The impact of lianas on radiative transfer and albedo of tropical forests

A modelling study

GHENT UNIVERSITY

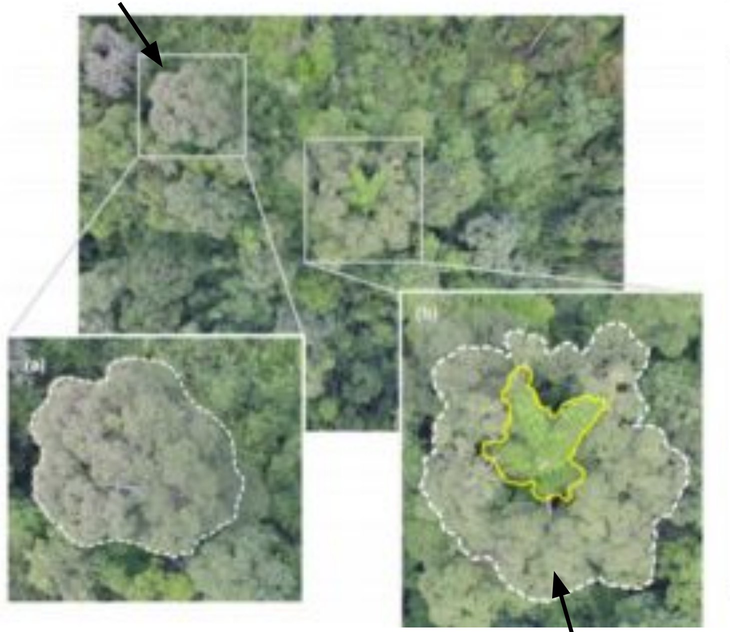
Félicien Meunier*, Alexey Shiklomanov, Michael Dietze, Marco Visser and Hans Verbeeck

EGU, 05/04/2020

In a nutshell

*** Felicien.Meunier@ugent.be**

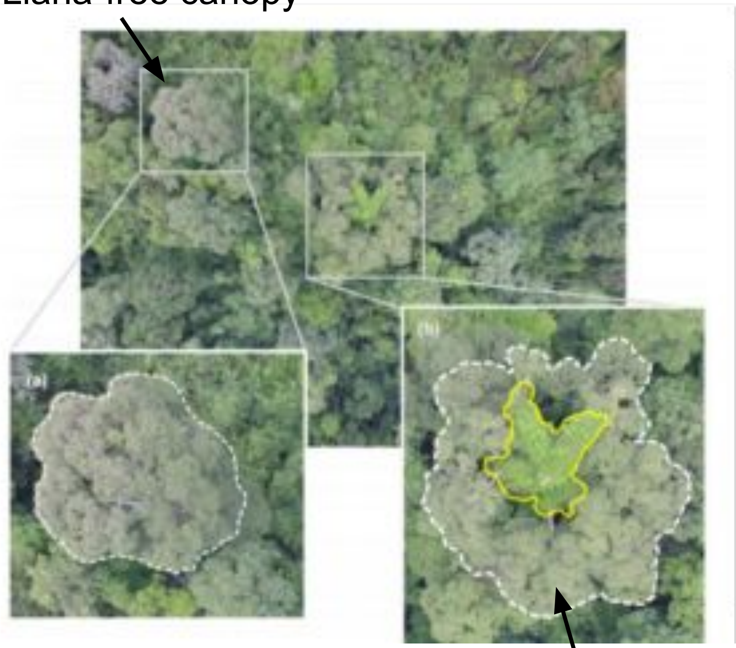
Lianas are visible from space!



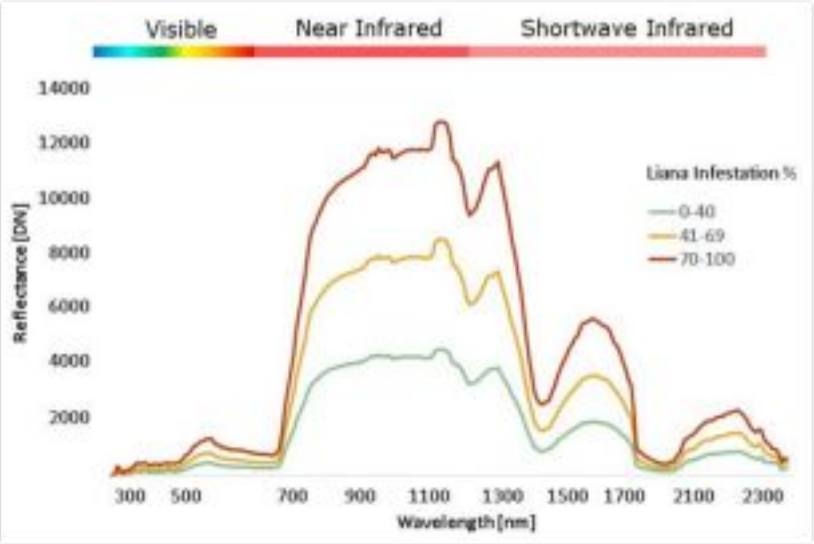
Waite et al., Journal of applied ecology, 2019

Lianas are visible from space →
← Forest spectrum is impacted by lianas

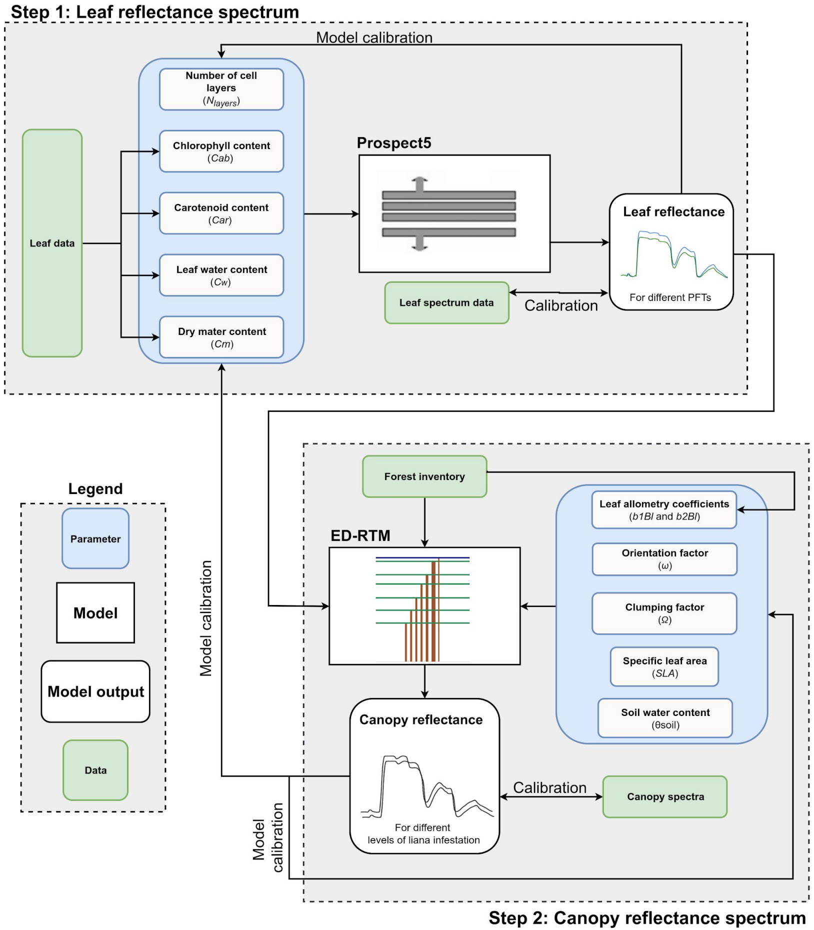
Liana-free canopy



Liana-infested tree



The study



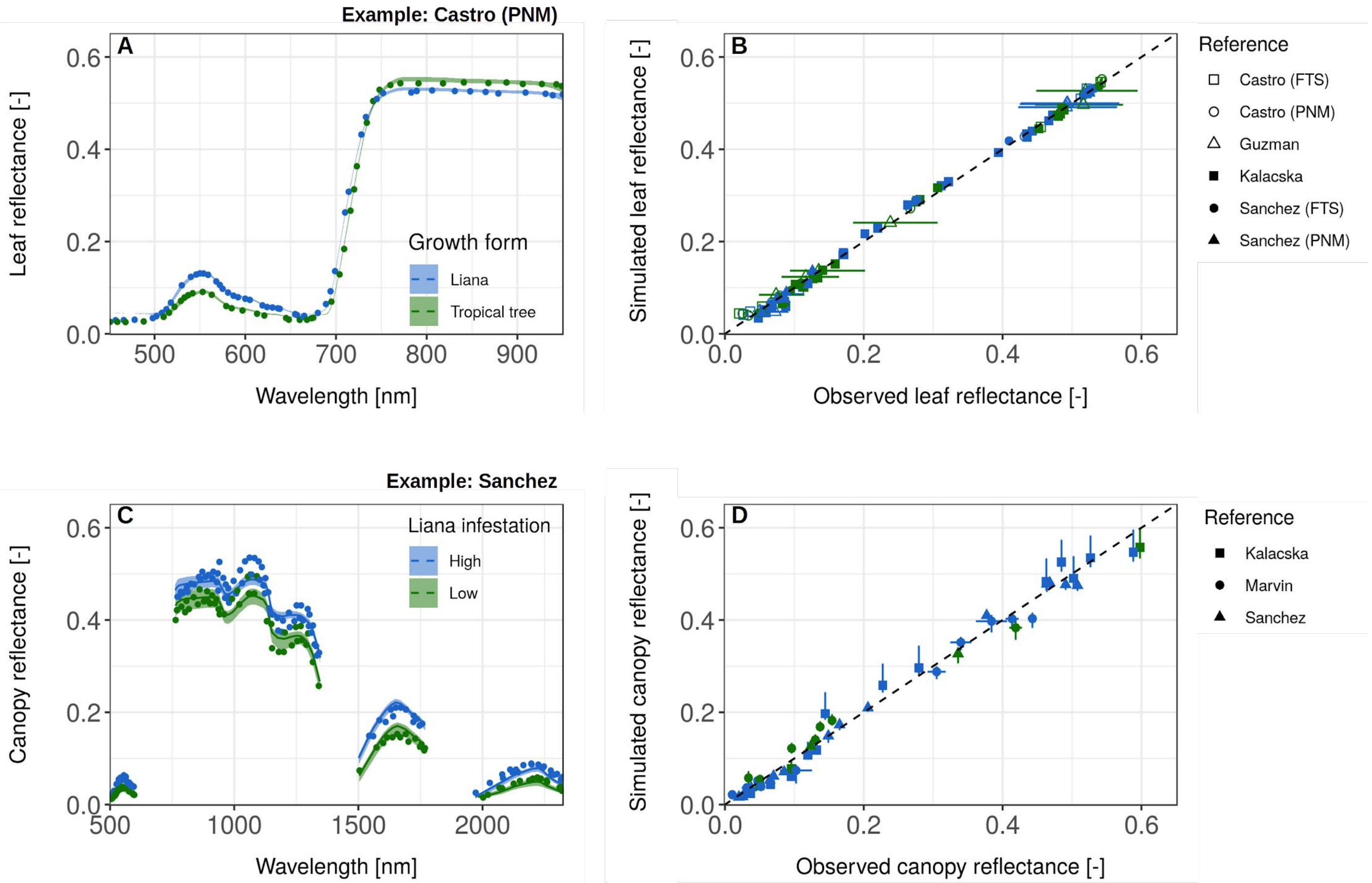
We used process-based models of the leaf (PROSPECT) and the canopy (ED-RTM) coupled to a bayesian parameter assimilation technique to reproduce forest canopy spectra as affected by lianas and derive the canopy changes due to liana-infestation.

