Exploitation des dimensions spatio-temporelles en télédétection-phenotypage

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Les 6 dimensions disponibles pour caractériser les traits

$$Trait = f\left[M\left(\boxed{x, y}, z, \lambda, \Omega, \boxed{t}\right)\right]$$

Measurement

Scanner

Imagerie

3D imagerie

Longueur d'onde

Direction

Temps

Echantillonnage du champ de rayonnement réfléchi / émis par les couverts végétaux

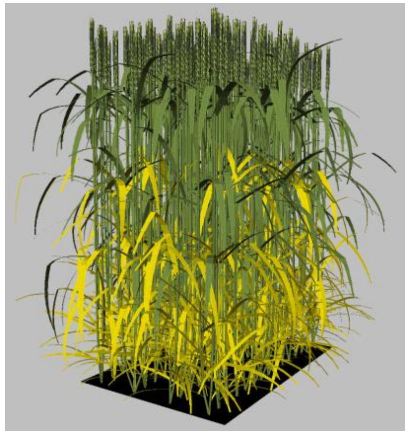
Les différents systèmes d’observation

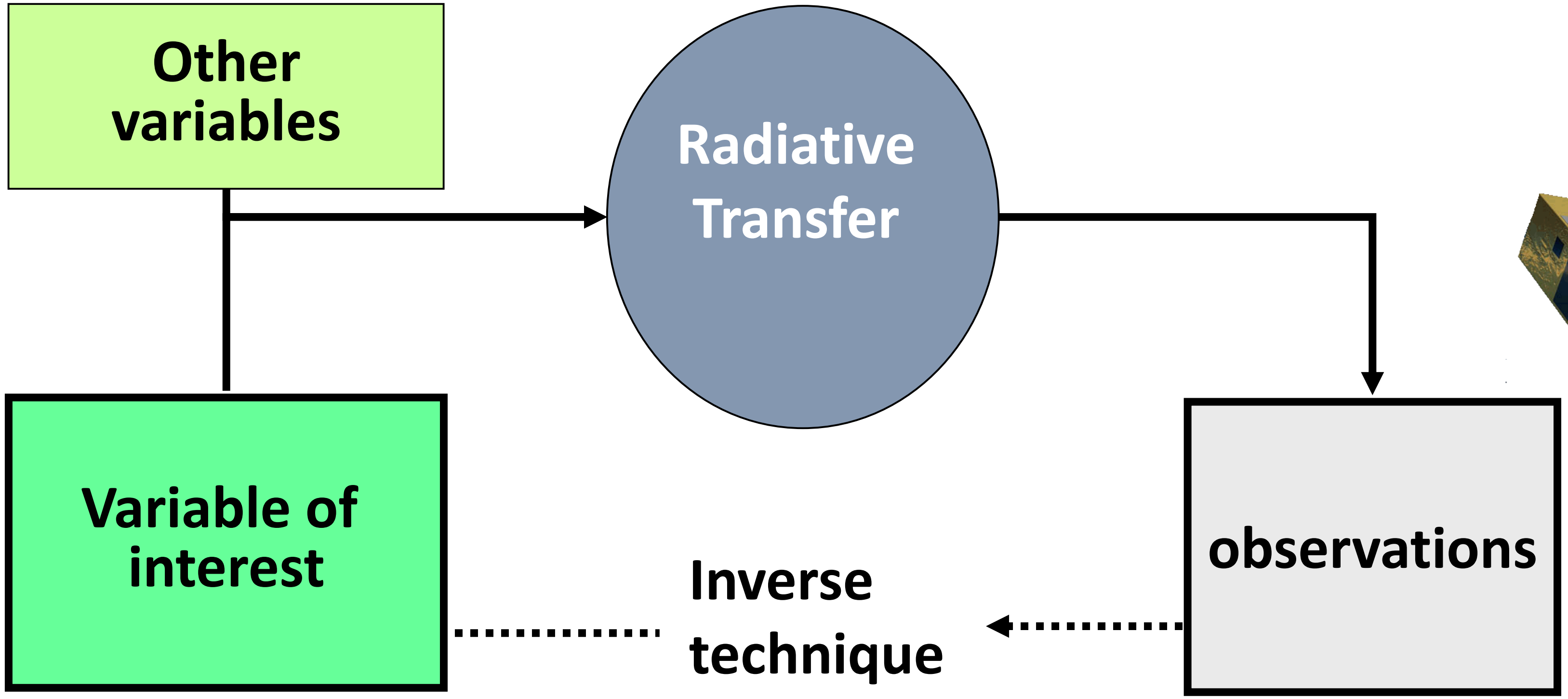
	Fixe	Porté	Tracteur	Phenomobile	Portique	Drone	Satellite
Résolution spatiale	1mm	0.2mm	0.5mm	0.5mm	0.5mm	0.5mm – 5cm	0.5m-10m
Couverture spatiale	<100m²	<1 ha	<5 ha	<5ha	<0.3ha	<15ha	>500km²
Temps de revisite	1h-1j	3j-30j	3j-30j	3j-30j	3h-30j	3h-30j	1j-10j
Directionnalité	0° ‖ 45°	0° & 45°	0°	0° & 45°	0° & 45°	0° (45°)	≈ 0°
Richesse Spectrale	RGB	RGB	RGB+Multi	RGB+Multi	RGB+Multi	RGB+Multi+IRT	Multi
3D	Non	Photo	Photo, LiDAR	Photo, LiDAR	Photo, LiDAR	Photo (LiDAR)	Non

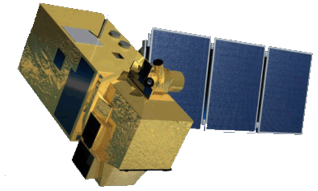
Tous les systèmes échantillonnent l’espace et le temps à des résolutions variables. Typiquement :

- **Temps: 1h -> 1 mois**
- **Espace: 1/10 mm -> km**

Trait estimation is an inverse problem







The inverse problem in remote sensing / phenotyping is generally ill-posed: several solutions may provide about the same radiometric response

Using constraints to regularize the inverse problem

- ❑ **Prior information on the distribution of the input variables**
  - o Introduced using:
    - ✓ Cost function with Bayesian term
      - LUT, iterative optimization
    - ✓ Machine learning trained over datasets generated using on the prior knowledge of the distributions
      - NNT, SVM, VIs …
  - o With limitations due to:
    - ✓ Knowledge of prior distribution
    - ✓ Uncertainties in the model / measurements

- ❑ **Temporal and spatial constraints**
  - o Based on the assumption of a continuum of canopy characteristics in the spatio-temporal domain.

