Toward a couple Carbon – Climate reanalysis of the 20th Century

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Challenge….

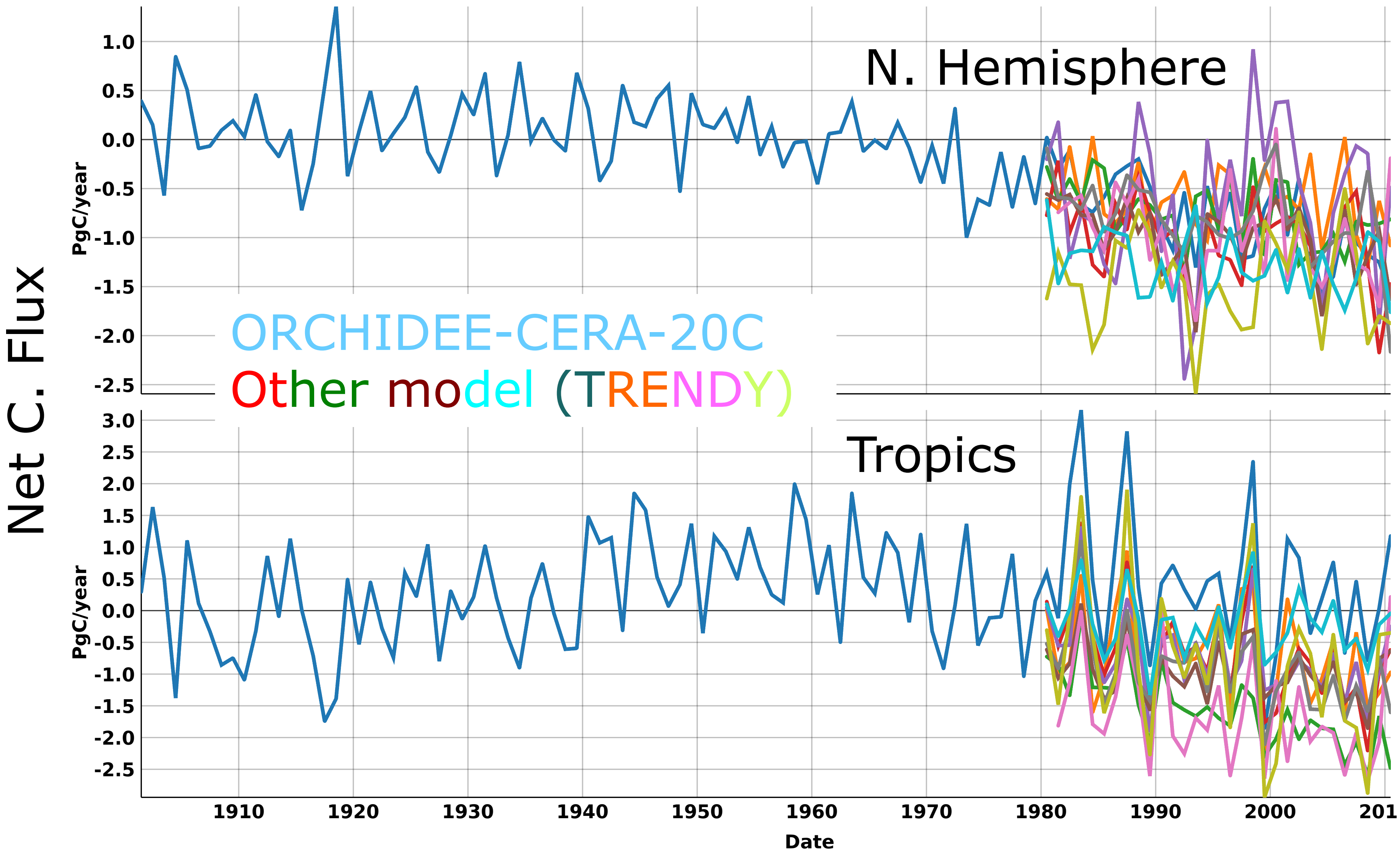
➔Long term objective: perform a “joint assimilation” including Carbon Cycle feedback on climate !

➔ERACLIM2 will only provide guidance for needed developments..

- Join assimilation should be done with CHTESSEL Land surface model of IFS
- Correction of state variable or model parameters ?

➔LSCE provide expertise & results with ORCHIDEE land surface model

Net Carbon flux still highly variables..



Parameter vs Process uncertainties

Estimation using Net Carbon Flux measurements (NEE) (Fluxnet sites)

Optimization of ORCHIDEE model parameters

Derivation of Model process vs parameter errors

Diagnostics in observation space

$$\underbrace{E\left[\mathbf{d}_o^b\left(\mathbf{d}_o^b\right)^T\right]}_{\text{Cross-product of prior residuals}} = \underbrace{\mathbf{HBH}^T}_{\text{Background error}} + \underbrace{\mathbf{R}}_{\text{Observation error}}$$

(Desroziers et al., 2005)

➔ Both errors are of similar magnitude..

Parameters vs State variables optimization

State var optimization (CTESSEL)	Parameter optimization (ORCHIDEE)
• Little assumption on processes • Maximum extraction of the obs information ($[CO_2]_{atm}$ includes all processes,..) • No insight on processes • C stocks cannot be assimilated easily • Only few data cover 20th C • No predicting capabilities	• Easier to use multi-data streams • Constrain all processes • Data dont need to cover the full period • Prediction capabilities • Rely on LSM structure • Missing processes ? • Heavier to handle

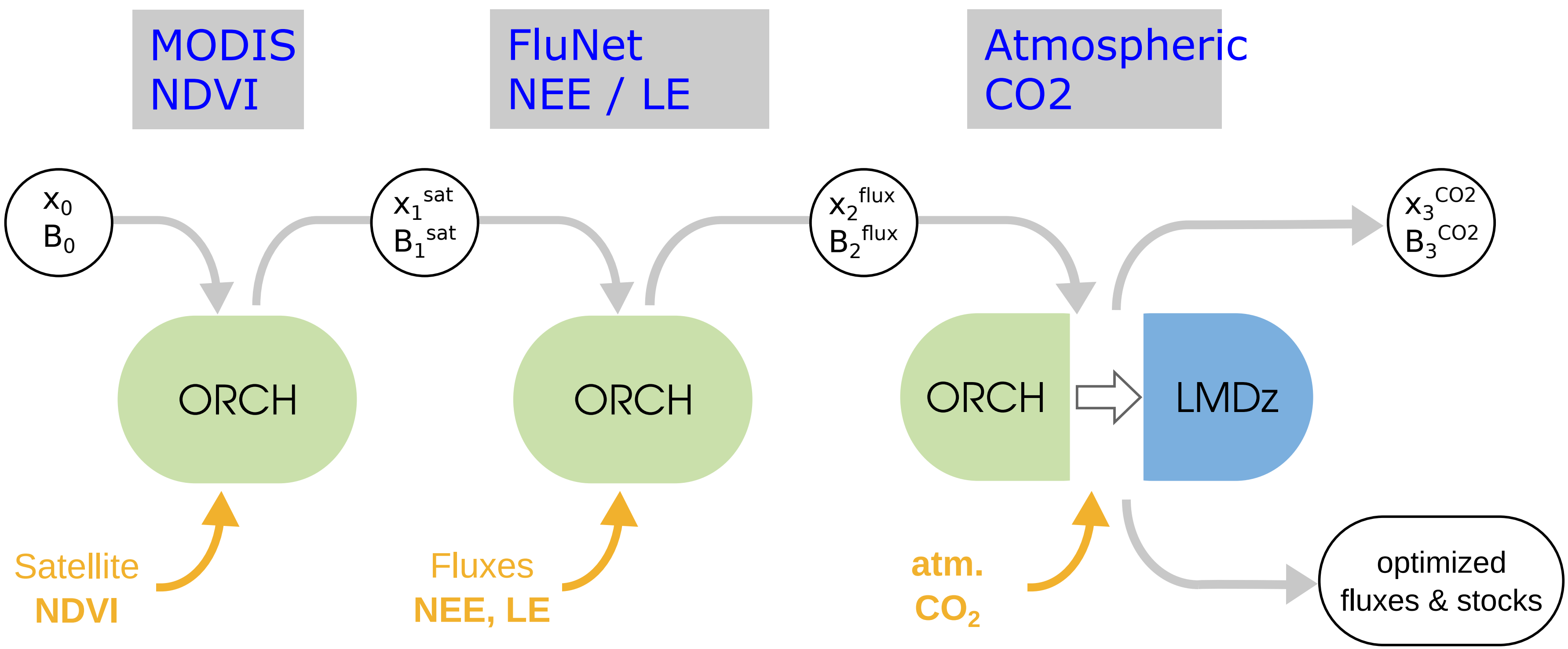
LSCE

Step wise data assimilation system

$$J(\mathrm{x}) = \tfrac{1}{2}(\mathbf{H}.\mathrm{x}-\mathrm{y})^T \mathbf{R}^{-1}(\mathbf{H}.\mathrm{x}-\mathrm{y}) + \tfrac{1}{2}(\mathrm{x}-\mathrm{x}_b)^T \mathbf{B}^{-1}(\mathrm{x}-\mathrm{x}_b)$$

Observation term

Prior parameter term (from previous step)



