THE ROYAL SOCIETY

**Tropical phenology: functional change in ecosystems across space and time**

January 15-16, 2018

# Towards a robust framework to quantify LAI and radiative transfer variations at tree and landscape levels in the tropics


Nicolas Barbier

Grégoire Vincent

Stéphane Momo

Institut de Recherche pour le Développement FRANCE

French National Research Institute for Sustainable Development

AMAP

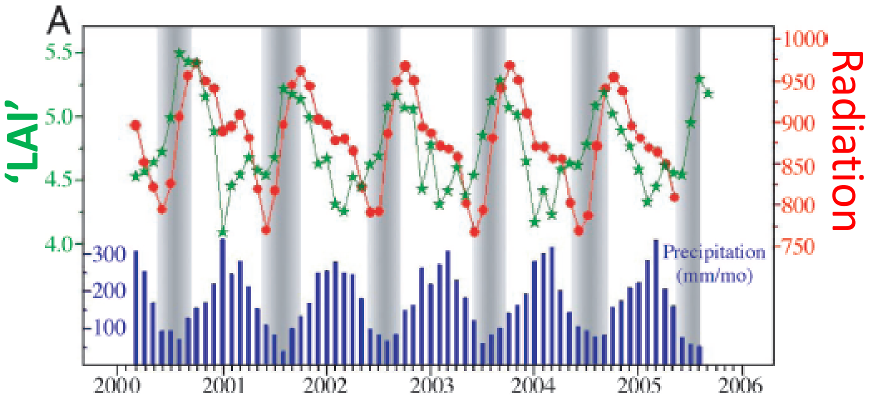
# Interest of (leaf) phenology (for us)

- Large scale ecosystem processes:
  - Drives $CO_2$ oscillation in the atmosphere, at least in temperate areas (Bonan, Science, 2008)
  - Drives evaporation and the onset of rain season (Wright et al., PNAS, 2017)
  - Variability in Amazon forest productivity is potentially larger than deforestation emissions on an annual basis (Morton et al., Nature, 2014)

- Resource partitioning at community and tree level (plant architecture)

# Phenological pattern and processes

- Oscillations in vegetation indices




PNAS

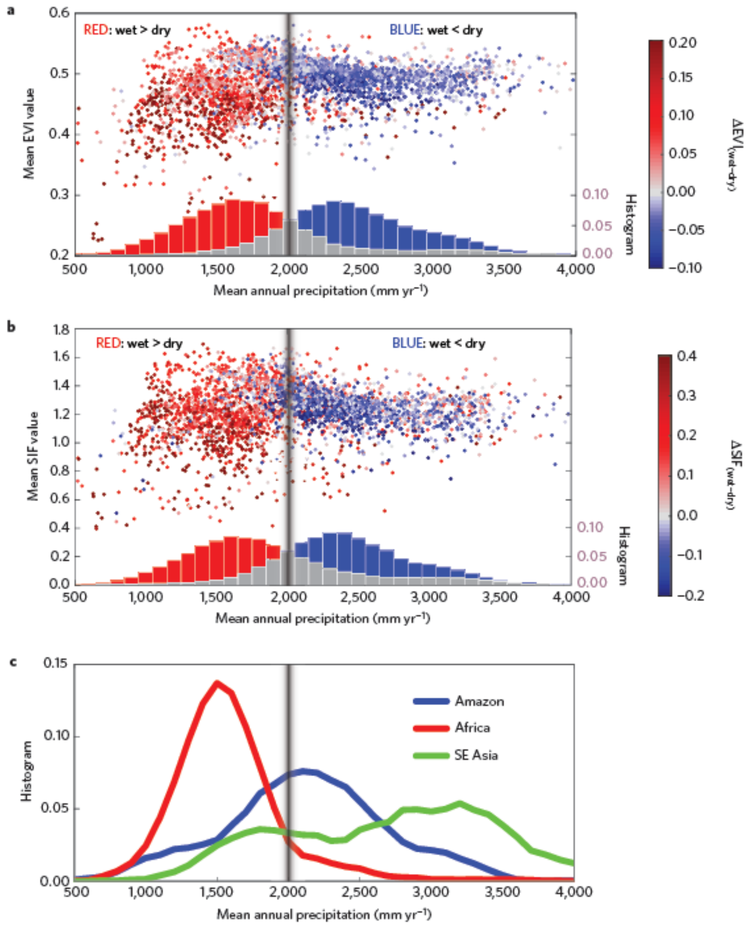
# Large seasonal swings in leaf area of Amazon rainforests

Ranga B. Myneni[a], Wenze Yang[a,b], Ramakrishna R. Nemani[c], Alfredo R. Huete[d], Robert E. Dickinson[e,f], Yuri Knyazikhin[a], Kamel Didan[d], Rong Fu[e], Robinson I. Negrón Juárez[e], Sassan S. Saatchi[g], Hirofumi Hashimoto[h], Kazuhito Ichii[i], Nikolay V. Shabanov[a], Bin Tan[a,j], Piyachat Ratana[d], Jeffrey L. Privette[k,l], Jeffrey T. Morisette[m], Eric F. Vermote[k,n], David P. Roy[o], Robert E. Wolfe[p], Mark A. Friedl[a], Steven W. Running[q], Petr Votava[h], Nazmi El-Saleous[r], Sadashiva Devadiga[r], Yin Su[a], and Vincent V. Salomonson[s]

nature geoscience
LETTERS
PUBLISHED ONLINE: 9 MARCH 2015 | DOI: 10.1038/NGEO2382

# Photosynthetic seasonality of global tropical forests constrained by hydroclimate

Kaiyu Guan[1,2]*, Ming Pan[1], Haibin Li[3], Adam Wolf[4], Jin Wu[5], David Medvigy[6], Kelly K. Caylor[1], Justin Sheffield[1], Eric F. Wood[1], Yadvinder Malhi[7], Miaoling Liang[1], John S. Kimball[8,9], Scott R. Saleska[5], Joe Berry[10], Joanna Joiner[11] and Alexei I. Lyapustin[11]



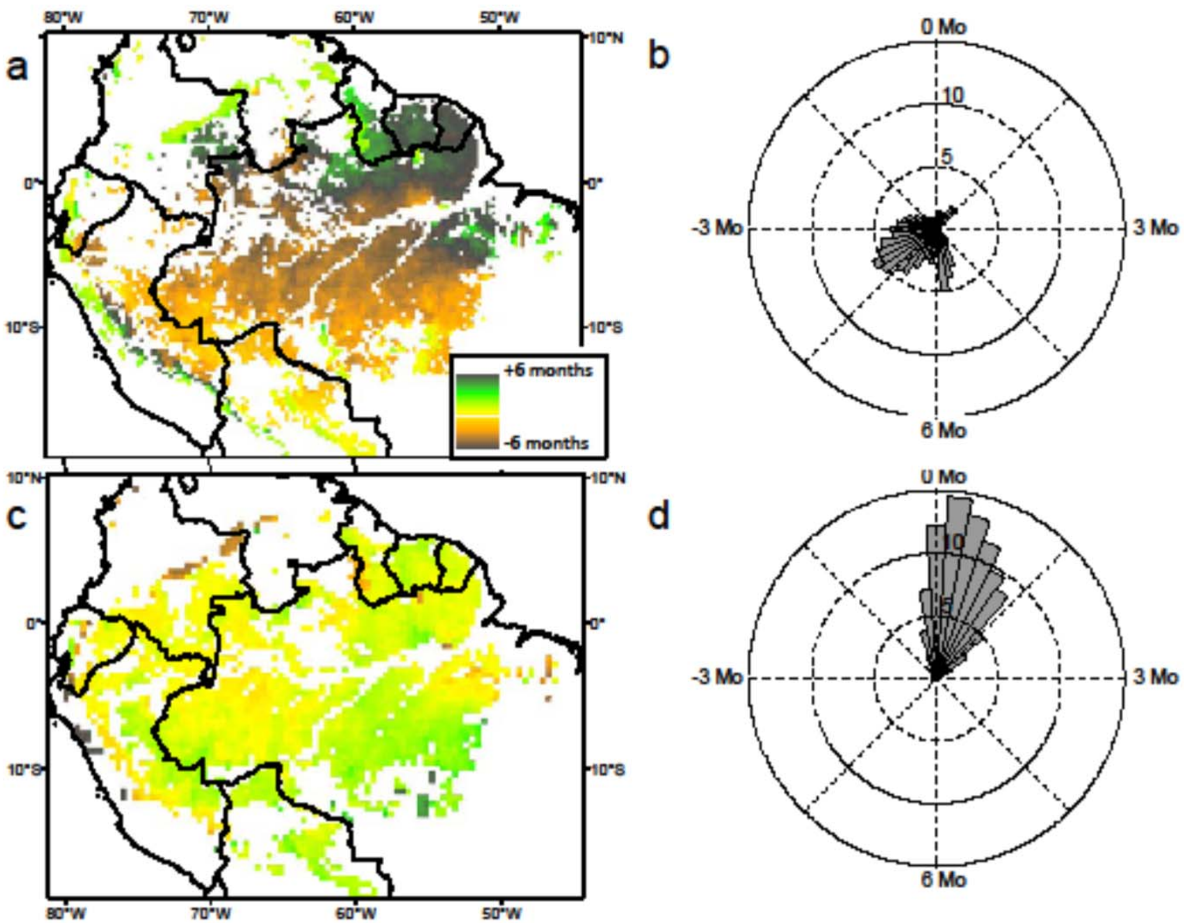
Global Change Biology

Global Change Biology (2011), doi: 10.1111/j.1365-2486.2011.02405.x

## Relationships between phenology, radiation and precipitation in the Amazon region

ANDREW V. BRADLEY*, FRANCE F. GERARD†, NICOLAS BARBIER‡, GRAHAM P. WEEDON§, LIANA O. ANDERSON¶||, CHRIS HUNTINGFORD†, LUIZ E. O. C. ARAGÃO**, PRZEMYSLAW ZELAZOWSKI¶ and EGIDIO ARAI||

# Phase shift between EVI and climate




Precipitation

Radiation

**Figure 4.** Maps and histograms (in %) of the seasonal phase shift between vegetation index (MODIS - EVI) and climate variables across Amazonia. (a, b) Seasonal phase shift with TRMM rainfall index. (c, d) Seasonal phase shift with GOES radiation (insolation) index. Areas in white are either non–forest or not significantly seasonal and/or correlated with the climate index.