The spatio-temporal continuum: the temporal dimension (1/2)

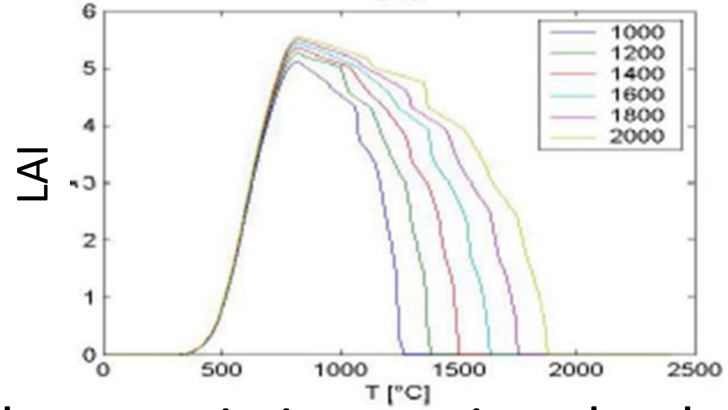
- Vegetation structure (LAI) results from incremental processes

$$LAI(t) = LAI(t-1) + \quad \Delta\, DM.SLA \quad - \quad \Delta LAI_{sen}$$

Daily Biomass produced & allocated to the leaves

Specific Leaf Area

Leaf duration



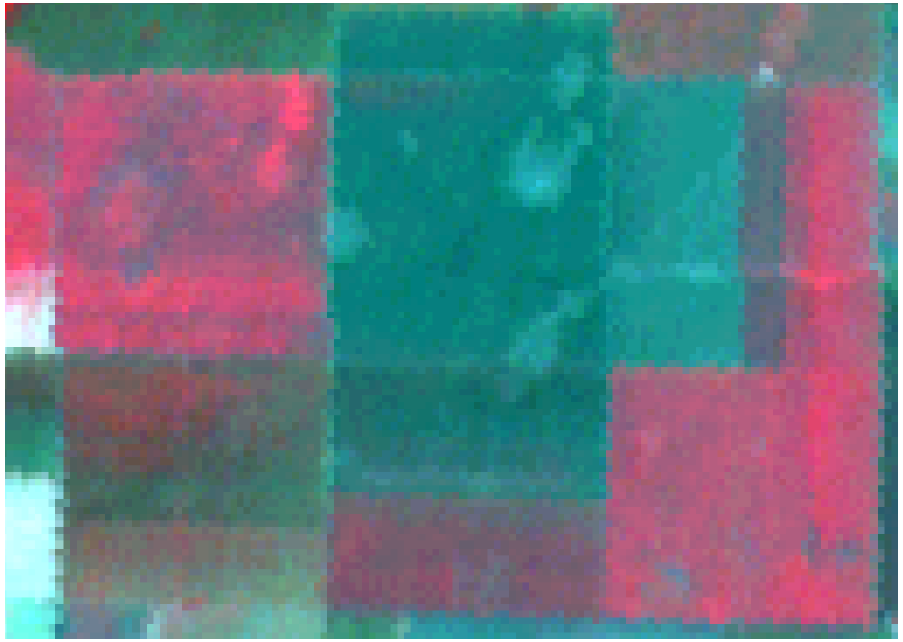
smooth dynamics

  - Other structural characteristics varying slowly (LAD …)

- Leaf properties varying also through incremental processes: smooth dynamics

The spatio-temporal continuum: the spatial dimension (2/2)

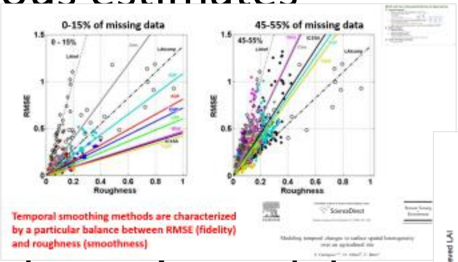
- Within a vegetation patch (few pixels in the same object), pixels in a neighborhood are generally showing a local gradient due to:
  - the PSF of the instrument/reprojection
  - Factors of local variability mainly linked to soil properties and crop implantation

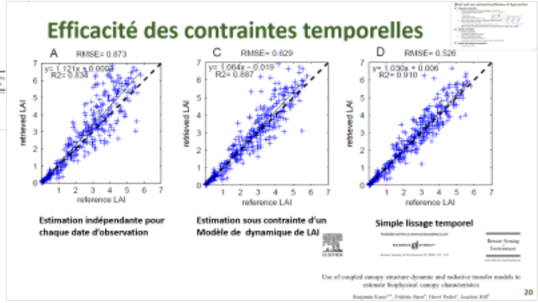


Working on local (3x3, 5x5 …) allows reducing problems due to multi-temporal registration accuracy

(Brief and non-exhaustive) Review of Approaches

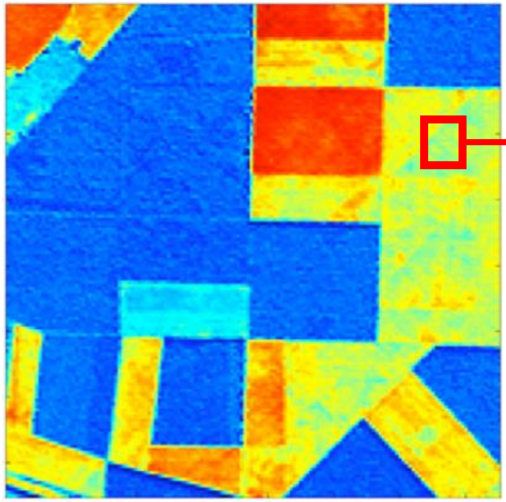
- **Temporal constraints**
  - Posterior processing: Filtering instantaneous estimates
    - ✓ Statistical operator (median / average …)
    - ✓ Savitsky-Golay
    - ✓ Logistic/ gaussian model
    - ✓ Semi-empirical model (Duveiller et al. 2011)
  - Within the inversion process: embedded dynamic model
    - ✓ local smoothness (Lewis et al. 2012)
    - ✓ Semi-empirical dynamic model: Kötz et al. 2005, Lauvernet et al. 2008
  - Steady values of surface characteristics for aerosol retrieval (Hagole et al. 2008)