To do so, we first compiled all existing data of liana leaf spectrum and all published spectra of canopy with contrasted levels of liana infestation. We calibrated liana (and co-occurring tree) leaf traits to reproduce their respective leaf spectra and feed that information into the canopy model.

These models can now serve to predict the impact of liana on light transmission in dense canopies, on the Energy budget of infested tropical forests and more generally on their functioning.

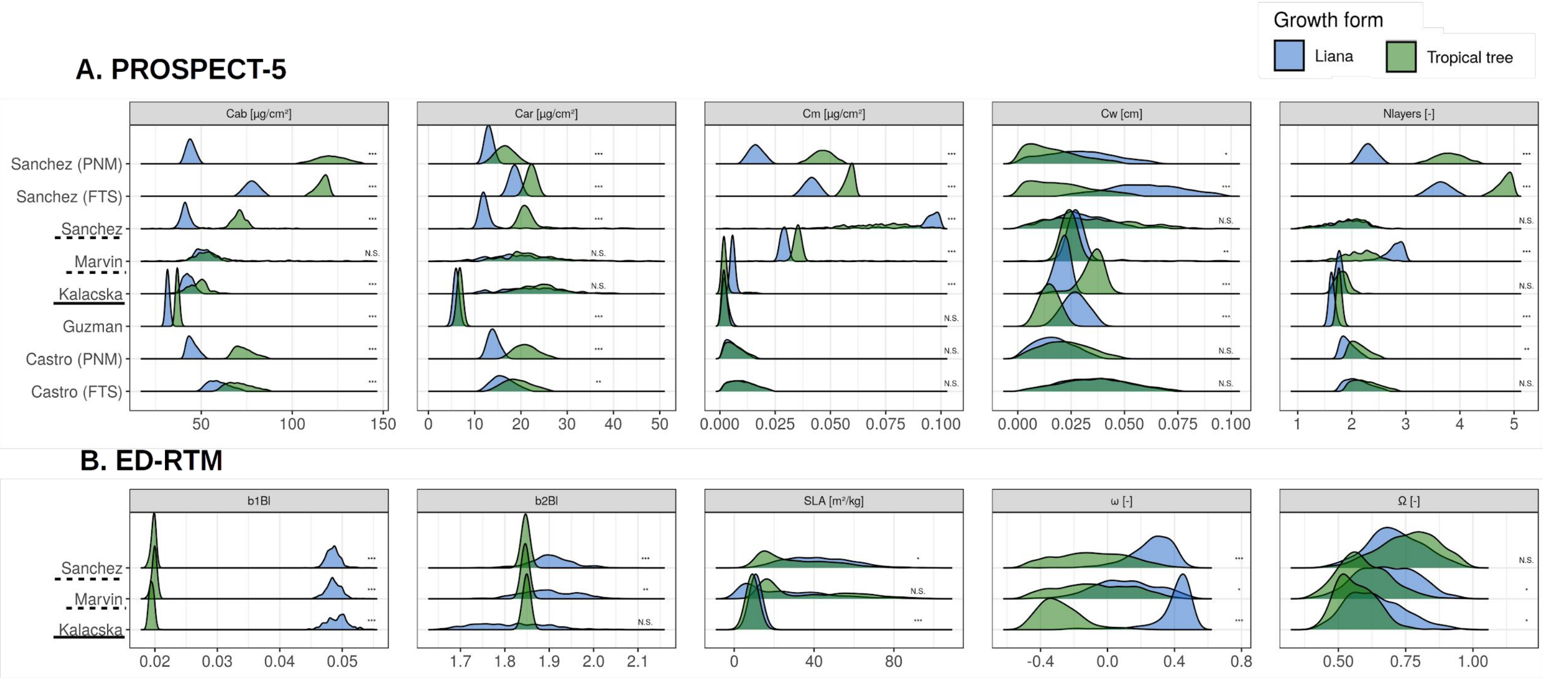
Results (calibration)

Leaf spectrum



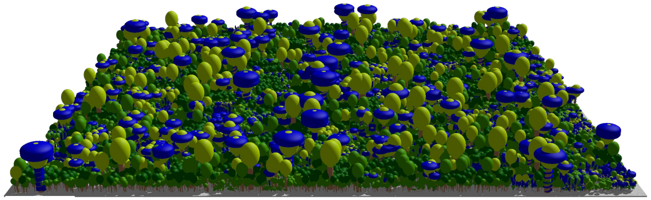
Canopy spectrum

Results (traits)

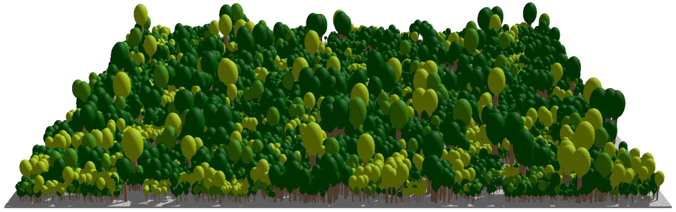


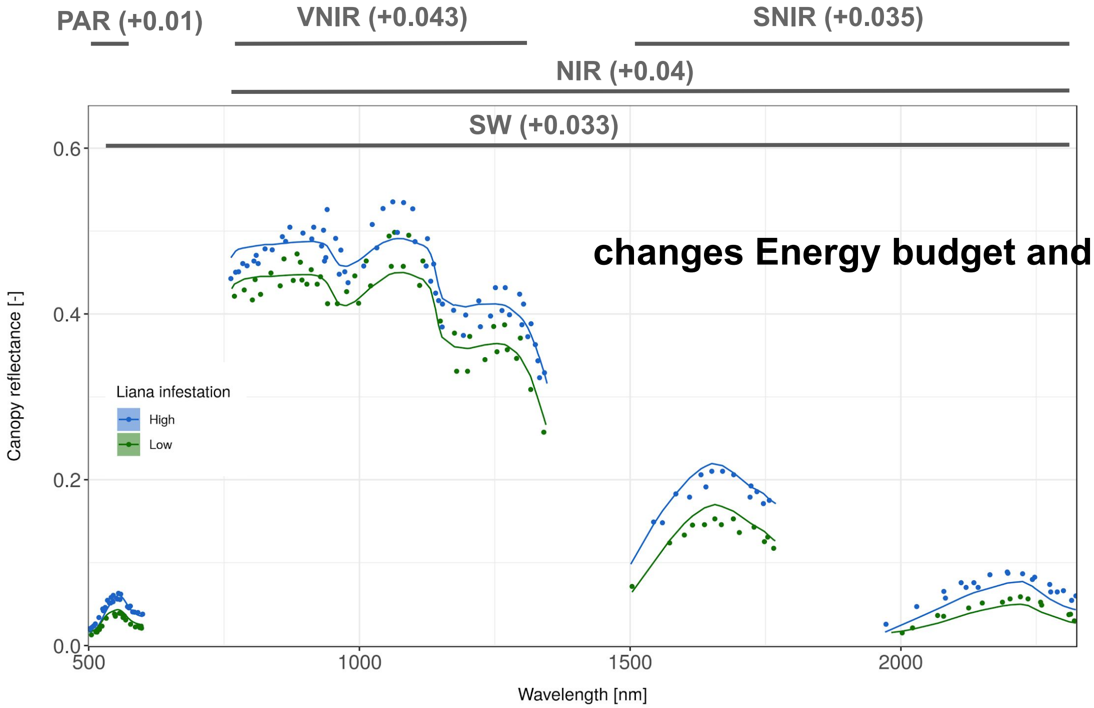
- Liana leaves differ from tree leaves by many aspects (pigment content is lower, leaves are “cheaper” and contain more water)
- Liana infest more in leaves than trees, liana canopies are more clumped, and their leaves are more horizontal.