# Phenological pattern and processes

- Oscillations in vegetation indices

- Combination of leaf aging/renewal and leaf area variation

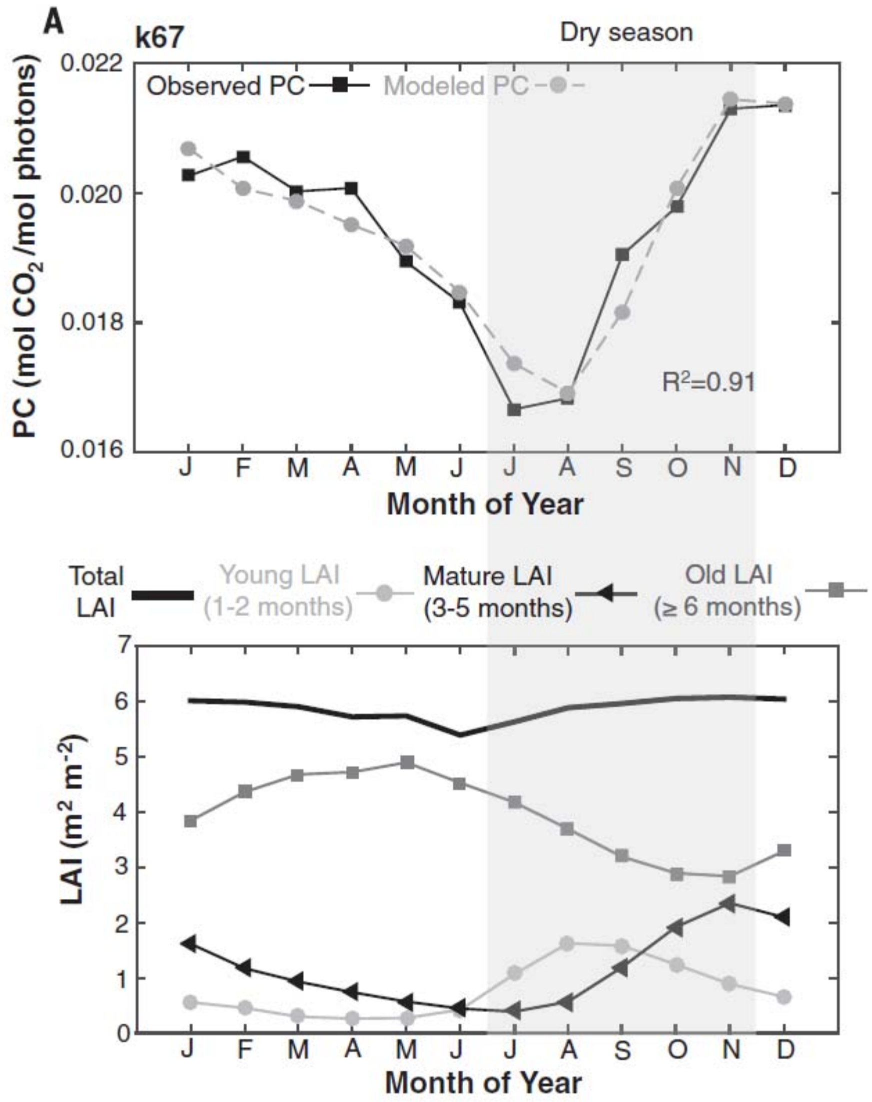
FOREST ECOLOGY

# Leaf development and demography explain photosynthetic seasonality in Amazon evergreen forests

Jin Wu,[1*] Loren P. Albert,[1] Aline P. Lopes,[2] Natalia Restrepo-Coupe,[1,3] Matthew Hayek,[4] Kenia T. Wiedemann,[1,4] Kaiyu Guan,[5,6] Scott C. Stark,[7] Bradley Christoffersen,[1,8] Neill Prohaska,[1] Julia V. Tavares,[2] Suelen Marostica,[2] Hideki Kobayashi,[9] Mauricio L. Ferreira,[10,11] Kleber Silva Campos,[12] Rodrigo da Silva,[12] Paulo M. Brando,[13,14] Dennis G. Dye,[15] Travis E. Huxman,[16] Alfredo R. Huete,[3] Bruce W. Nelson,[2] Scott R. Saleska[1*]

PC= 'photosynthetic capacity': amount of photosynthesis per unit of incoming light measured at flux tower

LAI based on phenocam observations



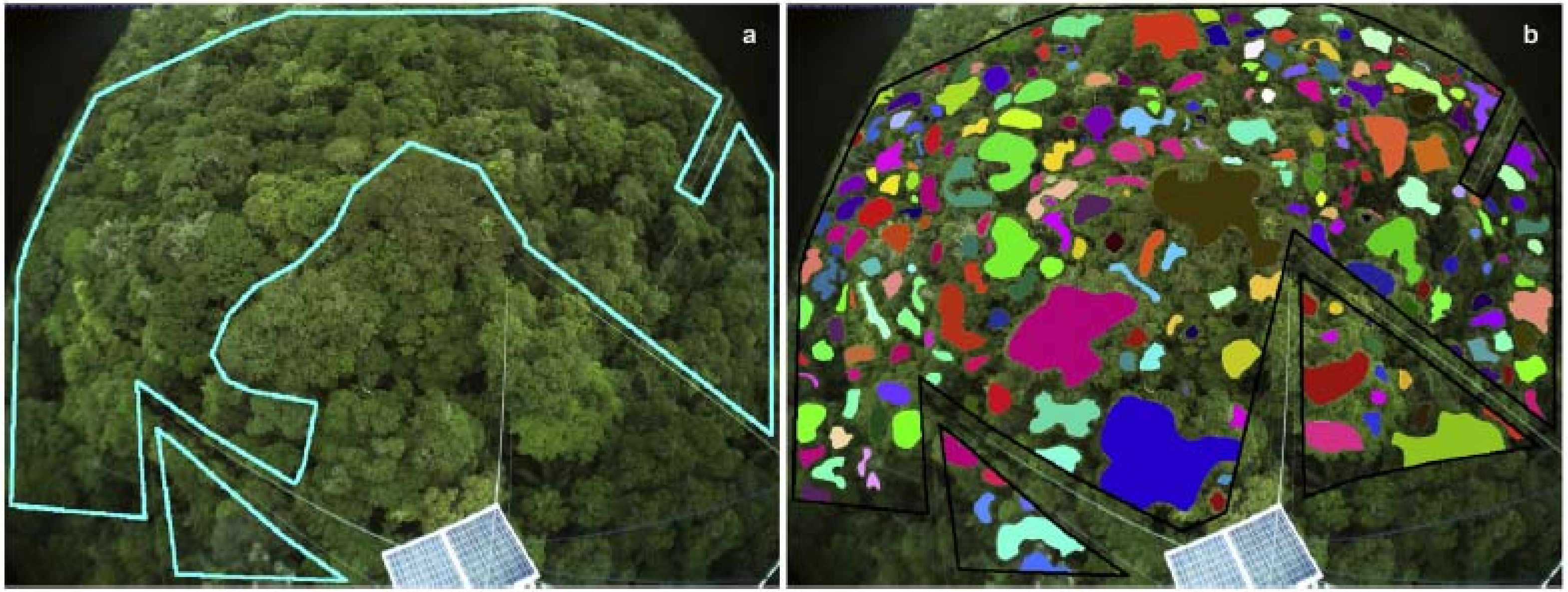



**Fig. 1.** Regions of interest used in digital analysis. The image area covers approximately four hectares. Radiometric intercalibration to a single reference date used the large forest area outlined in (a); corrected daily values of Green Chromatic Coordinate were then obtained for each of 267 individual crowns shown in (b).

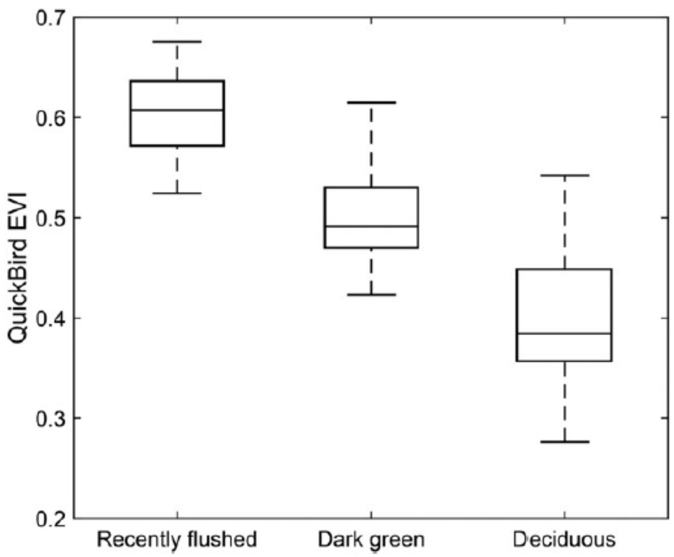
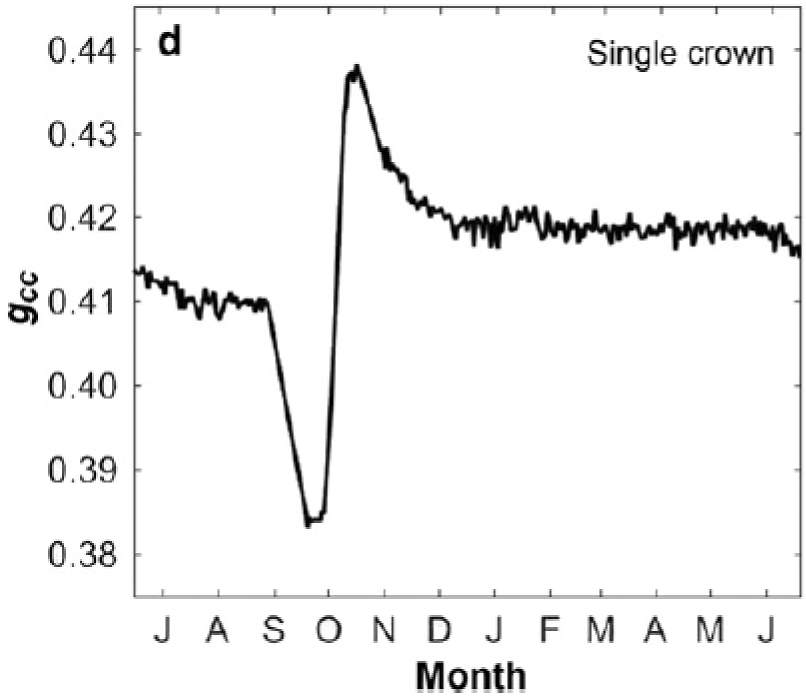