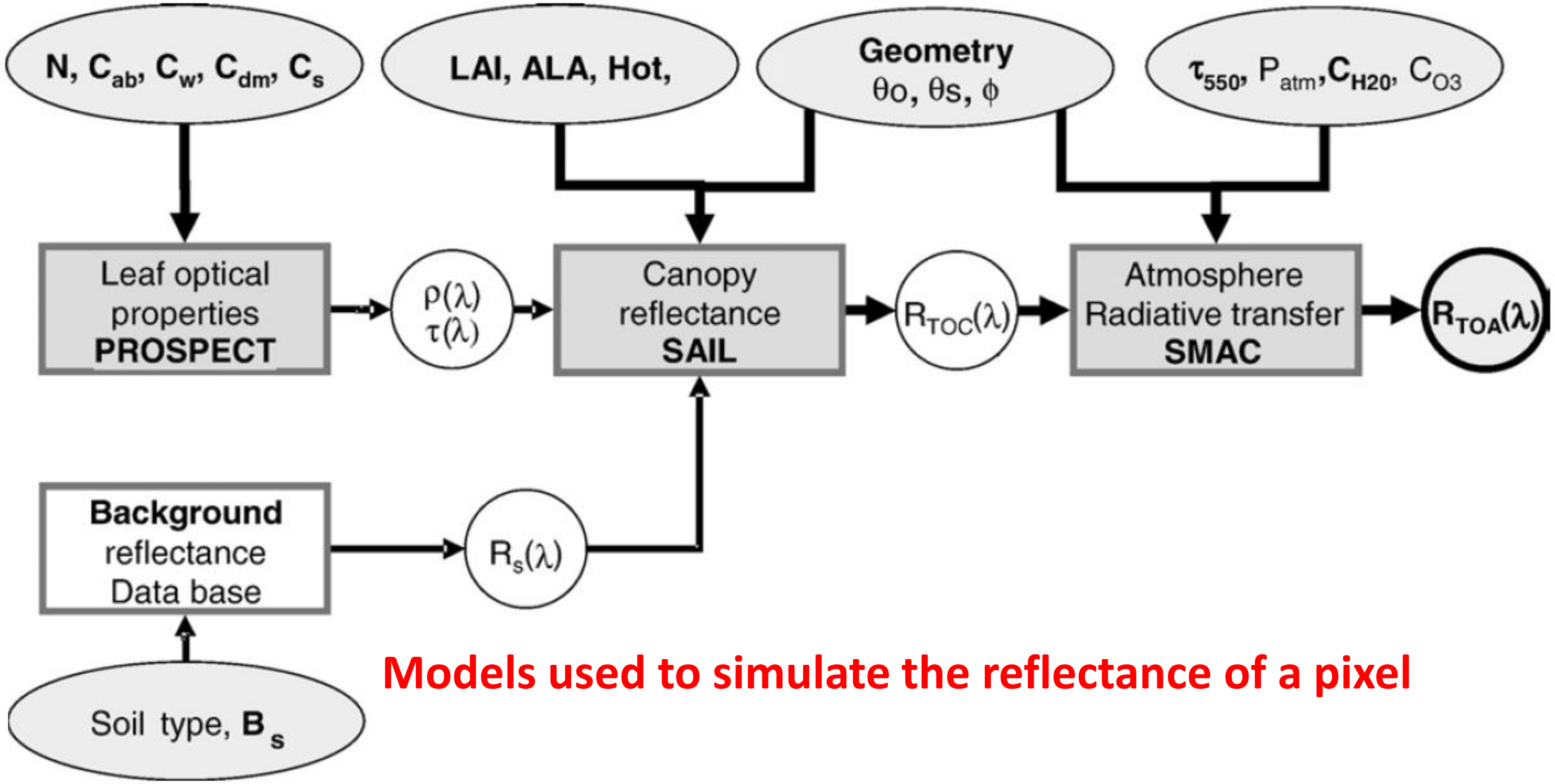
- **Spatial constraints**
  - Posterior processing
    - ✓ Spatial filtering (generally, averaging)
  - Within the inversion process
    - ✓ Atzberger 2004 (higher order statistics)
    - ✓ Atzberger & Richter 2012 (common variables within a 3x3 cell and field)
- **Spatial and temporal constraints**
    - ✓ Lauvernet et al. 2008

The proposed approach: Multitemporal-patch model inversion



For each pixel.date

$$\rho_{\mathrm{sim}} = \mathrm{SMAC}(\mathrm{SAIL}(\mathrm{PROSPECT}(N, C_{\mathrm{ab}}, C_{\mathrm{dm}}, C_{\mathrm{bp}}, H)\, \mathrm{LAI}, \mathrm{ALA}, \mathrm{Hot}, \mathrm{Rs}), \tau_{550})$$



Models used to simulate the reflectance of a pixel

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Multitemporal-patch ensemble inversion of coupled surface–atmosphere radiative transfer models for land surface characterization

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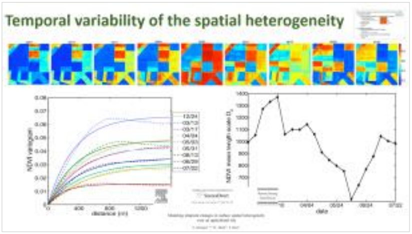
The proposed approach: type of constraints for the input variables

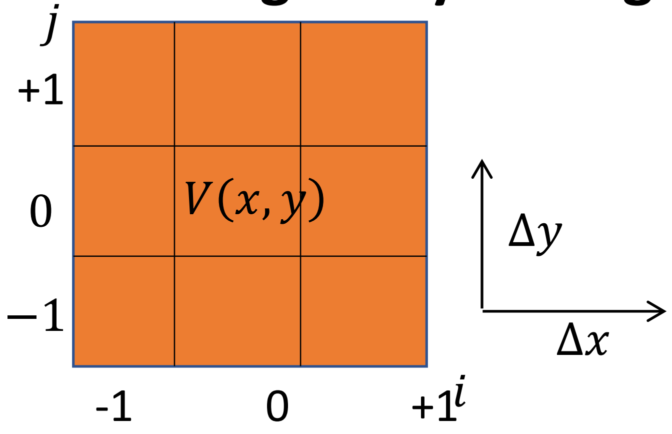


❑ Spatial constraints

- **Local scale (≈3x3 cell depends on the heterogeneity: variogram)**
  - ✓ No constraint (9 values)
  - ✓ local spatial gradient (3 values)

    $$V(x+i, y+j) = V(x,y) + i\Delta x + j\Delta y$$

  - ✓ Equality (1 value)



- **Field / Plot scale**
  - ✓ No constraint
  - ✓ Equality

❑ Temporal constraints

- **Local scale (small temporal window ≈5-10 days)**
  - ✓ No constraints
  - ✓ Smoothness (limited local variability)
- **Growth cycle scale (or part of it for real time estimation)**
  - ✓ No constraints
  - ✓ Equality

The proposed approach: possible constraints

Variables		Spatial Constraint		Temporal Constraint	
		3x3 cell	Field	local	cycle
Background	Ref. Spectra	gradient	-	-	Equality
	Brightness	equality	-	-	-
Canopy	LAI	gradient	-	-	Dyn. Model
	Cab	gradient	-	Smoothness	-
	Other	-	equality	-	Equality
Atmosphere	All	equality	equality	-	-

The proposed approach: the constraints actually used

Considering

- **a small portion of land (<km²)**
- **observed at 3 dates close together**

Assumptions

- Background: no constraints
- Canopy: no change with time
- Atmosphere: no change with space

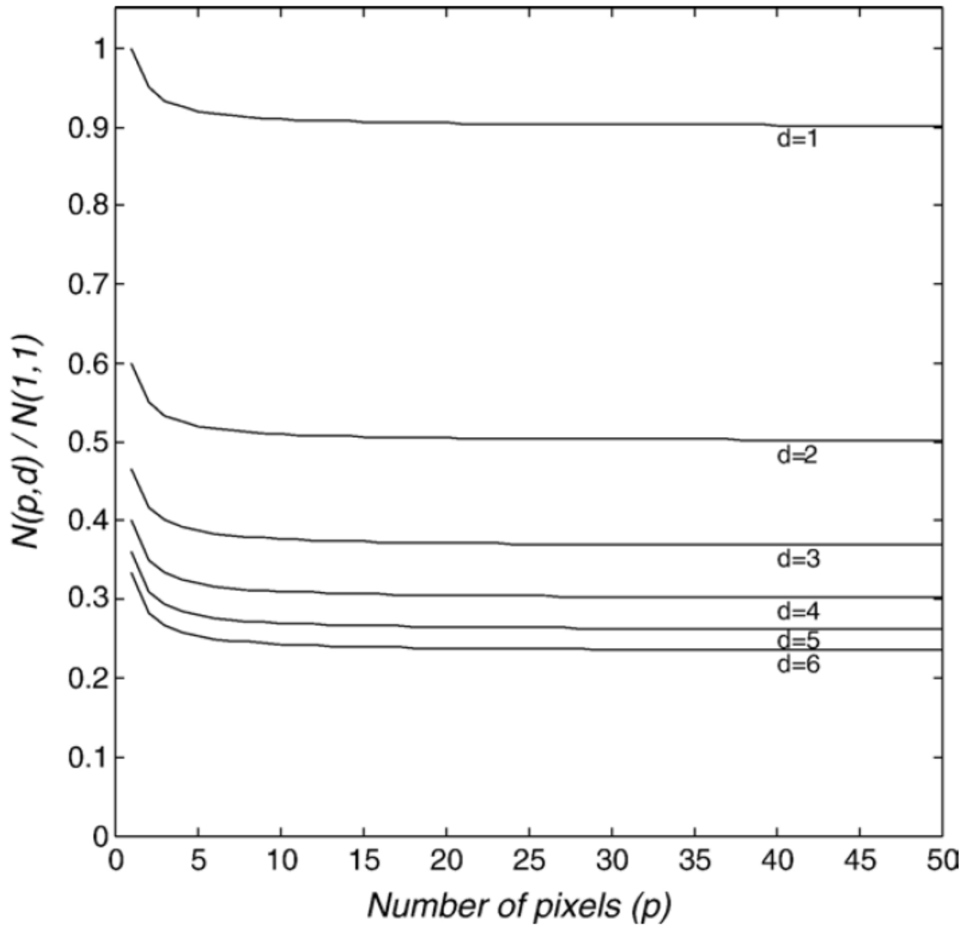
	Variables	Constraints		Distribution characteristics			
		Space	Time	Mode	Standard deviation	LB	UB
Background	Bs			0.8	0.3	0.3	1.3
Leaves	N		x	1.5	1	1	4.5
	C_{ab} (µg.cm^{-2})		x	50	30	15	100
	C_{dm} (g.cm^{-2})		x	0.0075	0.0075	0.002	0.02
	H		x	0.8	0.05	0.65	0.90
	C_{bp}		x	0.01	0.6	0	1.5
Canopy	LAI		x	1.5	1.5	0	8.5
	ALA (°)		x	60	20	30	85
	Hot		x	0.1	0.3	0.001	1
Atmosphere	τ_{550}	x		0.20; 0.35; 0.50			
	C_{H2O} (cm)	x		5.9; 2.0; 2.9			
	C_{O3} (db)	x		0.35; 0.50; 0.20			
	P_{atm} (mbar)	x		996 ; 936; 1057			
Geometry	φ (°)	x		58; 42; 41			
	θs (°)	x		46; 47; 45			
	θv (°)	x		15; 33; 2			

The proposed approach: limitation of the number of unknowns

N(p,d) : number of pixels and dates considered
p number of pixels
d number of dates

N(p,d)=d.Na + p.Nc+ d.p.Nb

Nb=1 Number of variables for the bakground
Nc=8 Number of variables for the canopy
Na=1 Number of variables for the atmosphere



The fraction of unknowns (N(p,d)/N(1,1)) does not vary much after 5 pixels extent and 3 observation dates
Application for p=25 and n=3

The proposed approach: implementation

$$\rho_{\text{sim}} = \text{SMAC}(\text{SAIL}(\text{PROSPECT}(N, C_{\text{ab}}, C_{\text{dm}}, C_{\text{bp}}, H)\,\text{LAI}, \text{ALA}, \text{Hot}, \text{Rs}), \tau_{550}) = M(A, C, \text{Bs})$$

