Assimilation of satellite fAPAR data within the ORCHIDEE biosphere model and its impacts on land surface carbon and energy fluxes

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Objectives

Improve ORCHIDEE vegetation model through parameter optimization

- ORCHIDEE: **global** vegetation model which parameterization may need tuning for specific sites
- Use of data at the **site level**

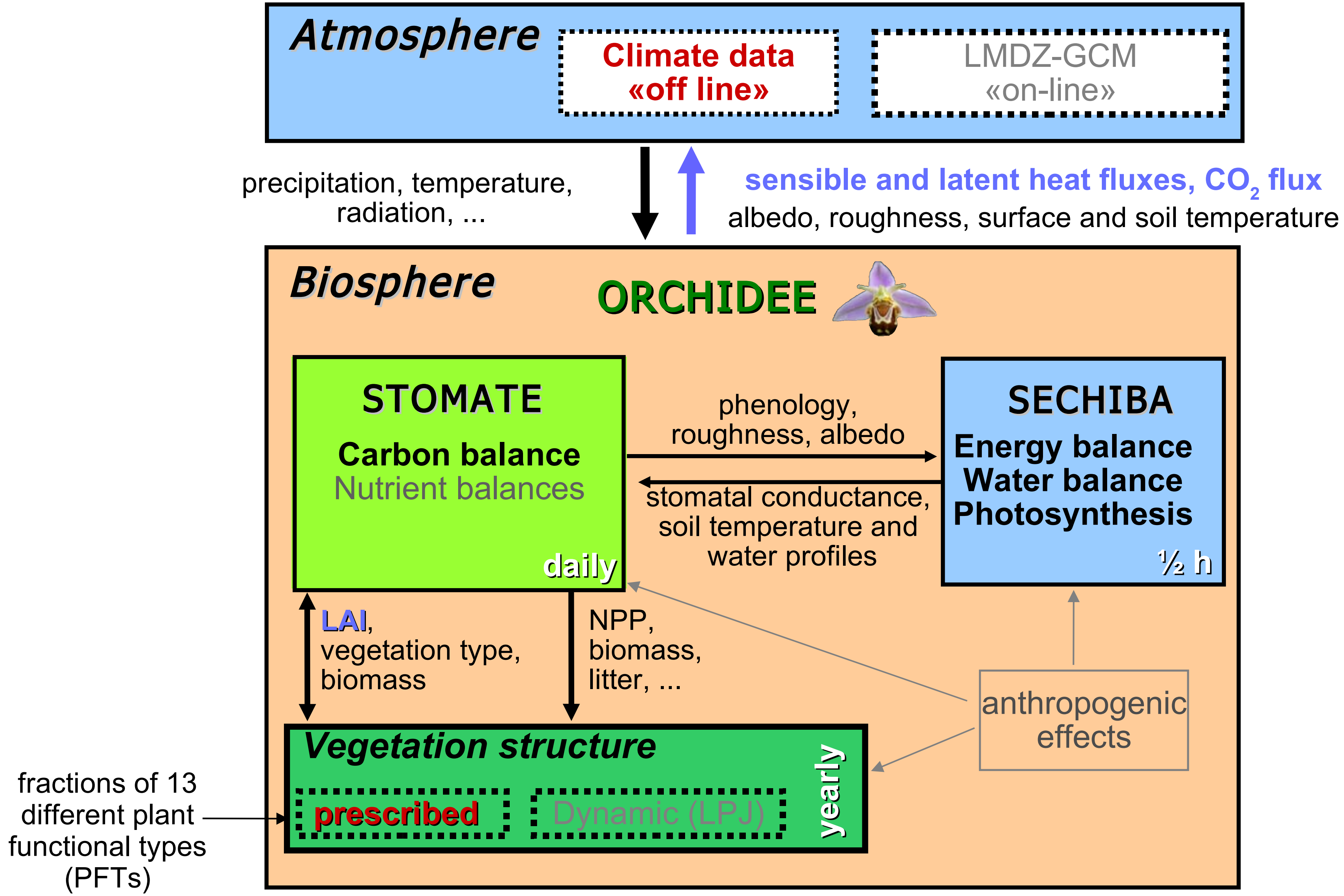
✔ *in situ* flux measurements of Net CO2, Sensible & Latent Heat, fluxes

✔ **potentials** of satellite fAPAR time series at High and Medium spatial resolutions

Main scientific questions

- Can we combine **flux data** and **satellite fAPAR** through an assimilation process?
- What do we learn on the model strengths and weaknesses?
- What is the “optimal” spatial resolution ?

The ORCHIDEE vegetation model

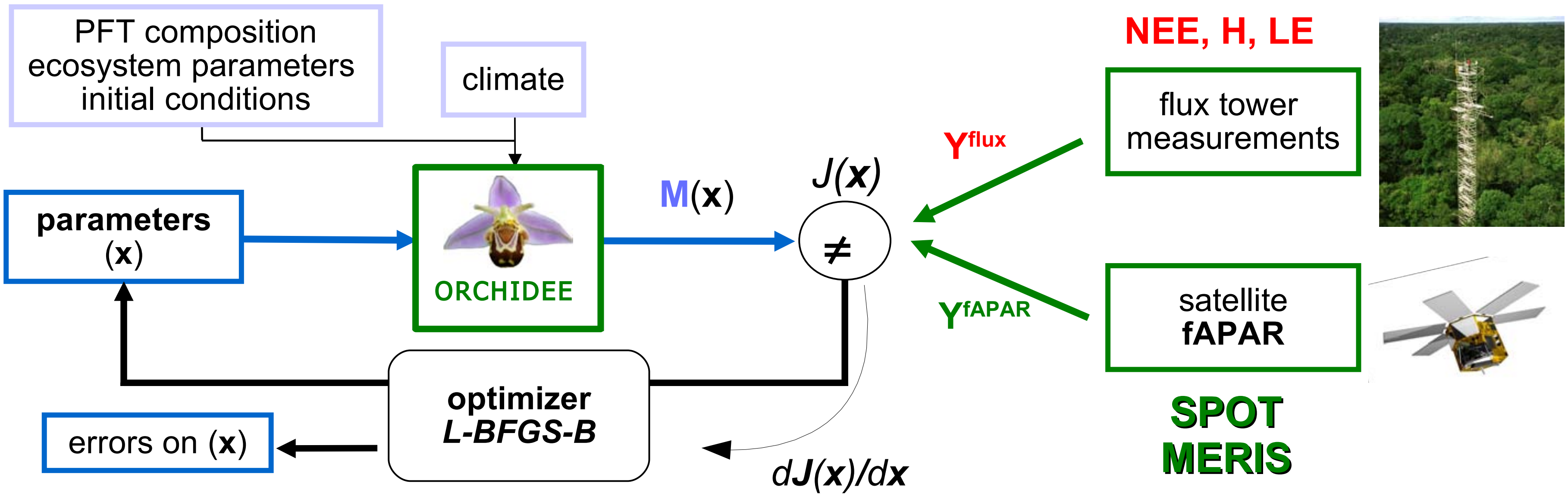


$$fAPAR(t) = \sum_i \alpha_i [1 - \exp(-K_i(t) . LAI_i(t))]$$

K: extinction coefficient

α: maximum vegetation fraction

Variational assimilation system



Bayesian optimization

$$J(\mathbf{X}) = (\mathbf{Y}^{flux}_{daily} - \mathbf{M}(\mathbf{x}))^T \mathbf{R}_{flux}^{-1} (\mathbf{Y}^{flux}_{daily} - \mathbf{M}(\mathbf{x})) + \quad \textit{daily means}$$