**Fig. 4.** Enhanced Vegetation Index of crown phenostages identified in a QuickBird true-color composite.



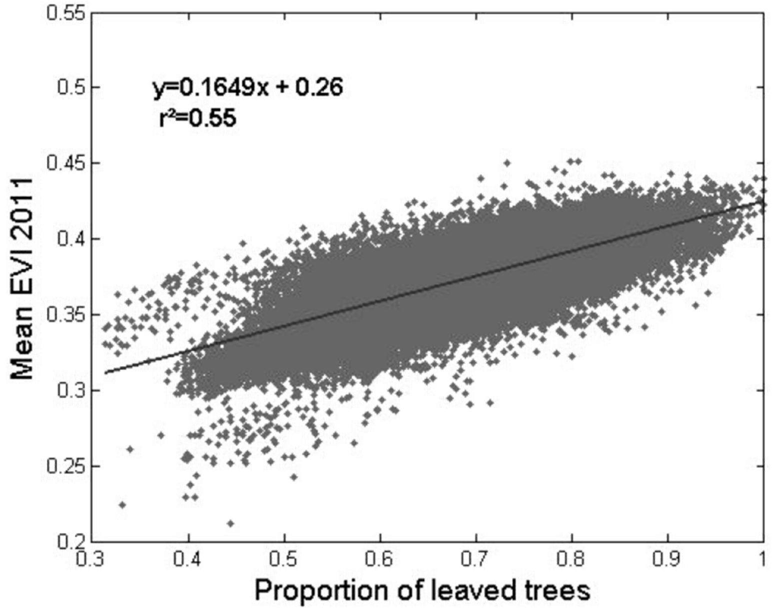

Pontes Lopez, RSE, 2016

Biogeosciences, 10, 6957–6967, 2013
www.biogeosciences.net/10/6957/2013/
doi:10.5194/bg-10-6957-2013


Biogeosciences Open Access

# Multiresolution quantification of deciduousness in West-Central African forests

G. Viennois[1], N. Barbier[2], I. Fabre[3], and P. Couteron[2]




Biogeosciences, 10, 7307–7321, 2013
www.biogeosciences.net/10/7307/2013/
doi:10.5194/bg-10-7307-2013


Biogeosciences Open Access

# Asynchronism in leaf and wood production in tropical forests: a study combining satellite and ground-based measurements

F. Wagner[1,2], V. Rossi[3,4], C. Stahl[1,5], D. Bonal[6], and B. Hérault[1]

"The time lag between peaks of EVI and wood production (109 days) revealed a substantial decoupling between the leaf renewal assumed to be driven by irradiance and the water-driven wood production."

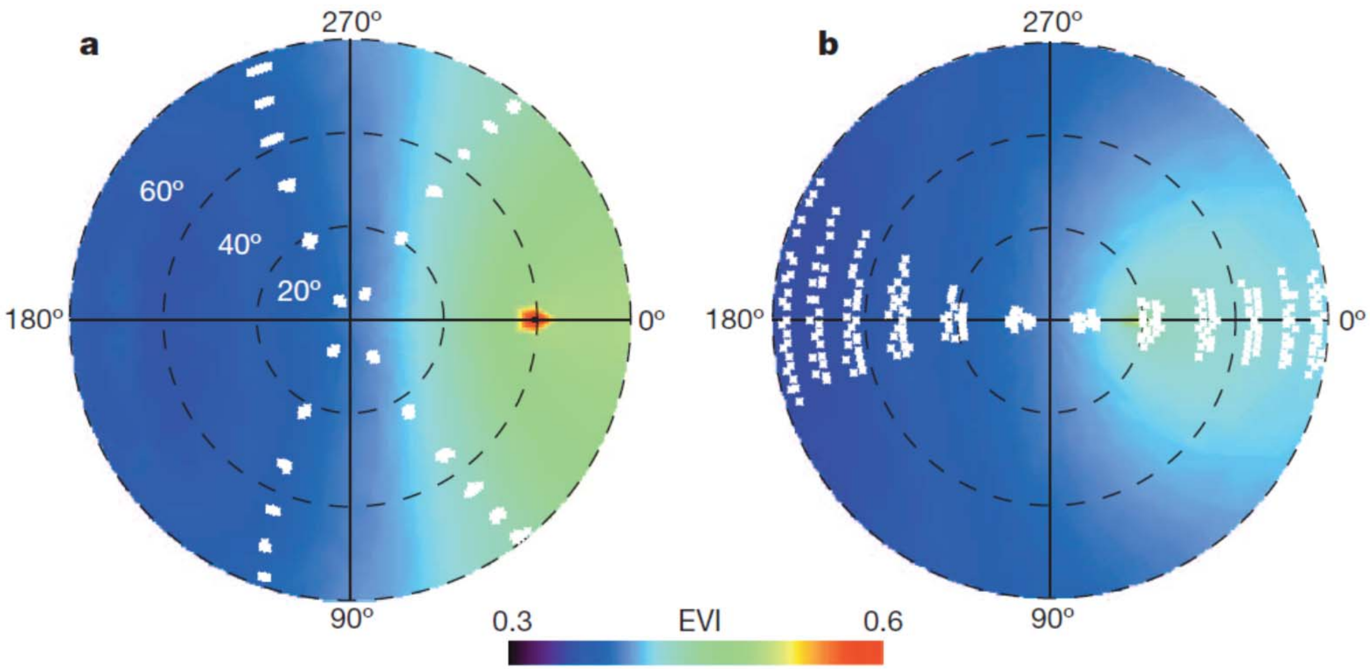
# Challenges and opportunities

- Instrumental effects

doi:10.1038/nature13006

# Amazon forests maintain consistent canopy structure and greenness during the dry season

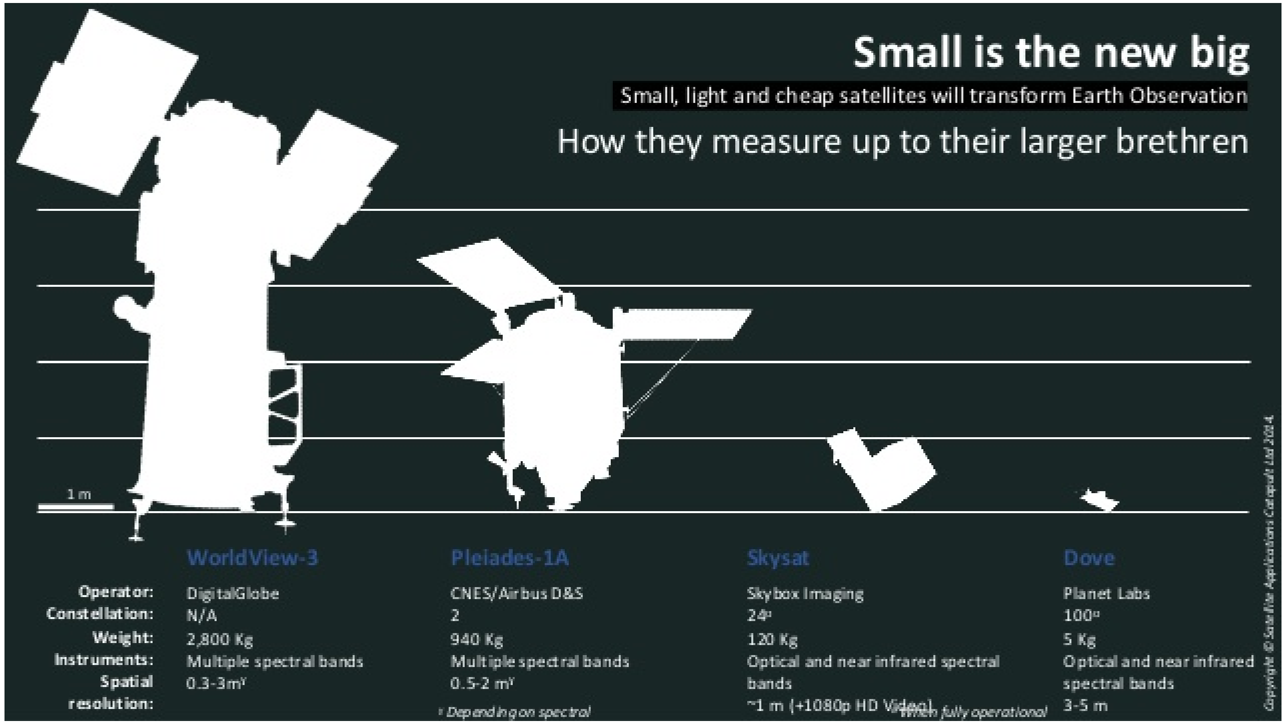
Douglas C. Morton[1], Jyoteshwar Nagol[2,3], Claudia C. Carabajal[1,4], Jacqueline Rosette[1,2,5], Michael Palace[6], Bruce D. Cook[1], Eric F. Vermote[1], David J. Harding[1] & Peter R. J. North[5]

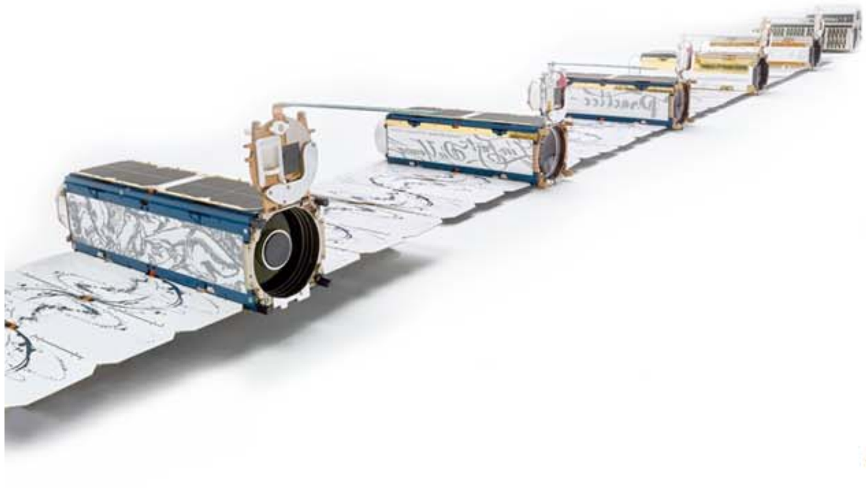


# Challenges and opportunities

- Instrumental variations

- Limited spatial resolution



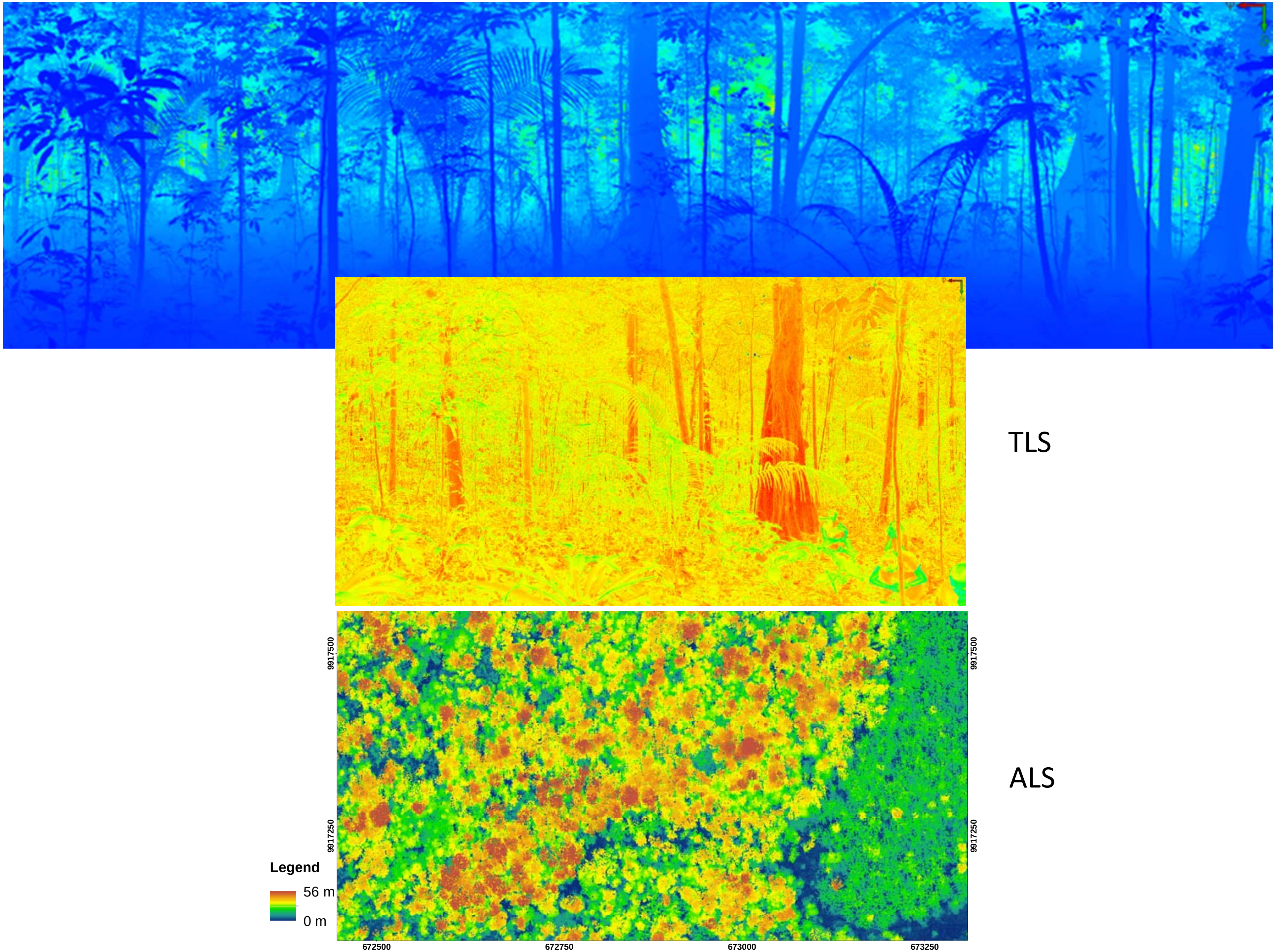
| | 175+ | 5 | 13 |
|---|---|---|---|
| | PLANETSCOPE | RAPIDEYE | SKYSAT |
| Collection capacity | 300 M $km^2$/day | 6.5 M $km^2$/day | 185 K $km^2$/day |

# Challenges and opportunities

- Instrumental variations

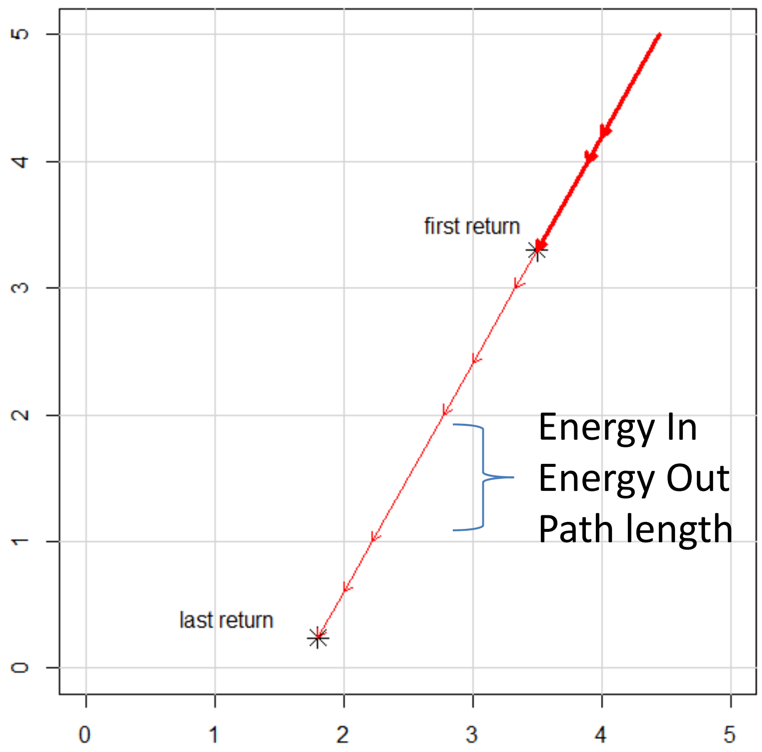
- Resolution

- Ground measurement of
  - Leaf area
  - Leaf age
  - Leaf angle distribution


TLS
ALS
Legend
56 m
0 m
9917500
9917250
672500
672750
673000
673250

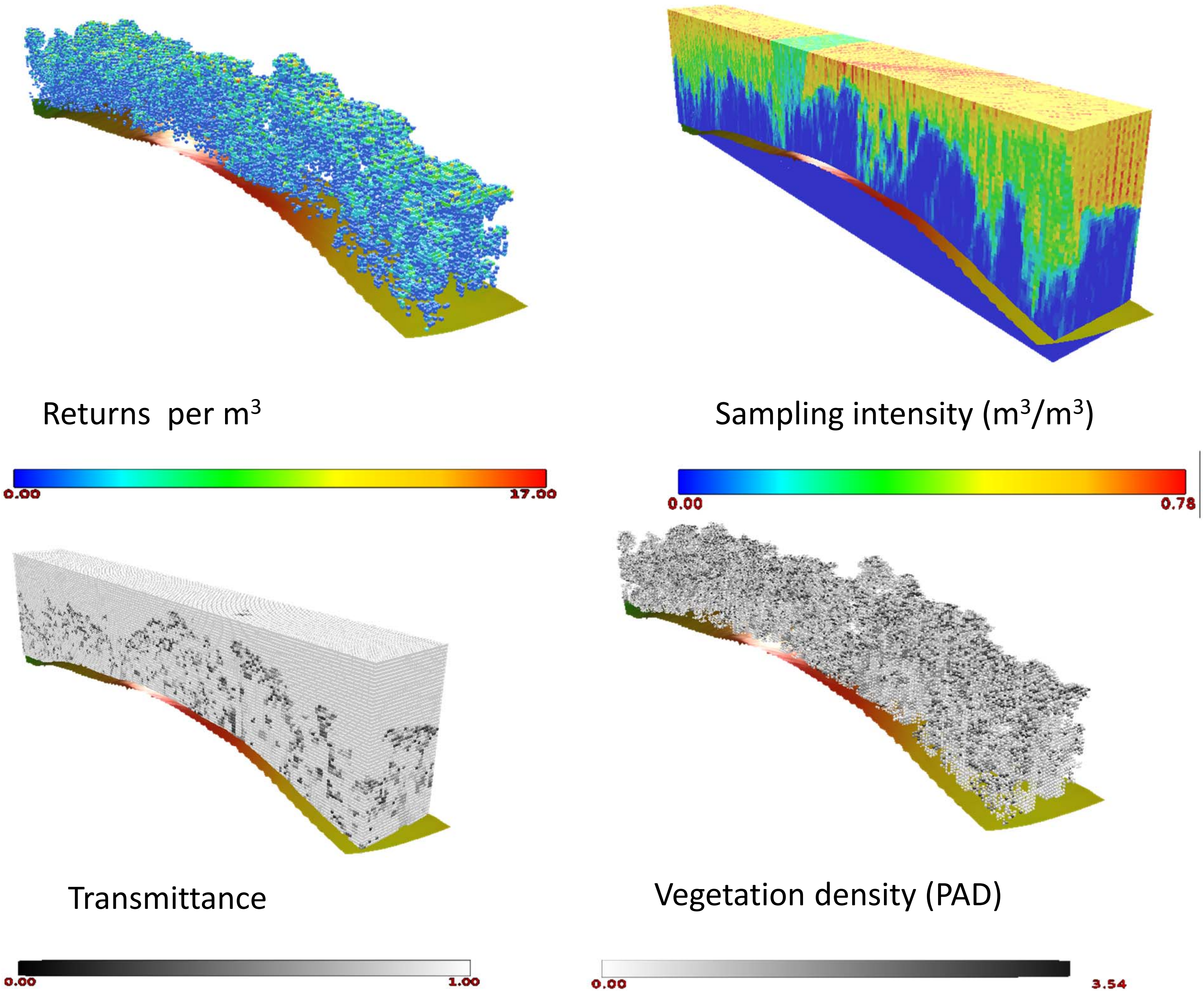
# AmapVox software

Accounting for varying sampling density in LiDAR data, to assess PAI/LAI

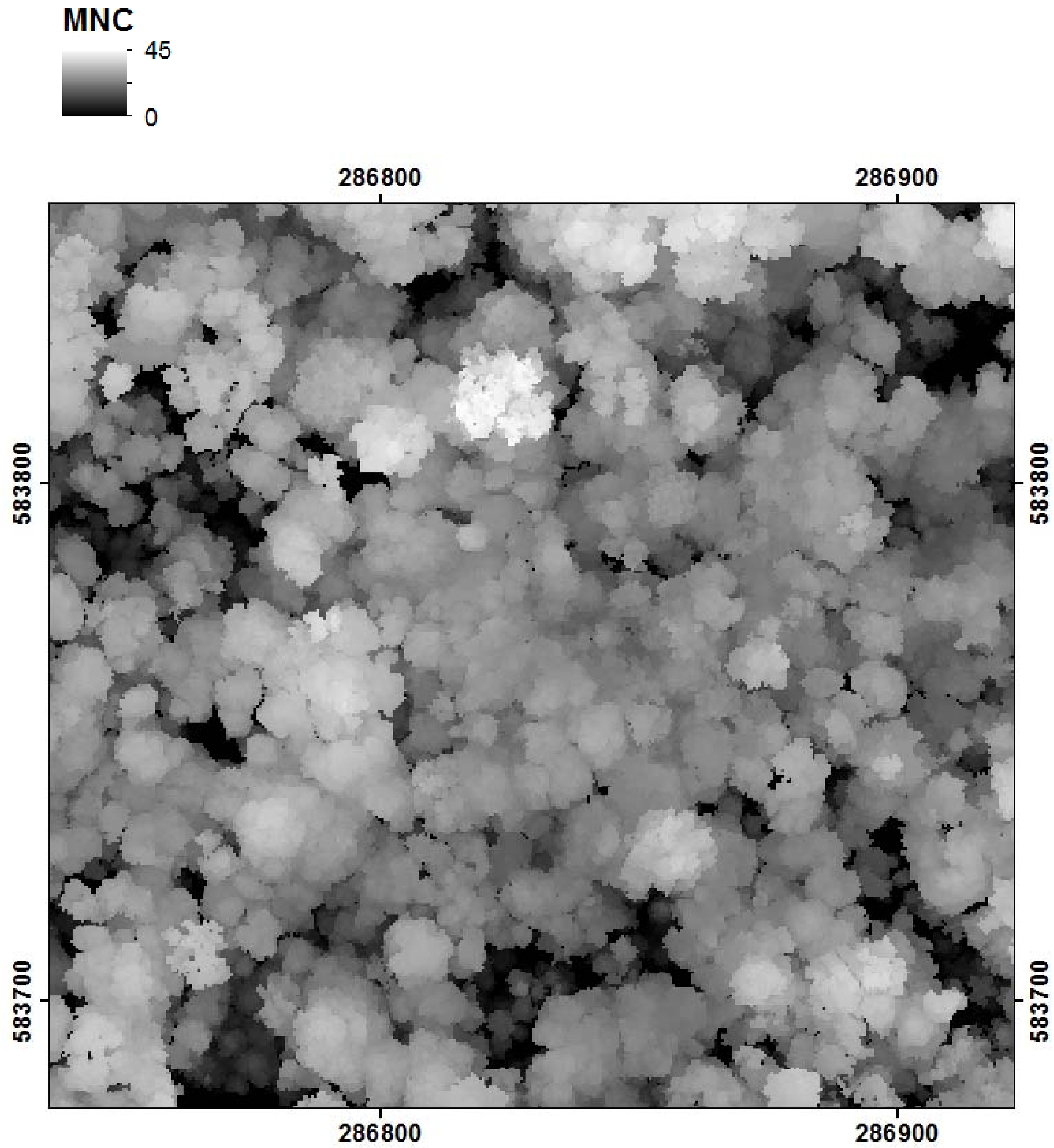



Incident laser pulse ray is traced through a 3D mesh

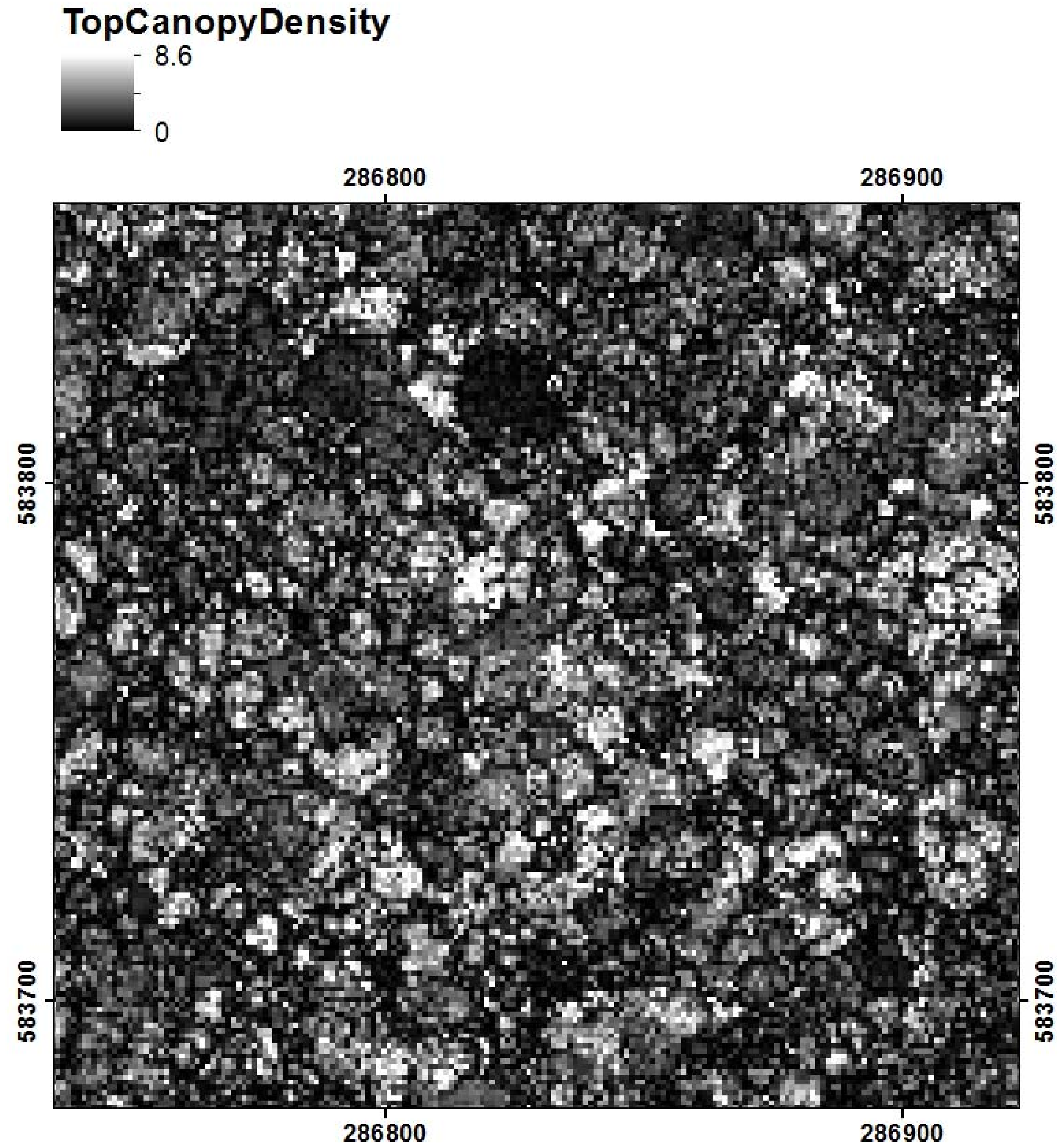
- For each traversed voxel the travelling energy is recorded as well the path length inside the voxel
- In case a target is met the corresponding intercepted energy is recorded. The travelling energy is updated accordingly
- This is done for all the emitted pulses entering the scene