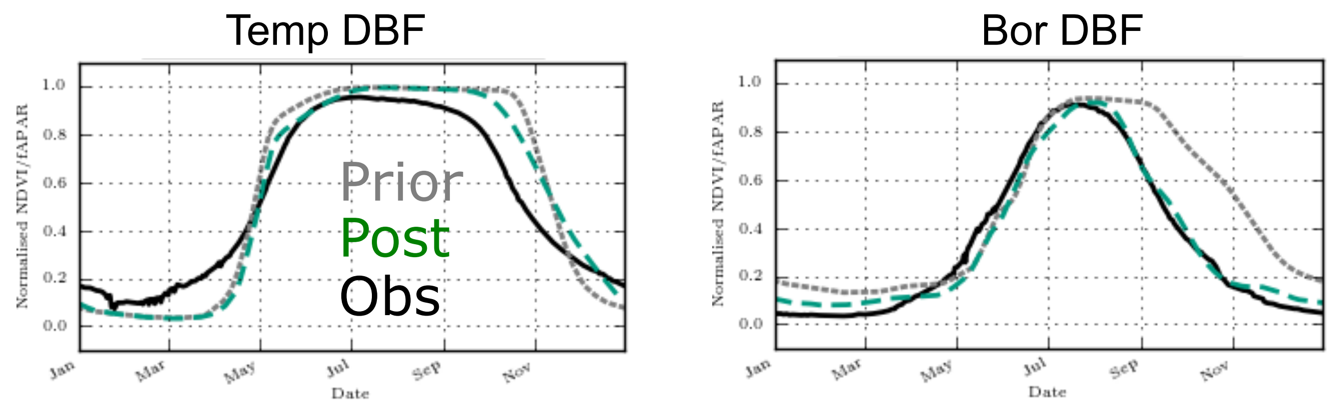
40 params | ≈ 100 params | ≈ 80 params

Assimilation of multiple data streams

LSCE

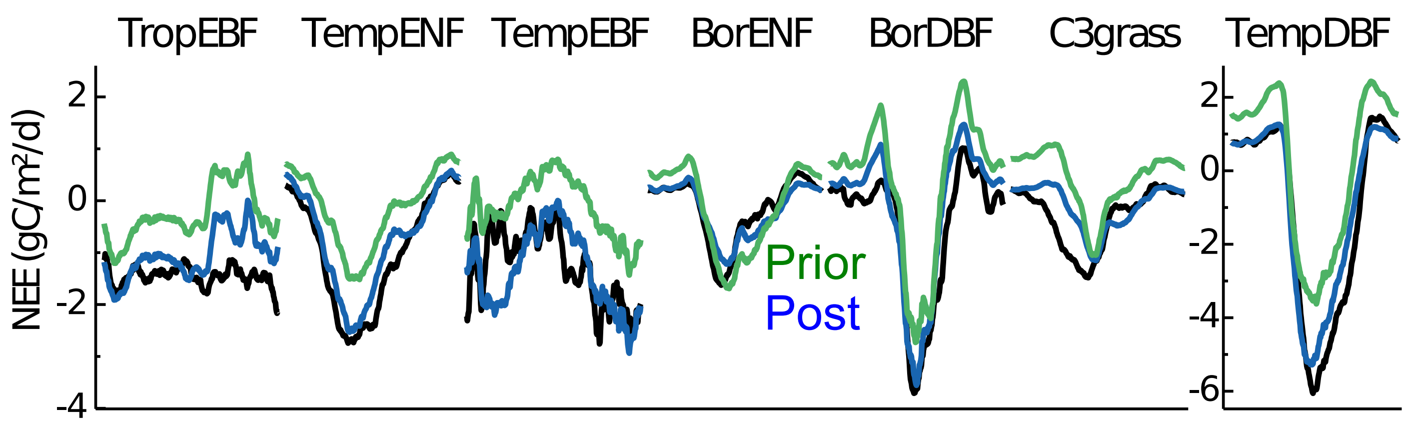
Step 1: MODIS-NDVI

4 params /PFT



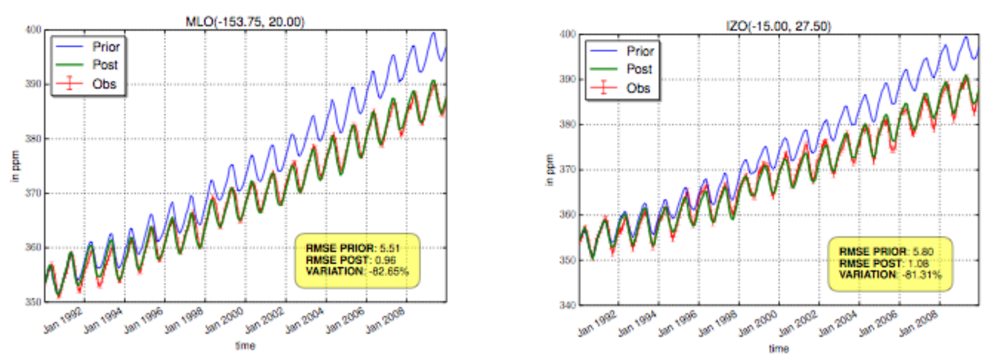
Step 2: 75 fluxnet data

≈ 20 params /PFT



Step 3: Atmospheric data

≈ 100 params total

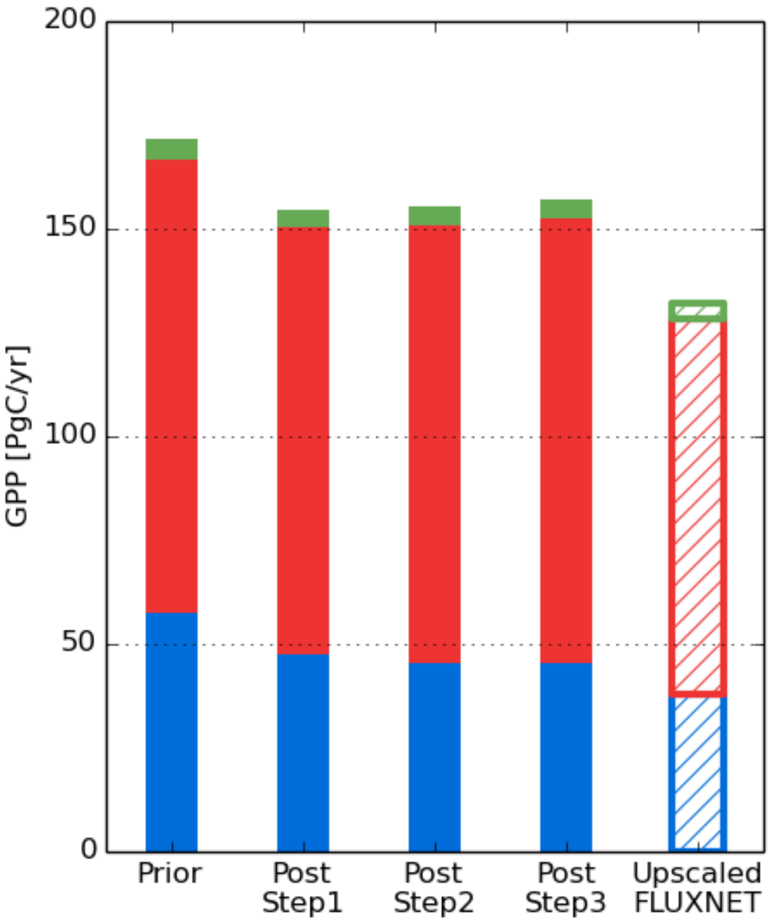


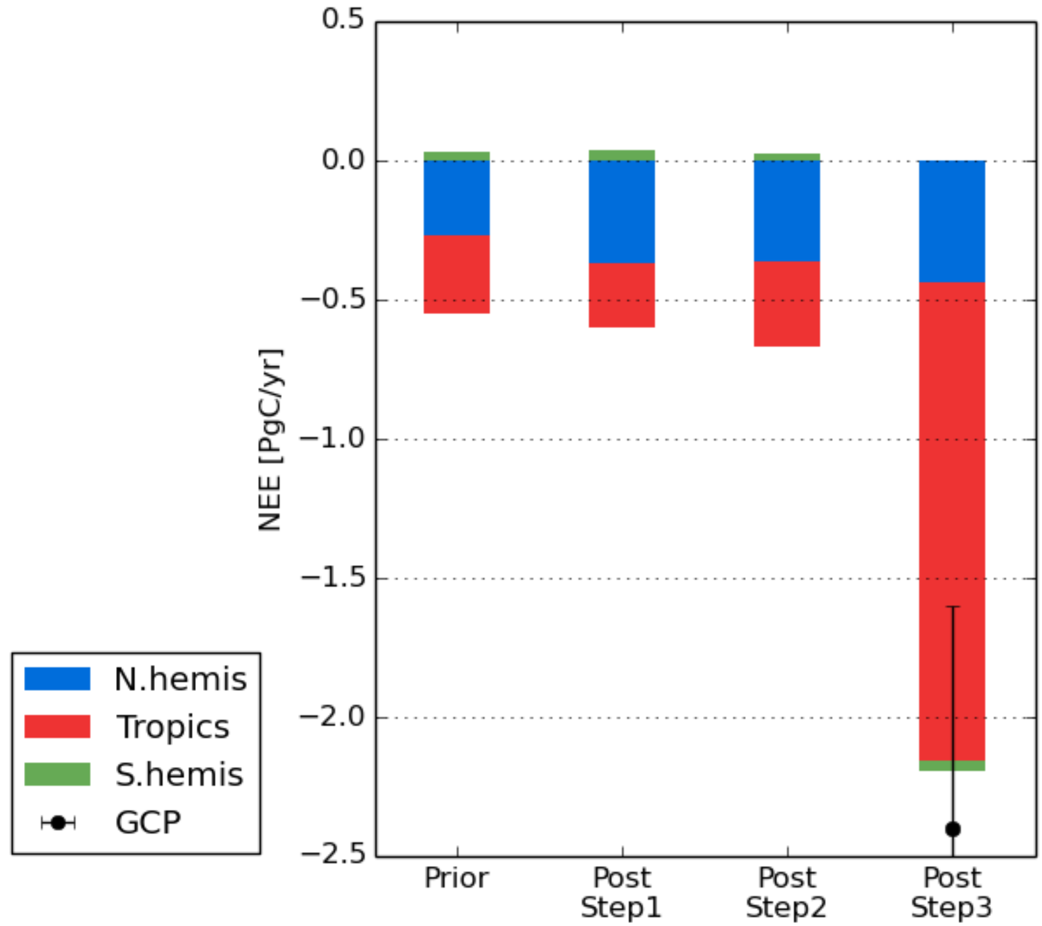
Impact on net and gross C budgets:

Gross Primary Productivity
→ (C uptake)

mean annual total
(1990-2010)

Net Ecosystem Exchange
→ (net CO_2 flux)





Peylin, P., et al., 2016.

