Calibration of a vegetation index to monitor *Eucalyptus* plantation leaf area index with MODIS reflectance time-series

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Introduction

Eucalyptus plantations :

- Main hard-wood species planted in the world
- Present in most tropical and subtropical regions world-wide
- Rapid expansion
- Environmental impact and sustainability issues
- Very useful & interesting model for scientific questions about tree growth and tree plantation development (rotation length of 6-7 years, productivity of ~40 m3/ha/y)

Iglesias-Trabado et al. 2009 (GIT-Forestry)

Introduction

Eucalyptus plantation leaf area index (LAI)

• Critical variable: at the crossroads of carbon, nutrient and water balance of the ecosystem, linked to NPP and plantation productivity

• LAI is very sensitive in forest process-based models, but generally difficult to simulate (necessary to calibrate models)

• LAI is highly variable in time and space, and difficult and time-consuming to measure with the currently available destructive or optical field methods.

The development of a method allowing the simple retrieval of LAI time series from freely available satellite data is therefore of considerable interest.

Introduction

LAI is ***linked with*** reflectance in Red and Near Infrared (NIR) bands

The high **spatial** and **temporal** variability of LAI can be seen on a CBERS satellite time-series above a plantation

Harvest and planting in 2005

Objectives

➔ Determine LAI quantitatively from Red and NIR reflectances

➔ Estimate LAI since the planting date of the current rotation

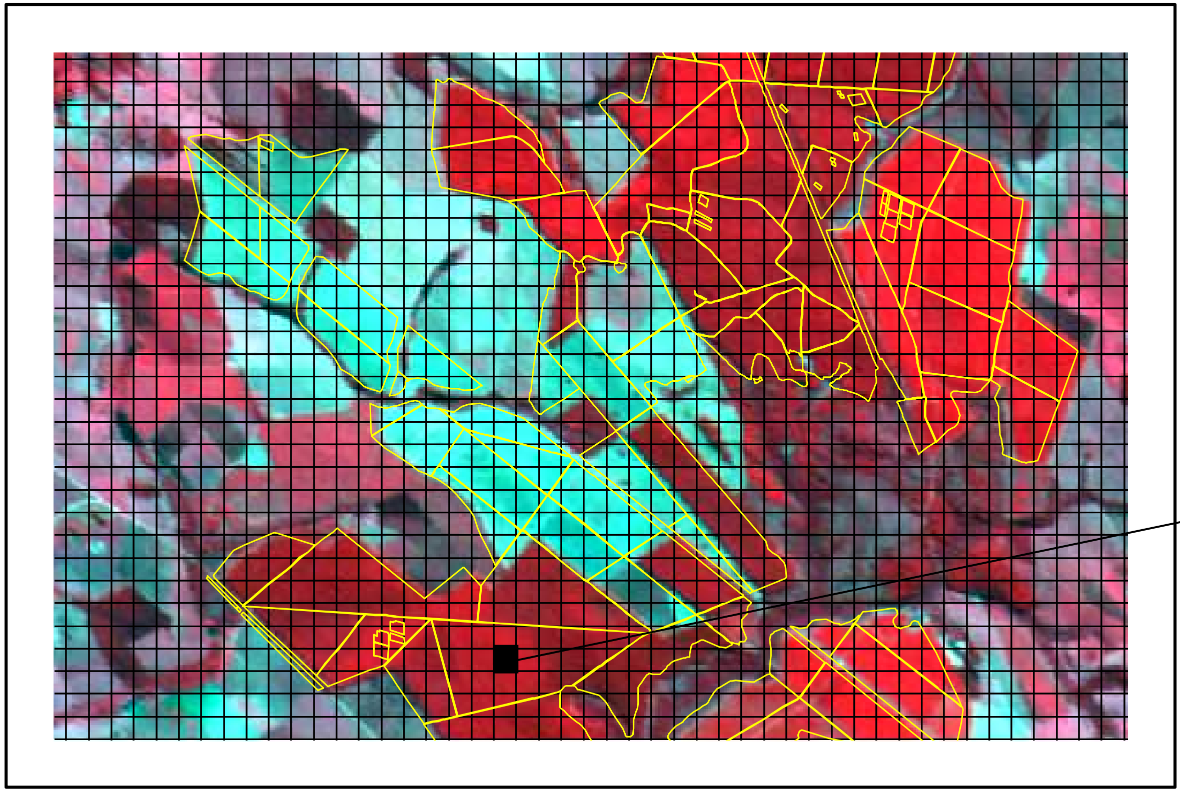
➔ Compare LAI-retrieval methods and their uncertainties, advantages, drawbacks