$$(\mathbf{Y}^{fAPAR} - \mathbf{M}(\mathbf{x}))^T \mathbf{R}_{fAPAR}^{-1} (\mathbf{Y}^{fAPAR} - \mathbf{M}(\mathbf{x})) + \quad \textit{weekly fAPAR}$$

$$(\mathbf{x} - \mathbf{x}_0)^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}_0) \quad \textit{prior information}$$

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

Data

Sites considered

- **Fontainebleau - 2006**: decideous forest (oak trees)
- **Le Bray - 2003:** pine forest
- **Puechabon - 2004:** mediterranean broadleaf evergreen forest (green oak trees)

Flux data

- Flux tower measurements of NEE, H, LE, at a half-hourly time step
- **Daily means** + temporal smoothing using a +- 15 days moving average window

Satellite fAPAR

- **Weekly** estimates from SPOT and MERIS - Neural Network estimation algorithm
- SPOT: few observations (cloudiness) ⇒ temporal extrapolation by a 2-sigmoid model corrected from seasonal trends using MERIS fAPAR data at 1km

  - ✔ **40m** : mean of the pixels around the flux tower
  - ✔ **1km** : pixels having the same vegetation composition than the flux tower pixel

Compatibility between fAPAR and flux data

Methodology

- 3 assimilations: flux only / fAPAR only / flux + fAPAR
- By how much has the fit between model/observations been improved?

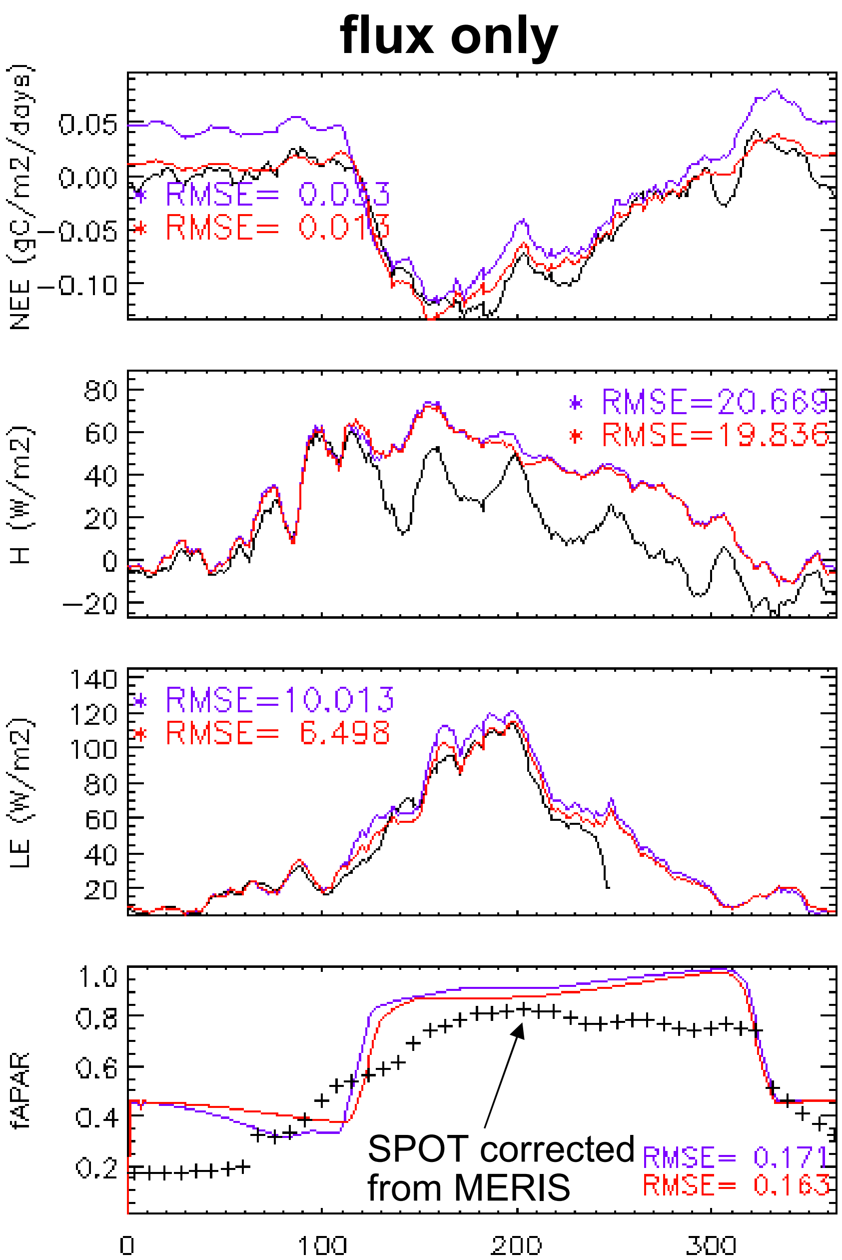
Governing processes and parameters to optimize

- Carbon assimilation → Vcmax_opt, Gsslope, **LAIMAX***, SLA, **Clumping***
- Autotrophic respiration → Fracgrowth_resp
- Heterotrophic respiration → Q10, KsoilC
- Plant phenology → **Kpheno_crit***, **Leafage***, **Senescence_T***, **LAI_init***
- Energy balance → Kalbedo_veg

**** fAPAR assimilation only***

Fontainebleau

Fontainebleau (2006) : decideous trees + grassland understory



observation
prior
posterior

- Very good agreement between ORCHIDEE and NEE & LE observations
- Misfit between model / measurements for H after leaf onset
- Low impact on posterior fAPAR simulations

