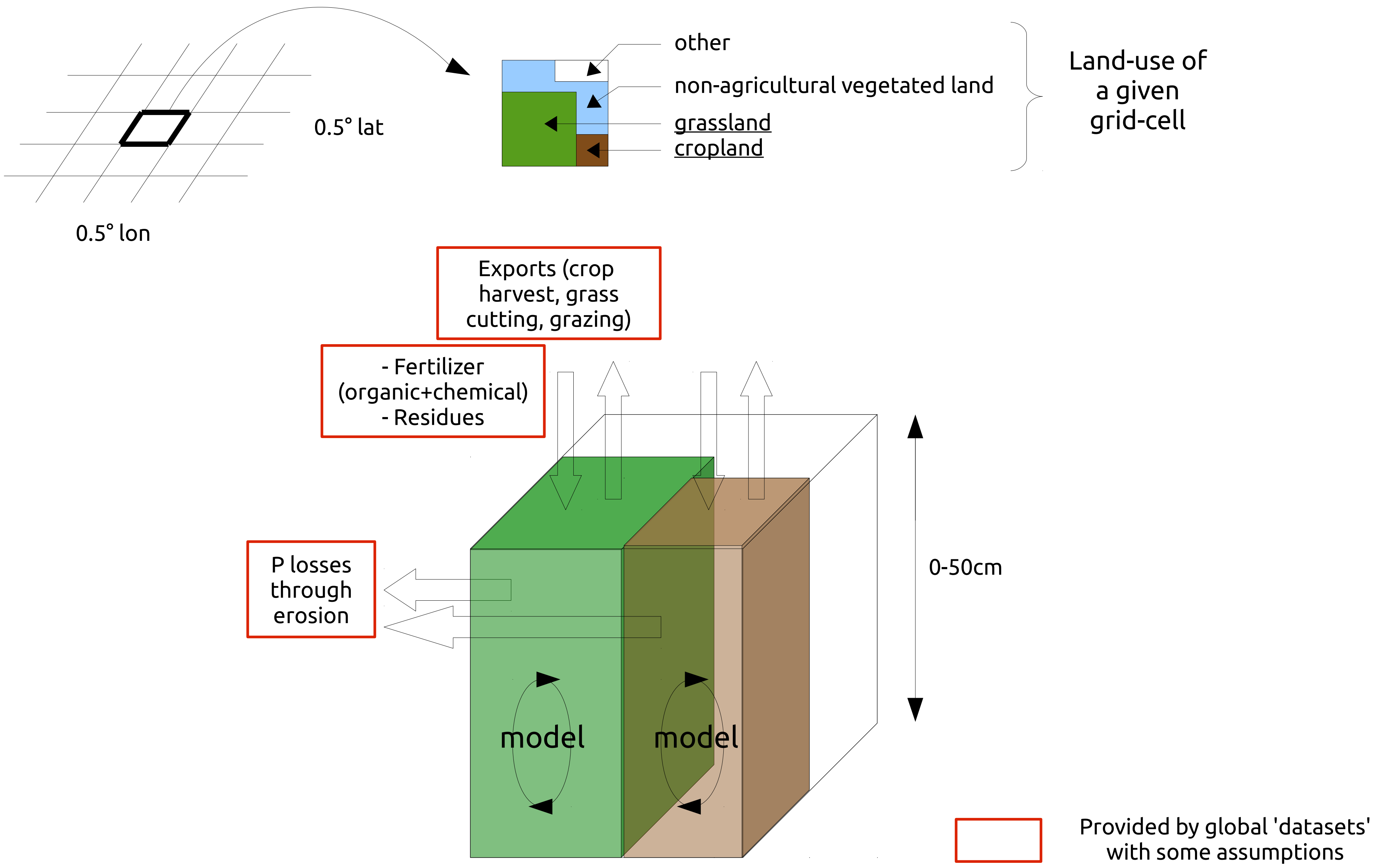


Uncertainty in each global dataset & model design: work in progress

Contribution of the different drivers : sensitivity tests

Method

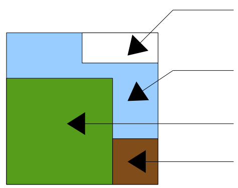
Historical evolution of soil P in cropland/grassland from ~1900 to 2000.



Method : LUC and Initial conditions

- Take into account the land-use change from y-1 to y:

$$\begin{cases} P_{crop}(y) = [P_{crop}(y-1).(f_{crop}(y-1) - \Delta_{crop}^{all-crop}) + \sum_{X \in grass, nonagri, other} P_X(y-1).\Delta_X^{crop}] / f_{crop}(y) \\ \forall\, y, P_{nonagri}(y) = P_{Yang} \\ \forall\, y, P_{other}(y) = 0 \end{cases}$$