Example of application



vs





changes Energy budget and hence forest dynamics:

Ecosystem GPP: -15%
Ecosystem NPP: -12%
Ecosystem WUE: -10%
Evapotranspiration: ≈0%

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EGU, 05/04/2020

Extended

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Lianas in Neotropical forests

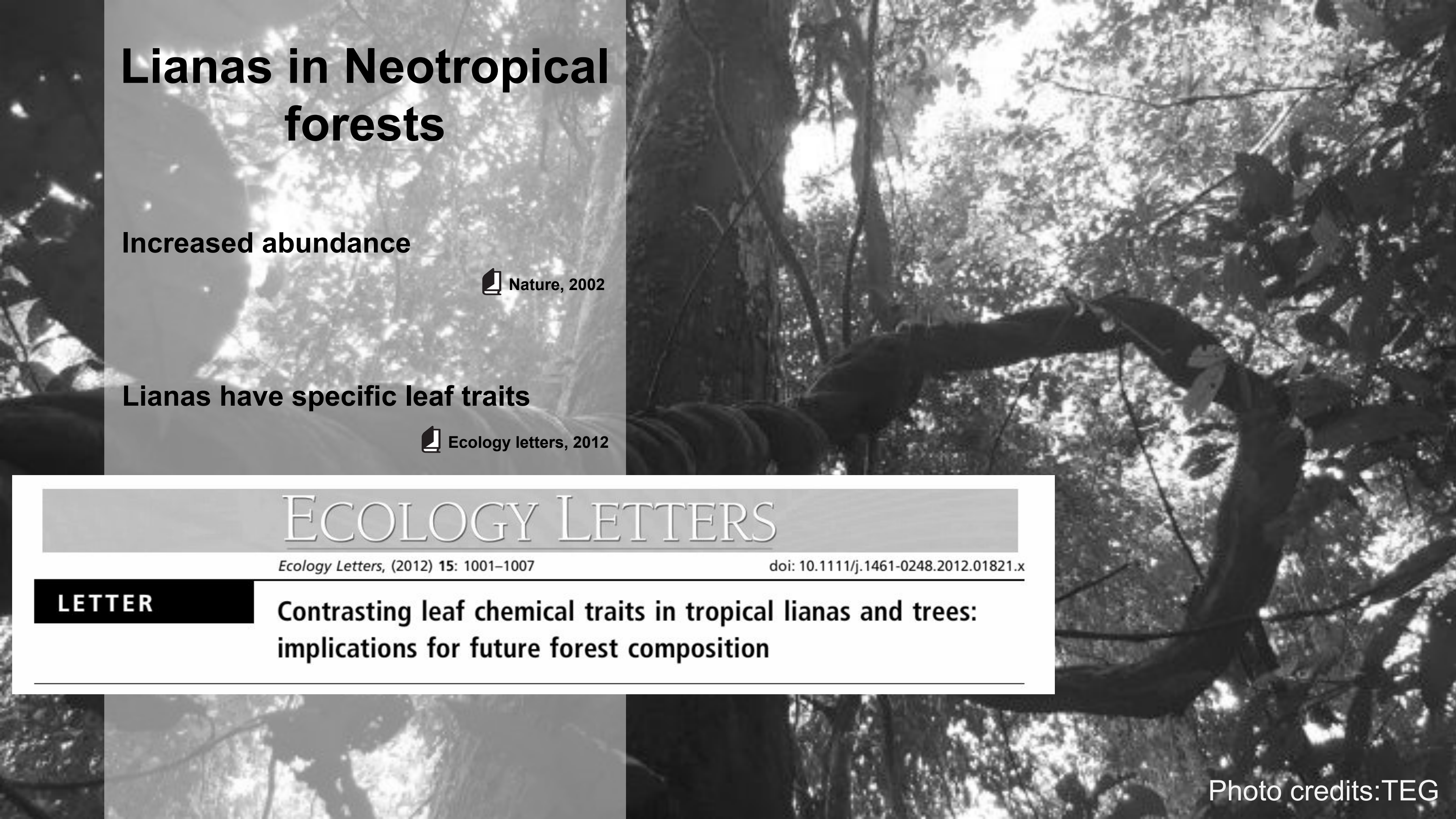
Increased abundance

Nature, 2002

Increasing dominance of large lianas in Amazonian forests

Oliver L. Phillips*, Rodolfo Vásquez Martínez†, Luzmila Arroyo‡§, Timothy R. Baker*, Timothy Killeen‡§||, Simon L. Lewis*¶, Yadvinder Malhi¶, Abel Monteagudo Mendoza†#, David Neill☆**, Percy Núñez Vargas#, Miguel Alexiades††, Carlos Cerón‡‡ Anthony Di Fiore§§, Terry Erwin||||, Anthony Jardim§, Walter Palacios☆, Mario Saldias§ & Barbara Vinceti¶

Photo credits:TEG



Lianas in Neotropical forests

Increased abundance

Nature, 2002

Lianas have specific leaf traits

Ecology letters, 2012

ECOLOGY LETTERS

Ecology Letters, (2012) **15**: 1001–1007 doi: 10.1111/j.1461-0248.2012.01821.x

LETTER

Contrasting leaf chemical traits in tropical lianas and trees: implications for future forest composition

Photo credits:TEG

Lianas in Neotropical forests

Increased abundance

Nature, 2002

Lianas have specific leaf traits

Ecology letters, 2012

No DVGMs include lianas

PNAS, 2016


LETTER

The importance of including lianas in global vegetation models

Hans Verbeeck[a,1] and Elizabeth Kearsley[a]

Photo credits:TEG

Lianas in Neotropical forests

Increased abundance

Nature, 2002

Lianas have specific leaf traits

Ecology letters, 2012

No DVGMs include lianas (expect us)

Received: 7 September 2018 | Revised: 2 July 2019 | Accepted: 4 July 2019
DOI: 10.1111/gcb.14769

PRIMARY RESEARCH ARTICLE

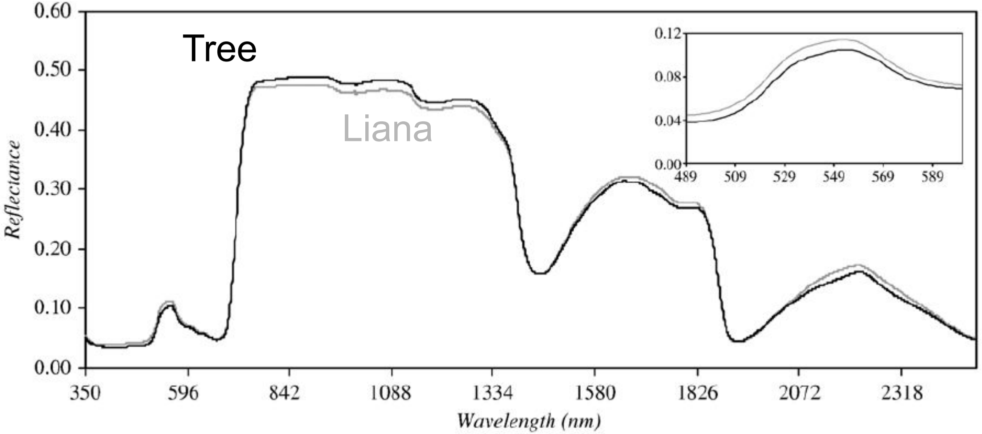
Global Change Biology WILEY

Modeling the impact of liana infestation on the demography and carbon cycle of tropical forests

Manfredo di Porcia e Brugnera[1] | Félicien Meunier[1,2] | Marcos Longo[3,4] | Sruthi M. Krishna Moorthy[1] | Hannes De Deurwaerder[1] | Stefan A. Schnitzer[5,6] | Damien Bonal[7] | Boris Faybishenko[8] | Hans Verbeeck[1]

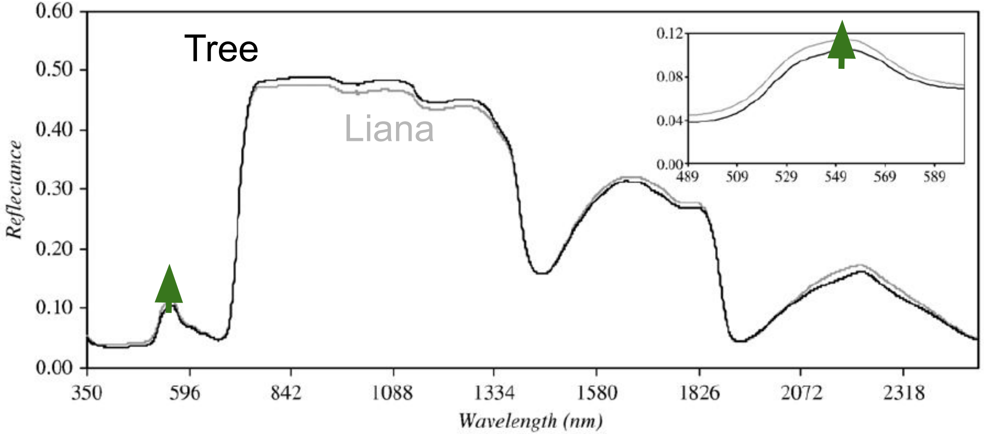
Photo credits:TEG

The concept



Kalacska et al., RSE, 2007

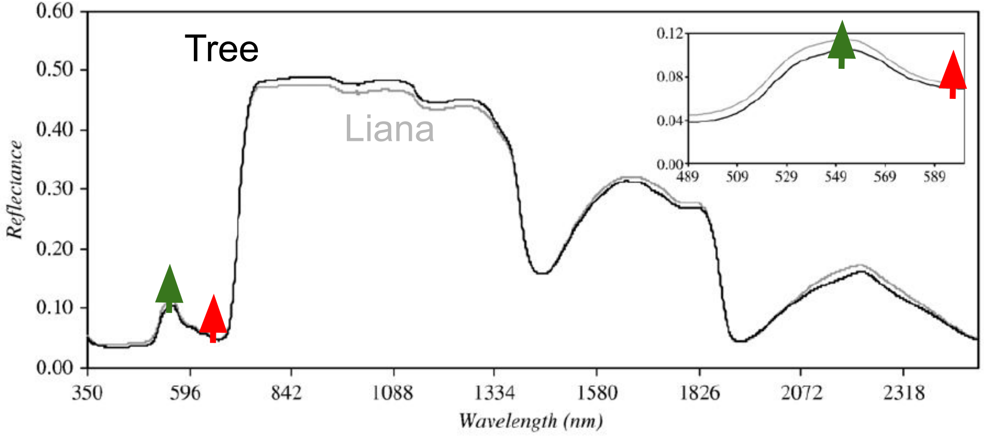
The concept



Spectral Region	Mechanisms Controlling Reflectance	Relevance to Liana-Tree Discrimination		
		Leaf-level	*Canopy-level*	*Physiology*
Visible	Chlorophyll and carotenoid concentrations[a]	Higher reflectance of lianas in green peak important[c,d,e]	Higher reflectance of lianas found with increasing abundance[b,e]	Lianas contain lower pigment levels[b,c,d] (but see refs. f & g)

Marvin et al., RSE, 2016

The concept



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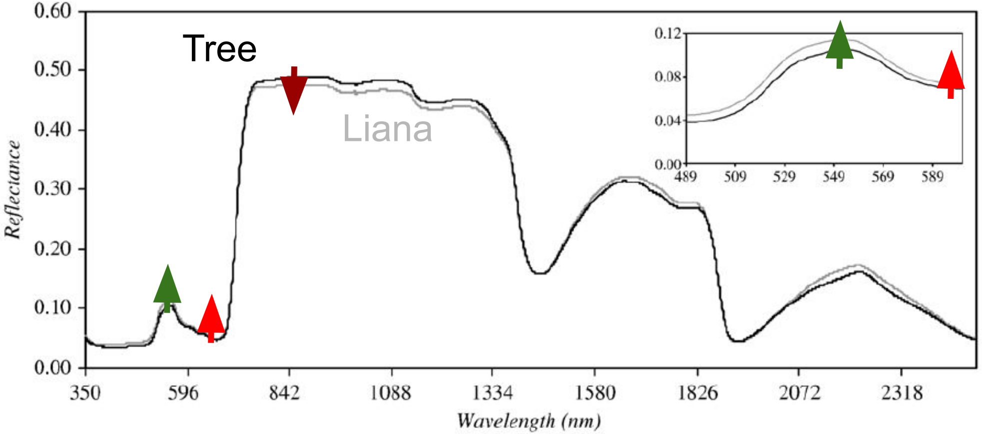
Red Edge	Chlorophyll content, biomass, water stress[a]	Higher reflectance of lianas in red edge important[c,d,e]	Same as visible but less important for discrimination[b,e]	Lianas contain lower chlorophyll[b,c,d] (but see refs. f & g)

Marvin et al., RSE, 2016

The concept



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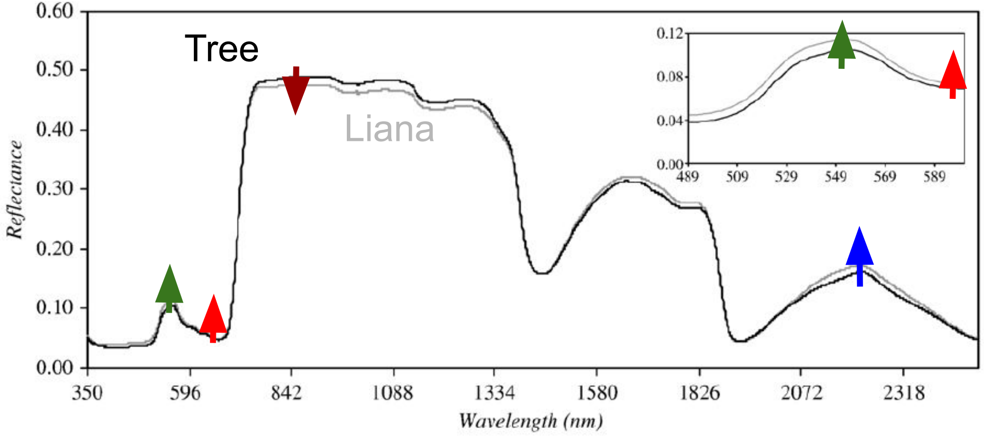
Near Infrared	Leaf internal structure, nitrogen concentration[a]	Results are mixed; spectral and physiological differences are inconclusive[b,c,e,f]		

Marvin et al., RSE, 2016

The concept



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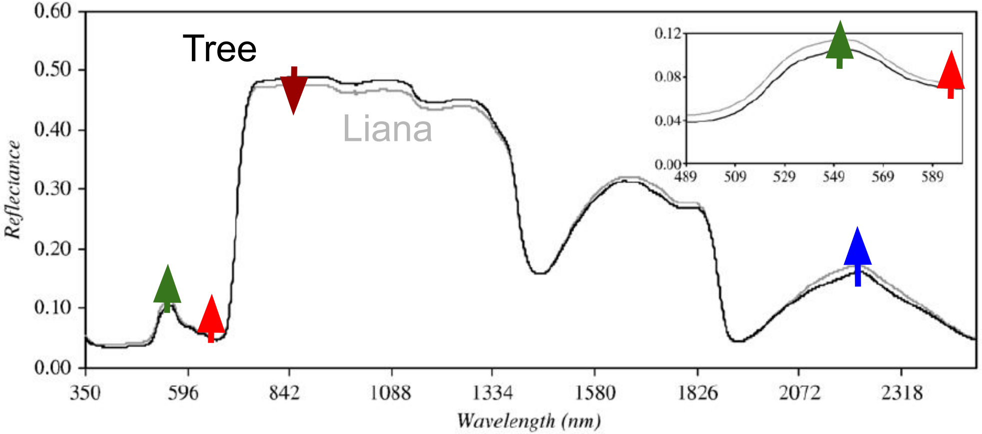
Near Infrared	Leaf internal structure, nitrogen concentration[a]	Results are mixed; spectral and physiological differences are inconclusive[b,c,e,f]		
Shortwave Infrared	Leaf water content, cellulose[a]	Most important region for discrimination[e,f]	By far the most important region for discrimination[e]	Leaf water content higher in lianas[d,f,g]

Marvin et al., RSE, 2016

The concept

Leaf-level → **Canopy-level**

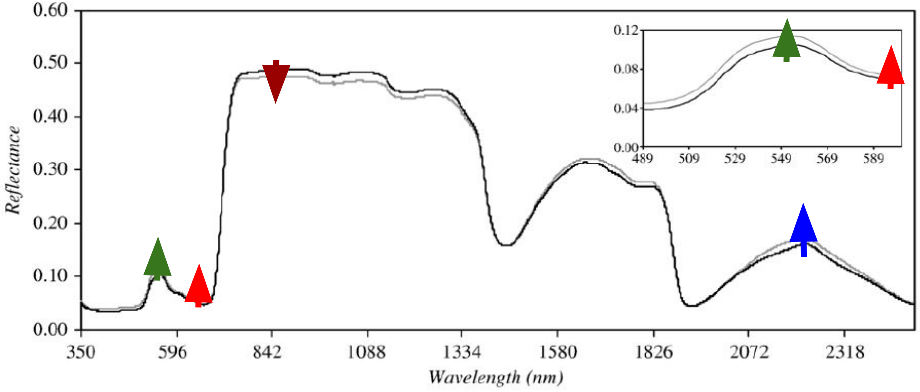


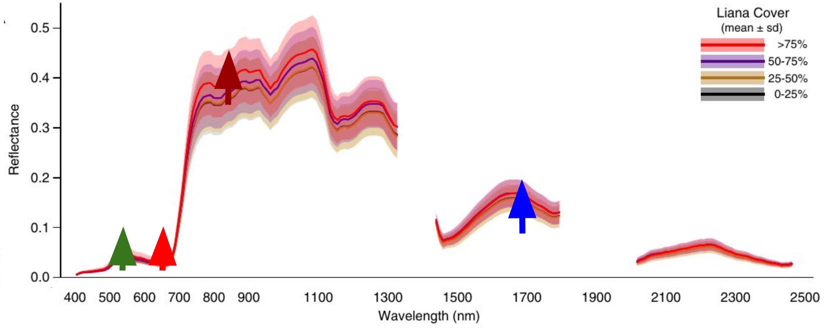
Waite et al., JoAE, 2019

The concept

Leaf-level

Canopy-level

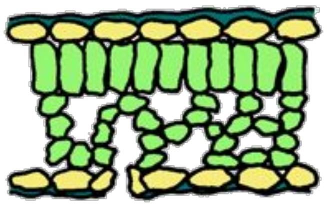


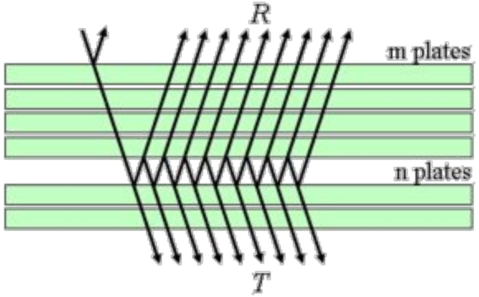


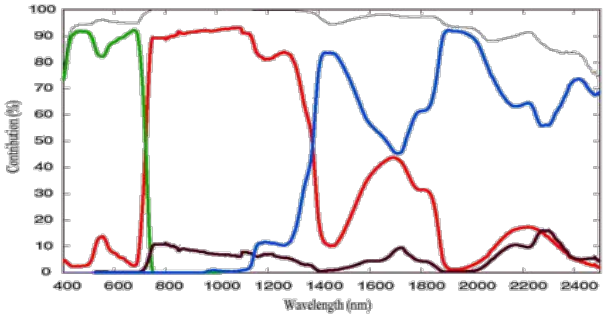
Canopy effects
(leaf angle, leaves distribution etc.)

Marvin et al., RSE, 2016

The PROSPECT model
(to model the leaf-level differences between lianas and trees)



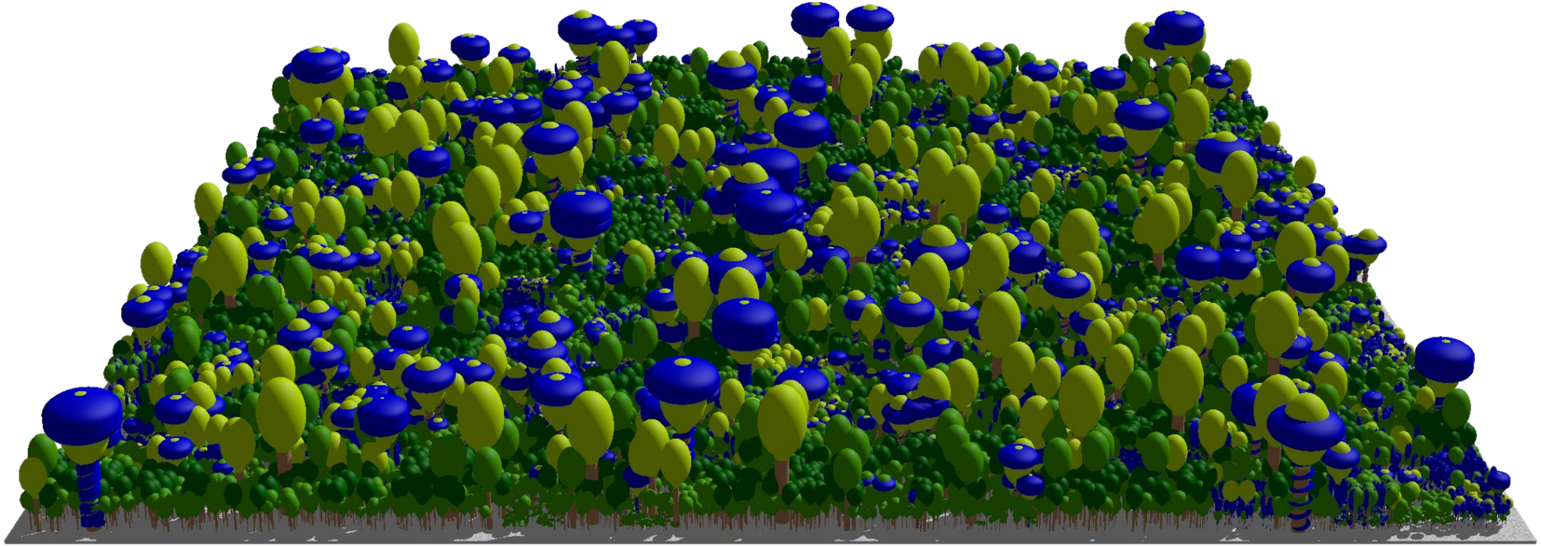




- PROSPECT is a leaf optical model that simulates directional–hemispherical reflectance and transmittance of various green monocotyledon and dicotyledon species, over the solar spectrum from 400 nm to 2500 nm
- 5 biophysical parameters (N_{layers}, C_{ab}, C_{ar}, C_m and C_w) that respectively represent the number of stacked layers, the leaf chlorophyll and carotenoid content, the leaf dry matter and its water content.

Féret et al., RSE, 2008

The Ecosystem Demography model
(to model the canopy-level differences between lianas and trees)

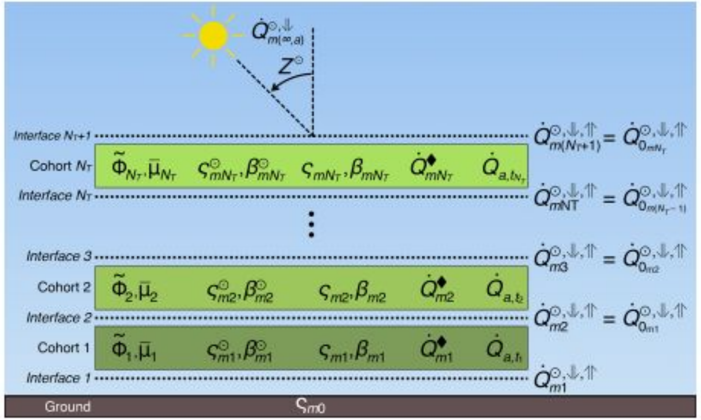


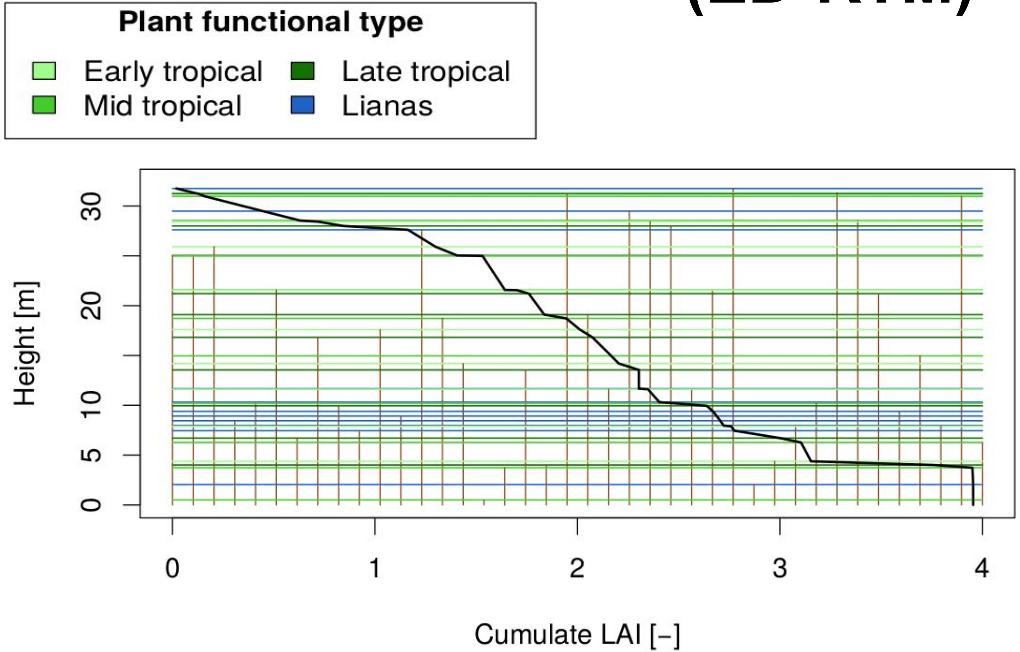
- ED is a cohort-based model, the state structure of which is a nested hierarchy of geographical grid cells (polygons and sites), landscape age classes (patches) and cohorts of trees of different sizes and PFTs
- Contains a RTM module (Energy budget). Three broad bands: Visible (photosynthesis), NIR and TIR
- Only DGVM that includes lianas

Longo et al., GMD, 2019

di Porcia e Brugnera et al., GCB, 2019

The RTM of the Ecosystem Demography model (ED-RTM)

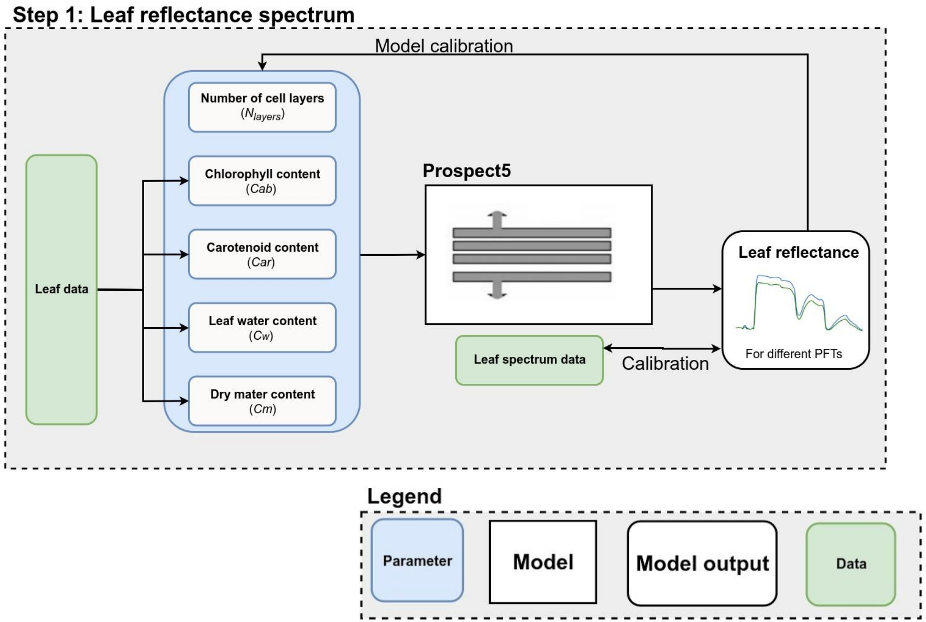




- Multilayer version of a two-stream model applied to the full solar spectrum
- 5 extra-parameters about leaf vertical distribution, clumping factor, leaf orientation etc.
- Extra-information required (date, location, inventory)
- Available at fine spectral resolution (1nm)

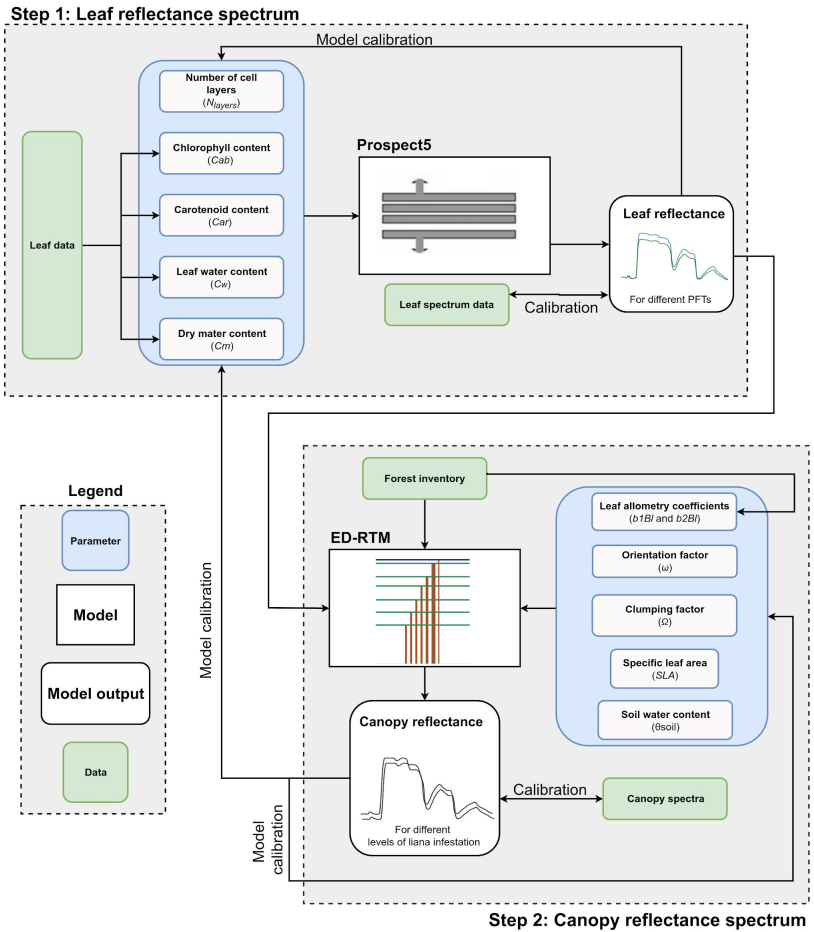
Longo et al., GMD, 2019

The workflow (step 1)



- Liana and tree leaf reflectance spectra available
- Bayesian calibration for each single study/site
- Growth-form comparison
  (Leaf biochemical and structural traits)
- Uncertainty analysis of the posterior distributions

The workflow (steps 1 and 2)



- Canopy spectra available for multiple liana-infestation levels
- Sequential two-steps process
  → Leaf posterior distributions are used as priors
- Bayesian calibration for each single study/site
- Growth-form comparison
  (Leaf AND canopy traits)
- Uncertainty analysis of the posterior distributions

Data collection (meta-analysis)

- Only a few key studies
- Raw data almost never available!
  → manual digitization
- Uncertainties almost never reported
- Only a few sites (mainly Panama)