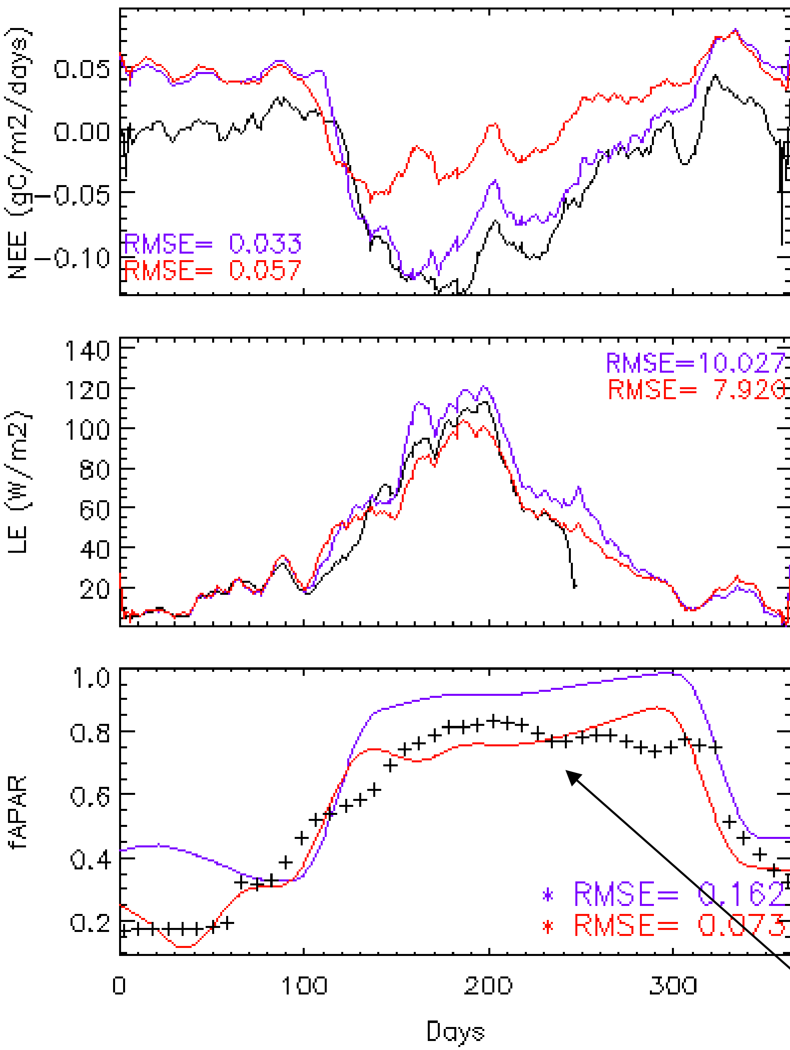
- Smooth temporal variation of fAPAR in the satellite producs / abrupts changes in the model (leaf onset, senescence)
  - ➔ processing of fAPAR satellite data
  - ➔ land-cover variability seen by satellites / mean behaviour simulated by ORCHIDEE

- No vertical mixing of vegetation in ORCHIDEE

Fontainebleau

Fontainebleau (2006) : decideous trees + grassland understory

SPOT fAPAR only

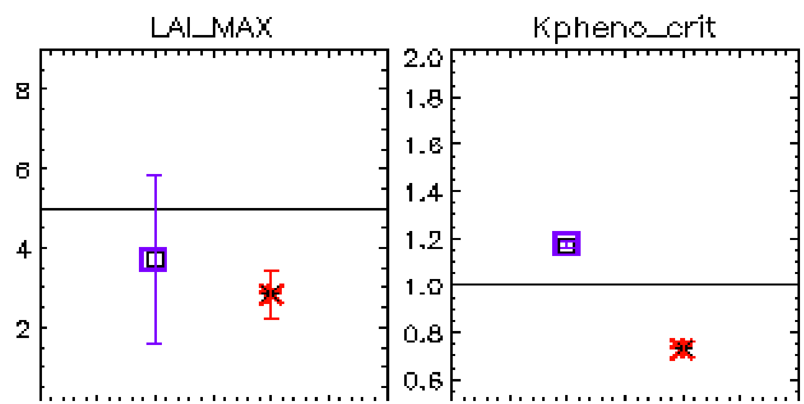


SPOT corrected from MERIS

observation **prior** **posterior**

- Strong reducing of the carbon uptake in summer (NEE)
- Advance of the start of the growing season

Optimized parameters

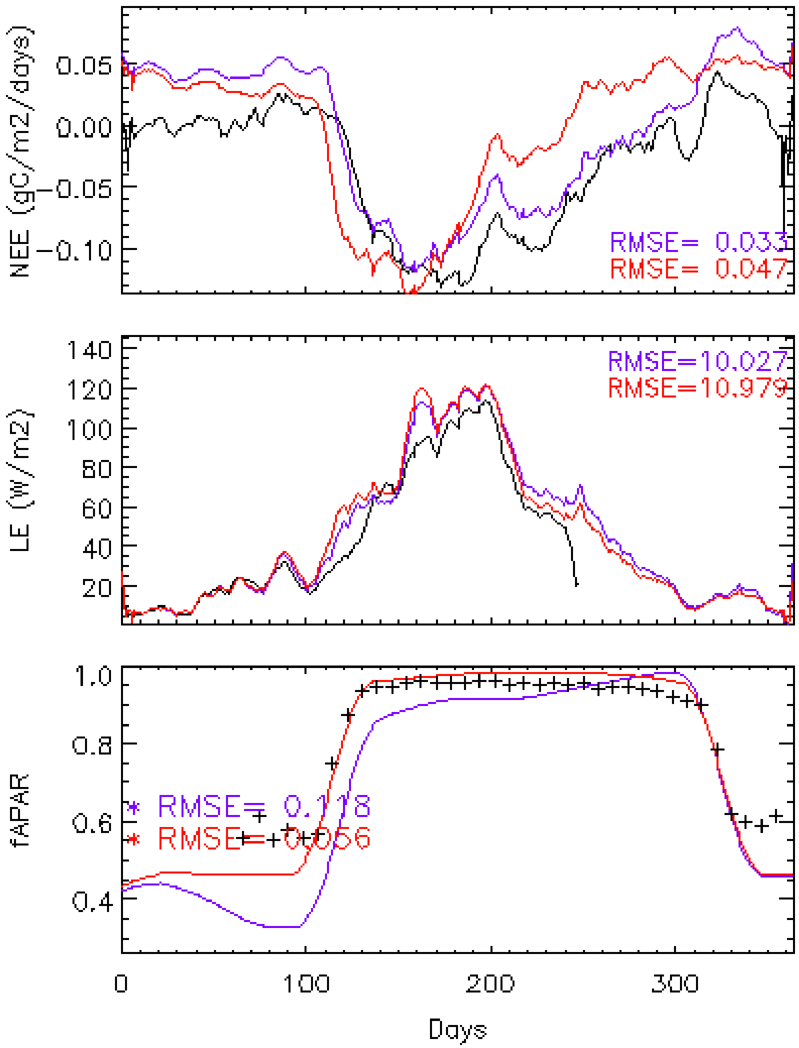


flux SPOT

Fontainebleau

Fontainebleau (2006) : decideous trees + grassland understory

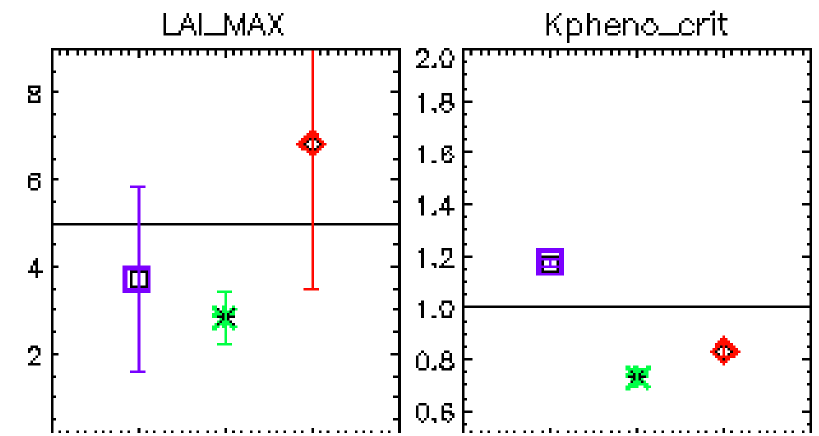
fAPAR *in situ* only



observation **prior** **posterior**

- Model / fAPAR data agreement: length of the growing season, slope of fAPAR increase
- Slight advance of the date of leaf onset:
  - ✔ assimilation problem of tuning initial LAI
  - ✔ model deficiency: different phasing between NEE and fAPAR?

Optimized parameters

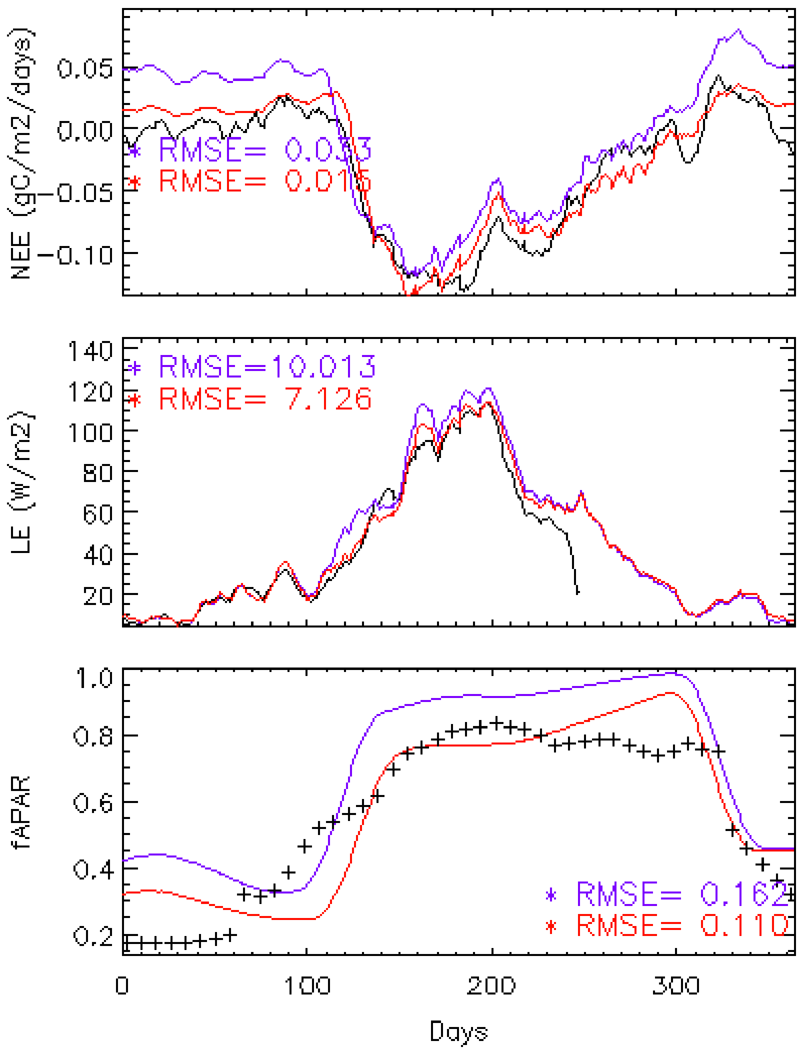


flux SPOT in situ fAPAR

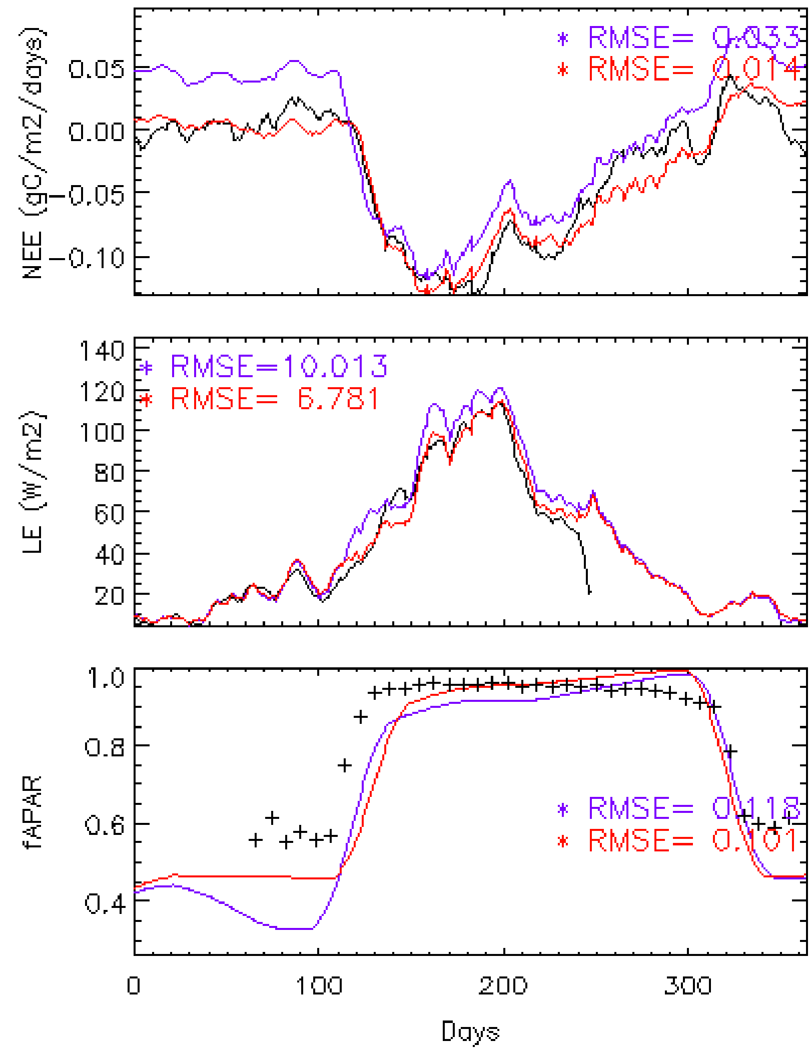
Fontainebleau

Fontainebleau (2006) : decideous trees + grassland understory

flux + SPOT fAPAR



flux + *in situ* fAPAR



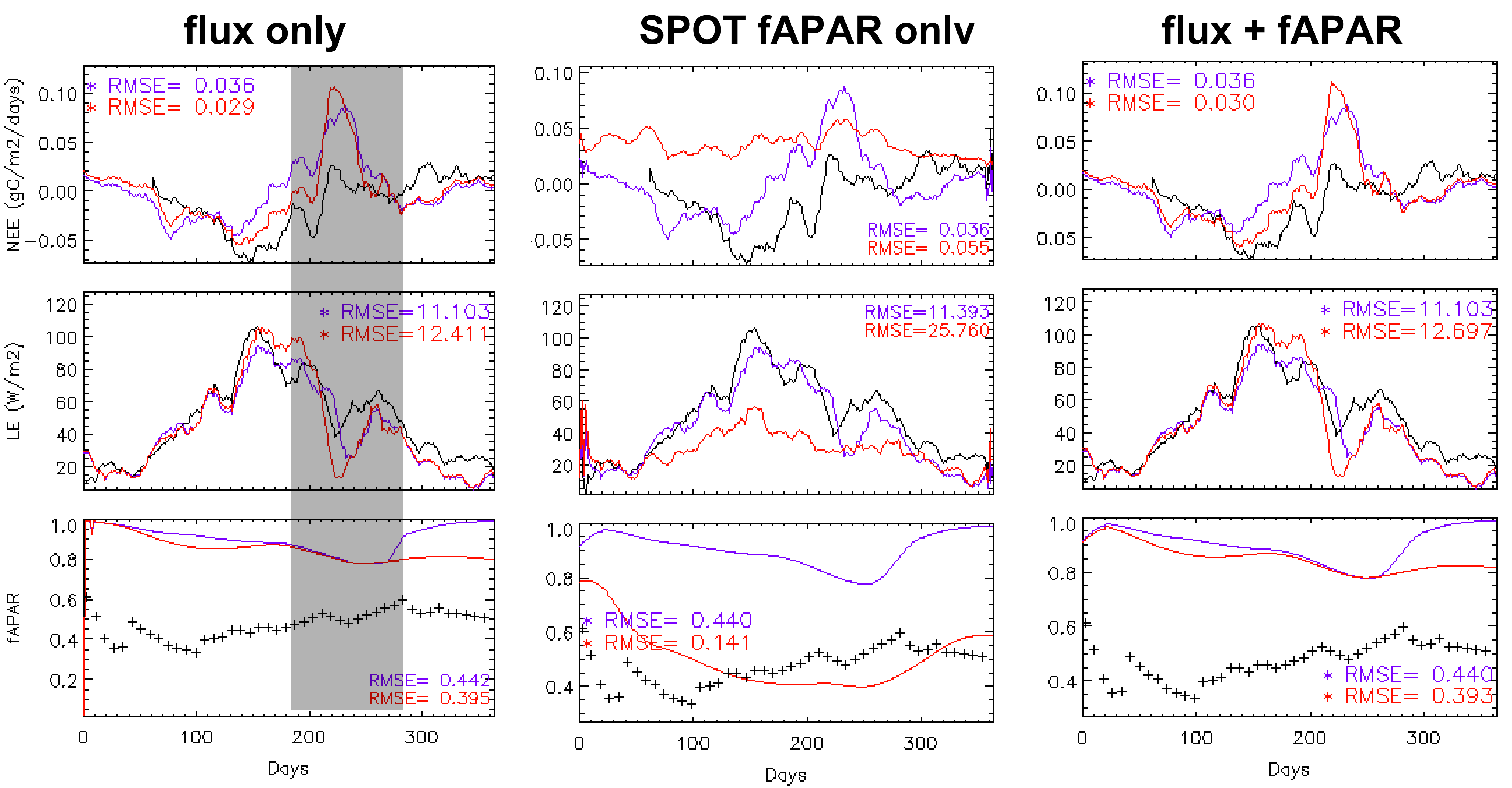
observation
prior
posterior

- flux data drive the assimilation results
- better agreement with *in situ* fAPAR data

Le Bray

Le Bray (2003) : pine trees + grassland understory

observation **prior** **posterior**



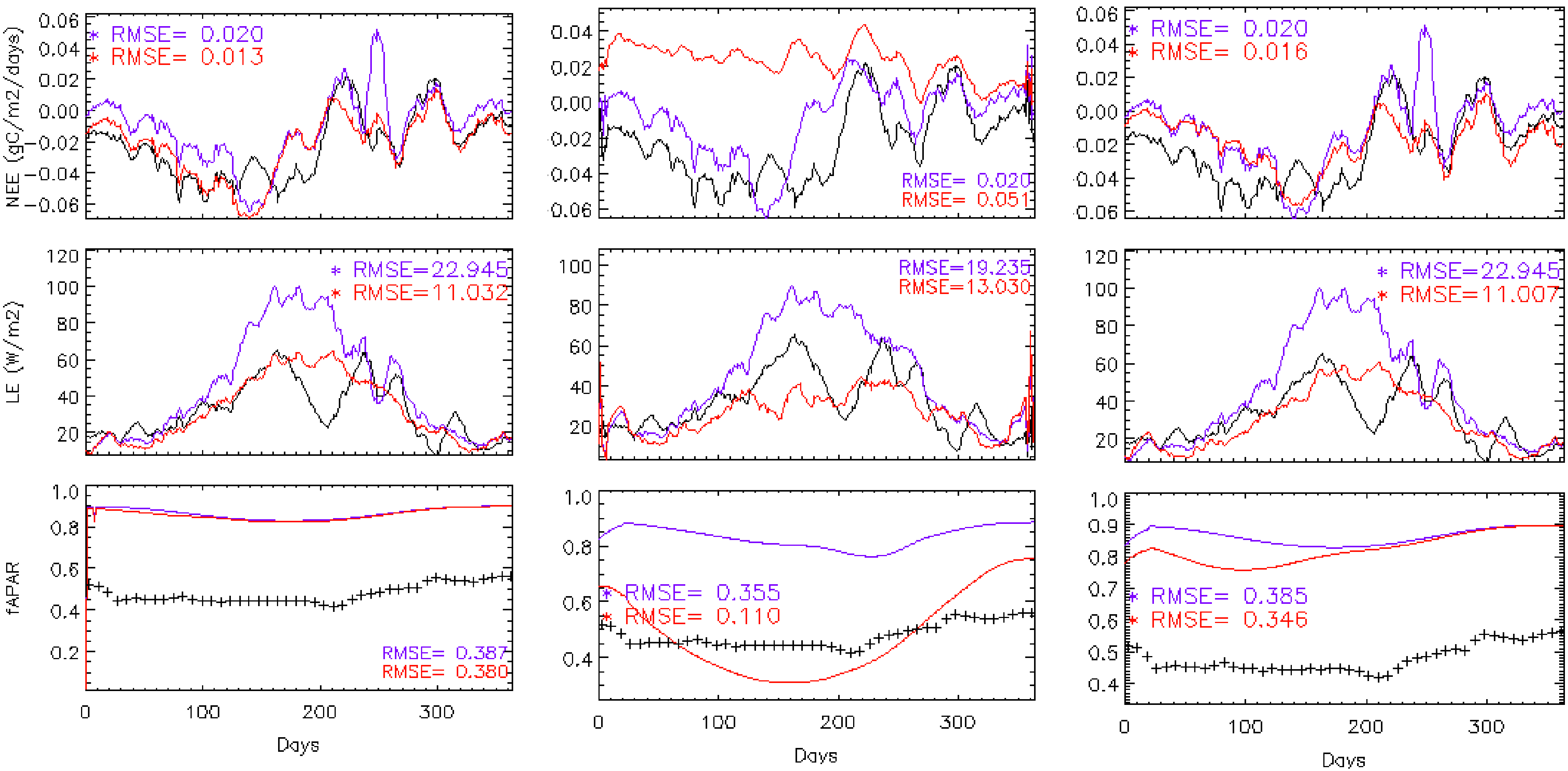
- 2003 drought summer event not well captured by the model
- Incompatibility of fAPAR levels between model/satellite product

Puechabon

Puechabon (2004) : mediterranean broadleaf evergreen trees

observation **prior** **posterior**

flux only **MERIS fAPAR only** **flux + fAPAR**



- simulated fAPAR reproduce the bowl-shape variation as in in site measurements, as well as the mean fAPAR level / low level for the satellite product
- similar findings than for Le Bray

Conclusions

- **ORCHIDEE** simulates quite well the flux seasonal variations (NEE in particular)

- Assimilation of fAPAR data creates some inconsistencies between NEE observations / model due to differences in:

  - ✔ fAPAR levels
  - ✔ seasonality (timing, smoothness)

    - ➔ need for **high temporal resolution** / **high spatial resolution** fAPAR data
    - ➔ need in site validation datasets

- Use of HR fAPAR data requires model improvements:

  - ✔ vegetation vertical mixing
  - ✔ phenology for some specific PFT

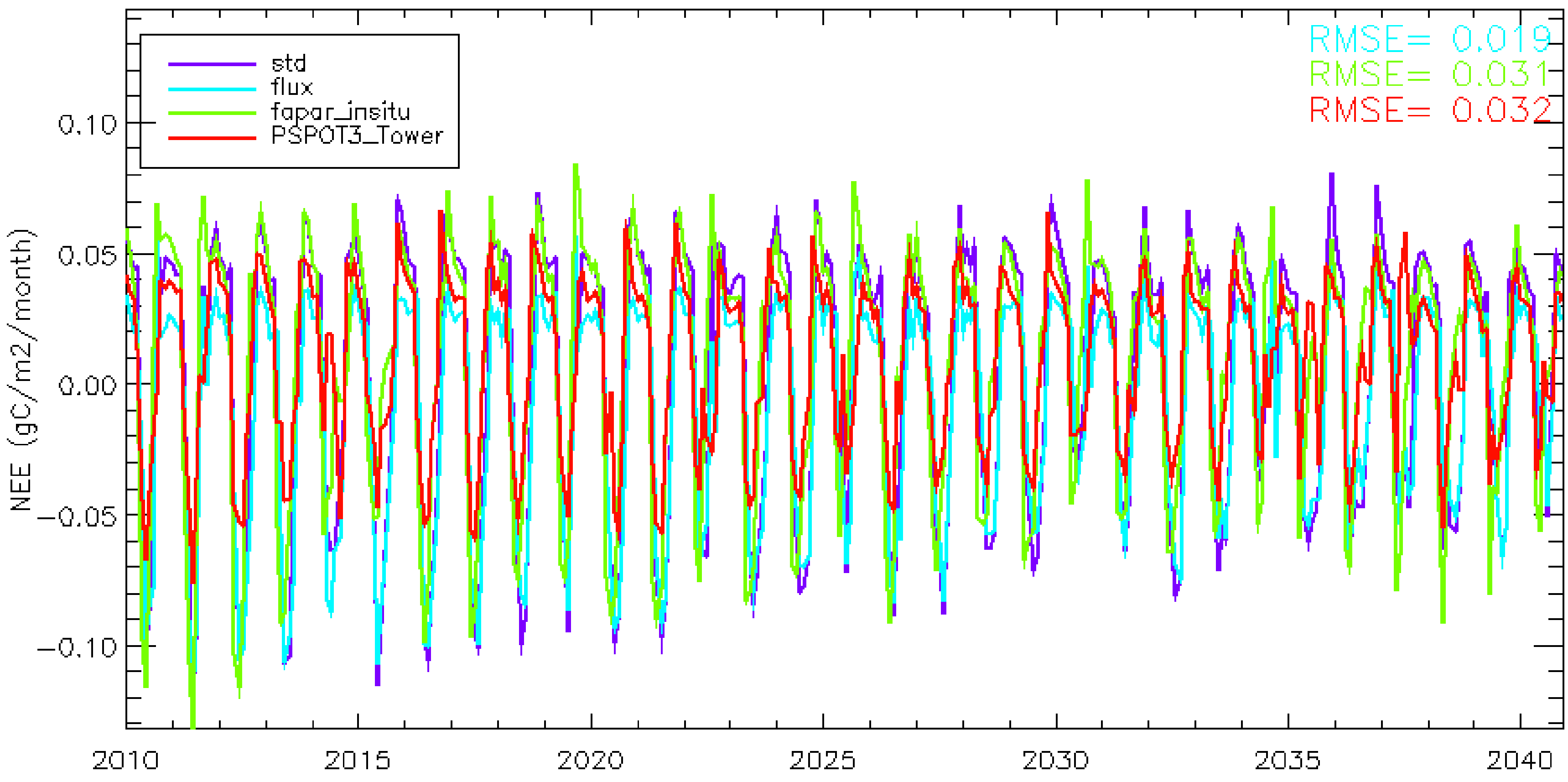
- Joint assimilation of flux & fAPAR data seems possible

- Need carefull examination of retrieved parameters and uncertainties

Impact of retrieved parameters on prognostic NEE simulations

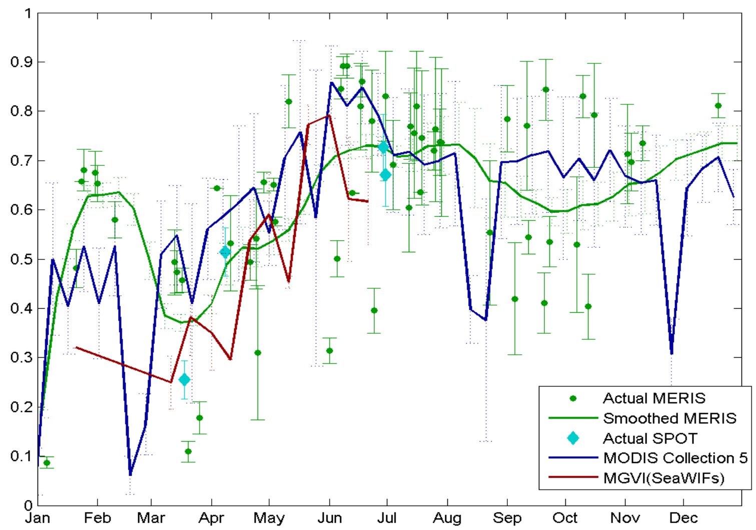
- Meteorological forcing derived from the coupled IPSL model **2010-2040**
- A1B scenario of CO_2 emission from IPCC
- Various sets of ORCHIDEE parameters derived from assimilation of various classes of data