Inversion (parameter estimation) using a variational approach: L-BFGS-B: quasi-newton algorithm to minimize the following cost functions:

- Single pixel and date solution:

$$J_{i,j}(A, C, \text{Bs}) = \sum_{\lambda} \frac{(\rho_{\text{mes},i,j} - \rho_{\text{sim}})^2}{\sigma^2_{\text{mes},i,j}} + \frac{(A - A_0)^2}{\sigma^2_A} + \frac{(C - C_0)^2}{\sigma^2_C} + \frac{(\text{Bs} - \text{Bs}_0)^2}{\sigma^2_{\text{Bs}}}$$

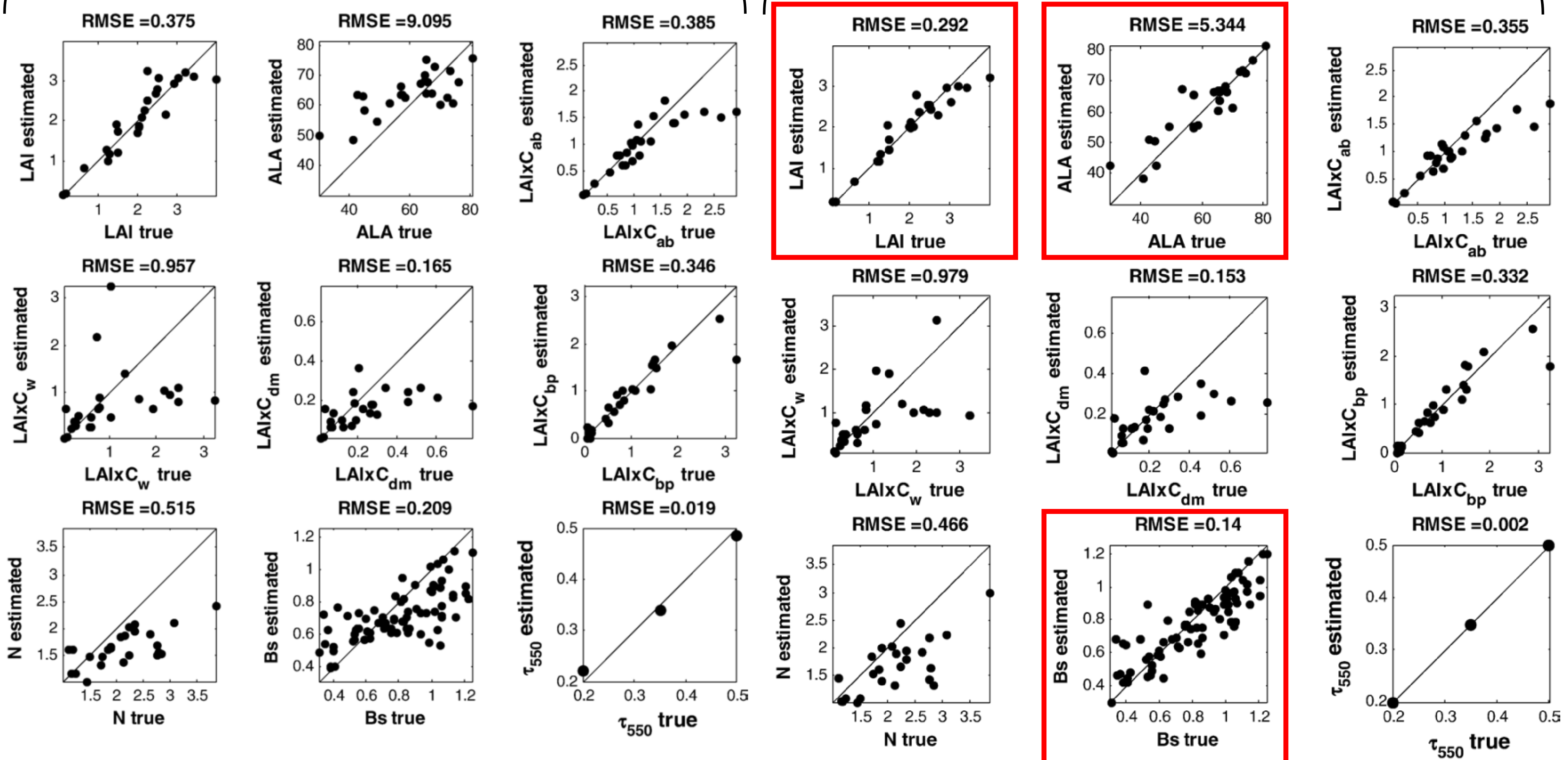
- Multitemporal-Patch inversion:

$$J(A, C, \text{Bs}) = \sum_{\text{dates}} \sum_{\text{pixels}} \sum_{\lambda} \frac{(\rho_{\text{mes}} - \rho_{\text{sim}})^2}{\sigma^2_{\text{mes}}} + \sum_{\text{dates}} \frac{(A - A_0)^2}{\sigma^2_A} + \sum_{\text{pixels}} \frac{(C - C_0)^2}{\sigma^2_C} + \sum_{\text{dates}} \sum_{\text{pixels}} \frac{(\text{Bs} - \text{Bs}_0)^2}{\sigma^2_{\text{Bs}}}$$

An adjoint model is used to compute analytically the gradient of the cost function.

The proposed approach: results

Single pixel.date inversion | **Multitemporal-Patch inversion**



Conclusion on the proposed approach

- Efficient for few variables that are known to be sensitive to compensation effects (LAI, ALA, Bs)
- Some variables appear to be almost insensitive: the atmosphere
  The atmospheric signal is very different from that of the canopy
- The proposed approach was based on model simulations. Need to be tested over actual observations
- Probably major improvement of the approach when using a model describing the dynamics of the main canopy structure variables: LAI

CONCLUSION / PERSPECTIVES

- Temporal constraints easy to impose and very efficient

- Spatial constraints more difficult because of the complexity and diversity of the spatial organization
  - Soil
  - Environment
  - Cultural practices

- Investigation of approaches based on process models: statistical models?