Reference	Study site(s)	Short name	Leaf reflectance spectrum range (nm)	Canopy reflectance spectrum range (nm)	Data source	Date of collection
Castro-Esau et al. (2003)	FTS, Panama PNM, Panama	Castro (FTS) Castro (PNM)	450-950	-	Digitized	2013/03 (dry season)
Guzmán et al. (2018)	SRNP, Costa Rica	Guzmán	450-950	-	Original	2017/05-07 (wet season)
Sanchez et al. (2009)	FTS, Panama PNM, Panama	Sanchez (FTS) Sanchez (PNM)	450-950	-	Digitized	2004/08 (wet season)
Kalacska et al. (2007)	PNM, Panama	Kalacska	400-2500	450-2250	Digitized	2004/12 (dry season)
Marvin et al. (2016)	Gigante, Panama	Marvin	-	400-2500	Digitized	2012/02 (dry season)
Sanchez et al. (2006)	PNM, Panama	Sanchez	-	400-2400	Digitized	2012/07 (wet season)

Data collection (meta-analysis)

Leaf-level

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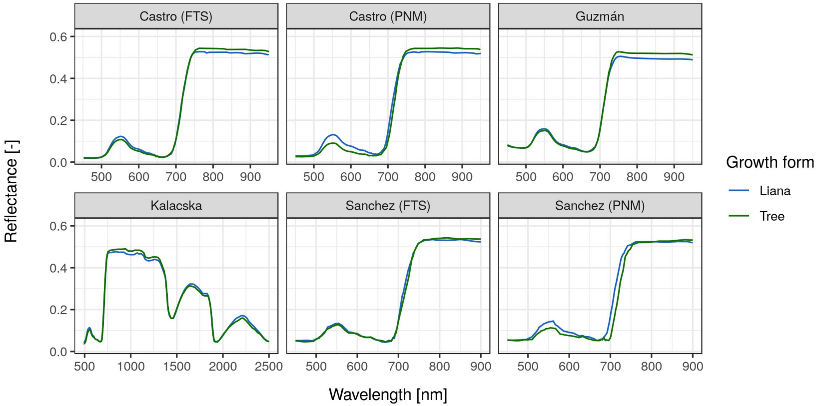
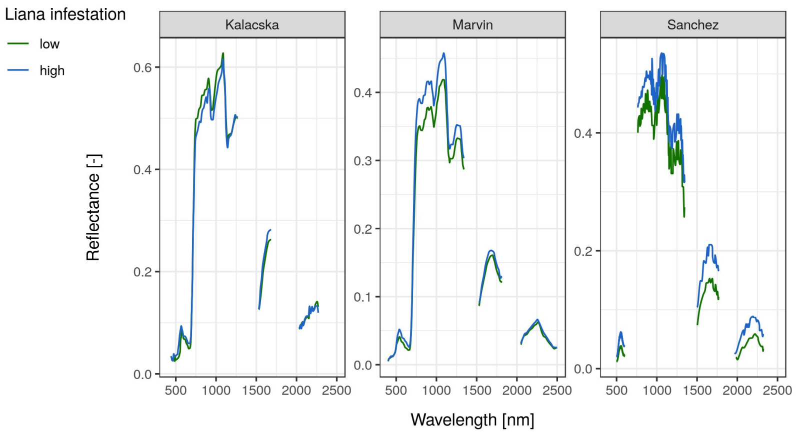
Canopy level

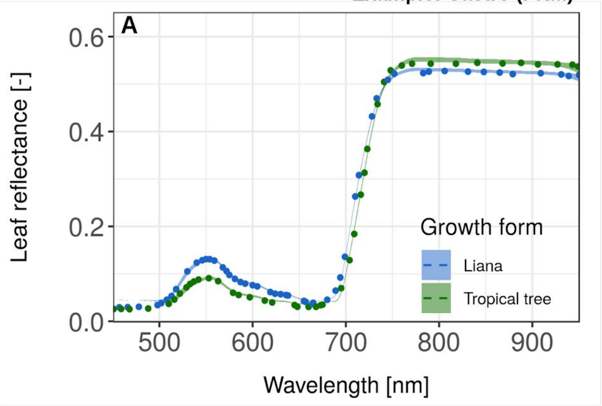




Results (Model calibration)

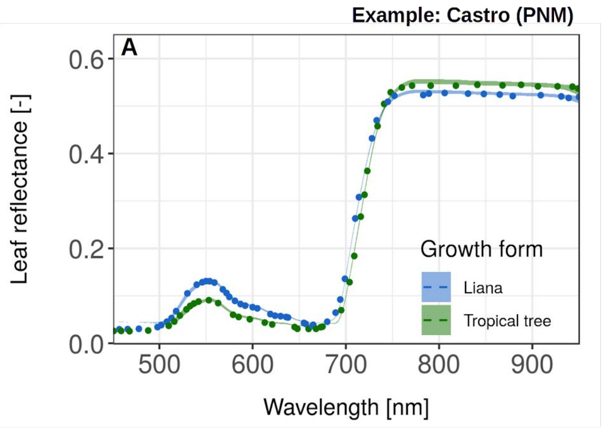
Leaf spectrum

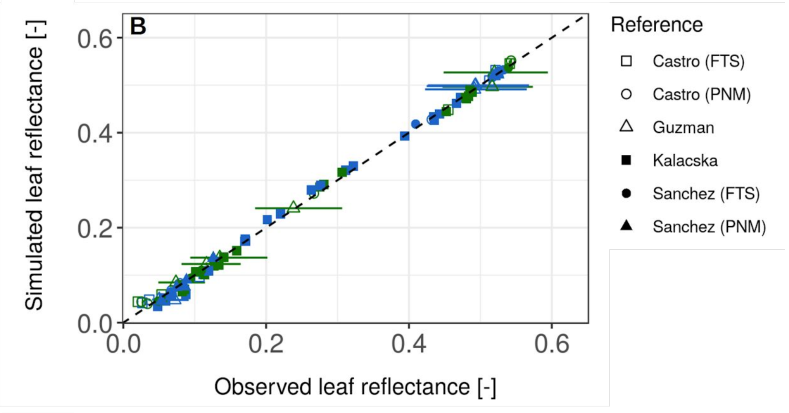
Example: Castro (PNM)



Results (Model calibration)

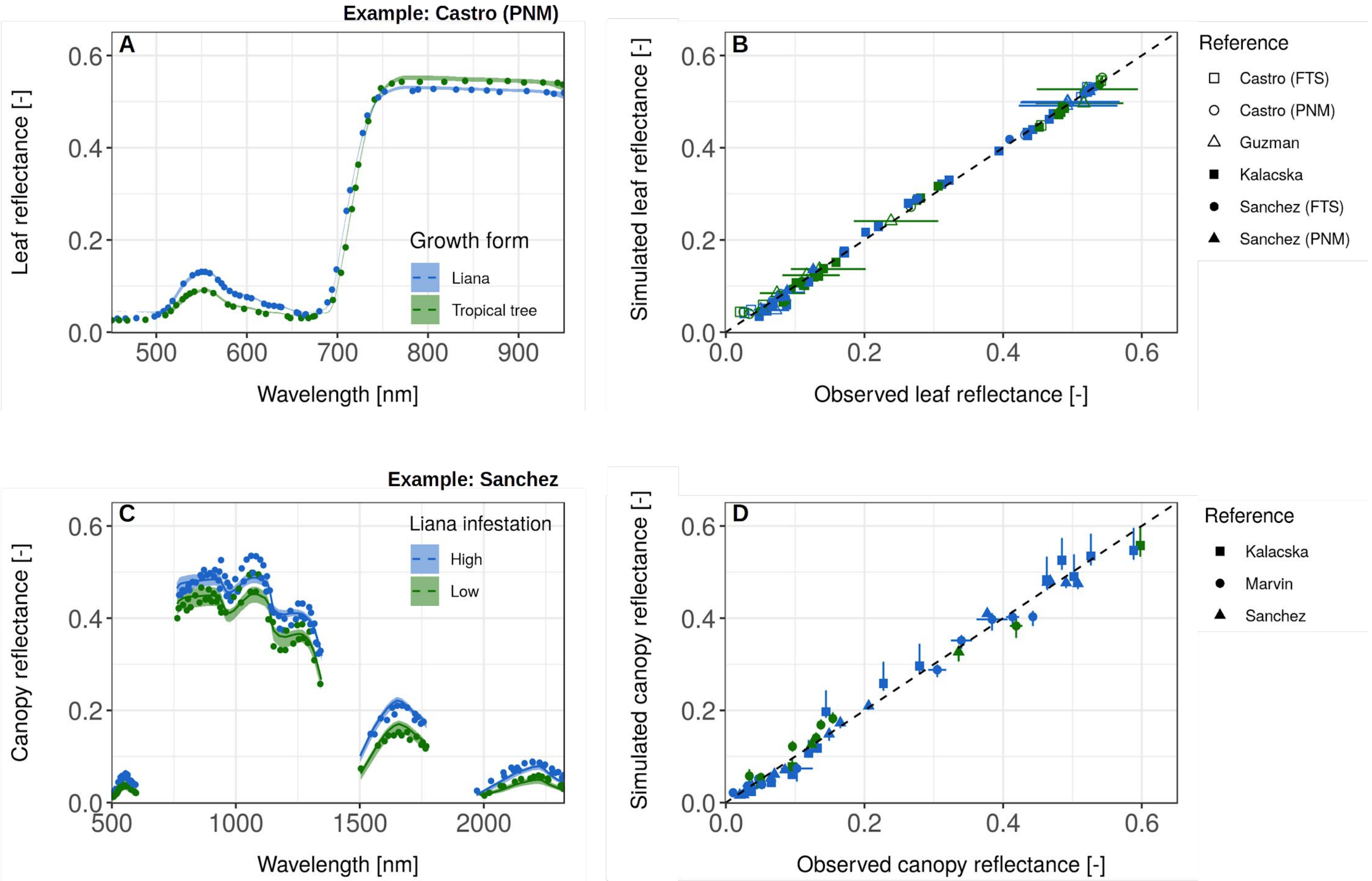
Leaf spectrum





Results (Model calibration)

Leaf spectrum



Canopy spectrum

Results (Model calibration)

			Visible (VIS)		Infrared (NIR)	
			RMSE	Bias	RMSE	Bias
Leaf	Model vs data	Tree	0.0123	-0.00569	0.00571	-0.00035
		Liana	0.0091	-0.00134	0.00522	0.00127
	Data vs Data	Tree - Liana	0.0137	-0.00818	0.0132	0.00514
	Model vs Model		0.0167	-0.01040	0.0131	0.00387
Canopy	Model vs data	Liana-free stands	0.0120	0.00225	0.0198	0.00144
		Liana-rich stands	0.0119	-0.00348	0.0209	-0.00067
	Data vs Data	Liana-free - Liana-rich	0.0143	-0.00111	0.0268	-0.0167
	Model vs Model		0.0120	-0.00388	0.0240	-0.0158

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\sum_{\lambda=1}^{m_i}\left(x_{i,\lambda} - \hat{x}_{i,\lambda}\right)^2}{N}}$$

$$Bias = \frac{\sum_{i=1}^{n}\sum_{\lambda=1}^{m_i}\left(x_{i,\lambda} - \hat{x}_{i,\lambda}\right)}{N}$$

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Model calibration performance

Model calibration performance

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Sim. errors < Obs. signal?