Progress made in 2017

- New model version & its Tangent Linear
- Improvement of the optimization framework
- Partial completion of the Bayesian optimization with the new ORC version
- Test of DA with new observations

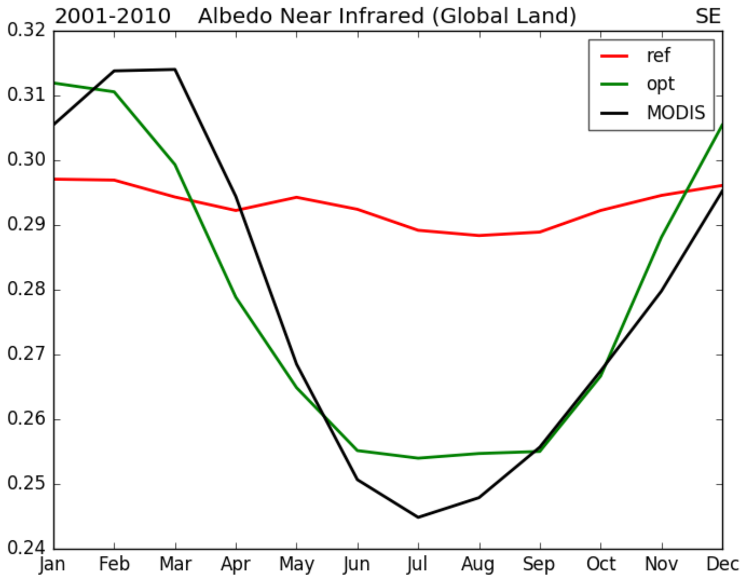
ALBEDO OPTIMIZATION

- Optimized albedo using MODIS observations (2001-2010)

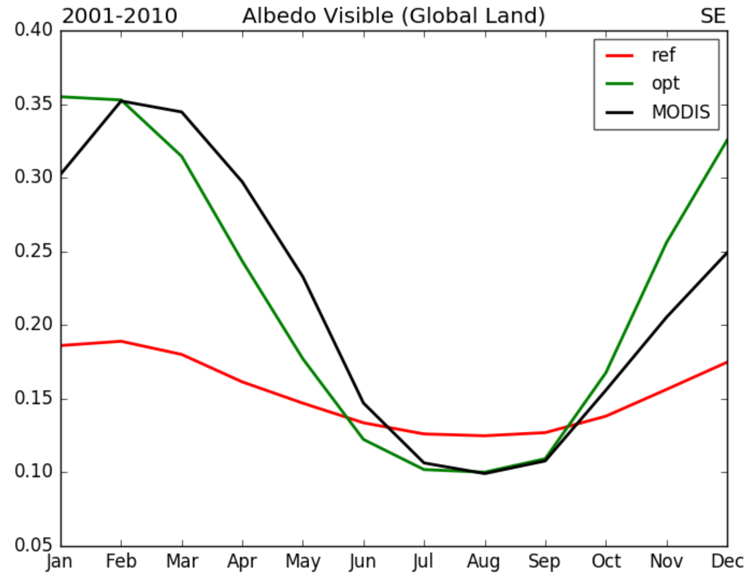
- Principle:
    - Step 1: « hand » optimization of snow albedo parameters (mean value, age dependency)
    - Step2:
      Bayesian calibration of vegetation albedo parameters (visible and near infrared) and bare soil albedo

- Everything is described under:
  https://orchidas.lsce.ipsl.fr/dev/fit2.php

ALBEDO OPTIMIZATION



Initial
Optim
Modis



➔ Initial seasonal cycle was not captured well

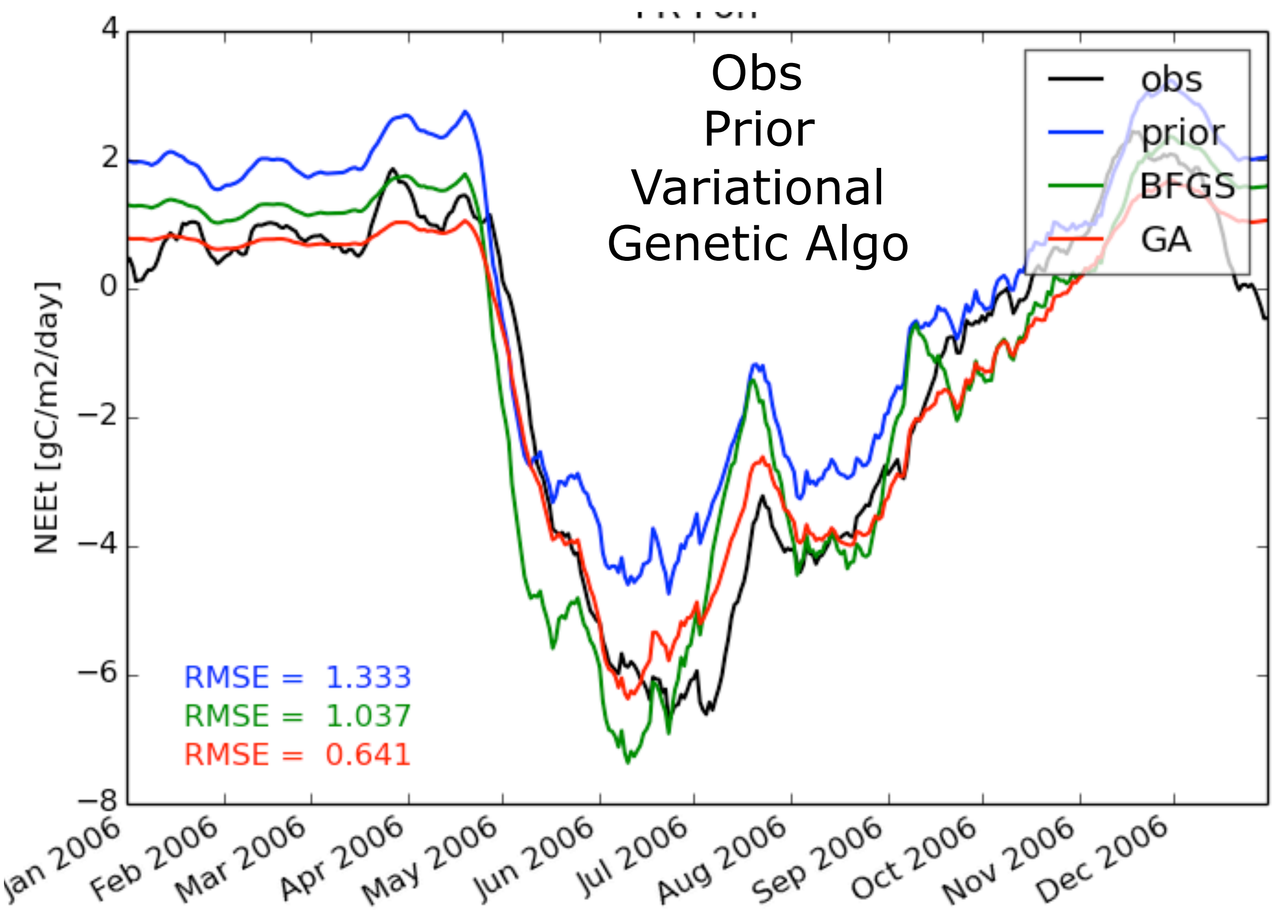
➔ Significant improvement after « Data Assimilation »

Fluxnet : Variational vs Monte Carlo

- Variational vs Genetic Algorithm minimization
- Using 72 FluxNet site observations (NEE, LE)
- 15 different optimizations starting from random priors

Example:

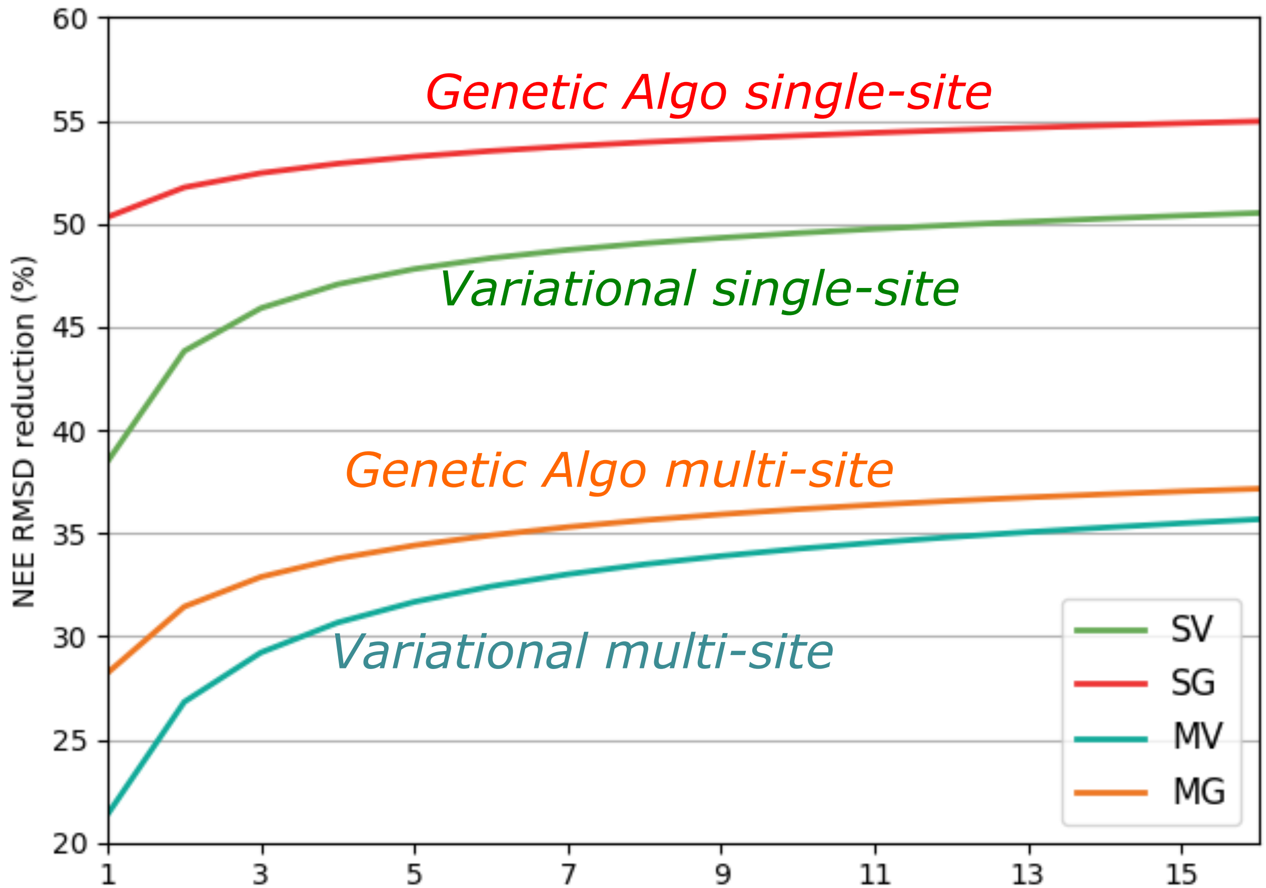
NEE for an Oak Forest (Fontainebleau site)