- For phenotyping applications
  - Tracking objects in high resolution (mm) images
  - Network of sites: assimilation in crop growth models: space= soil x environment x cultural practices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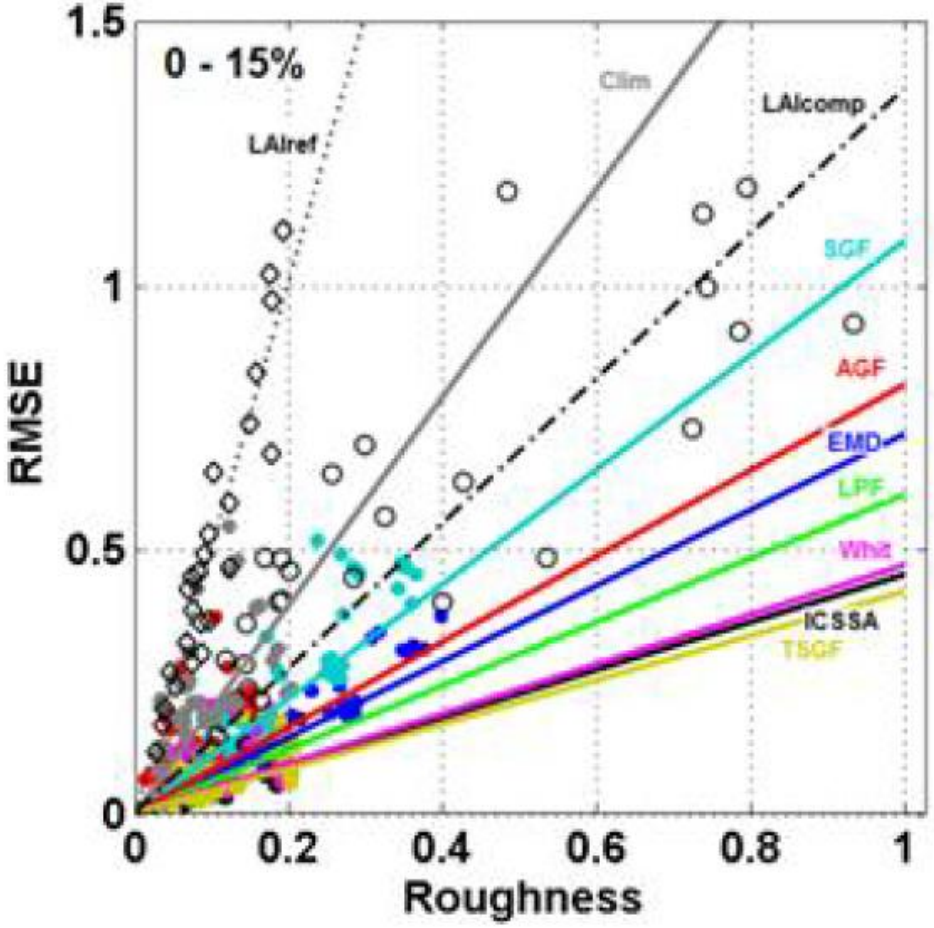
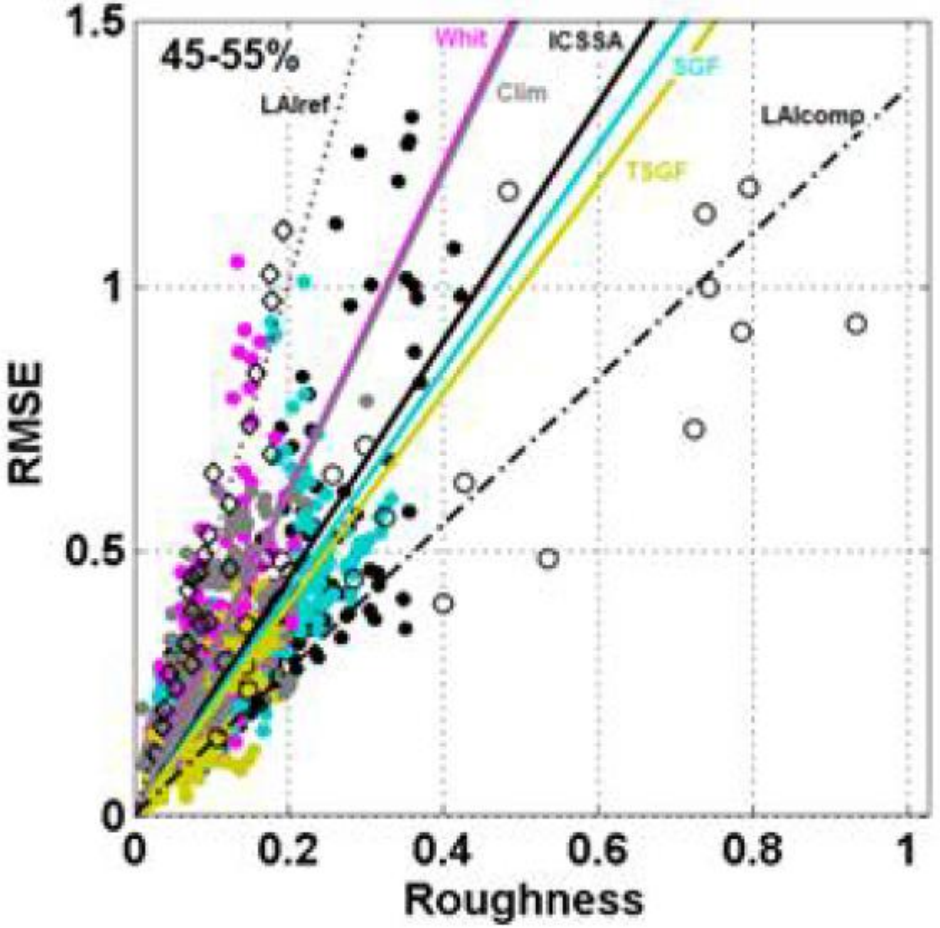
0-15% of missing data



45-55% of missing data



Temporal smoothing methods are characterized by a particular balance between RMSE (fidelity) and roughness (smoothness)

