Combination of 4D wheat architecture models and close range measurements for high throughput in field phenotyping: current status and prospects

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Combination of 4D wheat architecture models and close range measurements for high throughput in field phenotyping: current status and prospects

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Outlook

1. Background
2. Current focus and measurement systems
3. Use of 4D models
4. The Toulouse 2009 experiment
5. Conclusion

Importance of infield measurements

- Plants grown under artificial conditions do not display the same characteristics as in natural conditions
  - Soil
  - Climate
  - Competition between plants
- Infield phenotyping is therefore required to identify particular features
- It provides also pertinent information to design decision making rules to adapt cultural practices

State variables accessible from close range remote sensing at the canopy scale

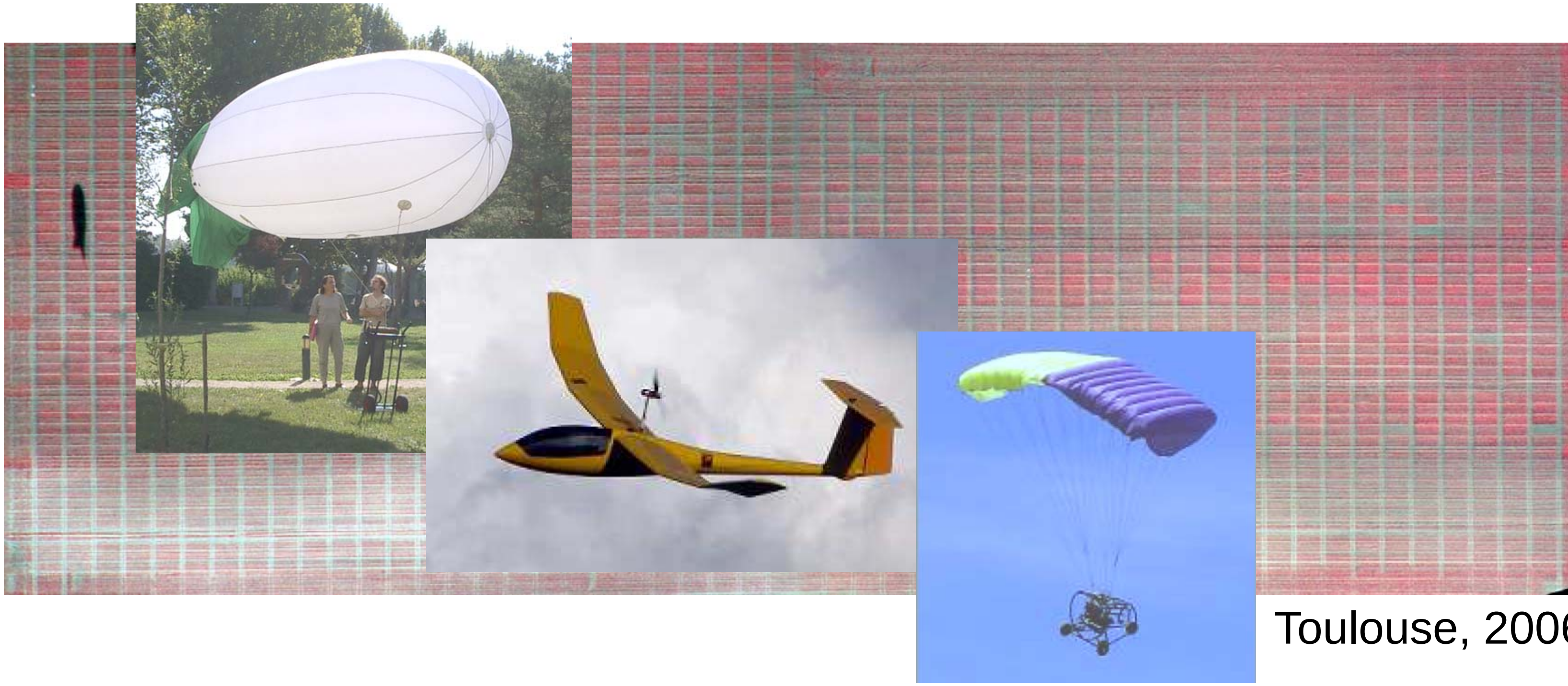
- **Photography**
  - Gap fraction: LAI
  - Color: senescence
  - 3D architecture: leaf inclination
- **Light transmittance**
  - LAI
  - fAPAR
- **Lidar**
  - Gap fraction
  - LAI
  - vertical profile of LAI
- **Reflectance**
  - LAI
  - fAPAR
  - chlorophyll
  - PRI (photochemical reflectance index)
- **Fluorescence**
  - blue
  - chlorophyll
- **Thermal Infrared**
  - Energy/water balance

Systems and vectors

	ULM	Drone	Balloons	Tractor / scouts	Human power	Autonomous
Altitude	150-3000 m	10-150m	10-150m	0.1-4m	0-4m	0-2m
Spatial resolution	+	++	++	++++	++++	++++
Time to complete measurements	++++	+++	++	++	+	++++
Calibration	++	++	++	++++	++++	++++
Control of directions	+	+	+	++++	+++	++++
Active systems	++	+	+	++++	+++	++
Weight	++	+	+	++++	+++	+++
Energy	++	+	+	++++	++	+
Stability	++	++	+	++++	+++	++++
Ability for continuous monitoring	+	++	++	+++	+++	++++
Cost	++++	+++	+++	++	++	+++
Systems		imaging			non imaging	
photo high resolution (<1mm)	+	+	+	++++	++++	+
light sensor (transmittance)				++	+++	++++
Lidar	+			++++	++	
broad band radiometer (passive)	++++	++++	++++	++++	++++	++
spectro radiometer (passive)	++	+	+	++++	+++	+
radiometer (active)	+			++++	+++	
fluorescence	+			++++	++++	++++
thermal infrared	++++	+++	+++	++	++	