Fluxnet : Variational vs Monte Carlo

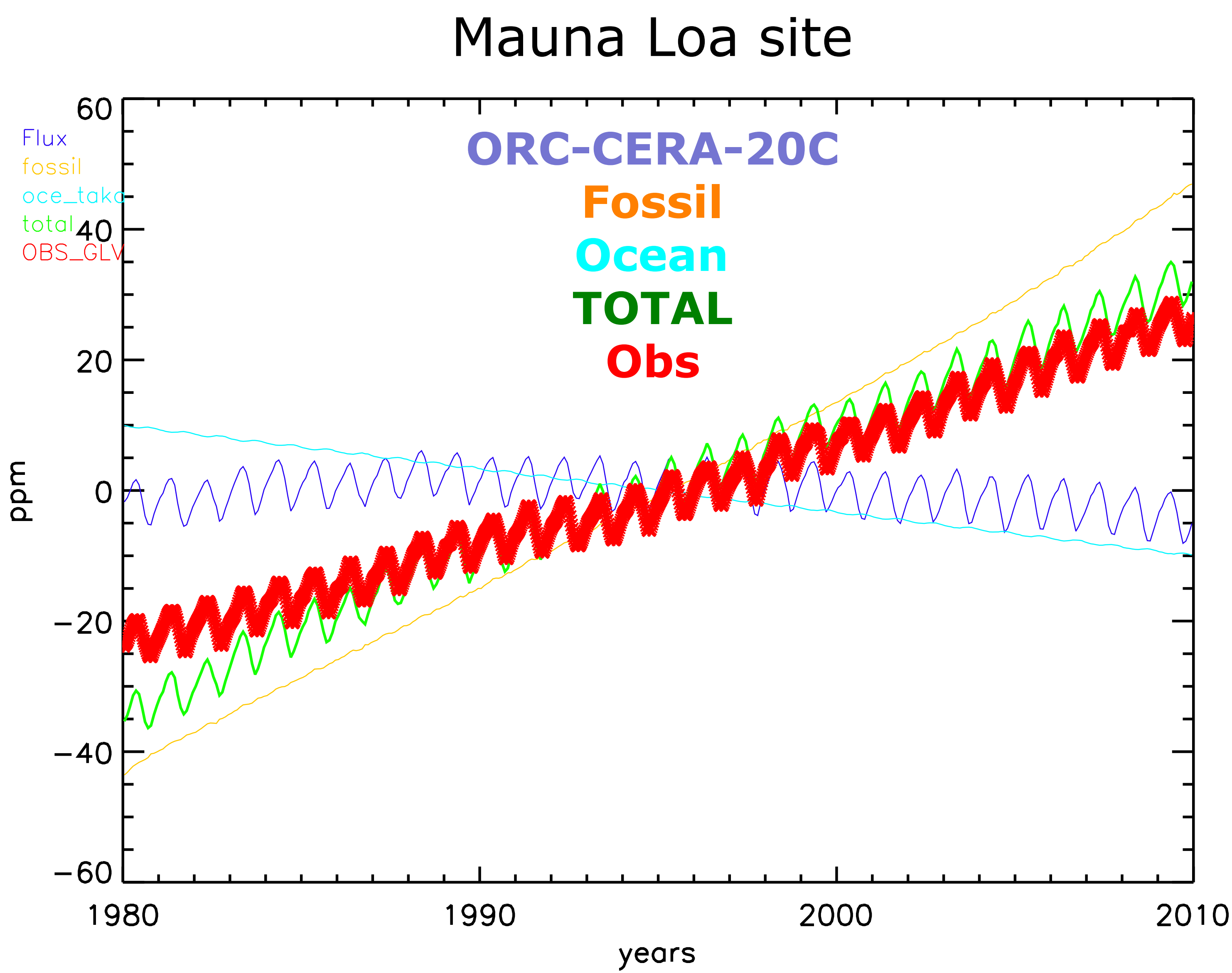
Variational vs Genetic Algo; 72 FluxNet sites

RMS Error ruduction (%)



Number of first guesses

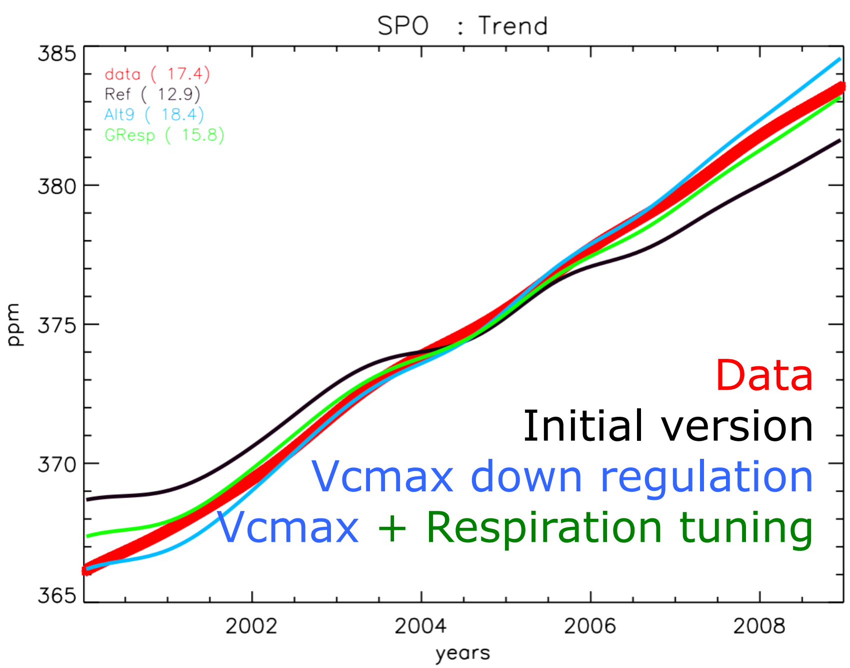
Atmospheric constraint

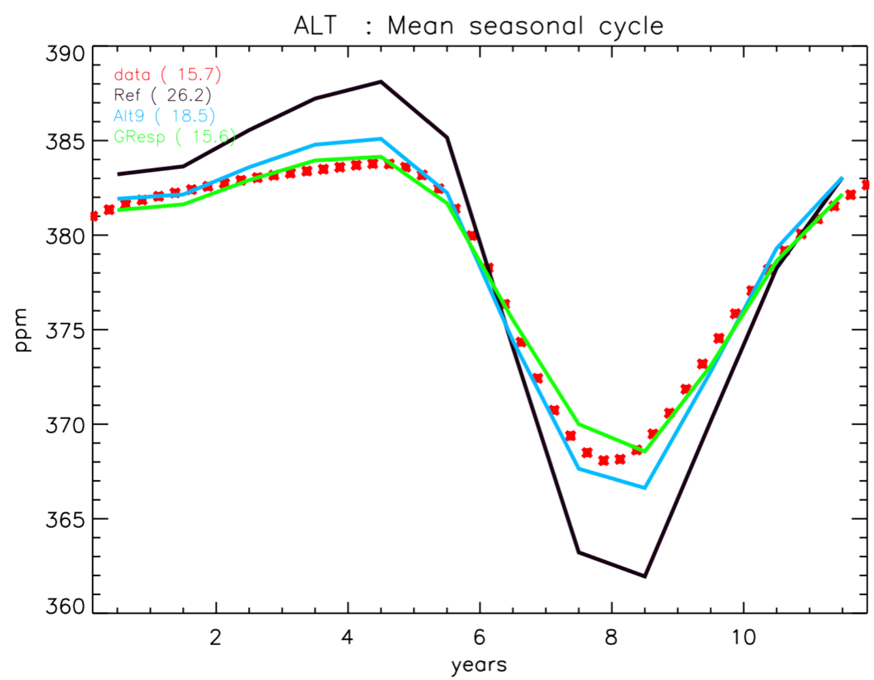


Atmospheric constraint

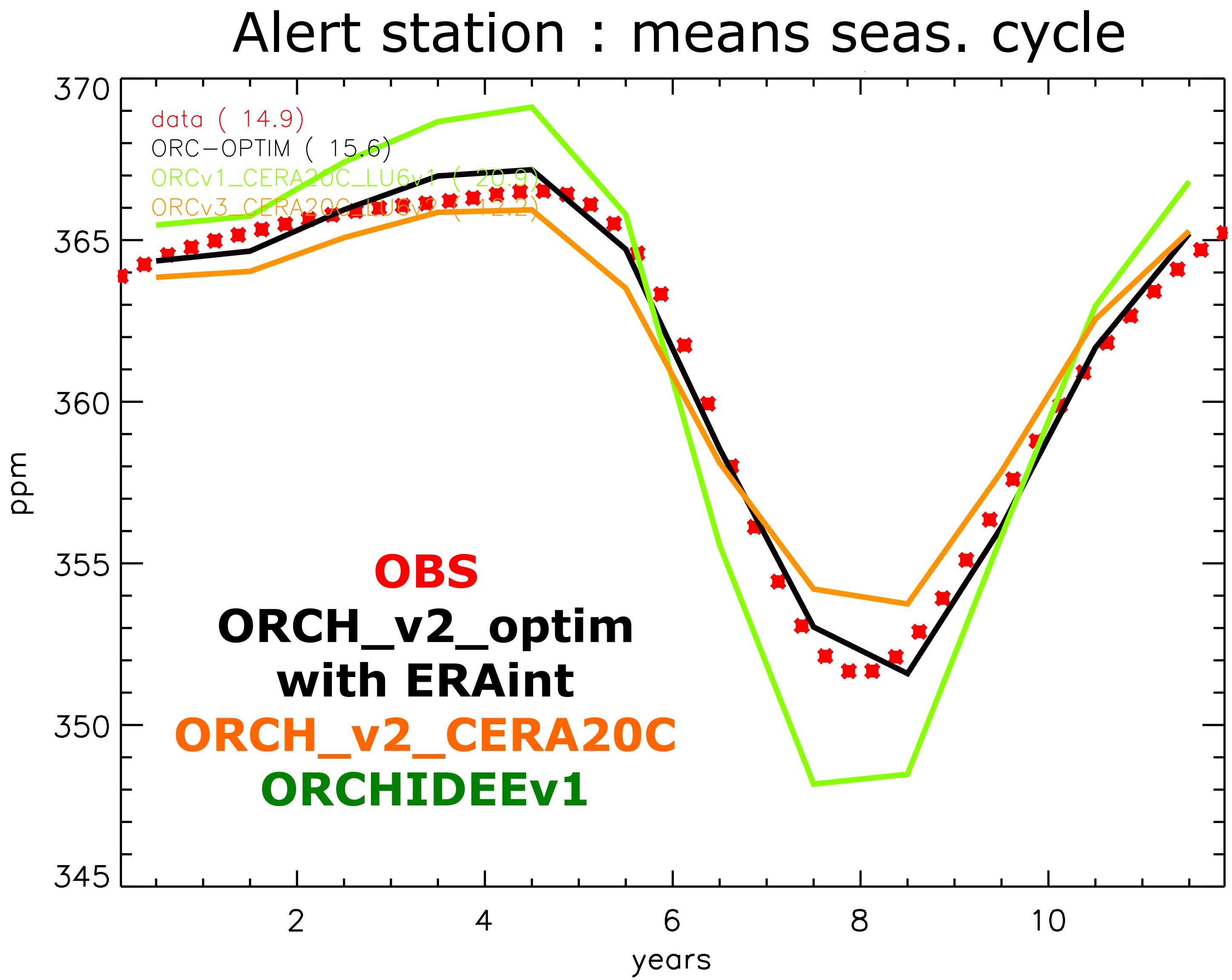
➔ **Optimization** of key parameters (Vcmax, LAImax,…) using trial-error approach with atm. CO2 concentrations (LMDz)

