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Using spatial constraints into a variational data assimilation scheme of remote sensing images. Example on the simple crop model Bonsaï.

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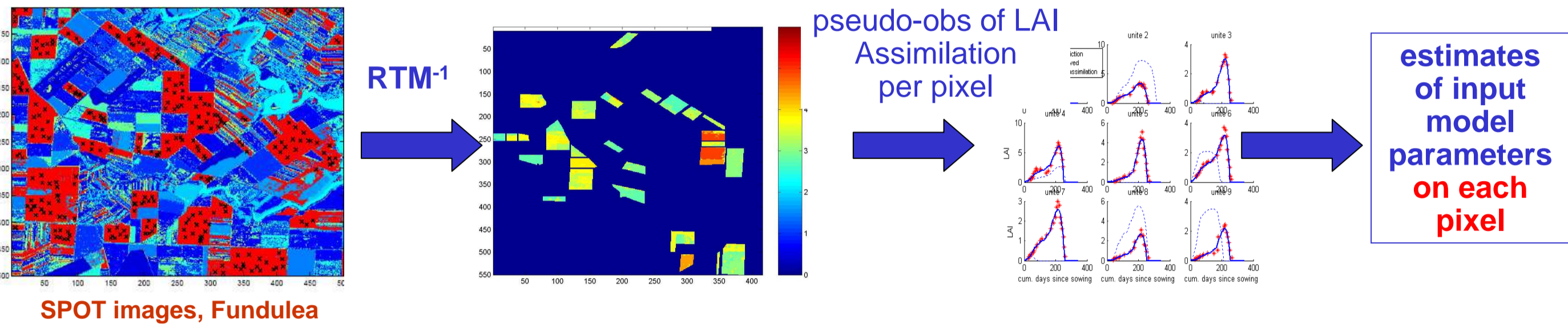
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Introduction

Assimilation of remote sensing data into crop models is generally applied pixel by pixel, while the whole image data is available :



1. classical method (on single pixel) ignores possible spatial structures
2. spatial properties of time series of images = additional source of information
3. inverse problem is generally ill-posed when applied at the pixel level
4. repeating the same action a great number of times is not computer efficient

Objectives

- to exploit some spatial structures of the parameters to reduce the size of the problem and make its inversion manageable.
- to process concurrently a large set of pixels using variational assimilation
- Application on a simple model of plant growth, the BONSAÏ model

BONSAÏ model

BONSAÏ (Baret, 1986; Lauvernet 2005) is a semi-mecanistic model that simulates LAI in function of cumulated day-degrees :

$$LAI_t = L_{max} \cdot \left(\frac{1}{(1 + e^{-A(ST_t - t_0 - (\Delta T_s + T_i))})^C} - e^{B(ST_t - t_0 - (\Delta T_s + T_i))} \right)$$

$$A = \frac{1}{T_i} \cdot \log \left(\left(e^{\frac{B}{C} \cdot (\Delta T_s + T_i)} - 1 \right) \right)$$

t_0 = the growing date
 L_{max} = max value of LAI
 B = additional parameter
 $T_i, \Delta T_s$ = temperature thresholds
 C = generalized logistic
 A = growing speed, calibrated

Variational data assimilation theory

State Variables
LAI, biomass, ...

model

$$\frac{dX}{dt} = F(X, K)$$

$X(0) = u$

Parameters Variables

Initial Conditions

cost fonction

$$J(K) = \frac{1}{2} \|C \cdot X(K) - X_{obs}\|_{\mathcal{X}_{obs}}^2 + \frac{1}{2} \|K - K_0\|_{\mathcal{K}}^2$$

adjoint model

$$\frac{dP}{dt} + \left[\frac{\partial F}{\partial X} \right]^T P = C^T (CX - X_{obs})$$