Fontainebleau (monthly means)

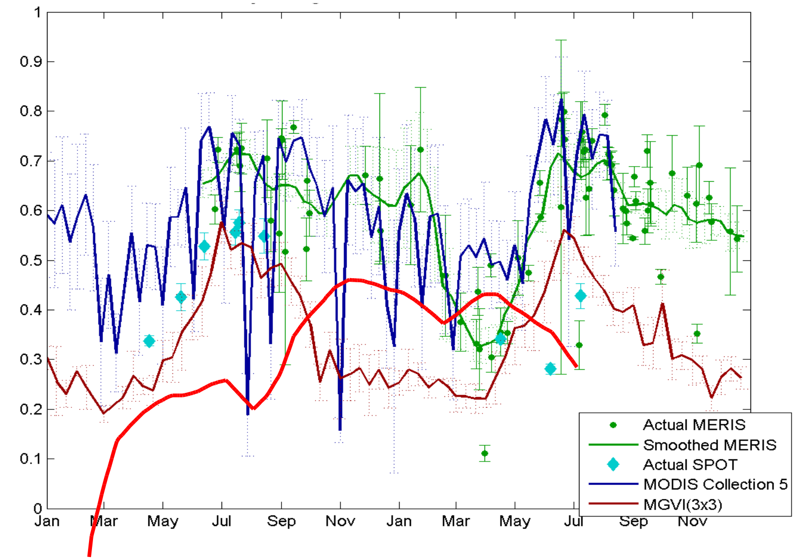


Satellite fAPAR data comparison

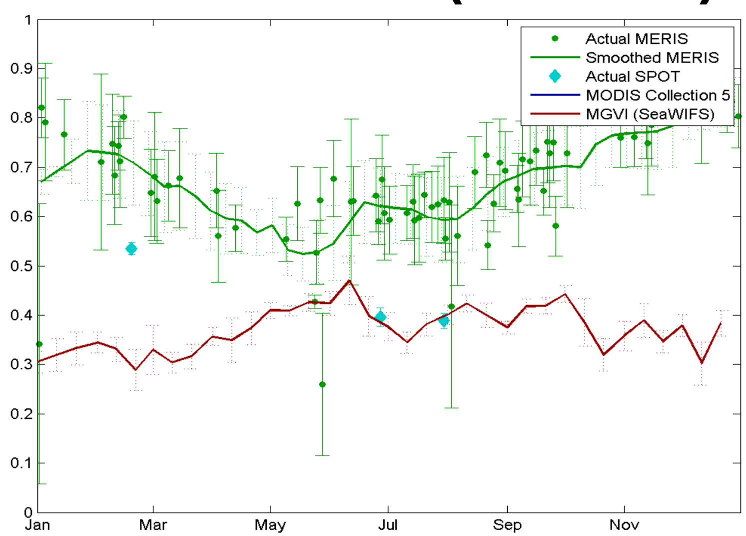
Fontainebleau (3x3 km2)

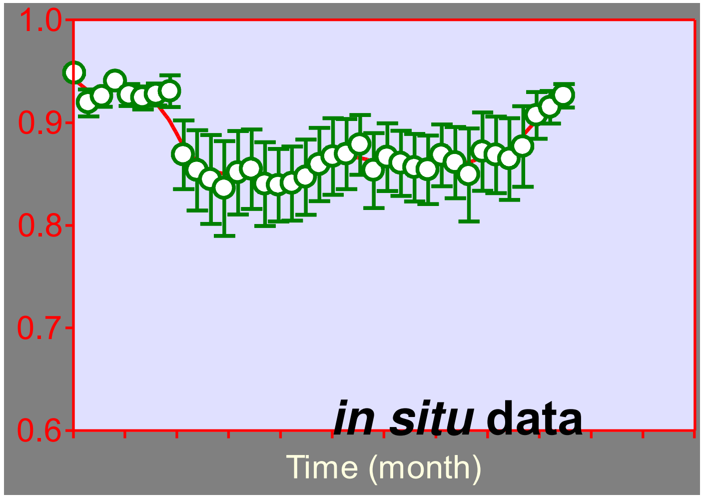


Le Bray (3x3 km2)



Puechabon (3x3 km2)





Compatibility model / satellite fAPAR with the spatial scale

Principles

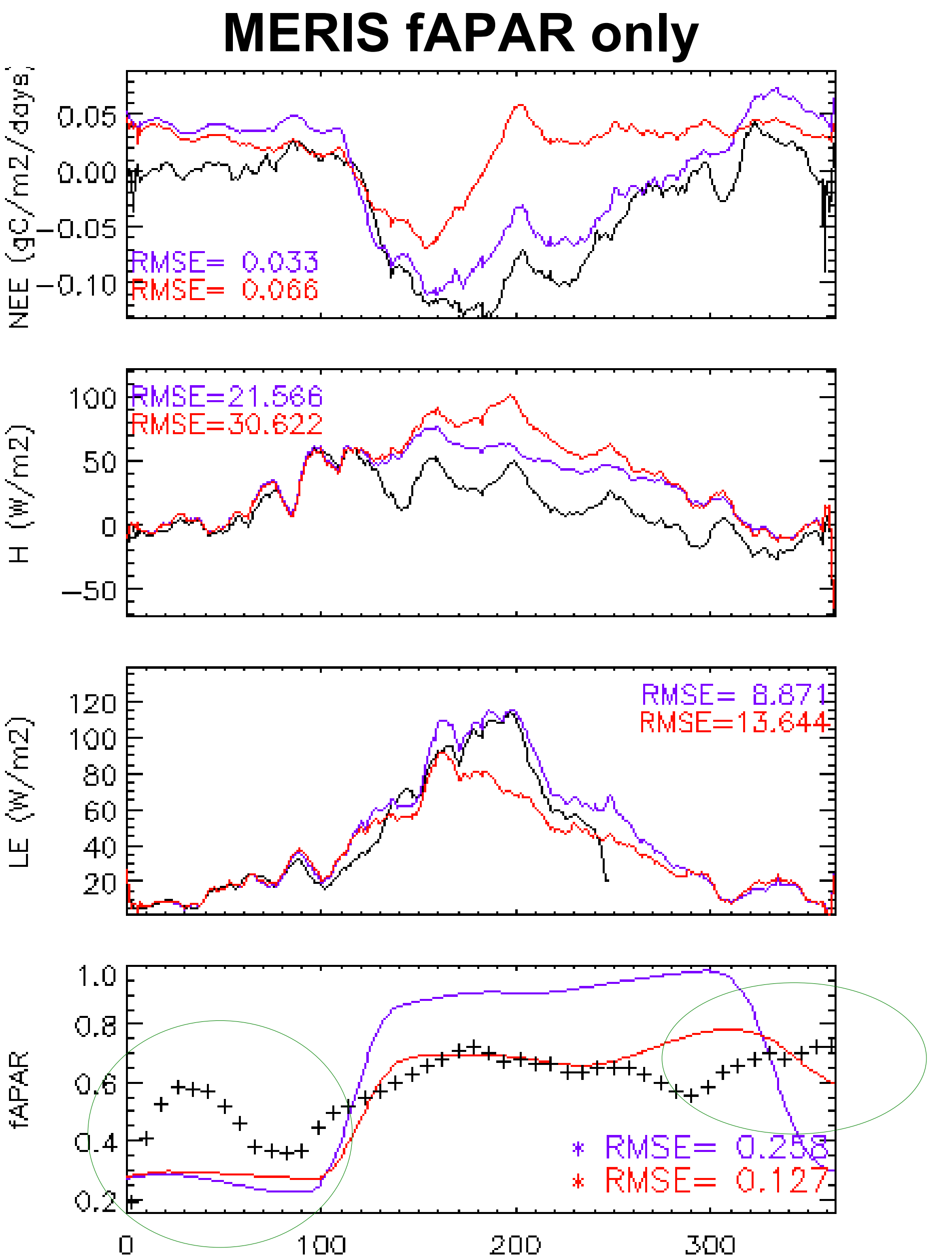
- Assimilation of fAPAR data at 40m / 1km / 10km
- Assess the model/measurements misfit