➔ Design a specific, calibrated vegetation index

Methods

MODIS data extraction and filtering:

- 16-days composite image (MOD13Q1 product) since 2000 ☺
- ~250 m resolution for Red and NIR bands ☹
- Extraction of best MODIS pixel per stand (see *le Maire et al. RSE 2011*)



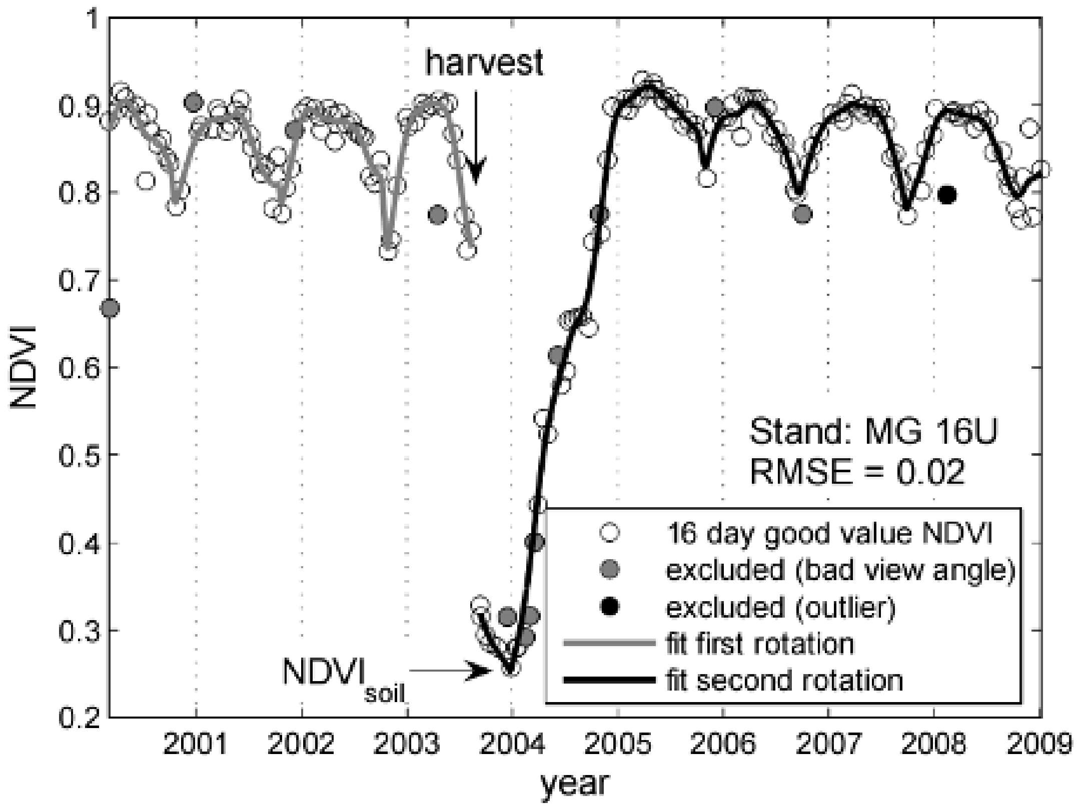
Background: CBERS false color
Polygons: stand delineation from company
Grid: MODIS pixels grid

Selected "best pixel", representative of the stand

Methods

MODIS data extraction and filtering:

- Quality check within MODIS product
- Acquisition geometries (sun and view angles, relative azimuth)
- Smoothing and interpolation with cubic spline for vegetation indices



