

STRUCTURE 3D DE LA VÉGÉTATION : DE LA QUANTIFICATION LOCALE À LA MODÉLISATION ET LA SIMULATION MASSIVE POUR TESTER À GRANDE ÉCHELLE LE POTENTIEL DES OBSERVATIONS SATELLITAIRES

Pierre Couteron – UMR AMAP

Équipe UMR AMAP



Antin C., Barczi J.-F., Barbier N., Blanchard E., Birnbaum P., Dauzat J., Griffon S., Guitet S., Heurtebize J., Lavalley C., Momo S., Pargal S., Pélissier R., Ploton P., Proisy C., Réjou-Méchain M., Texier N., Verley Ph., Viennois G., Vincent G. *et al.*

Partenaires :

- Univ. Yaoundé 1 - ENS (Cameroun) : B. Sonké
- NRSC (Inde) : V.K. Dadhwal, C.S. Jha
- Univ. Estadual. Amapà, Embrapa (Brésil) : P. Aparecio, E. Sotta
- TU Dresden (Allemagne) : U. Berger
- UMR CESBIO : J.-Ph. Gastellu-Etchegorry
- UMR TETIS: S. Durrieu, ESPACE-DEV

PLAN DE L'EXPOSÉ

○ Contexte

- Enjeux liés à l'observation spatiale de la végétation
- Les verrous et les défis

○ Mesures et simulations

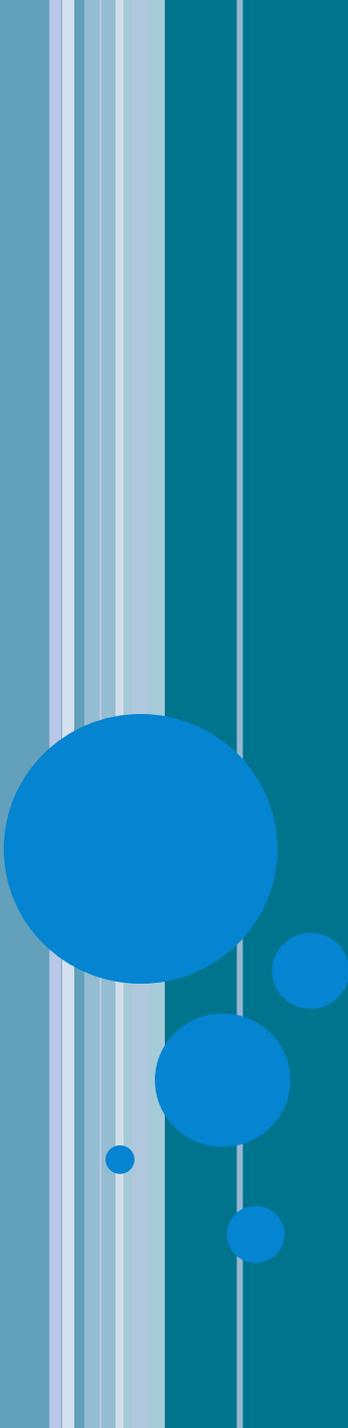
- « Maquettes » de végétation
- Nouvelles méthodes de mesure in situ (« Lidars »)

○ Vers des chaînes d'analyse/ simulation intégrées

- Exemple de travaux en cours
- Perspectives

- **Focus** : forêts tropicales « naturelles », approche des canopées par images optiques



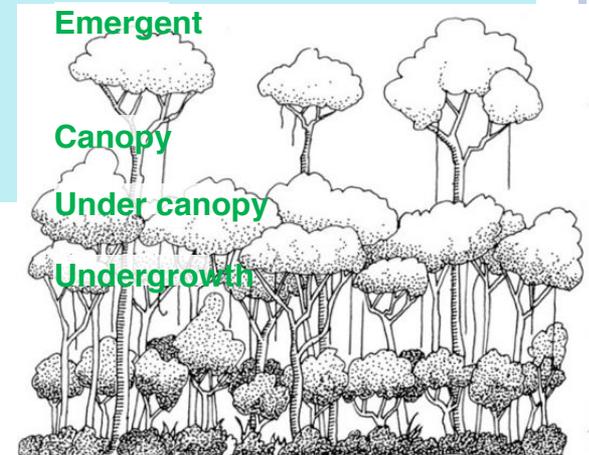


Contexte thématique

Observation spatiale des forêts tropicales humides

ENJEUX LIÉS AUX FORÊTS TROPICALES

- Interface 2 conventions ONU :
 - CNUCC: climat
 - CDB: biodiversité
- Enjeux pour le développement durable :
 - Cartographier ressources/ services?
 - Comment cela varie dans l'espace?
 - Changement temporels récents/ actuels?
 - Changements à venir?
- Evaluer à grande échelle, suivi temporel
 - Central : Structure forestière 3D
 - Verrou : Relier le terrain à l'Obs. Spatiale



QUANTIFIER LA STRUCTURE FORESTIÈRE 3D

○ Important pour :

- Caractériser la dégradation et suivre la dynamique
- Ecologie (trouées, mortalité ...)
- Interactions forêt – atmosphère
- Biodiversité: types de forêts, habitats, ...
- Services écologiques (stocks de carbone, eau, ...)

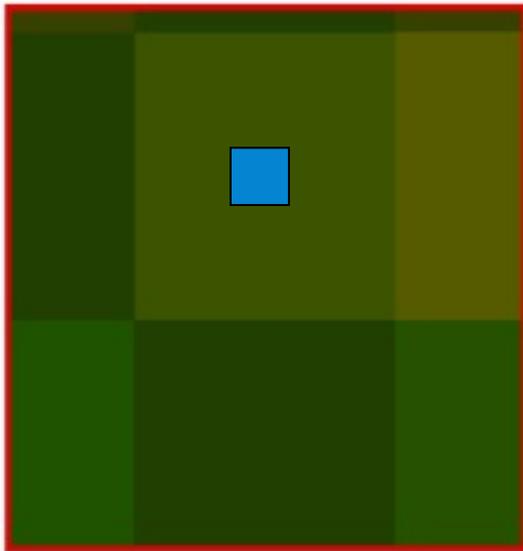
○ Mesures de terrain :

- Essentielles, mais ...
- Coût, faible couverture, répétitivité

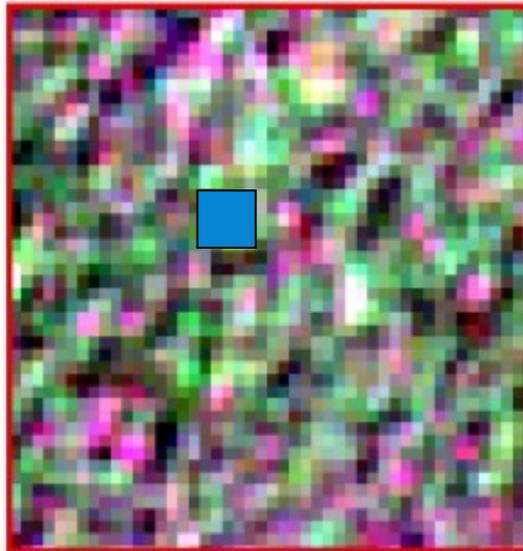


DU TERRAIN À LA RÉOLUTION MOYENNE

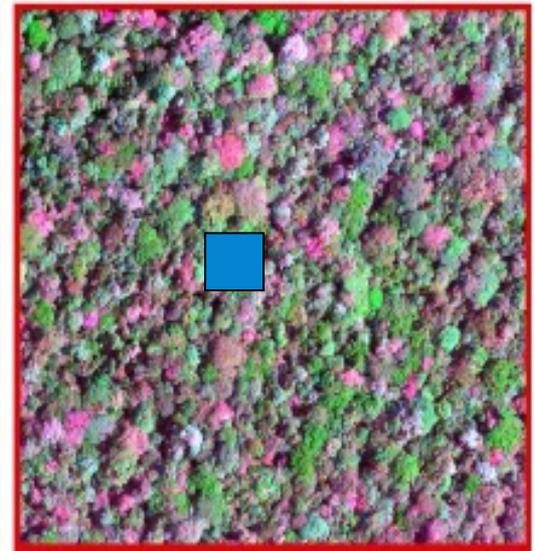
MODIS



SPOT 5



GeoEye



0.5 km



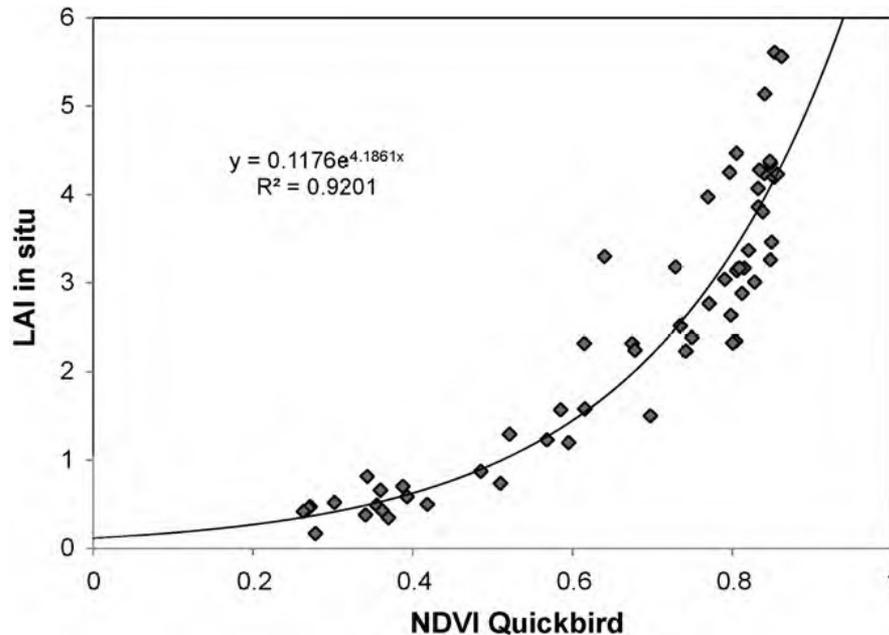
OBSERVATION SPATIALE : CONTRAINTES

- **Saturation des approches “par pixels”**,
 - aux résolutions hautes (5 m - 50 m)
 - à moyennes (100 m – 250 m)
- **Images optiques :**
 - Indices (NDVI, EVI): saturation, pas de lien direct avec taille du tronc et biomasse
- **Radar (RSO):**
 - Bande L: saturation c. 100 – 150 Mg/ha (satellites)
 - Bande P (satellite à venir) tend à saturer vers 250 Mg/ha, mais interférométrie, tomographie ...
- **Opportunité :**
 - Diversification des signaux,
 - Agilité, accessibilité
 - Gain en résolution (THRS)

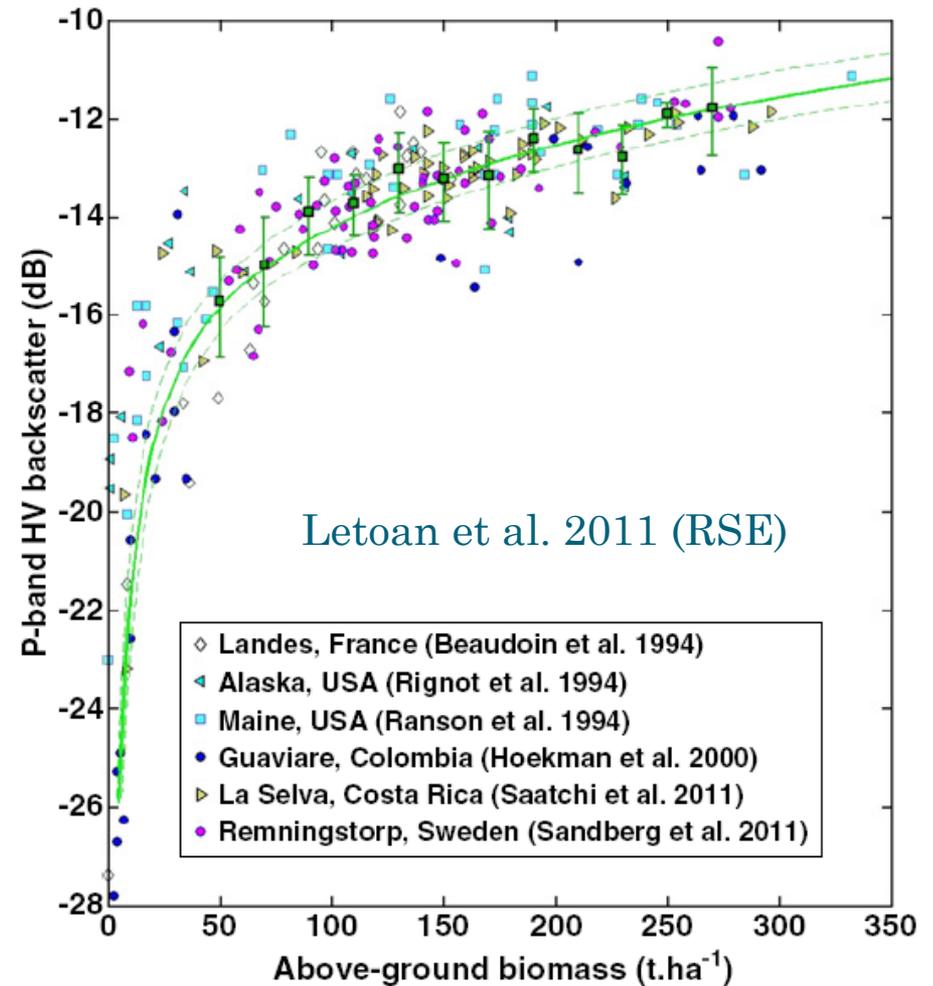


SATURATION DU SIGNAL NIVEAUX INTERMÉDIAIRE DE BIOMASSE OU LAI

LAI champ de Mais, optique (Quickbird)



RADAR, (Bande P)



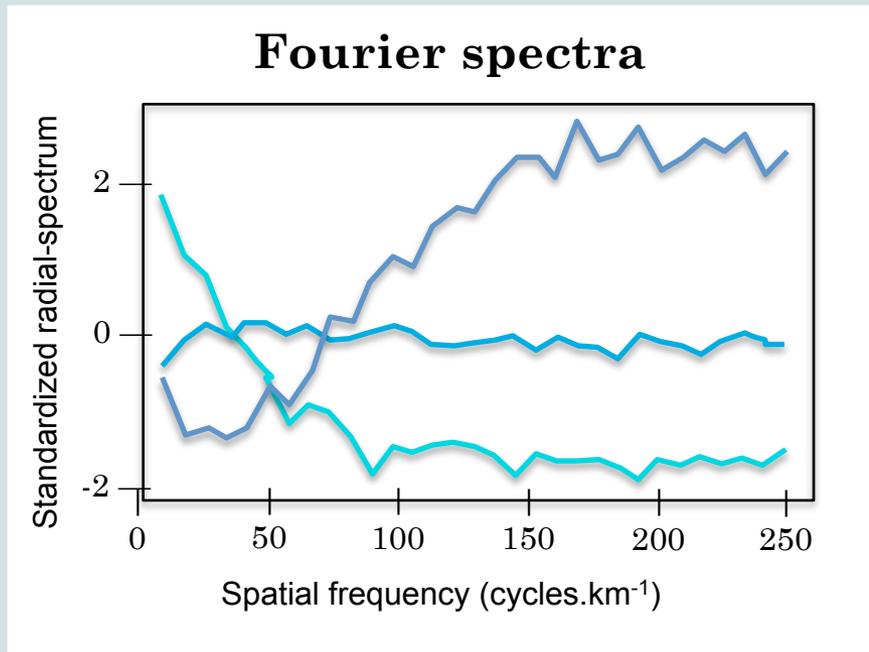


ANALYSE DE TEXTURE DES IMAGES OPTIQUES DE CANOPÉE

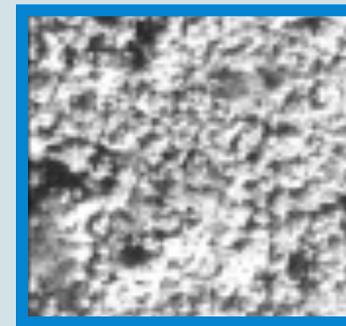
THRS CANOPY IMAGE TEXTURE ANALYSIS

MÉTHODE FOTO : FOURIER_BASED TEXTURAL ORDINATION

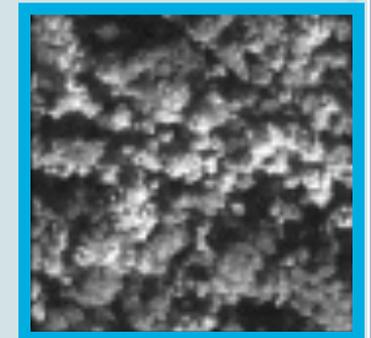
(Couteron 2002, Couteron et al. 2005, JAE)



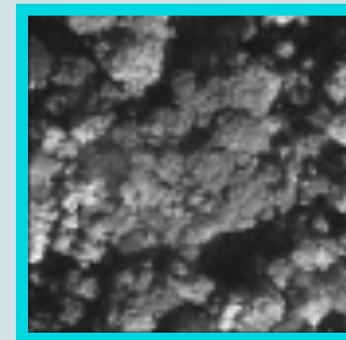
Grain fin



Intermédiaire



100 m



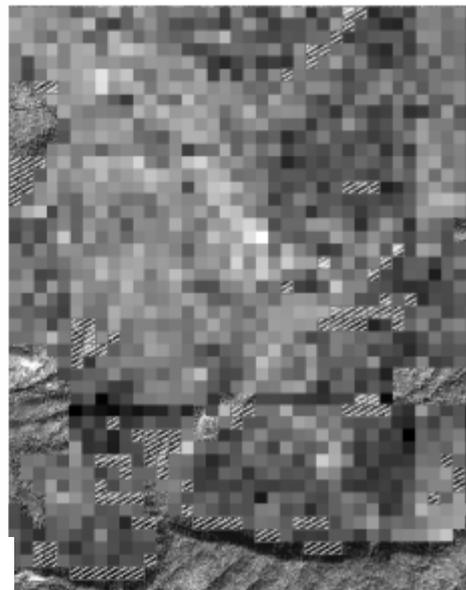
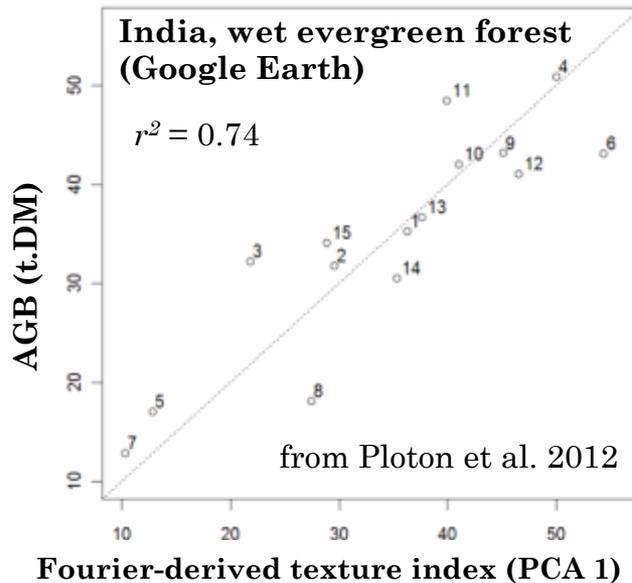
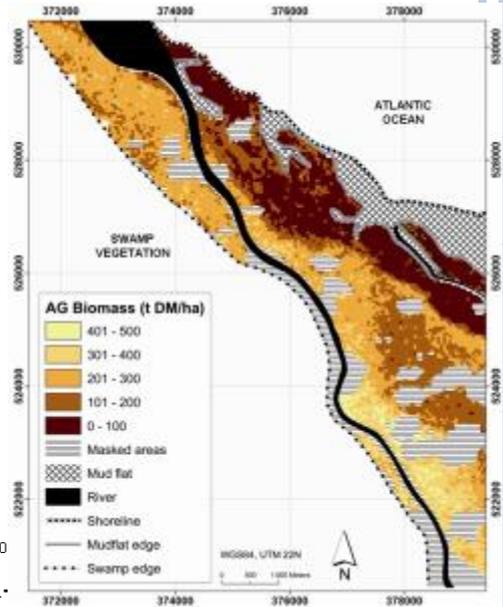
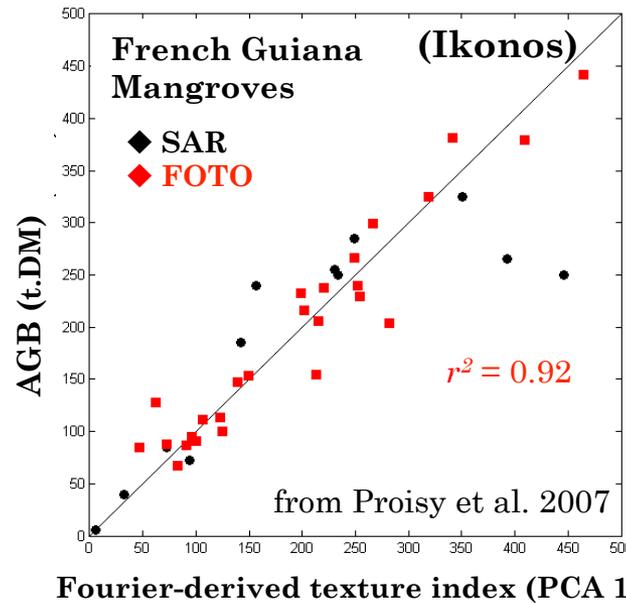
Grain grossier

D'après Ploton *et al.* 2013



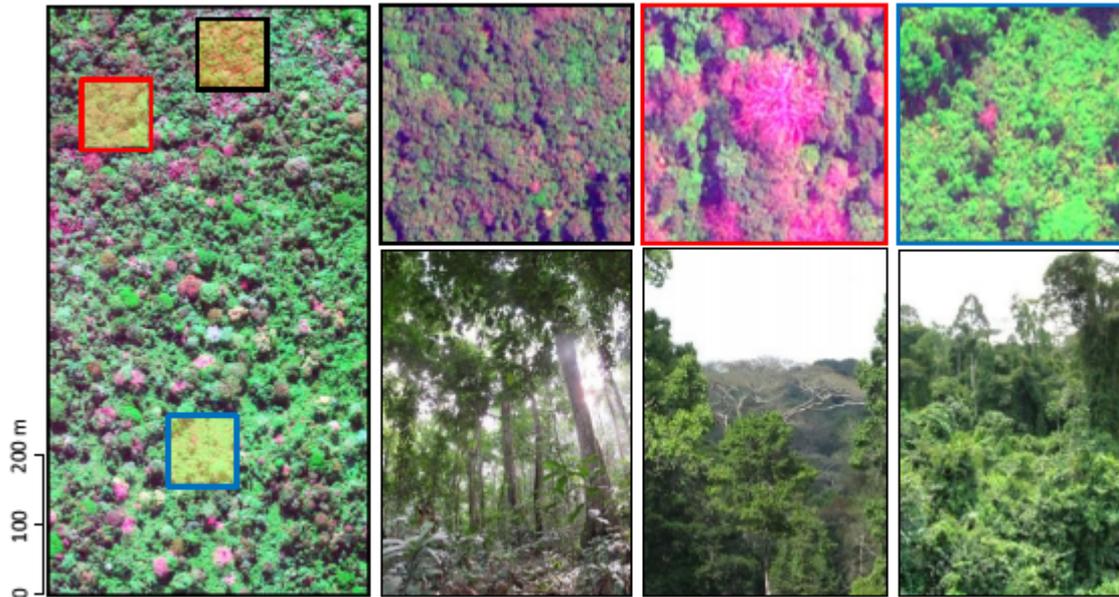
FOTO: prédiction de la biomasse épigée

- Sans saturation...
- Mais résultats « locaux »
- type de forêts,
- acquisition de l'image



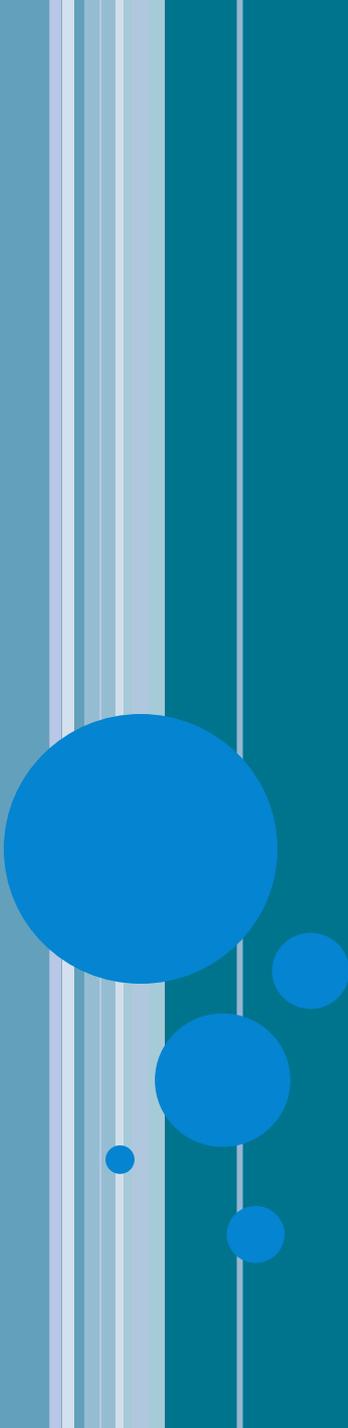
AUTRES DIFFICULTÉS :

- **Variabilité des forêts naturelles** : un même site en Afrique centrale



- **Variabilité des conditions d'acquisition**
- **Influence la radiométrie (BRDF) et la texture**





Des mesures aux simulations

Augmenter la base expérimentale

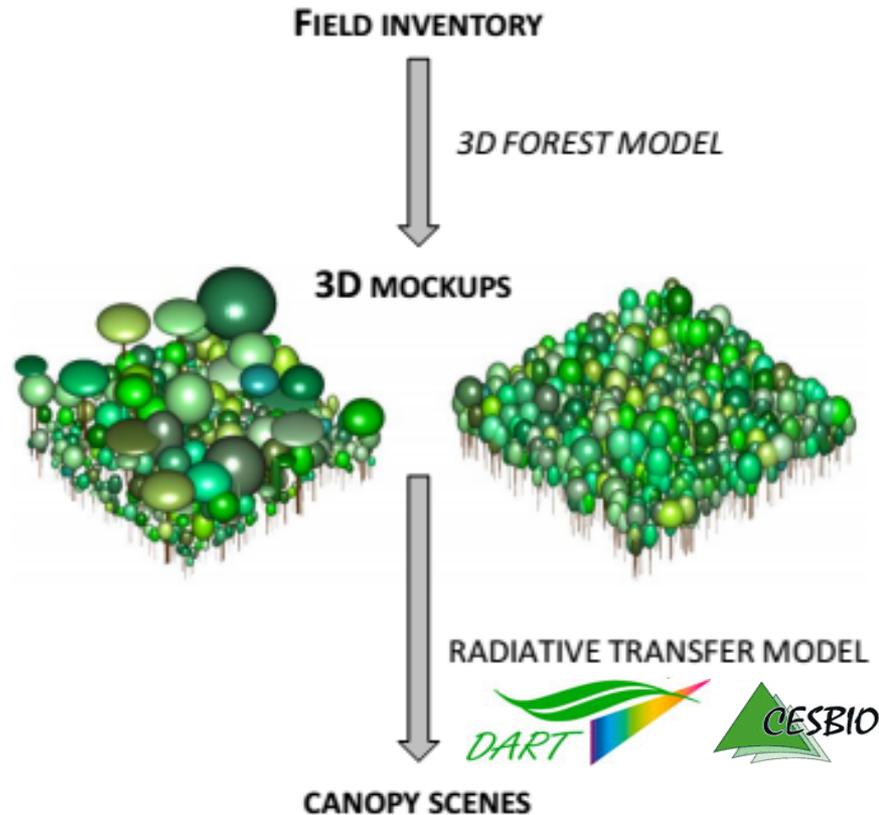
MIEUX UTILISER LES DONNÉES SATELLITALES?

- **Améliorer et augmenter l'information de terrain :**
 - Mesures non-destructives :
biomasse, forme des arbres (T-Lidar)
- **Intégrer l'information aéroportée :**
 - Techniquement performante (A-Lidar)
 - mais limitée dans les pays tropicaux (coût, autorisations, ...)
- **Sur ces bases, simuler :**
 - « Maquettes » 3D d'arbres et de peuplements
 - Scènes satellitales : interaction signal - maquettes
 - Variabilité des peuplements, des acquisitions
- **Tester (calibrer?) les inversions**



DU TERRAIN AUX IMAGES : CHANGER D'ÉCHELLE

- Terrain : trop peu de données / aux sources de variations multiples



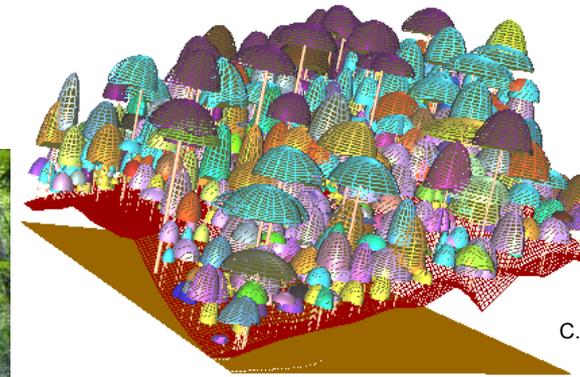
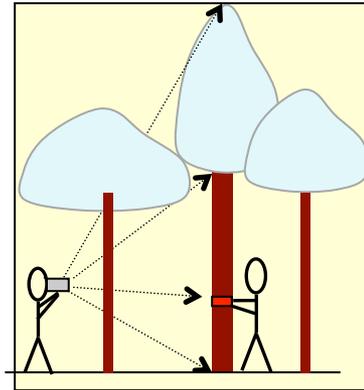
Maquettes : arbres?
Peuplements?
Restitution? Simulations?

Ploton 2017,
Ploton et al. 2017, RSE, soumis

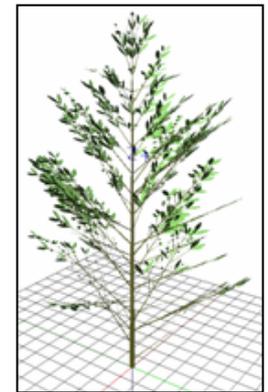


MESURER LA FORÊT ...

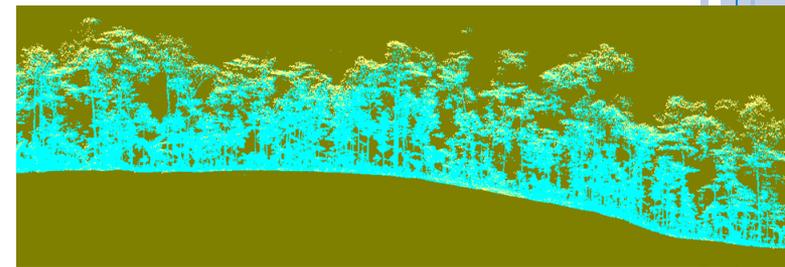
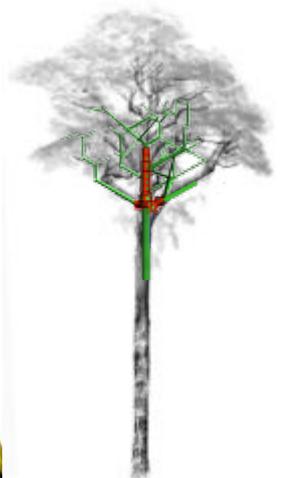
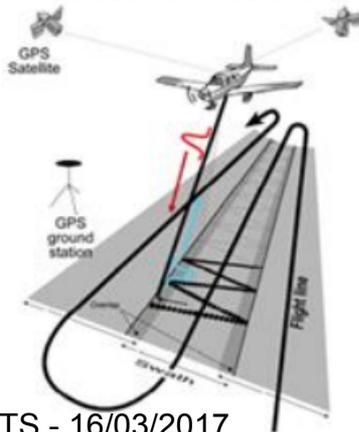
- Morpho-dendrométrie



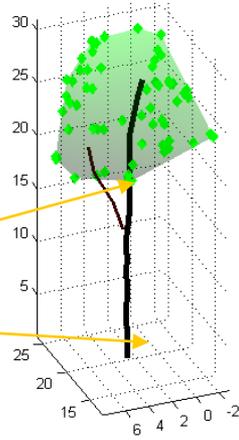
- Architecture botanique



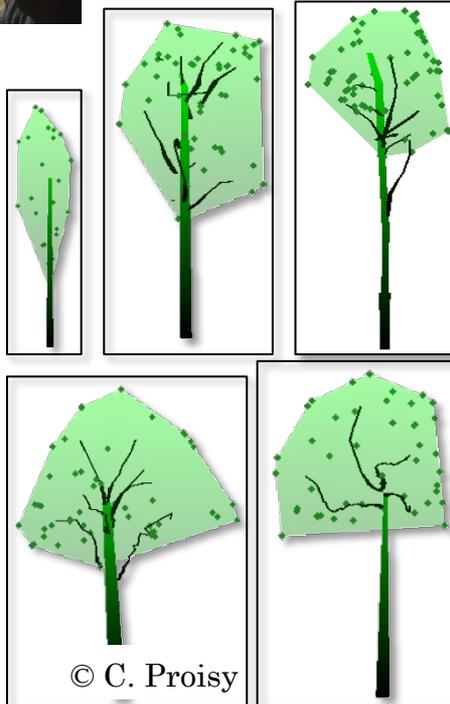
- Scans lasers (Lidars)



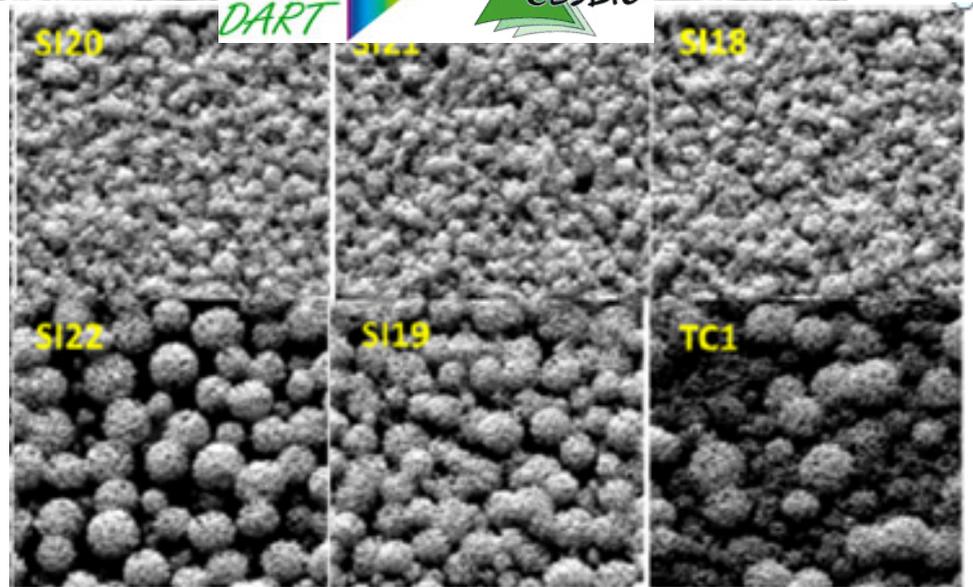
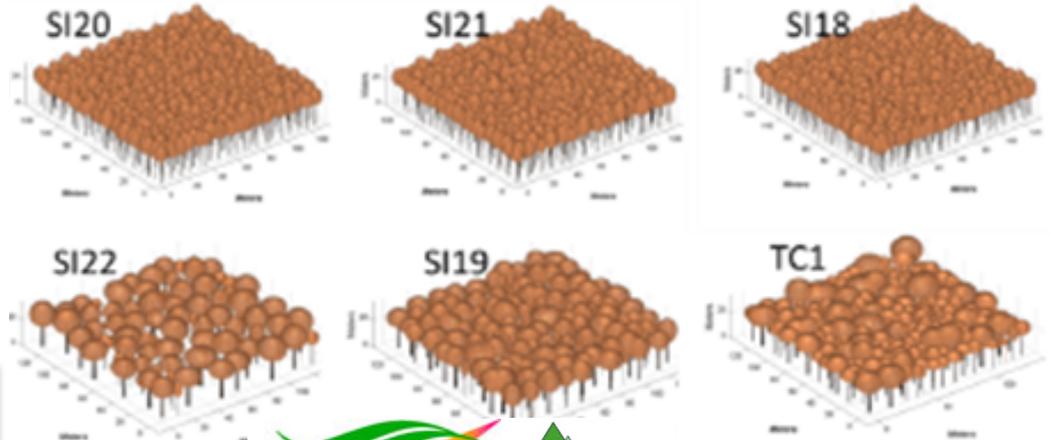
MAQUETTES PAR ENVELOPPES MORPHOLOGIQUES MANGROVES AMAZONIENNES



© C. Proisy

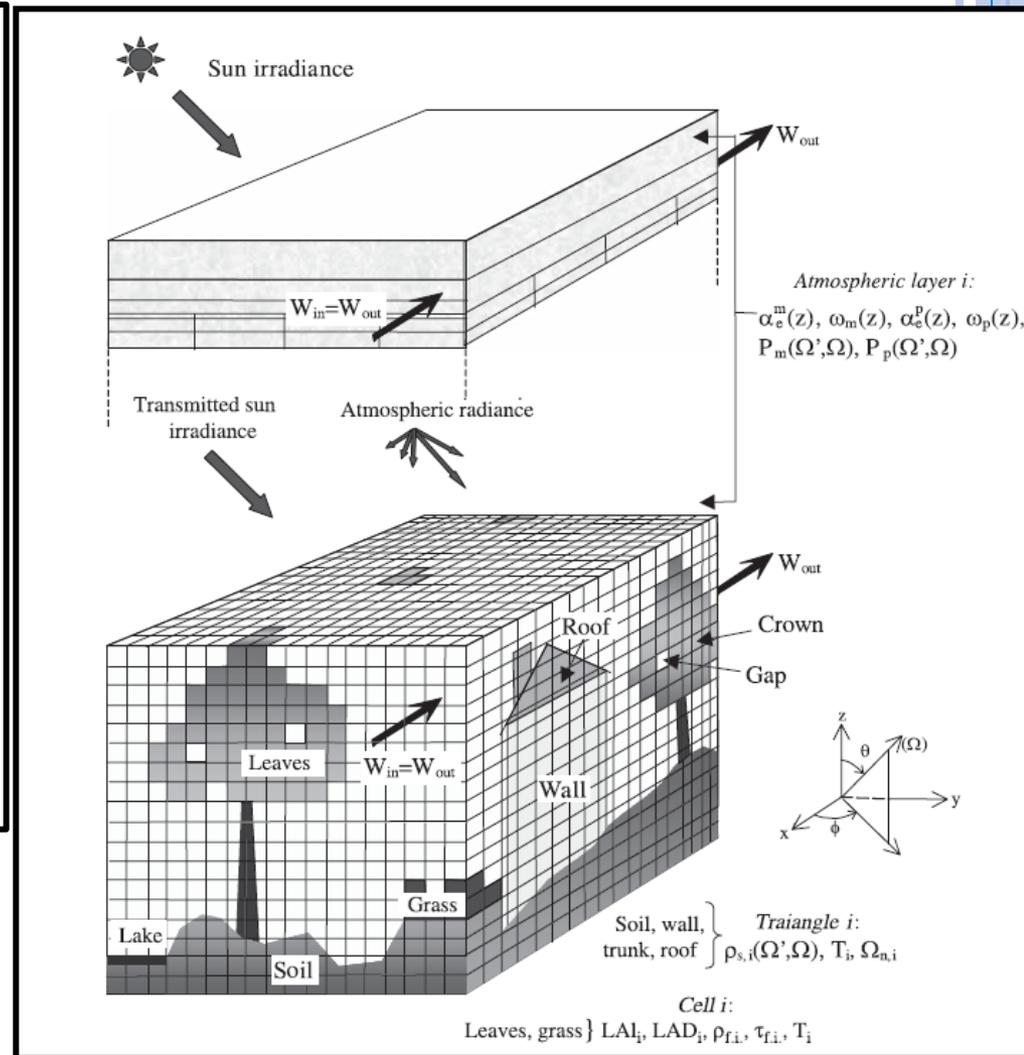


© C. Proisy



DART, Modèle de transfert radiatif

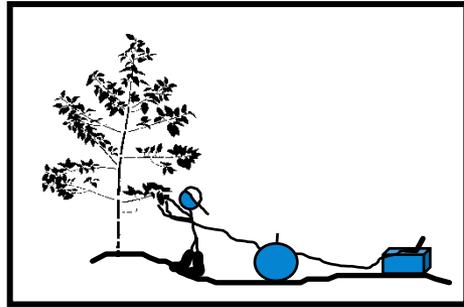
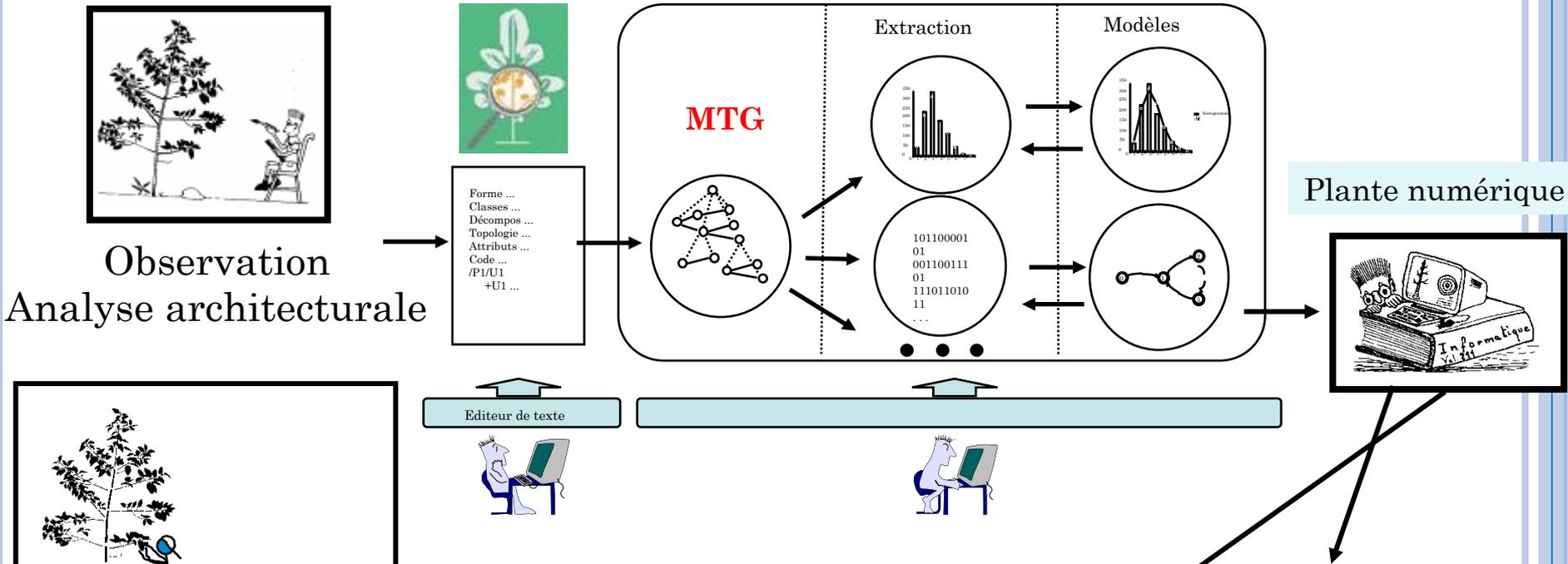
- bien établi
- lancé de rayon (milieux turbides/solides) pour scènes 3D



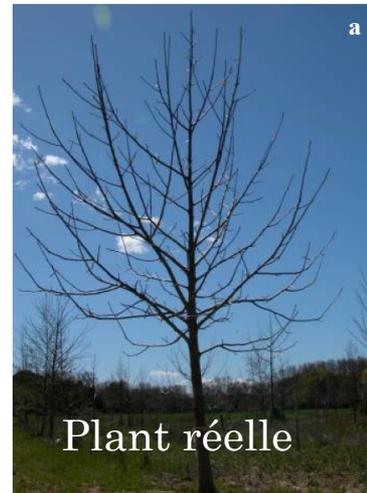
Gastellu-Etchegorry. Meteorol Atm Phys (2008)



SIMULATIONS BOTANIQUES DÉTAILLÉES



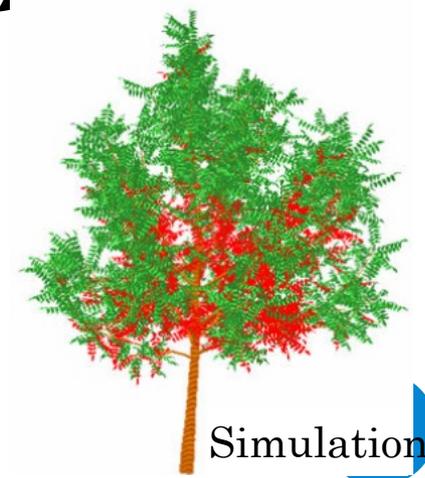
Mesures



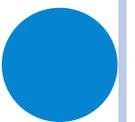
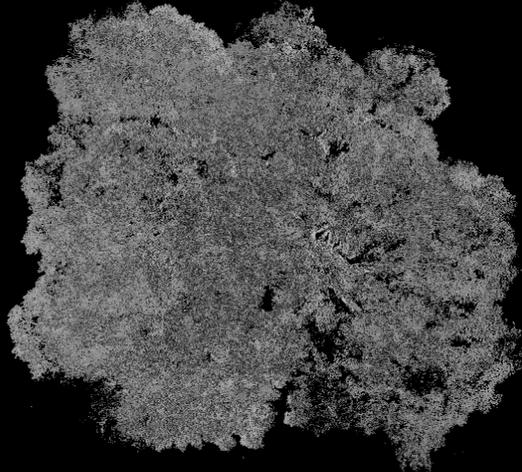
Plant réelle



Visualisation



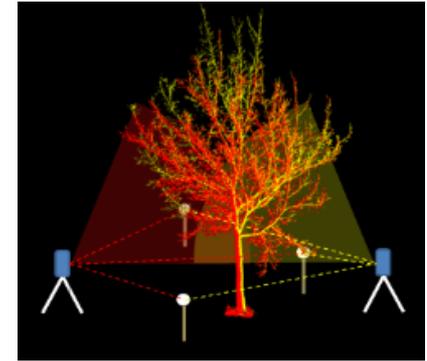
Simulation



ARBRE INDIVIDUEL DEPUIS NUAGE T-LIDAR

- Plusieurs possibilités :

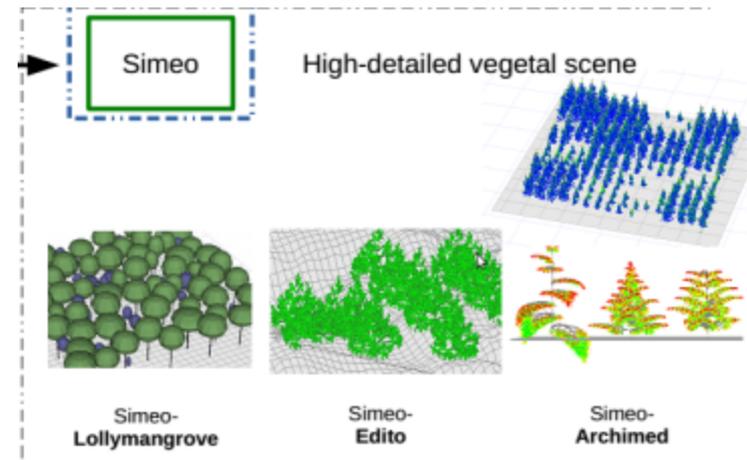
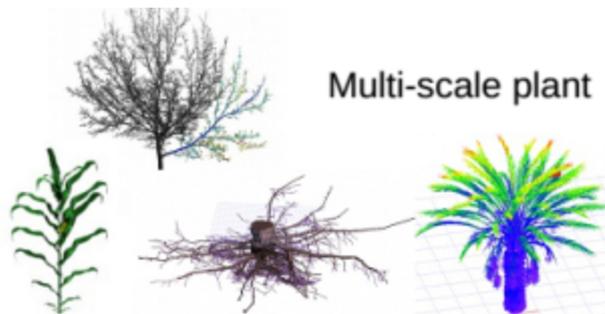
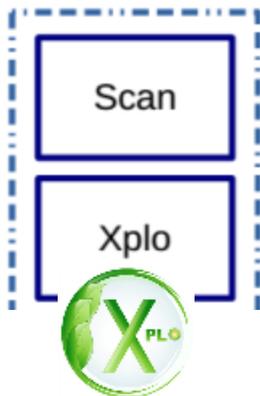
- Liste : Simple Tree (in Computree)
- Bons résultats, mais limites pour corriger, pas d'apport de l'expertise botanique



- AMAPstudio – Scan

Website : <http://amapstudio.cirad.fr/soft/scan/start>

- Correction/ amélioration manuelle des résultats automatiques
- Intégré dans la suite AmapStudio

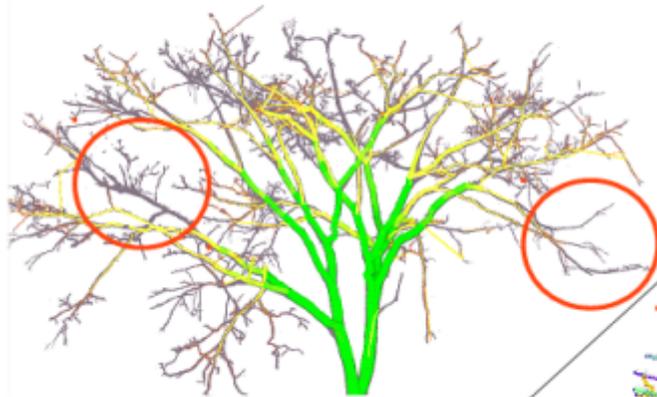


- Clavier pour « naviguer » dans la topologie
- Reprise dans Xplo pour éditions, extractions



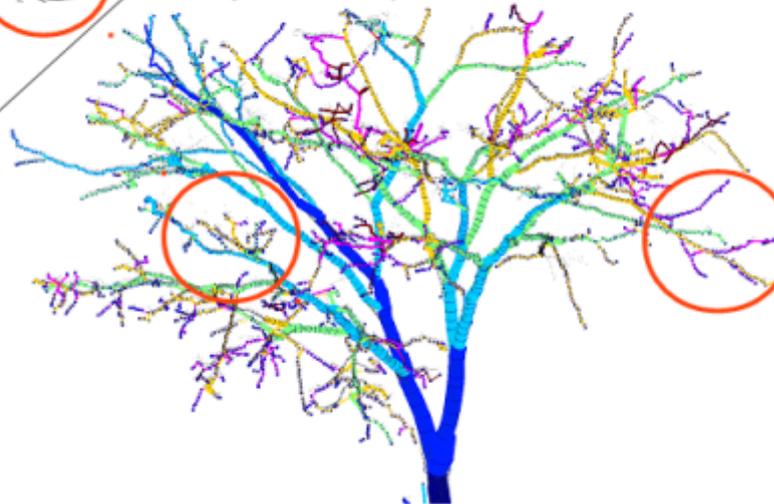
AMÉLIORATION DE LA DESCRIPTION DE LA COURONNE

Crown quantitative improvement with Scan



SimpleTree output

SimpleTree output edited with Scan



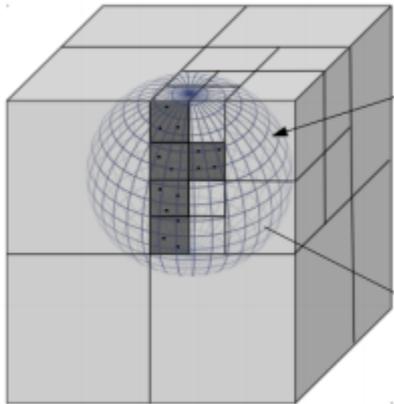
Amélioration des allométries non destructives
Cf. S. Momo Takoudjou



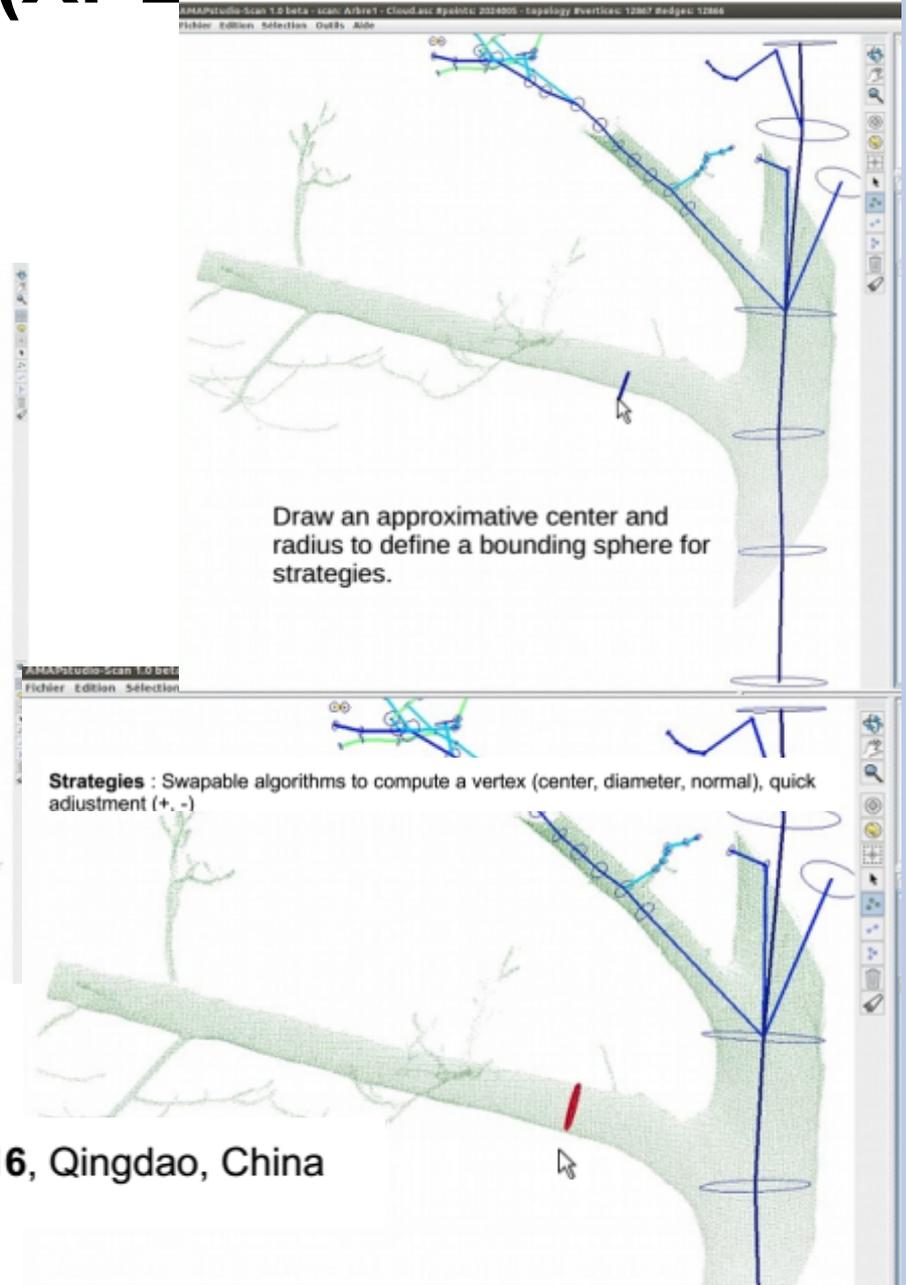
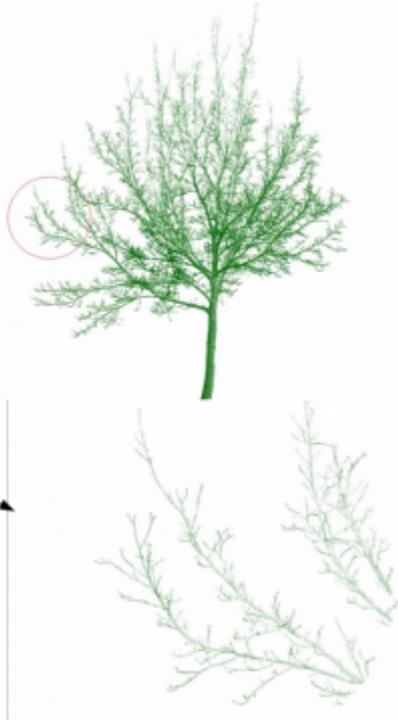
UTILISATION DE SCAN (XPLO)

Technical specificities

Octree and Focus:
Boosted local point reloading



Full scan octree and sphere intersection



Draw an approximative center and radius to define a bounding sphere for strategies.

Strategies : Swapable algorithms to compute a vertex (center, diameter, normal), quick adjustment (+, -)

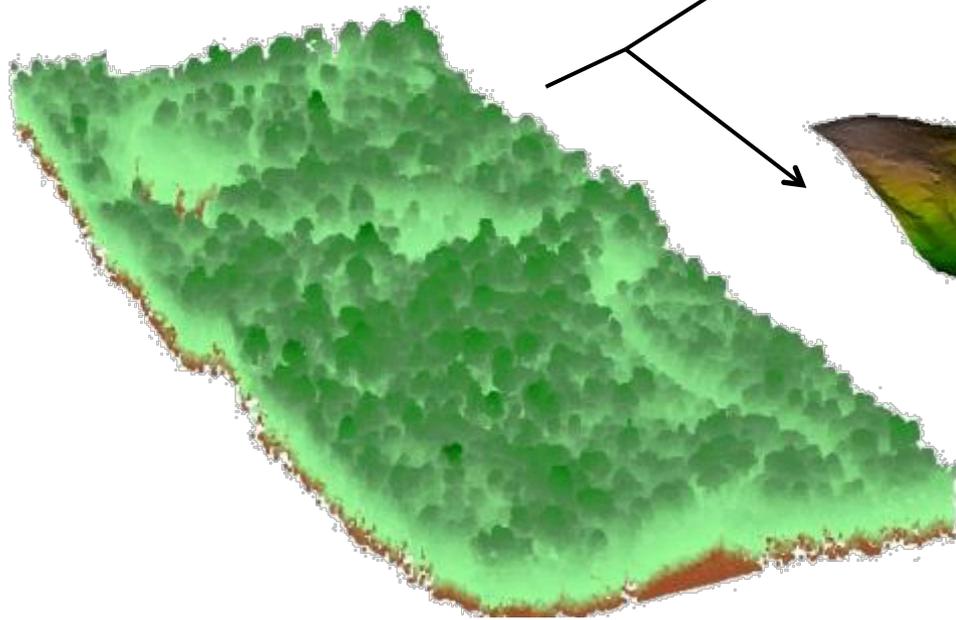
S. Griffon et F. De Coligny

7-11 November : Poster + Demo at **FSPMA 2016**, Qingdao, China

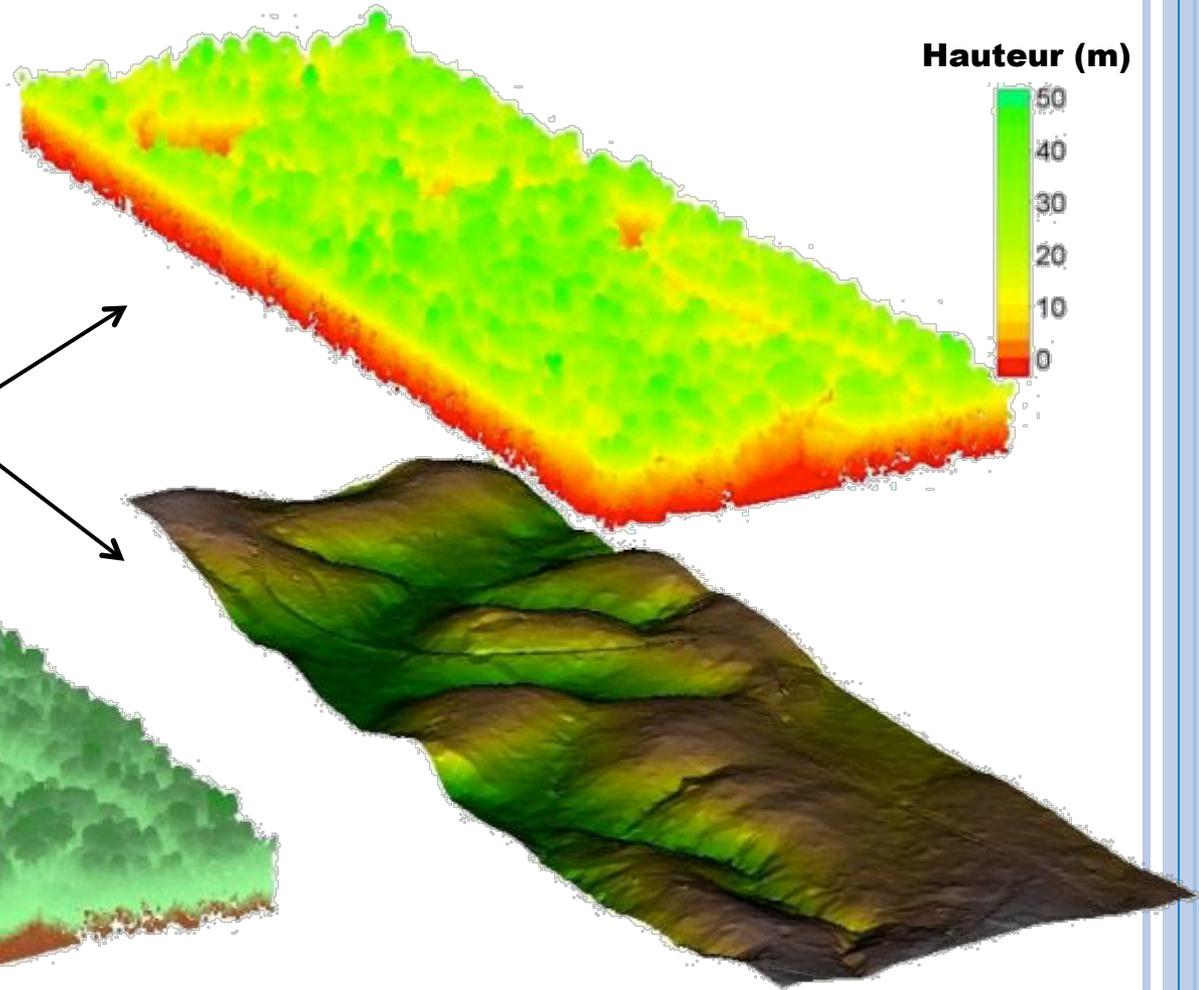
Echelle peuplement : A-Lidar (aérien), traitement du nuage de points

Forme d'onde complète

**Nuage des points
« végétation »**



Nuage brut (x,y,z échos)



Modèle numérique de tes reins (DTM)



LA HAUTEUR DE LA CANOPÉE PRÉDIT LA BIOMASSE

Terra Firme forest aboveground biomass map

Mabounie - Gabon

Submission:
Jan. 2013

PI:
Tariq Stévant (MBG)

Mapping:
Nicolas Barbier (IRD - AMAP)

Data collection:
N. Barbier, P. Ploton, V. Droissart (IRD AMAP)
Y. Isembe, J.-N. Boussiengui (CENAREST)
K. Stark, S. Griffith, A. Boulot (Golder Assoc.)
Vincent, Yves, Kairo,
John, Petit Jean and co. (Field assistants)

Base data:
1 ha plots
LiDAR acquisition Aerodata 2007
Canopy height model
& topographic moisture index

Projection:
WGS 84 - UTM 32S

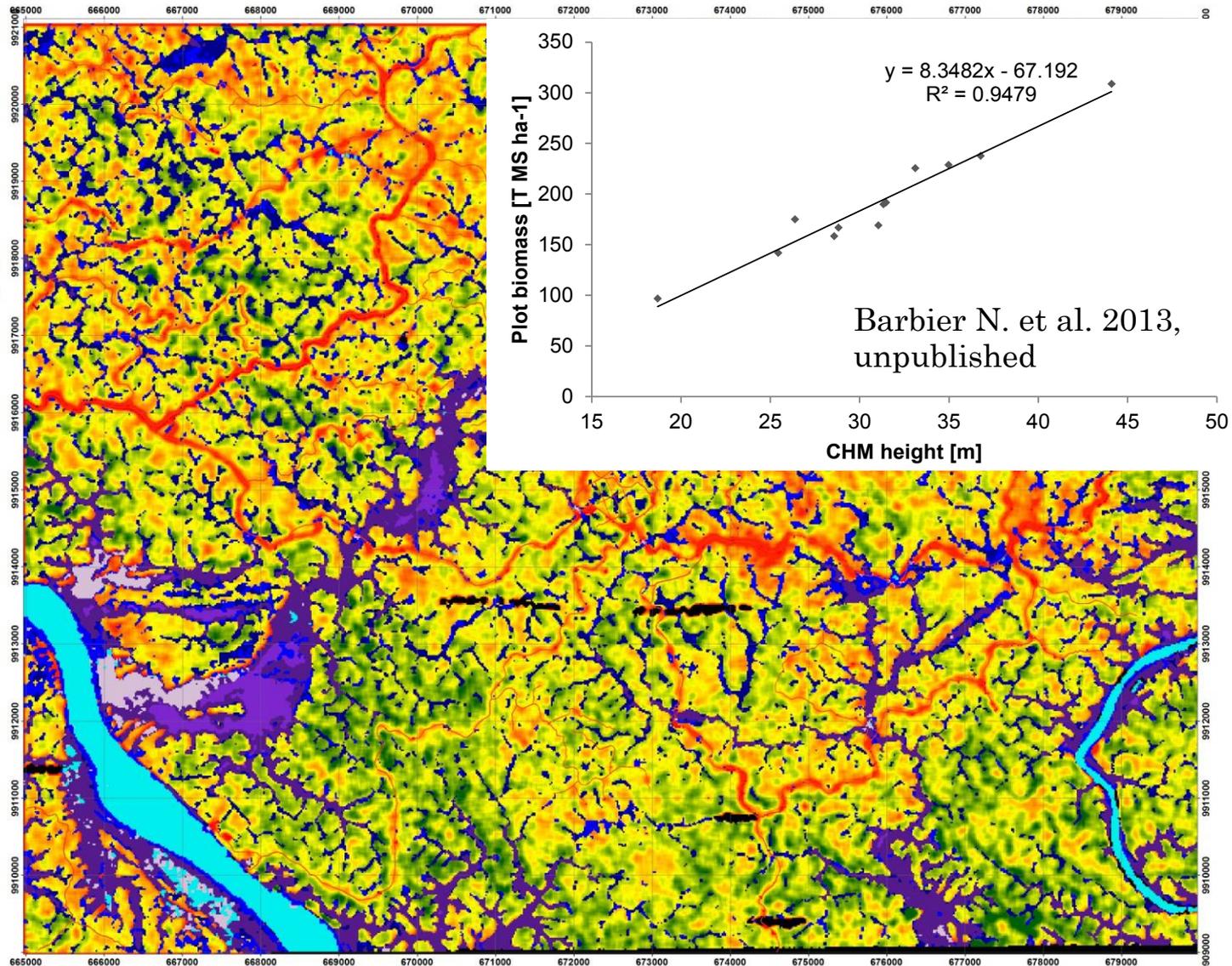


MISSOURI BOTANICAL GARDEN

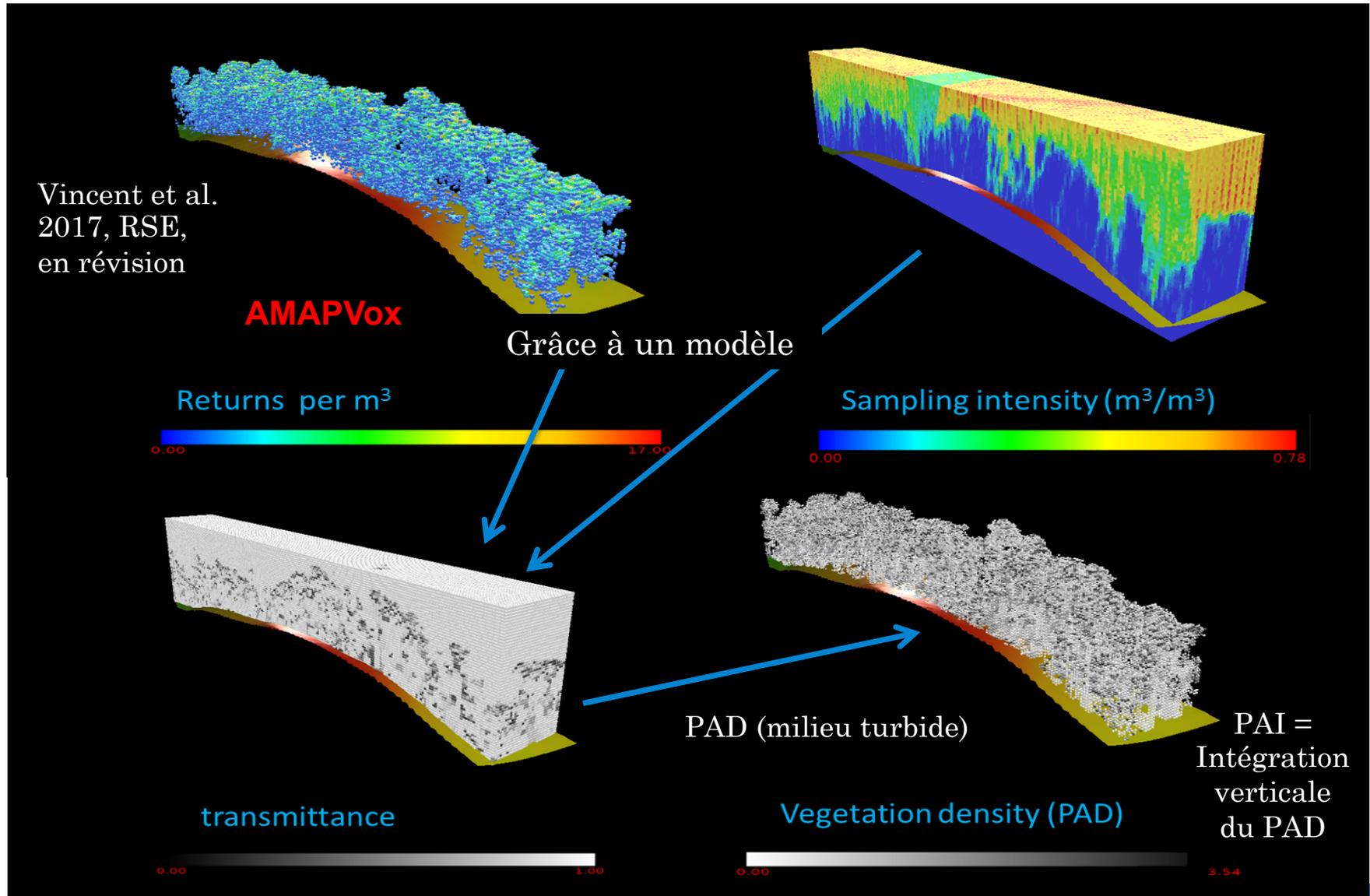
AGB Biomass [T DM/ha]



- Unclassified - No data
- Built up - Bare
- Open Water
- Swamp grassland
- Pure Raphia stands
- Mixed swamp forests
- Low flooded forest
- High flooded forest

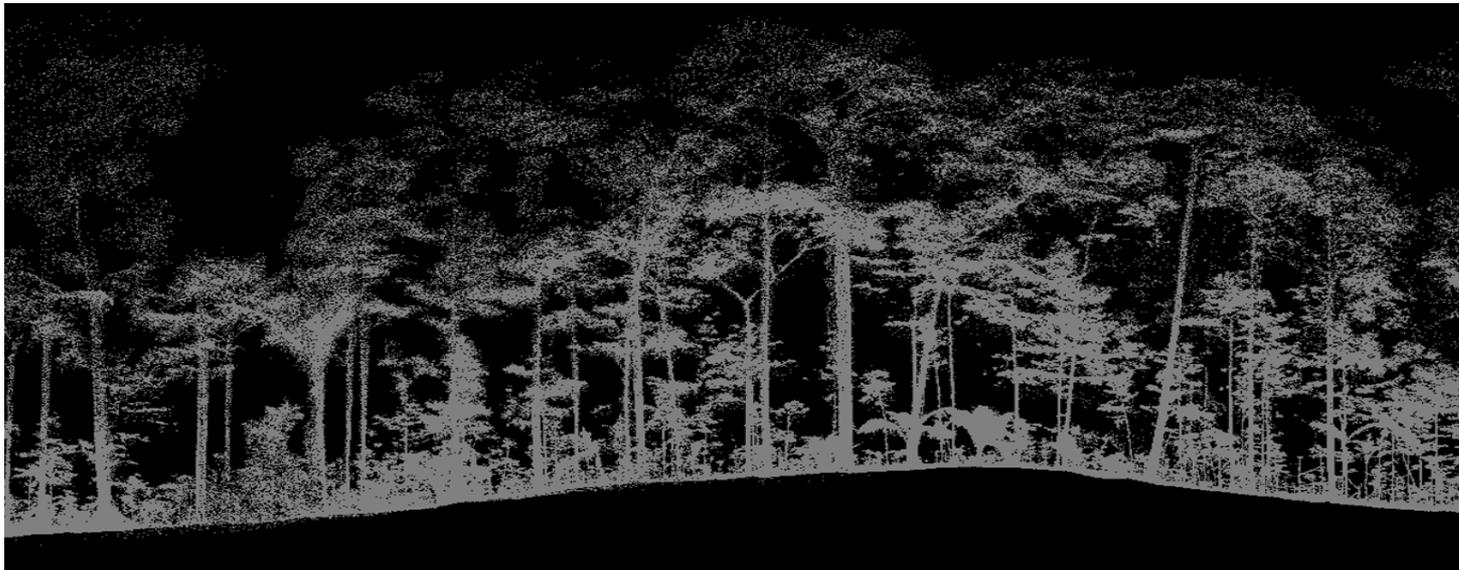
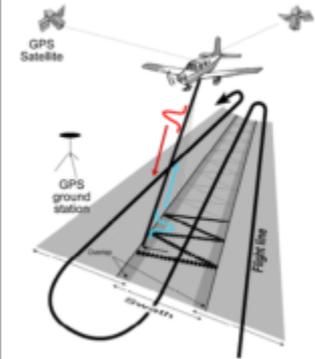
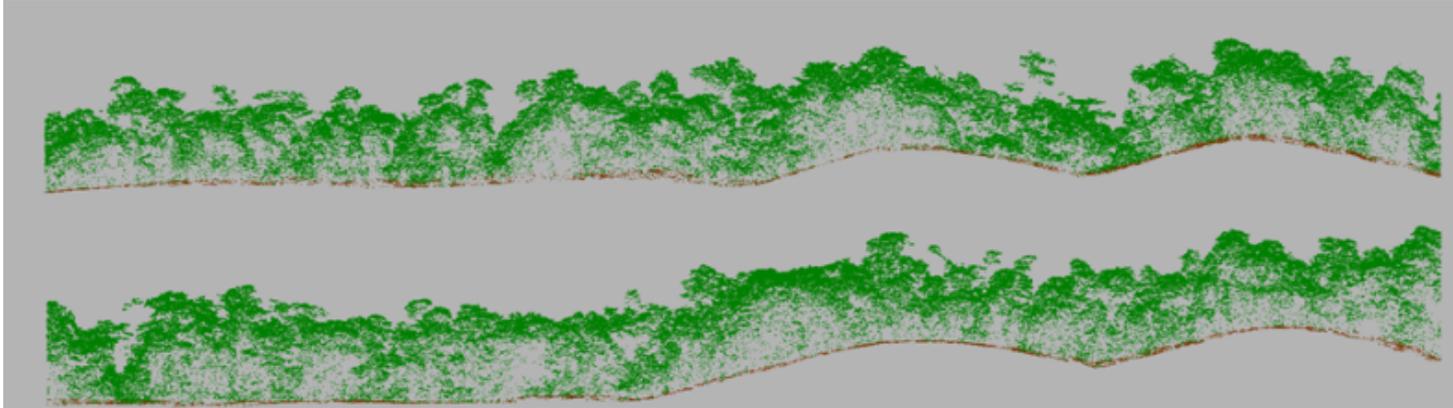


A-LIDAR, PRÉDICTION DU PAI

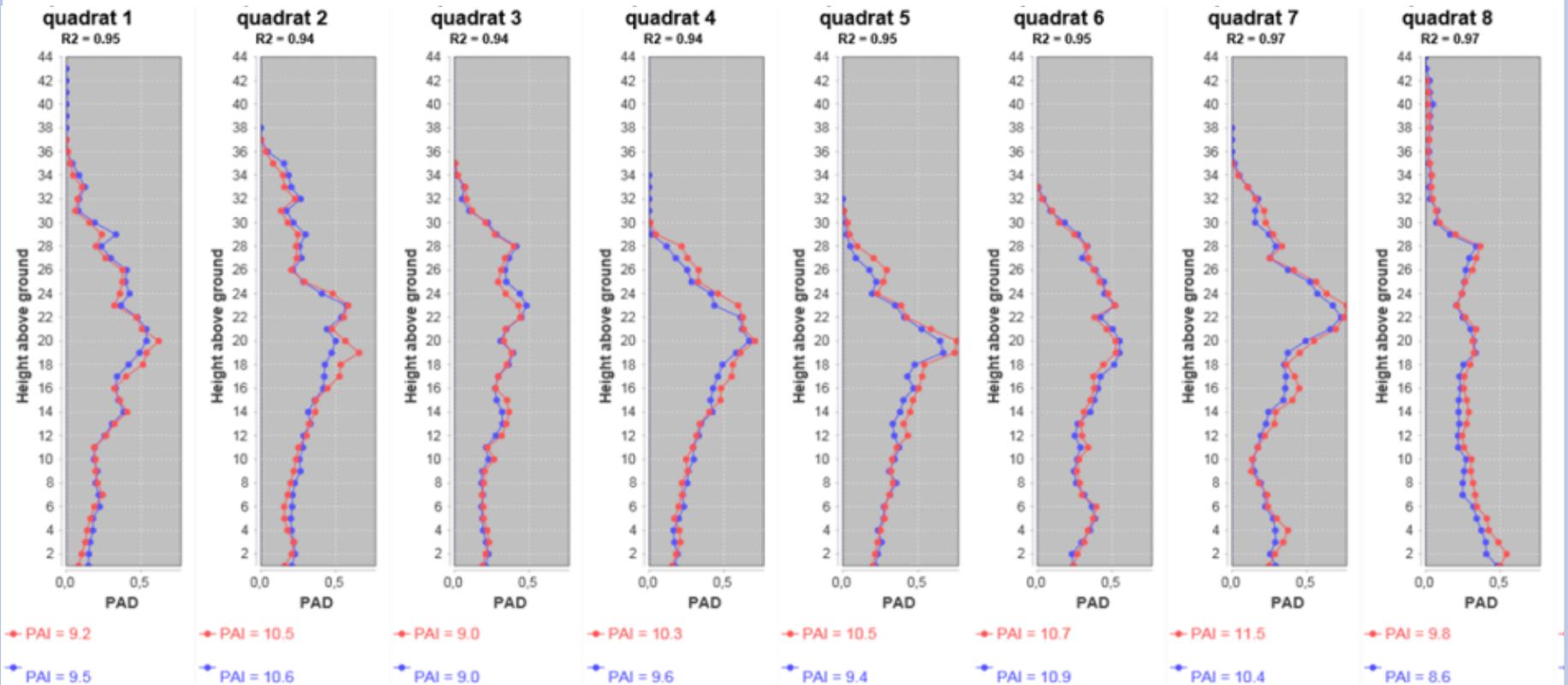


Echelle peuplement T-Lidar

- Alternative/ fusion A-Lidar: PAI (LAI), cohérence avec A-Lidar?



Comparer les profils de forêt tropicale A-Lidar et T-Lidar



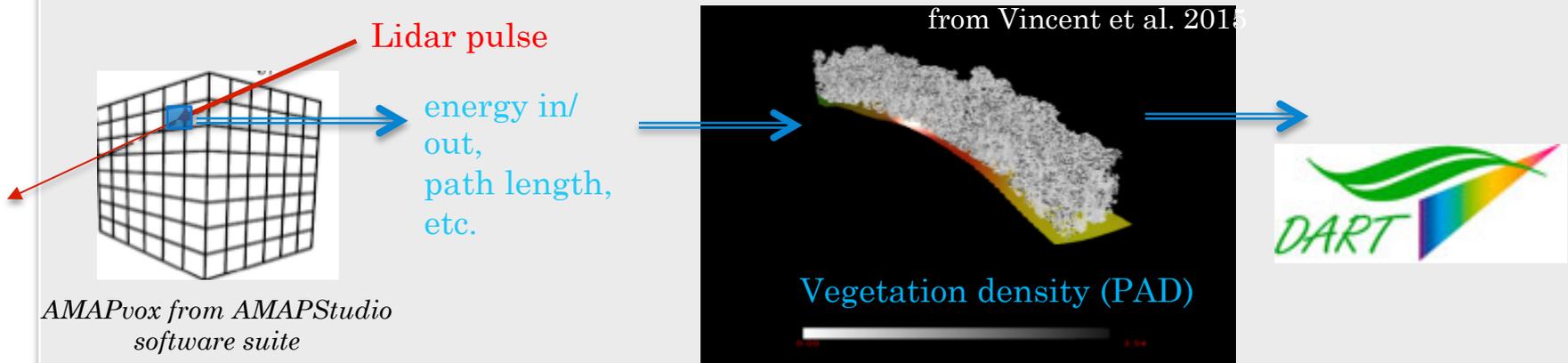
*Separating foliage from the wood is made possible by combining **geometrical characteristics** from the dense point cloud and **return intensity** (reflectance)*

Vincent G, Antin C, Dauzat J, Grau E, Durrieu S (2015) