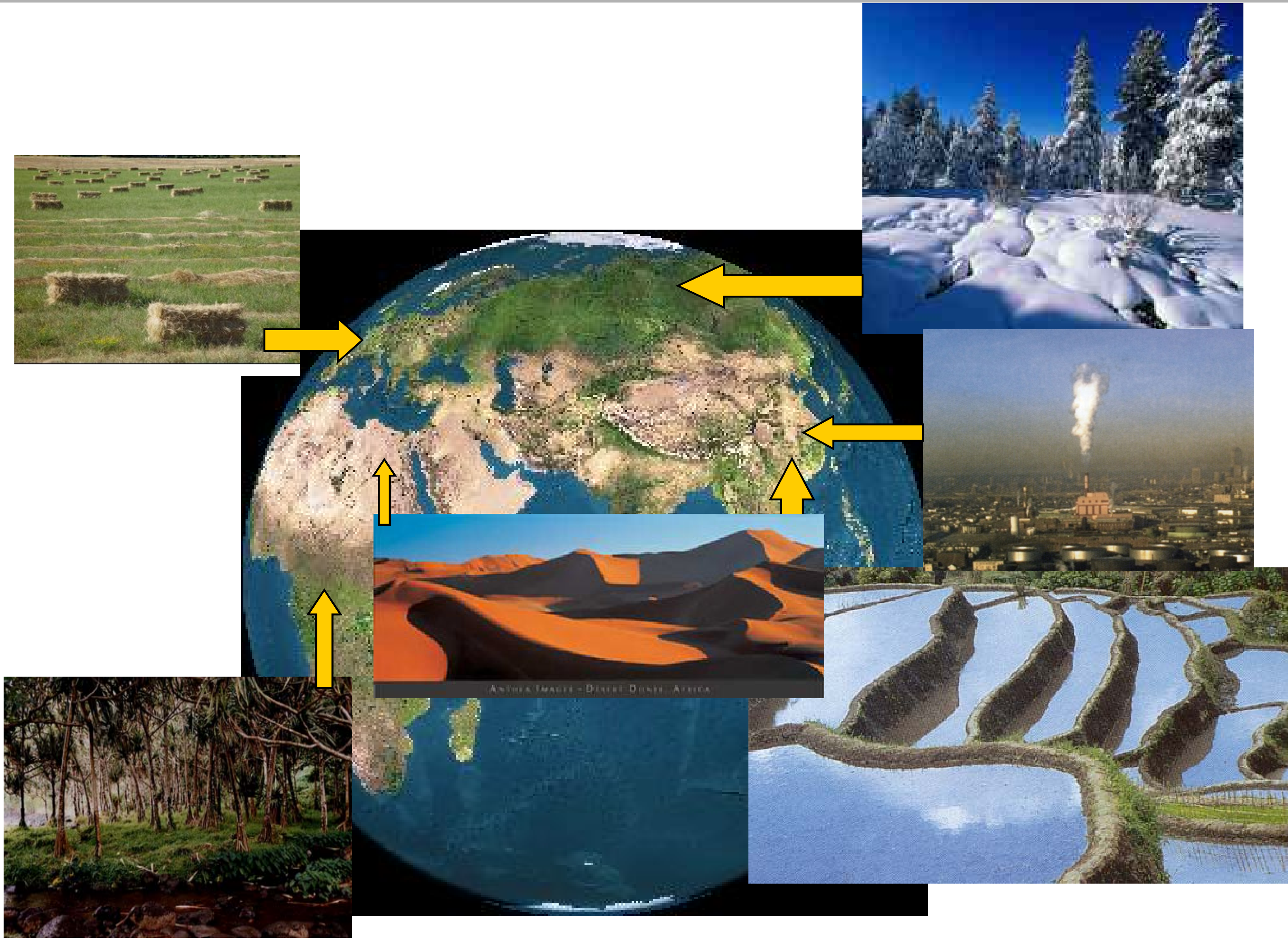
Land carbon and vegetation models at LSCE

Philippe Peylin, Philippe Ciais, N. Viovy, N. DeNoblet, V. Bellasem,

N. Vuichard, P. Cadule, P. Friedlingstein, F. Maignan,

H. Verbeeck, C. Bacour, C. Ottle,….

Continental surface modeling



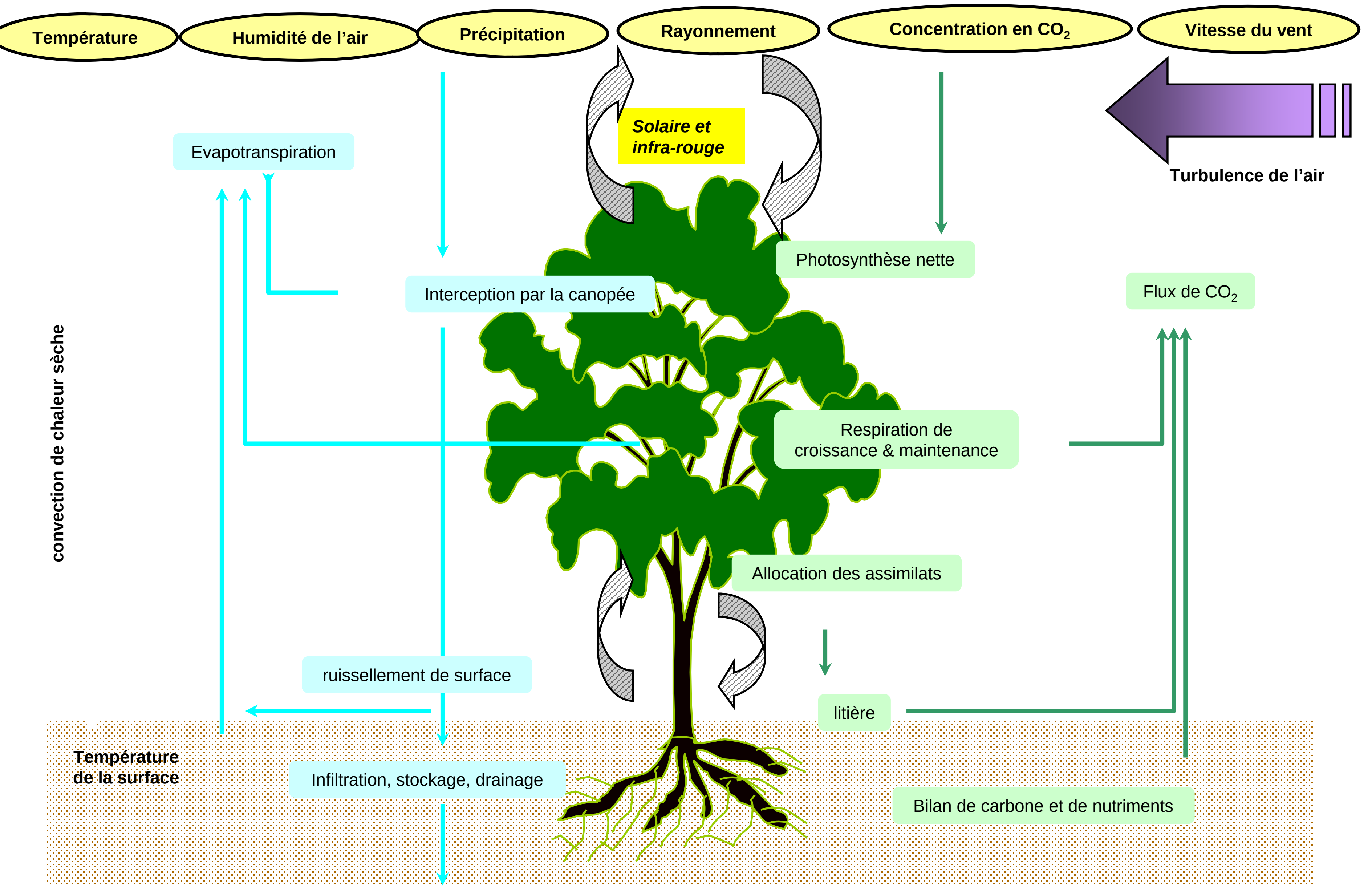
Outline

- Land surface model at LSCE: ORCHIDEE
- Model evaluation at the site level
  & Recent model improvements
- Running projects and Studies
- Data Assimilation with ORCHIDEE

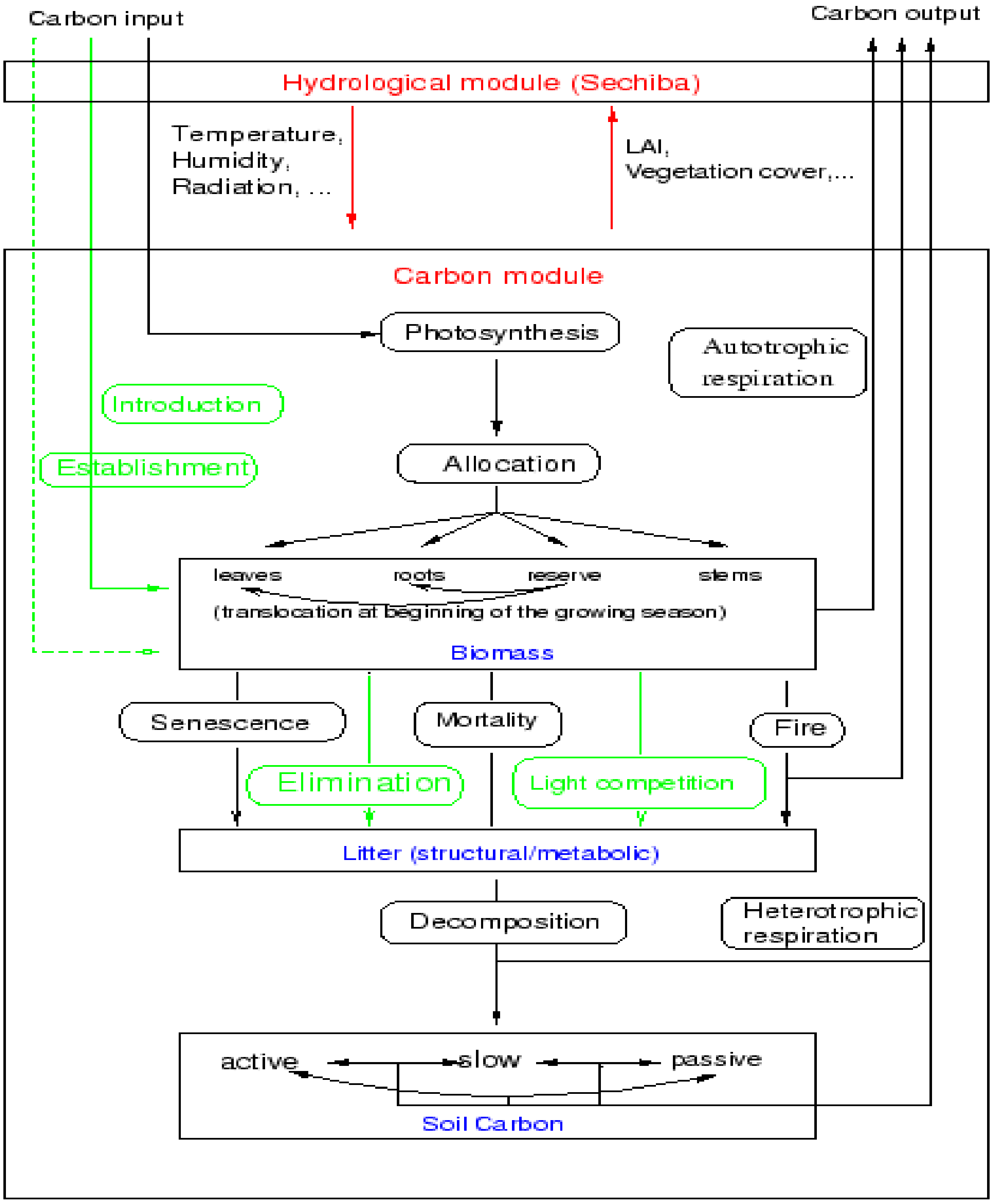
ORCHIDEE

- ORganizing Carbon and Hydrology In Dynamic EcosystEms
- Process-driven global ecosystem model
- Energy, Water, Carbone, N, balances
- Plant Functional Types PFT’s approach
- Computes its own phenology

Major processes simulated by ORCHIDEE



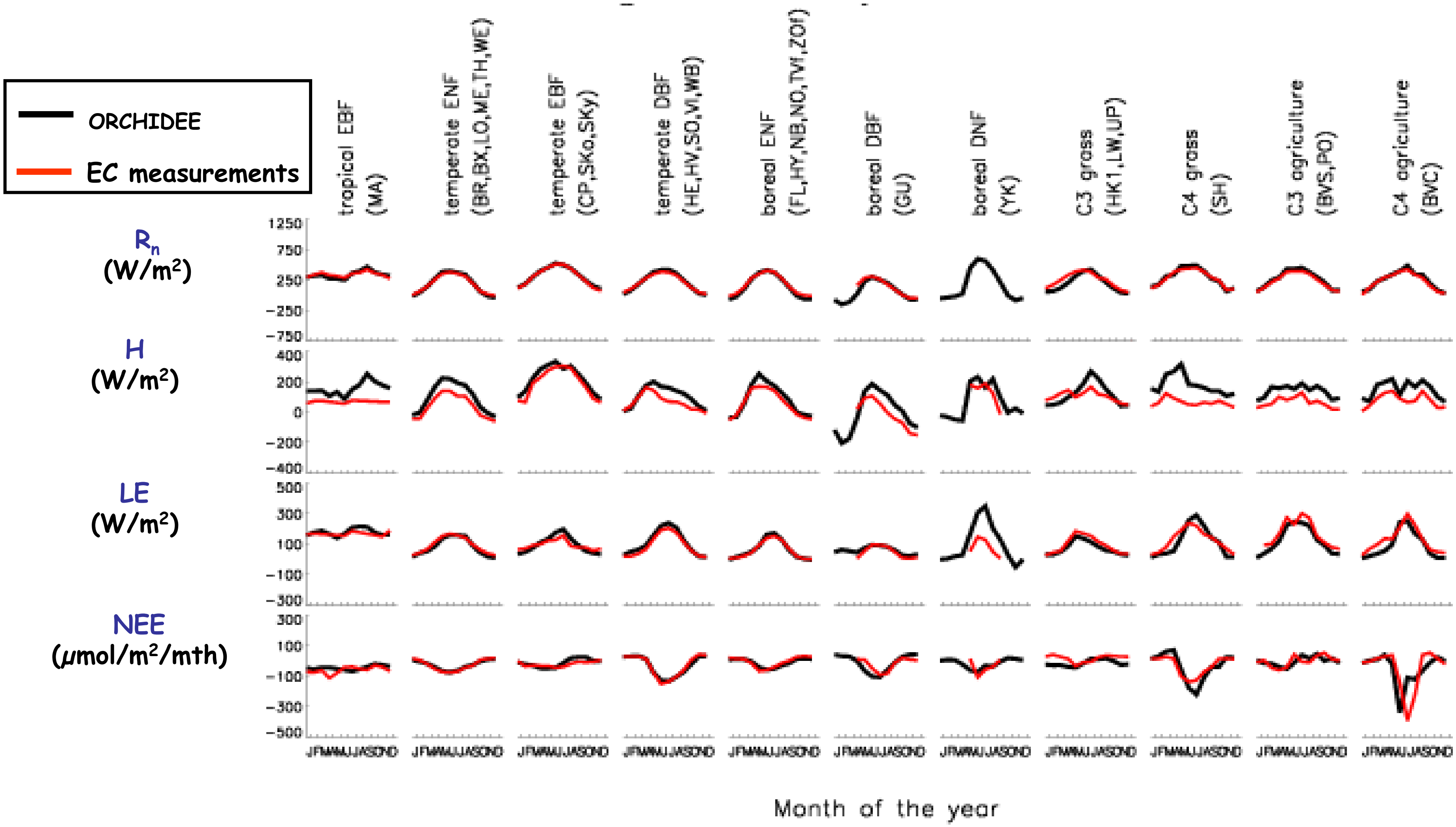
Below ground Carbon cycle



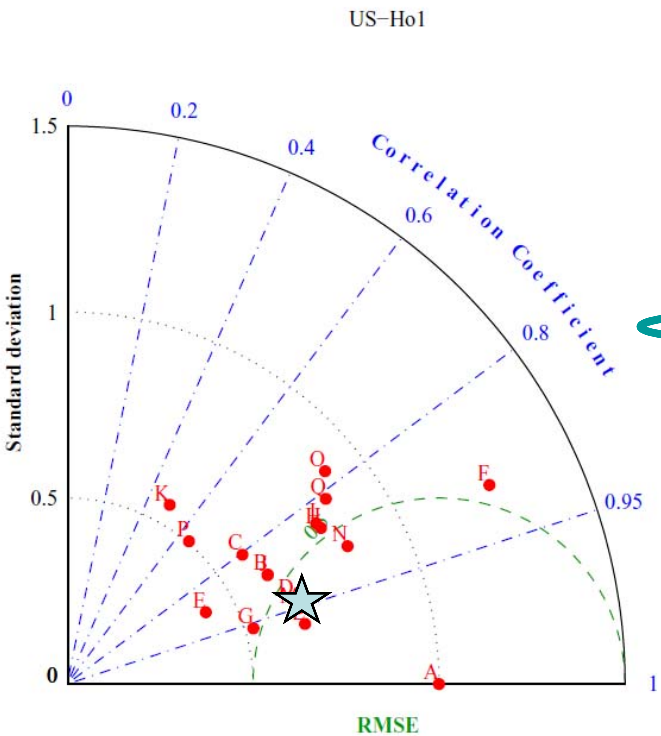
ORCHIDEE performances (site level) & Recent improvements

Extensive evaluation over more than 30 sites

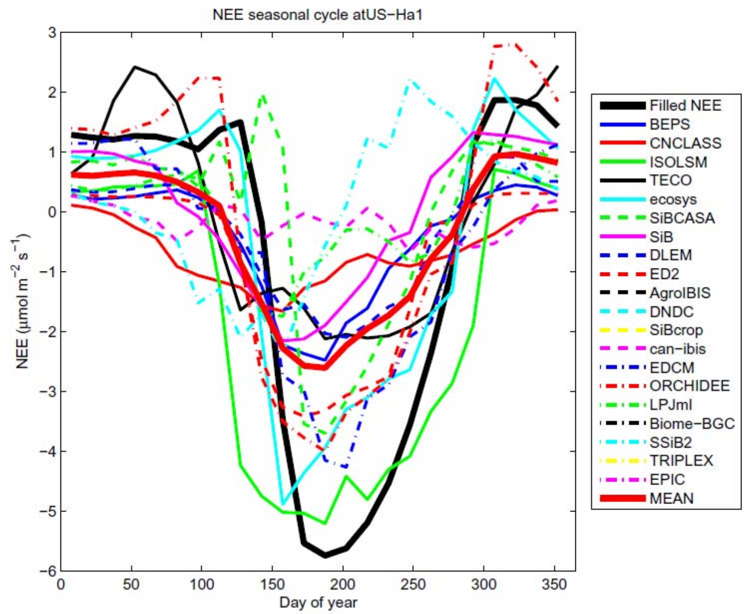
Average seasonal cycle

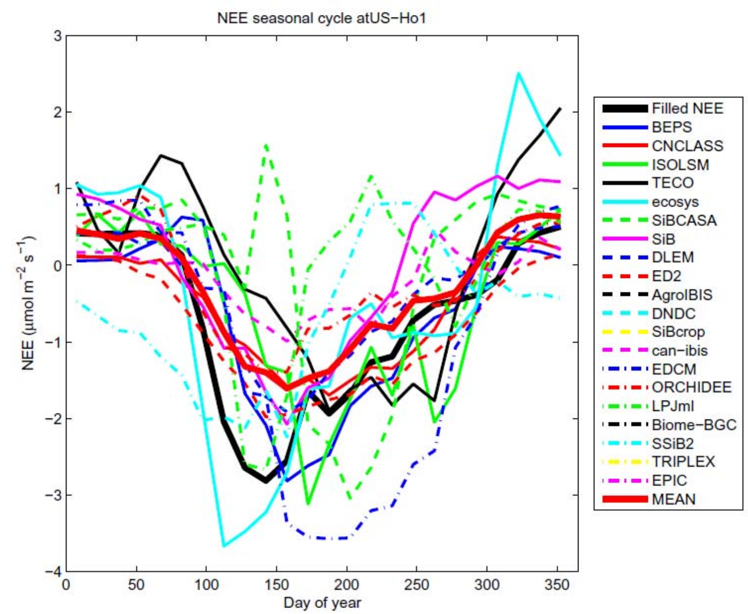


NACP model intercomparison : NEE



A OBS
B BEPS
C can-ibis
D CNCLASS
E DLEM
F ecosys
G ED2
H EDCM
I ISOLSM
J LoTEC-DA
K LPJ
L MEAN
M ORCHIDEE
N SiB
O SiBCASA
P SSiB2
Q TECO

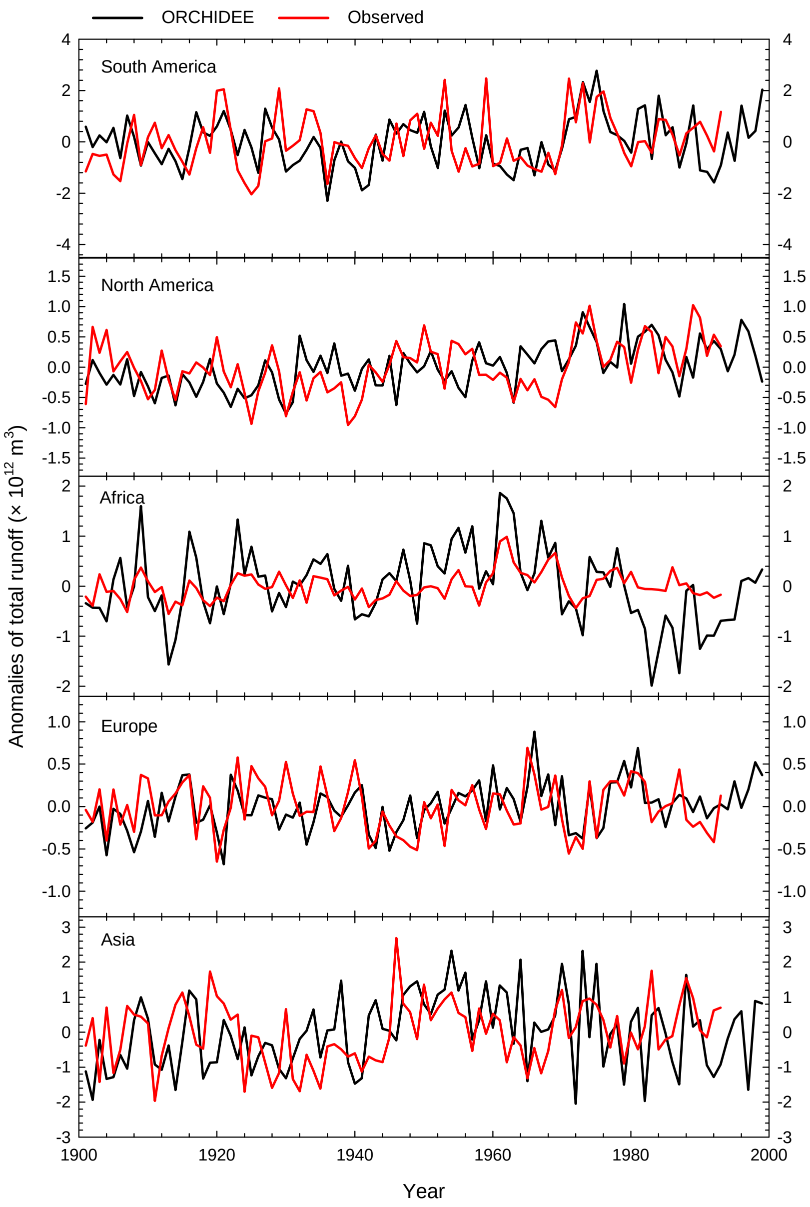




Water cycle validation

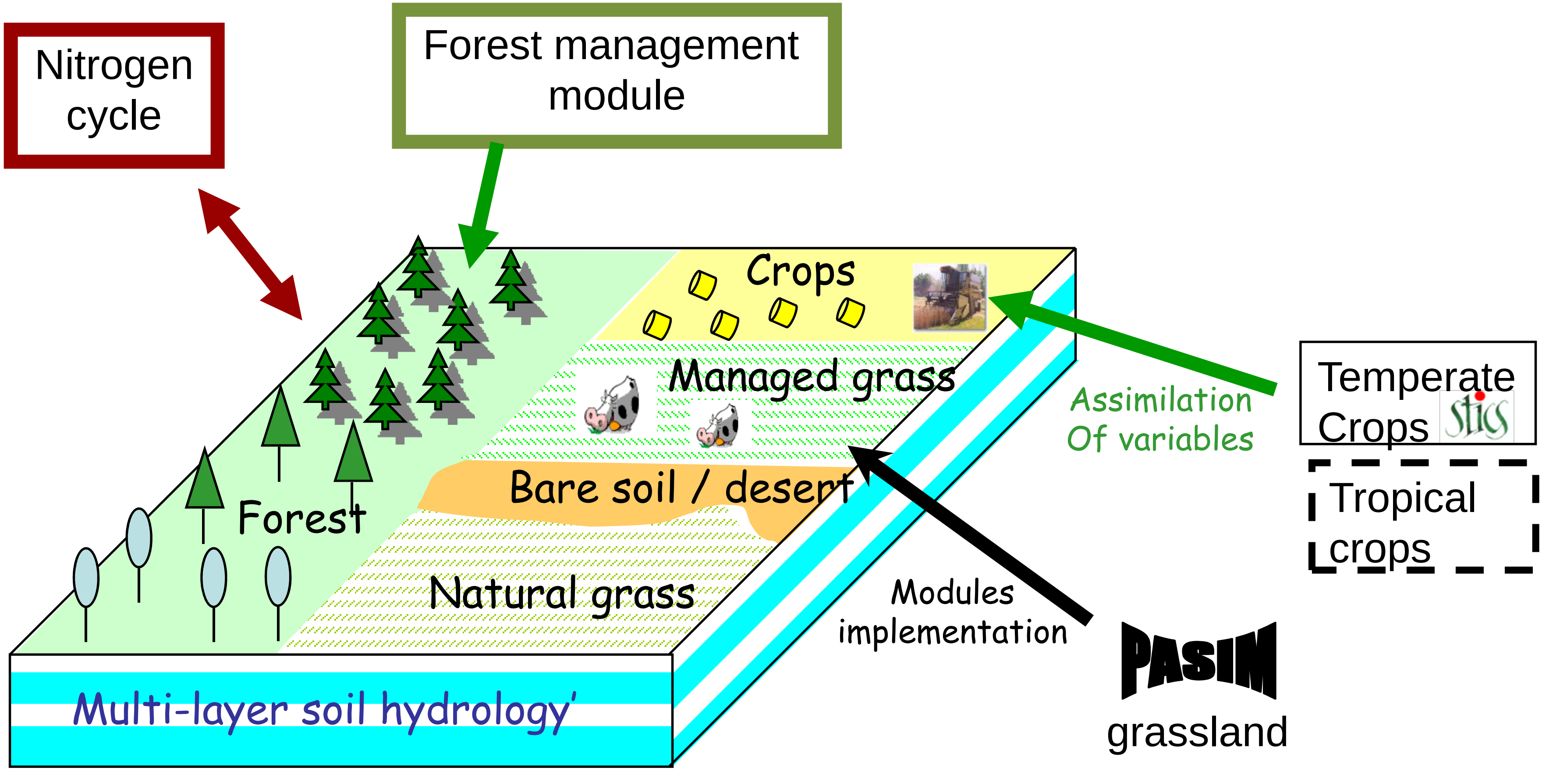
- Change in runoff comparison with data

(Labat et al., 2004)



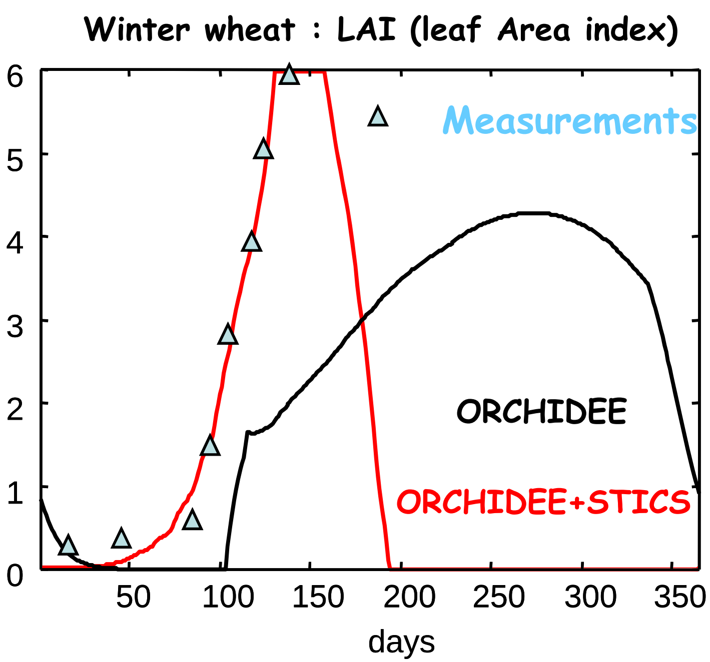
Piao et al., submitted

Recent improvements of ORCHIDEE



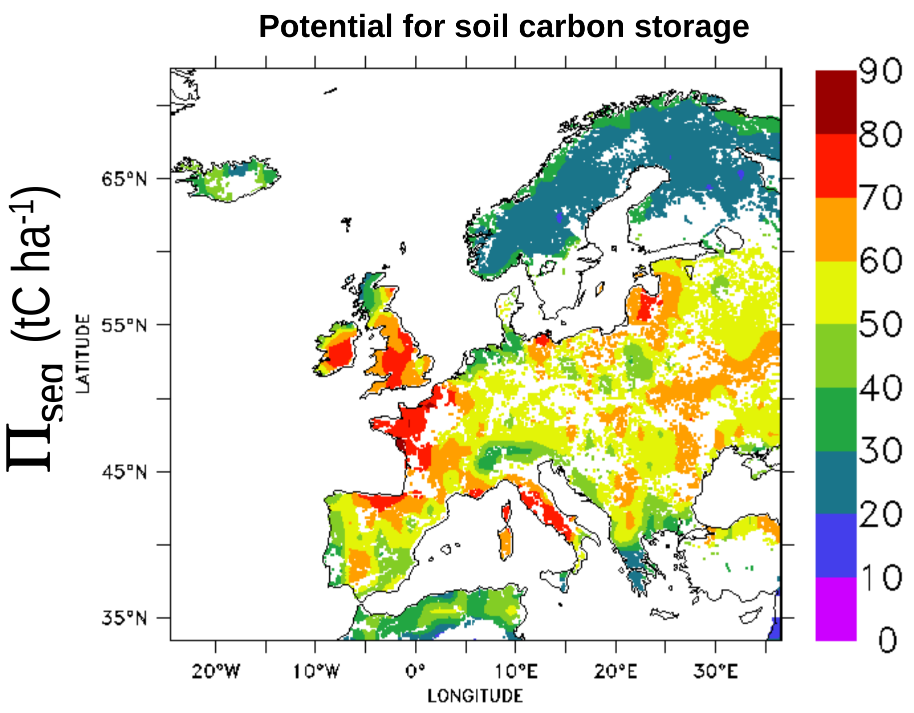
STICS

➔ **Improve "phenology" for cropland**



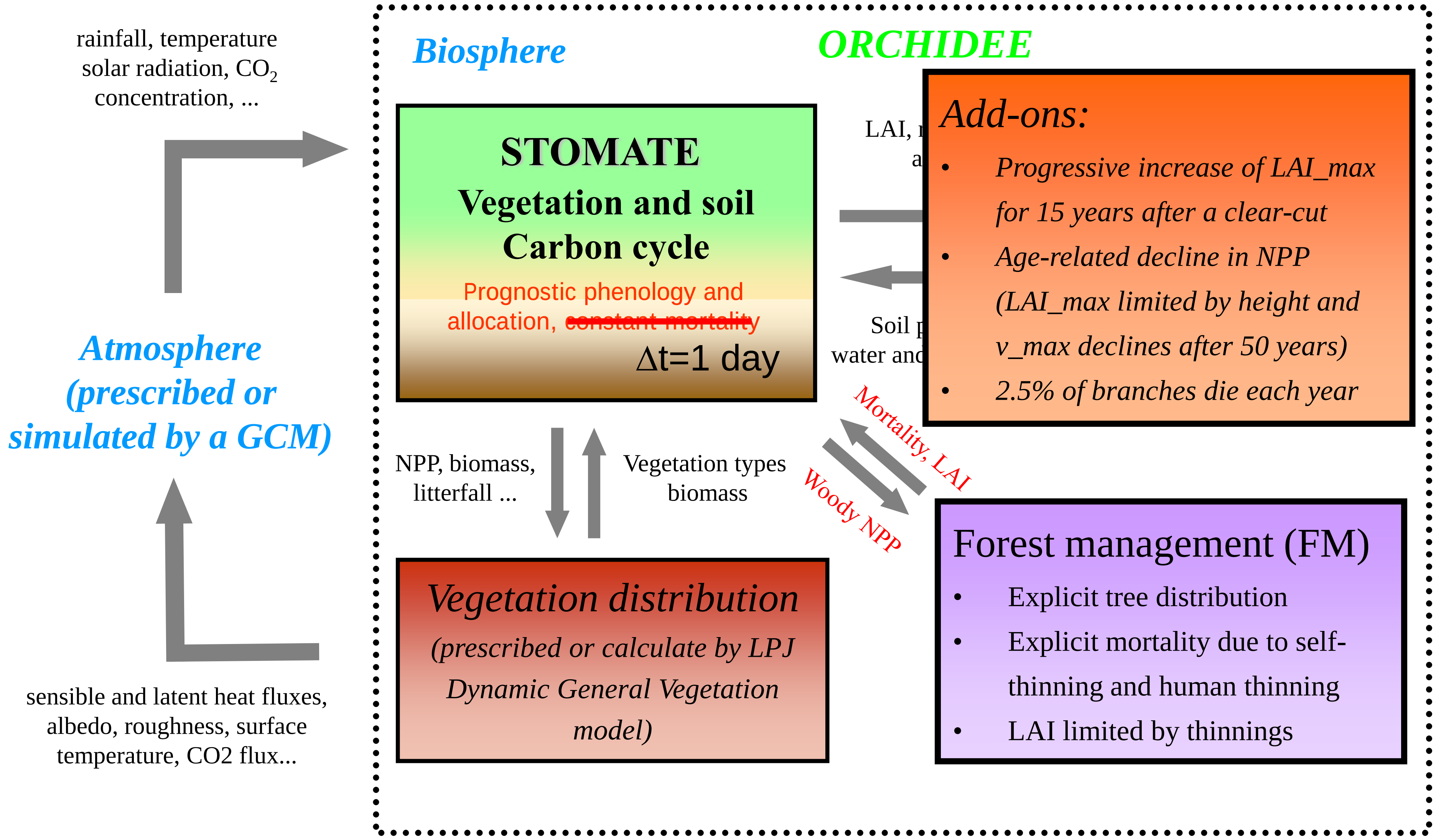
PASIM

➔ **Improve soil carbon estimates for managed pasture**



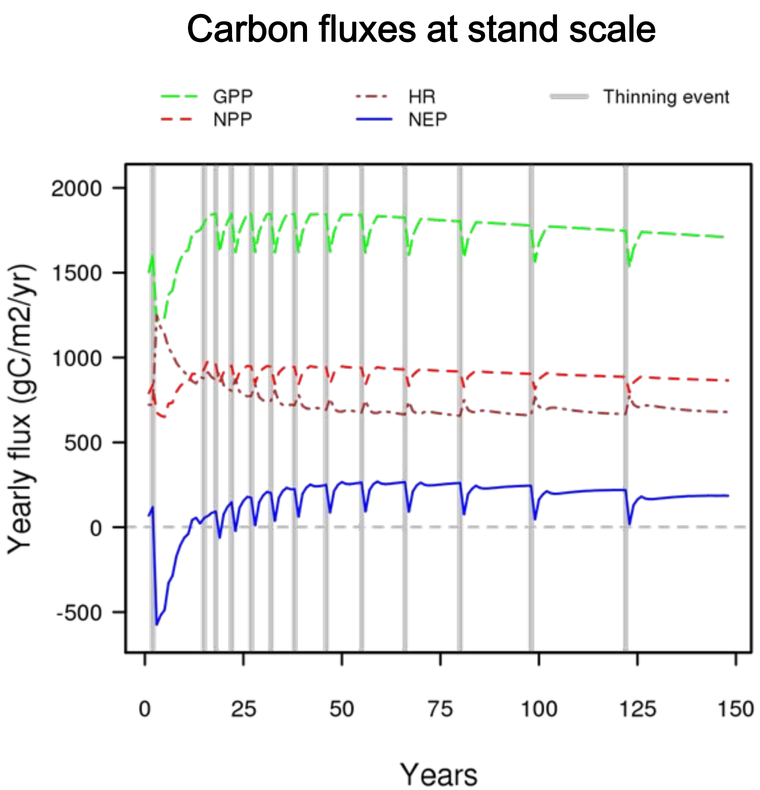
A Forest Management Module for ORCHIDEE

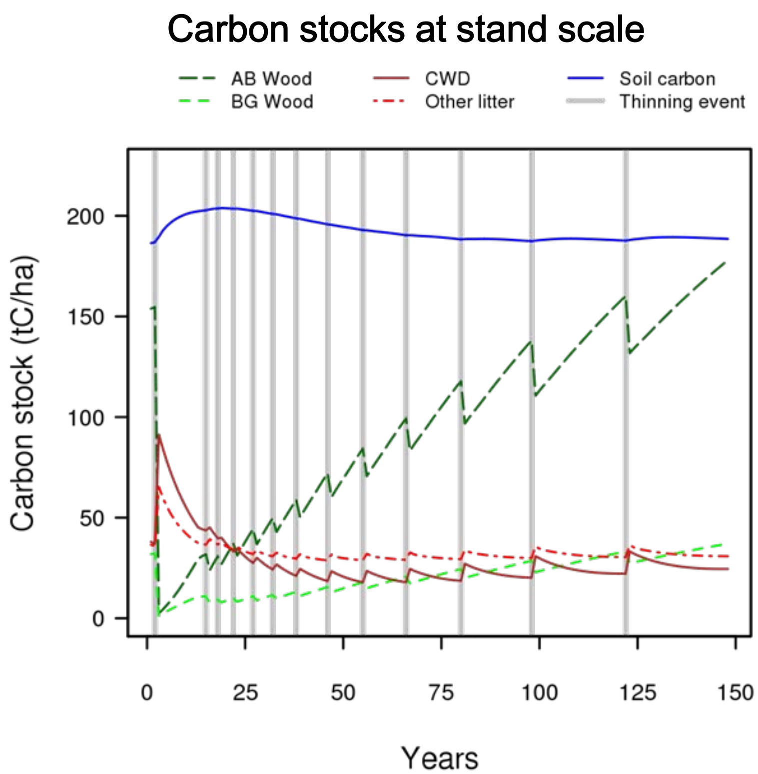
ORCHIDEE, coupled with FM module



RESULTS with Forest Module

Impact of management on stocks & fluxes

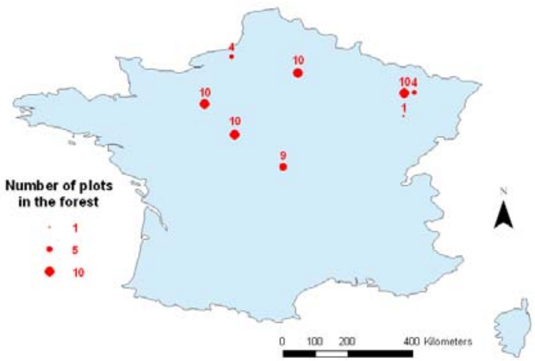




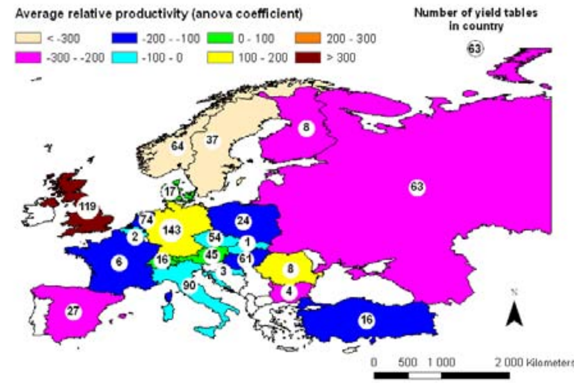
- Effect of management on fluxes and stocks
  - Periodic decrease of above-ground stocks
  - Drop in GPP
  - Slow changes in soil carbon during the rotation

RESULTS with Forest Module

Validation: 2 different datasets



Permanent monitoring plots: LERFOB

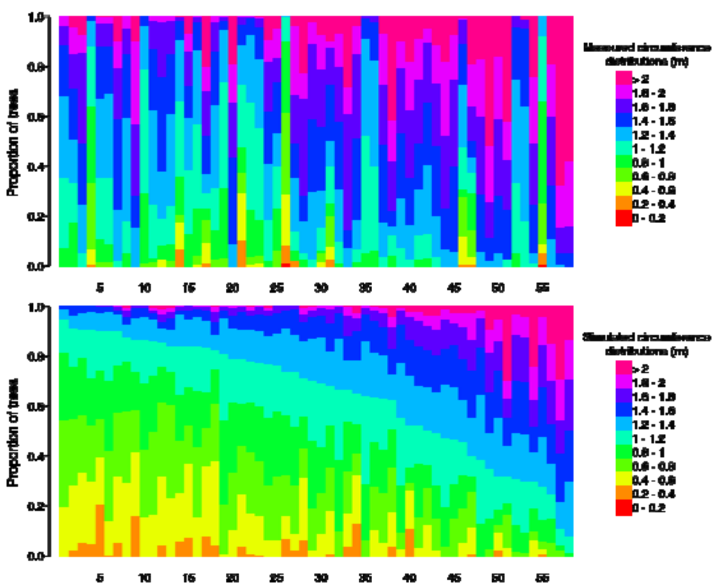


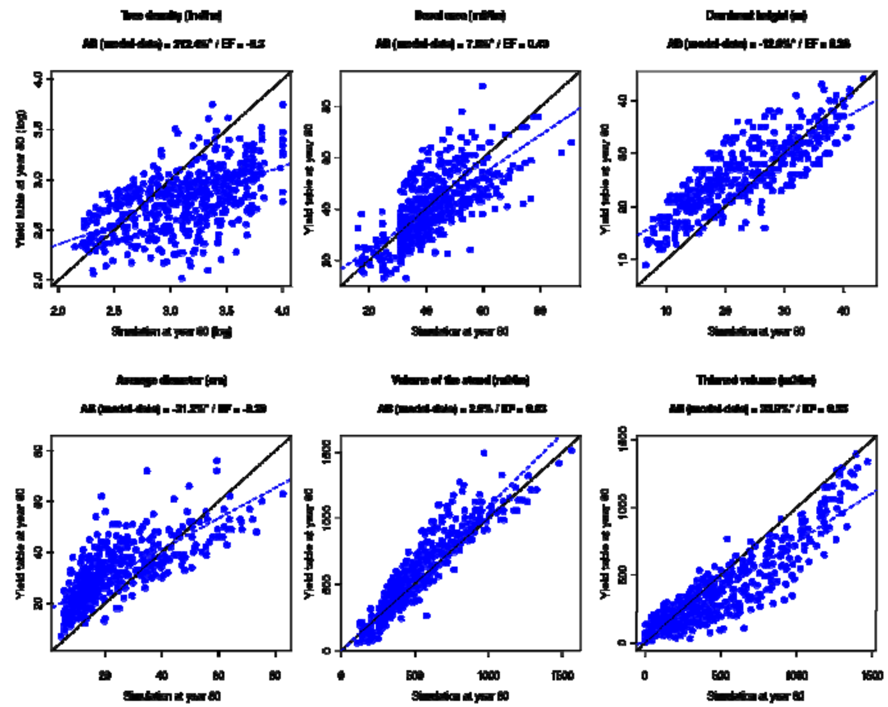
Yield tables: Teobaldelli et al., 2009

Circumference distribution

Data

Model





Running projects & studies Parameterizations

- Forest growth (V. Bellassem)
- Wetland dynamics & CH4 emissions (S. Piao + PhD B. Ringeval)
- Frozen C decomposition (post-doc D. Khvorostyanov + new post-doc)
- Fire (Boreal: phD A. Rubtsov ; Global: collab. with Quest group in UK)
- Weathering of Carbonates (phD M. Roland + collab I. Janssens)
- Advanced soil C-N decomposition model (S. Zaehle + post-doc)

Running projects & studies
Regional developments

- Eastern China cold grasslands (phD K.Tan)
- Siberian crop abandonment (post-doc N. Vuichard + collab. With R. Valentini)
- Carboafrica (phD P. Brender ?)
- Arctic and boreal vegetation (phD Tao Wang ?)
- Amazon (post-doc H. Verbeeck)
- France (high resolution simulation ; future climate change impacts)
- Europe (carboeurope)
  - Model intercomparison with climate + CO_2
  - New model intercomparison with Climate + CO_2 + land use
  - Site level evaluation (ongoing)
  - Forest inventory NPP comparison

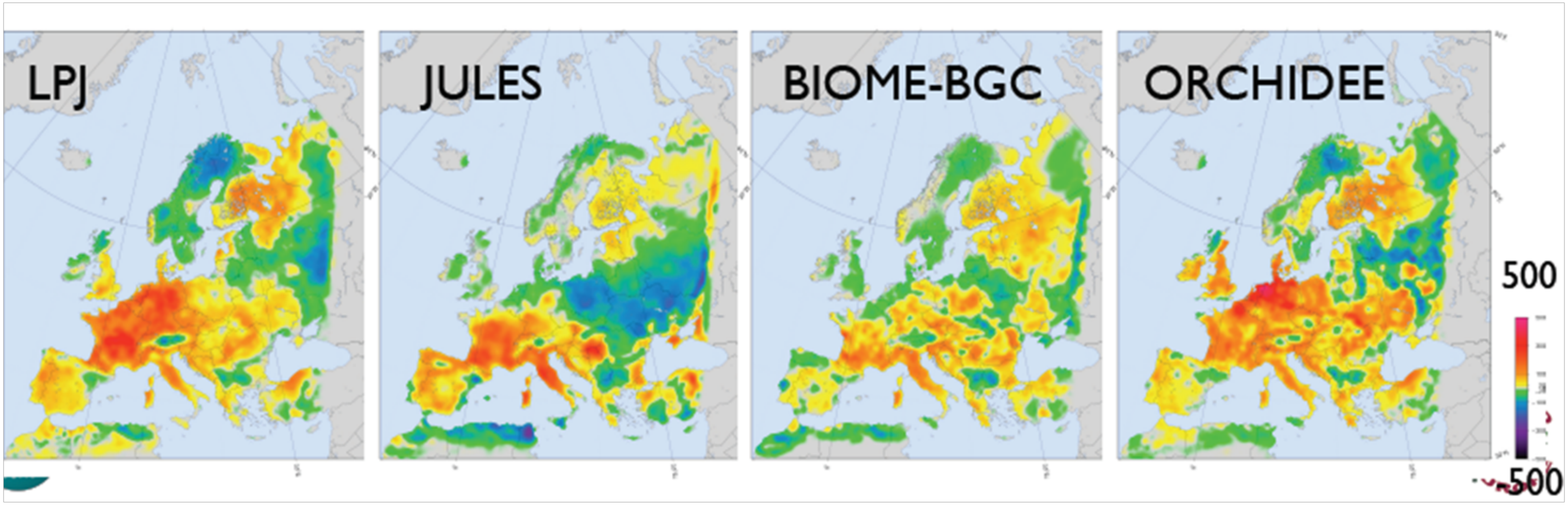
CarboEurope project

➔ **Mean Carbone Uptake by Europe : ~ 0.15 - 0.3 GtC/ yr**

➔ **Impact of extreme climate events (i.e. 2003 summer drought)**

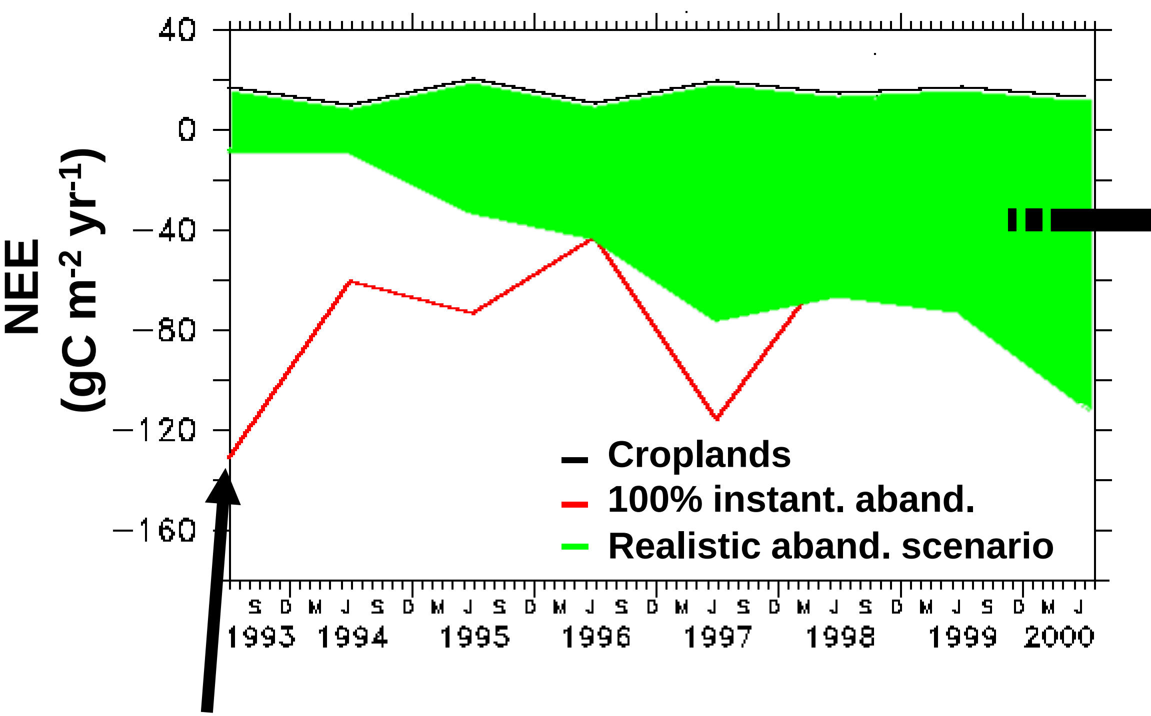
Flux anomaly : 2003 vs Mean

Comparison of several biosphere models
(CarboEurope project)

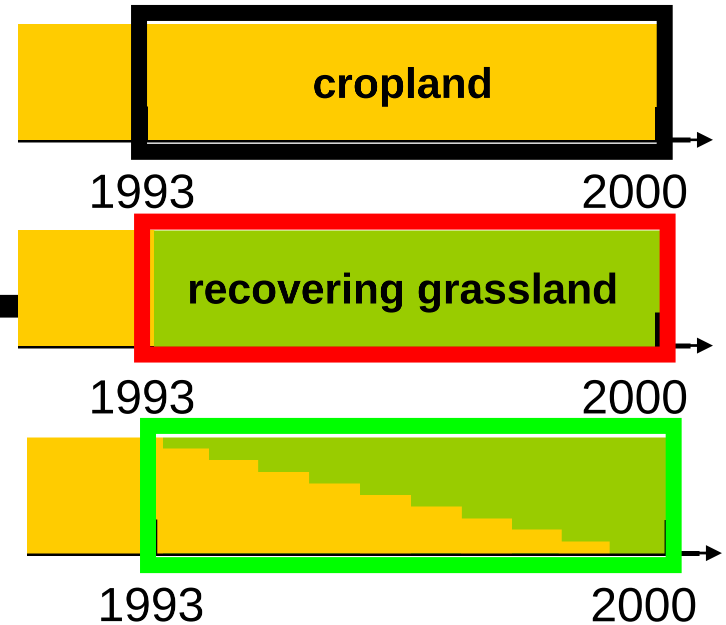


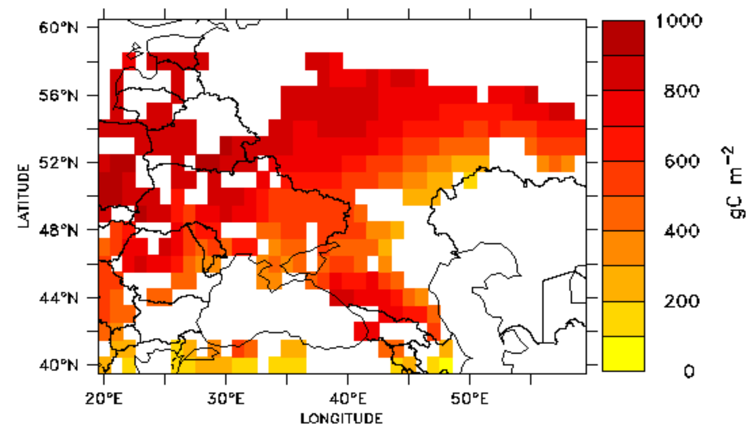
➔ **Anomalous C-release in 2003 : ~ 0.3 GtC / yr**

Carbon sequestration due to the abandonment of croplands in the former USSR since 1990



Abandonment of cultivation



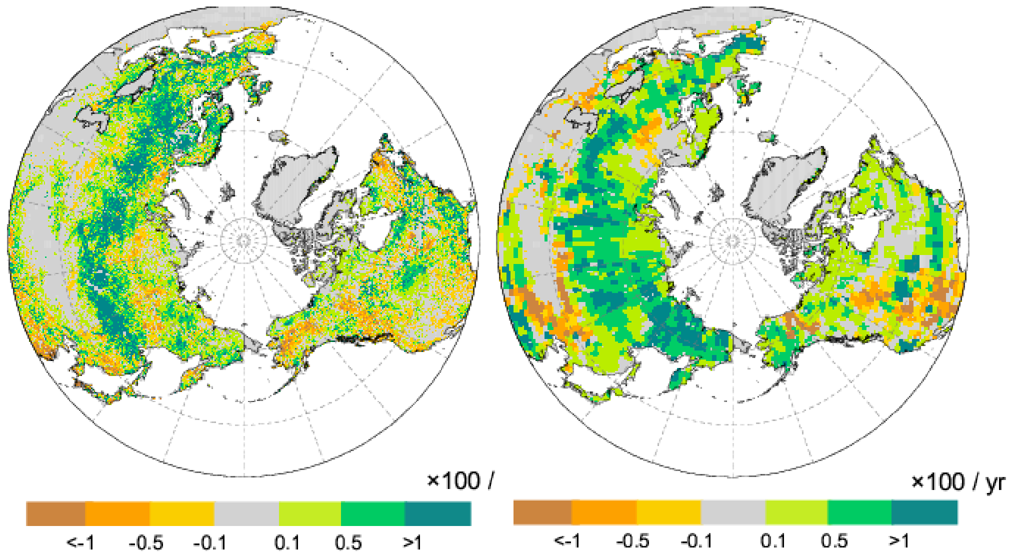


Change in Northern Hemisphere Spring LAI

- A) detection

LAI trend (1982-2002)

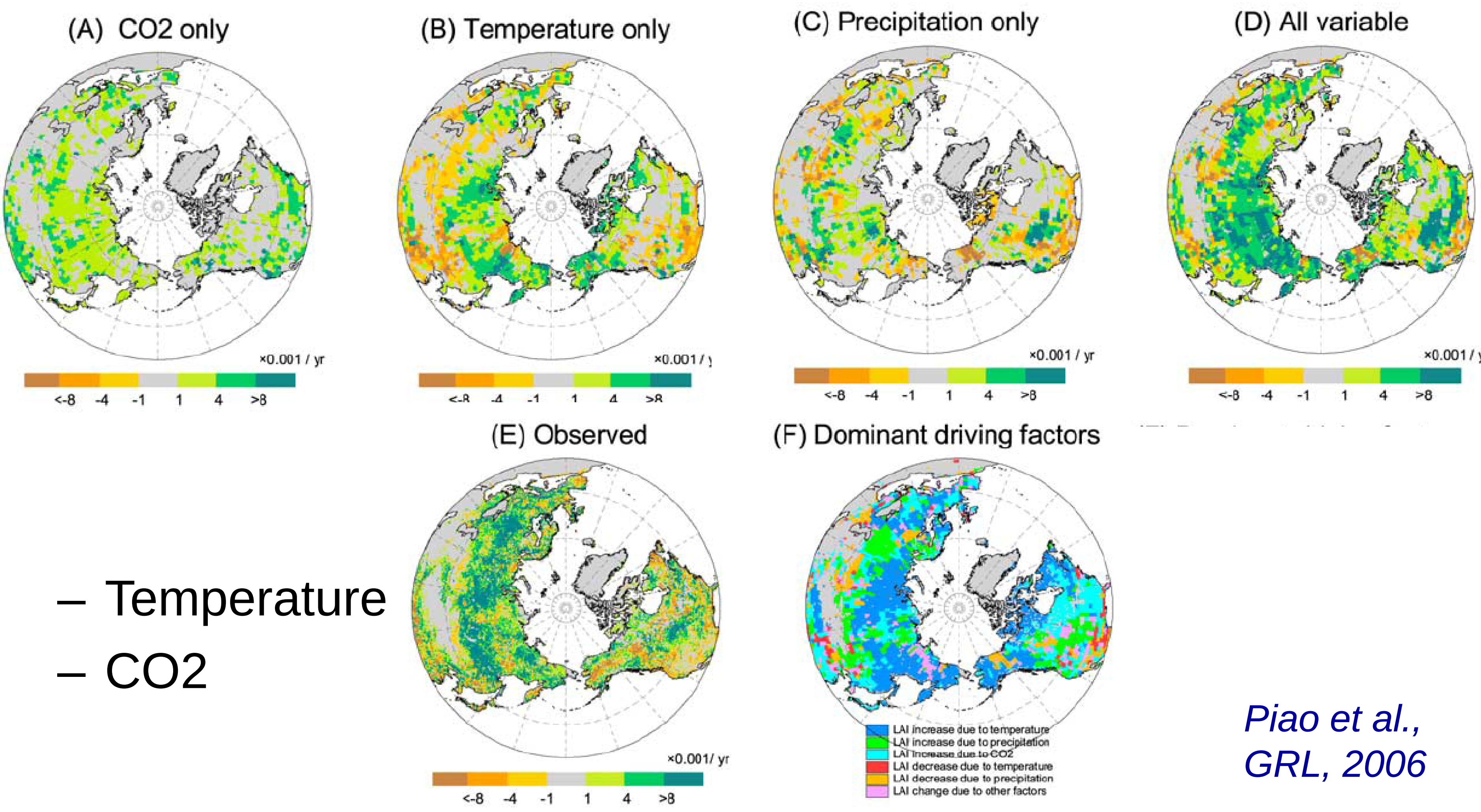
NOAA data   ORCHIDEE offline



Piao et al., GRL, 2006

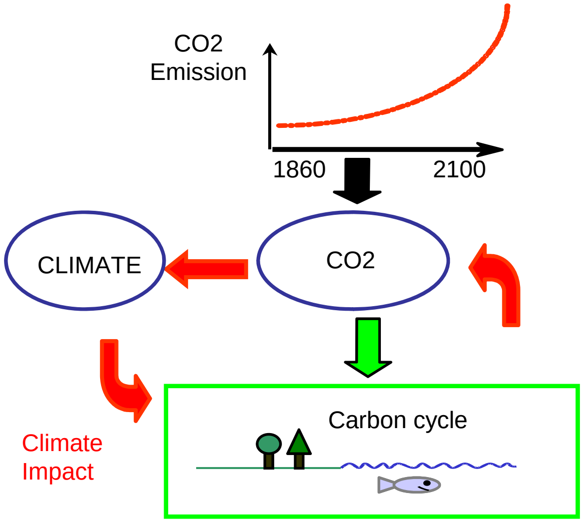
Change in Northern Hemisphere Spring LAI

- B) Attribution
  - Temperature
  - CO2



Piao et al., GRL, 2006

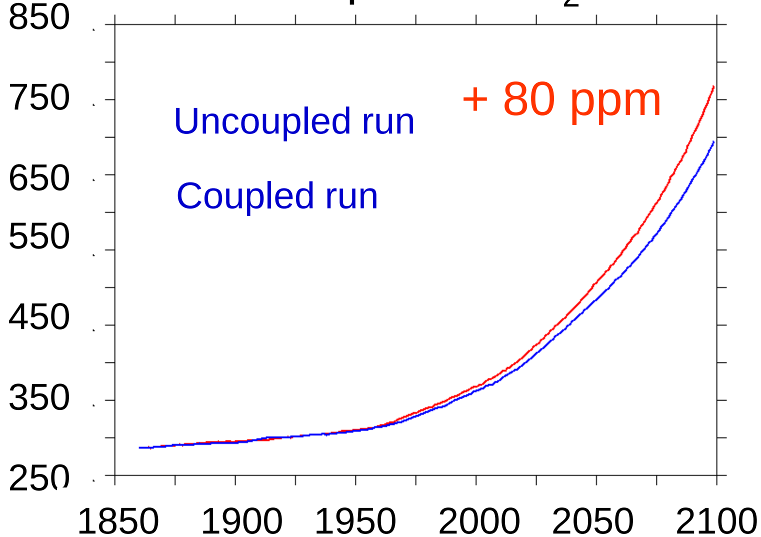
Climate-carbon cycle feedback



Coupled run

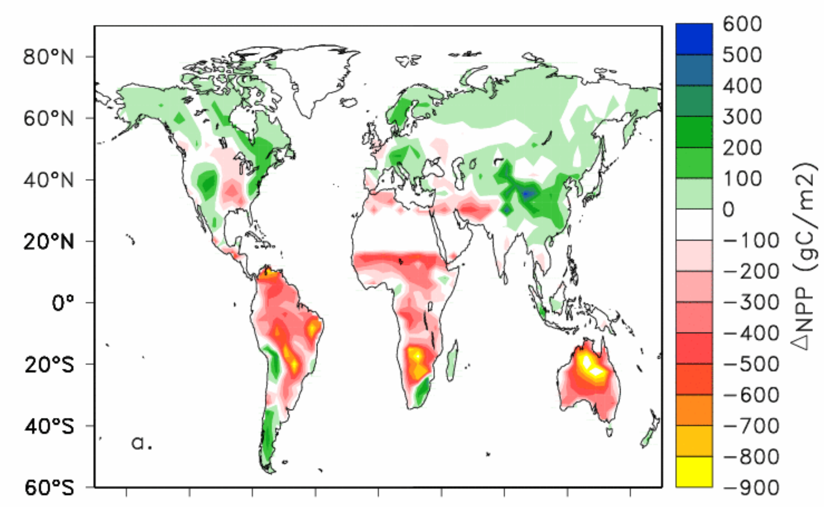
With impact of climate change on the carbon cycle

Atmospheric CO_2



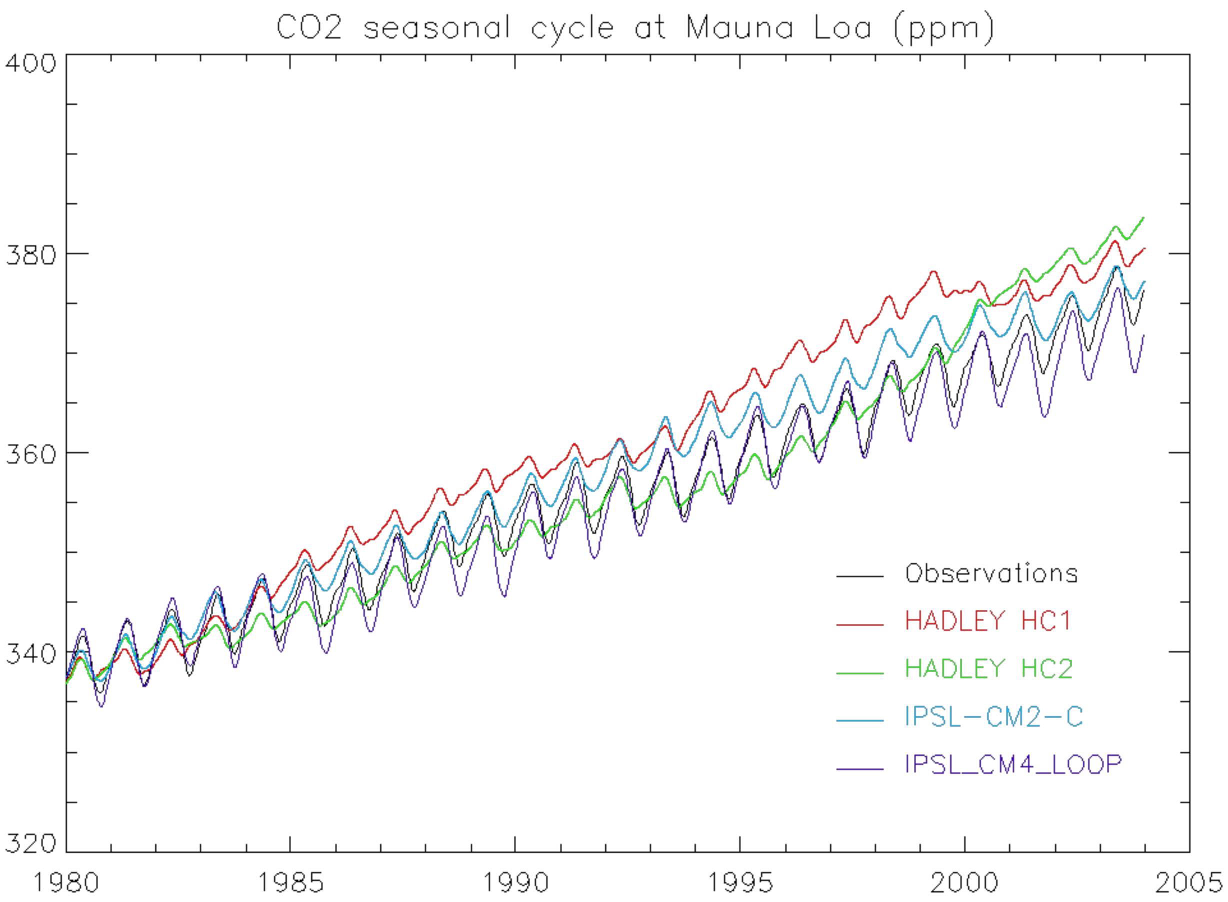
Friedlingstein et al., GRL, 2001
Dufresne et al., GRL, 2002

Climate impact on land productivity



Berthelot et al., GBC, 2002

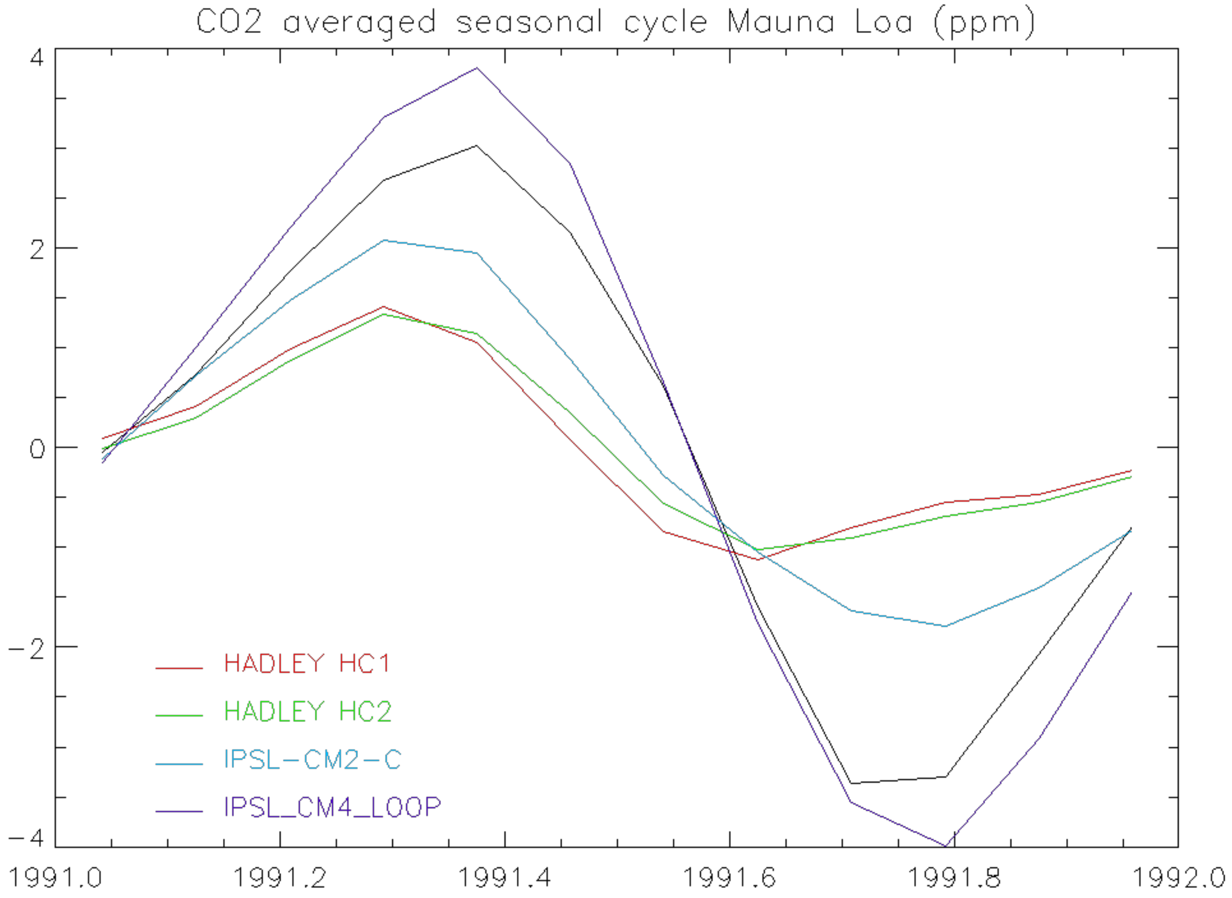
Model validation with atmospheric CO2



- Seasonal cycle
- Long term trend

Cadule et al., in prep

Mauna Loa mean seasonal cycle



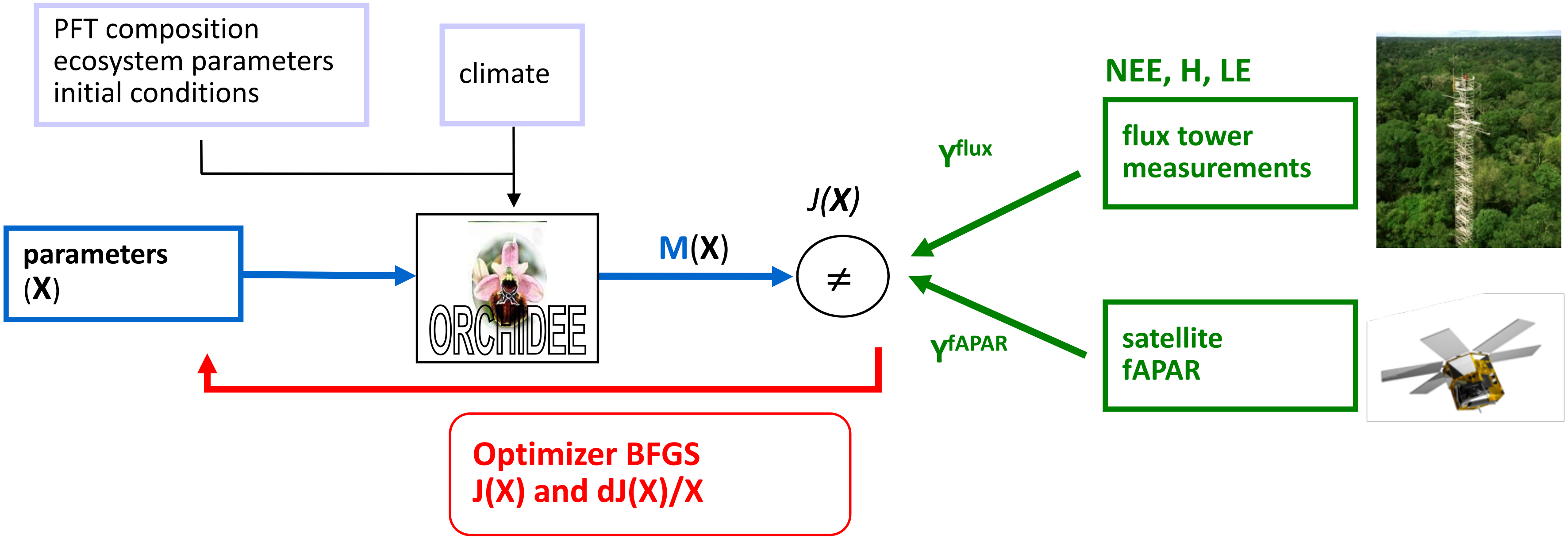
- Test on carbon cycle sensitivity to climate ?

Cadule et al., in prep

Data assimilation system at LSCE

- Optimize model trajectory using current current observations (i.e. satellite fAPAR,…)
- Optimize model parameters using current observations (i.e. Flux data, atmospheric CO_2,…)
- Optimize model initial conditions: C-pools

Variational data assimilation system



Bayesian optimization

$$J(X) = (Y^{flux}_{season} - M(x))^T R_{season}^{-1} (Y^{flux}_{season} - M(x)) + (Y^{fAPAR} - M(x))^T R_{fAPAR}^{-1} (Y^{fAPAR} - M(x)) + (x - x_p)^T B^{-1} (x - x_p)$$

- ✓iterative minimization of *J(X)*
- ✓bound constrained optimization
- ✓***dJ(x)/dx*** computed using the **Tangent Linear** version of ORCHIDEE

Governing processes and parameters to optimize

Net SW downwelling Radiation

$$Rn = (1 - kalbedo)\, R^{i}_{lw} + R^{i}_{sw} - \varepsilon\sigma T^{4}_{surface}$$

Assimilation

$$A = Vc.(1 - \Gamma^{*}/C_i) - Rd \qquad V_c = \frac{fstress.Vc\,max\,.Ci}{Ci + Kc\,.(1 + \frac{O_i}{K_o})}$$

Evapo transpiration

$$A = 1/r_a + r_s\,(C_a - C_i)$$

$$ET = \sum_i \frac{K_E}{r_a + r_s}(q_i - q_{air})$$

$$1/r_s = gslope\ A.RH/C_a + g_0$$

Sensible heat

$$H = \frac{kcapa\, C_{sol}}{r_a}(T_{surf} - T_{air})$$

$$r_a = \frac{1}{kra.C_d(krugo)}$$

Maintenance resp.

$$Rm = krespm \sum_i \lambda_i B_i\, f(T_{surface})$$

Growth resp.

$$Rg = krespg\,(A - Rm)$$

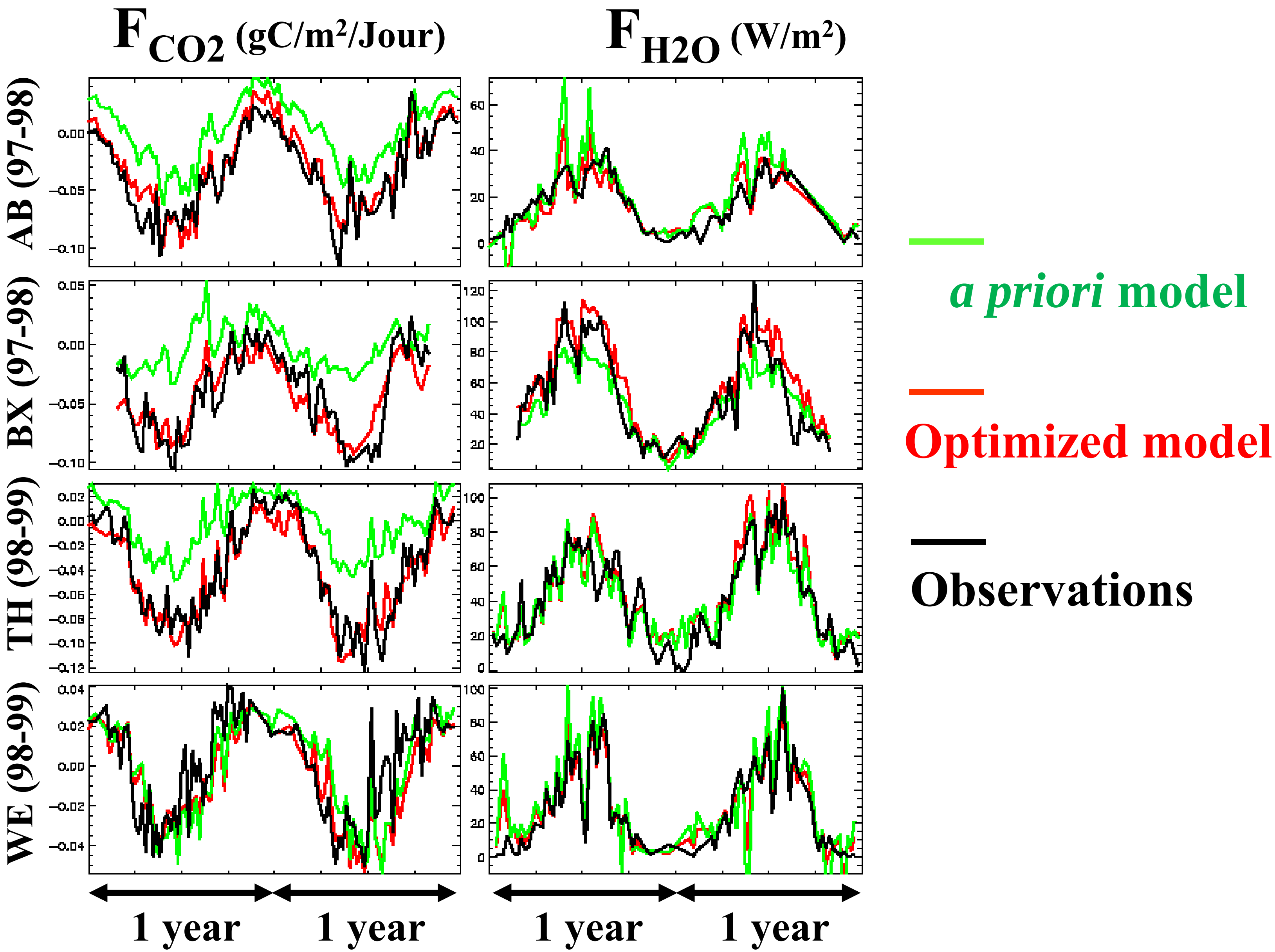
Heterotrophic resp.

$$Rh = kresph \sum_s m_s B_s\, g(swc)(kQ10)^{\frac{T_{soil}}{10}}$$

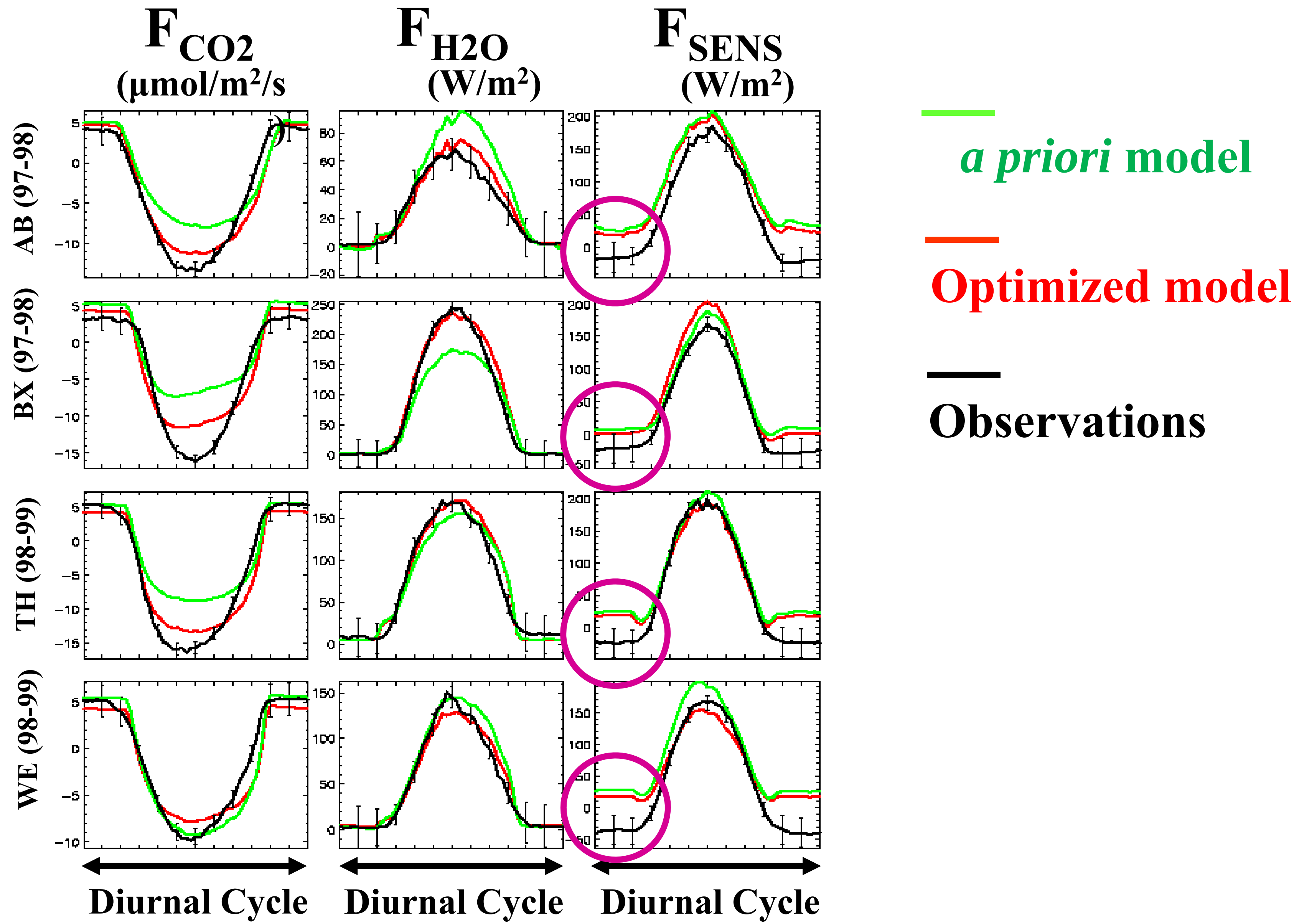
NEE

$$NEE = Rm + Rg + Rh - A$$

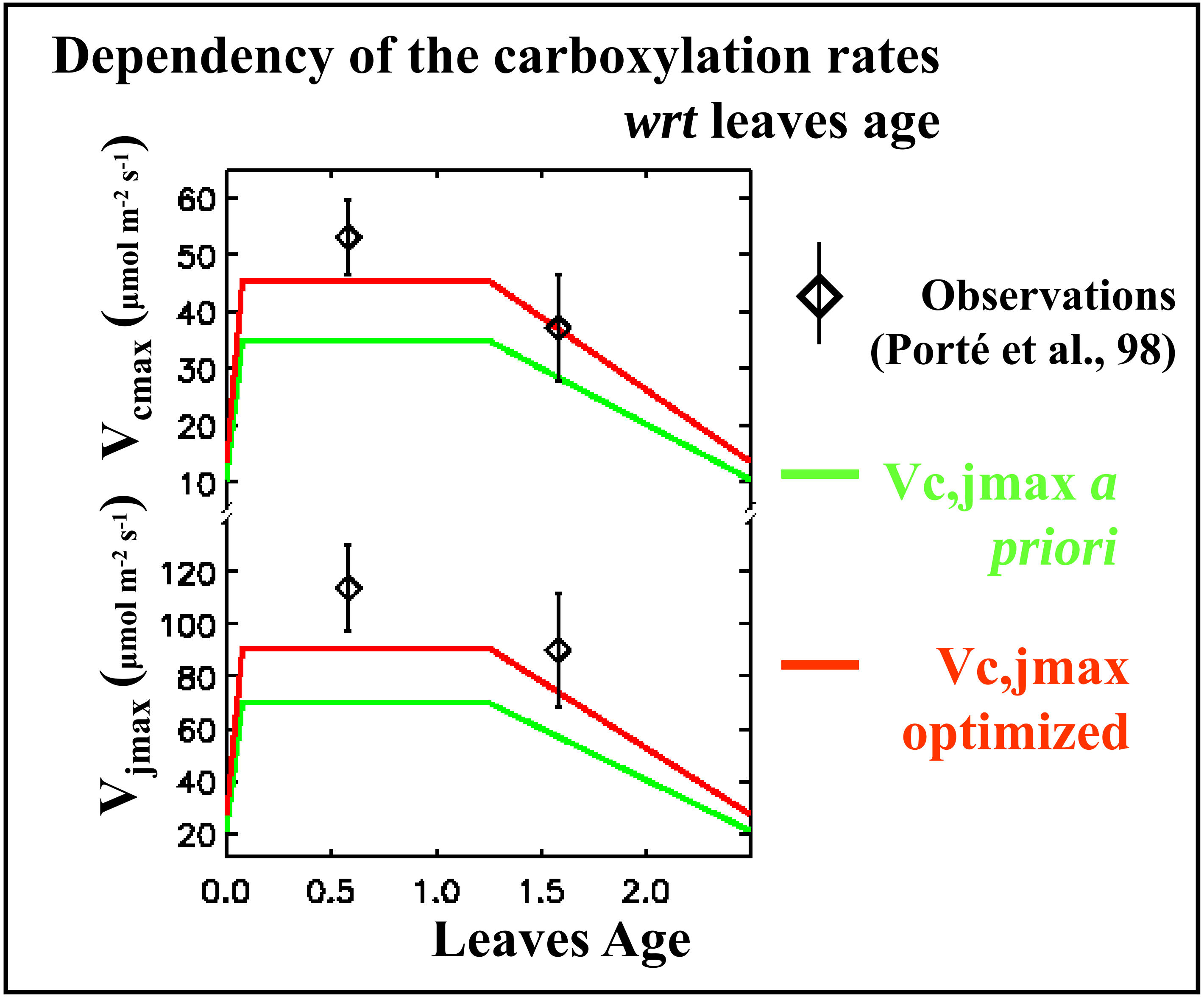
Seasonal cycle fit: temperate conifers



Diurnal cycle fit: temperate conifers

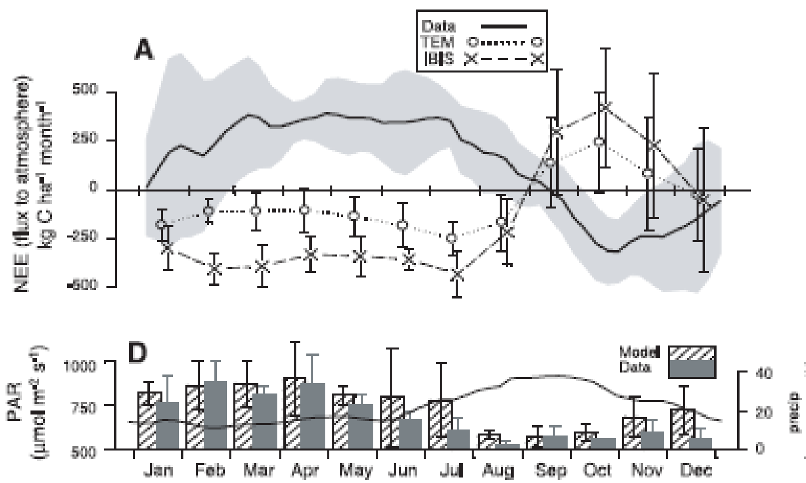


Comparison with independant data: K_{vmax}



Counterintuitive seasonal NEE patterns in (parts of) the Amazon

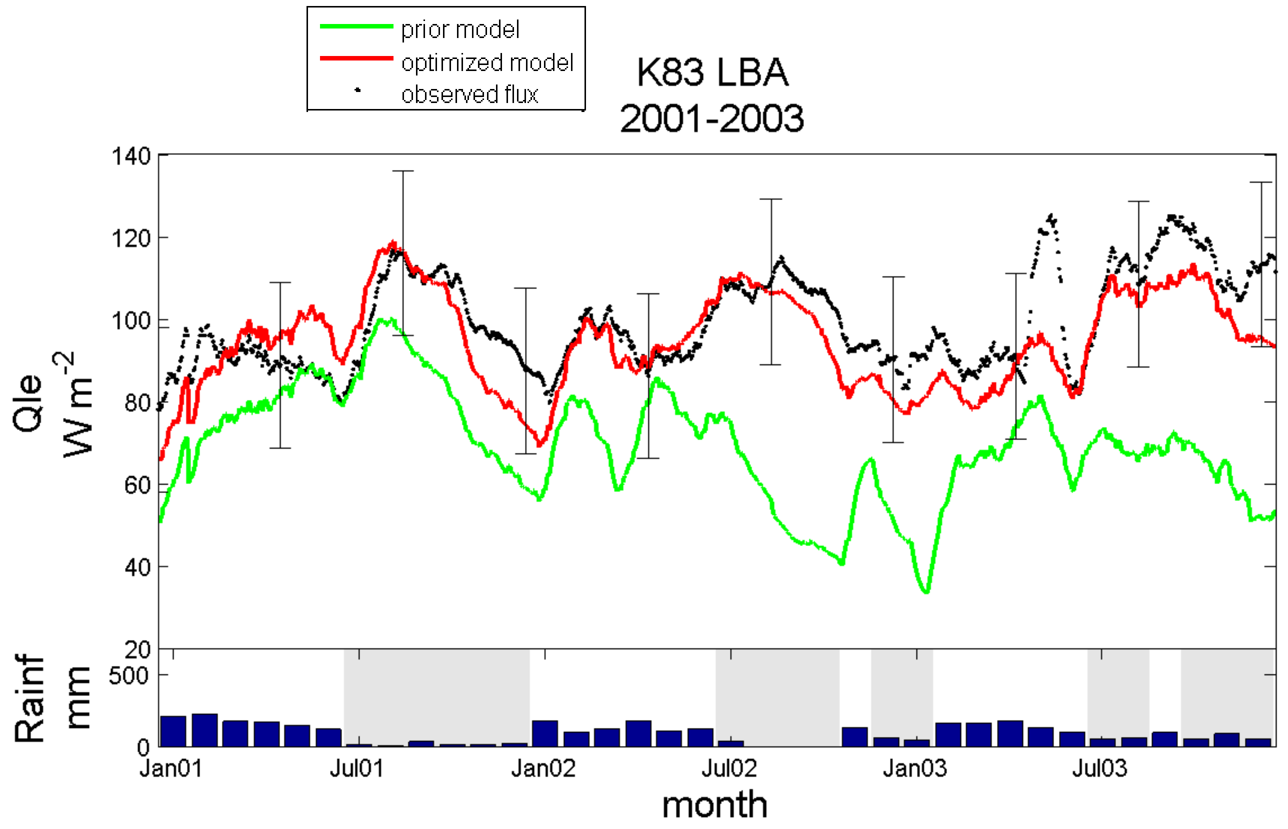
Saleska et al. Science, 2003



Wet Dry

➔ Carbon uptake during the dry season

Latent heat flux results

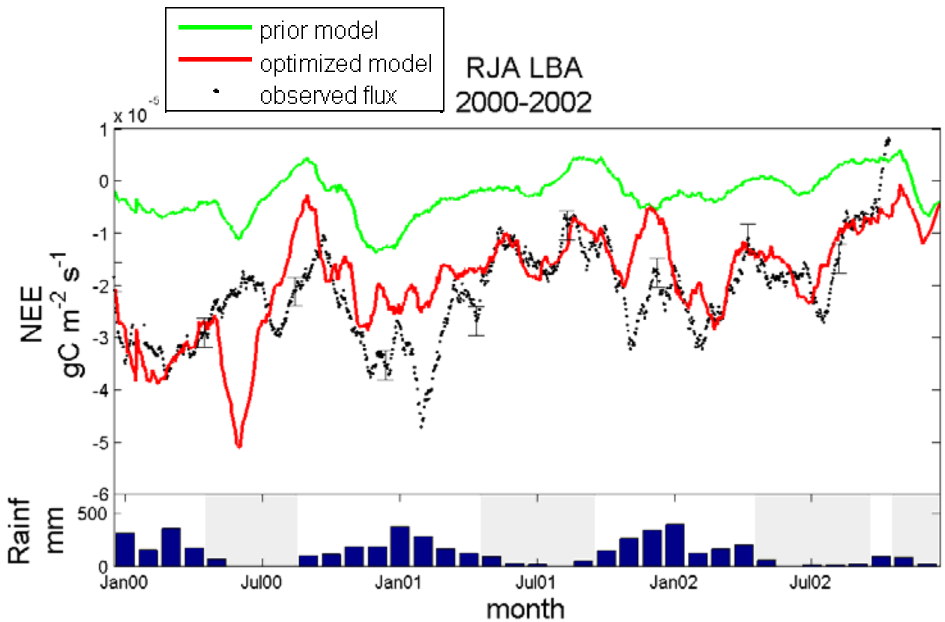


Soil depth (m)	
prior	optim
2.0	6.8

Higher soil depth confirms previous studies: e.g. Kleidon et al. 1999

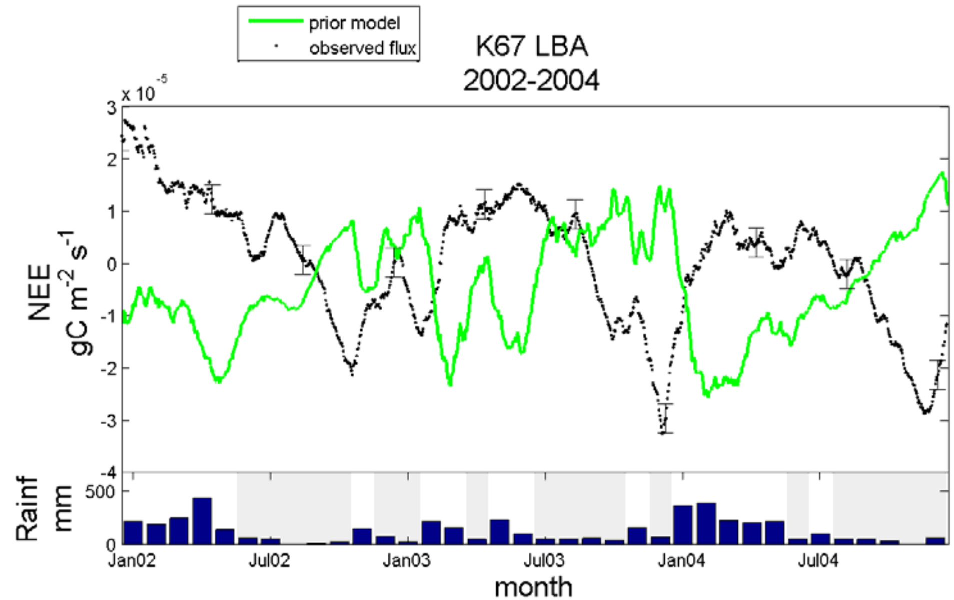
NEE results

Reserve Jarú: Soil depth 3.5m



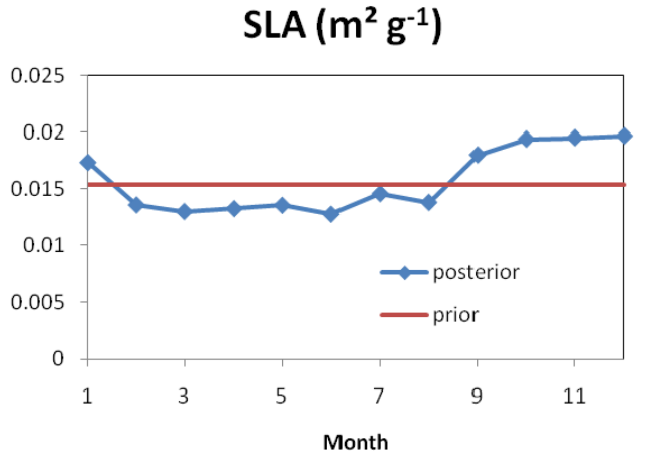
Expected behaviour

Tapajós km 67: Soil depth 10m

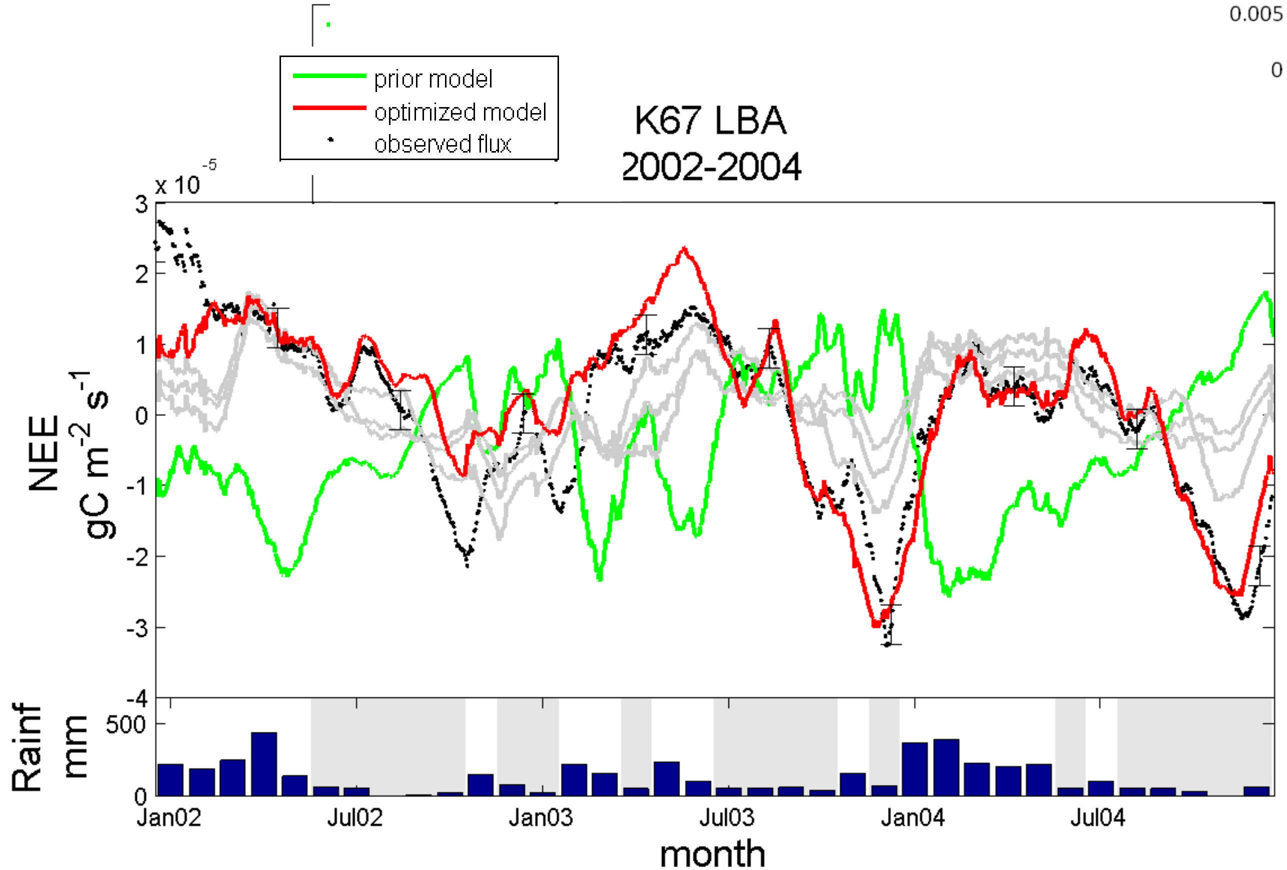


Counterintuitive behaviour

NEE results



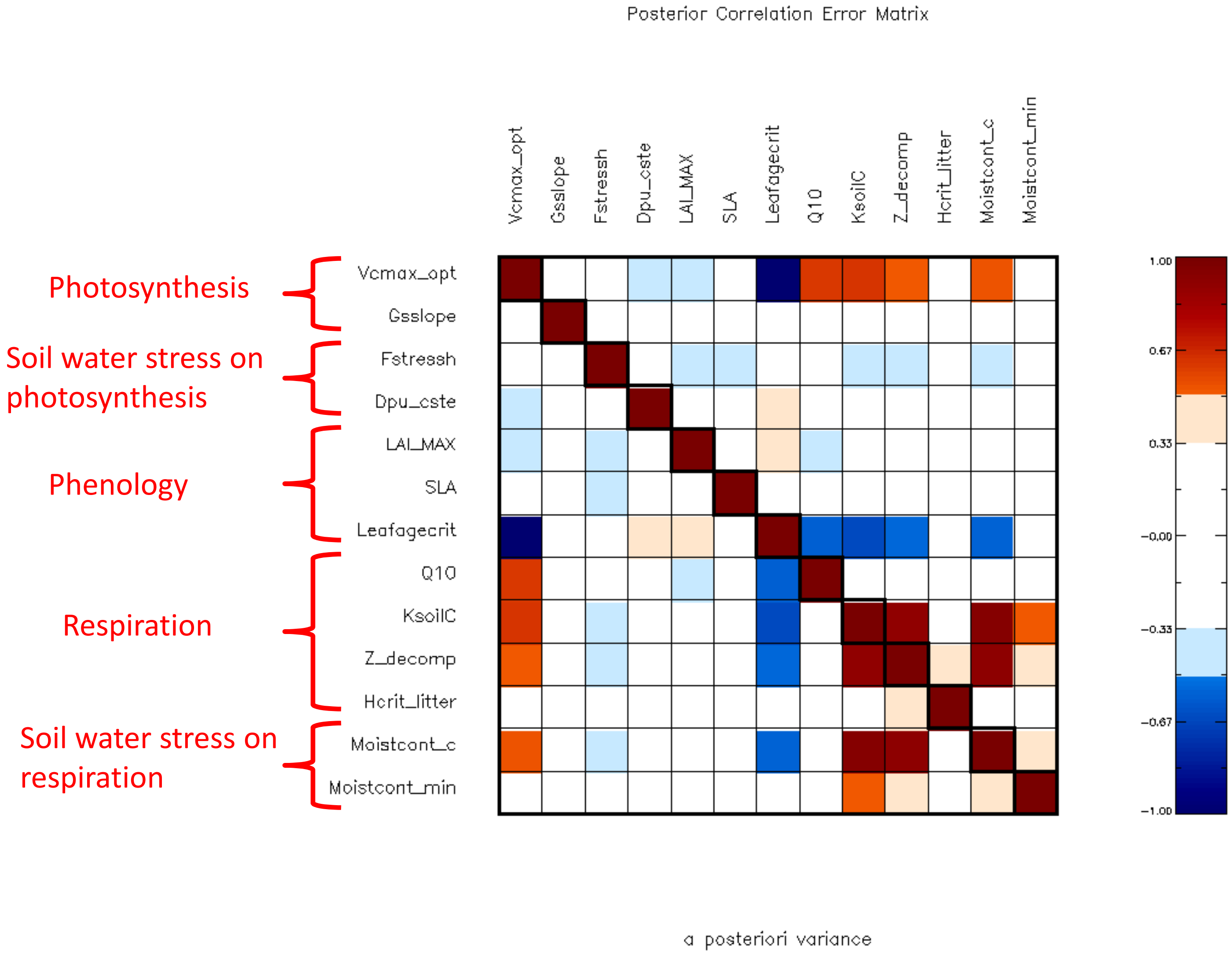
Optimisation with Vcmax and SLA varying each month



Adaptation of leafs to high light conditions

Leaf flush /increased photosynthetic capacity observed: field data (Malhado et al. 2009, Bonal et al. 2008); modelling (Poulter et al. 2009); remote sensing (Myneni et al. 2007).

Parameter Error correlations



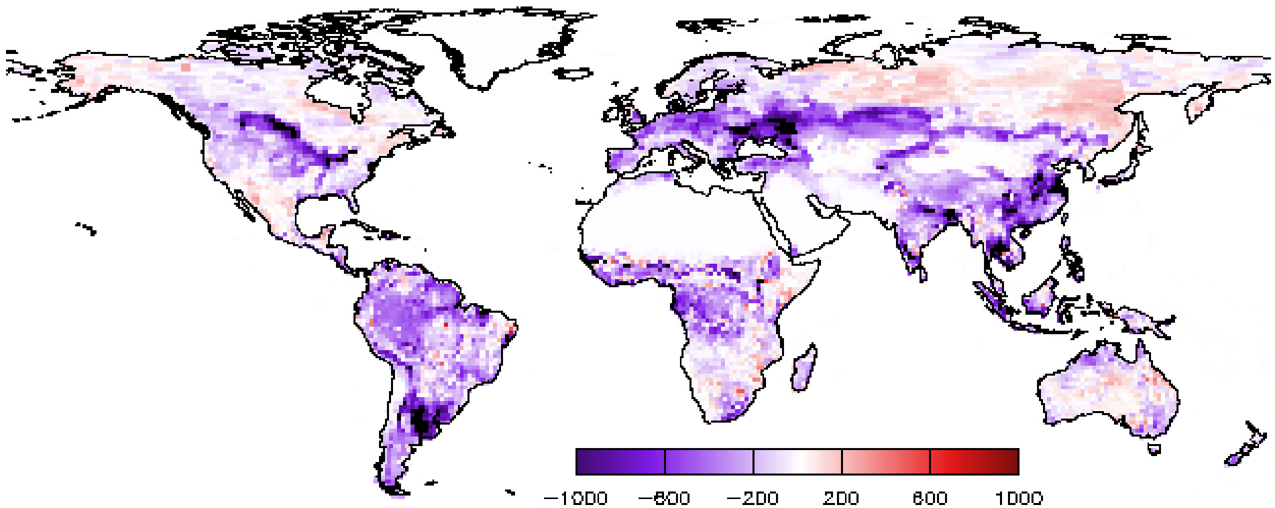
Assimilation of MODIS data

- Global scale assimilation..
  (following Demarty et al. 2005)

- Assimilation of MODIS fAPAR data to correct the simulated LAI of ORCHIDEE
  ➔ correct the trajectory of the model

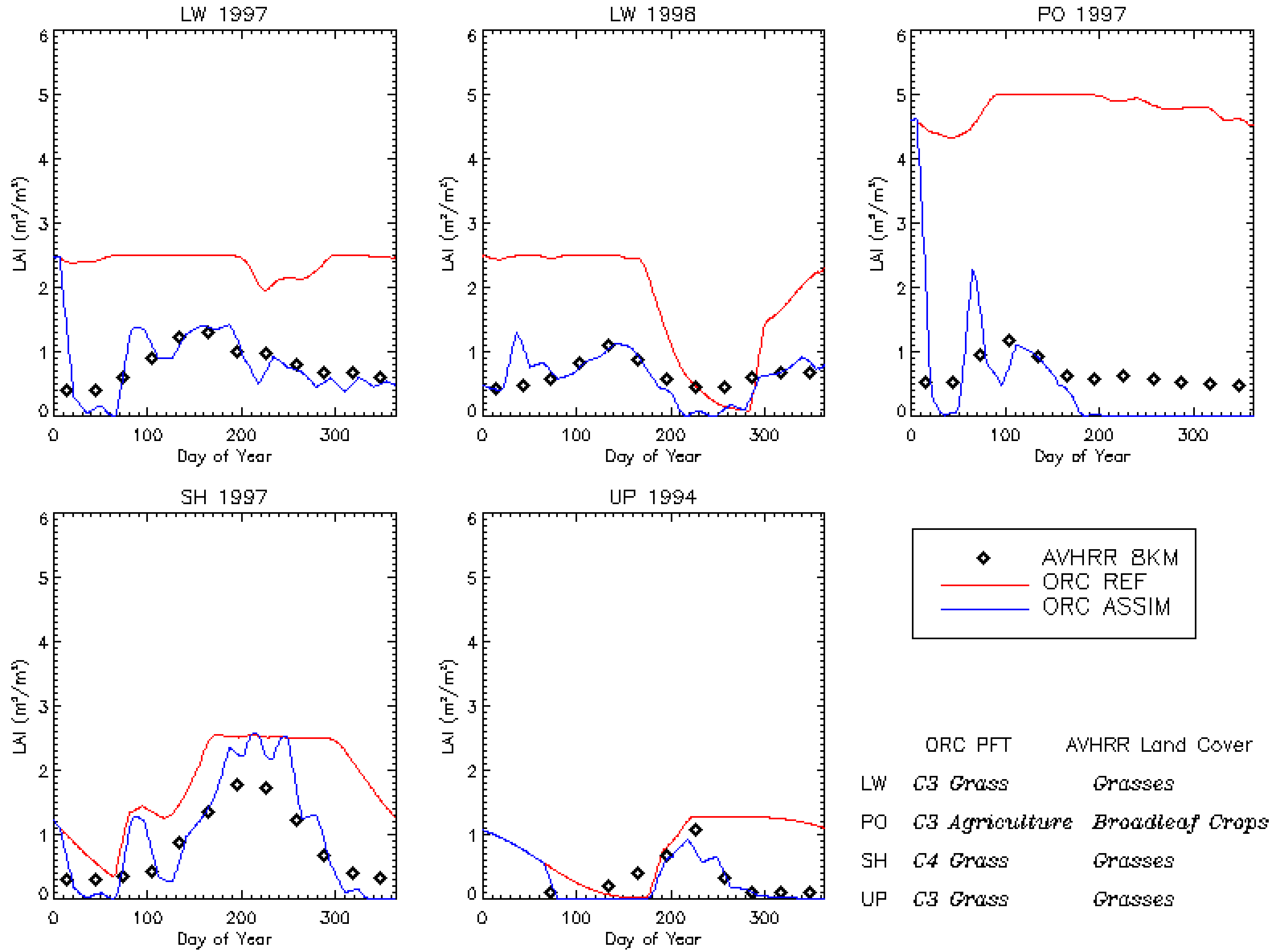
Assimilation of MODIS data

2000 GPP differences
(assim – ref)
gC/m^2/year



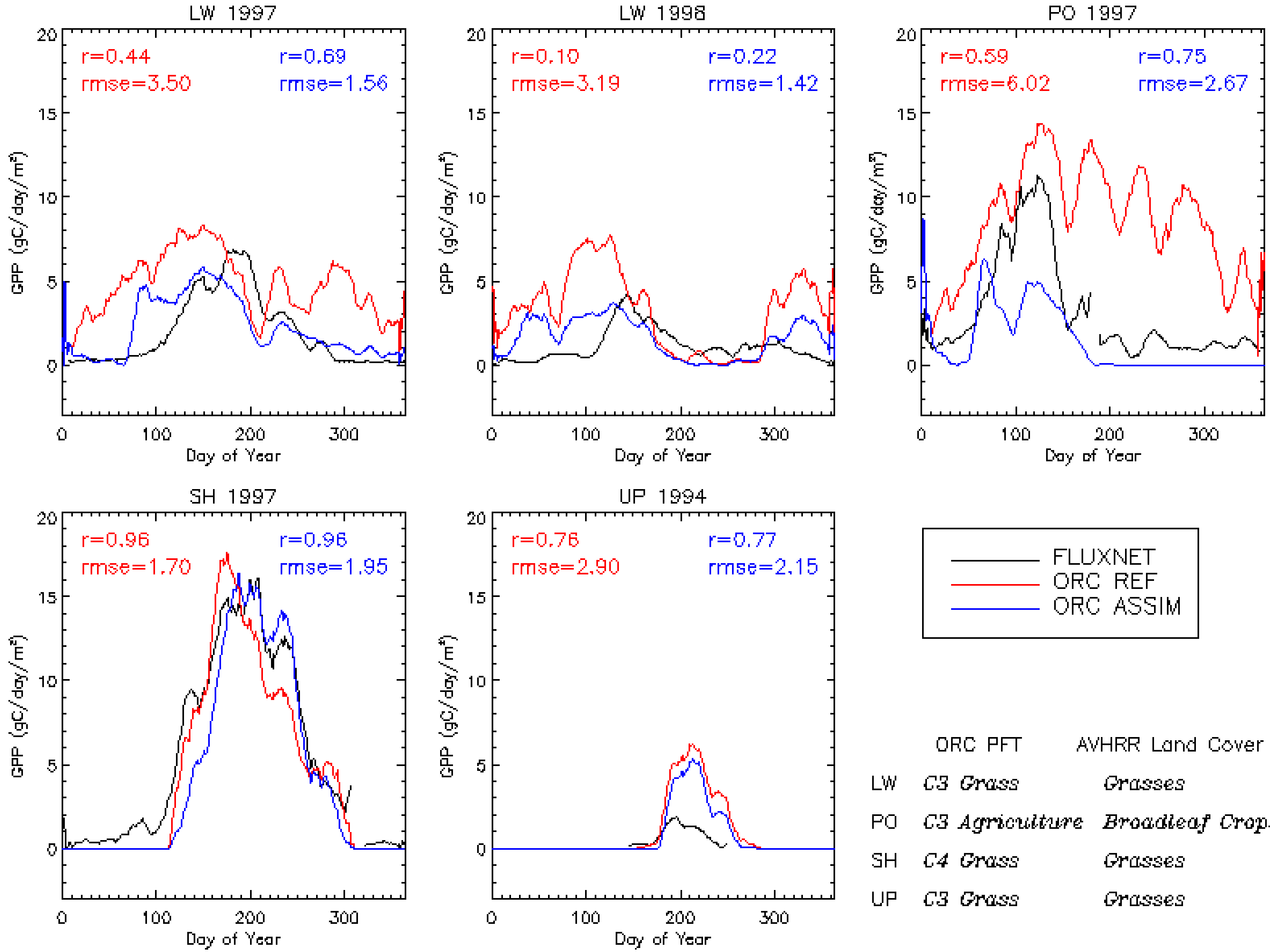
- On a global scale, assimilation of LAI MODIS for years 2000-2001
  - ➲ advance of the greening and decrease of the growing season length over northern temperate latitudes
  - ➲ decrease of the GPP
- ➔ Improvement of 25% for GPP RMSE over 40 FLUXNET sites

Assimilation of MODIS data



	ORC PFT	AVHRR Land Cover
LW	*C3 Grass*	*Grasses*
PO	*C3 Agriculture*	*Broadleaf Crops*
SH	*C4 Grass*	*Grasses*
UP	*C3 Grass*	*Grasses*

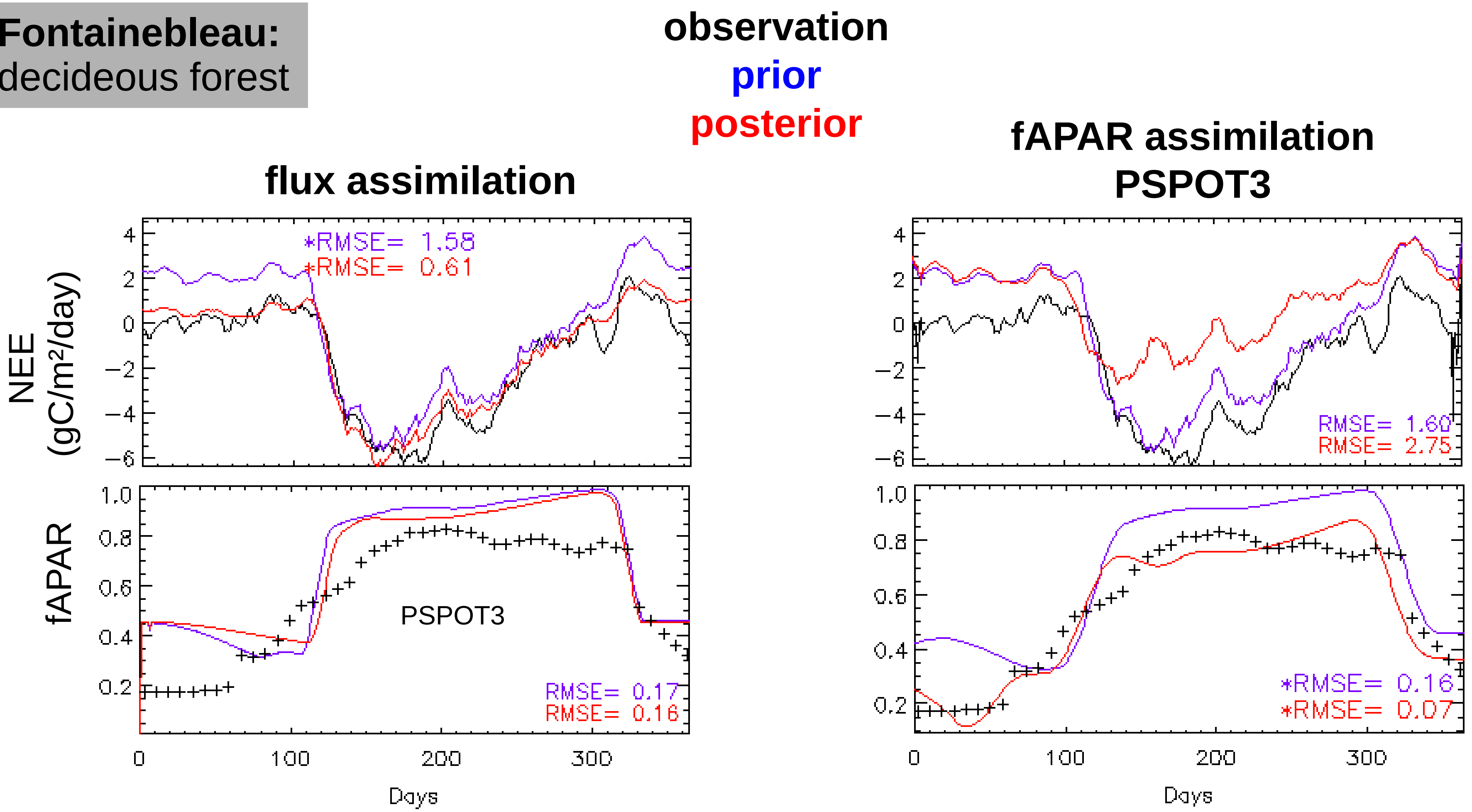
Assimilation of MODIS data: validation



	ORC PFT	AVHRR Land Cover
LW	*C3 Grass*	*Grasses*
PO	*C3 Agriculture*	*Broadleaf Crops*
SH	*C4 Grass*	*Grasses*
UP	*C3 Grass*	*Grasses*

Parameter optimization at site level: can we use satellite fAPAR and Flux data ?