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	Data vs Data	Liana-free - Liana-rich	0.0143	-0.00111	0.0268	-0.0167
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Model ability to reproduce differences

Model ability to reproduce differences

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\sum_{\lambda=1}^{m_i}\left(x_{i,\lambda} - \hat{x}_{i,\lambda}\right)^2}{N}}$$

$$Bias = \frac{\sum_{i=1}^{n}\sum_{\lambda=1}^{m_i}\left(x_{i,\lambda} - \hat{x}_{i,\lambda}\right)}{N}$$

Results (Model calibration)

			Visible (VIS)		Infrared (NIR)	
			RMSE	Bias	RMSE	Bias
Leaf	Model vs data	Tree	0.0123	-0.00569	0.00571	-0.00035
		Liana	0.0091	-0.00134	0.00522	0.00127
	Data vs Data	Tree - Liana	0.0137	-0.00818	0.0132	0.00514
	Model vs Model		0.0167	-0.01040	0.0131	0.00387
Canopy	Model vs data	Liana-free stands	0.0120	0.00225	0.0198	0.00144
		Liana-rich stands	0.0119	-0.00348	0.0209	-0.00067
	Data vs Data	Liana-free - Liana-rich	0.0143	-0.00111	0.0268	-0.0167
	Model vs Model		0.0120	-0.00388	0.0240	-0.0158

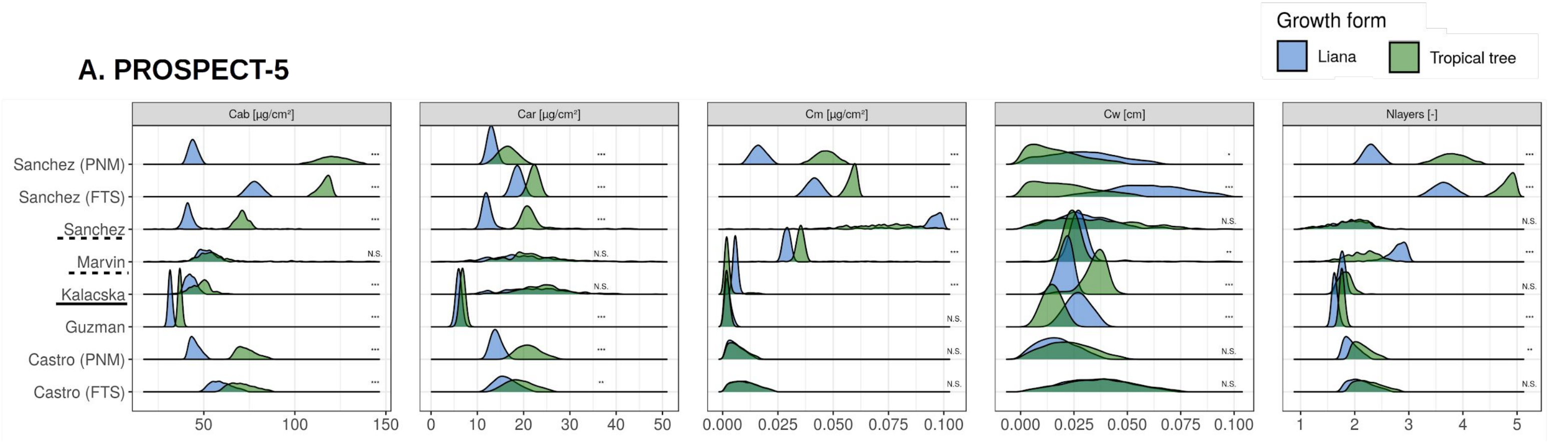
Model calibration performance

Sim. errors < Obs. signal?

Model ability to reproduce differences

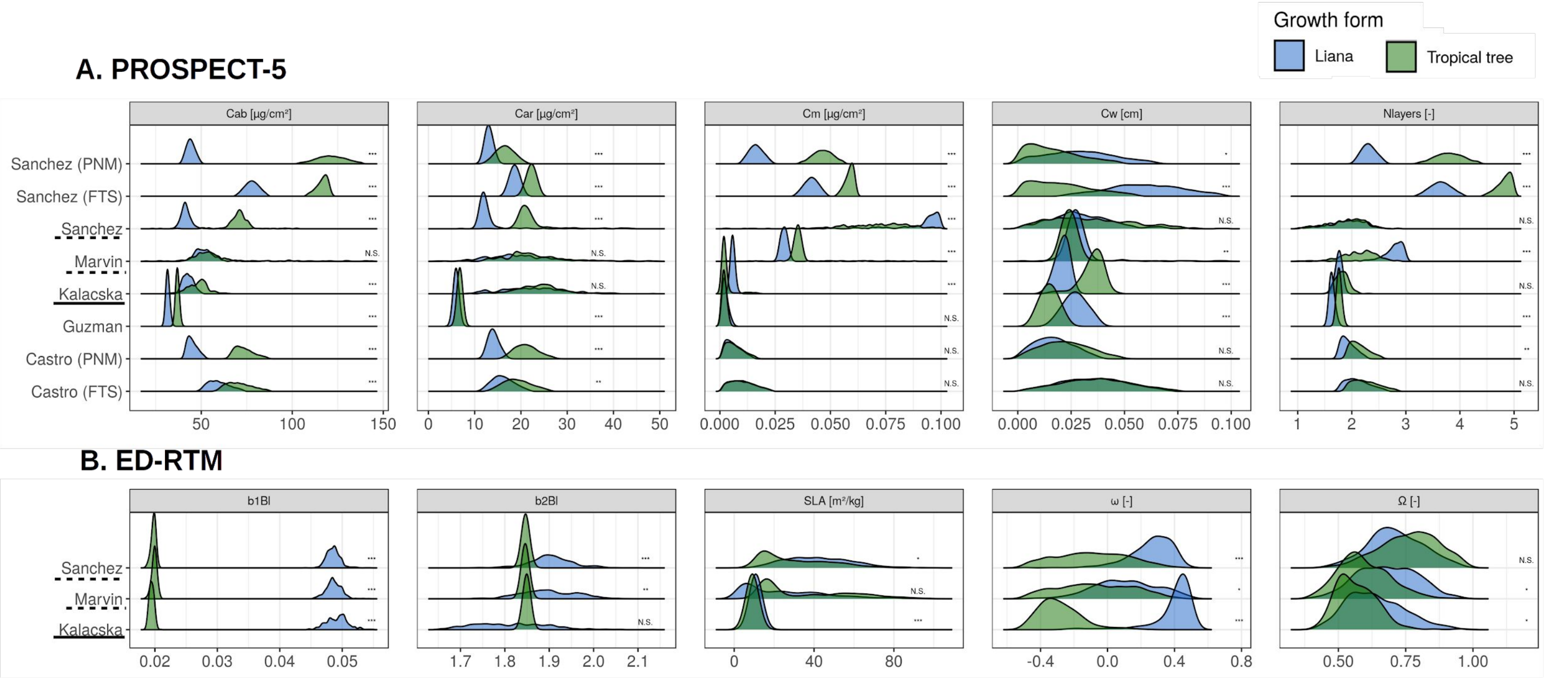
- Small biases, small RMSE in both the VIS and the NIR at leaf and canopy levels
- Simulation errors almost always smaller than observed signals
- Similar magnitude and direction of the differences at leaf and canopy levels

Results (traits)



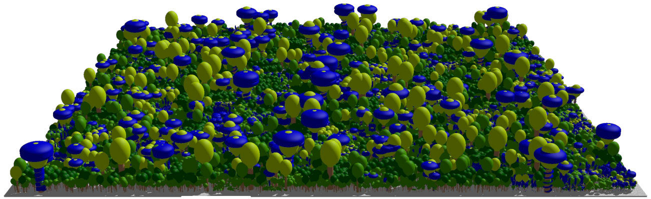
- Pigment content (Cab = Chlorophyll, Car = carotenoid) systematically lower in liana leaves
- Lianas have often “cheaper” leaves (thinner: Nlayers << and low dry matter content Cm)
- Lianas have also often larger water content (Cw)

Results (traits)