Marsden et al. FEM 2010

Methods

Test of two methods for LAI retrieval *(le Maire et al. 2011, RSE)*

Vegetation index (VI)

- Choice of best type of vegetation index based on LAI measurements
- Calibration of the index based on satellite images (VI coefficients) and LAI measurements (regression VI vs. LAI)
- Calculation of LAI time-series from VI time-series
- Comparison between estimated and measured LAI (should be on a different dataset)

RTM inversion

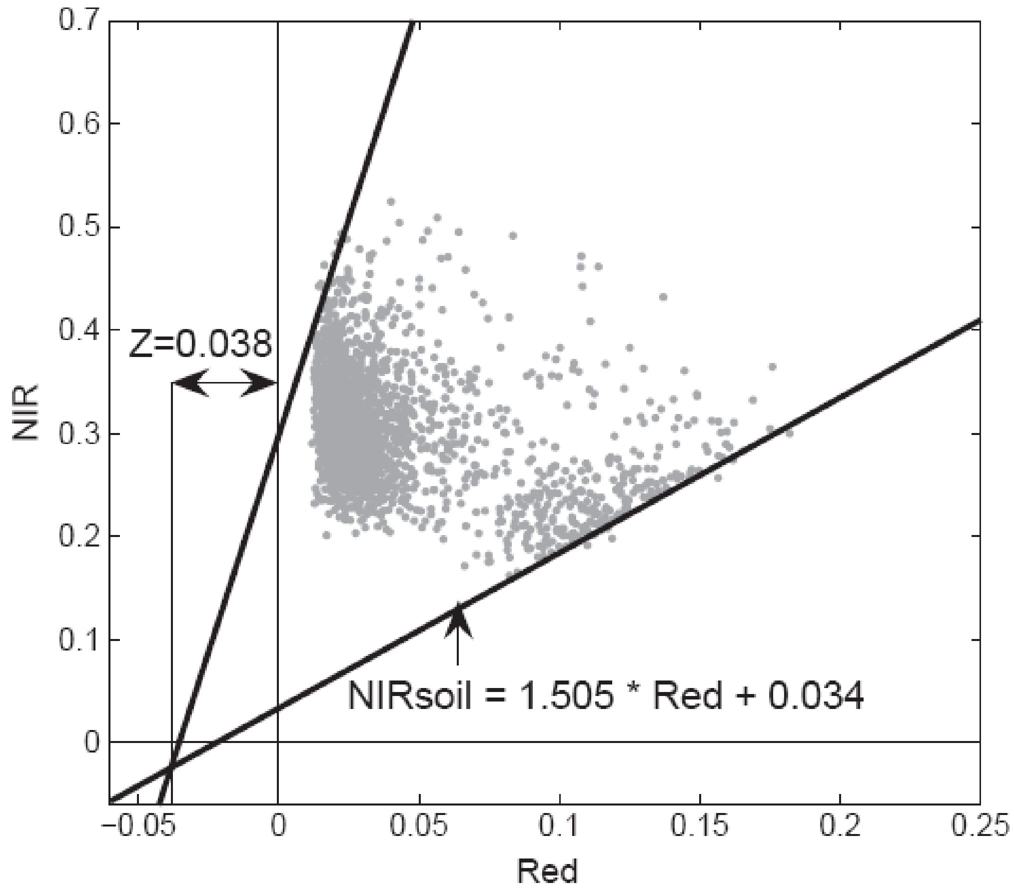
- Choice of a forest radiative transfer model
- Inversion of the model: need of constraining the model for many variables because there are only 2 bands that are used
- Choice of the variables and parameters constrained in the model, and measurements of their values
- Once constrained, the model is inverted considering the acquisition geometry, RSR, etc.
- Comparison between estimated and measured LAI

Methods

Vegetation index (VI)

- GESAVI (Gilabert et al. 2002) was the best index among the ones that were tested
- It is a soil-adjusted vegetation index (based on soil line)
- It also uses a Z factor calibrated with the « maximum LAI » line

$$GESAVI = \frac{NIR - a*red - b}{red + Z}$$



Methods

RTM inversion

- The PROSAIL model was chosen for its recognized simplicity & efficiency
- PROSAIL= PROSPECT (leaf) + 4SAIL2 (canopy) + SOILSPECT (soil)