P: soil P pool ; f: grid-cell fraction; Δ: land conversion

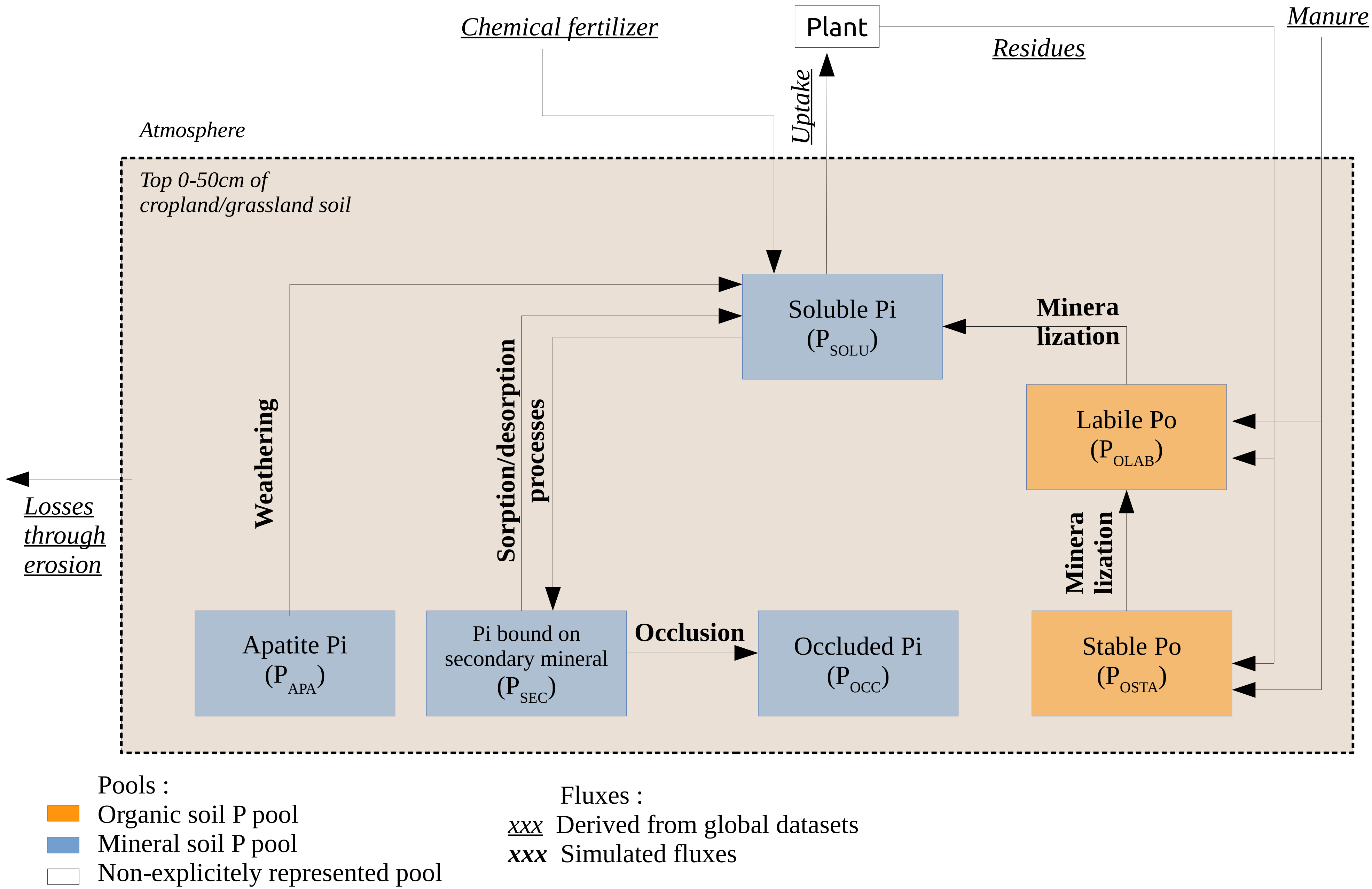
P_{Yang} : current P in unmanaged soil (Yang et al., 2013) ~ geology

- Initial conditions :

P_{Yang} prescribed to agricultural soils in 1700
then 200 years of simulation (~spin-up) with :
- constant soil input/output (=1900 level)
- land-use change

Method : Model of soil P dynamic

Hedley, parameterizations based on DGVM

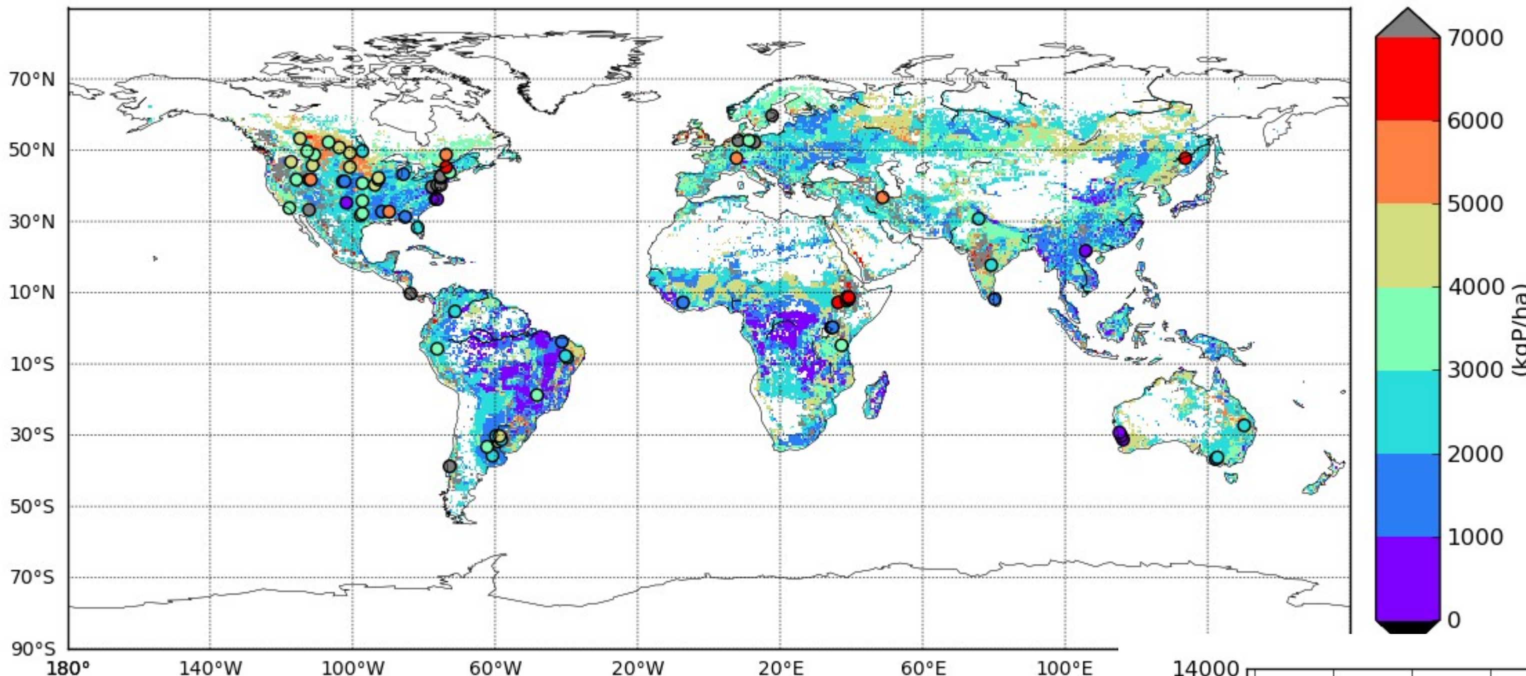


Work in progress !