Tractor/scouts based systems present the main advantages

Why not using airborne systems



Toulouse, 2006

Lack of stability
Radiometric calibration more difficult
Directional effects
Stability (balloon)
Ease of deployment
Need imaging systems (cost, weight)

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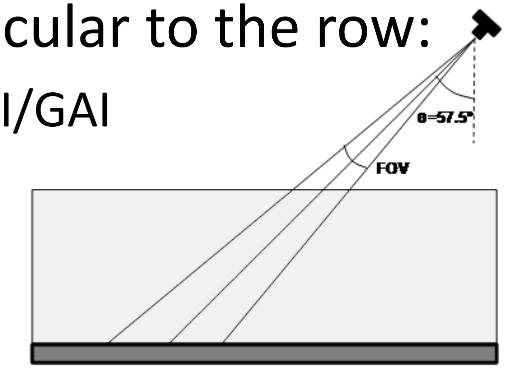
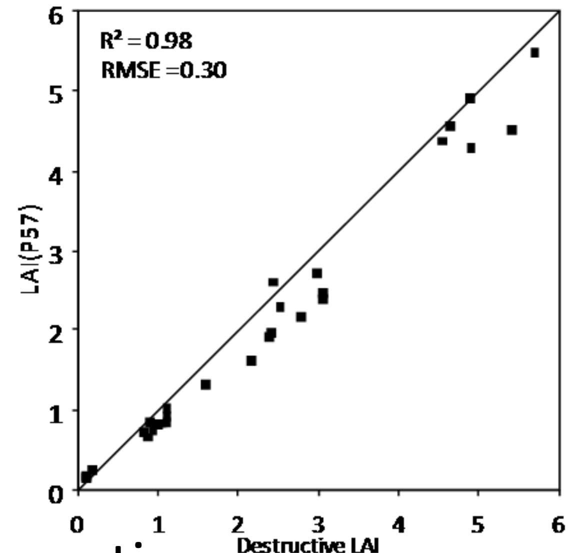
Current focus

- Variables targeted:
  - LAI (continuous for phenology)
  - fAPAR (continuous for photosynthesis)
  - Architecture characteristics (used later for precision farming)
  - Chlorophyll content: indicator of nitrogen nutrition
  - PRI (stress evaluation)
- The systems used
  - Tractor borne system combining
    - Photographs: access to LAI, structure
    - Spectroradiometers: access to chlorophyll and PRI
  - Continuous measurements of light transmittance with autonomous systems
    - fAPAR
    - LAI
    - senescence