Input parameter		Units	Constant value	Function of
PROSPECT 4				
N_{struc}	Leaf structure parameter		1.54	
Chl	Leaf chlorophyll content	$\mu g\ cm^{-2}$	55.0	
Cw	Leaf water content	$g\ cm^{-2}$	0.0145	
SLA	Specific leaf area	$cm^2 g^{-1}$		[Age, LAI]
4SAIL2				
LAI_c	Crown leaf area index	$m^2 m^{-2}$		Inverted
ν	Parameter of the beta LIDF			[Age]
μ	Parameter of the beta LIDF			[Age]
s_ℓ	Hot spot size parameter		0.05	
f_B	Fraction brown leaf area	Unitless	0	
C_v	Vertical crown cover fraction	Unitless		[LAI_c]
ξ	Tree shape factor		0.28	
SOILSPECT				
h	Rugosity		0.47	
b	Parameter of the phase function		5.84	
c	Parameter of the phase function		−3.13	
ω_{red}	Soil albedo in red spectral band			[Site]
ω_{NIR}	Soil albedo in NIR spectral band			[Site]
Sun-object-sensor geometry				
θ_s	Solar zenith angle	°		[Site, Date]
θ_o	Observation zenith angle	°		[Site, Date]
ψ	Relative azimuth angle	°		[Site, Date]
s	Proportion of diffuse radiation	Unitless	0.4	

LAI is the only unknown variable …

… but all other variables are taken into account (= forced) in the model

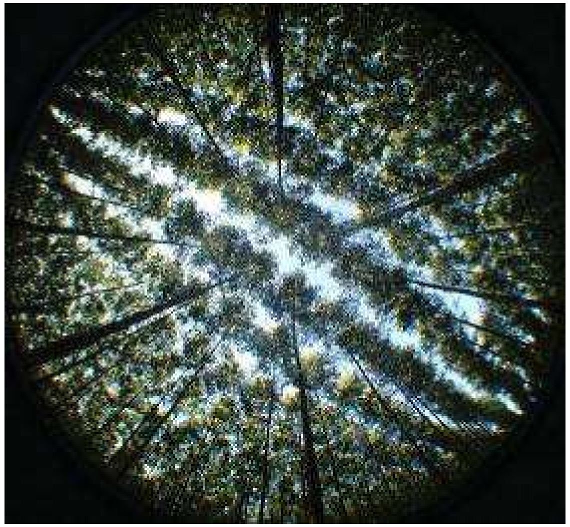
Methods

Field measurements

➔ 20 destructive LAI measurements on 9 contrasted stands, in dry and wet seasons

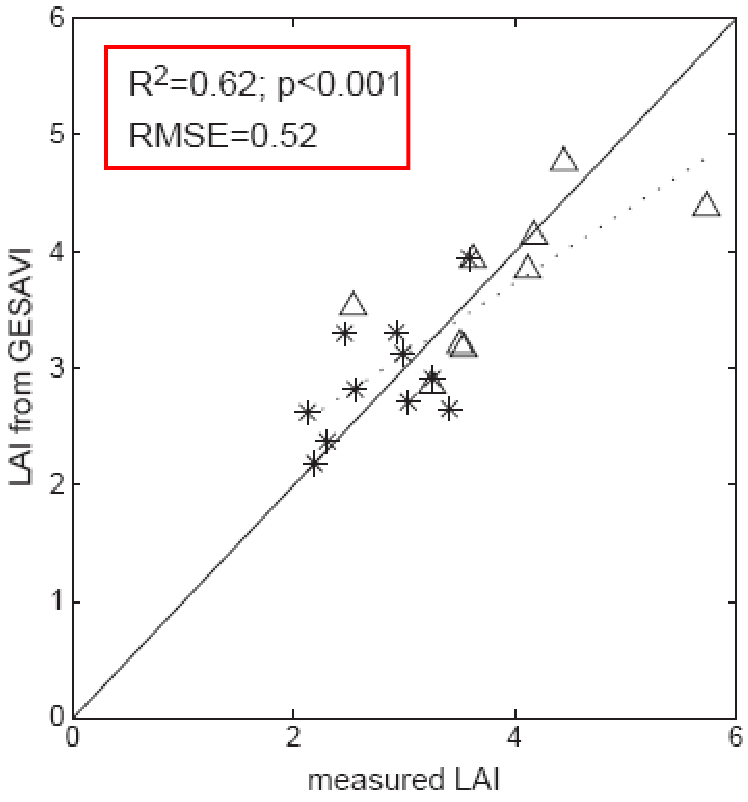
➔ Other measurements: SLA, leaf angles, chlorophyll, leaf reflectance, etc. for model inversion