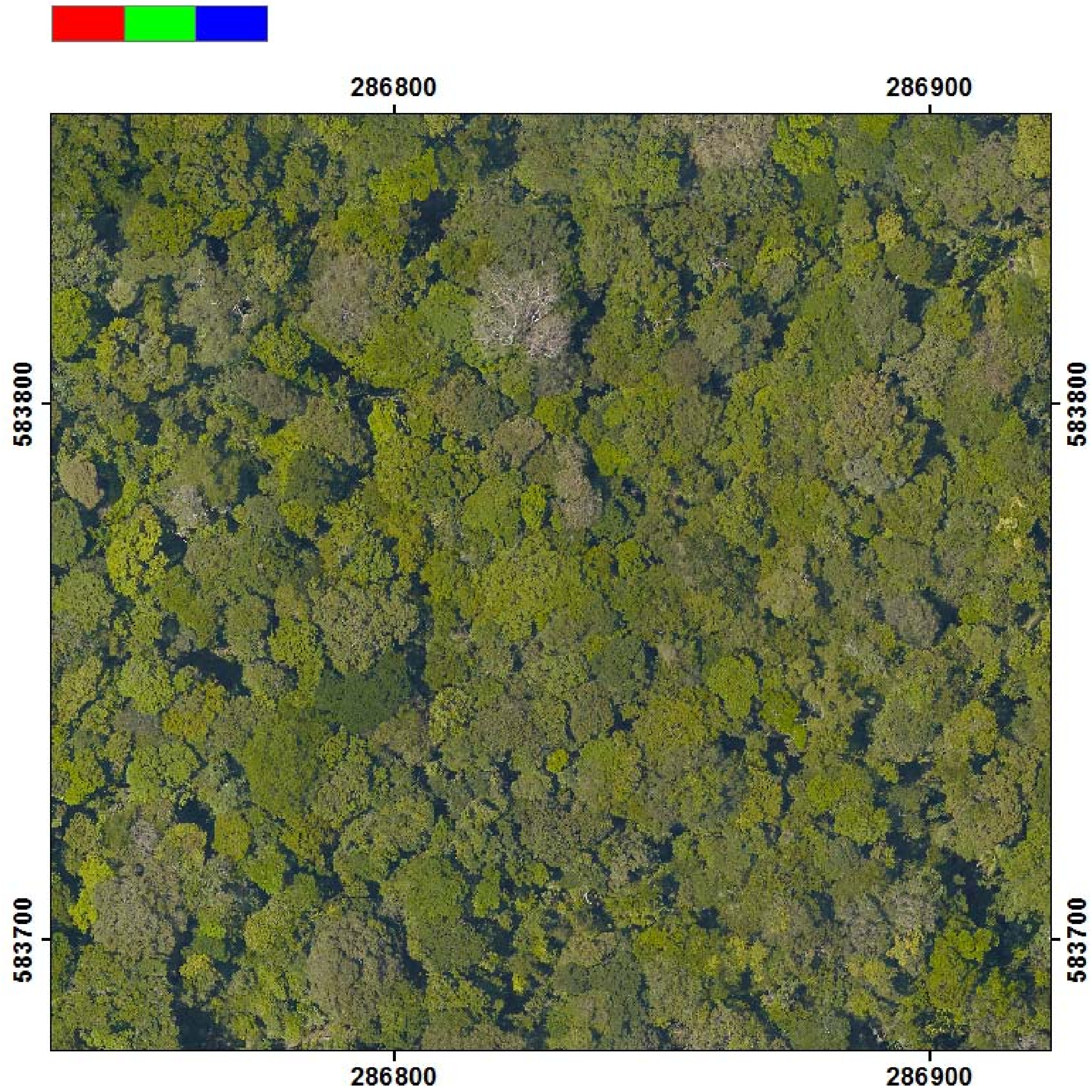
Returns per m3
0.00
17.00
Sampling intensity (m3/m3)
0.00
0.78
Transmittance
0.00
1.00
Vegetation density (PAD)
0.00
3.54



MNC
45
0
286800
286900
583800
583700



TopCanopyDensity
8.6
0
286800
286900
583800
583700


286800
286900
583800
583700
286800
286900
583800
583700

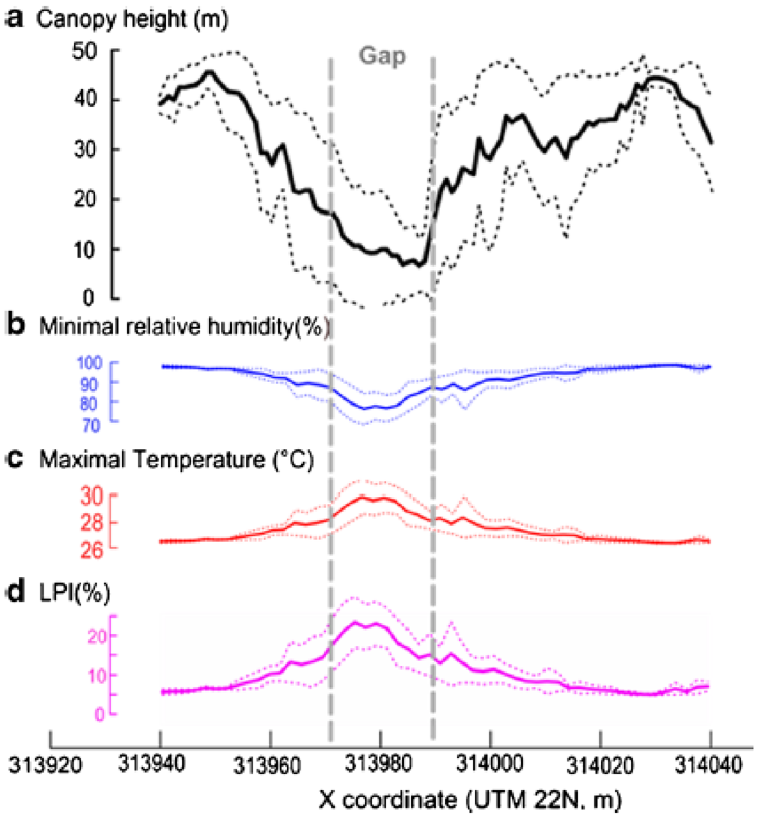
Annals of Forest Science (2017) 74: 32
DOI 10.1007/s13595-017-0628-z