$P(T) = 0$

optimality condition

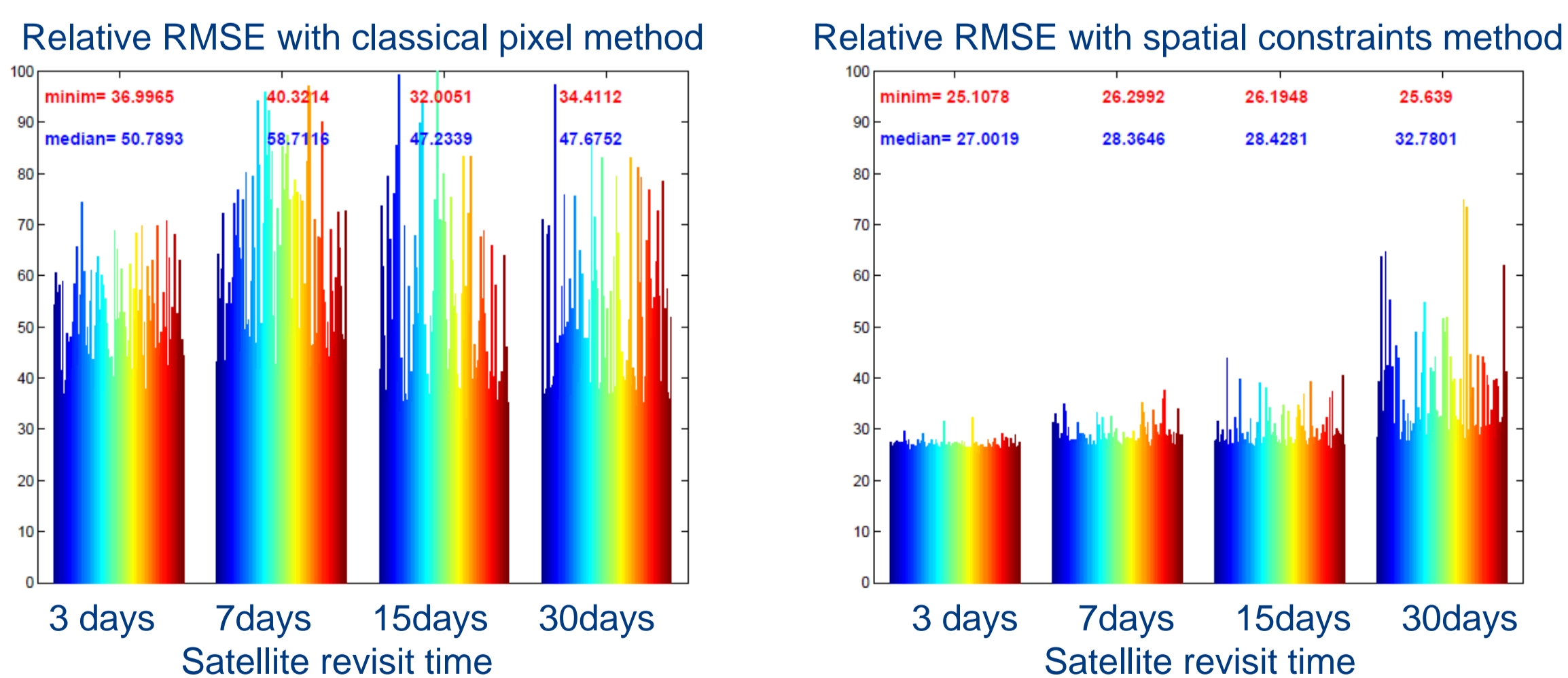
$$\nabla_K J = - \left[\frac{\partial F}{\partial K} \right]^T P + K - K_0$$

Optimality System contains ALL available information : observations, model, statistics, prior information...

Adjoint model is performed with TAPENADE DA tool.