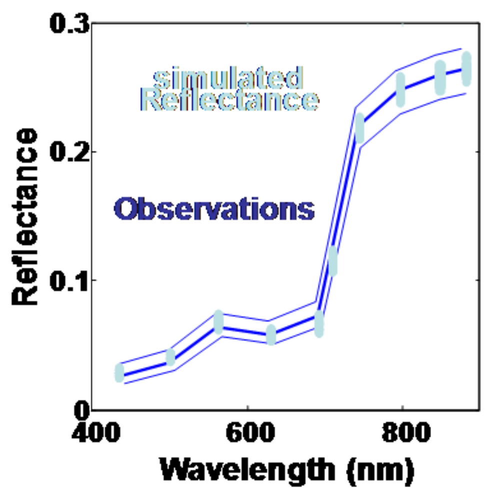
Justification for the system design

- Photo @57.5° perpendicular to the row:
  - good estimates of the PAI/GAI

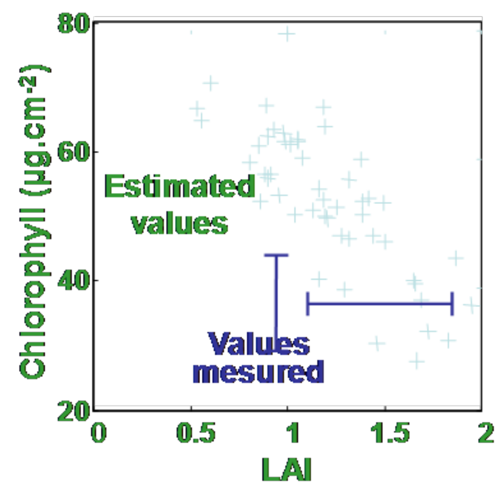




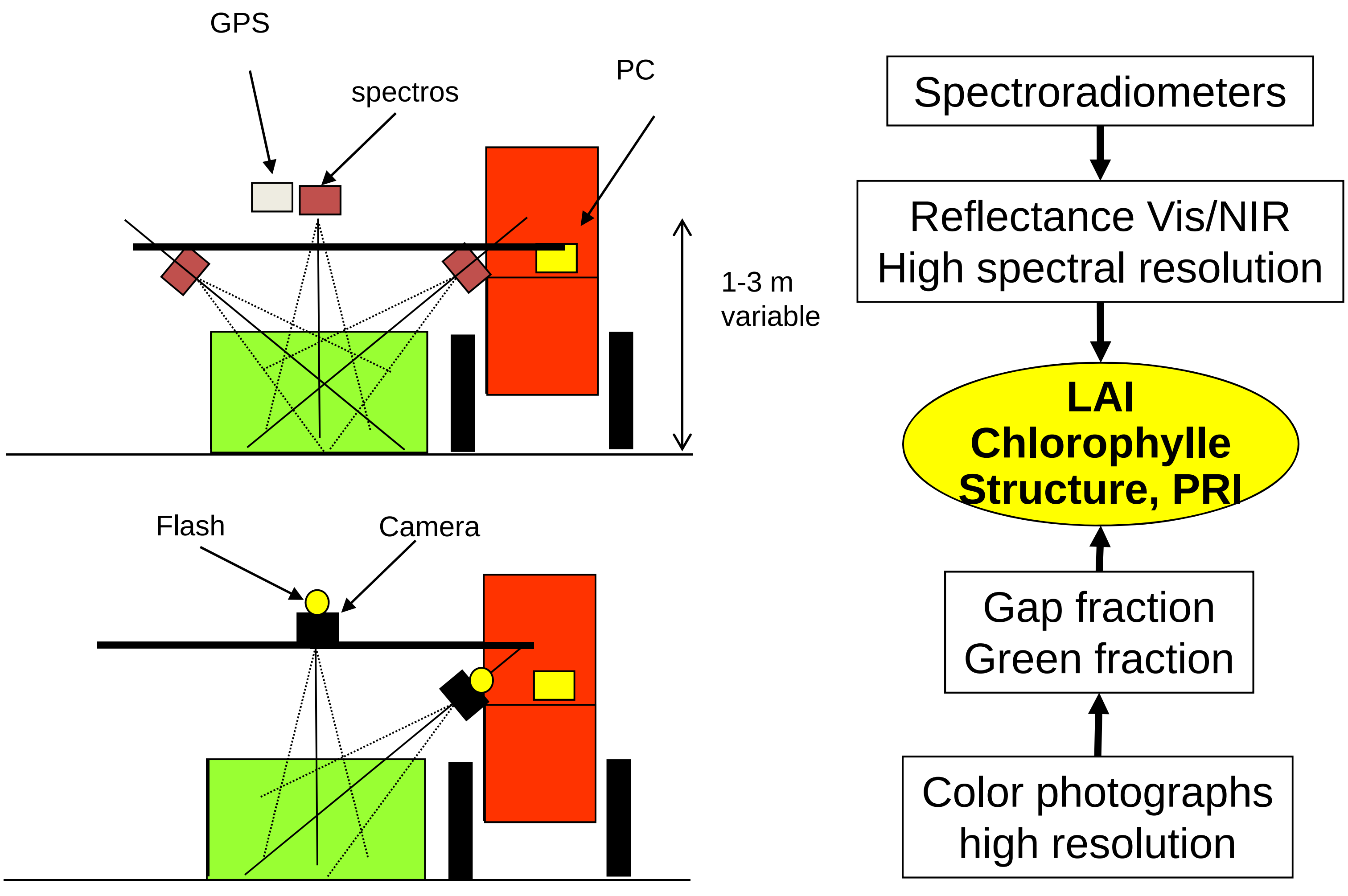
- Photo @0°
  - estimate of canopy structure
- Spectroradiometer with the same view configuration
  - access to chlorophyll and PRI in combination with gap fraction from photos



beterave, Grignon, 1990

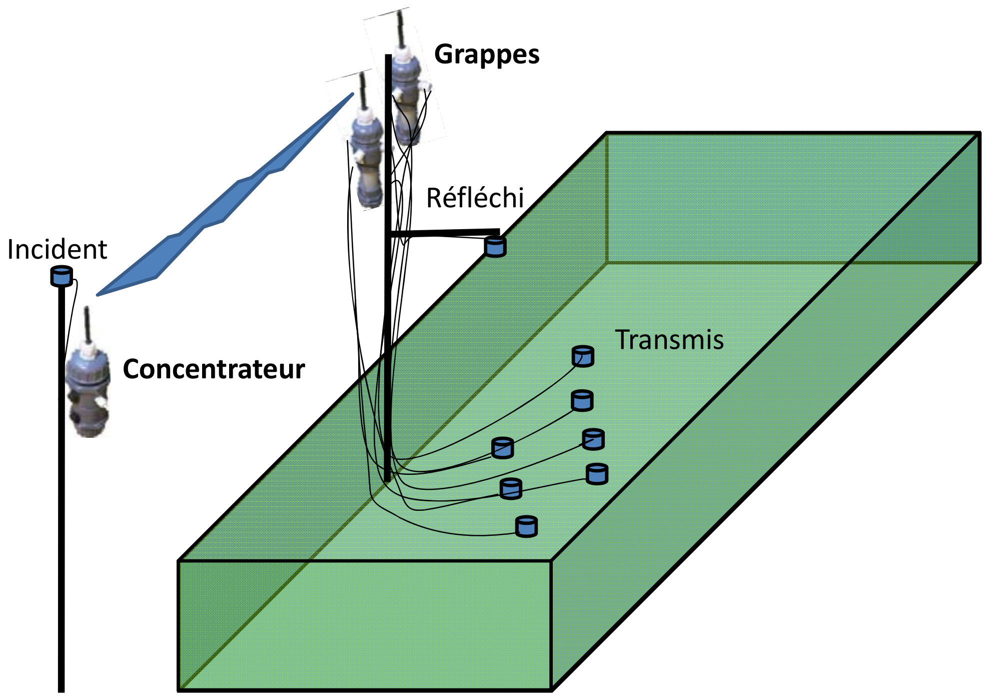


The tractor borne system used



The tractor borne system used

Continuous monitoring of fAPAR & LAI



PAR@METER systems

- 7 transmitted sensors
- 1 reflected
- measurements every 5 minutes
- 3 months autonomy (energy/memory)

