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

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Challenge….

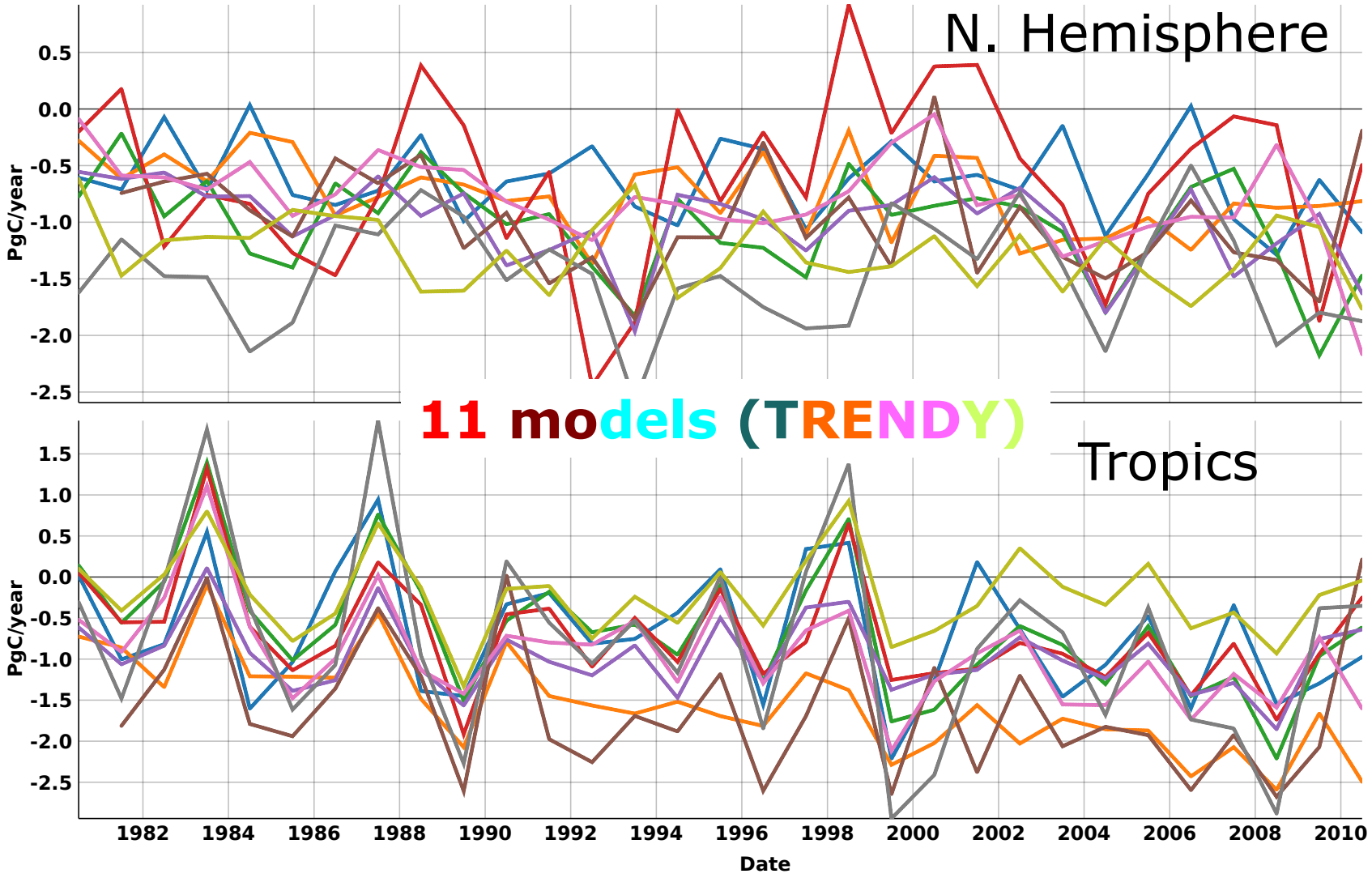
➔Long term objective: perform a “joint assimilation” including Carbon Cycle feedback on climate !

- 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..

Net C. Flux

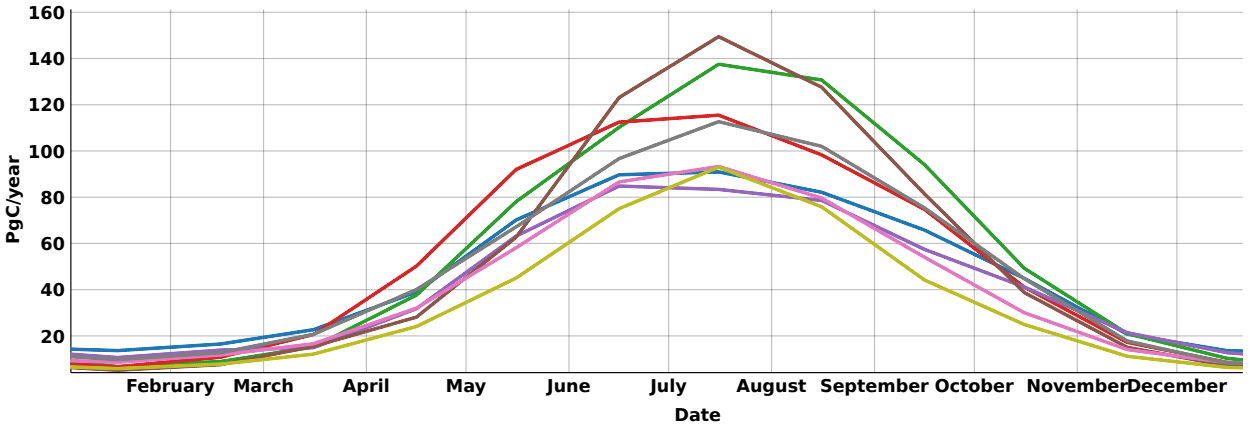


Gross Carbon flux still highly variables

Gross Primary Production

Large amplitude differences at high latitudes

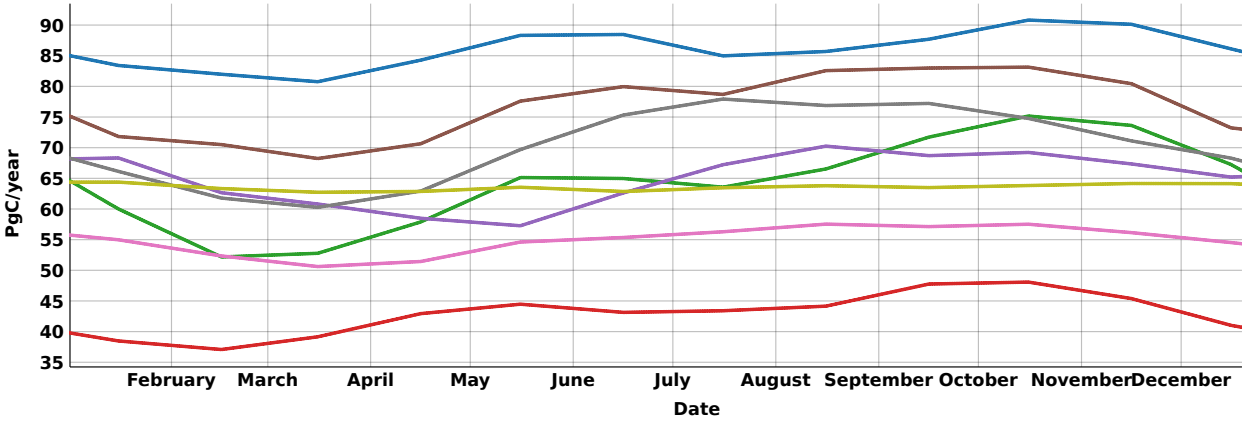
N. Hemisphere



11 models (TRENDY)

Large phase differences in the Tropics

Tropics



Parameter vs State variable optimization

State variable optimization

- Less assumption on processes
- Maximum extraction of the obs information ($[CO2]_{atm}$ includes all processes,..)

- Few insight on the processes
- C stocks cannot be assimilated easily
- Only few data cover 20th C
- No predicting capabilities

Parameter optimization

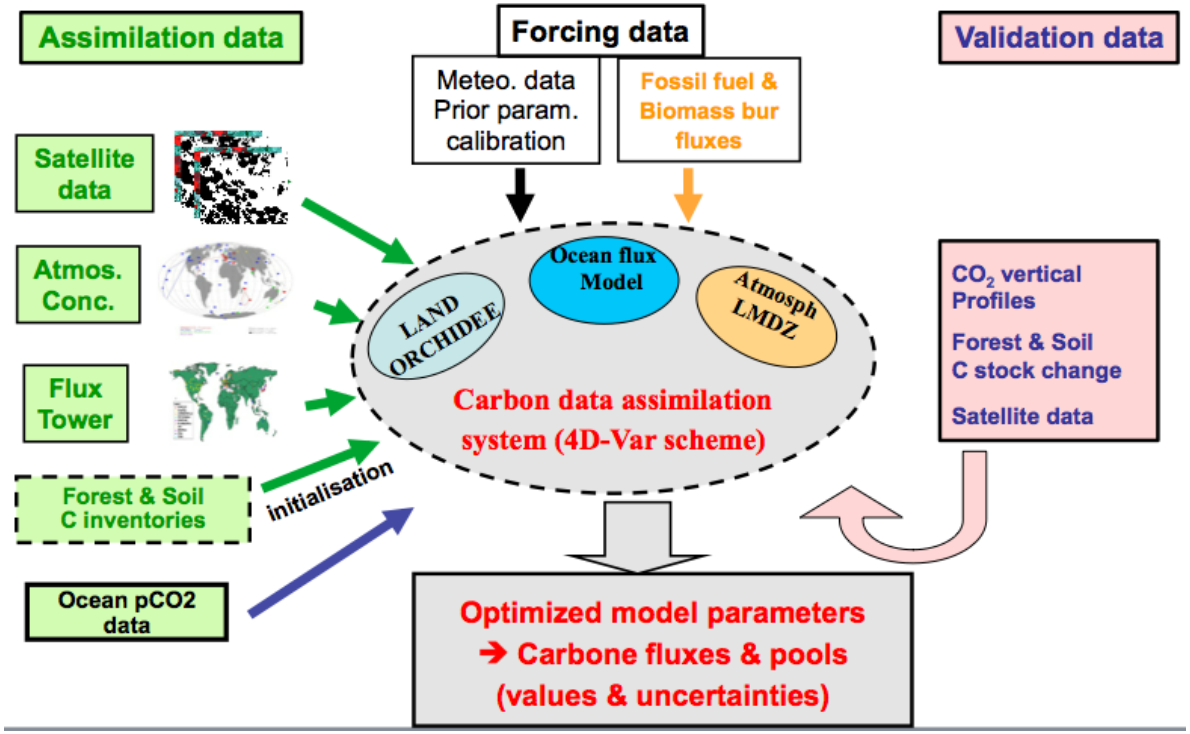
- Easier to use multi-data streams
- Constrain all processes
- Data dont need to cover the full period
- Prediction capabilities

- Rely on LSM structure
- Missing processes ?
- Heavier to handle

Optimizing ORCHIDEE model parameters

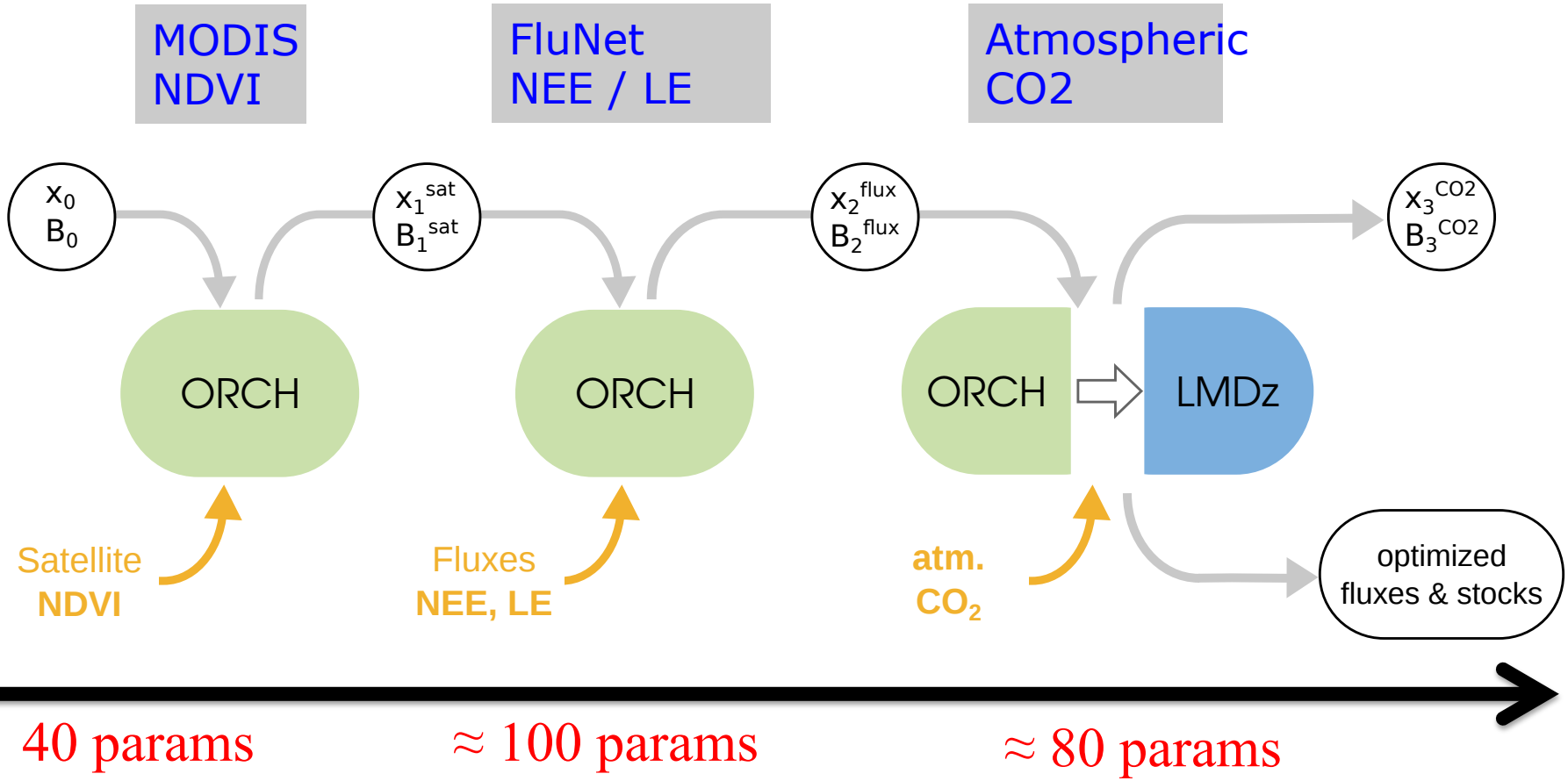
- Optimization using
  - Atmospheric CO2 data
  - MODIS – NDVI measurements
  - FluxNet (NEE, LE) measurements

Carbon Cycle Data Assimilation System



Step wise data assimilation system

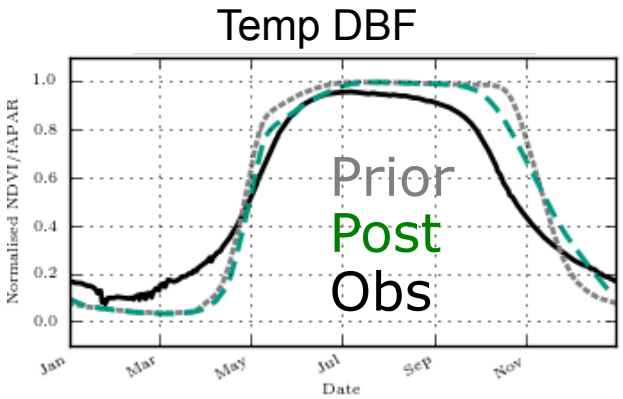
$$J(x) = \underbrace{\tfrac{1}{2}(\mathbf{H}.x-y)^T \mathbf{R}^{-1}(\mathbf{H}.x-y)}_{\text{Observation term}} + \underbrace{\tfrac{1}{2}(x-x_b)^T \mathbf{B}^{-1}(x-x_b)}_{\text{Prior parameter term (from previous step)}}$$

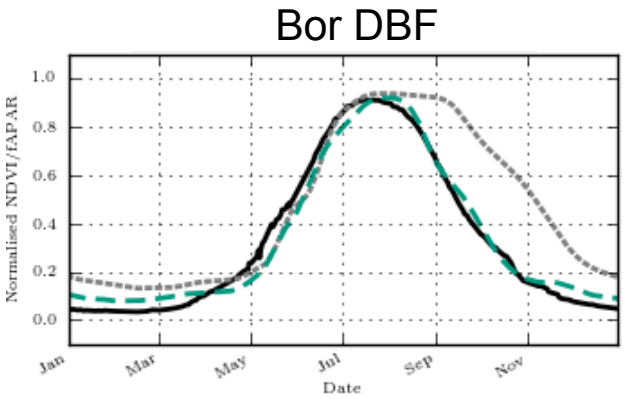


Assimilation of multiple data streams

Step 1:
MODIS-NDVI

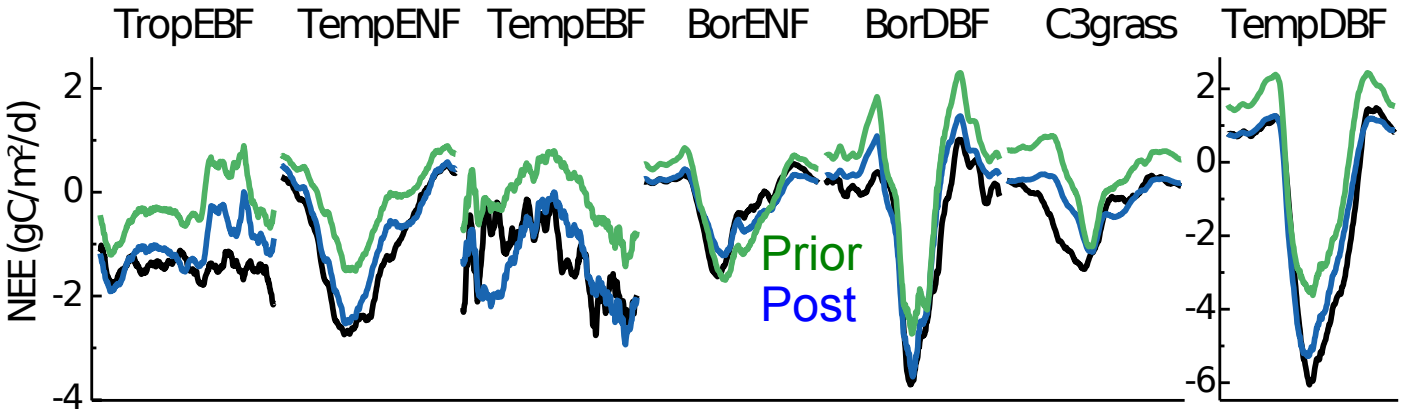
4 params /PFT





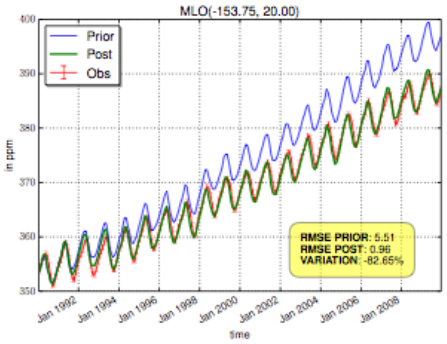
Step 2:
75 fluxnet data

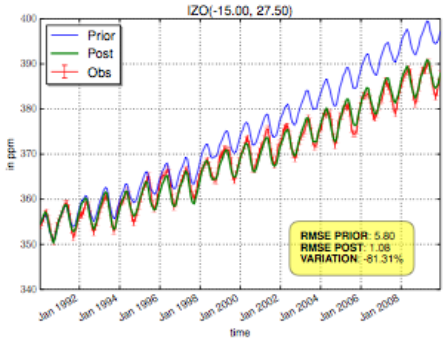
≈ 20 params /PFT



Step 3:
Atmospheric data

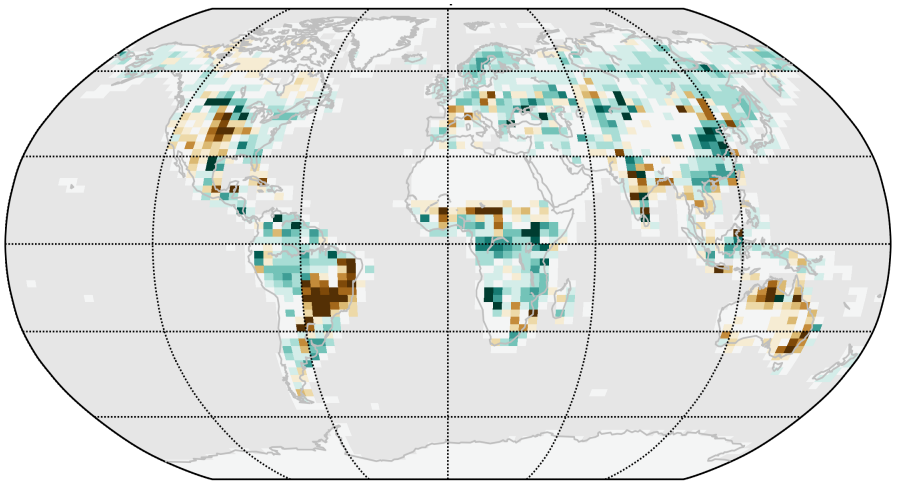
≈ 100 params total



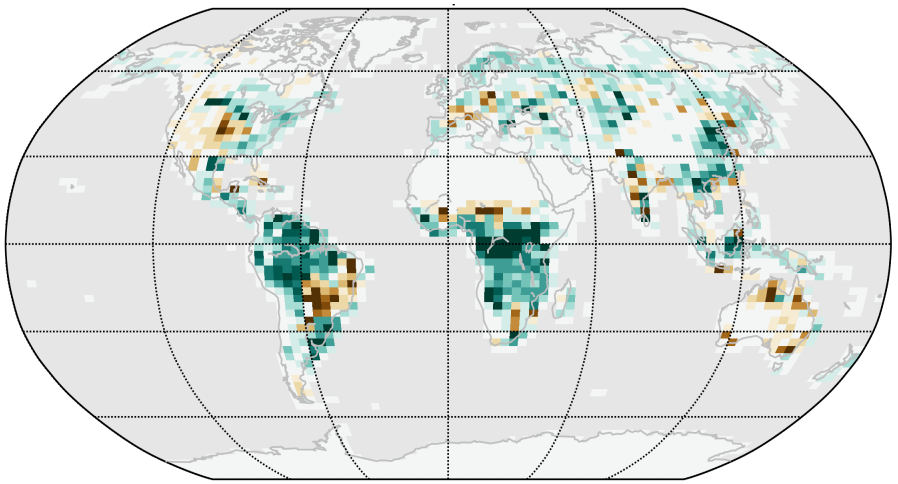


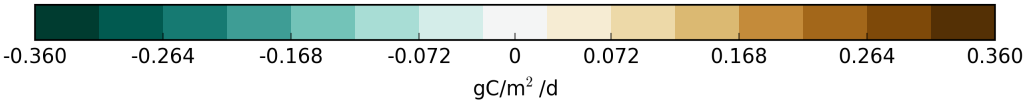
Impact on the global carbon fluxes

NEE - Prior



NEE - Posterior





gC/m2/day

➔ Significant changes over the tropics..

LSCE

Current updates :

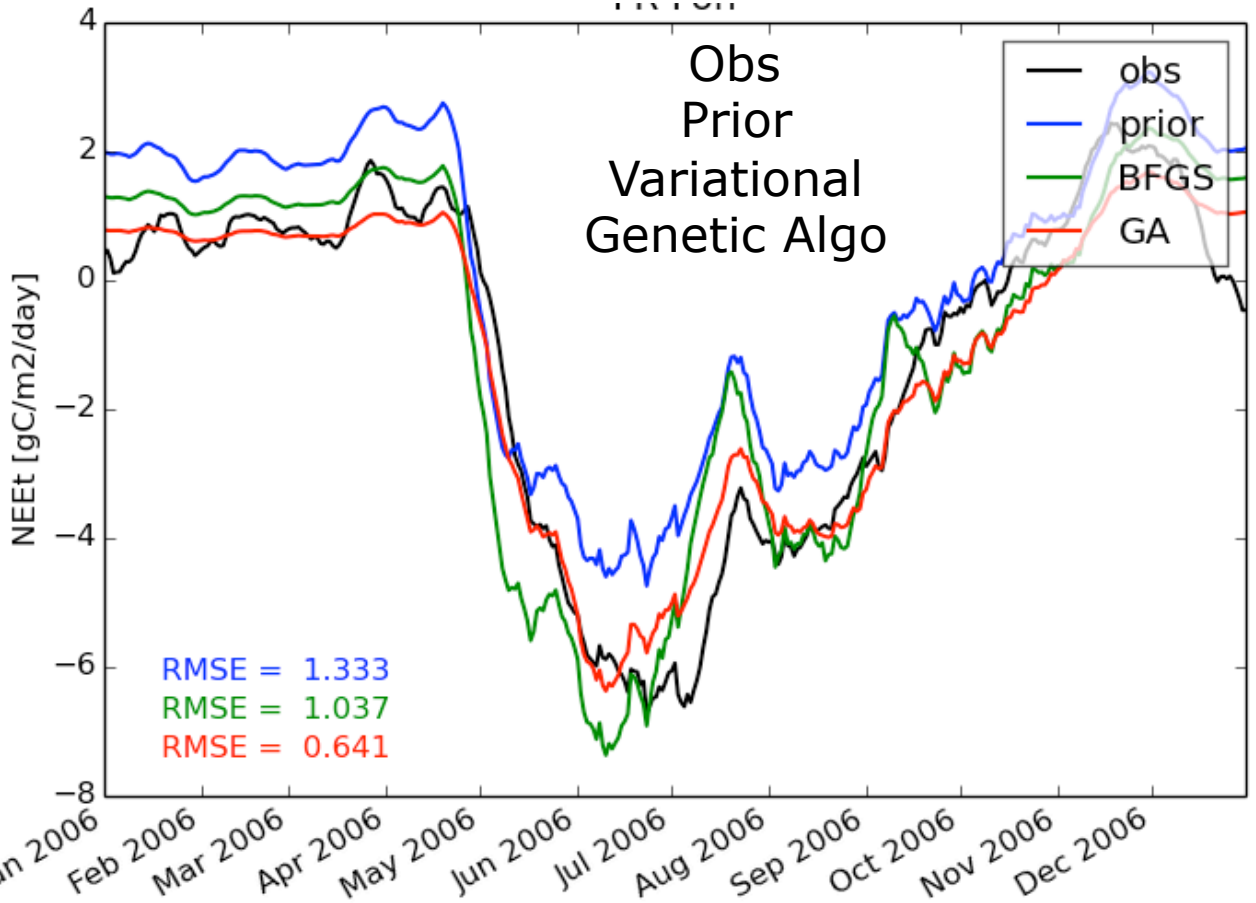
- Update of the Tangent Linear model
- Improvement of the optimization framework
- Ongoing assimilations with the new ORCHIDEE version
- Inclusion of new observations

Variational vs Monte Carlo optimization

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

Example:

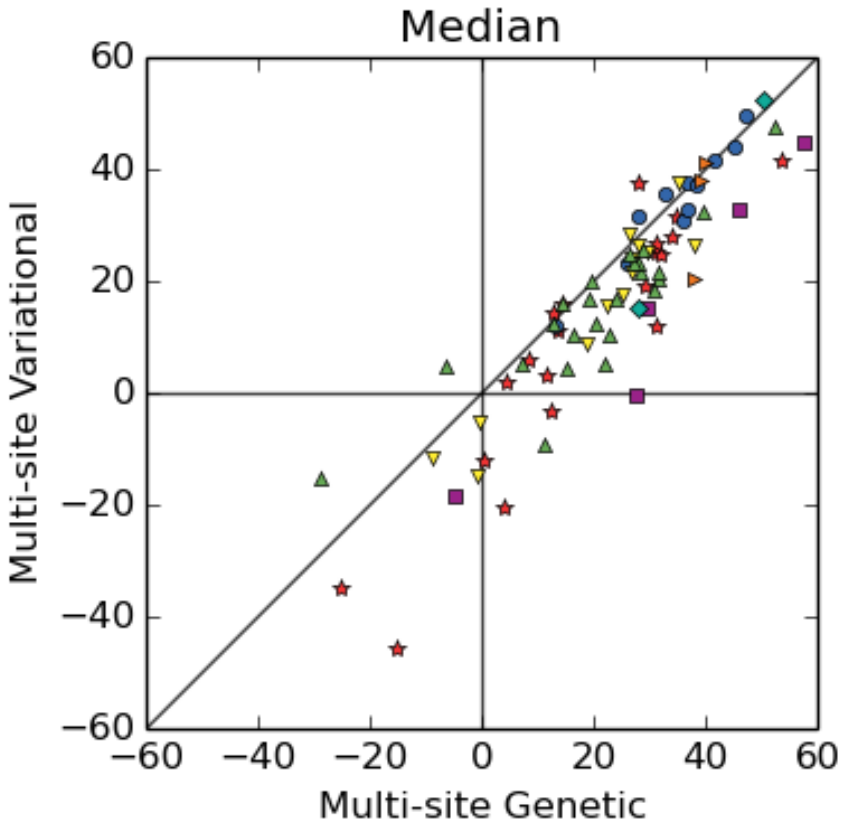
NEE for an Oak Forest (Fontainebleau site)

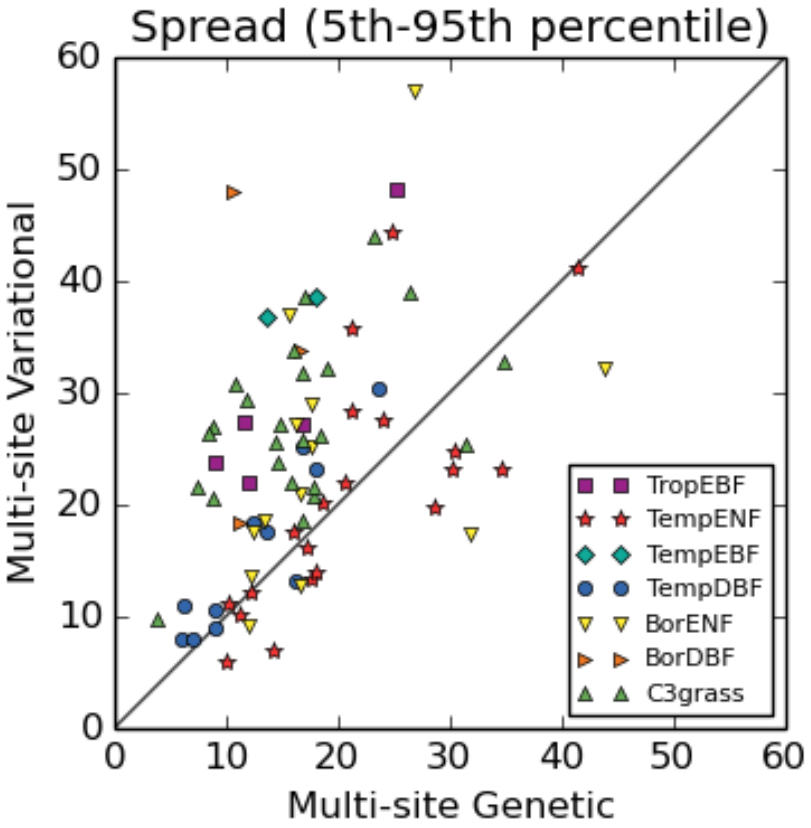


Variational vs Monte Carlo optimization

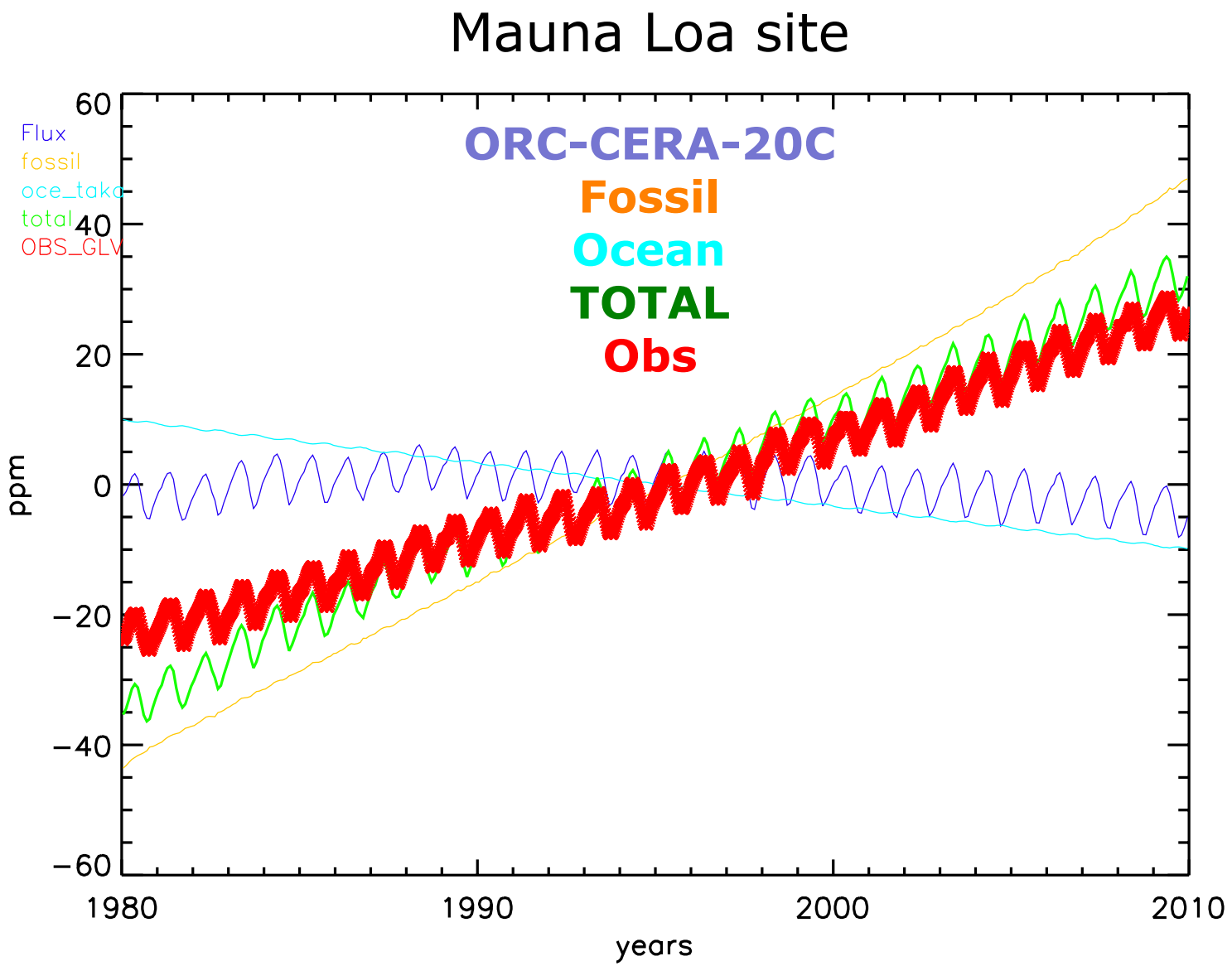
- Variational vs Genetic Algorithm minimization
- Using 72 FluxNet site observations (NEE, LE)
- 15 different optimizations starting from random priors

Mean NEE RMSE reduction (%)

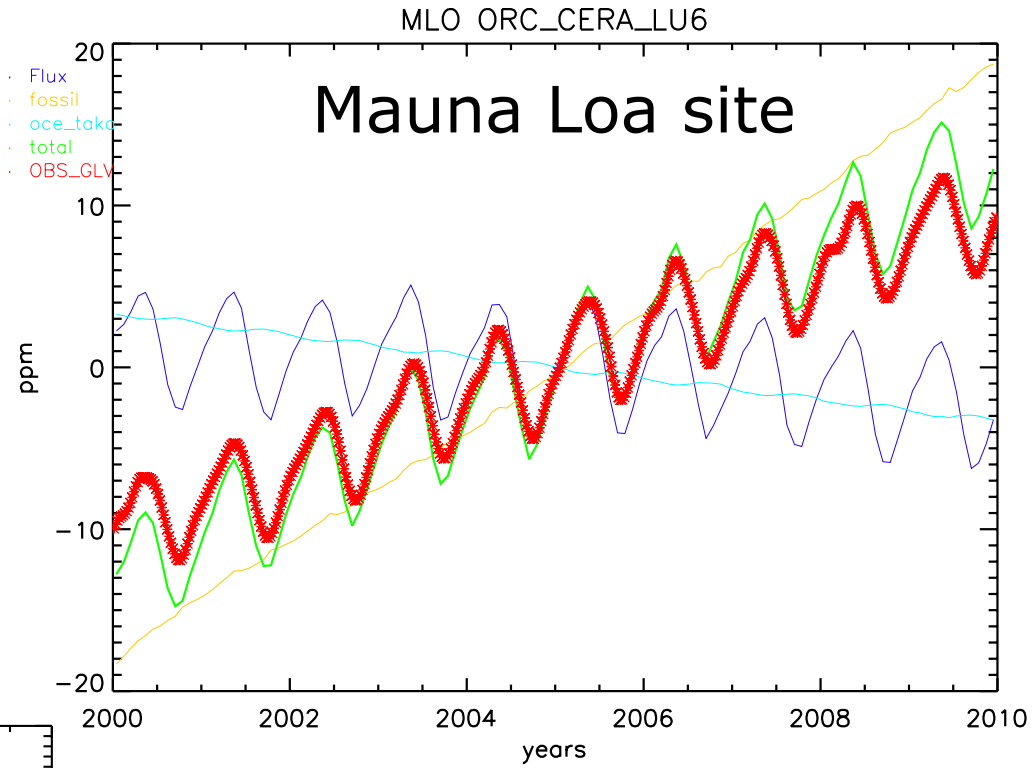


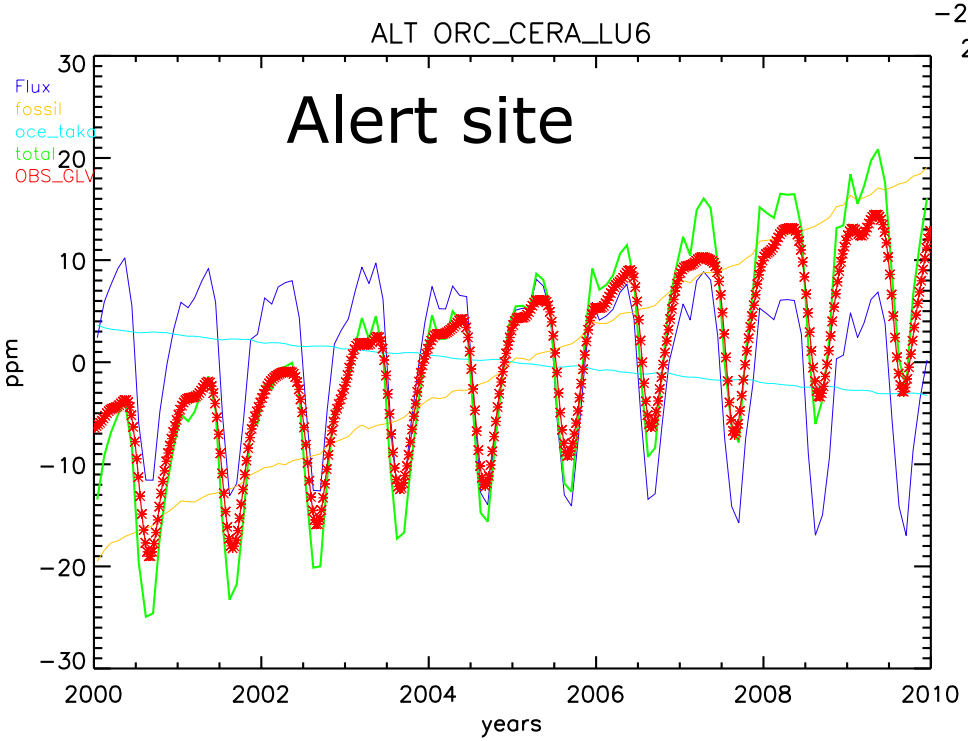


Atmospheric constraint



Atmospheric constraint





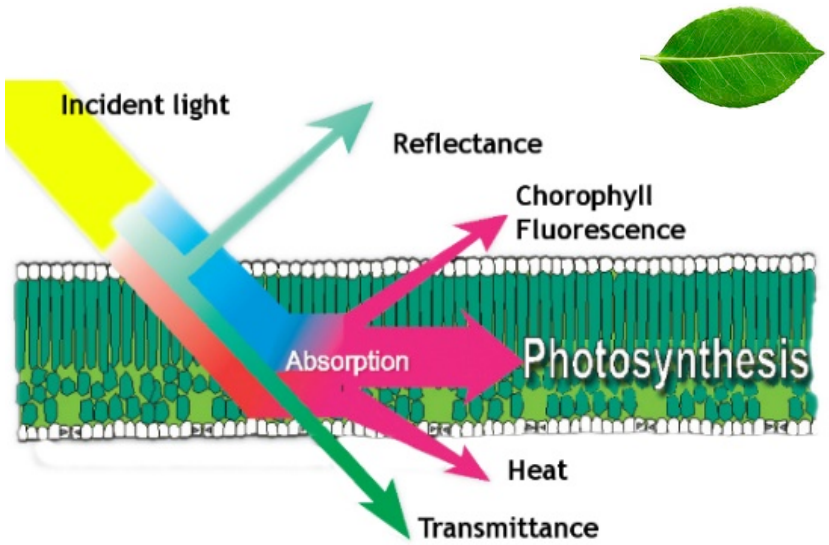
ORC-CERA-20C
Fossil
Ocean
TOTAL
Obs

LSCE

Assimilation of new recent observations to better constraint gross C fluxes

Potential Solar Induce Fluorescence data

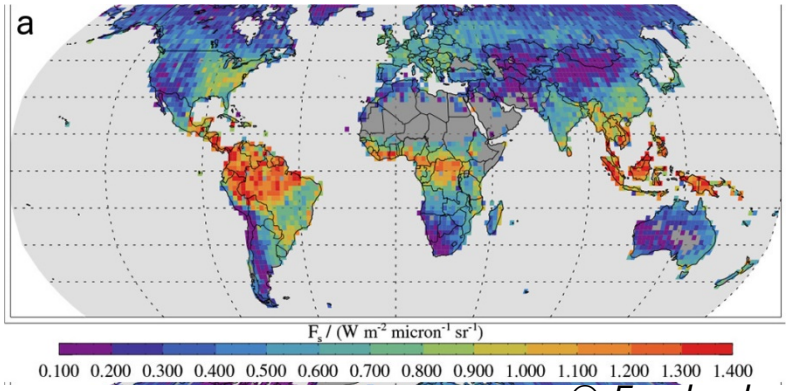
Solar Fluorescence (SIF)



SIF = function (GPP, T,…)

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

GOME-2 SIF



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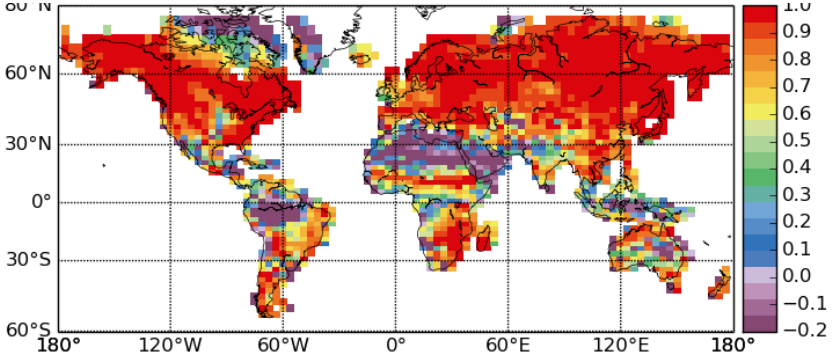
Correlation: ORCHIDEE-GPP vs SIF



➔ Regional scale information for phase (& synoptic events)

Optimisation set-up

- Simple linear relationship between GPP and SIF:

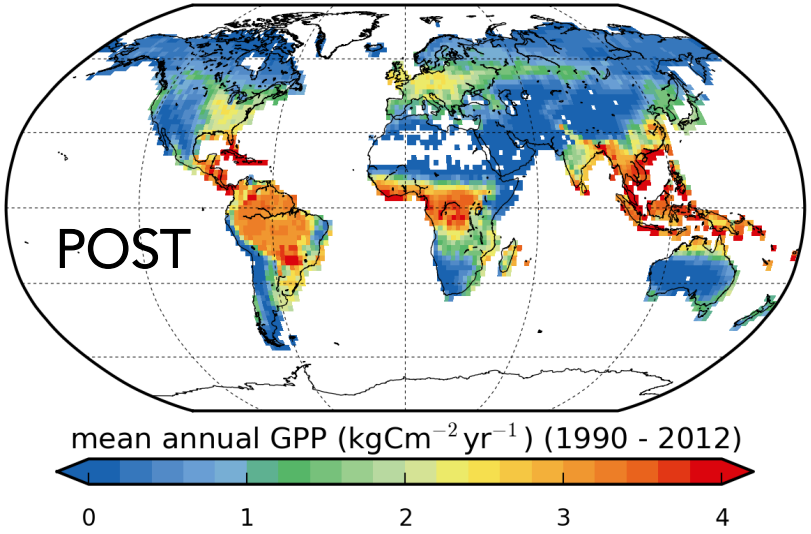
$$SIF = a\,GPP + b$$

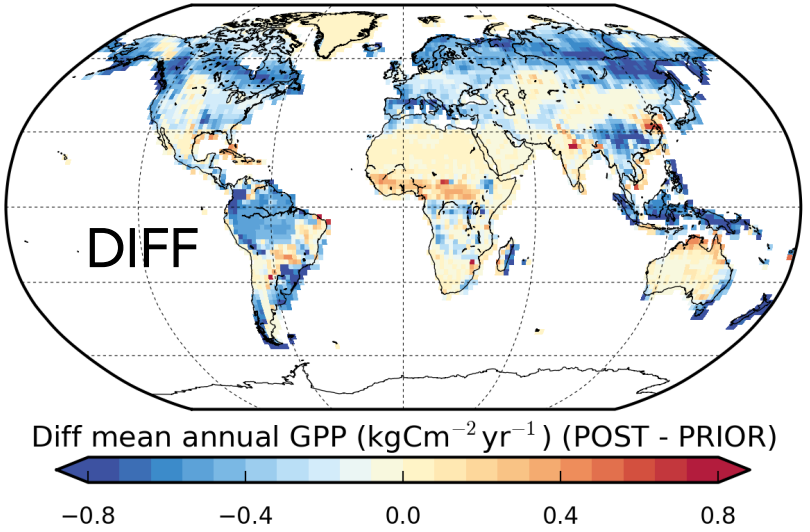
- Constrain 'a' and 'b' (slope and offset) parameters in addition to photosynthesis and phenology parameters for ALL vegetated PFTs

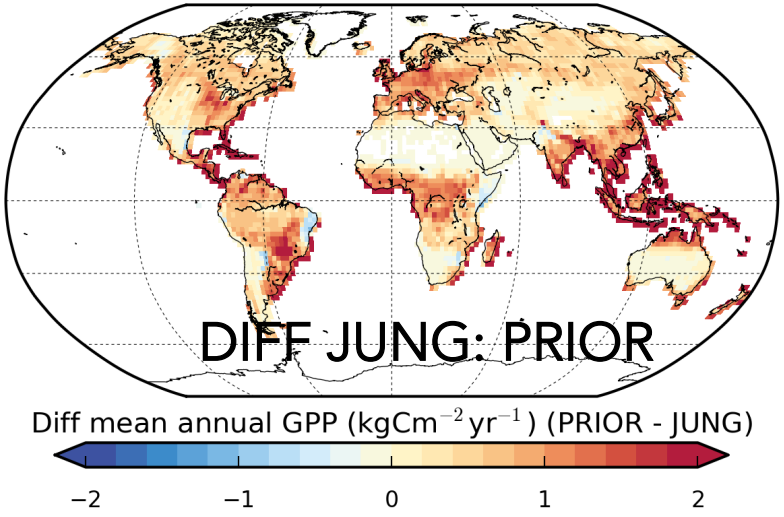
- Use GOME2 SIF data (Köhler et al., 2015)
- 15 grid cells chosen randomly per PFT
- 12-16 parameters per PFT
- Multi-site optimisation performed for each PFT
- 4D – variational/finite difference data assimilation system

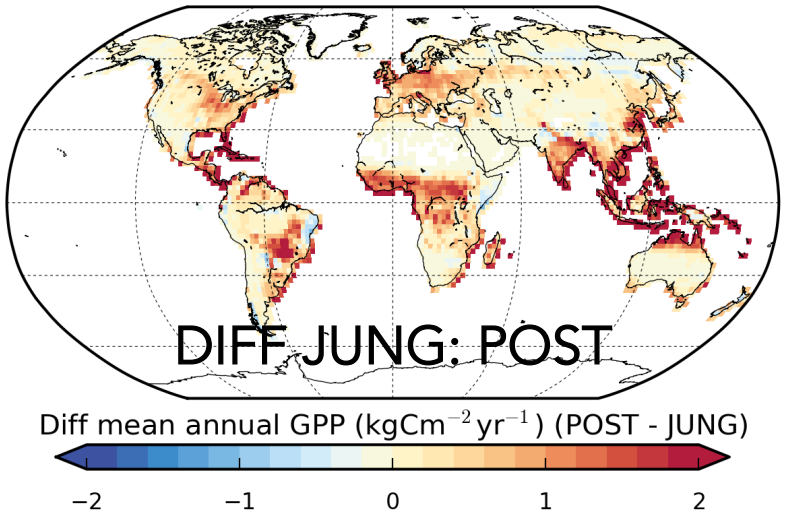
Spatial distribution

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









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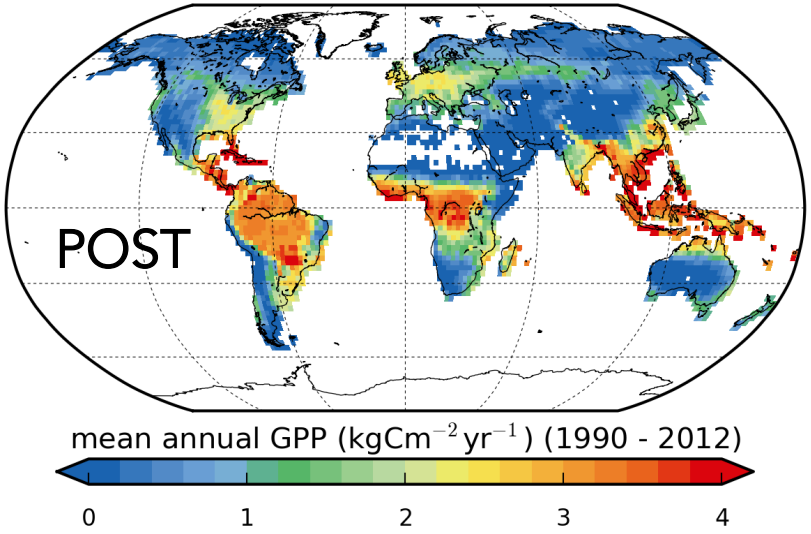
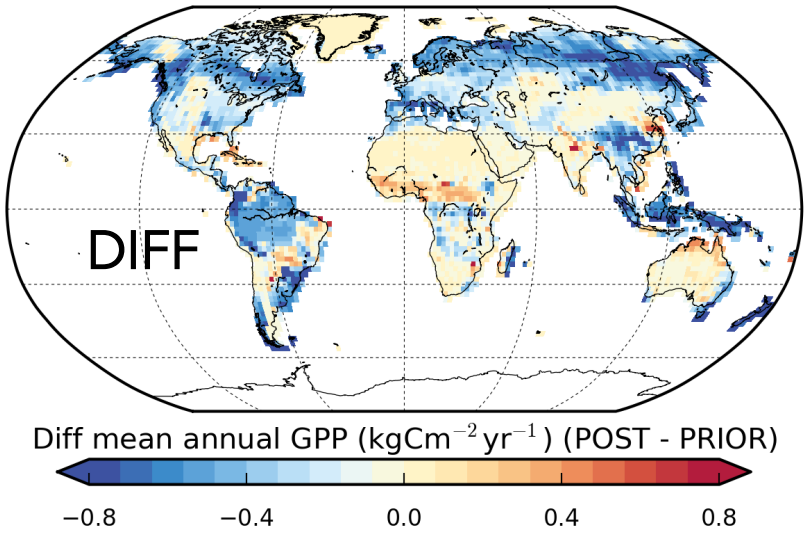
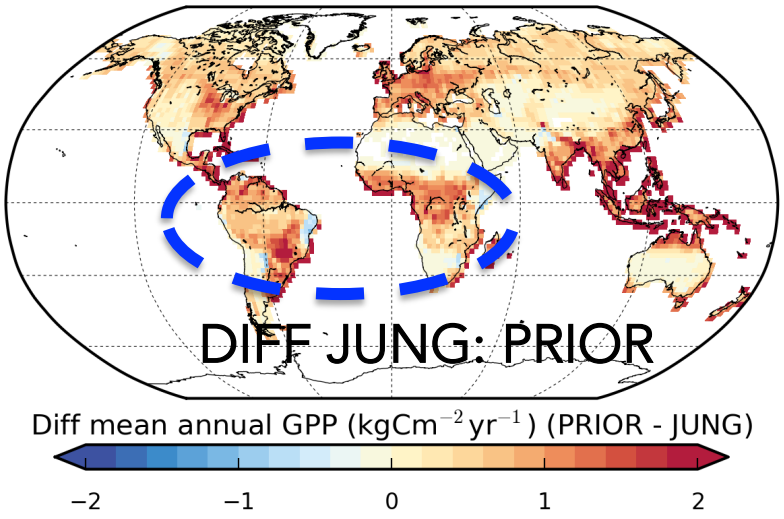
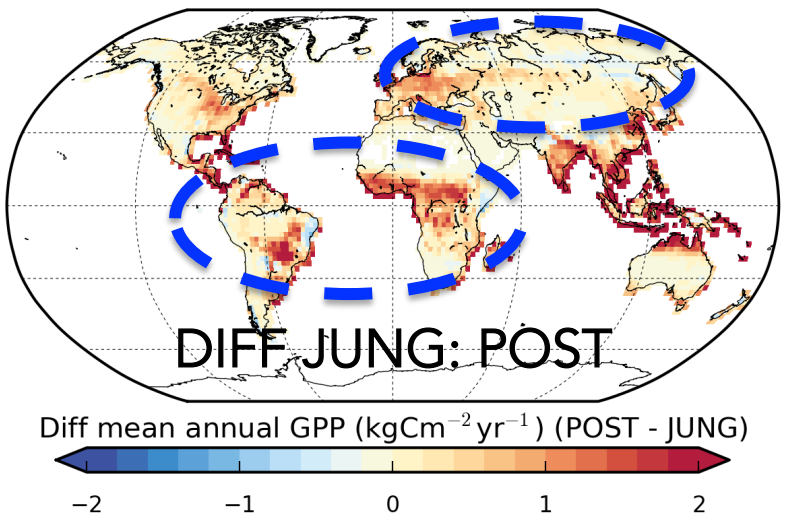


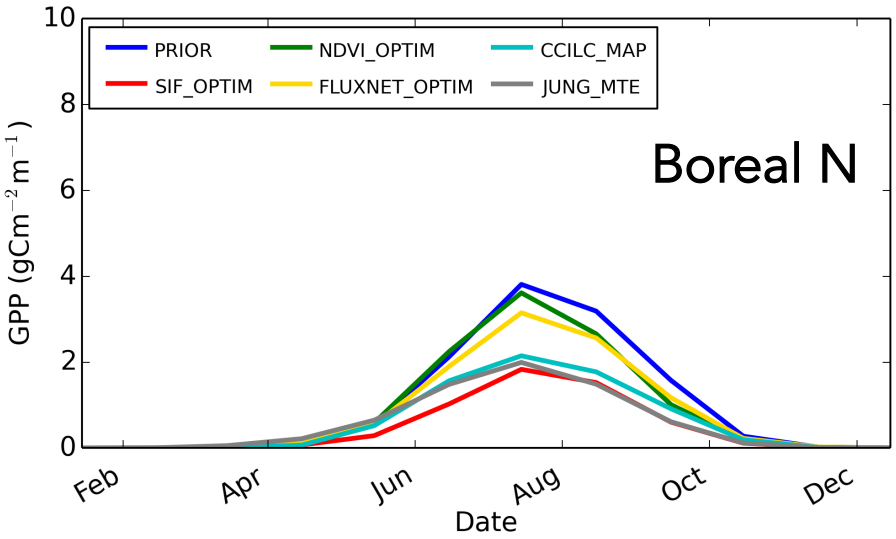


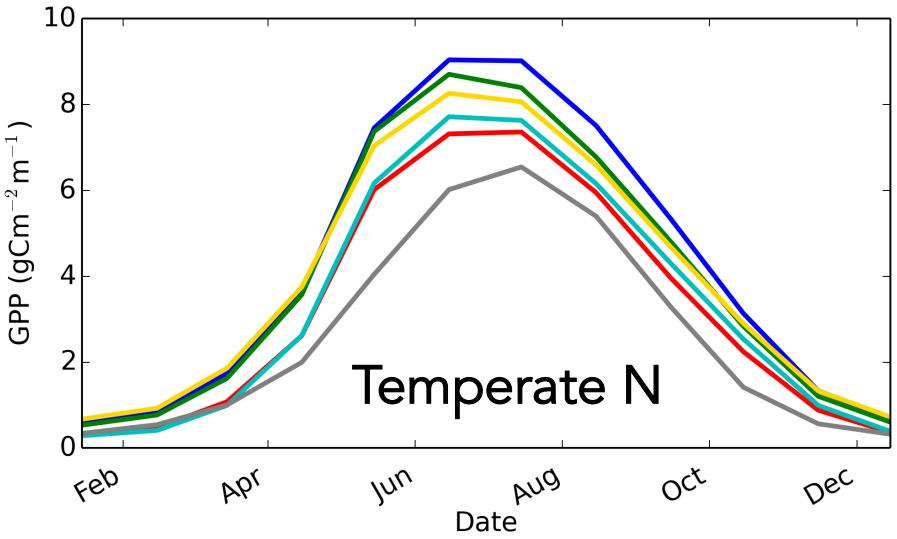




Mean seasonal cycles

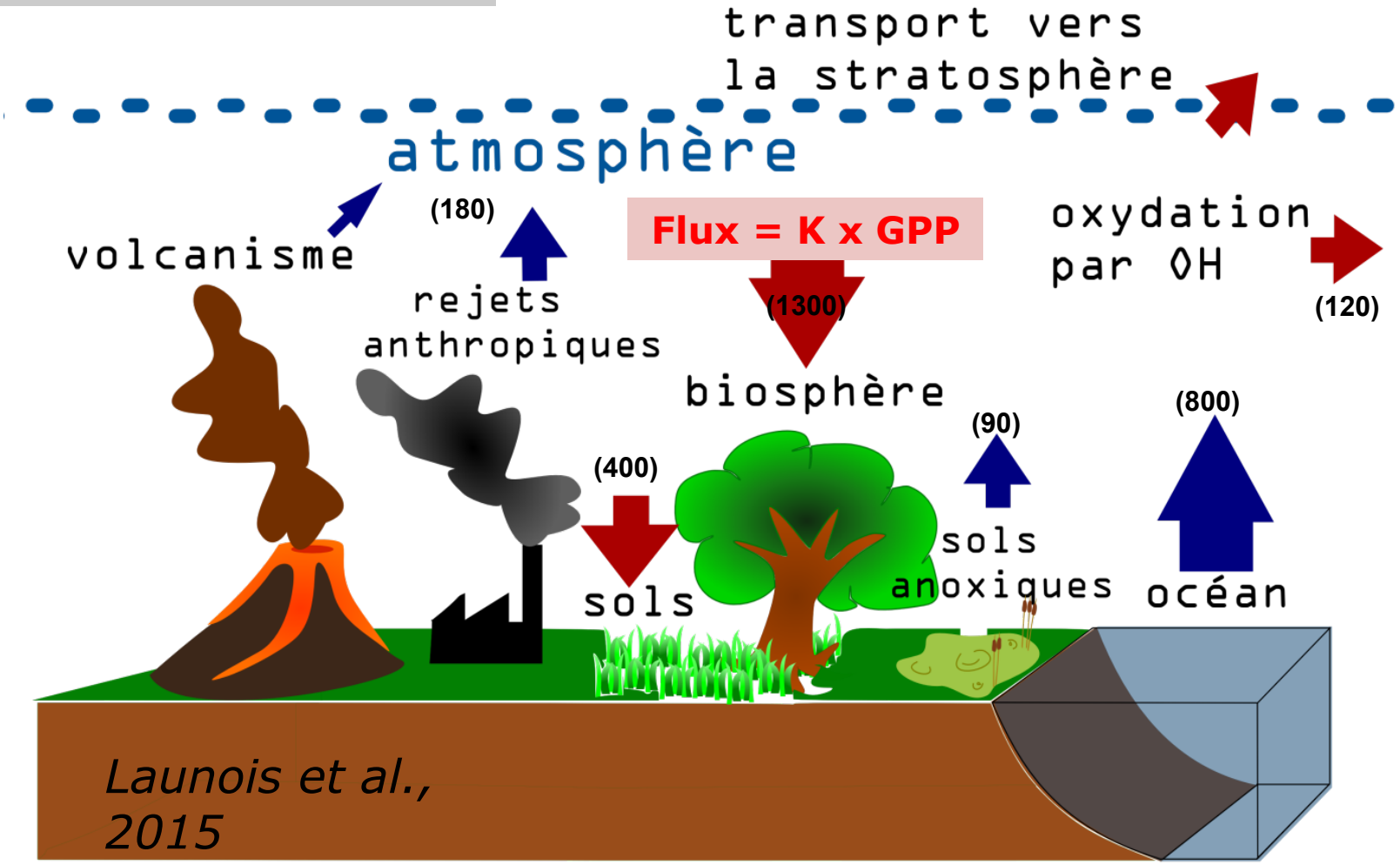
Prior
Posterior assimilating SIF
Posterior assimilating NDVI
"Benchmark"





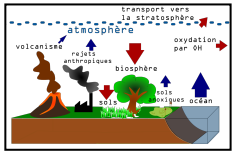
Atmospheric [COS]: potential tracer of Photosynthesis (GPP) budget

COS cycle (GgS/yr):



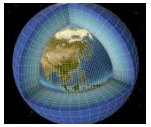
Potential of atmospheric COS & CO2

(Ex: using TRENDY simulations)



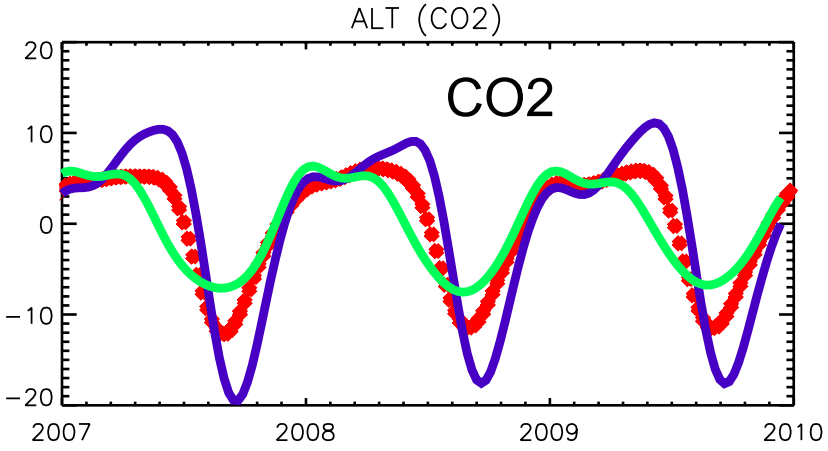
CO2 Flux
Scenario = f(model NEE)

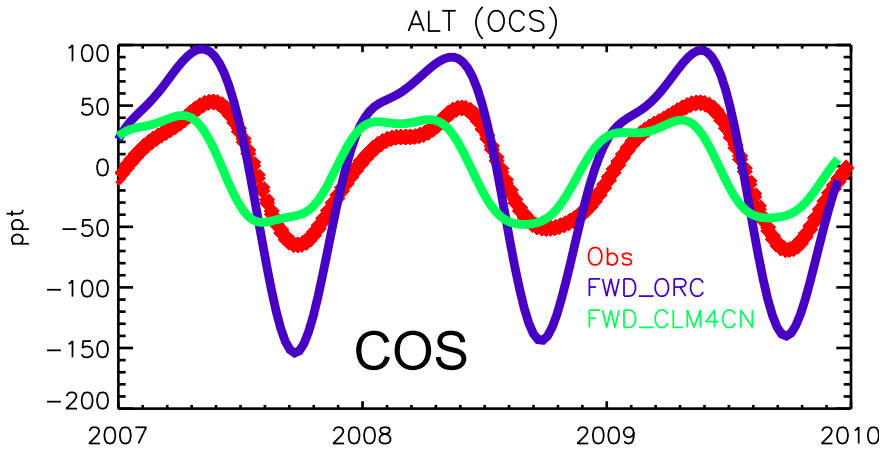
LMDz



COS Flux
Scenario Fbio = f(model GPP)

Obs ORCHIDEE CLM4CN





➔ New information at continental scale

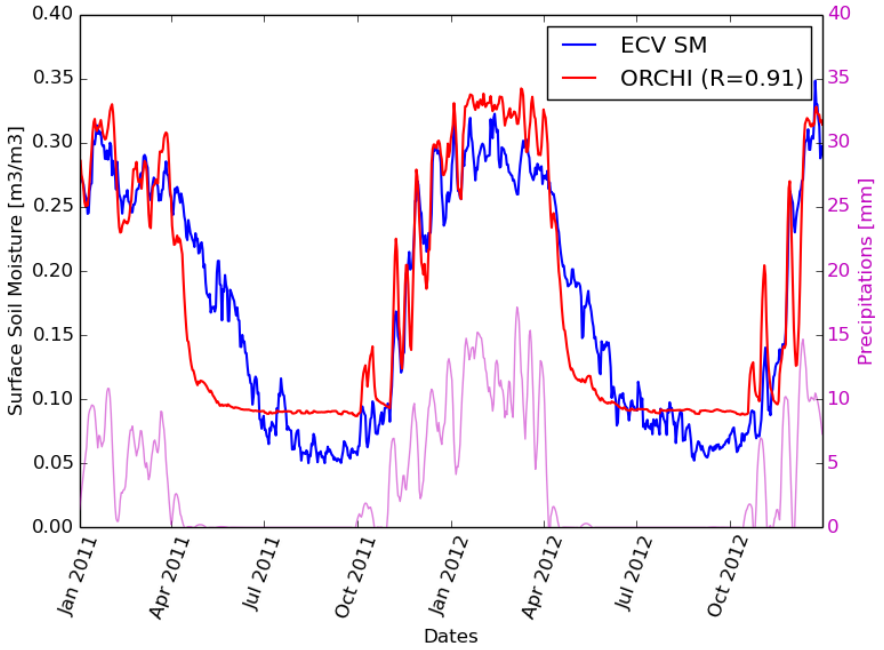
Collaboration: S. Belviso, T. Launois

Potential of Surface Soil Moisture data

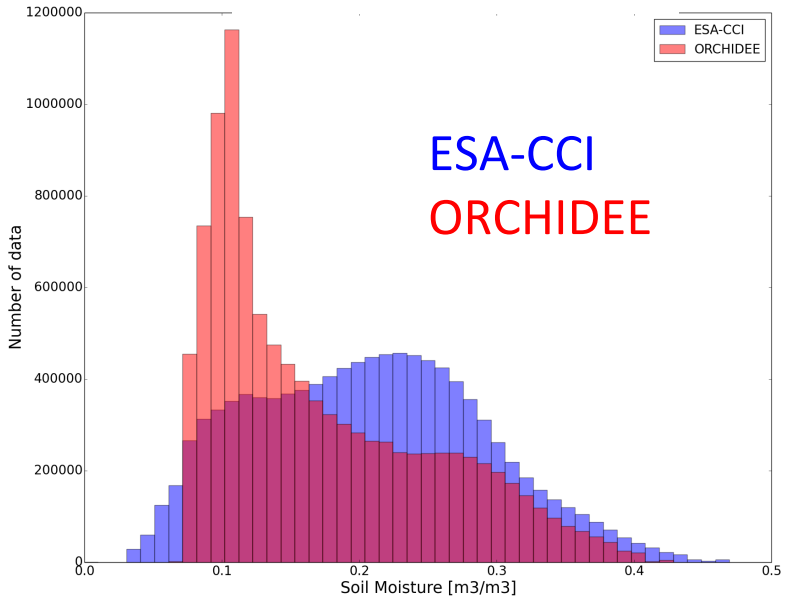
➔ Using the ESA – CCI surface moisture product (35 years)

➔ 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-1…

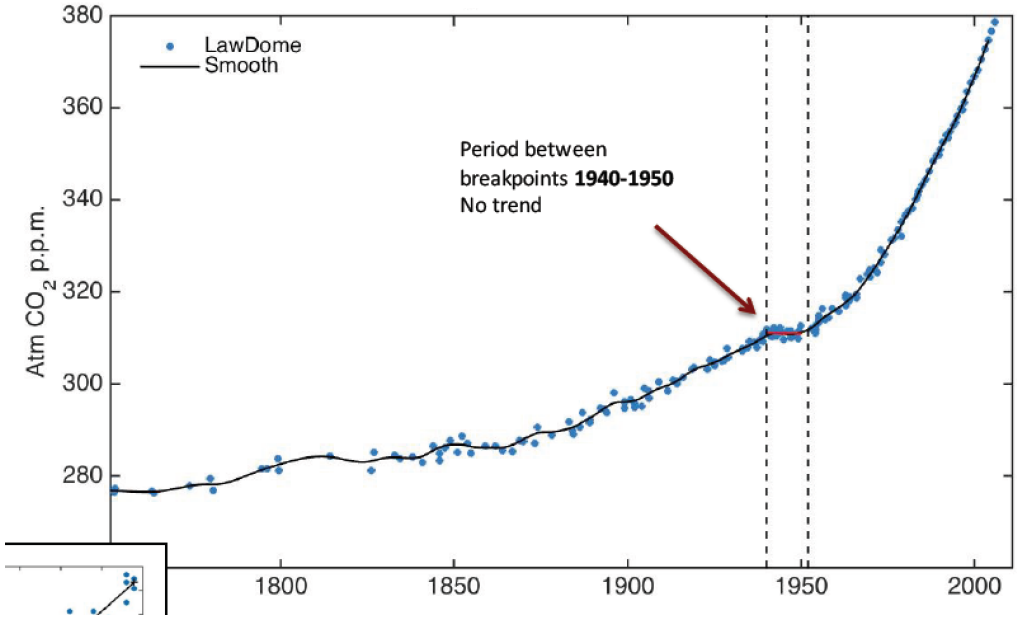
➔ "Investigation" for an homogeneous earth system reanalysis including Carbon-cycle.

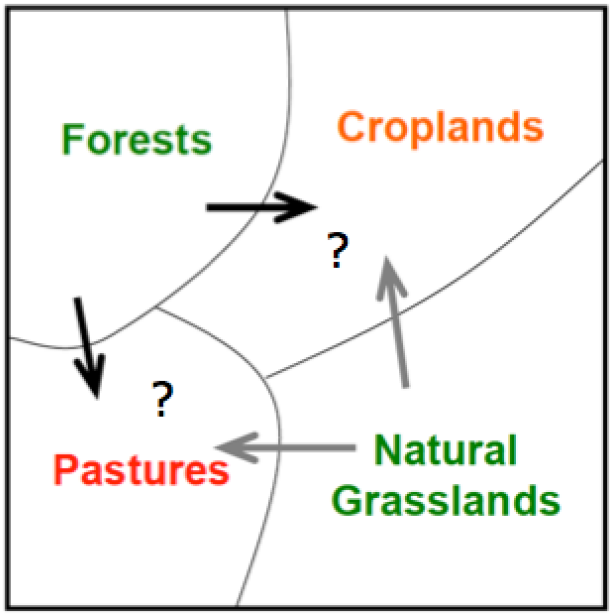
- Objective for the Land:
  Apply a "Carbon Cycle Data Assimilation System" over the whole 20th century using:
  - Atm CO2: **in situ recent data + *Ice core data***
  - Satellite NDVI: **GIMS (AVHRR) long record**
  - FluxNet data: **(NEE, LE)**
  - Possibly forest age **: Age reconstruction**
  - New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

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

Optimization of Land use change

Atm. [CO2]





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

Outlook - 2

- Potential iterative approach:

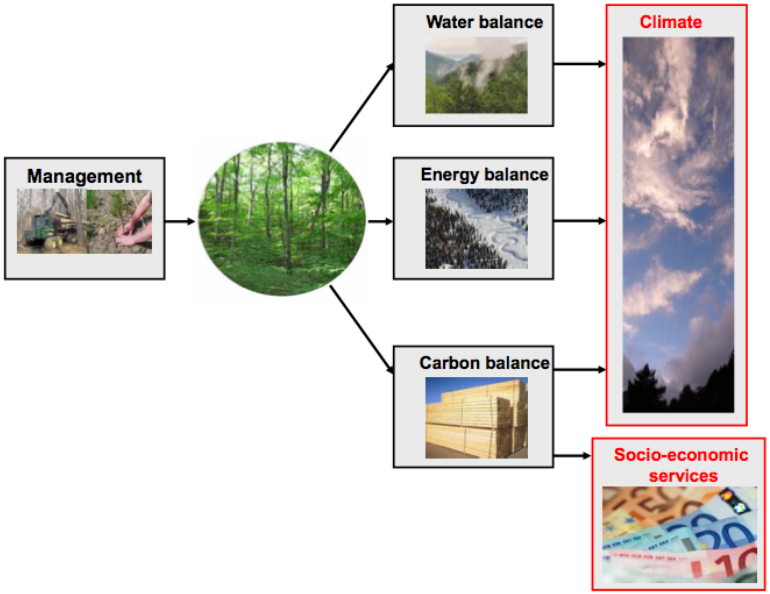
1. IFS ➔ climate reanalysis
2. ORCHIDEE + Climate reanalyse + Observations ➔ C – Cycle reanalysis
3. IFS + C-Cycle forcing ➔ New climate reanalysis

Thank you…

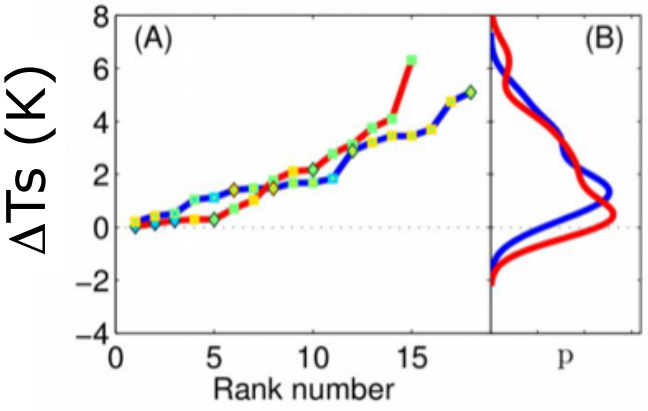
Potential of joint C/W/E assimilation

- Land cover changes

Land cover management



Effect on surface climate (Analysis from nearby FluxNet sites)



Luyssaert et al. 2014

Land cover effect
Land management effect

➔ link betw biogeochemical and biophysical cycles

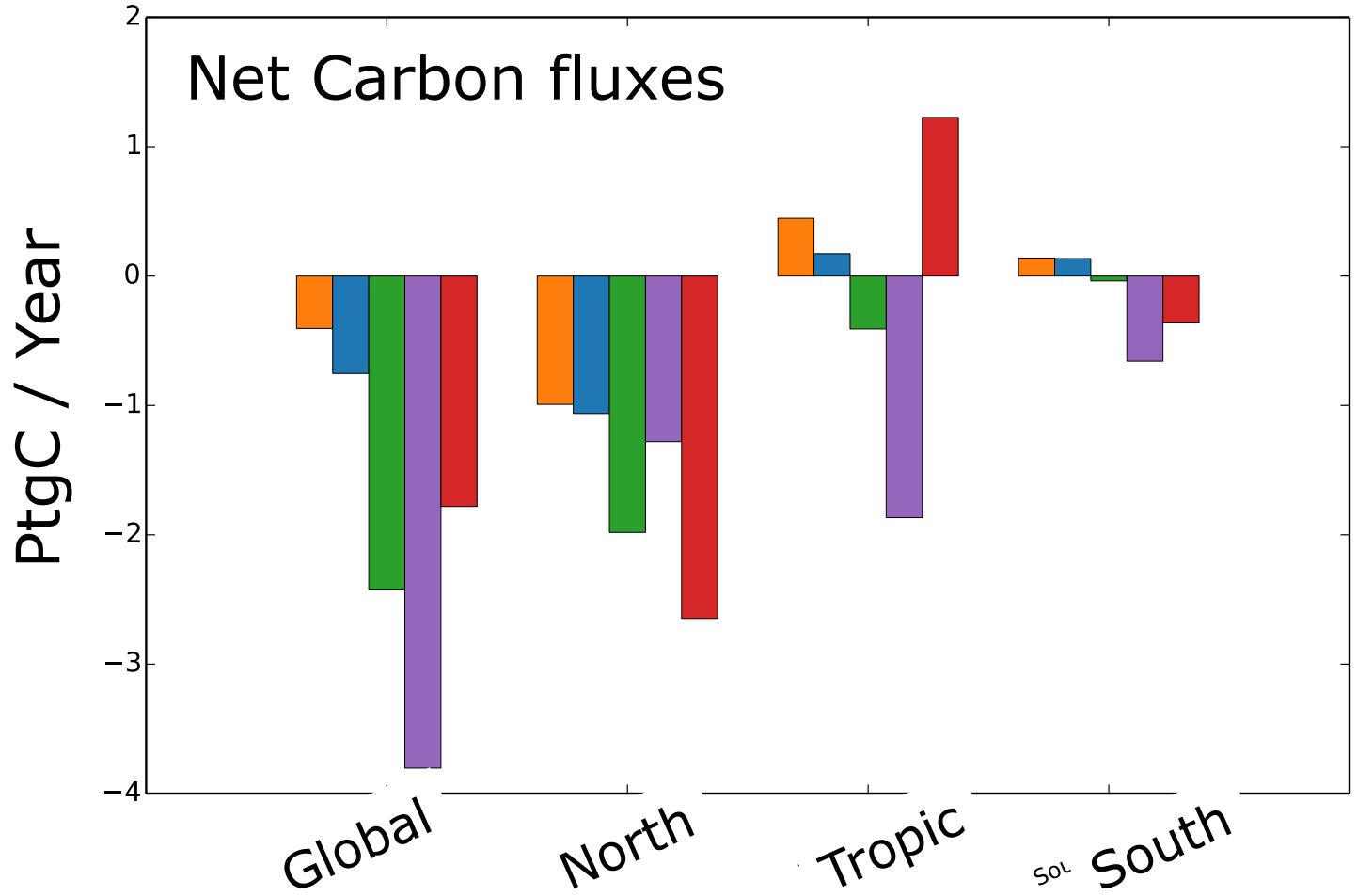
Carbon reanalysis: evaluation of CERA-20C ORCHIDEE simulation

Land Use → **LUCMIP6** **LUCMIP5**

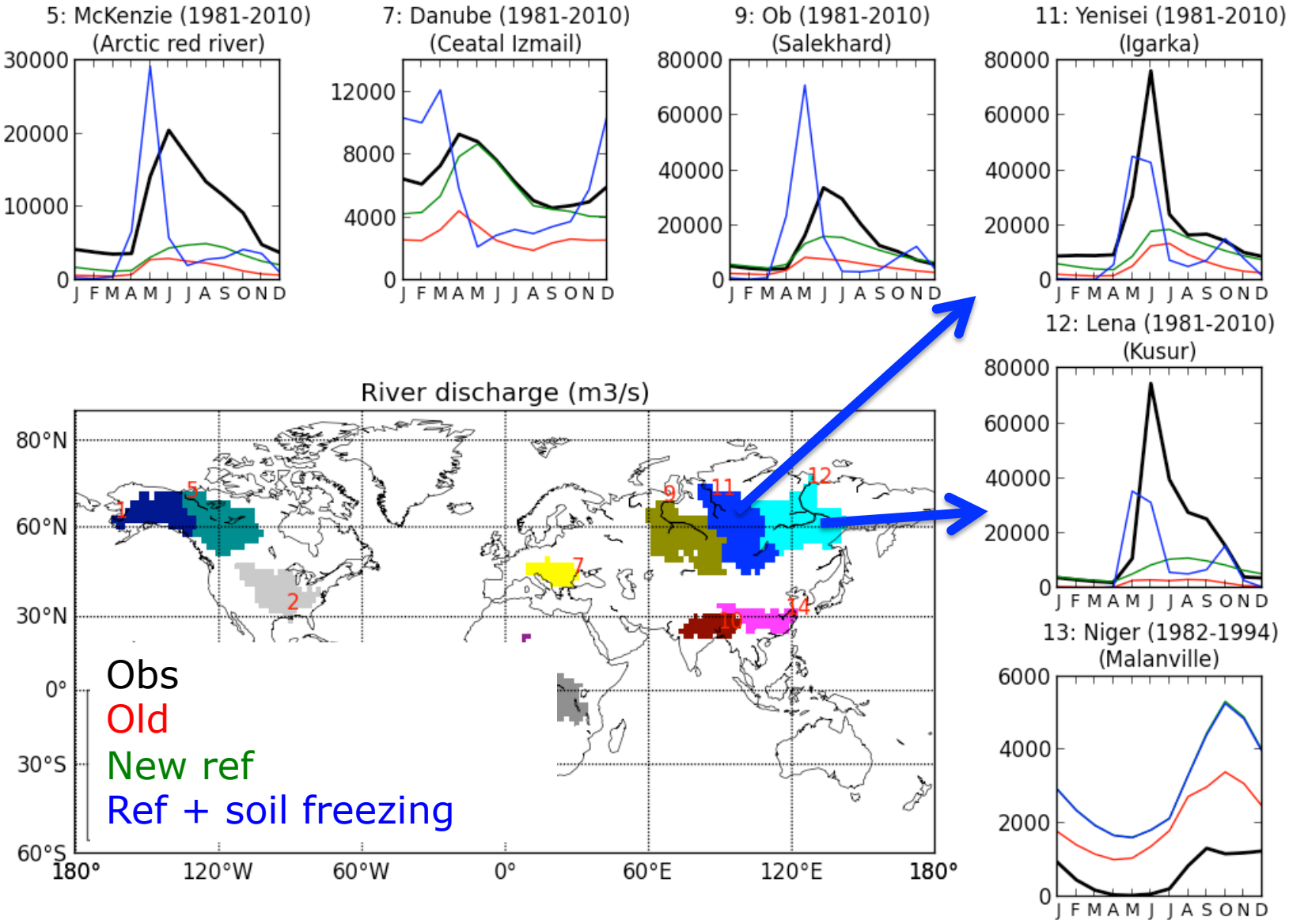
Meteo variant → **CRUNCEP**

Model version → **ORC-CMIP5**

CO_2 Inversion → **MACC2**



Coupling of Water – Carbon - Energy



Coupling of Water – Carbon - Energy

But at the same time

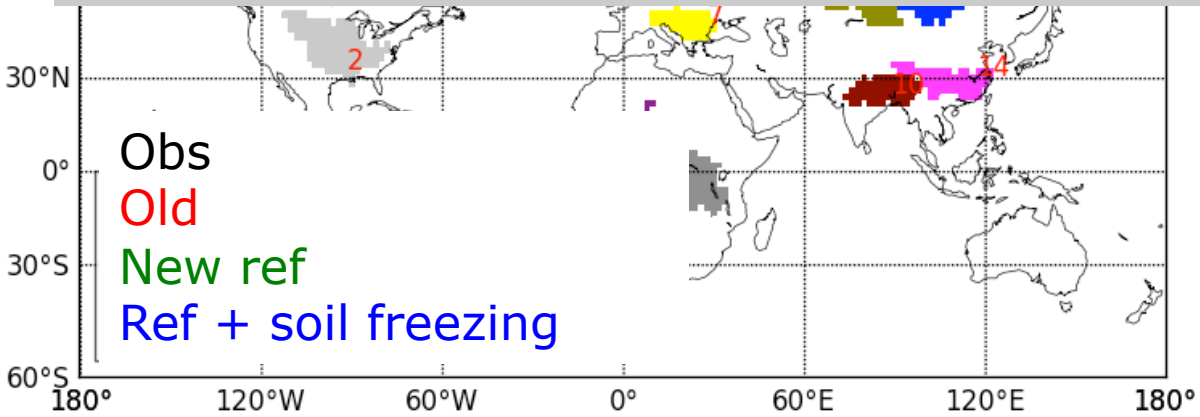
➔Drying of the soil in Siberia

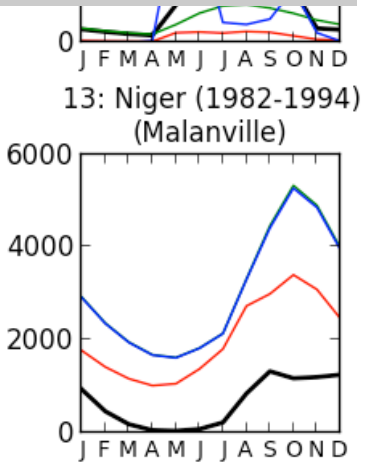
➔Too large water stress during summer

➔Prevent vegetation to develop leaves

➔Drop of Transpiration and Carbon uptake !