Evaluation

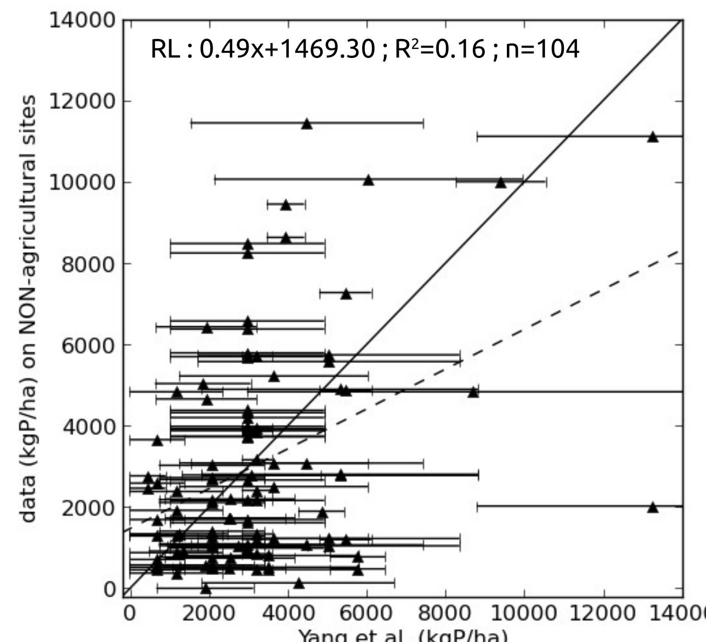
Against a database compiling measurements on cropland/pasture sites from the literature (Augusto et al. unpublsihed)

Simulation vs. Measurements for total cropland soil P



Relatively poor but :
- Some processes not yet represented
- Limitations in the measurements (bulk density)
- If geology plays a key-role =>

model/data score on agricultural sites < Yang/data score on non-agri sites



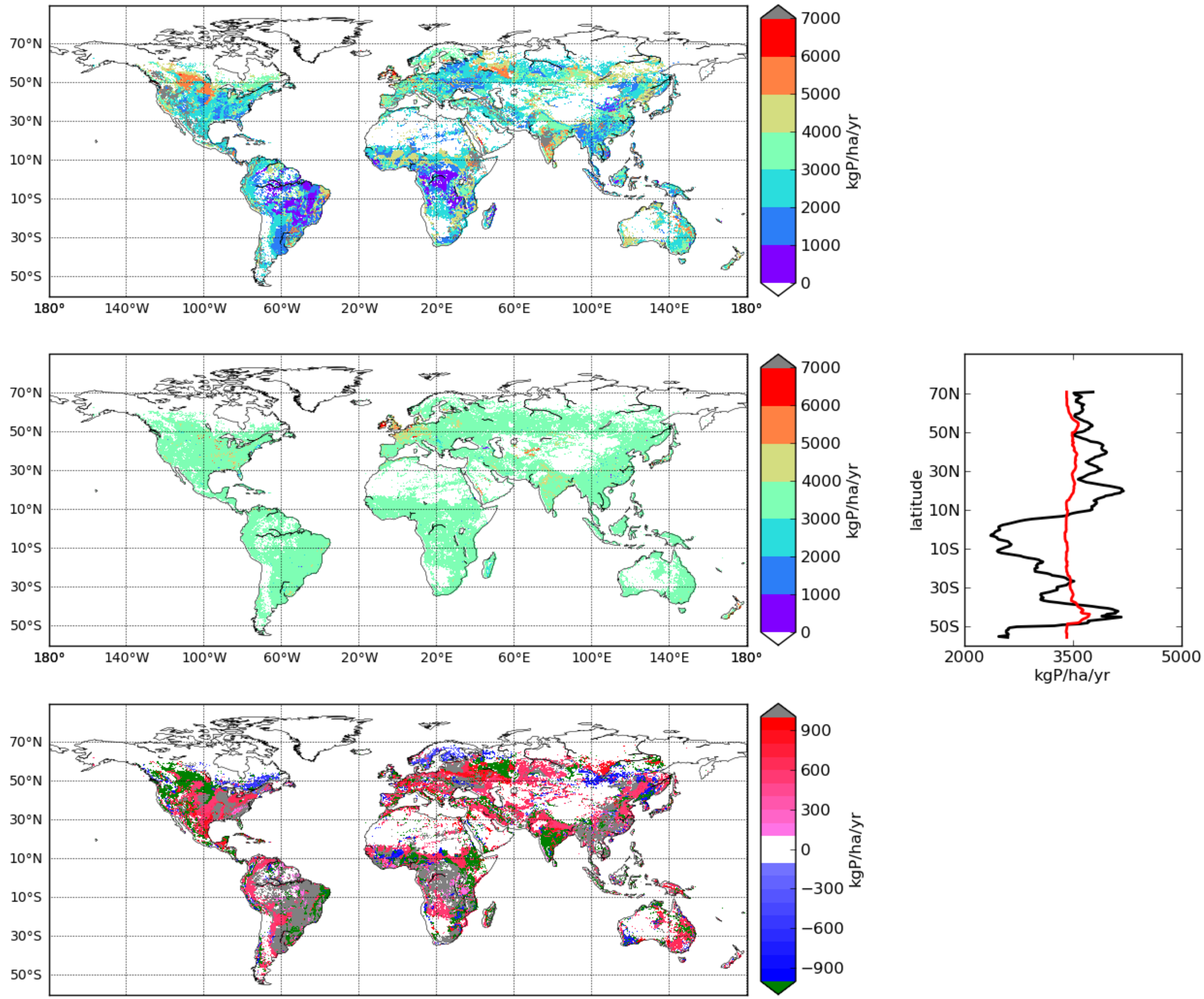
Results : drivers of the current spatial variability

E.g. : effect of 'geology' on simulated current soil P

Total cropland soil P (A)

Total cropland soil P after removing spatial variability in 'geology' (B)

(B) - (A)