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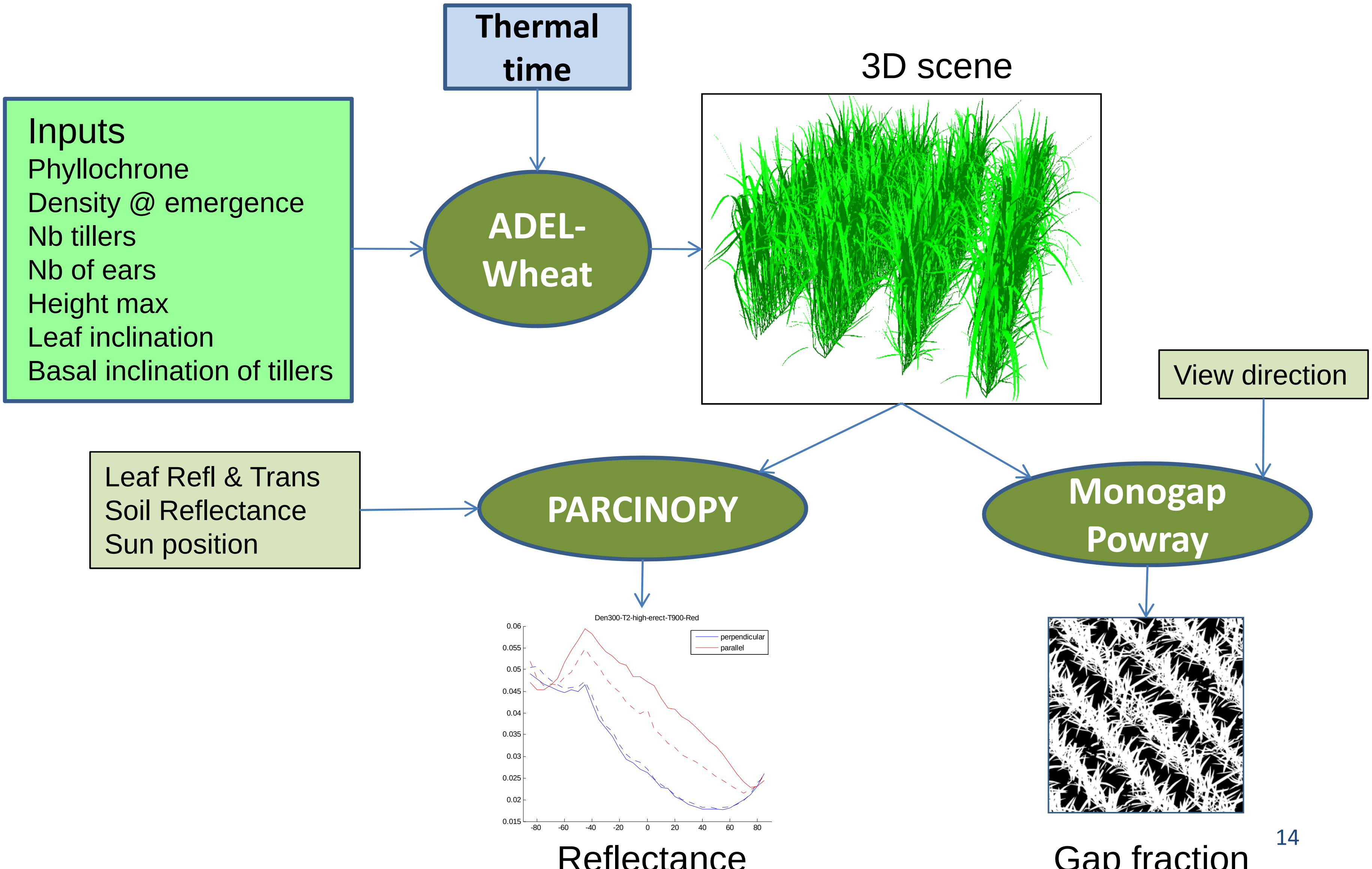
The approach for data interpretation: use of 3D models