Fontainebleau:
decideous forest



✓strong decrease of the carbon uptake during the growing season

Model data fusion : Next steps for the Carbon Cycle ?

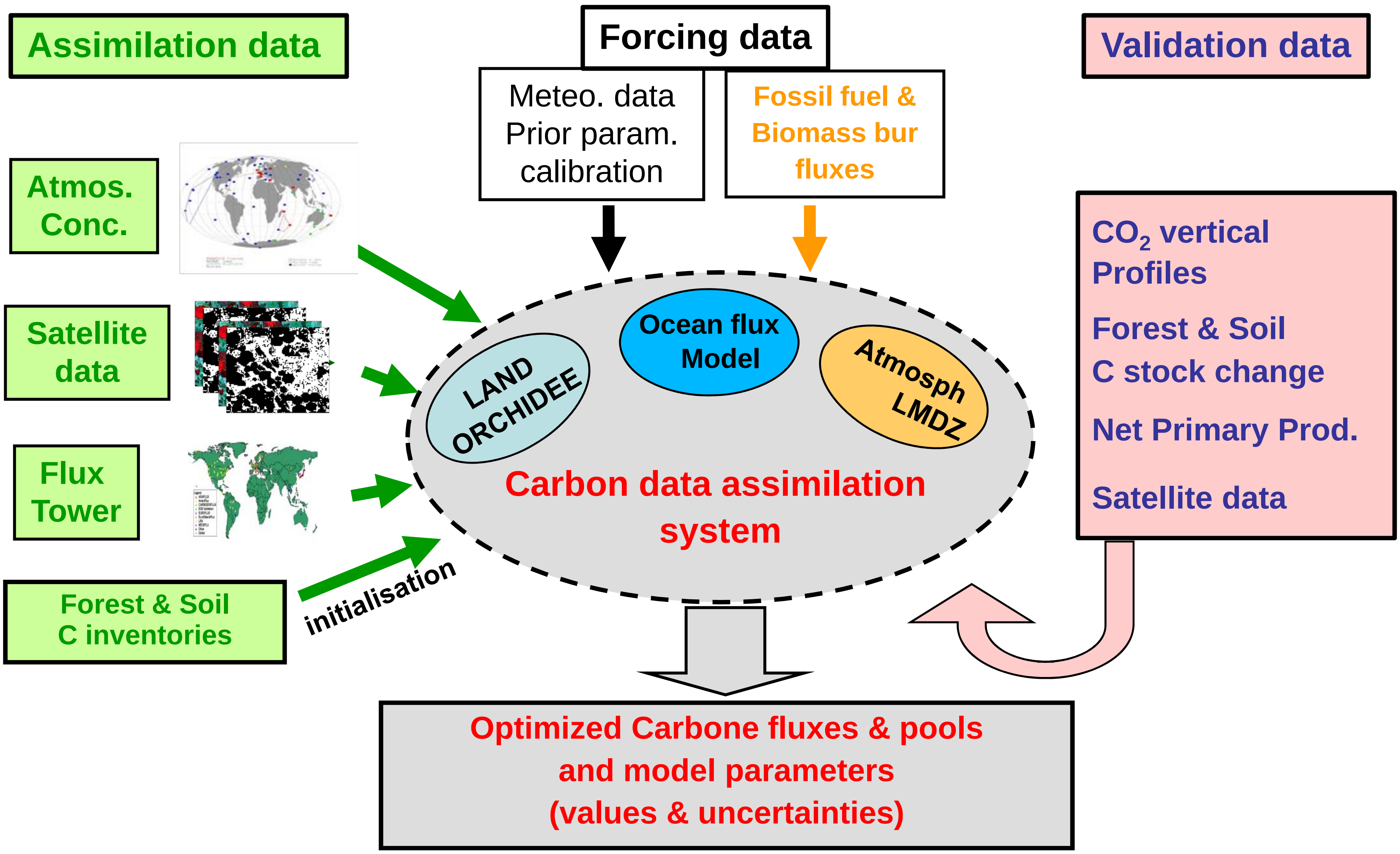
- Improve “Operational operators”
  - Satellite data → use RT code

- Better handle non-linearities & Thresholds

- Multi-data assimilation systems
  - Data relevant for all temporal scales
  - in particular Biomass data, Atm. CO_2, …

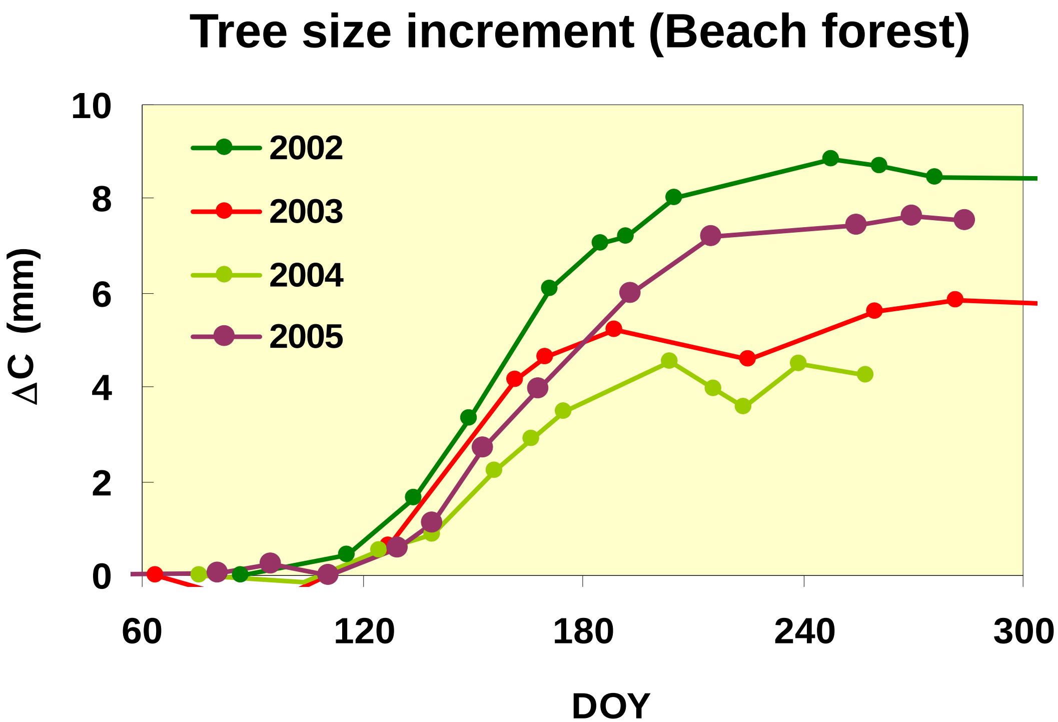
- Incude Water cycle data in the assimilation…

CARBONES project : 30-yrs of carbon fluxes using several data stream



Challenges for the Biogeochemical cycles

- Soil processes (carbon dynamic)
- Land u
- Specie
  to clim
- Biotic (
  (i.e. ins

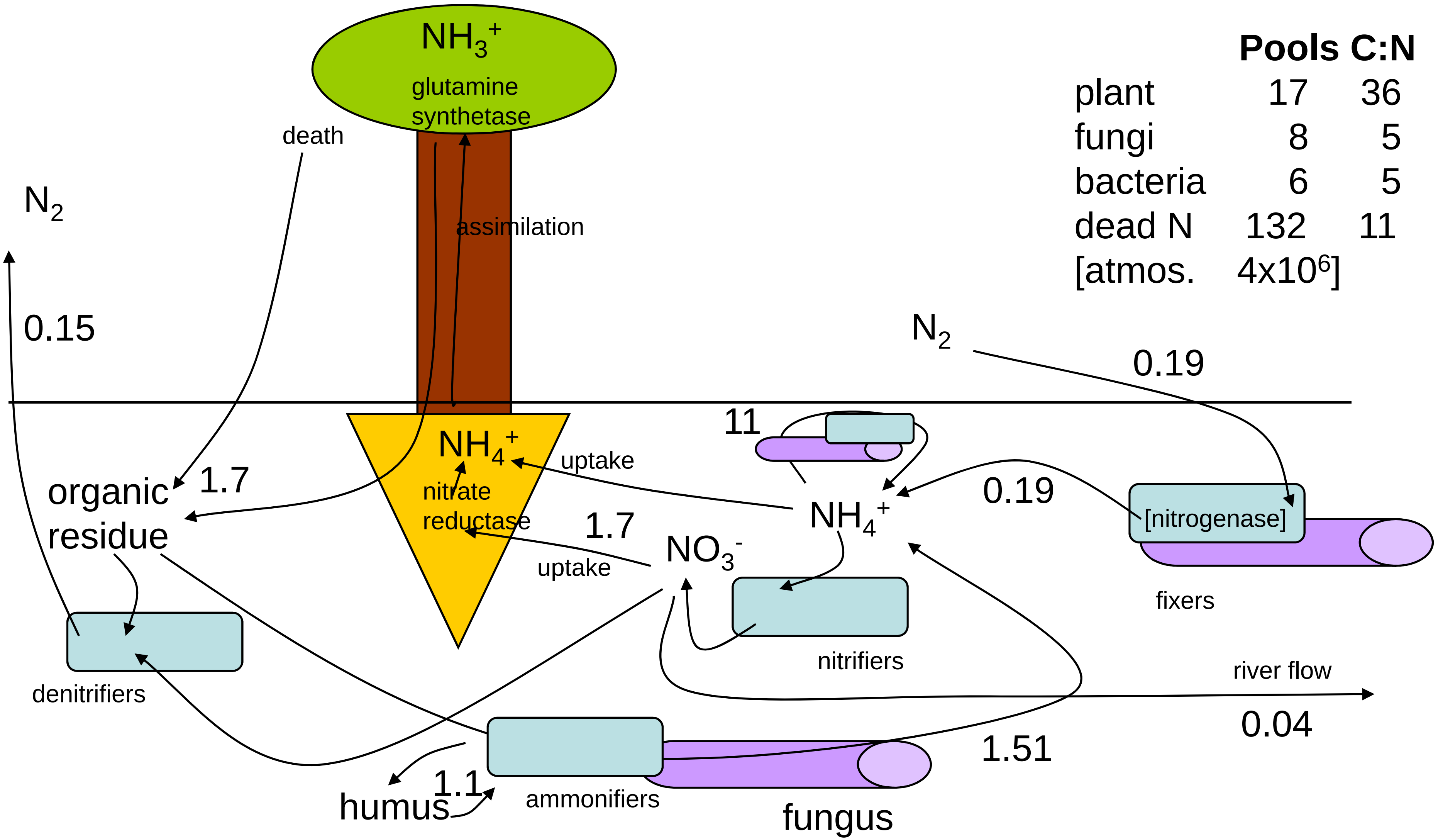


- Lag effects of climate extreme

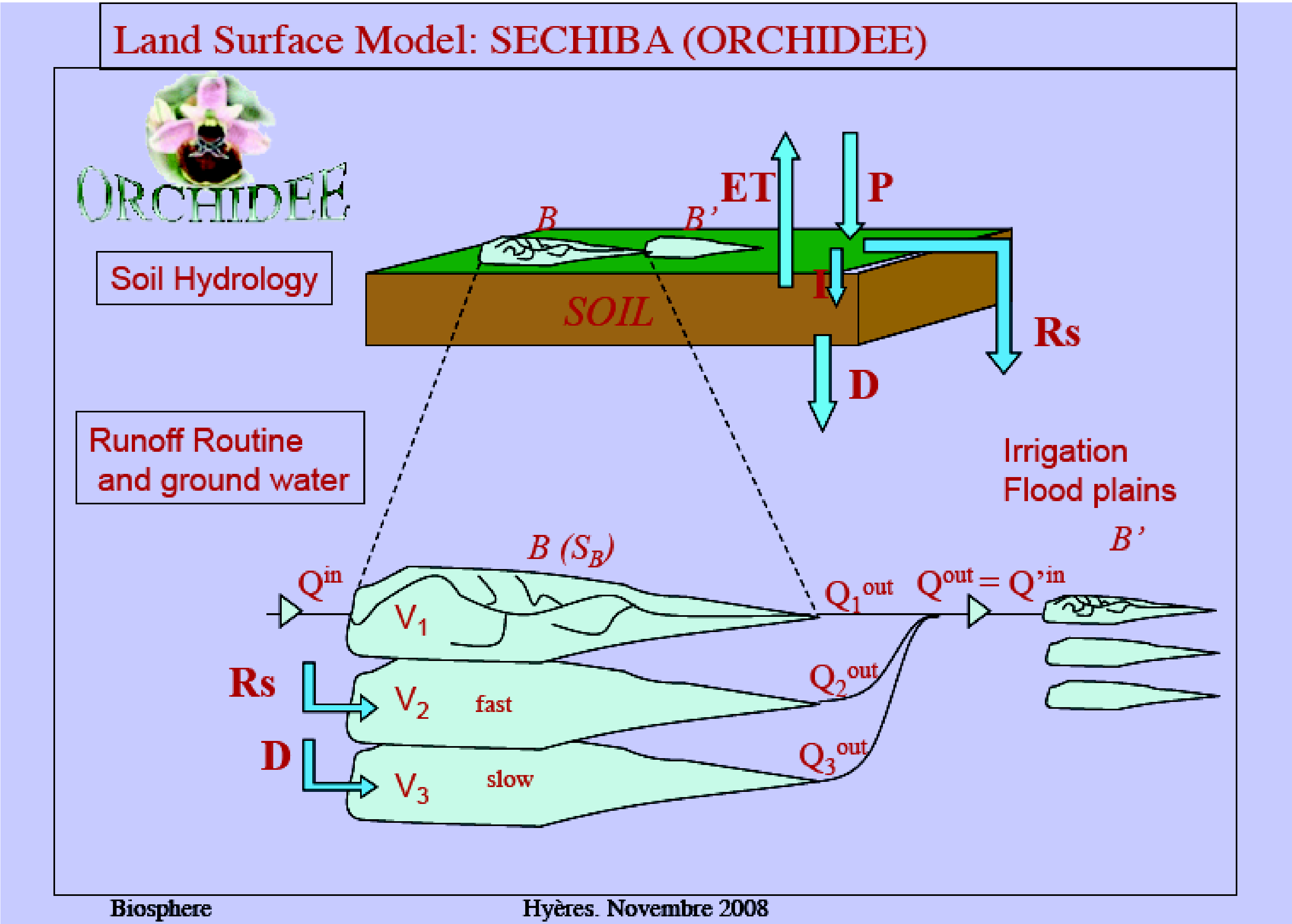
Additional material

The terrestrial nitrogen cycle (PgN yr^{-1})

	Pools	C:N
plant	17	36
fungi	8	5
bacteria	6	5
dead N	132	11
[atmos.	$4x10^6$]	



Water routing + irrigation computed in a consistent manner



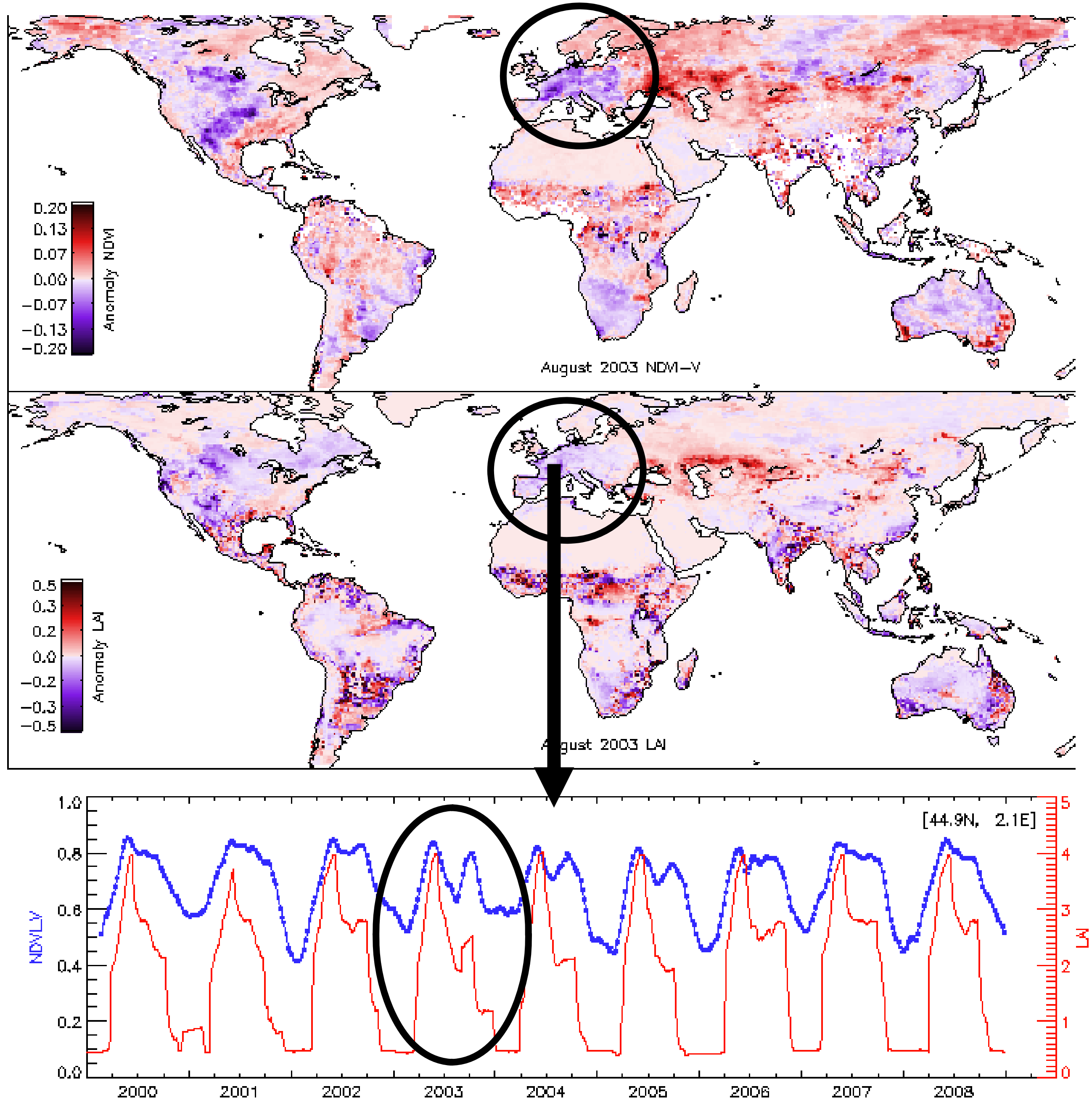
Ngo-duc et al, WRR, 2007

Comparaison NDVI ⇔ ORCHIDEE LAI

Anomalie de NDVI (MODIS)

