Energy and CO_2 fluxes in temperate deciduous broadleaf forests: using local eddy-covariance data for a global optimization of the ORCHIDEE model

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Abstract

We develop a variational data assimilation system to assimilate simultaneously 12 datasets of daily flux measurements (net CO_2 flux NEE and latent heat flux LE) with the ORCHIDEE biosphere model. The goal is to derive a unique set of optimized parameters shared by these 12 sites of temperate deciduous broadleaved forests.

The compared analysis of this multi-site approach to the prior model and the site-specific optimizations leads to the following conclusions:

- Improved model-data fit, with good multi-site performances
- Multi-site set of parameters often consistent with the site-specific ones
- Improvement of both photosynthesis and respiration, evaluated using estimates of gross primary productivity (GPP) and ecosystem respiration (R_{eco}).
- Improvement of the model phenology at the global scale with multi-site parameters, evaluated by comparing the modeled leaf area index (LAI) with MODIS measurements of normalized difference vegetation index (NDVI).

Table 1. List of optimized parameters

Parameter	Description
V_{cmax}	Maximum carboxylation rate (µmol.m^{-2}.s^{-1})
$G_{s,slope}$	Ball-Berry slope
$c_{T,opt}$	Offset in the optimal photosynthesis temperature function (°C)
$c_{T,min}$	Offset in the minimal photosynthesis temperature function (°C)
SLA	Specific leaf area (LAI per dry matter content, m^2.g^{-1})
LAI_{MAX}	Maximum LAI per PFT (m^2.m^{-2})
$K_{lai,happy}$	LAI threshold to stop carbohydrate use
$K_{pheno,crit}$	Multiplicative factor of GDD threshold to start the growing season
$c_{T,senescence}$	Offset in the temperature threshold triggering the senescence (°C)
$L_{agecrit}$	Average critical age of the leaves (days)
Hum_{cste}	Root profile
Dpu_{cste}	Total depth of the soil water pool (m)
Q10	Temperature dependence of the heterotrophic respiration
K_{soilC}	Multiplicative factor of the initial carbon pools
$HR_{H,b}$	Linear term for moisture control of the heterotrophic respiration
$HR_{H,c}$	Offset of the moisture control of the heterotrophic respiration
MR_a	Slope of the temperature control of the maintenance respiration
MR_b	Offset of the temperature control of the maintenance respiration
GR_{frac}	Fraction of biomass available for growth respiration
$Z0_{overheight}$	Characteristic rugosity length (m)
$K_{albedo,veg}$	Multiplying factor of the surface albedo

Vegetation model

The ORCHIDEE (Organizing Carbon and Hydrology In Dynamic Ecosystems) model calculates the carbon and water cycles in the different soil and vegetation pools and resolves the diurnal cycle of fluxes, using the concept of plant functional types (PFT) to describe the vegetation. The different carbon pool sizes are brought to steady state before each run with a model spin up during 1300 years.

Variational data assimilation

Minimization of the Gaussian cost function J :

$$J(\mathbf{x}) = \frac{1}{2}\left[(\mathbf{Y} - H(\mathbf{x}))^t \mathbf{R}^{-1}(\mathbf{Y} - H(\mathbf{x})) + (\mathbf{x} - \mathbf{x}_b)^t \mathbf{P}_b^{-1}(\mathbf{x} - \mathbf{x}_b)\right]$$

Flux data

We use measured, gap-filled fluxes of net ecosystem exchange (NEE) and latent heat fluxes (LE), part of the Fluxnet network. Daily means are computed from at the half hourly data. Days with less than 80% of half-hourly data are not assimilated.