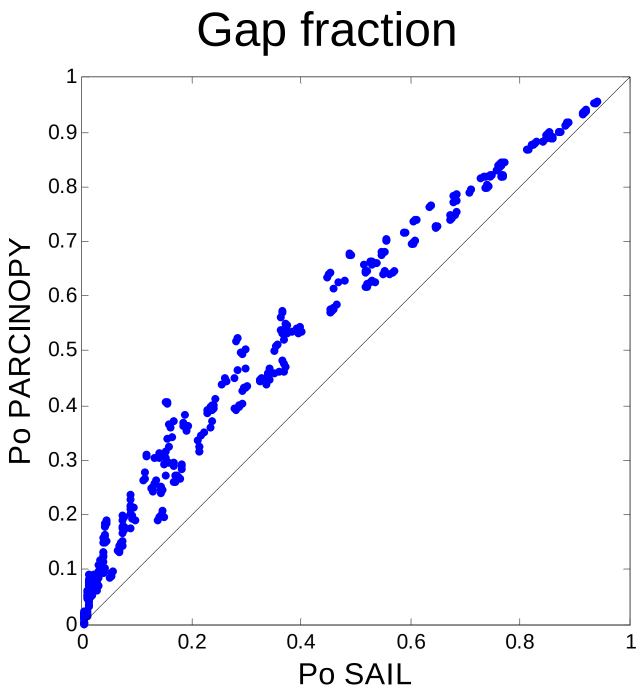


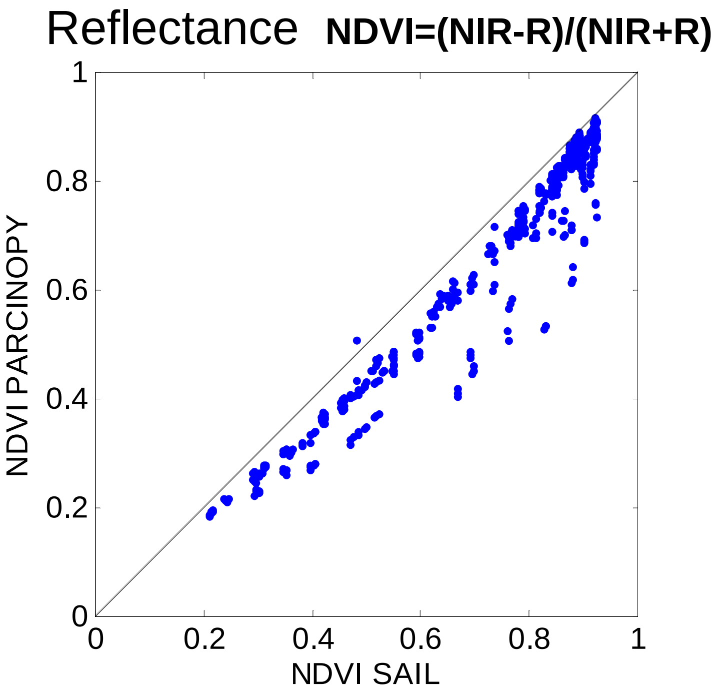
Simulations of 3D canopies

Parameters (units)	Value levels
Thermal time (°Cd)	400, 600, 800, 900, 1000, 1200
Density (plant/m^2)	150, 300, 500
Number of tiller	2, 4
Distance between the top of tiller and main stem (cm)	3 or 6 with a deviation
Height of plant	low, medium, high
Leaf inclination	plagiophile, erectophile
Distance between rows (cm)	12
Difference of azimuth between parent axe and tiller (°)	75 with a deviation U(-2.5,2.5)
Azimuth deviation from successive order (°)	180 with a deviation U(-5,5)
Basal inclination of tiller (°)	60 with a deviation U(-2.5,2.5)

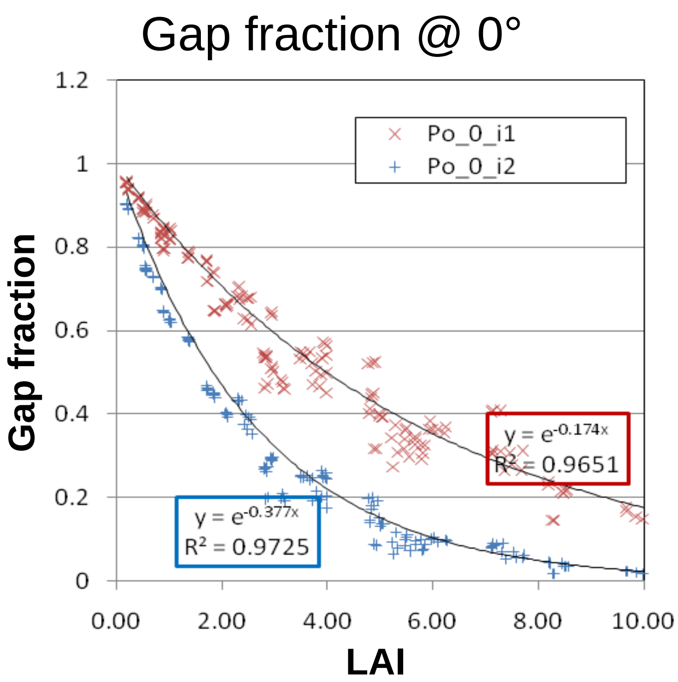
Parameters	Value levels
Solar zenith angle (°)	45
Direction of illumination (azimuth angle)	Parallel or perpendicular to row
Spectral bands	Blue, green, red and NIR
Reflectance and transmittance of leaf	See table 4
Reflectance of soil	See table 4
View zenith angle for gap fractions (°)	0, 57

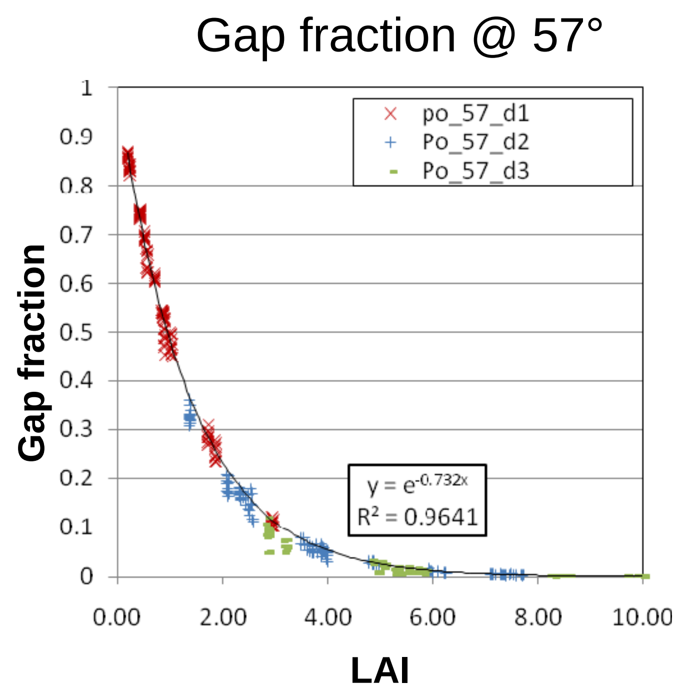
Interest of 3D models versus 1D (SAIL)