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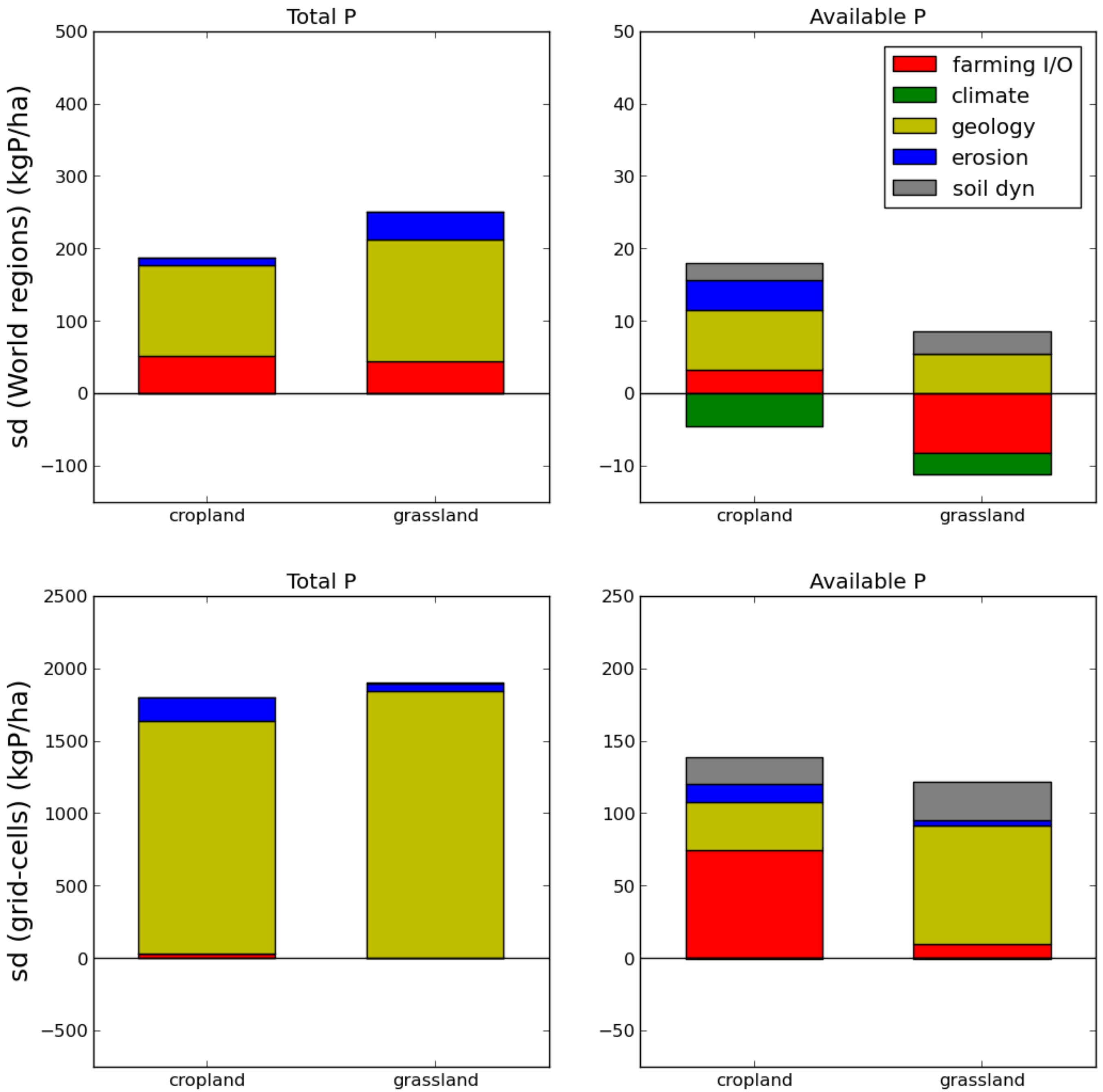
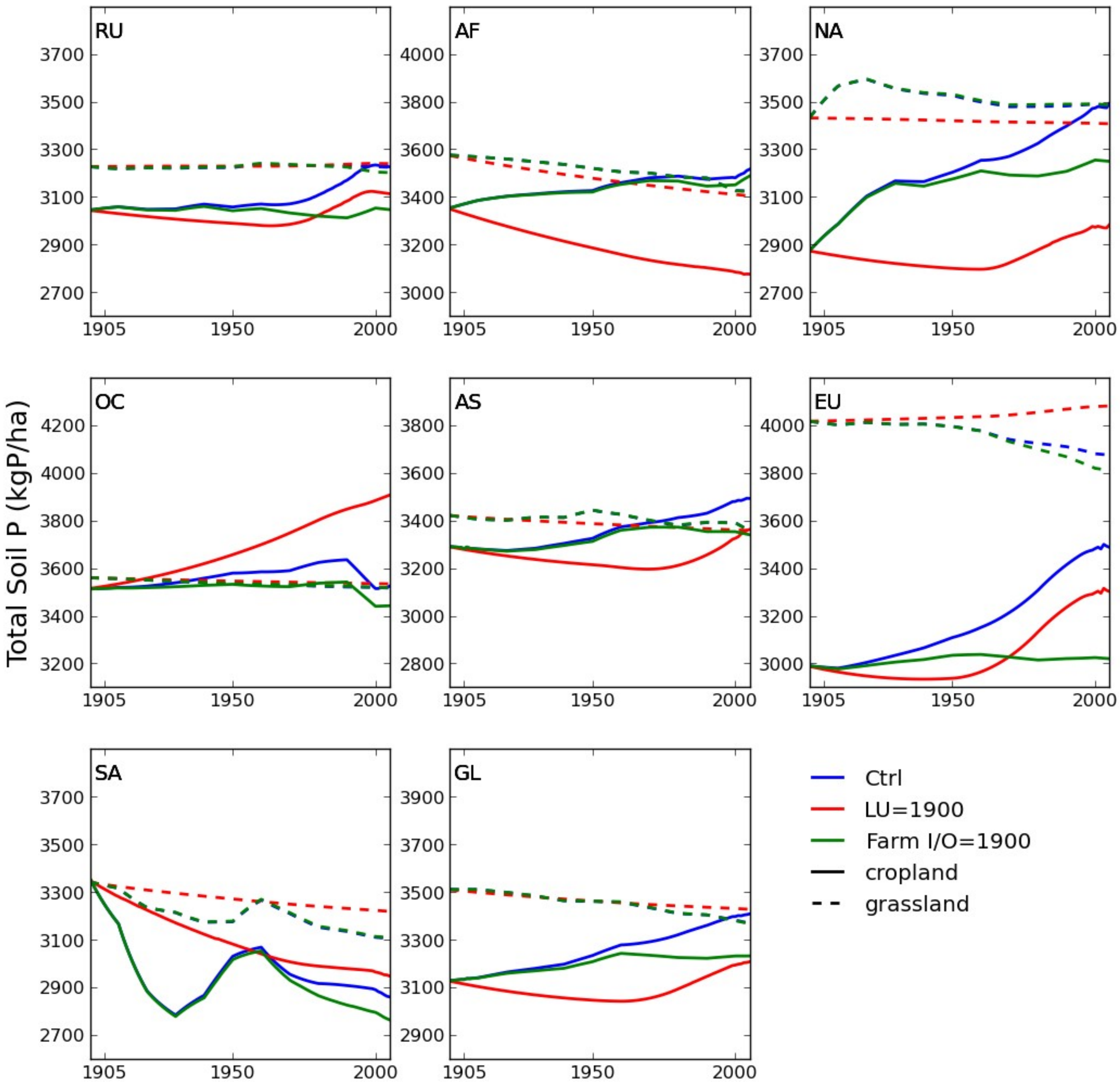


Drivers contribution to the spatial variability of soil P (total and available) at different scales

Results : drivers of temporal variations



20th century evolution of total soil P for large World regions

Conclusion :

Work in progress !