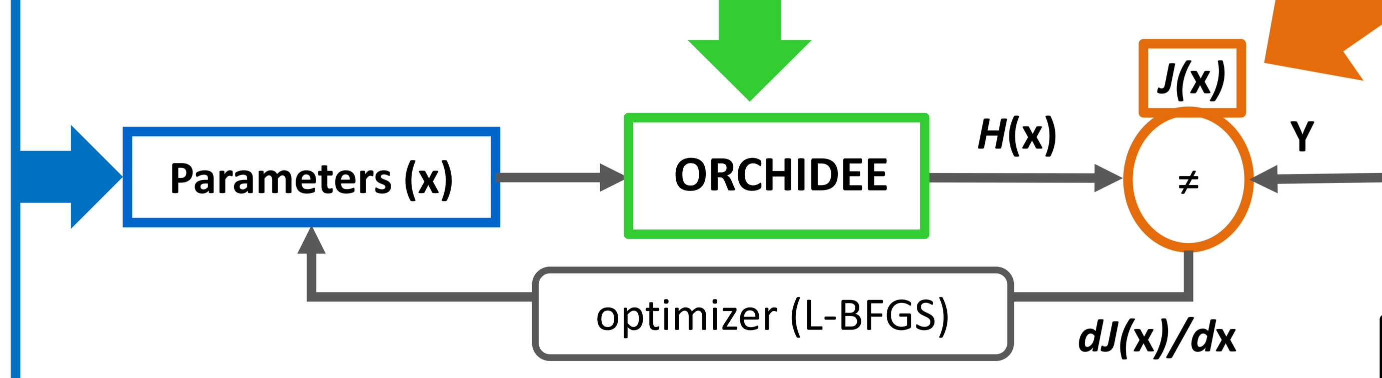

Fig. 1. Schematic view of the inversion system.

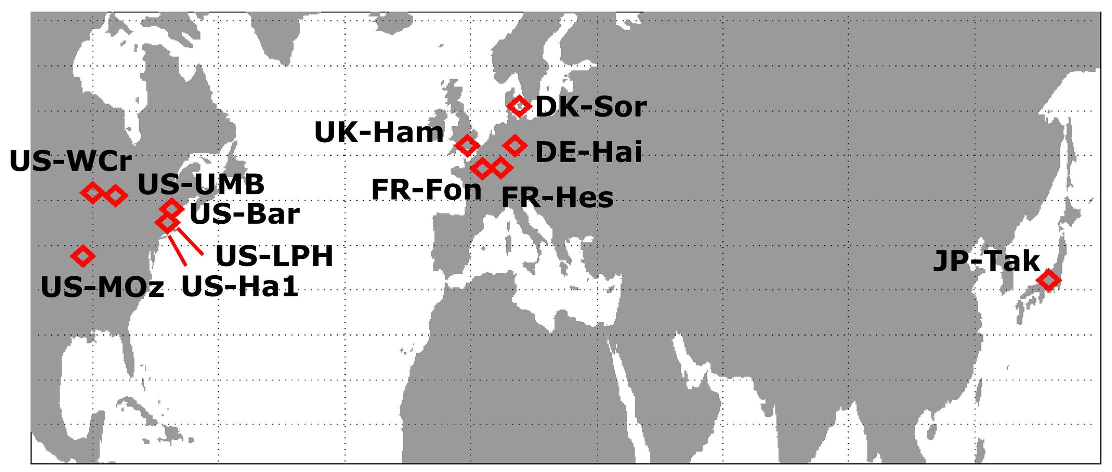

Fig. 2. Fluxnet sites used in this study. Their vegetation cover contains >70% of deciduous broadleaved forests.

1. Model-data fit

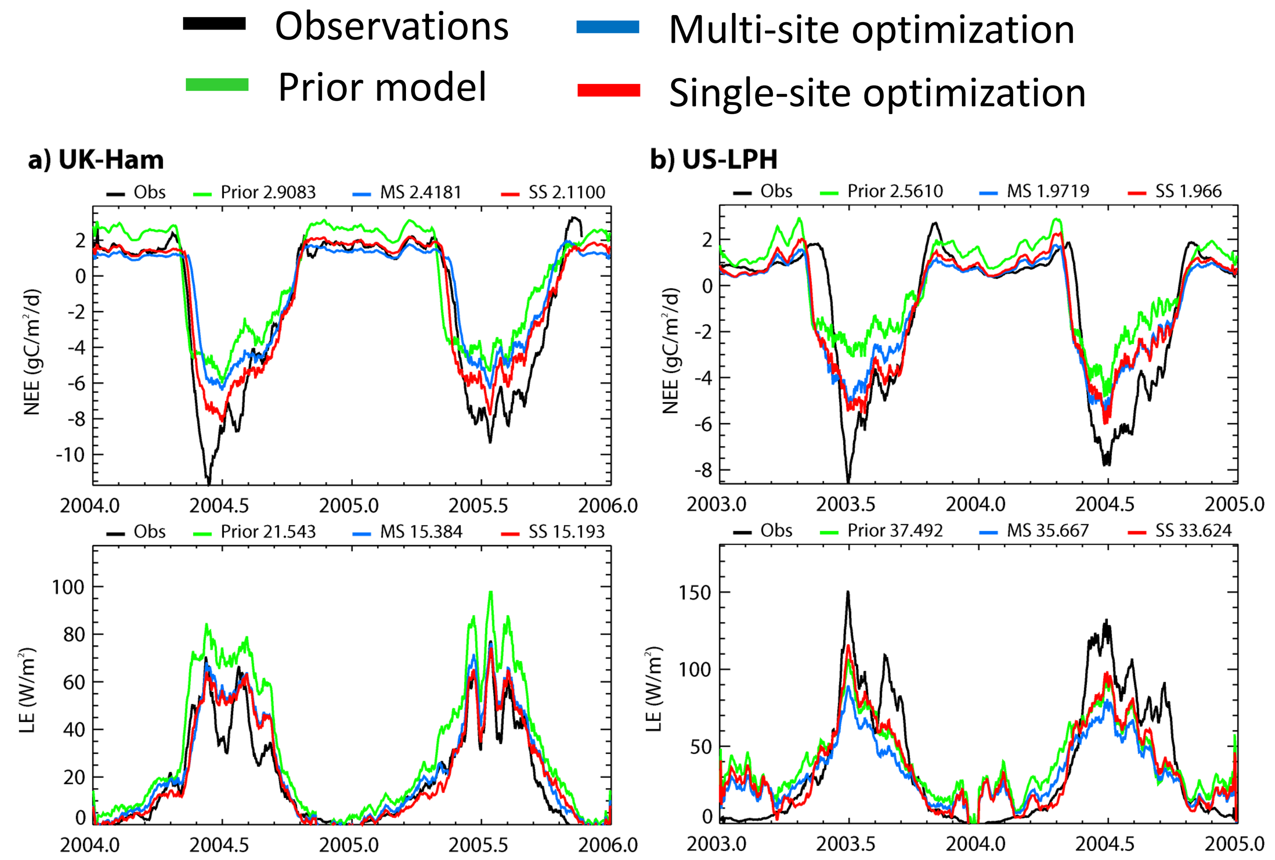

Fig. 3. Seasonal cycles of NEE and LE at two of the twelve sites used in this study : a) UK-Ham and b) US-LPH.