Results for gap fraction



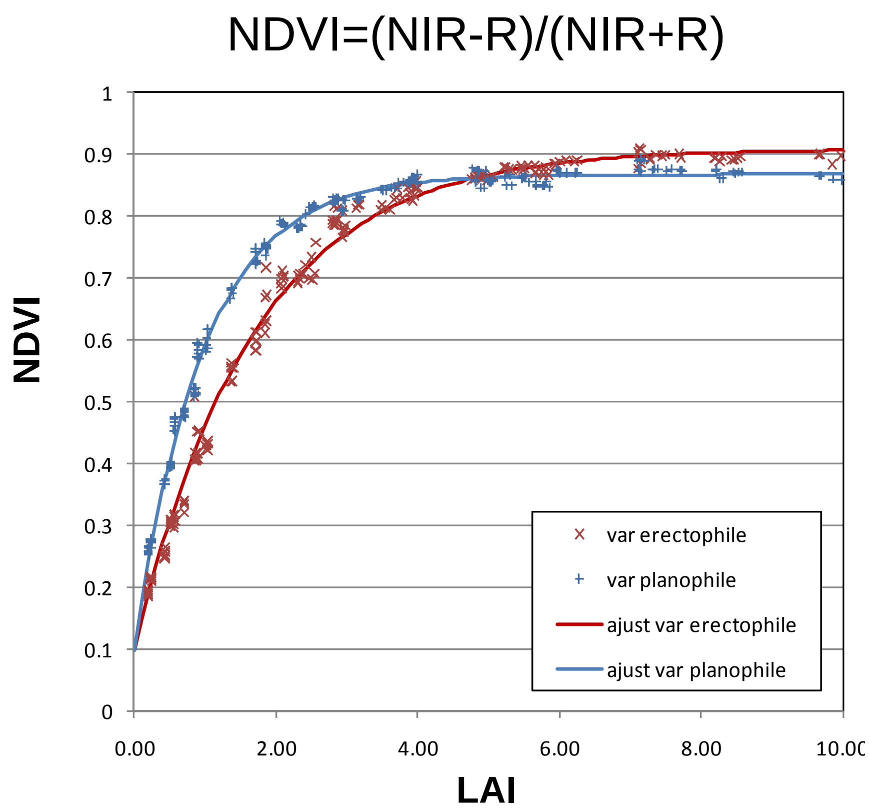


Sensitivity mainly to leaf inclination
Small saturation effects

Almost independency from leaf inclination
Saturation for LAI>4

Synergy between both directions
to estimate leaf inclination

Results for reflectance



Sensitivity mainly to leaf inclination
Saturation for LAI>4

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The experiment in Toulouse in 2009

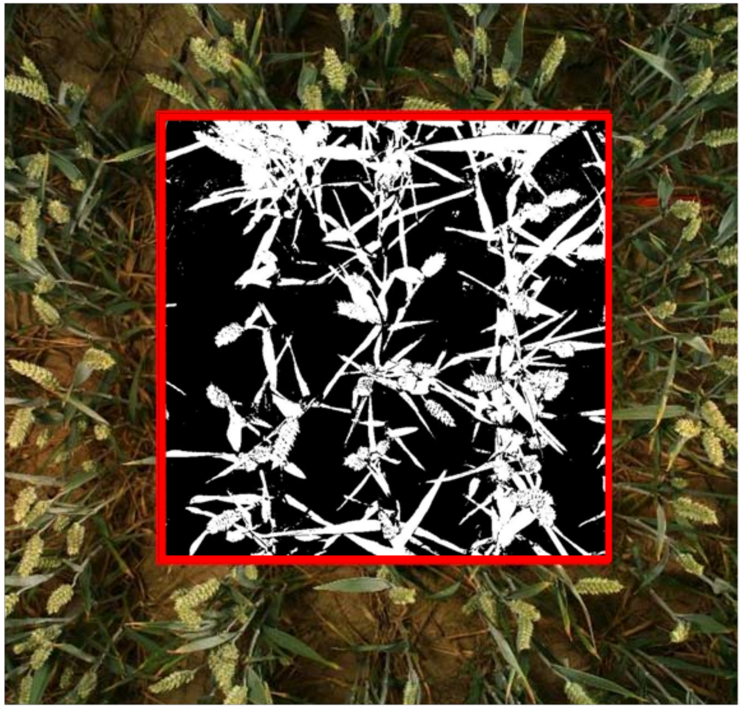
Experimental design
6 contrasted cultivars
2 nitrogen levels
2 densities
3 replicates

Destructive measurements
LAI
Biomass
Structure
Nitrogen content

Tractor borne remote sensing
Photo @0° & @57°
Reflectance spectra @0° & @57°

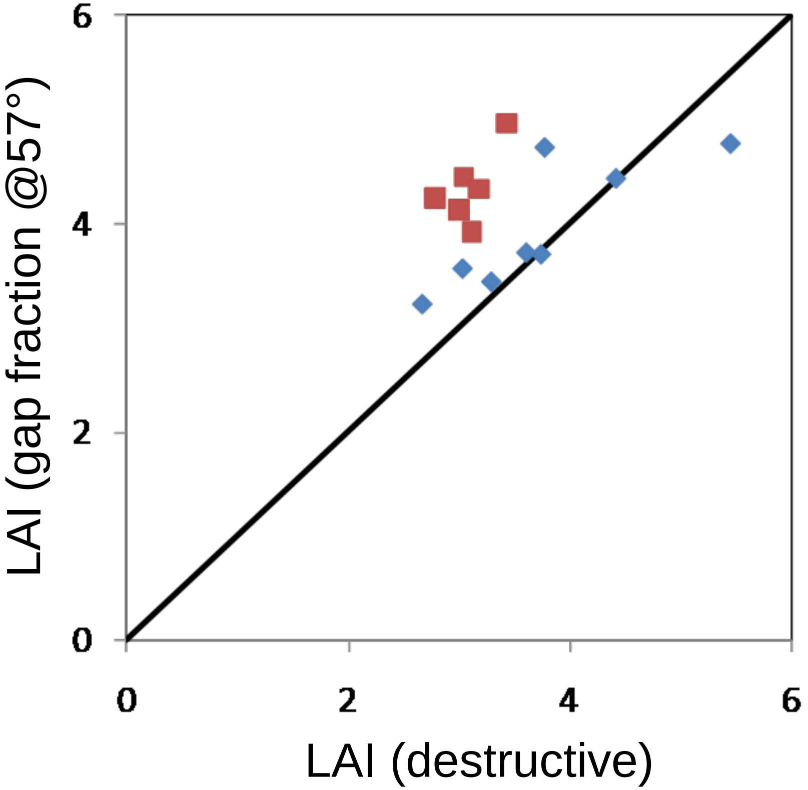
Continuous PAR balance
PAR@METER in 15 plots