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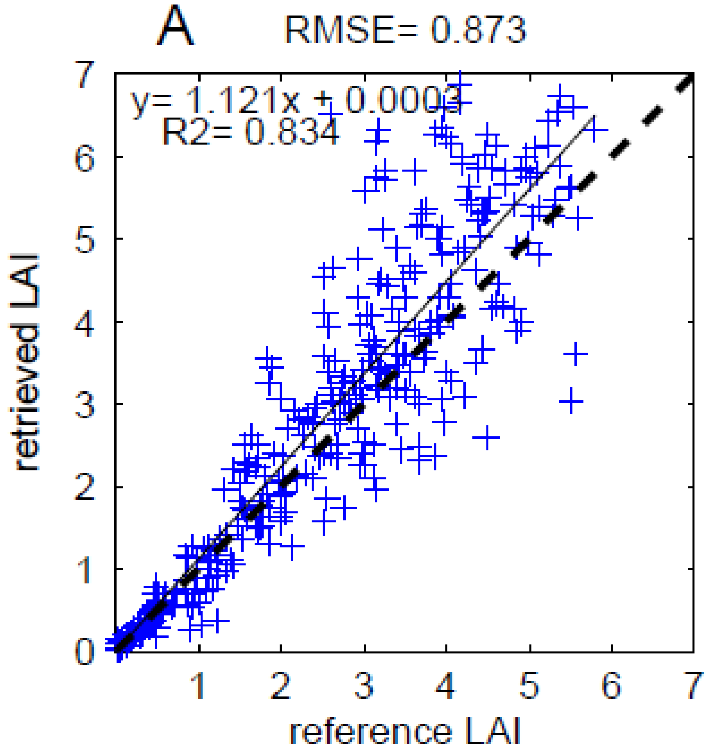
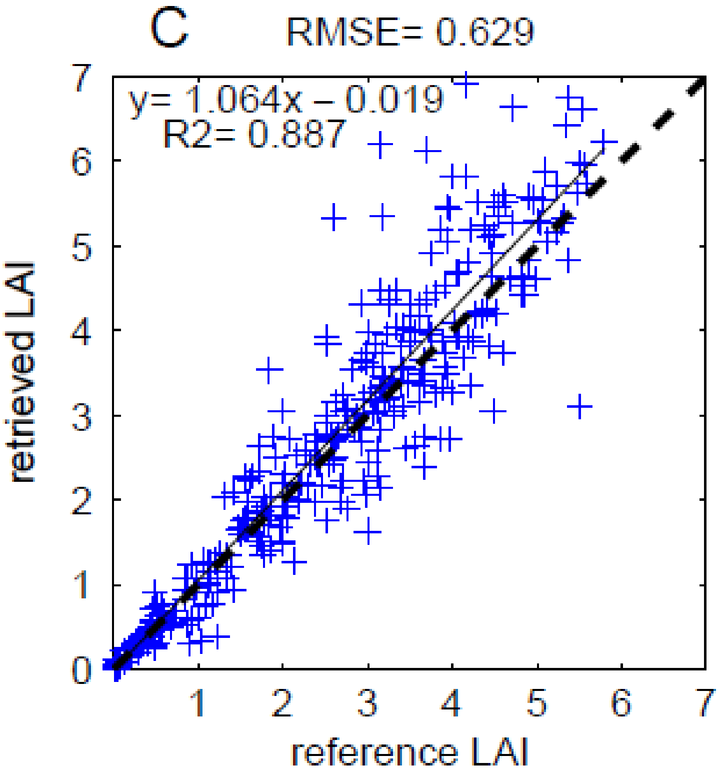
Modeling temporal changes in surface spatial heterogeneity over an agricultural site