→ 1. directional derivatives and 2. transposition

Evaluation of both DA methods on parameter estimation

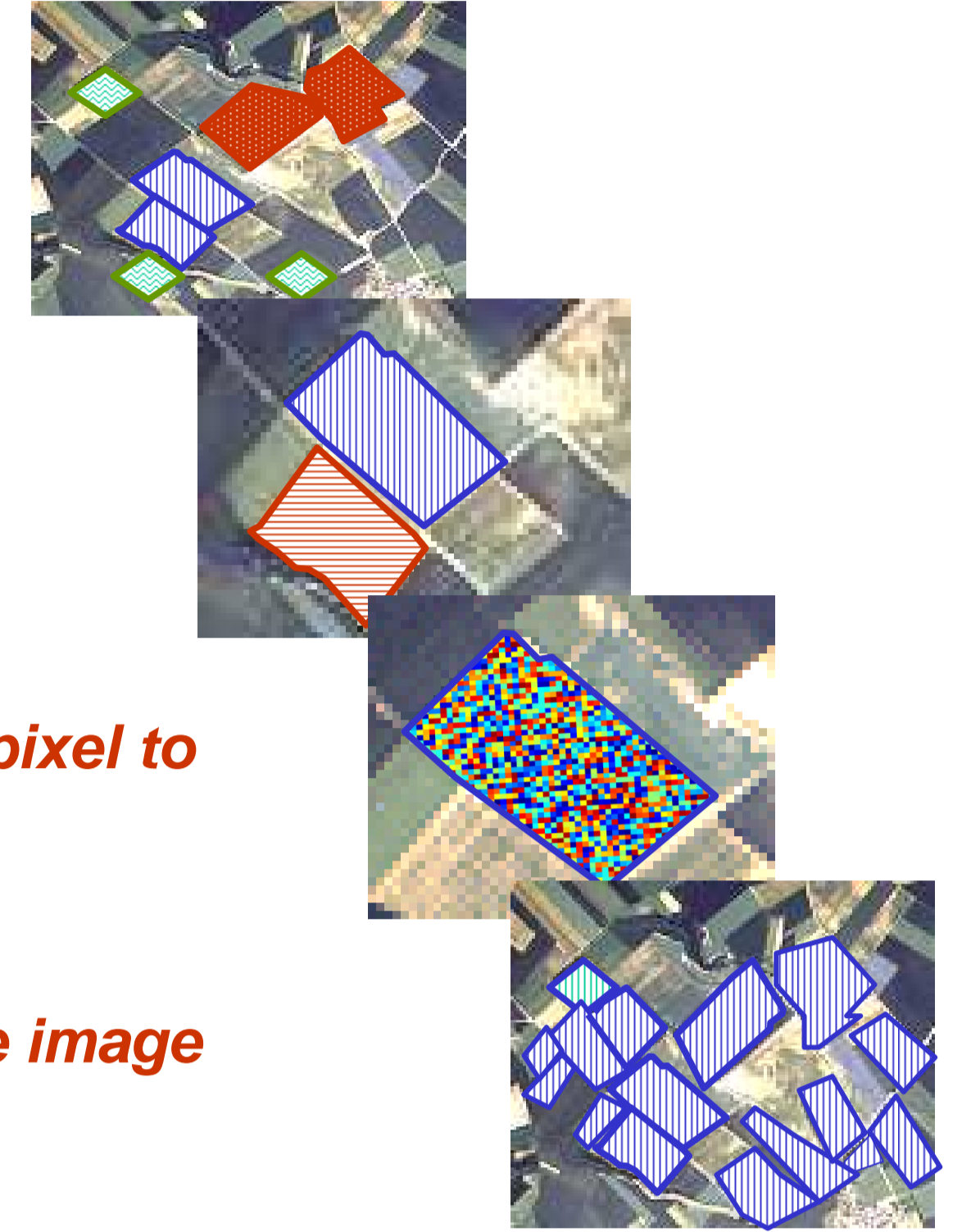


- Better global identification: 48% → 28% RRMSE
- Stability considering satellite revisit time
- Reduction of the inverse problem size : 600 → 314 parameters to estimate
- Better parameters estimation that are more and less influent (growing date)

Which spatial structures to which parameters?

The method proposed here assumes that the parameters are governed by spatial structures depending on several levels:

- Cultivar level**
phenological stages, leaves properties → stable on all fields from same cultivar
- Field level**
agricultural practices → stable on all pixels from same field
- Pixel level**
soil properties → different from one pixel to another
- Non-significant and not sensitive** → stable on the whole image

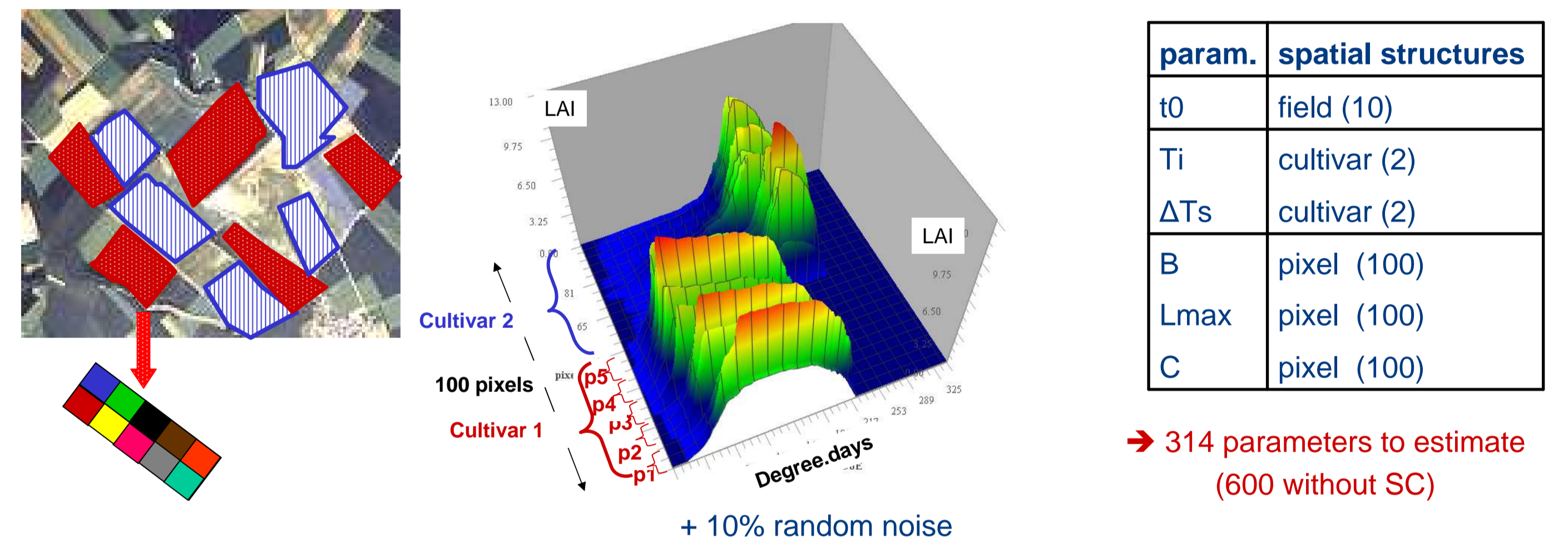


We now have to estimate all these parameters considering these constraints and dependencies

⚠ The connectivity between neighbour pixels & correlation are not taken into account here.

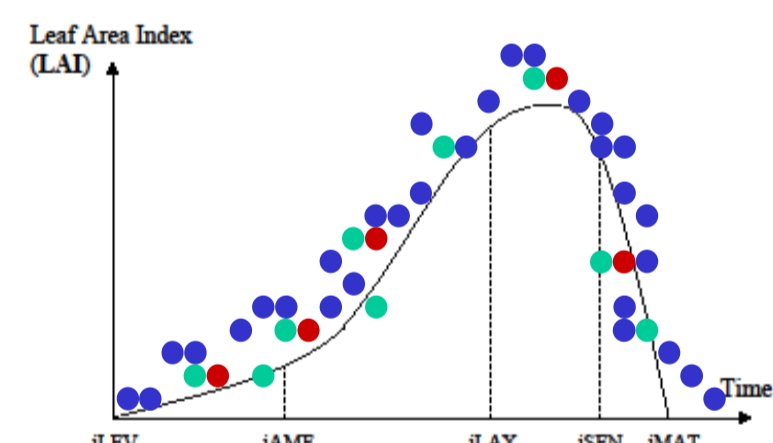
Twin experiments to test sensitivity of the spatial constraints method on the satellite revisit time

- Generation of noisy LAI observations: 2 cultivar, 5 fields/cultivar, 10 pix/field