LAI estimated from photos



Automatic extraction and classification

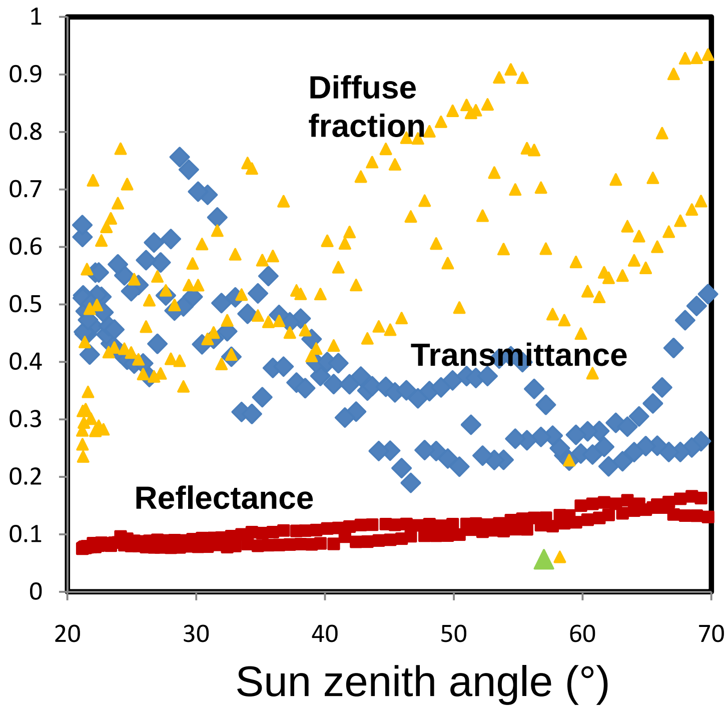
Flowering stage

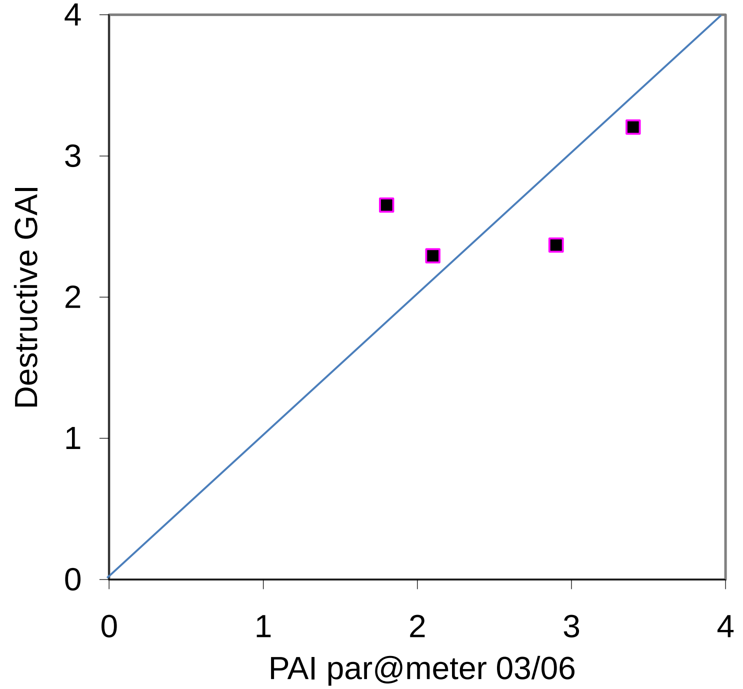


Good performances but:
- Relatively low LAI (little saturation)
- Effect of spikes