➔ Gap fraction measurements on 16 stands, both seasons (with fisheye pictures), for model inversion test (not presented here)

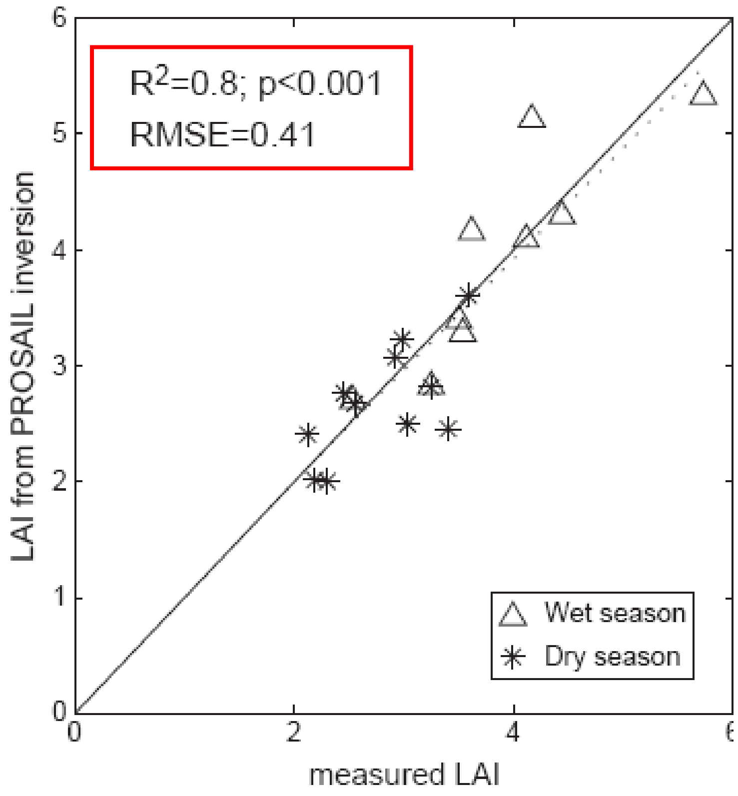


Results

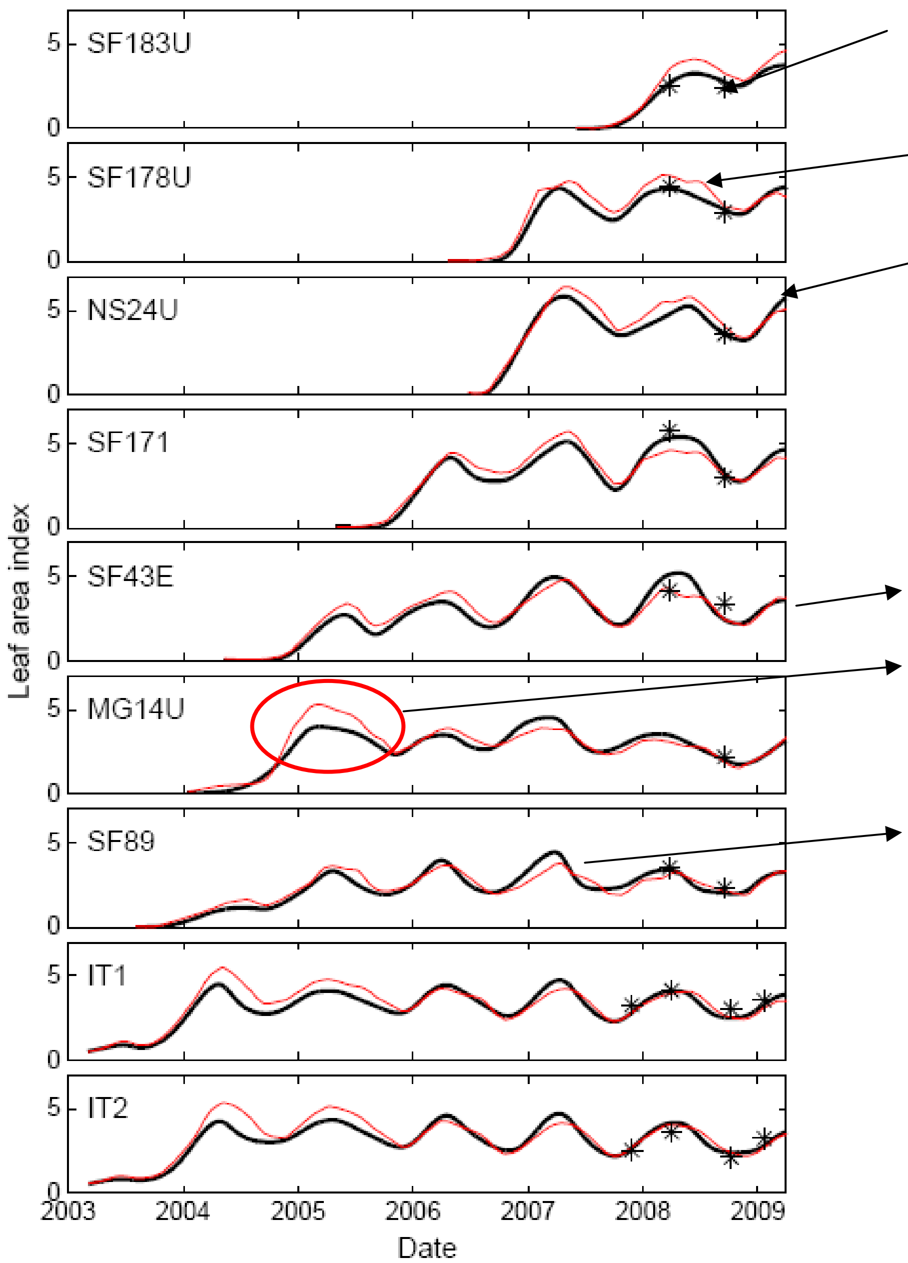
GESAVI



RTM inversion



Results



* Destructive measurements

LAI estimated from GESAVI

LAI estimated from RTM inversion

Results are close most of the time

Large difference the first year (canopy closure)

Small temporal shift

Results

Vegetation index (VI)

- Advantages:
  - Very easy to calibrate and apply
  - Robust, precise except for high LAI values
- Drawbacks:
  - needs a lot of LAI field measurements to calibrate the relationships on different conditions
  - needs other LAI data for a validation
  - needs visual interpretation of the NIR-Red scatter-plot

RTM inversion

- Advantages:
  - Slightly better results than VI, for high LAI values & first years
  - Takes into account geometry effects (e.g. sun angle varying with season)
  - Takes into account confounding factors (leaf angle, crown cover, SLA, etc.)
- Drawbacks
  - Requires many other measurements (no easier than LAI)
  - Uncertainty is still high

Based on these results, is it possible to construct a methodology which combines the advantages of these methods ?