S. Garrigues [a,*], D. Allard [b], F. Baret [c]

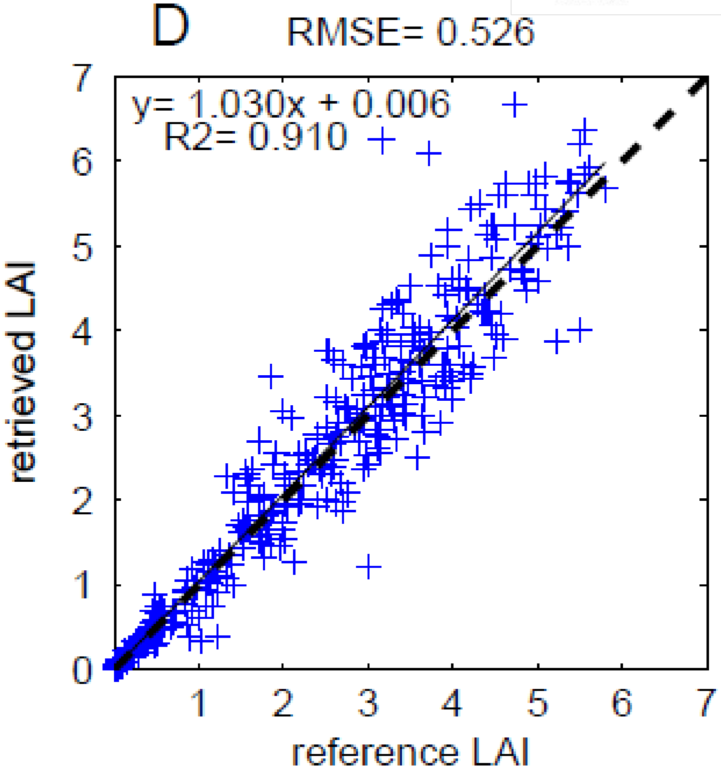
Efficacité des contraintes temporelles



Estimation indépendante pour chaque date d'observation



Estimation sous contrainte d'un Modèle de dynamique de LAI



Simple lissage temporel

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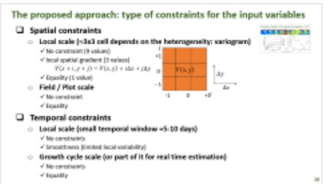
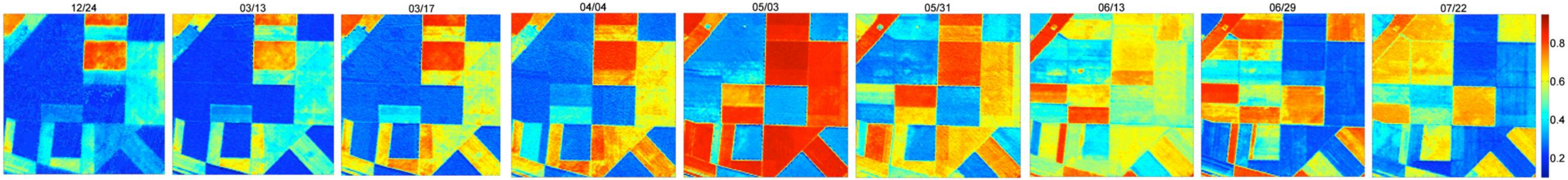
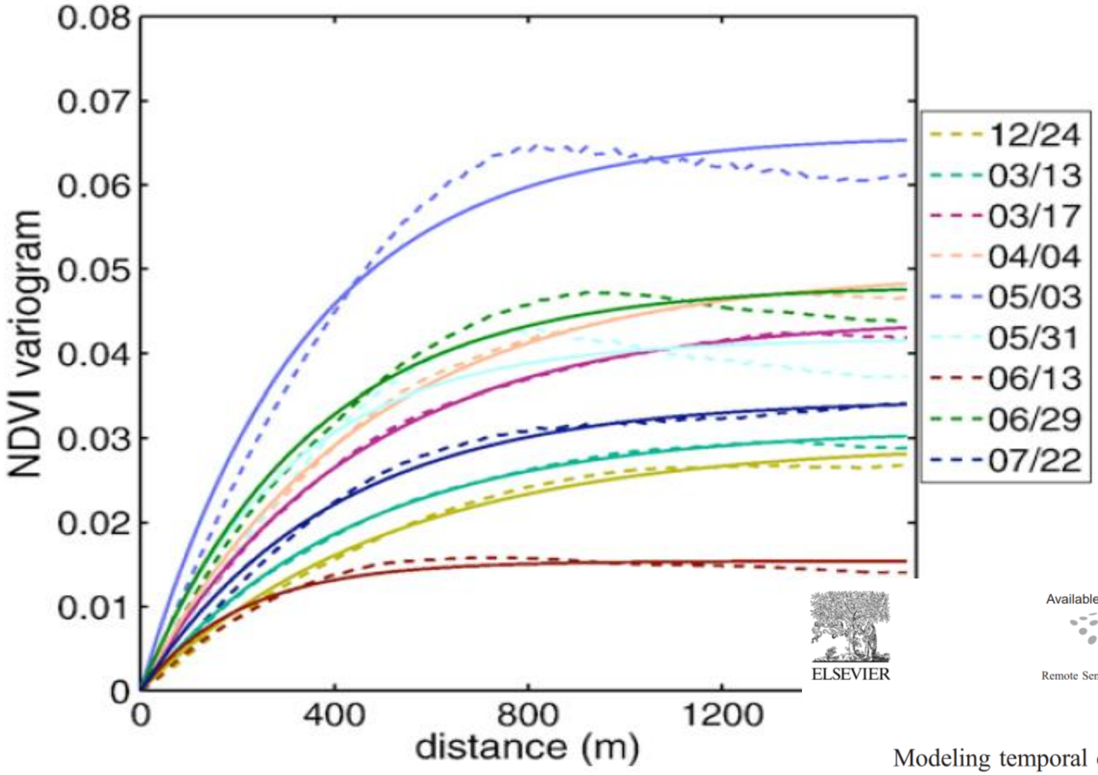
Use of coupled canopy structure dynamic and radiative transfer models to estimate biophysical canopy characteristics

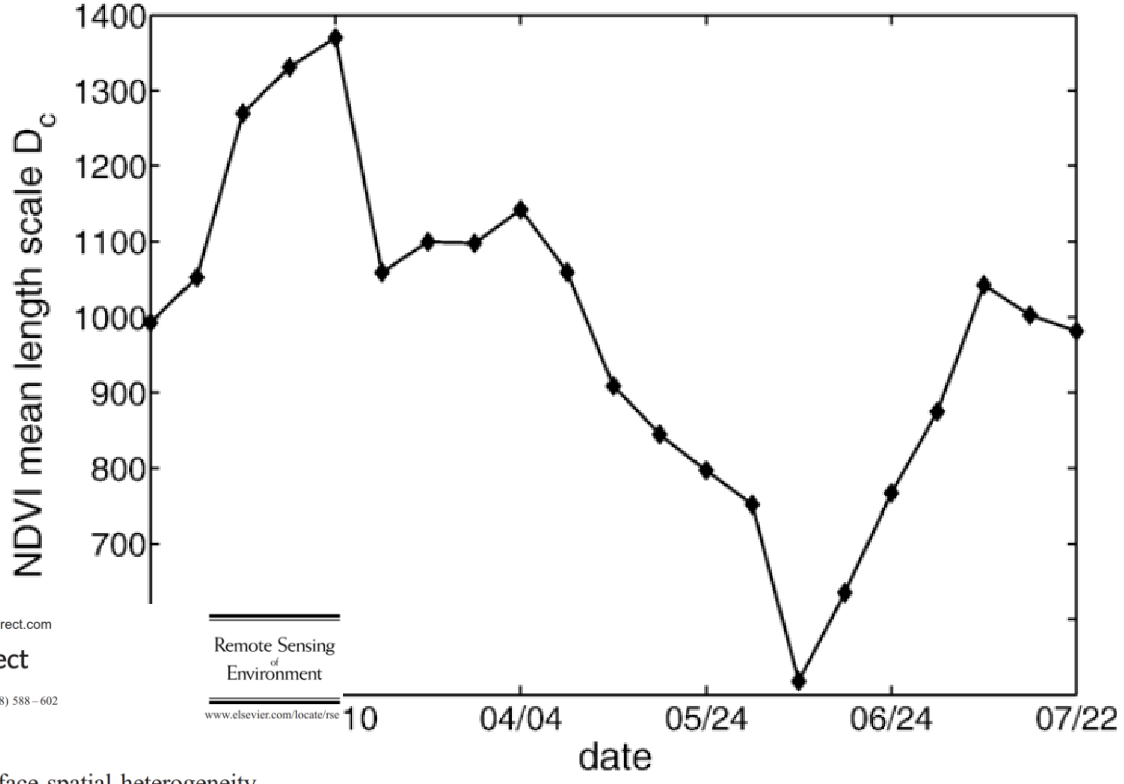
Benjamin Koetz[a,*], Frédéric Baret[b], Hervé Poilvé[c], Joachim Hill[d]

Temporal variability of the spatial heterogeneity









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