➔Potential large feed back on Precipitations



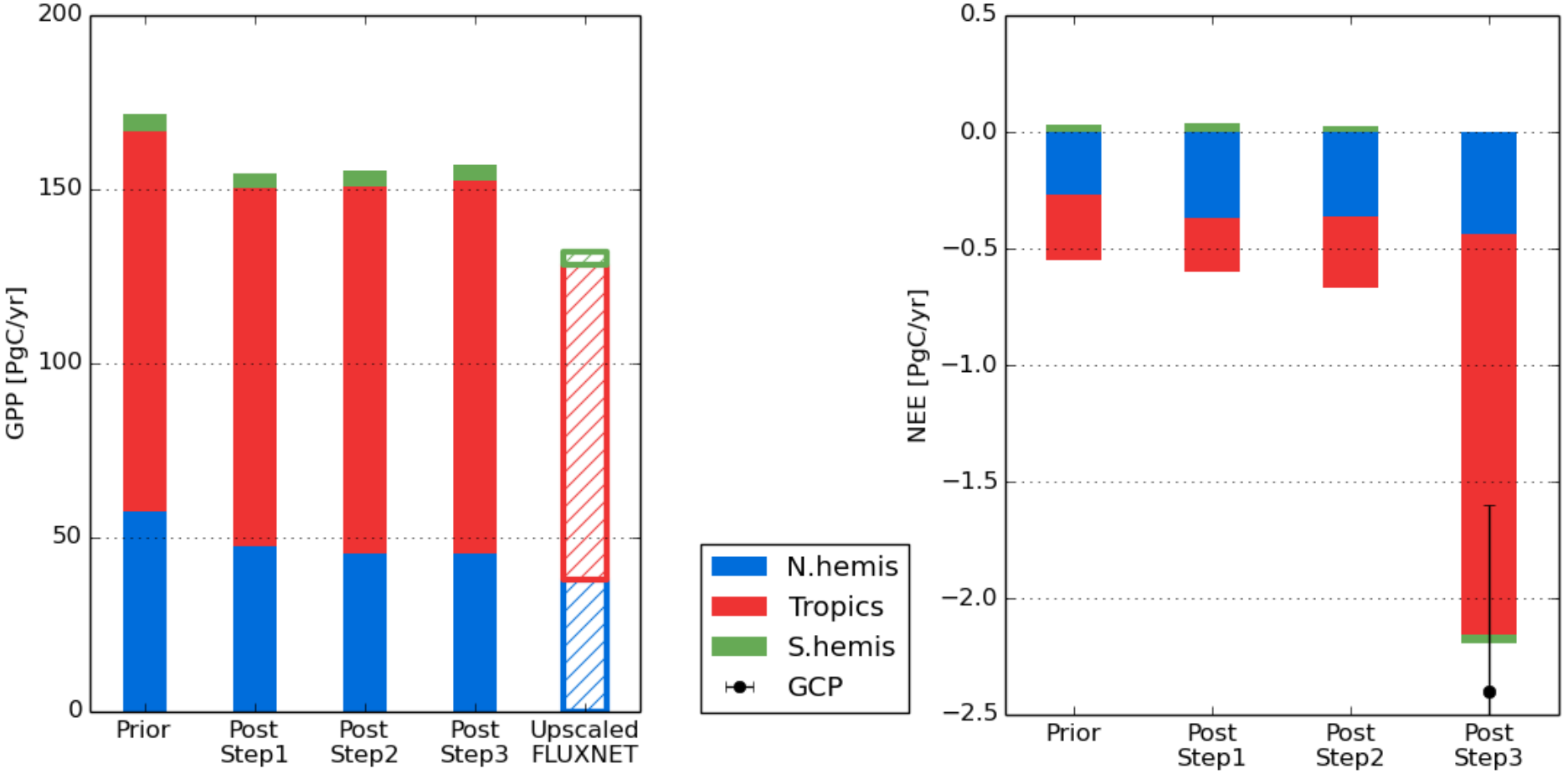


Impact on Gross / Net carbon fluxes

Gross Primary Productivity
→ (C uptake)

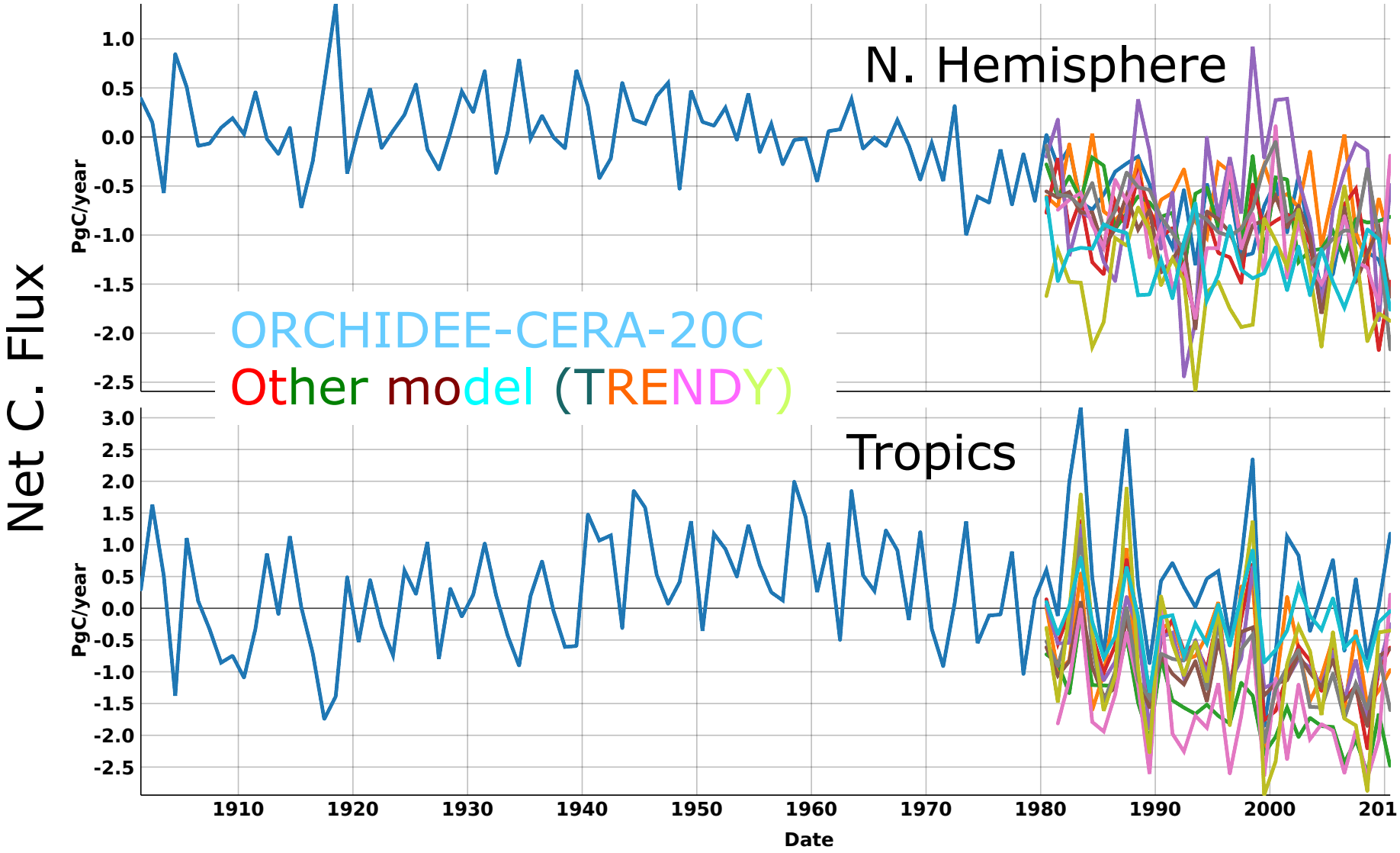
mean annual total
(1990-2010)

Net Ecosystem Exchange
→ (net CO_2 flux)



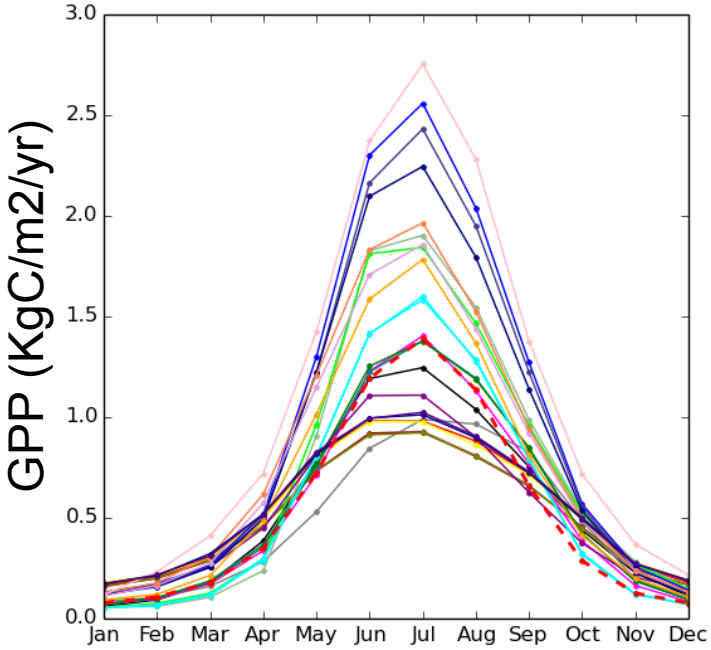
Peylin, P., et al., 2016.

Net Carbon flux still highly variables..



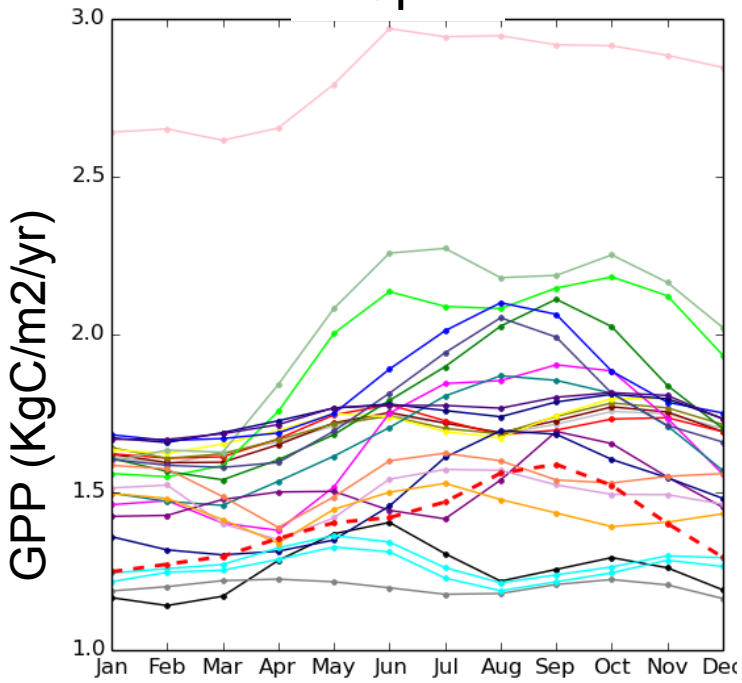
Large differences between model GPP

Northern land > 30°N



Large amplitude differences at high latitudes

Tropics



Large phase differences in the Tropics

CMIP5 simulations

- BNU-ESM
- CanESM2
- CCSM4
- CESM1-BGC
- CESM1-CAM5
- CESM1-FASTCHEM
- CESM1-WACCM
- CNRM-ESM1
- GFDL-ESM2G
- GFDL-ESM2M
- HadGEM2-CC
- HadGEM2-ES
- inmcm4
- IPSL-CM5A-LR
- IPSL-CM5A-MR
- IPSL-CM5B-LR
- MIROC-ESM-CHEM
- MIROC-ESM
- MPI-ESM-LR
- MPI-ESM-MR
- MPI-ESM-P
- MRI-ESM1
- NorESM1-ME
- NorESM1-M
- Flux-MTE