Role of geology in spatial distribution of total vs. available P

The uncertainty in each dataset and model design HAS to be taken into account :
- For the evaluation
- For the estimates of the drivers

Backup :

- slide avec table résumant les global datasets utilisées
- slide avec un résumé du calcul des différents flux

$$P_{TOT} = P_{APA} + P_{SEC} + P_{OCC} + P_{SOLU} + P_{OSTA} + P_{OLAB}$$

$$fP_{APA}^{SOLU} = k_w . g_1(T) . g_2(W) . P_{APA}$$

Weathering: k_W = 0.0001 yr^{-1} (Buendia et al. 2010)
$g_1(T)$; $g_2(W)$: functions of soil water content and T => Goll et al., 2014 ?

$$P_{SEC} = S_{max} . [\frac{K_S . P_{SOLU}}{1 + K_S . P_{SOLU}}]$$

Sorption/desorption equilibrium:
Use of an isotherm equation (MacGehan and Lewis, 2002)
Langmuir equation
With S_{max} : maximum sorption capacity (saturation) (Wang et al., 2010)

$$fP_{SEC}^{OCC} = k_{occ} . P_{SEC}$$

Occlusion : k_{occ}= 1.2e-5 yr-1 (Yang et al. (2014))

$$fP_{OSTA}^{OLAB} = k_{m1} . P_{OSTA} . h_1(T) . h_2(W)$$

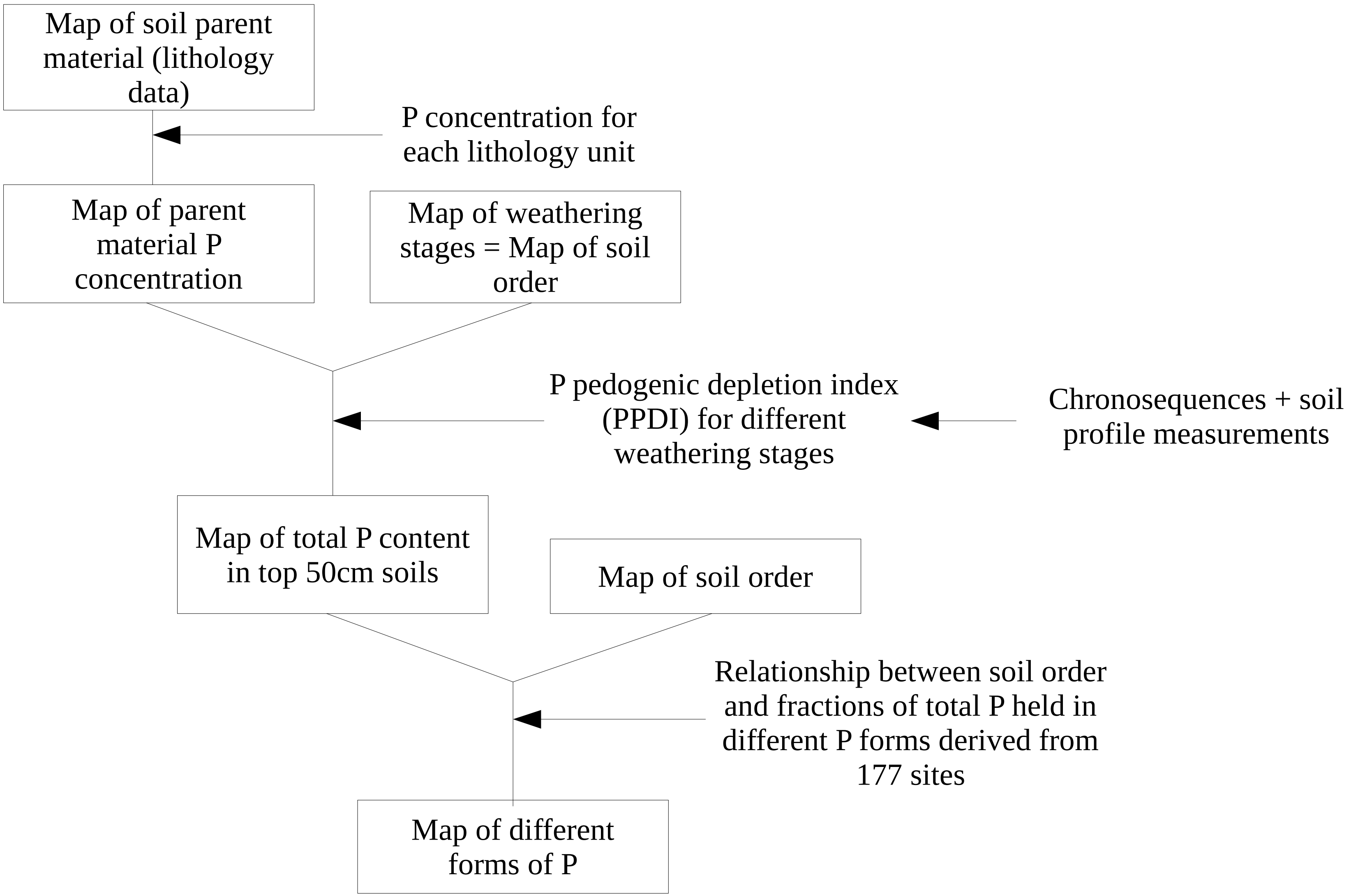
$$fP_{OLAB}^{SOLU} = k_{m2} . P_{OLAB} . h_1(T) . h_2(W)$$

Fluxes of mineralization of organic matter: k_{m1}, k_{m2} : turnover rates for stable and labile pools ??
$h_1(T)$; $h_2(W)$: same as the one used in the ORCHIDEE

II – Global datasets : 1) Yang et al. (2013)

Description :
Maps (0.5°lat x0.5°lon) of different forms of P (following **Hedley fractionation method**) for **unmanaged** soils (0-50cm) at current time period

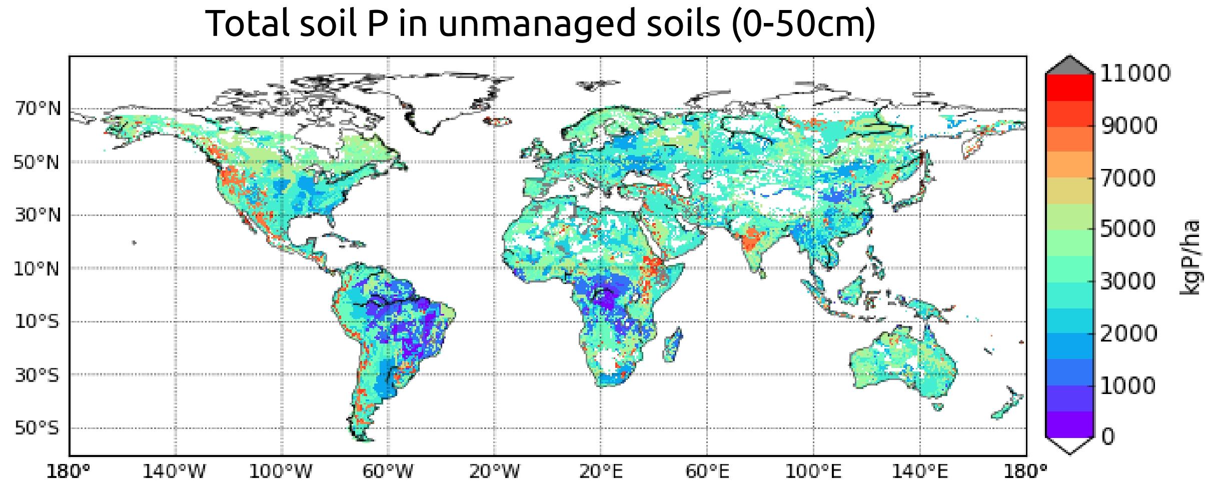
Methods :