Increased fAPAR agreement at larger spatial resolution

- **HR**: local heterogeneity seen by the satellite / mean behaviour simulated by ORCHIDEE
- **MR**: spatial aggregation smoothes out the errors in satellite data and model (mis-partitioning the scene into PFTs smoothes)
-
- **Impact on the retrieved parameters**:
  - ✔ differences in the parameter estimates comprised within their error bars (except for Kpheno_crit)
  - ✔ increased uncertainty at medium & coarse spatial resolutions (lesser visibility of a parameter, higher degrees of freedom)

Compatibility model / satellite fAPAR with the spatial scale

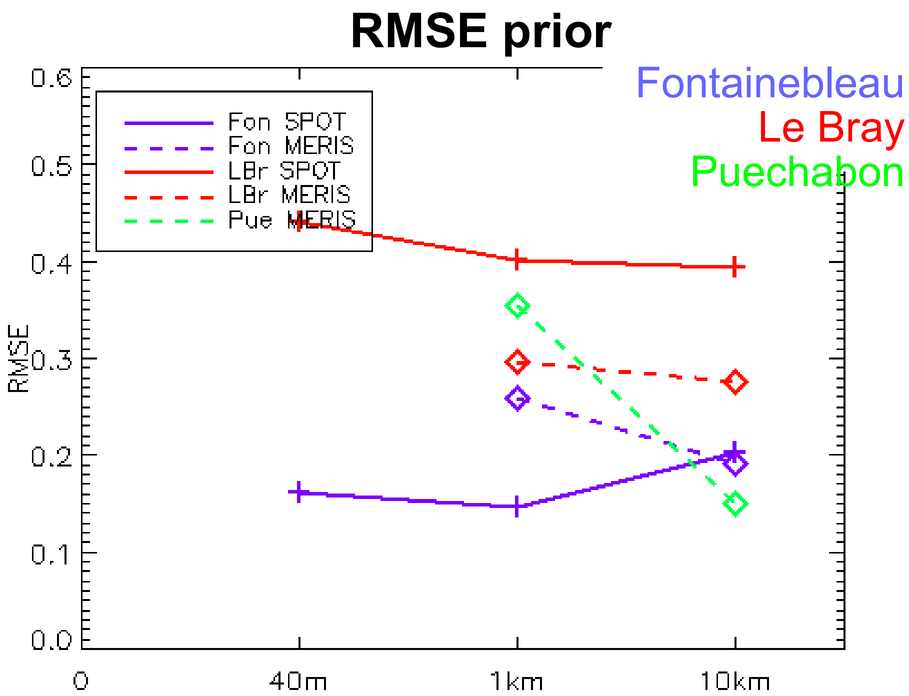
Fontainebleau

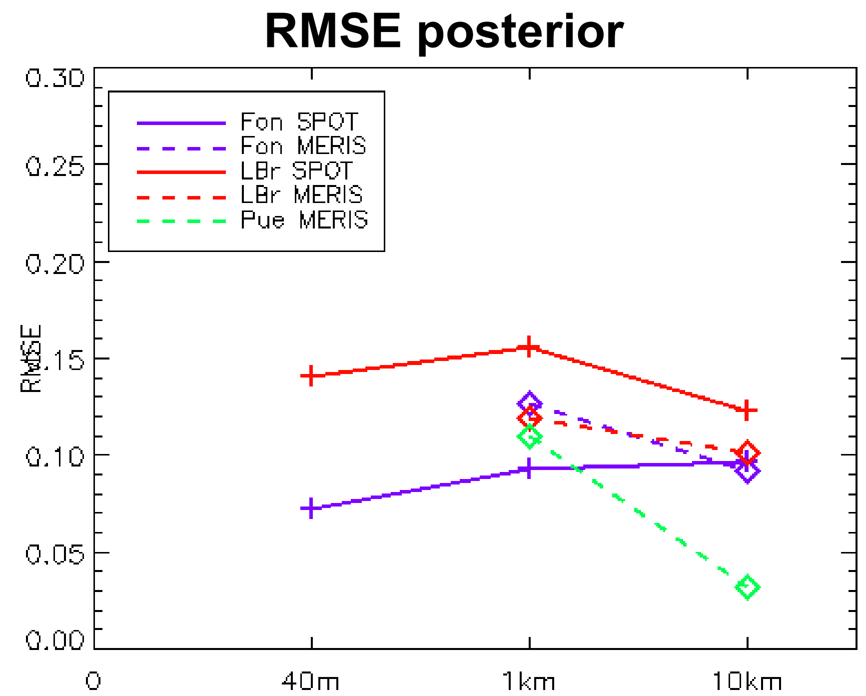


- Problems of fAPAR levels in winter
  - ➔ residual atmospheric effects
  - ➔ high illumination angles not properly accounted for in the estimation algorithm

- Again, strong decrease of the net carbon assimilation in summer (NEE)

Compatibility model / satellite fAPAR with the spatial scale





- Better agreement at 10km than at 40m
  - ✔ **model:** each individual Vegetation Type has its individual “different” seasonal response and spatial mean is smoother than each individual
  - ✔ **satellite:** locally strong spatial heterogeneities in the satellite products are smoothed out at larger spatial resolutions

- **PFT dependant / spatial heterogeneity**