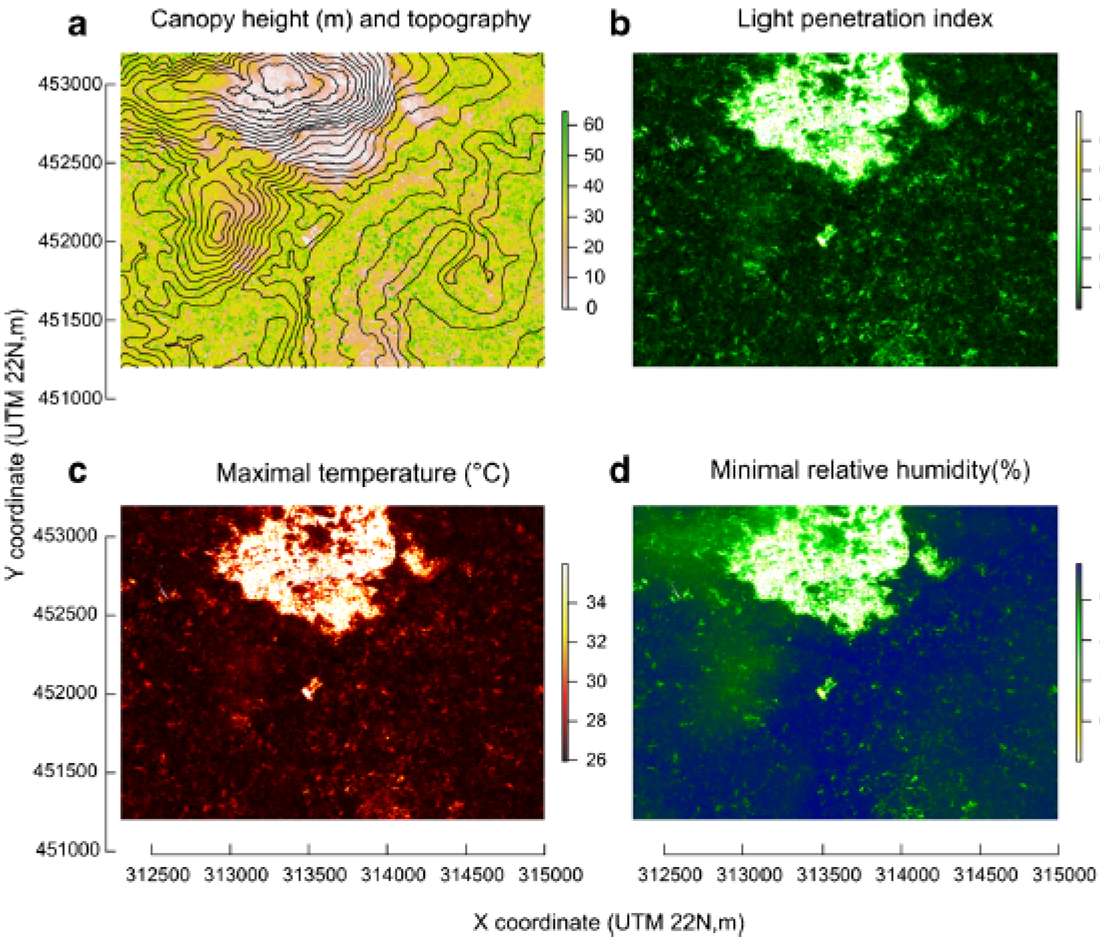
CrossMark

ORIGINAL PAPER

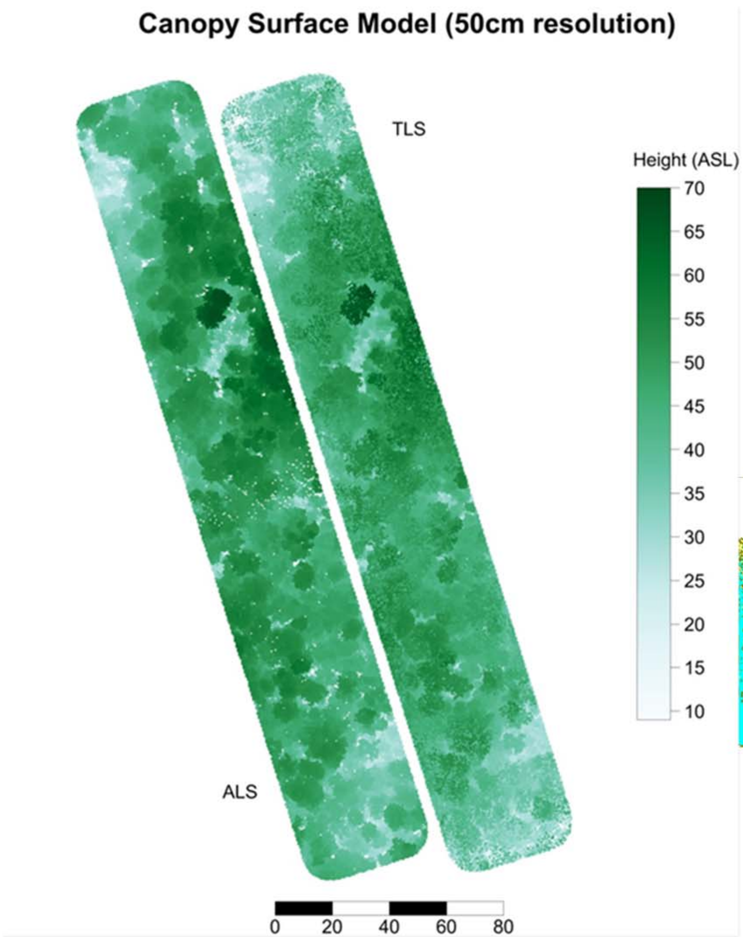
# Quantifying micro-environmental variation in tropical rainforest understory at landscape scale by combining airborne LiDAR scanning and a sensor network

**Blaise Tymen[1] · Grégoire Vincent[2] · Elodie A. Courtois[3,4] · Julien Heurtebize[2] · Jean Dauzat[2] · Isabelle Marechaux[1] · Jérôme Chave[1]**

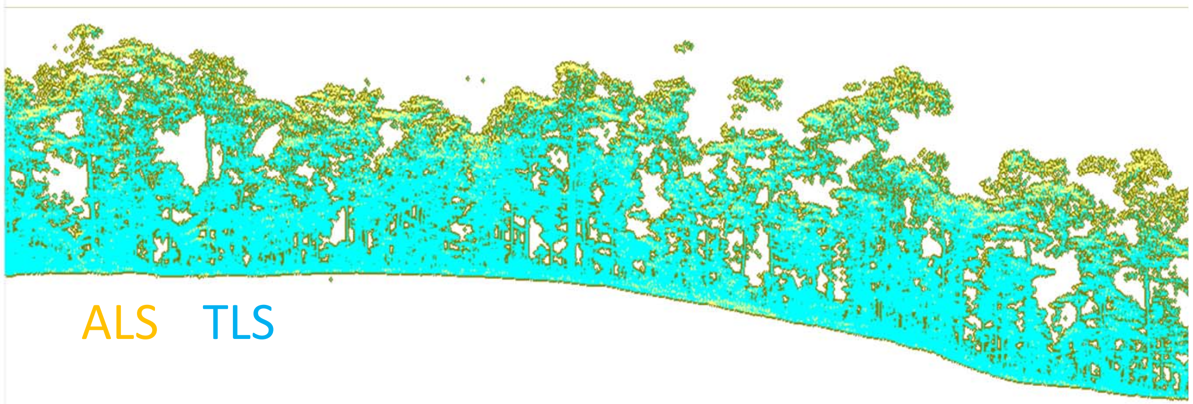


# Comparing ALS to TLS




- Co-registered ALS/TLS data set
- 30*250m forest track (Sept. 2013)
- 75 TLS scan positions 10 x 10m grid




Vincent et al., Silvilaser, 2015

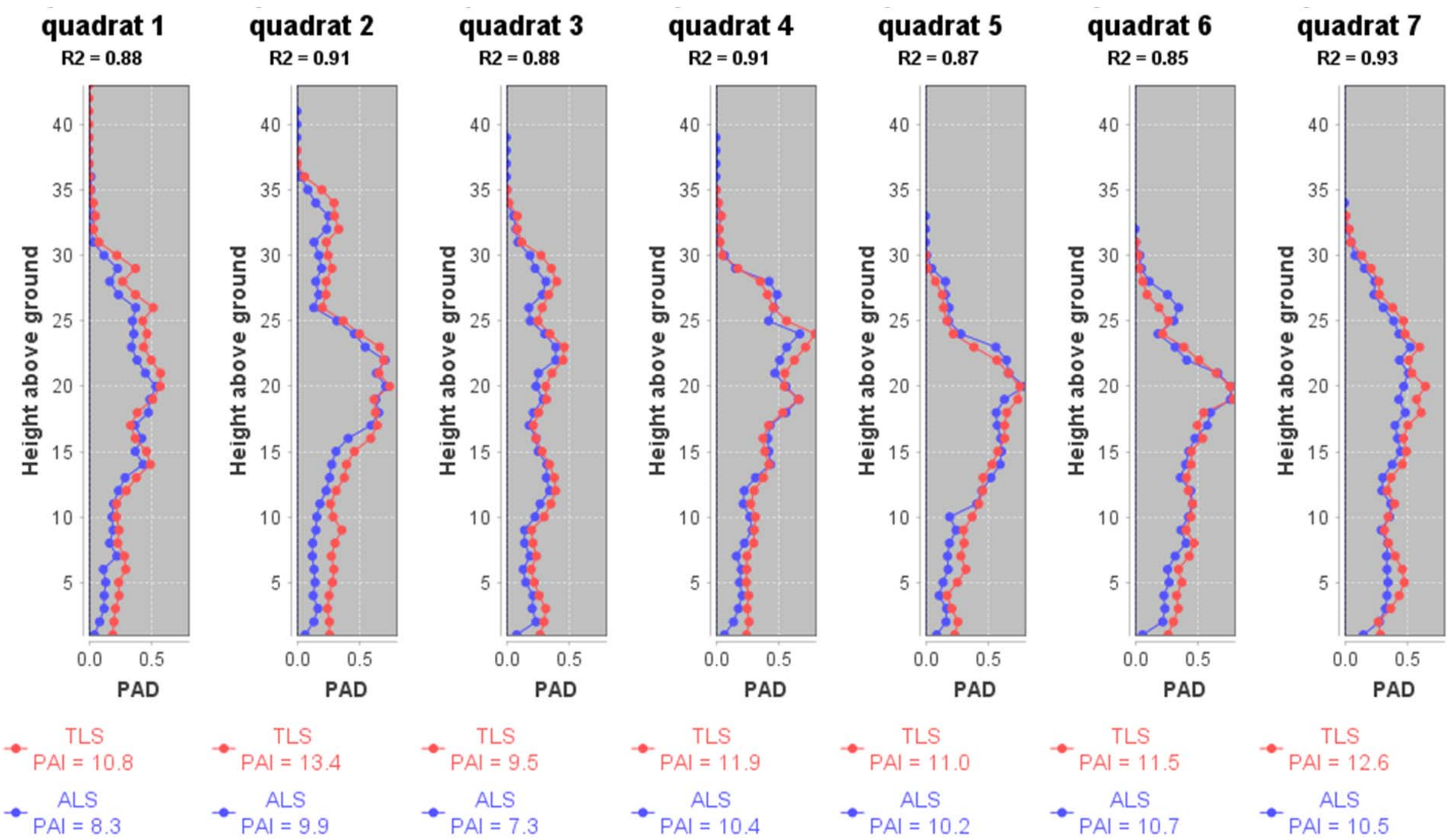
# Comparing ALS to TLS

| TLS Riegl VZ400 | ALS Riegl LMSQ560 |
|---|---|
| ~ $10^9$ pulses | ~ $10^5$ pulses |
| Sampling rate (m3) 100%<br>99% of voxels > 500 pulses | Sampling rate (m3) 65%;<br>average: 3.6 shots/m3 |
| +/- 90 deg. (hemispherical) | +/- 20 deg. (sub-nadir) |
| 1550 nm | 1550nm |
| Discrete return | Full wave form |
| Footprint size ~cm | Footprint size ~ dm |
| Upwards ; unknown fraction of energy is lost | Downwards ; no energy loss;<br>Occluded area corrected using multiresolution approach |