Trend (SPO)	Mean seas. Cycle (ALT)

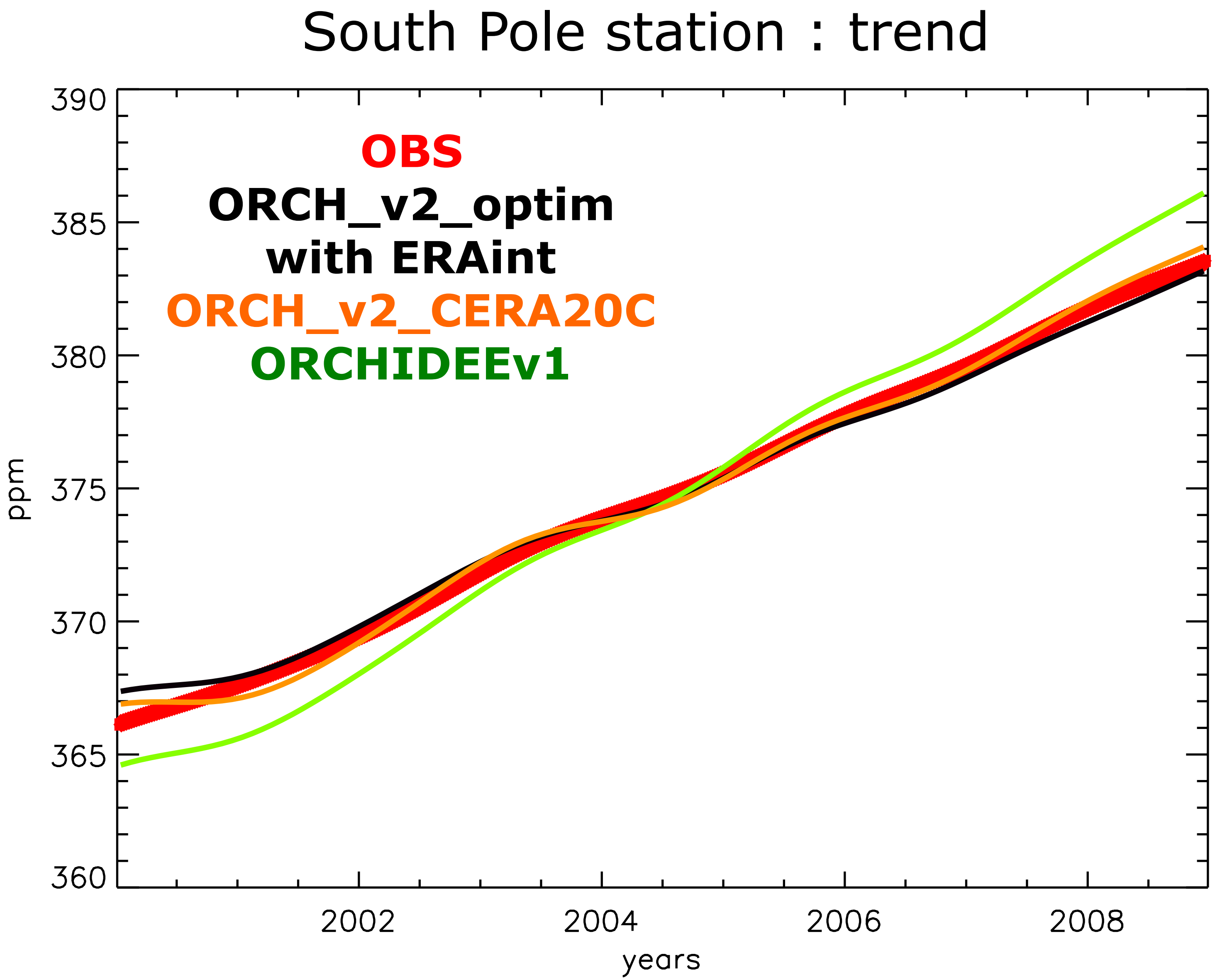




Atmospheric constraint



Atmospheric constraint



Carbon cycle constraints

A Promising futur..

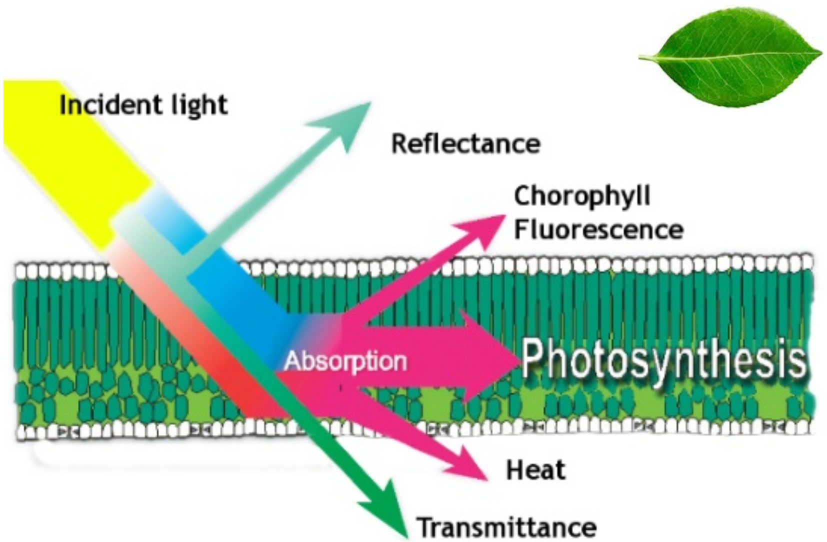
Assimilation of new recent observations

to better constraint gross C fluxes

LSCE

Solar Induce Fluorescence data

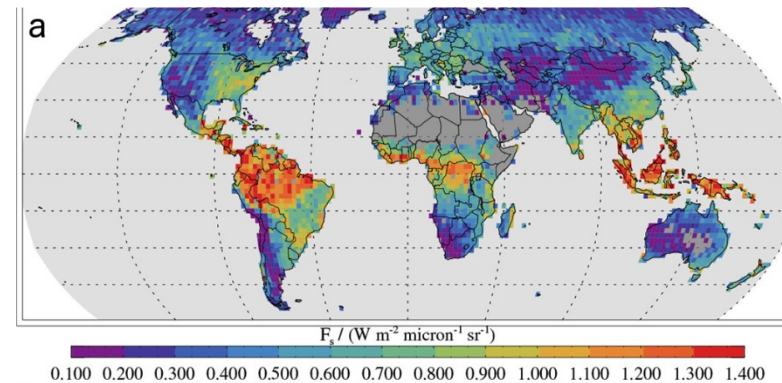
Solar Fluorescence (SIF)



SIF = function (GPP, T,...)

→ Use SIF satellite data
(GOME-2 from Köhler et al., 2015)

GOME-2 SIF



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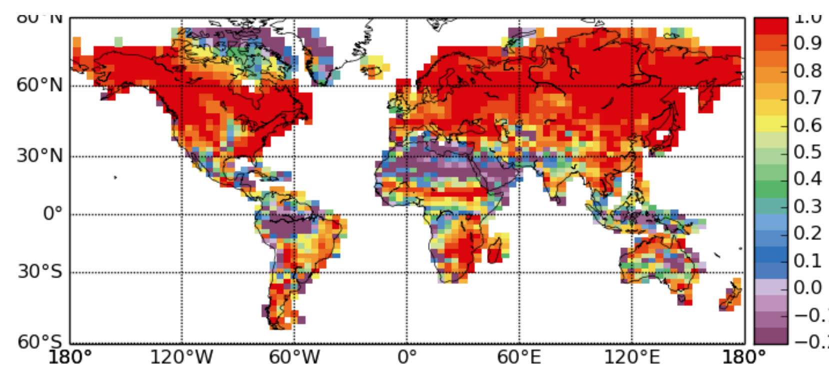
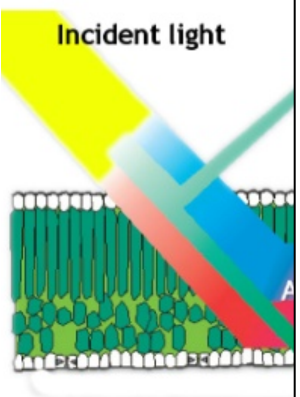
Correlation: ORCHIDEE-GPP vs SIF



➔ Regional scale information for phase (& synoptic events)

Solar Induce Fluorescence data

Solar Flu



SIF = fun

→ Use S
(GOME-2 fro

RESEARCH | *REMOTE SENSING*

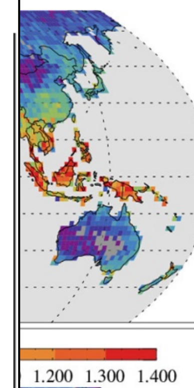
RESEARCH ARTICLE

CARBON CYCLE

Contrasting carbon cycle responses of the tropical continents to the 2015–2016 El Niño