Used :
- as soil P content for non-agricultural vegetated land fraction at any time
- as initial conditions for cropland/pasture fraction

II – Global datasets : 1) Yang et al. (2013)

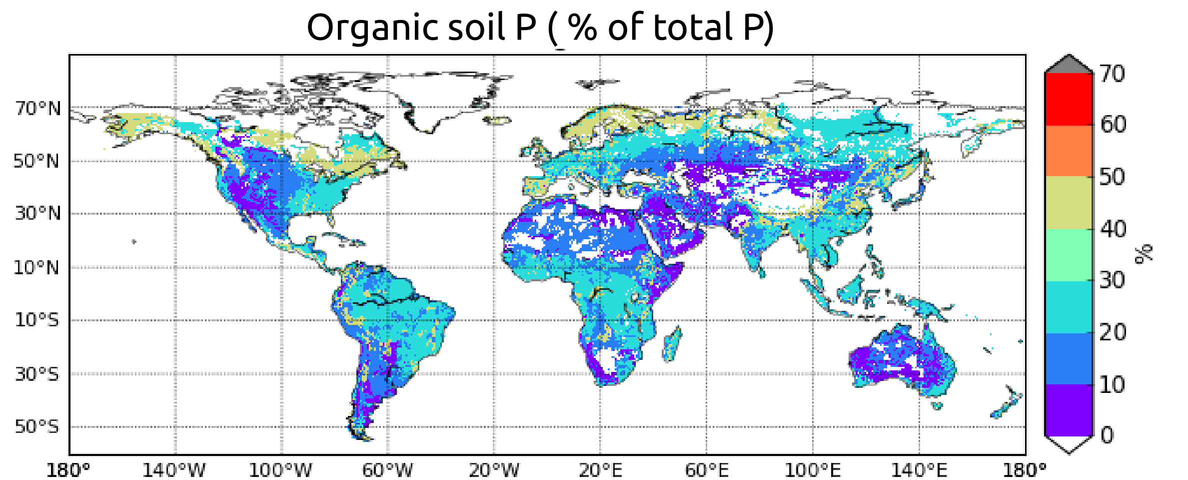
Total and group of factions given by **Hedley sequential fractionation method** *Hedley and Stewart (1982)*



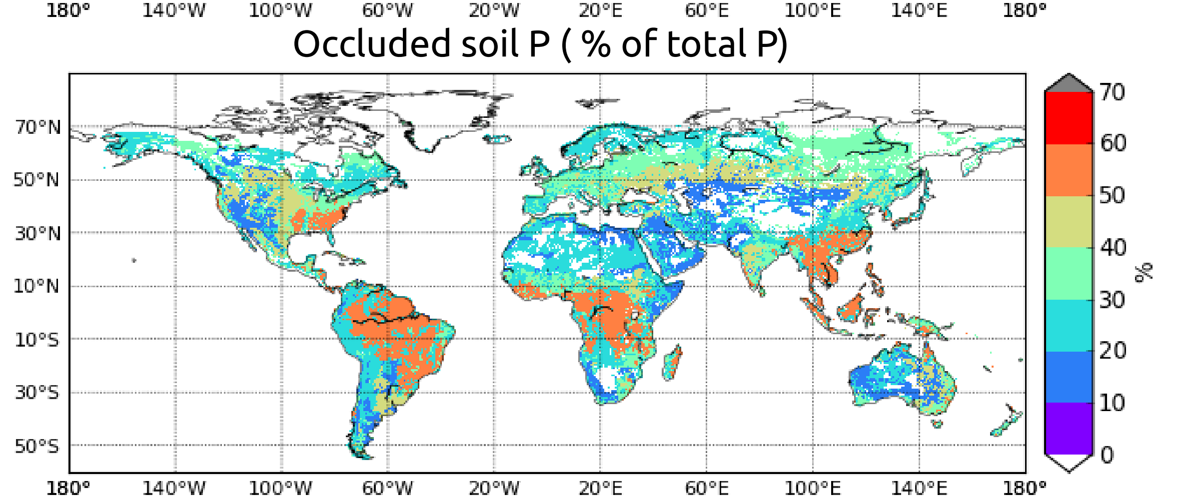
e.g.

→ Organic

labile + more stable Po ; low in tropics : leaching, adsorption on secondary minerals, occlusion under low soil pH, higher mineralization



→ Occluded



II – Global datasets : 2) Bouwman et al. (2011)

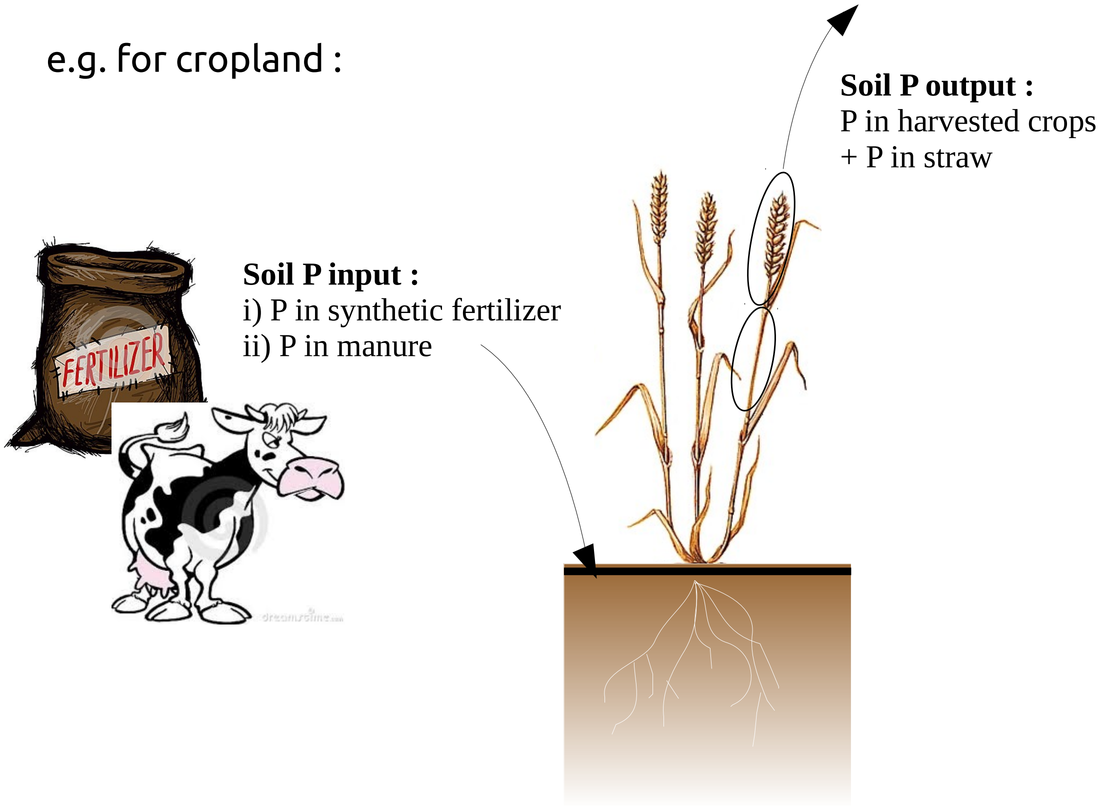
Description :