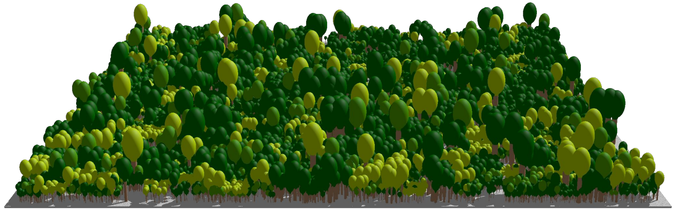


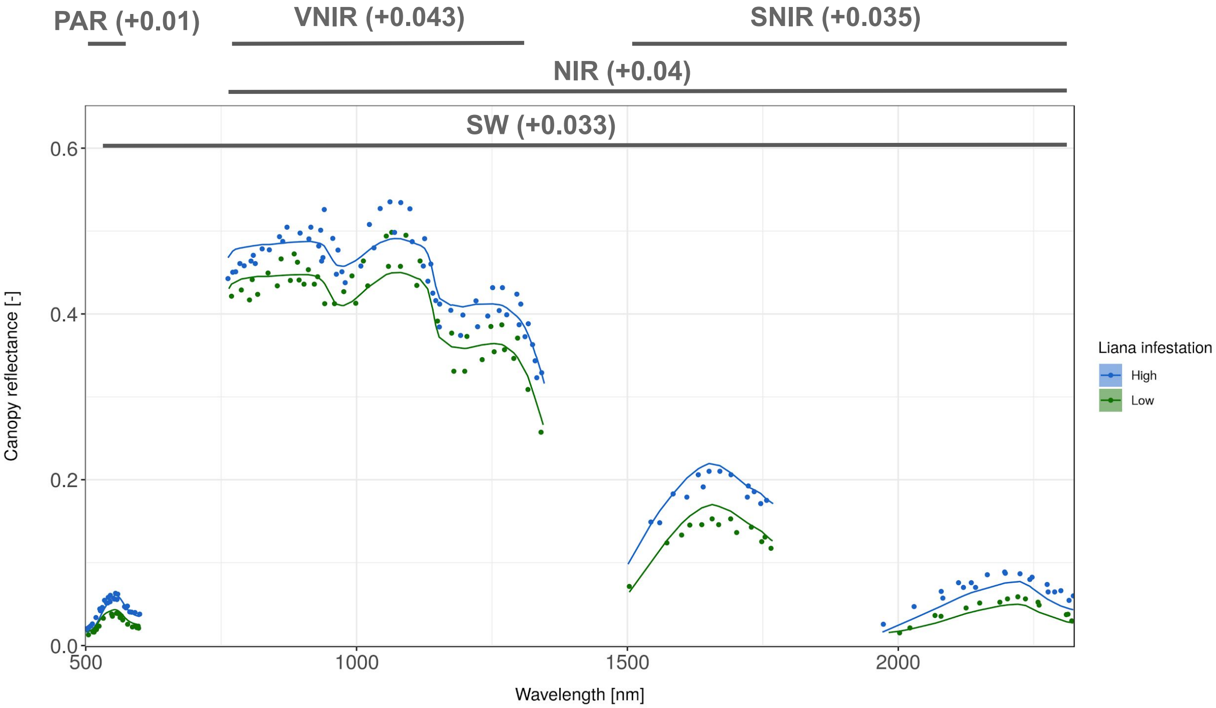
- Liana individual invest more in leaves (b1Bl and b2Bl = leaf allometric coefficients) than same size trees
- Liana canopy more clumped (Ω = clumping factor) and have more horizontal leaves (ω)

Application (albedo)

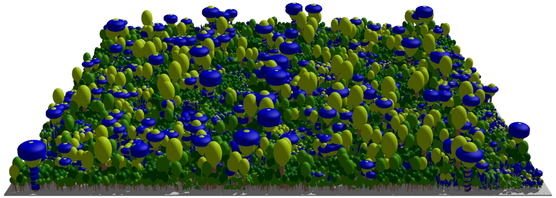


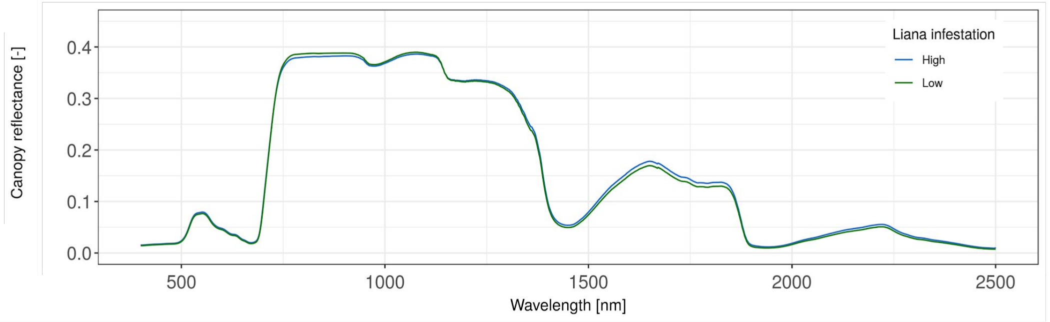
vs

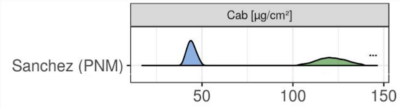




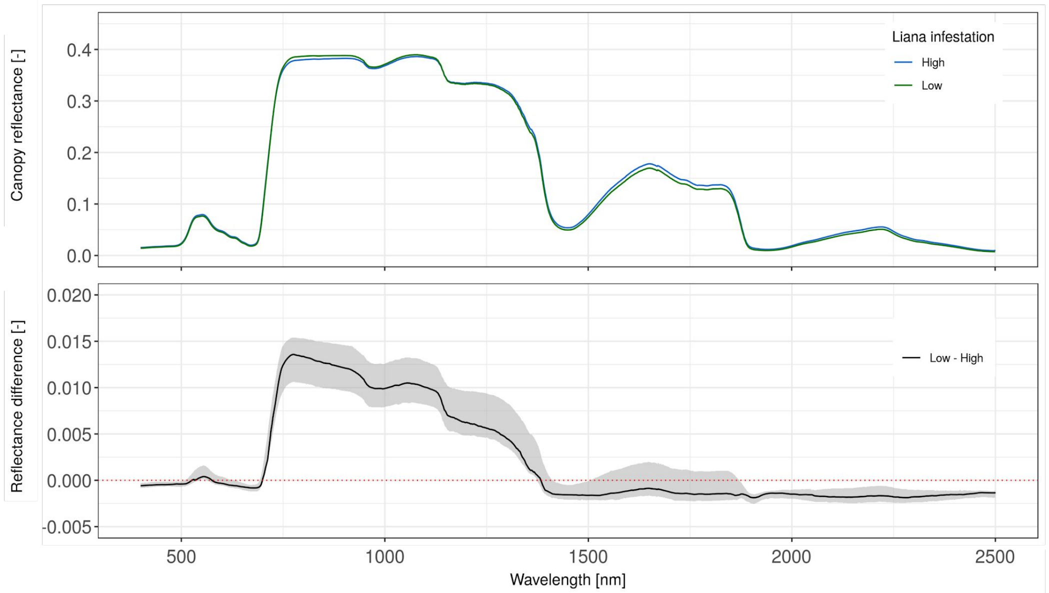
Application (remote sensing)

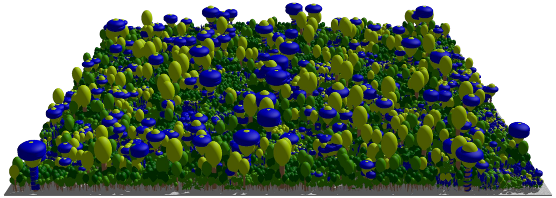


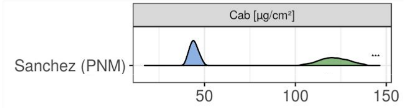




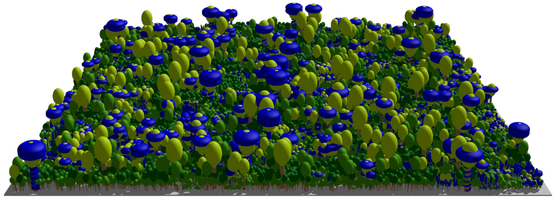
Application (remote sensing)

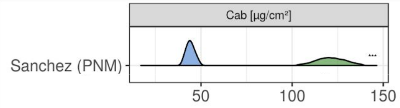


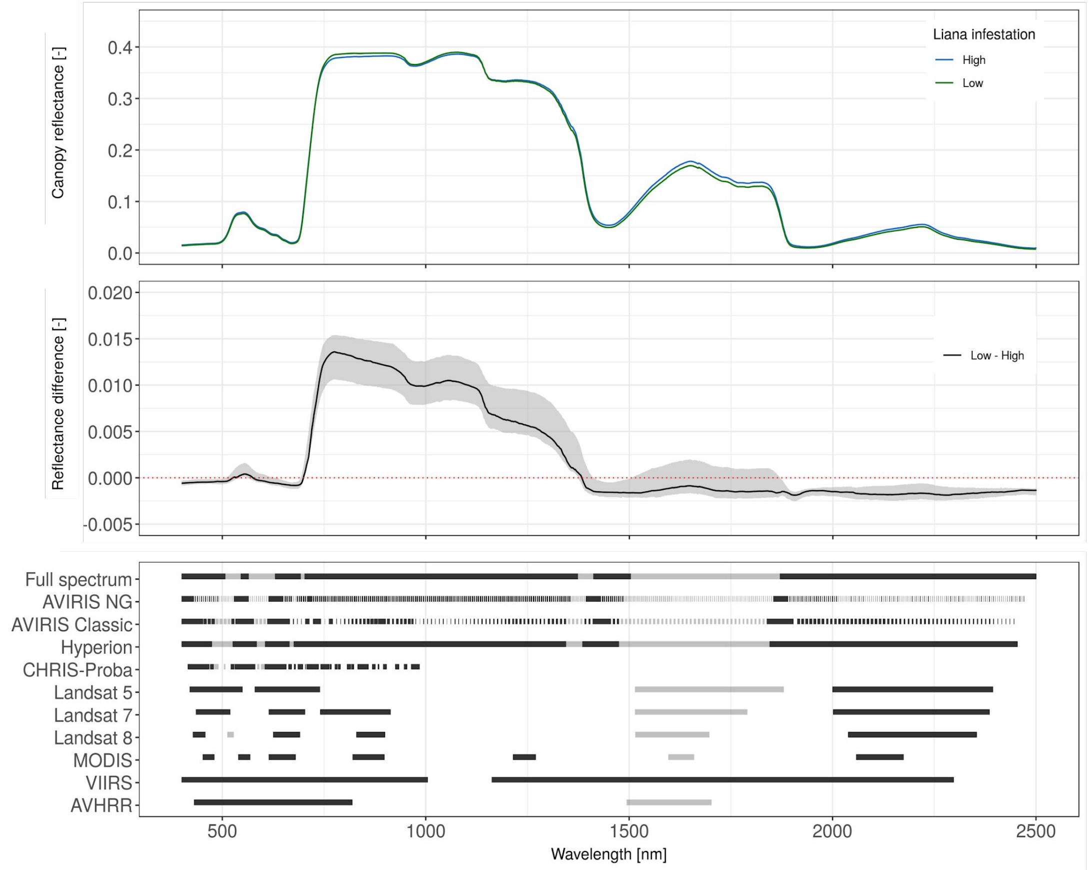




Application (remote sensing)







Conclusion

Meta-analysis of tropical (liana) optical parameters

Implemented in process-based leaf and canopy models

Models and data indicate biochemical and structural traits differences between L and T

Applications for RS and impact on global energy budget