Vincent et al., Silvilaser, 2015

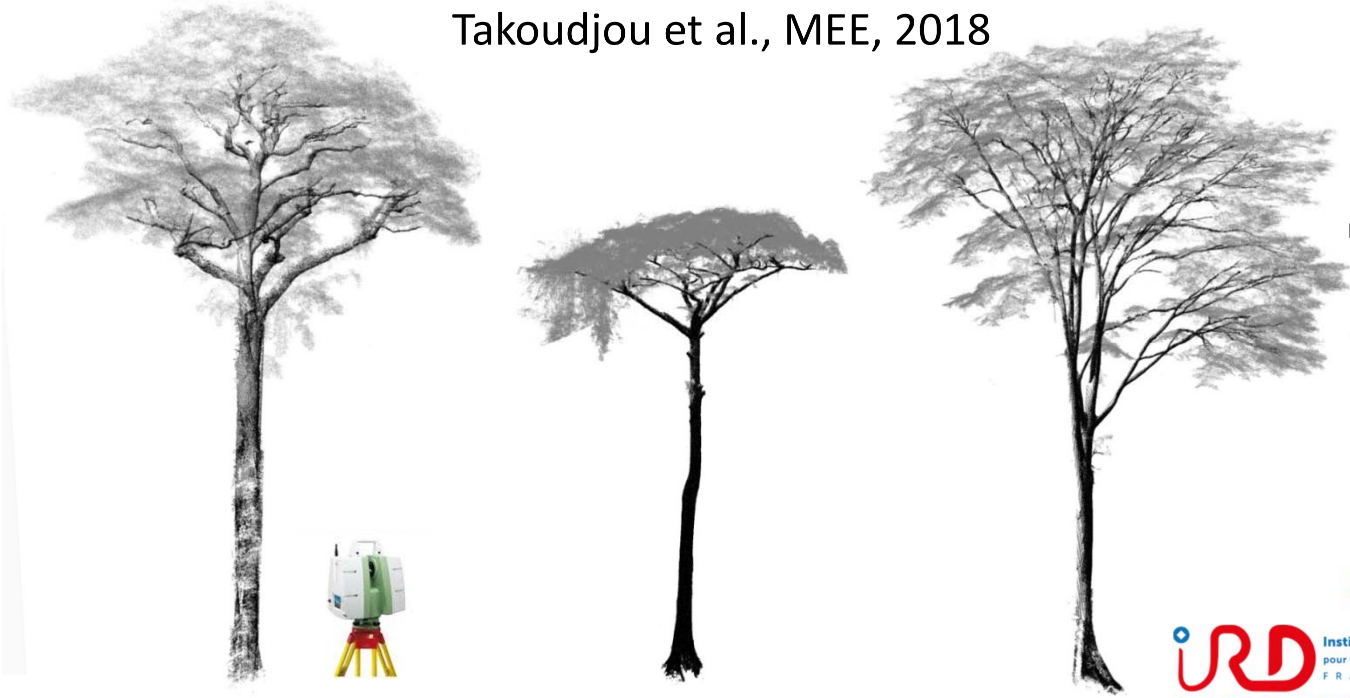
# Comparing ALS to TLS

~20 % underestimation with ALS, but otherwise coherent




Vincent et al., Silvilaser, 2015

Takoudjou et al., MEE, 2018



LaBosystE Laboratoire de Botanique systématique et d'Ecologie

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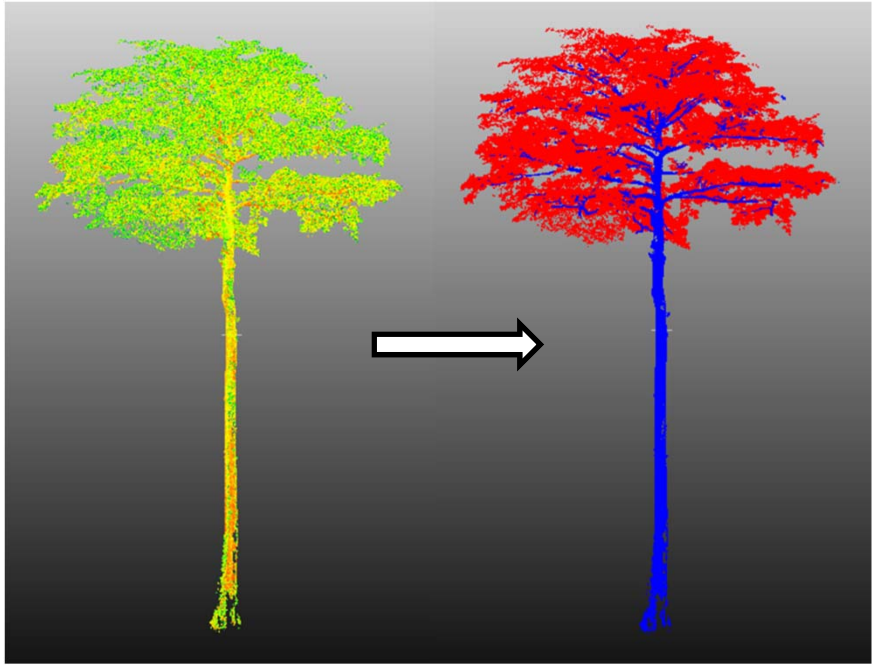
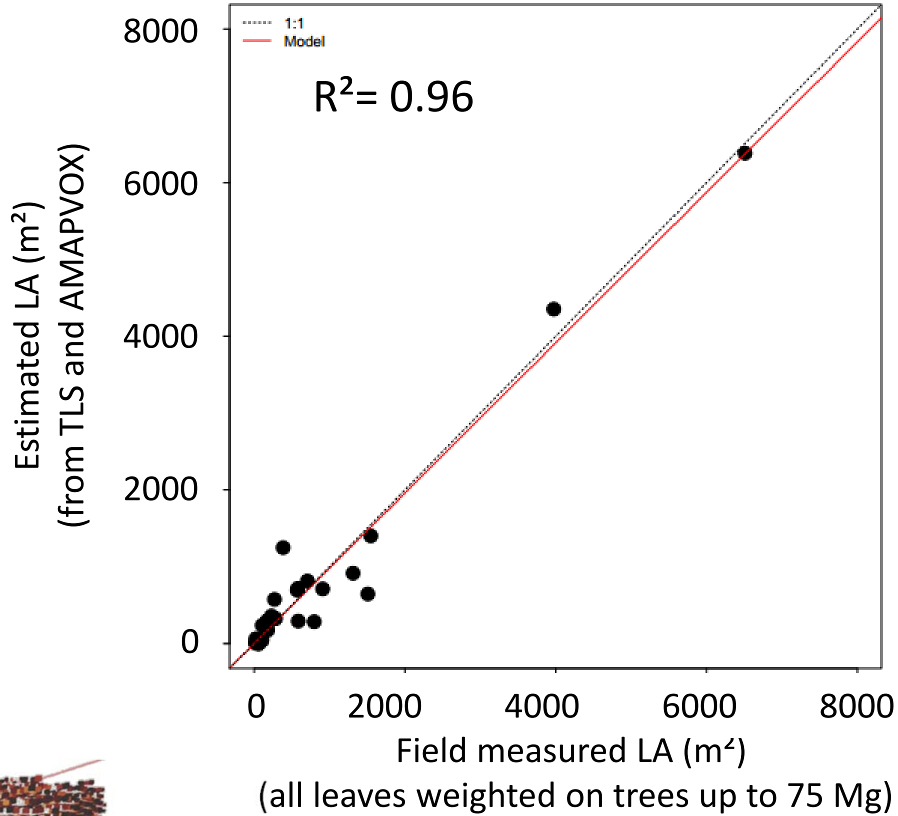
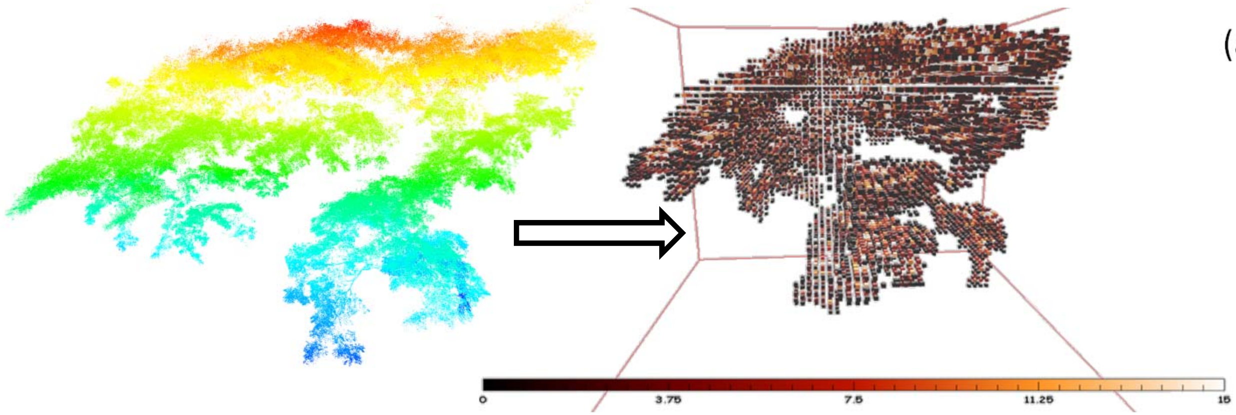
# Validating LAI with destructive data






Takoudjou et al. In prep.

# Challenges and opportunities

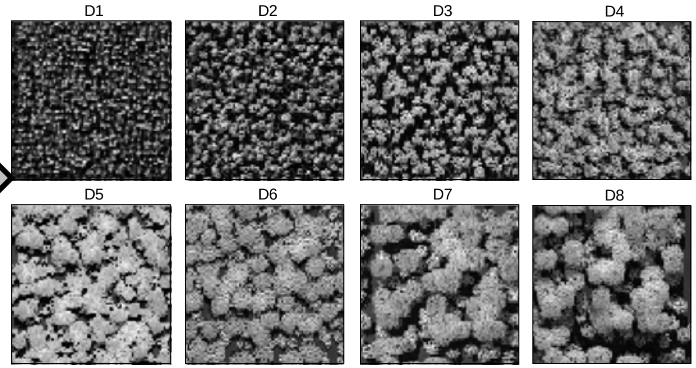
- Instrumental variations
- Resolution
- Ground measurement of
  - Leaf area
  - Leaf age
  - Leaf angle distribution
- Radiative Transfer Modelling

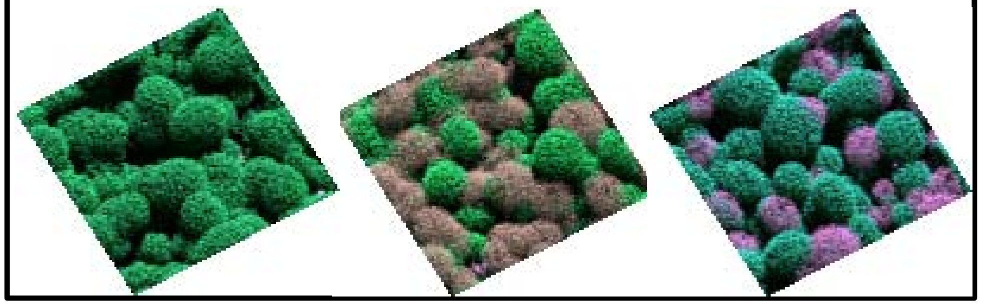
# A biological / physical modelling framework

3D stand models
Or **VOXEL scenes**

Radiative transfer (DART)

Canopy images



Barbier et al., AFS, 2011

# Towards a robust framework

- Improved ‘ground’ data
  - repeat passive optical and LiDAR drone passes
  - voxelisation


- Better control of multitemporal satellite optical data:
  - multiplying viewing angles
  - increasing resolution

- Better RT modeling (Morton et al., Nature, 2014; Wu et al. New Phytologist, 2018)