- IMAGE : Integrated Model to Assess the Global Environment

Bouwman et al. (2006)

- Maps (0.5°lat x0.5°lon) of soil P budget terms for cropland & pasture
- Avalaible at different time-steps : **1900, 1950-60-70-80-90, 2000**

e.g. for cropland :



Methods :

Maps =f(country-scale information Ex : crop production from FAO , 0.5°x0.5° map Ex : landuse map , database Ex : P content in each crop product)

Before 1970 : no FAO information => information about population density, etc.

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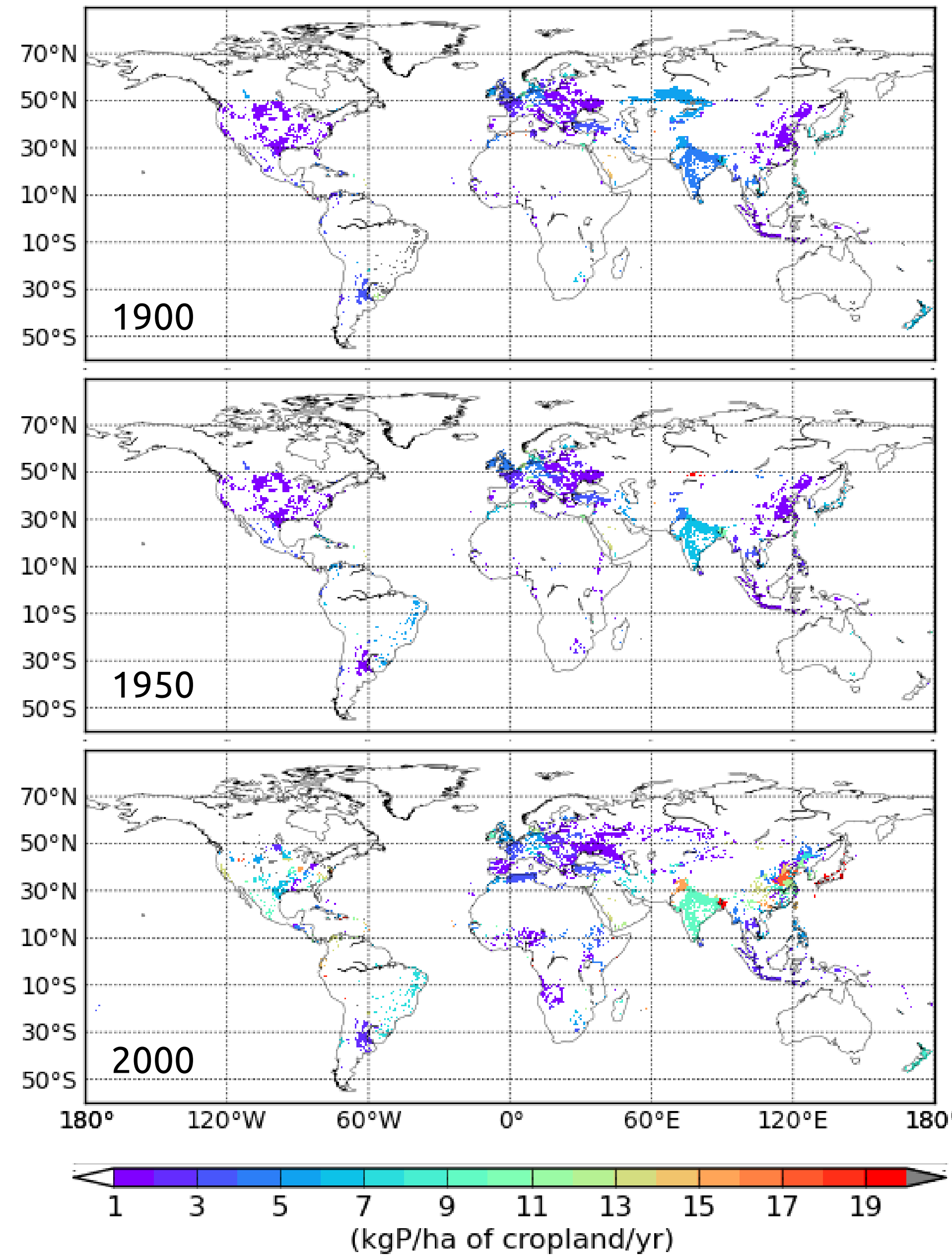
e.g. P in manure applied on cropland