Method II

(1) the database

• Calibrate a VI on a large dataset created with the PROSAIL RTM

• Need to generate a set of model input combinations

• The distributions and correlations between these inputs must correspond to reality

➔ use of the simulated dataset obtained on 16 stands to have a dataset of thousands of values of Red (measured), NIR (measured) and associated LAI (simulated)

Method II

(2) the index type

Most 2-bands VI with Red and NIR bands are constructed based on the model:

$$VI = \frac{aNIR + bRED + c}{dNIR + eRED + f}$$

VI	a	b	c	d	e	f
DVI	1	-1	0	0	0	0
RVI	1	0	0	0	1	0
NDVI	1	-1	0	1	1	0
PVI	1	*-B*	*-A*	0	0	$\sqrt{1+B^2}$
SAVI	(1+L)	-(1+L)	0	1	1	L
TSAVI	*B*	$-B^2$	*-A*B*	*B*	1	$-A*B+X(1+B^2)$
OSAVI	1	-1	0	1	1	*Y*
GESAVI	1	-1.505	-0.034	0	1	0.0383

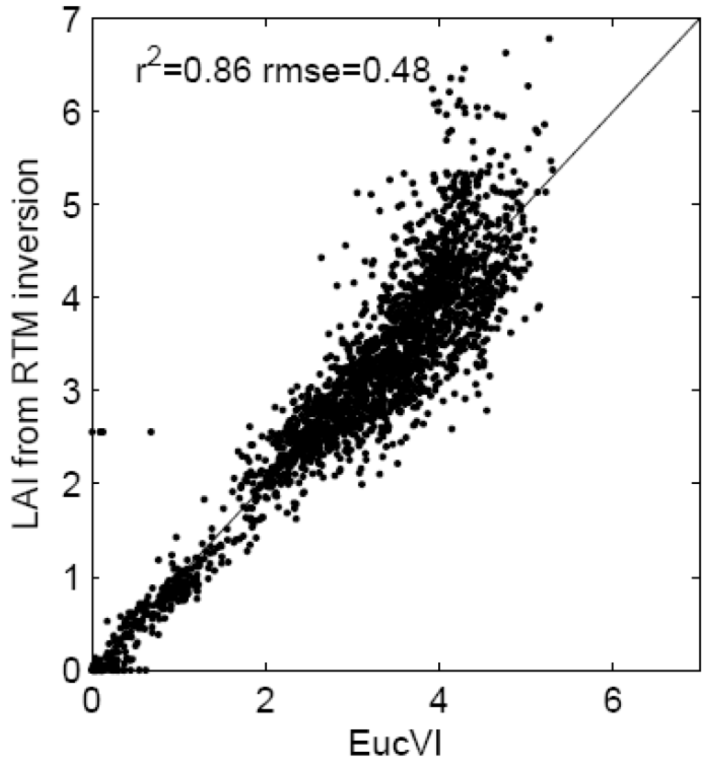
Rough index calibration = **find the parameters [a,…,f]** which minimize the squared difference between VI and LAI. This calibration is done on the synthetic database generated by PROSAIL