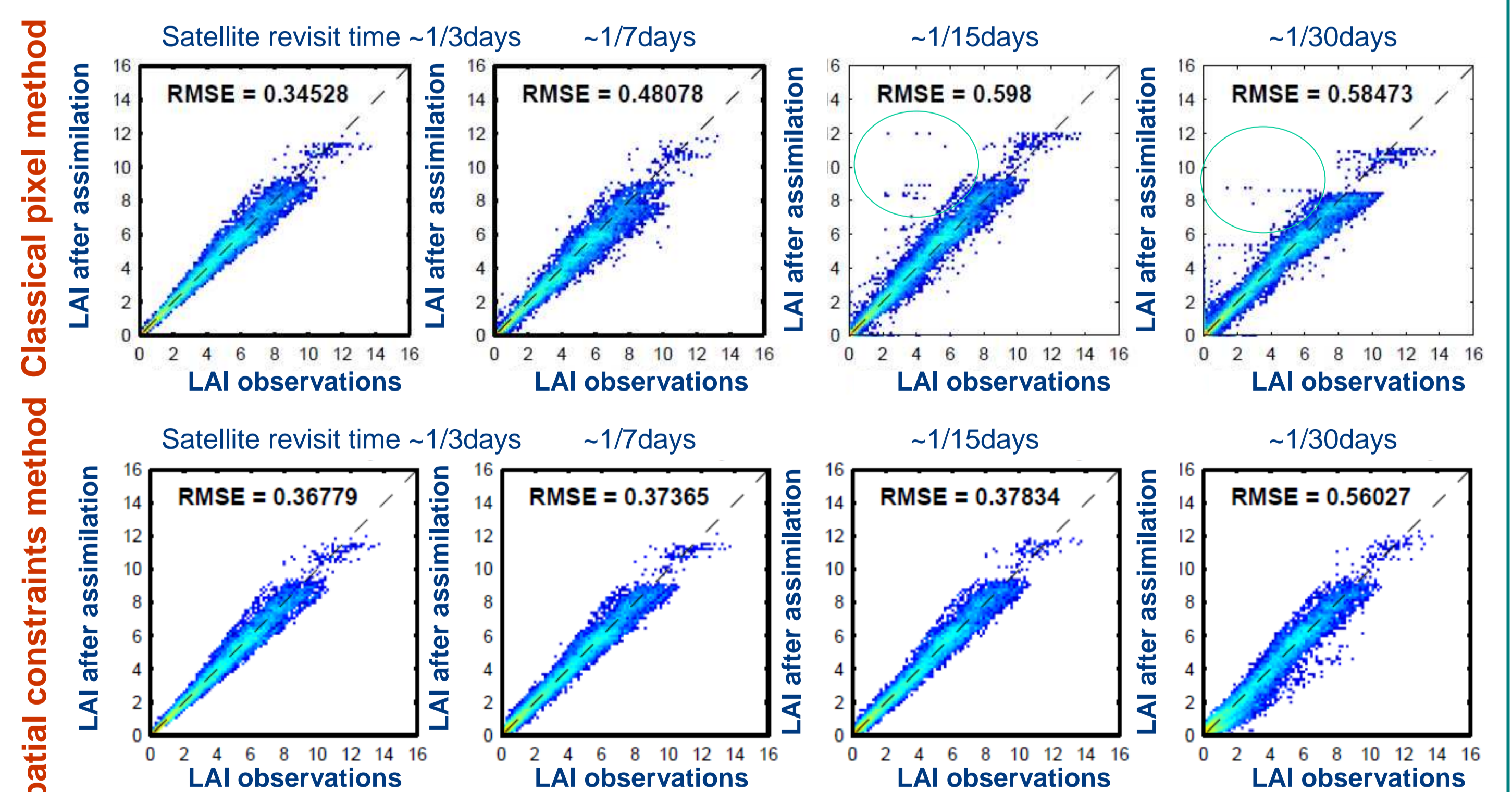


- 4 types of satellite revisit time : every 3 days, 7 days, 15 days, 30 days
- on 100 cases of probability (uniform(0.5)) to be cloud masked

- 58 obs. for 3 days frequency (0 - 120)
- 24 obs. for 7 days (0 - 50)
- 11 obs. for 15 days (0 - 22)
- 6 obs. for 30 days (0 - 12)



Evaluation of both DA methods on LAI estimation



- As satisfying as pixel method when lot of data to assimilate
- The CS method is more robust if less available observations
- Results are more precise and stable → 1/7days without → 1/15days with SC
- Even with very poor obs. (1/30days → still no local min)
- Convergence : 3000 → 50 iterations but same CPU