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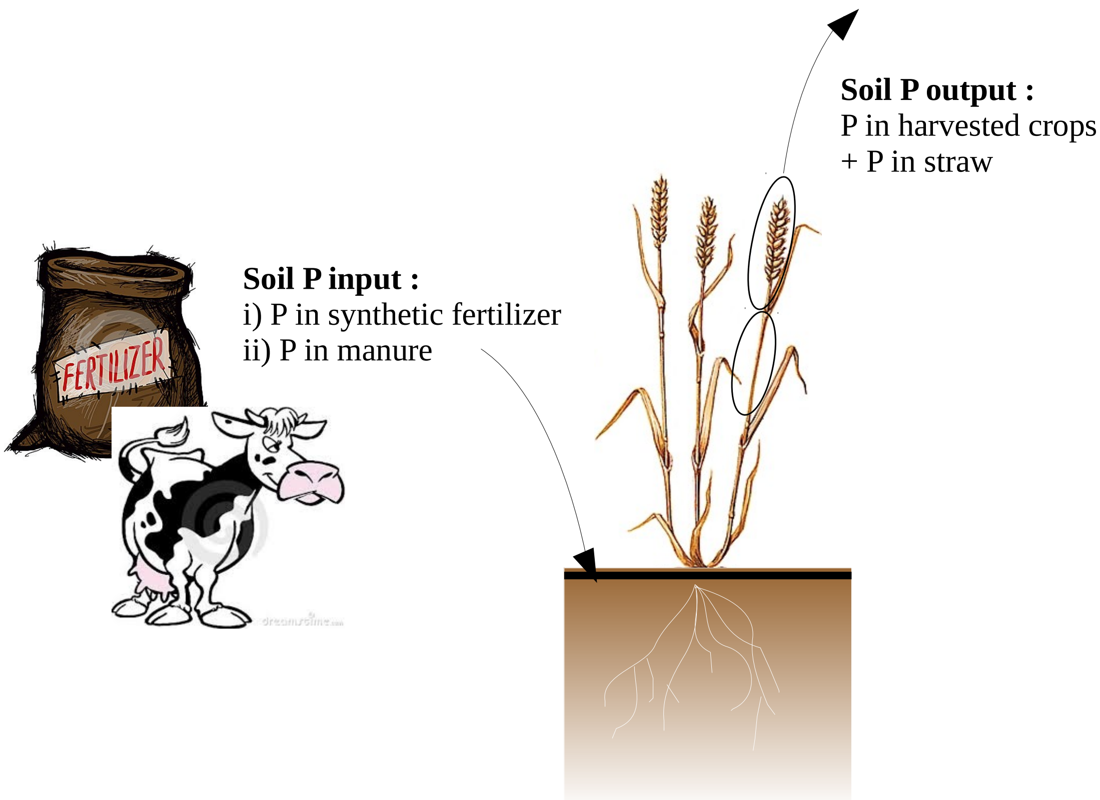

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II – Global datasets : 3) Landuse Harmonization; Hurtt et al. (2011) (http://luh.umd.edu/data.php)

Description :

Fraction + transitions for 5 land-use types :
cropland, **pasture**, urban, primary and secondary

1500-2006

Maps (0.5°lat x0.5°lon)

Methods :

- grid-cell fractions: HYDE database v3.1, *Klein Goldewijk et al. (2010,11*)
FAOSTAT + historical statistics about population +
satellite-derived current land cover + algorithm

- agricultural land-use transitions *Hurtt et al. (2006)*
minimum transition rates + shifting cultivation in Tropics

Use :

e.g. for cropland :

$$Pool_{cropland}(y)=[Pool_{cropland}(y-1)*frac_{cropland}(y-1)+Pool_{pasture}(y-1)*\Delta_{pasture}+Pool_{Yang}*\Delta_{nonagri}]/frac_{cropland}(y)$$

With $\Delta_{pasture}$ (resp. $\Delta_{pasture}$) = pasture (resp. non-agricultural vegetated area) converted into cropland from y-1 to y

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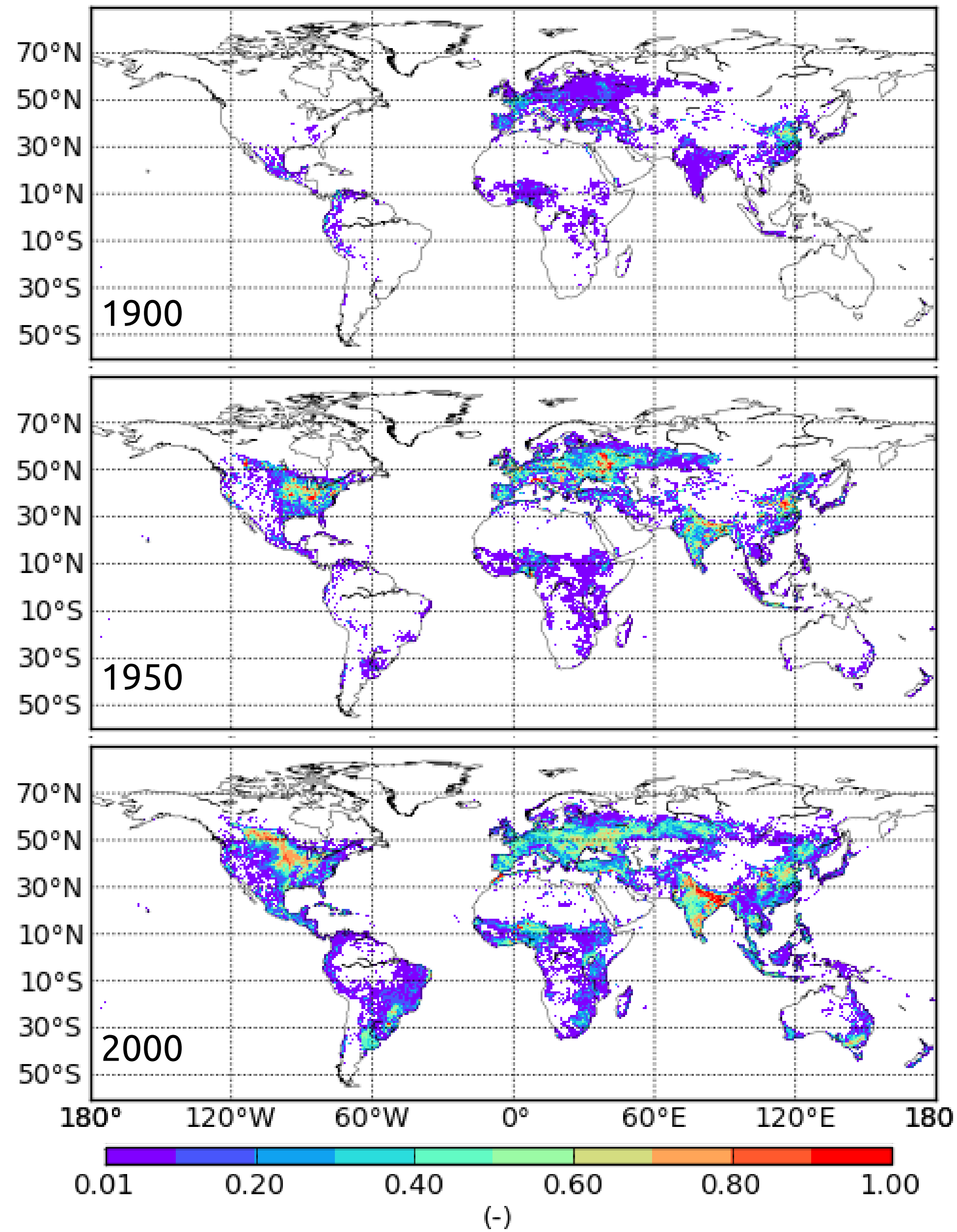
e.g. cropland fraction



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