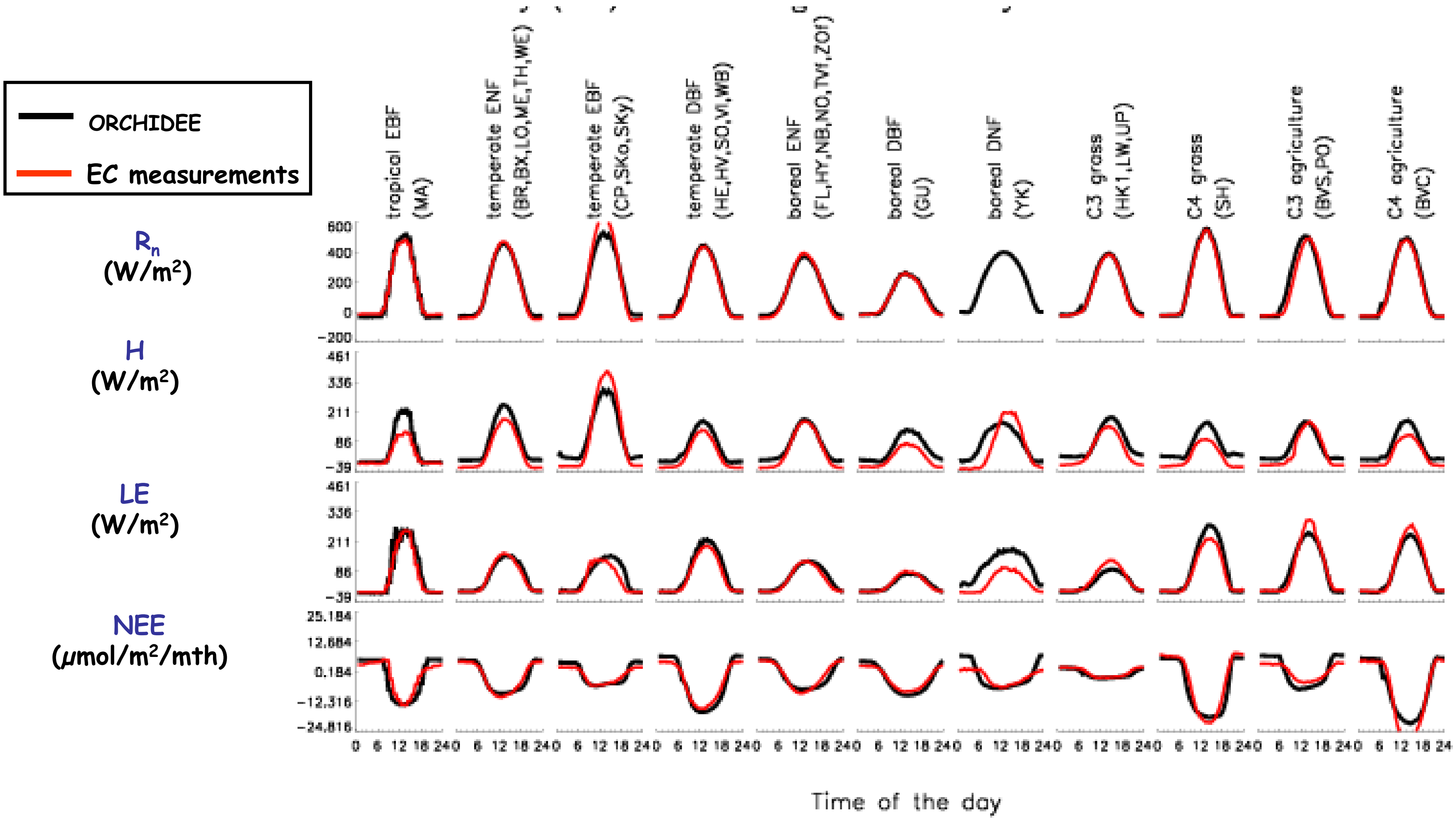
Anomalie de LAI (ORCHIDEE)

Pixel de forêt (Massif Central)

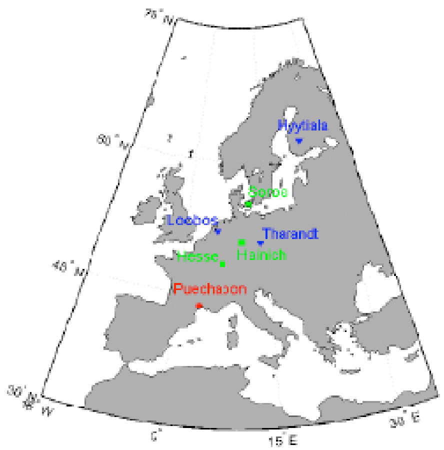


Extensive evaluation over more than 30 sites

Average diurnal cycle (JJA)



Existence of critical periods



A critical period is :

- A one-month interval
- The flux anomaly during that month significantly correlates with the annual flux anomaly
- The flux anomaly during that month explains at least 1% of the annual variance

Analysis is carried out at seven CARBOEUROPE sites :

- Conifers : Loobos, Hyytiala, Tharandt
- Broadleaved deciduous : Hainich, Hesse
- Broadleaved evergreen : Puéchabon

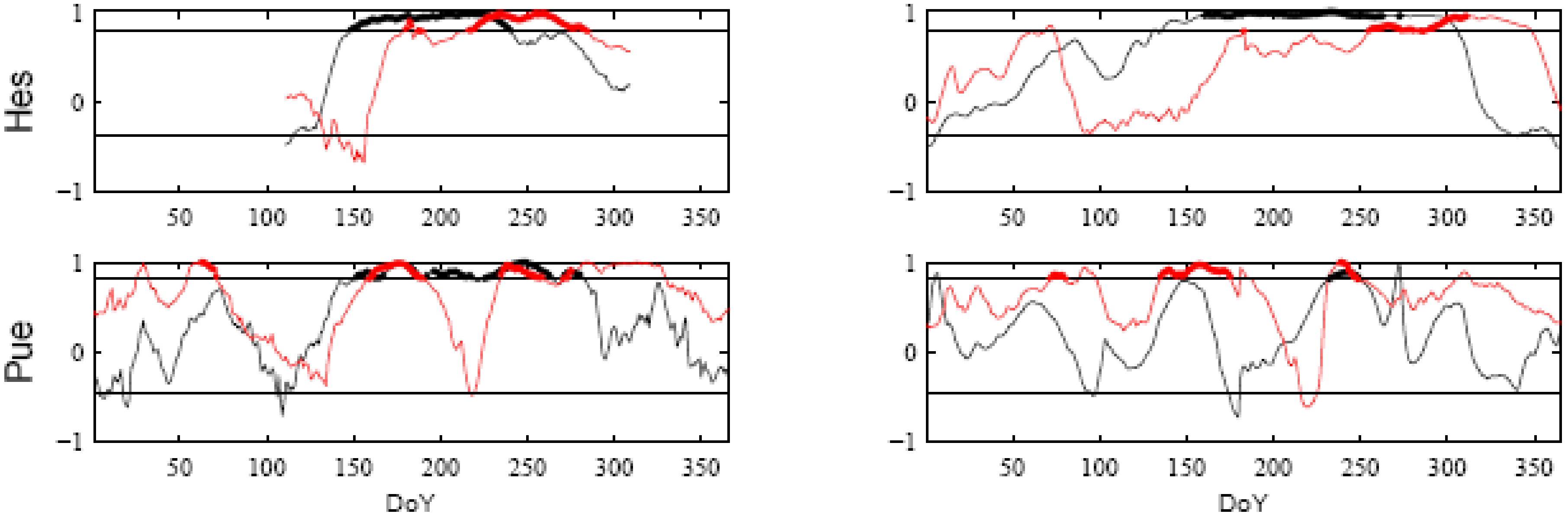
Lemaire et al. in prep

Assessing hot spots in data and model :

GPP

CRITICAL PERIODS = HOT SPOTS

TER



Observations

ORCHIDEE Model

Long-term Proxies of extreme years relating drougth and C fluxes:

Crop Yields
(FAO)

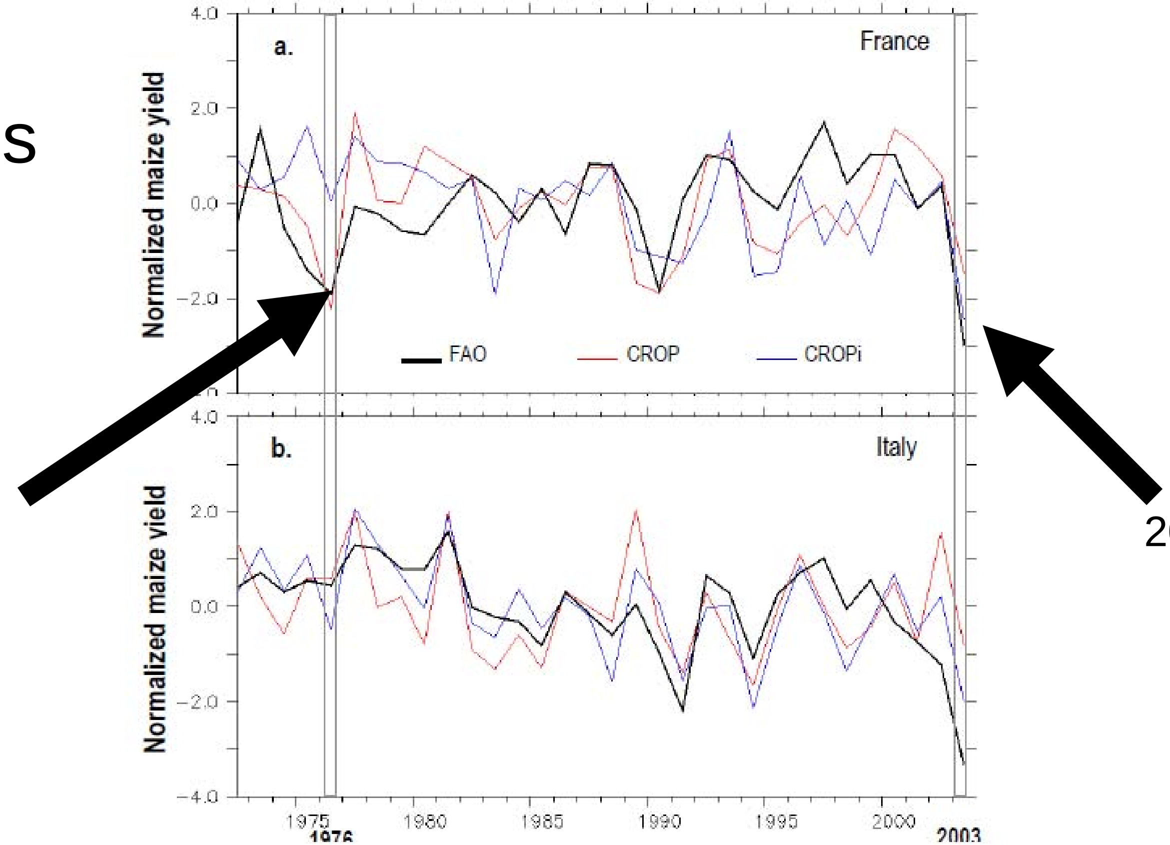
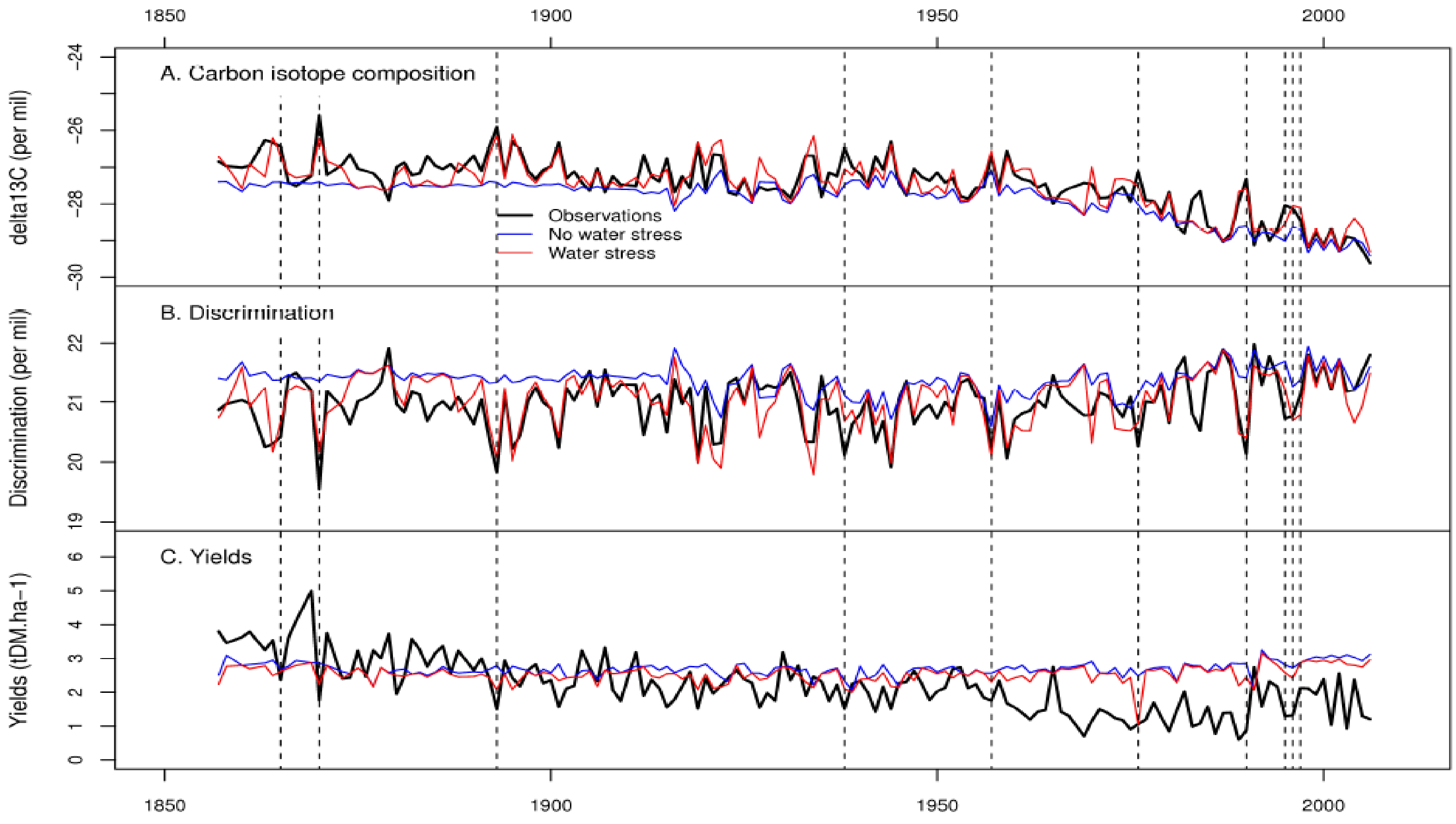


Figure 2. Normalized yield ((Yield-Mean)/Std.Dev.) 1972-2003 series simulated by ORCHIDEE-STICS non-irrigated (CROP : red) and irrigated (CROPi : blue) compared with FAO data (black) for maize in **a.** France and **b.** Italy. The gray boxes indicate the 1976 and 2003 extreme events.

P.C. Smith et al. 2009, in press

Long-term proxies of extreme years relating drought and C fluxes:

C isotope of plant biomass in grassland (Rothamsted - England)



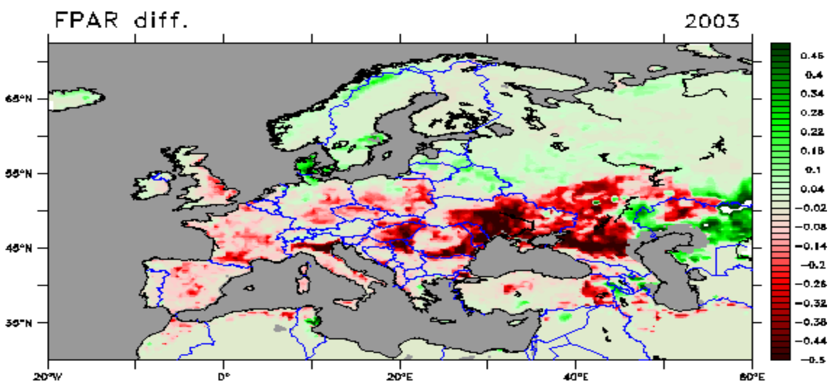
10 Dryest spring

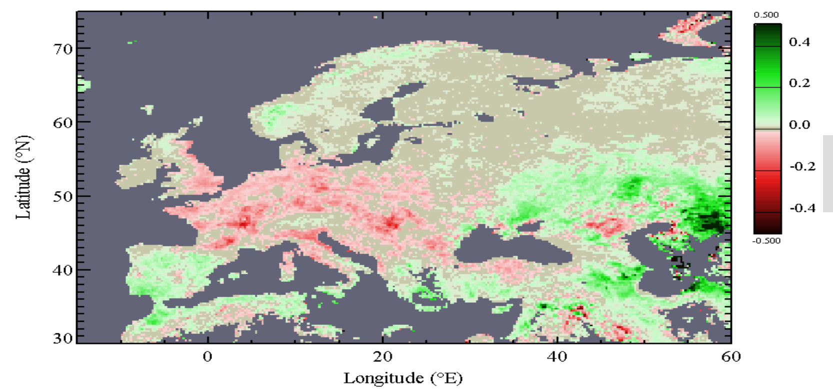
Eglin et al., in prep

Validation by remote sensing

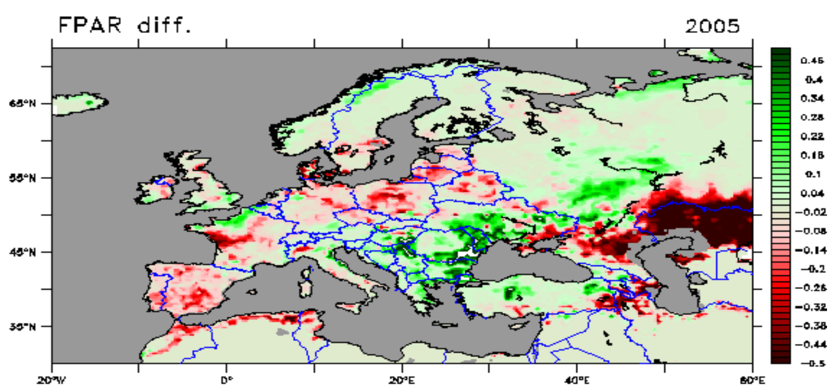
FPAR Fraction of Absorbed Photosynthetically Active Radiation anomalies in summer (JAS)

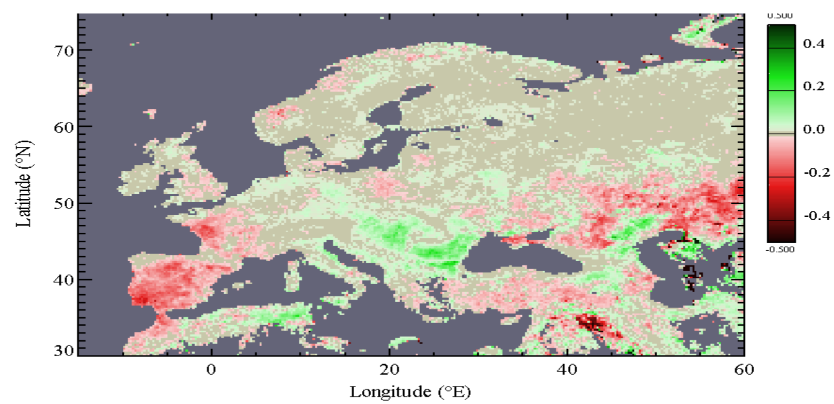
FPAR modeled relative anomaly (% of normal)	FPAR from MODIS anomaly (% of normal)





2003





2005