LAI estimated from PAR@METER

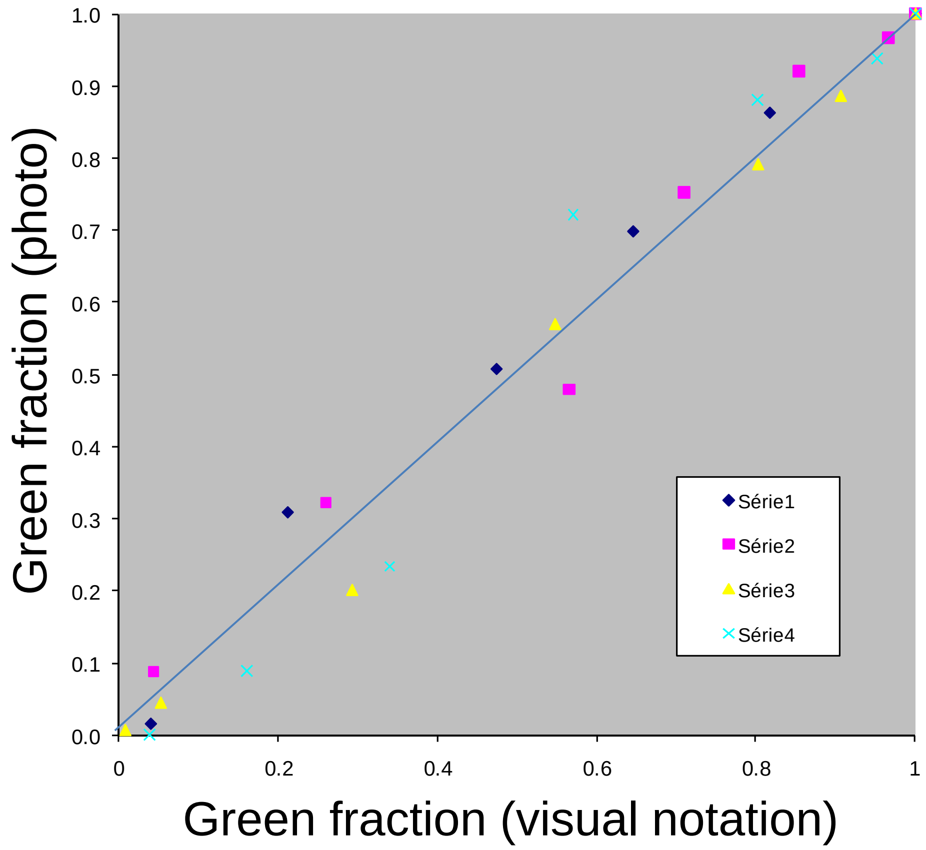
Flowering stage





Some technical problems (solved)
Good estimates at flowering
Effect of senescent leaves during grain filling period
Refinement on:
- spatial sampling
- estimation method

Monitoring the dynamics of senescence



Very good monitoring of senescence from photos

… a lot more soon to be available

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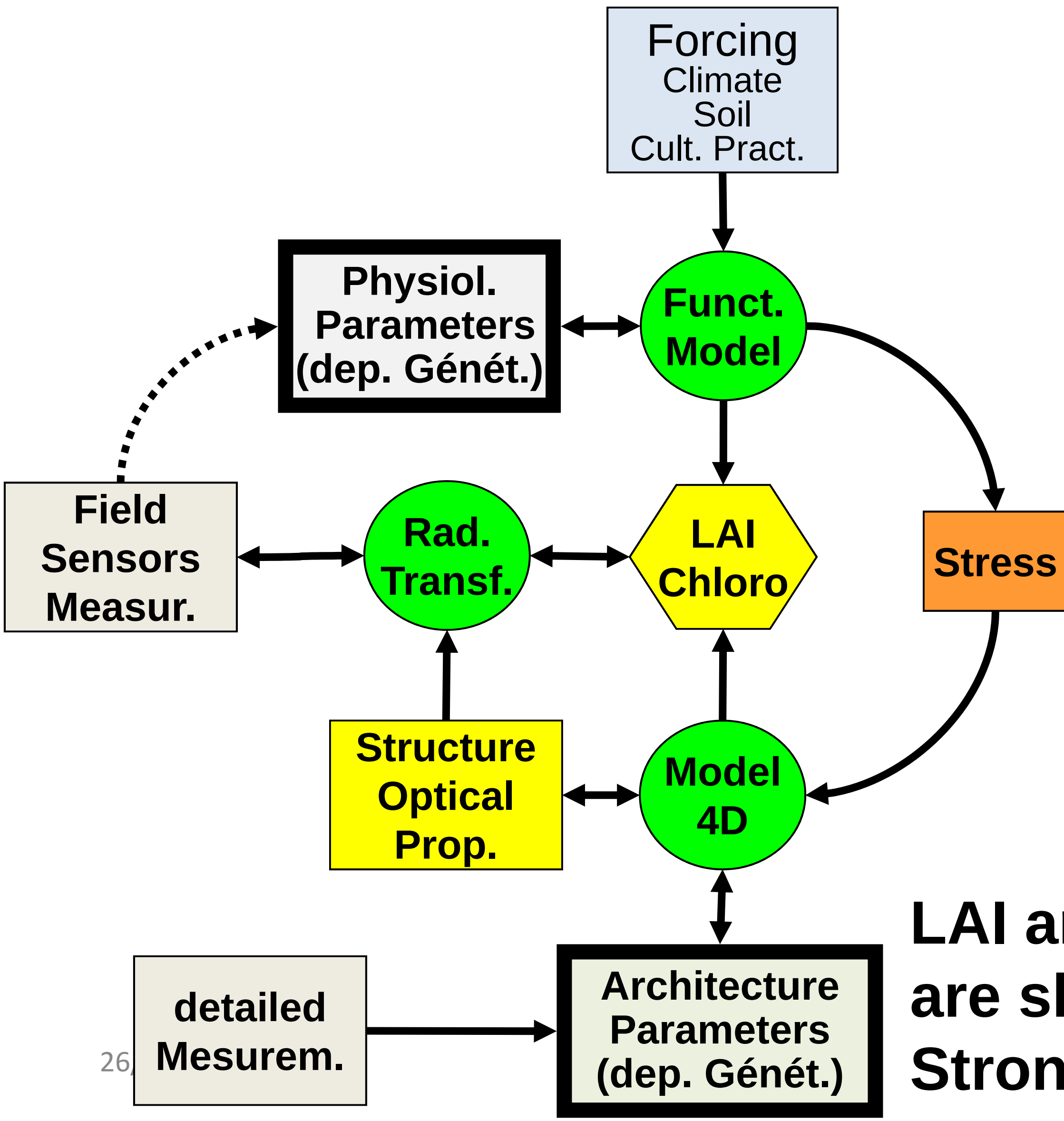
Conclusion

- Lot of potentials for phenotyping
  - LAI
  - Chlorophyll
  - Architecture
  - fAPAR
  - Stress (PRI)
- Some improvement to get operational systems
- Extensive use of 3D models for optimal configuration selection, sensitivity analysis and transformation into canopy state variables
- Coupling with canopy functioning models to identify genotype dependent parameters related to specific processes

General approach foreseen



1. Estimates of functional traits by empirical methods
2. Use of functioning model: Genetic parameters
3. Improving consistency between measurements and models
4. Use of 4D models
5. Adjusting 4D model parameters from detailed measurements
6. Coupling 4D to functioning models

LAI and Chlorophyll Variables are shared by the three models: Strong consistency required