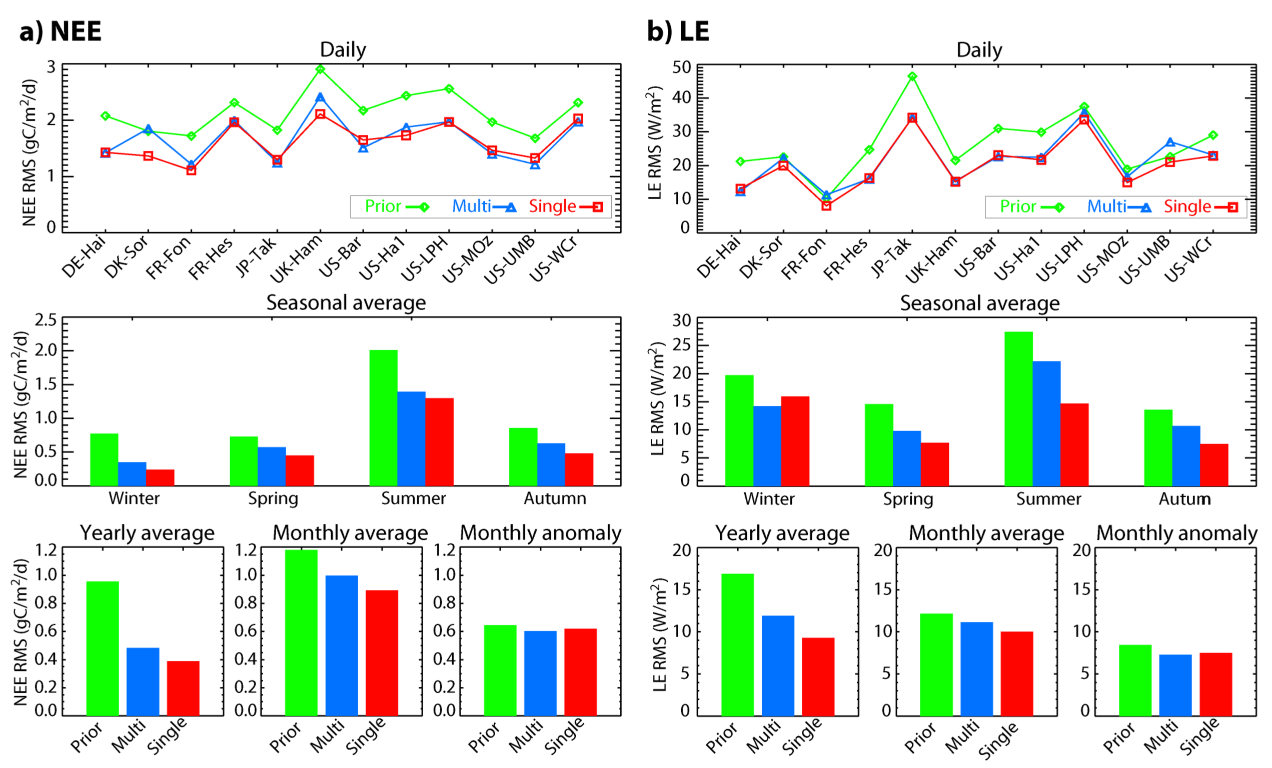

Fig. 4. RMSs at different time scales for a) NEE and b) LE.

NEE :

- Significant correction of the prior winter carbon release after optimization (Fig. 3)

→ Explains most of the significant yearly RMS (Fig. 4 a))

→ Strongly linked to the initial carbon pools (K_{soilC}, Fig. 5)

- Improvement of summer uptake, but not always enough
- Correction of phase shift, but interannual variations

LE :

- General decrease of LE after optimizations (Fig. 3 b))
- Improvement of the "LE seasonality"

→ Consistent with observations (Fig. 4 b))

→ General consistency between multi-site optimizations and site-specific ones

2. Analysis of the parameters

- Confirms the trend of optimized fluxes : lower respirations, a shortened growing season, a reduced LE, and a possible reduction of GPP (Fig. 4).
- Pros : the multi-site approach finds a middle ground between site-specific values for more than half of the parameters.
- Cons : Large spread between some sie-specific values, along with small uncertainties ($G_{s,slope}$, $K_{pheno,crit}$, $c_{senescence}$).