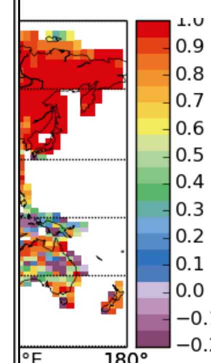
Junjie Liu,[1*] Kevin W. Bowman,[1] David S. Schimel,[1] Nicolas C. Parazoo,[1] Zhe Jiang,[2] Meemong Lee,[1] A. Anthony Bloom,[1] Debra Wunch,[3] Christian Frankenberg,[1,4] Ying Sun,[1†] Christopher W. O'Dell,[5] Kevin R. Gurney,[6] Dimitris Menemenlis,[1] Michelle Gierach,[1] David Crisp,[1] Annmarie Eldering[1]

The 2015–2016 El Niño led to historically high temperatures and low precipitation over the tropics, while the growth rate of atmospheric carbon dioxide (CO_2) was the largest on record. Here we quantify the response of tropical net biosphere exchange, gross primary production, biomass burning, and respiration to these climate anomalies by assimilating column CO_2, solar-induced chlorophyll fluorescence, and carbon monoxide observations from multiple satellites. Relative to the 2011 La Niña, the pantropical biosphere released 2.5 ± 0.34 gigatons more carbon into the atmosphere in 2015, consisting of approximately even contributions from three tropical continents but dominated by diverse carbon exchange processes. The heterogeneity of the carbon-exchange processes indicated here challenges previous studies that suggested that a single dominant process determines carbon cycle interannual variability.



Frankenberg

P vs SIF



mation
events)

Optimisation set-up

- Simple linear relationship between GPP and SIF:

$$SIF = a\,GPP + b$$

- Constrain ‘a’ and ‘b’ (slope and offset) parameters in addition to photosynthesis and phenology parameters for ALL vegetated PFTs

- Use GOME2 SIF data (Köhler et al., 2015)
- 15 grid cells chosen randomly per PFT
- 12-16 parameters per PFT
- Multi-site optimisation performed for each PFT
- 4D – variational/finite difference data assimilation system

MacBean et al. submitted

Optimisation set-up

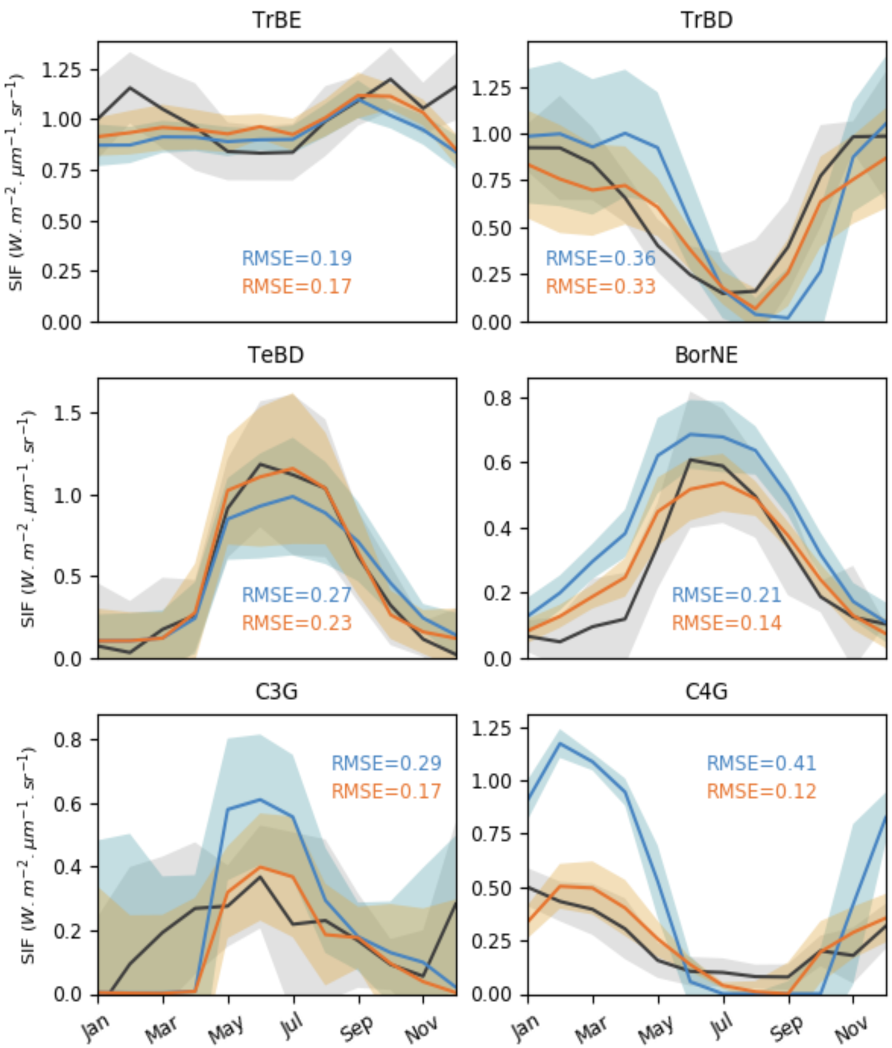
- New mechanistic GPP – SIF relationship:

  SCOPE model f(GPP, Temp, Vcmax,…)

- Constrain several parameters of SCOPE and the photosynthesis & phenology model for ALL vegetated PFTs

- Use OCO2 SIF data
- 15 grid cells chosen randomly per PFT
- 12-16 parameters per PFT
- Multi-site optimisation performed for each PFT
- 4D – variational/finite difference data assimilation system

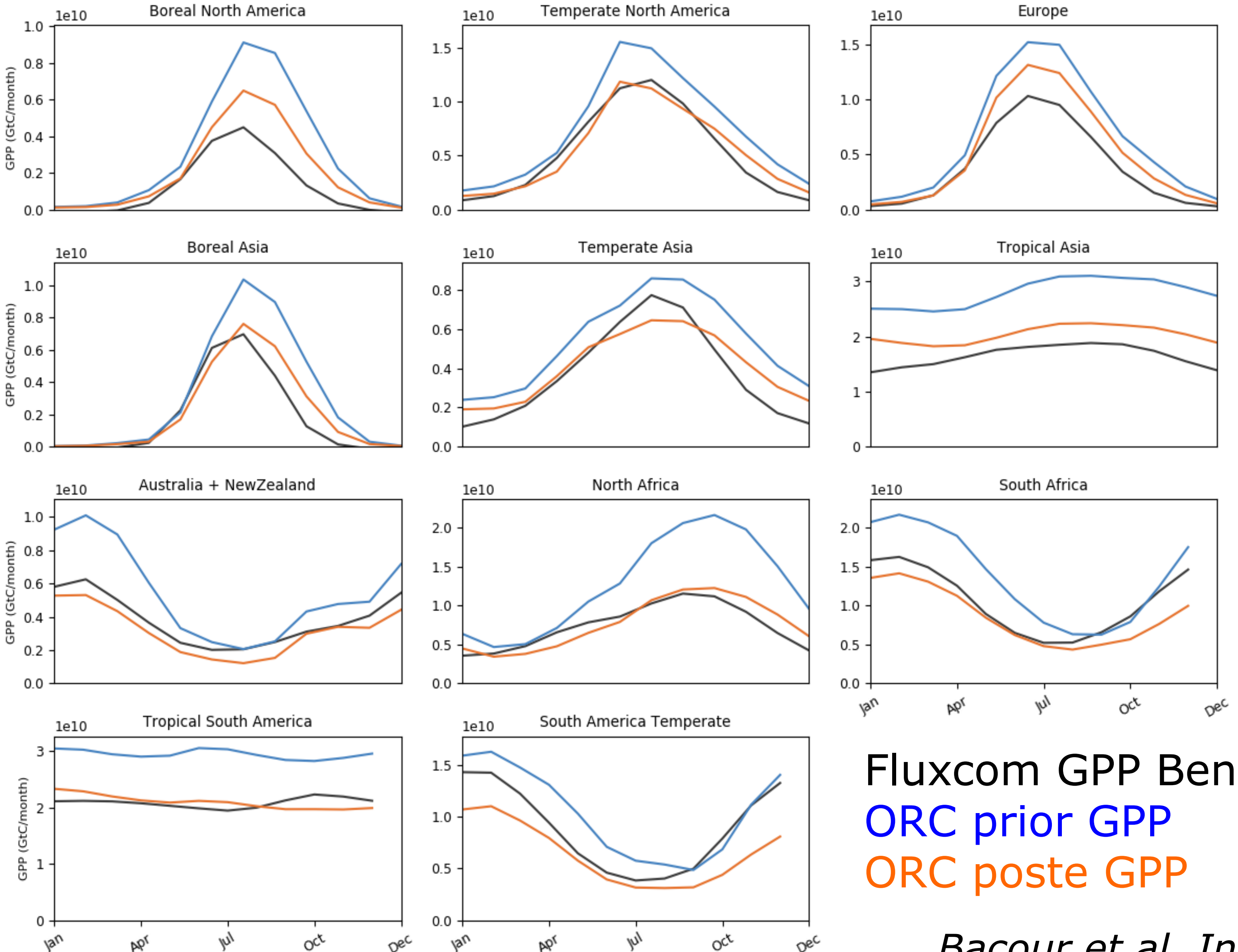
OCO2 fluorescence assimilation



OCO2 SIF
ORC prior SIF
ORC poste SIF

Bacour et al. In prep

OCO2 fluorescence assimilation



Fluxcom GPP Benchmark
ORC prior GPP
ORC poste GPP

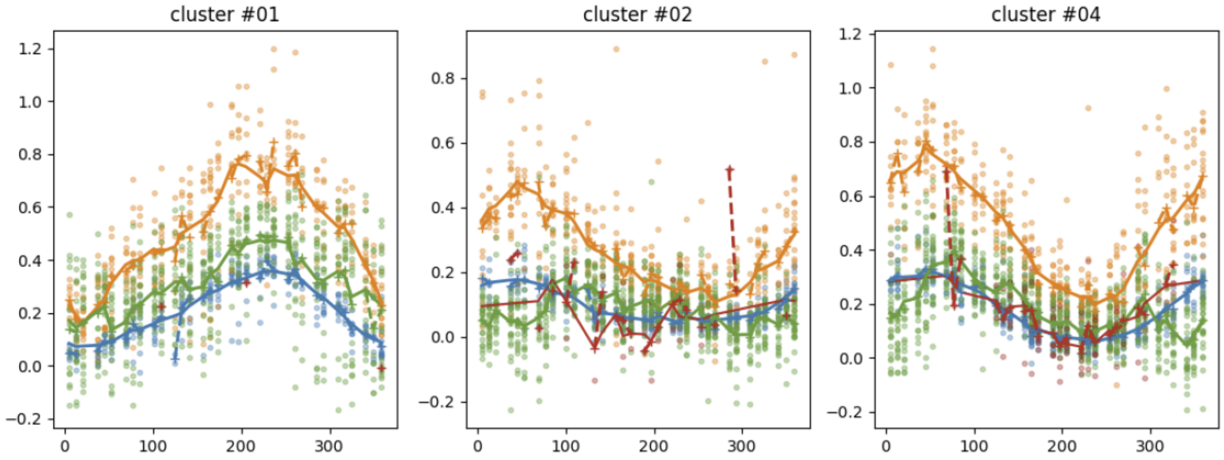
Bacour et al. In prep

But cautious with existing biaises..