Results II

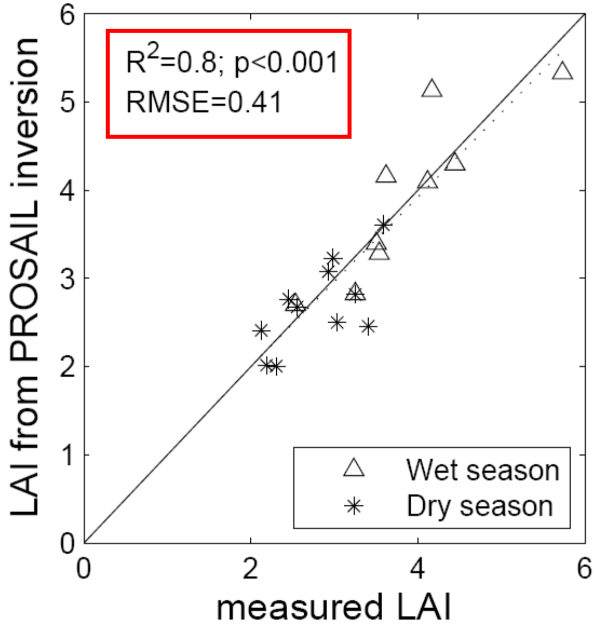
« EucVI » index

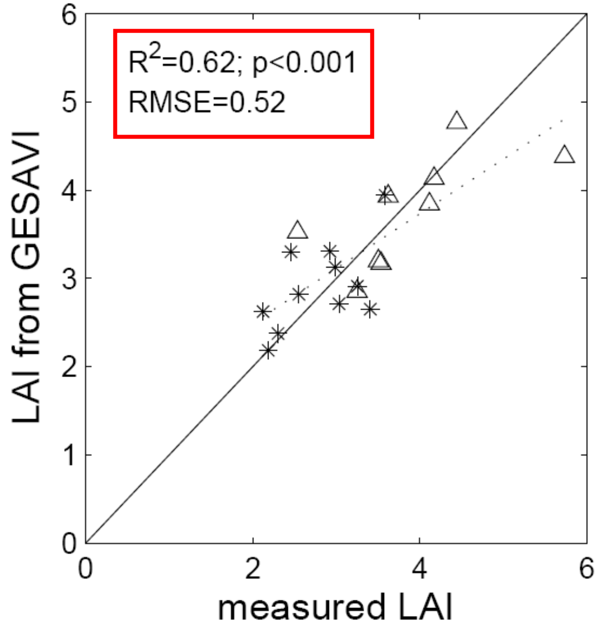
$$VI = \frac{aNIR + bRED + c}{dNIR + eRED + f}$$

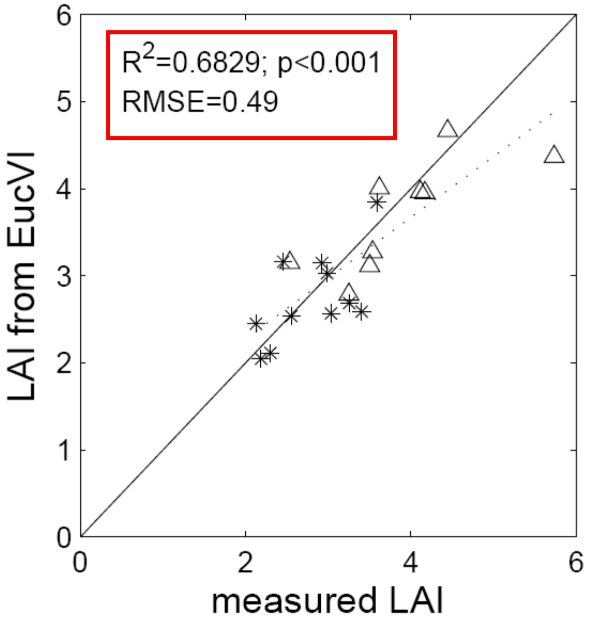
VI	a	b	c	d	e	f
EucVI	4.95	-9.32	0.005	0.46	6.97	0.0911



Results II







Slight improvement compared to GESAVI

Does not reach inversion results: Other information not contained in Red and NIR reflectances are used in RTM inversion (stand age, acquisition geometry, etc.)

Note that the **measured** LAI is used here as an **independent validation** (like for RTM inversion)

Conclusion

- Both VI and RTM inversion are efficient methods for LAI estimations (RMSE<0.5), with only two bands

- RTM inversion gives better results than VI because it takes into account acquisition geometry, stand age, etc. which impact on other confounding factors

- VI are much more simple to apply; RTM can be used to calibrate a VI; VI is therefore a very simplified RTM inversion

- With MODIS data, LAI can be estimated since the planting date, which opens perspectives for data assimilation/forcing into ecophysiological process-based models (G'Day, 3PG,…)

- Further work is needed :
    - for small stands which do not have a MODIS pixel entirely contained in the stand
    - for the use of other bands (but with a resolution of 500 m)→ unmixing technique
    - to pay more attention to the first year of the rotation (before canopy closure)

Thank you for your attention !

For further informations:

- le Maire et al.. (2011). Leaf area index estimation with MODIS reflectance time series and model inversion during full rotations of Eucalyptus plantations. *Remote Sensing of Environment, 115*, 586-599
- Marsden et al. (2010). Relating MODIS vegetation index time-series with structure, light absorption and stem production of fast-growing Eucalyptus plantations. *Forest Ecology and Management, 259*, 1741-1753

… and XV SBSR proceedings