→ Needs model improvement

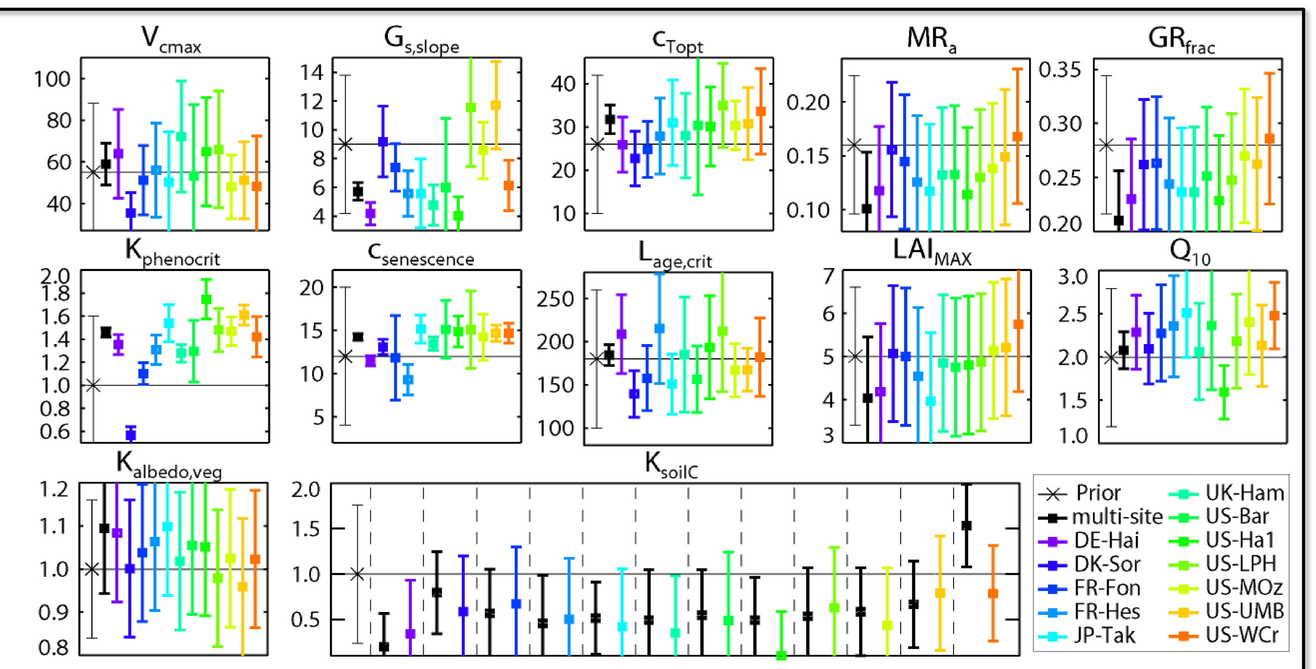

Fig. 4. Prior and optimized values of the parameters.

3. Local evaluation : photosynthesis/respiration

Comparison of the model with gross carbon fluxes (GPP and R_{eco}) from standard flux-partitioning (Fig. 6) :

→ The decrease of both modeled fluxes after the optimization is consistent with the flux estimates

→ The modeled GPP is sometimes decreased too much

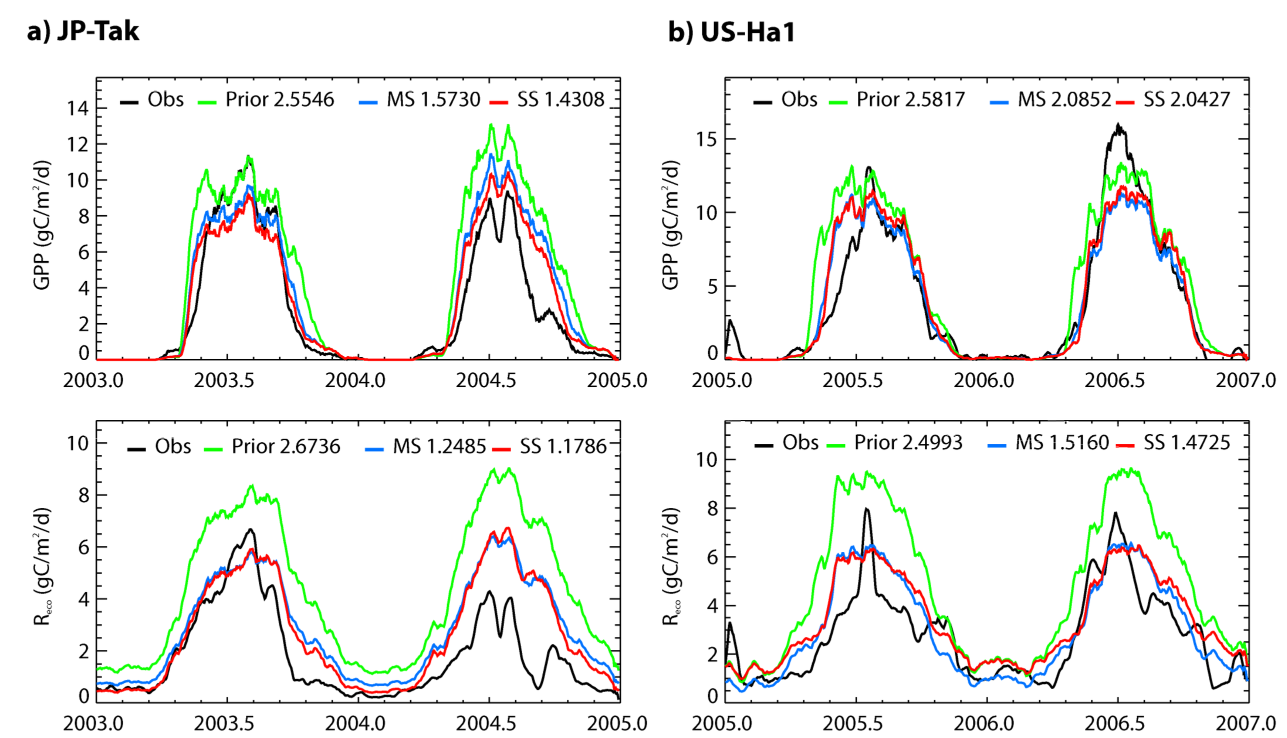

Fig. 6. Seasonal cycles of GPP and R_{eco} at sites a) JP-Tak and b) US-Ha1.

4. Global evaluation : phenology

Run of the ORCHIDEE model at the global scale with prior parameters, then using multi-site-optimized parameters.

→ Comparison to MODIS NDVI for pixels with deciduous broadleaved forests « footprint » above 50%

Correlation between modeled fPAR and NDVI (Fig. 7) :

→ NH : very good prior (r^2>0.88), small but consistent improvement

→ SH : poor prior (r^2<0.5), improvement except in Oceania

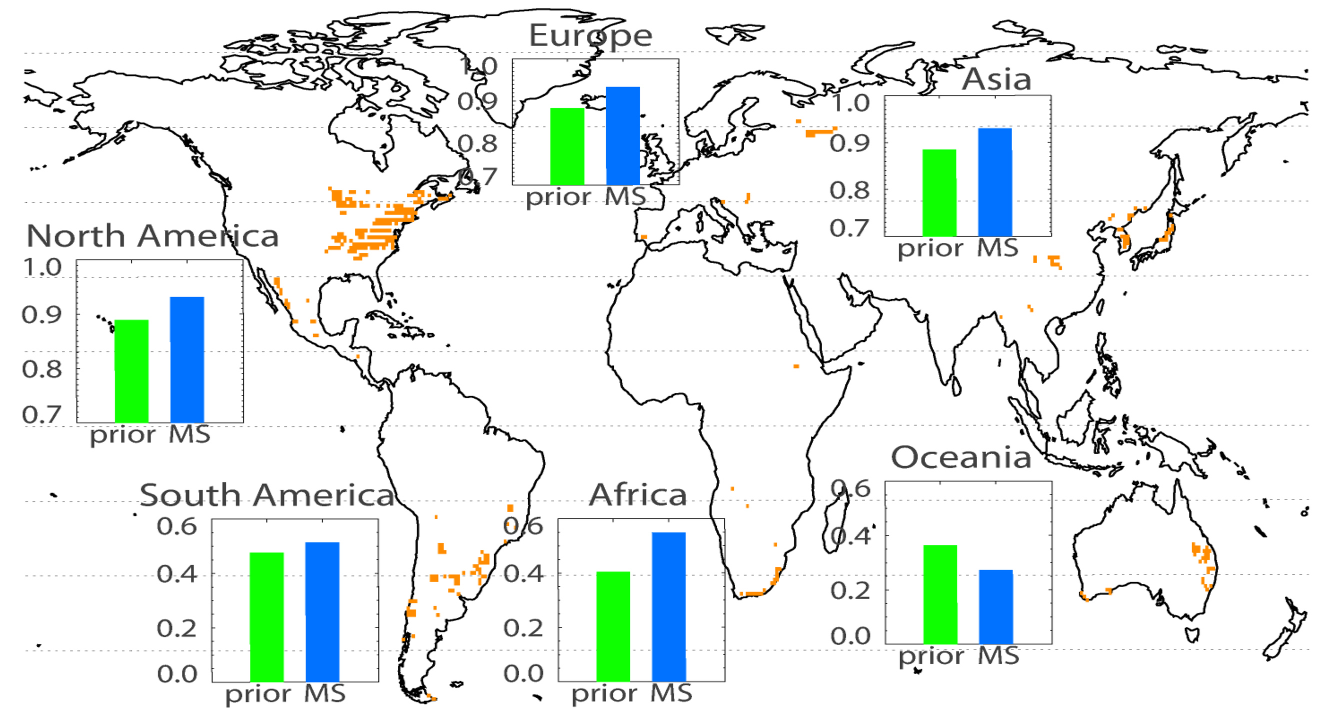

Fig. 7. Continental medians of NDVI/FPAR correlations in the prior model (green) and after the multi-site optimization (blue), using weekly time series for the 2000-2008 period and the ERA-I simulation. Correlations are only calculated where cycles in NDVI and FPAR are detected (orange boxes).

References : **Krinner et al.** (2005), *Global Biogeochemical Cycles*, *19*, GB1015. **Santaren et al.** (2007), *Global Biogeochem. Cycles*, *21*, GB2013.
Maignan et al. (2011), *Geoscientific Model Developpement Discussion*, *4*, 907-941.

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