TrBD

Tropical Broadleaf Deciduous

Solar Induce Fluorescence



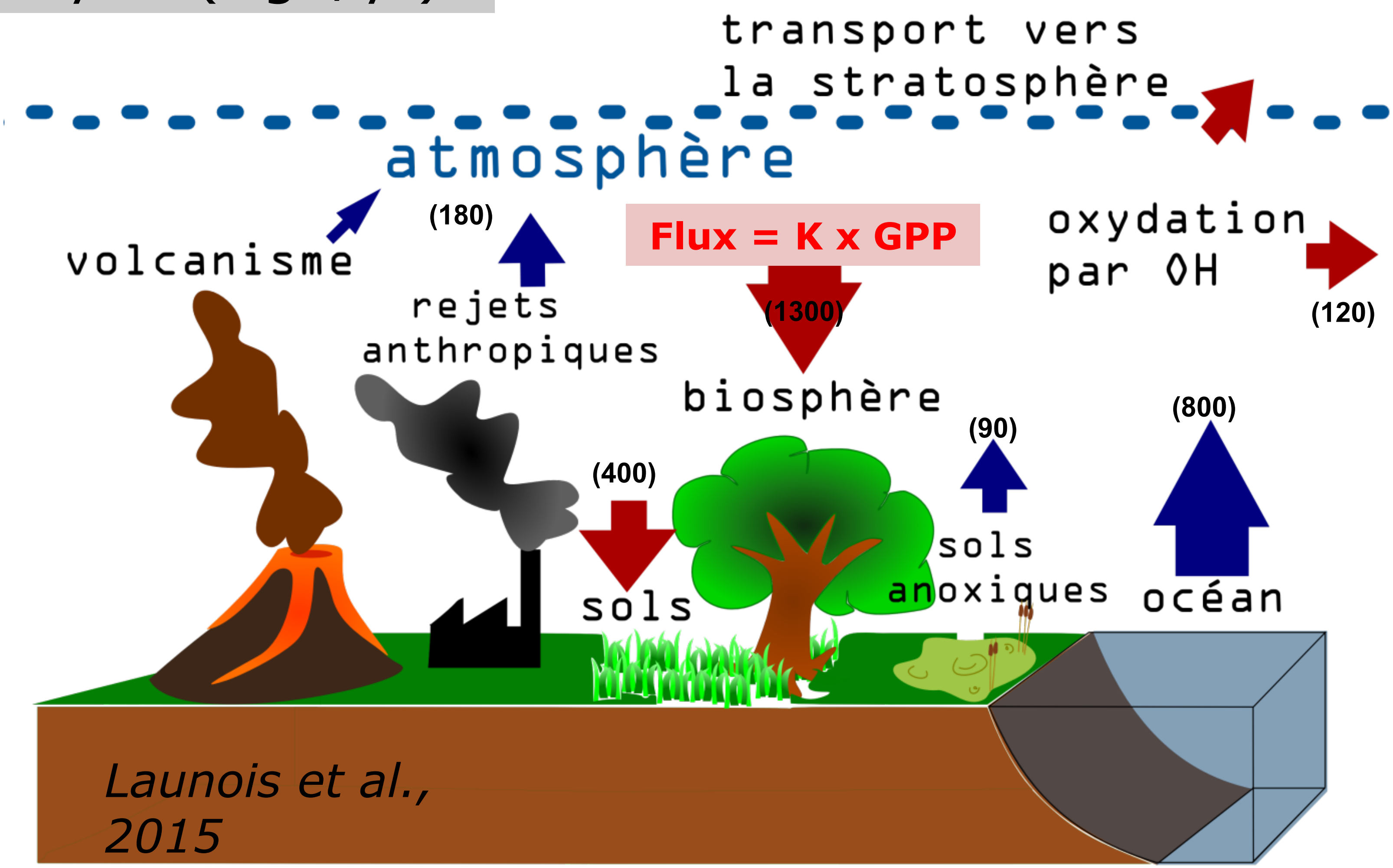
GOME2-1 GOME2-2 OCO2 GOSAT

➔ Large differencese between product

➔ Data assimilation should be very done carfully possibly solving for biaises..

Atmospheric [COS]: potential tracer of Photosynthesis (GPP) budget

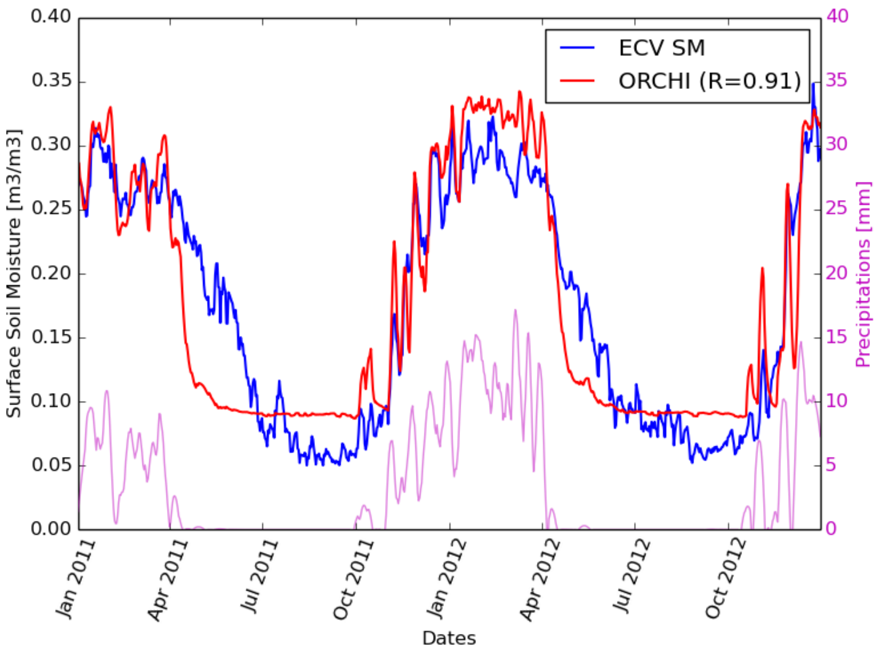
COS cycle (GgS/yr):



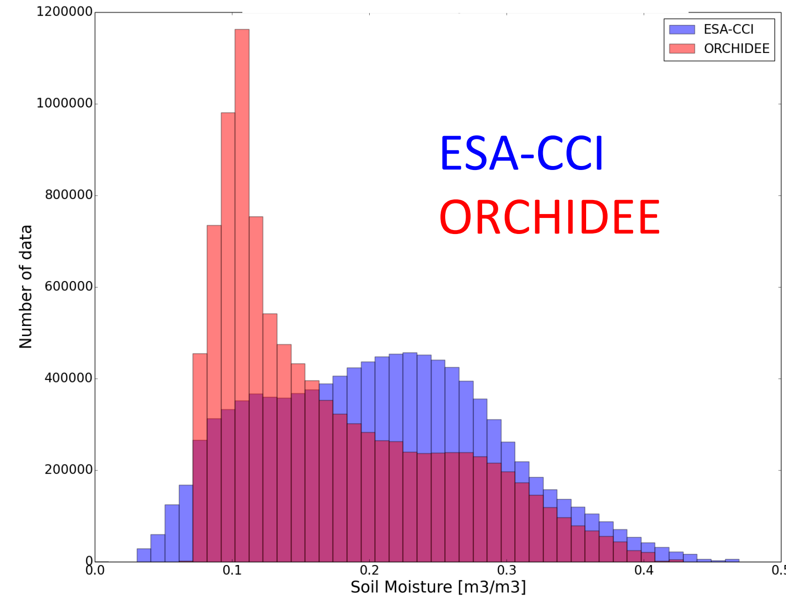
Potential of Surface Soil Moisture data

- ➔ Using the ESA – CCI surface moisture product (35 years)
- ➔ Comparing with ORCHIDEE surface soil moisture

Ex: Brazil site



Global distribution



- ➔ Drying in ORCHIDEE after the rain even is too rapid !
- ➔ large potential to optimize soil moisture parameters

C. Ottle ; B. Delorme, P. Peylin

Outlook: Strategy -1…

➔ "Investigation" for an homogeneous earth system reanalysis including Carbon-cycle.

- Objective for the Land: Apply a "Carbon Cycle Data Assimilation System" over the 20th century using:
  - Atm CO2: **in situ recent data + *Ice core data***
  - Satellite NDVI: **GIMS (AVHRR) long record**
  - FluxNet data: **(NEE, LE)**
  - Possibly forest age **: Age reconstruction**
  - New satellite data **: SIF**
  - Atmospheric tracer **: COS ?**
  - **Surface soil moisture data**

➔ Challenging to optimize model over long period

Outlook : strategy - 2

- State optimization within IFS:

    1. Need to improve CTESSEL land surface model
    2. Global coverage observations are only "indirectly" related to model carbon variables.. (NDVI, SIF, XCO2, ….)
    3. In situ data are still very scare !!

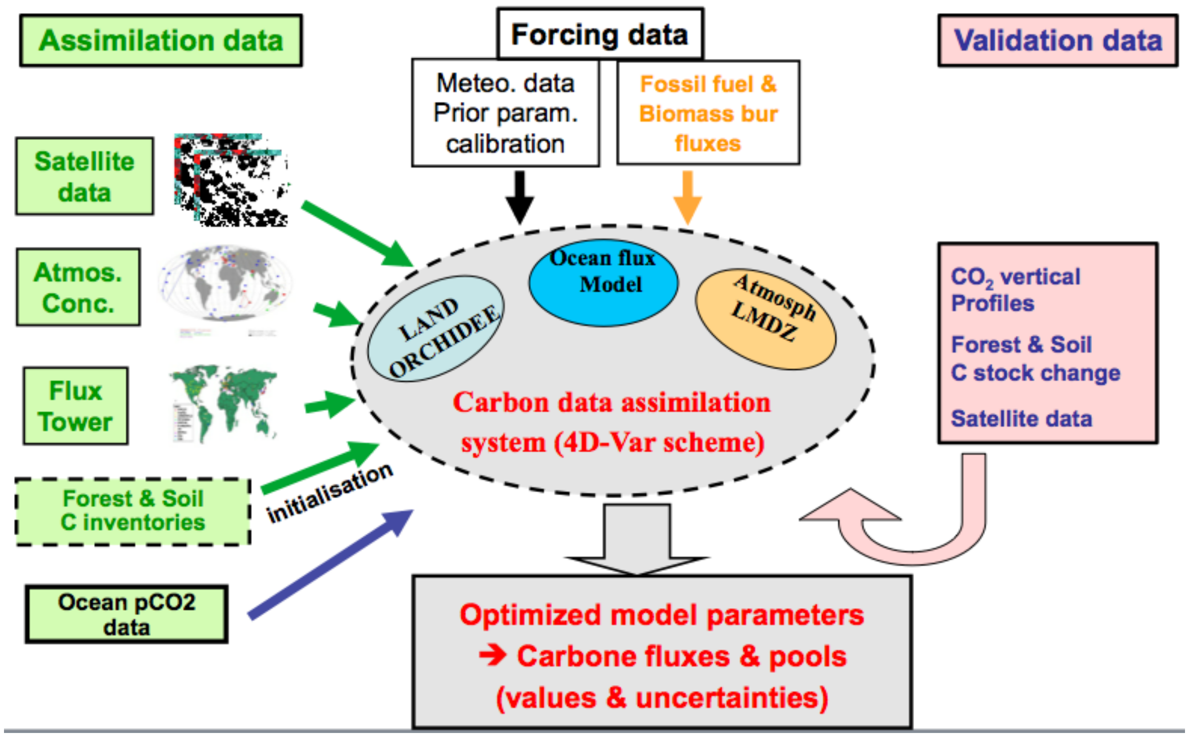
➔ No obvious best strategy !

Thank you…

Optimizing ORCHIDEE model parameters

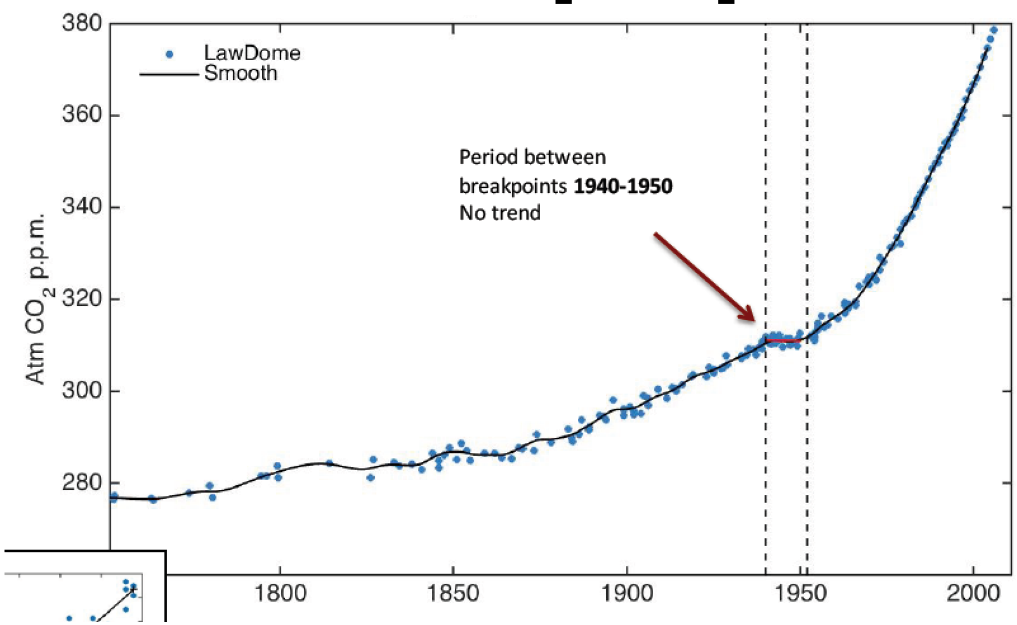
- Optimization using
  - Atmospheric CO2 data
  - MODIS – NDVI measurements
  - FluxNet (NEE, LE) measurements

Carbon Cycle Data Assimilation System

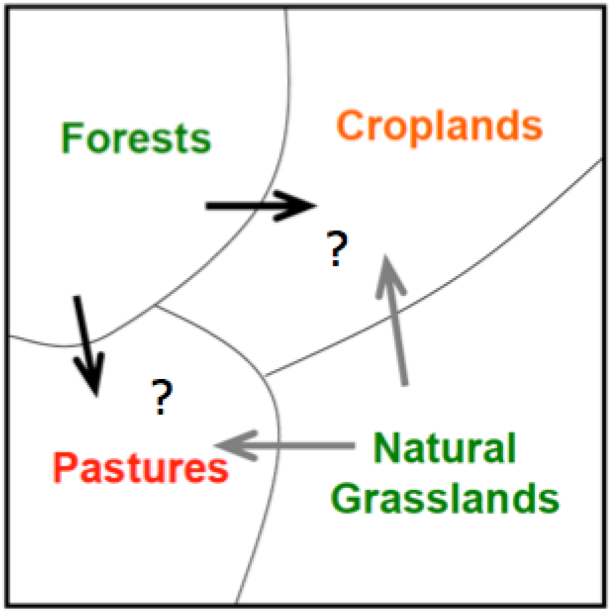


Use the full Atmospheric CO2 record.. to correct for Land Use Change..

Atm. [CO2]



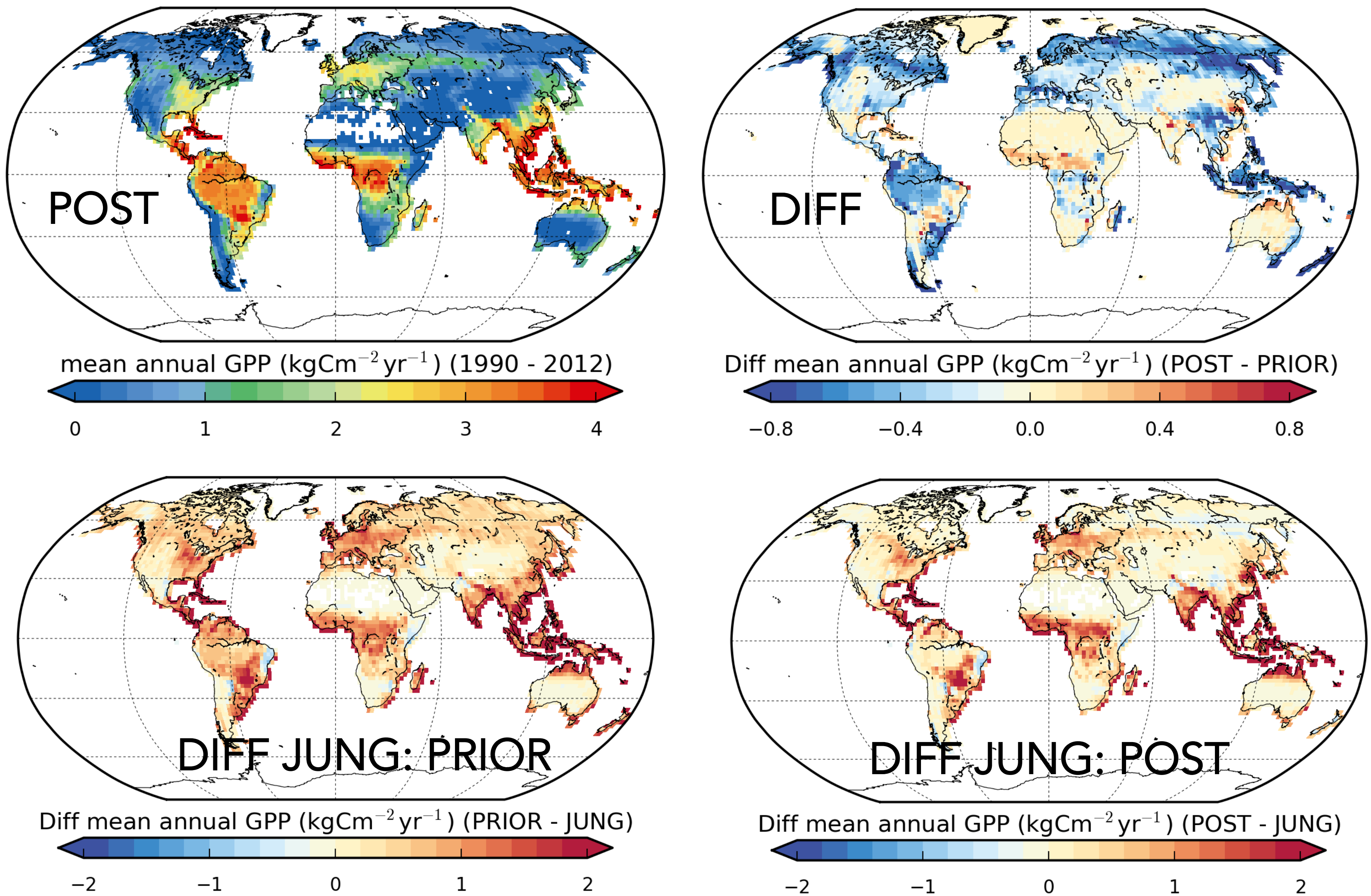
Optimization of Land use change



➔ Difficult process as Land Cover is an input of the model and given the need to have a "large assimilation time window"

Spatial distribution

- Dramatic reduction in global annual mean GPP (1990-2010):
  prior: 172PgC; posterior: 147PgC; (cf. JUNG MTE: 132PgC)



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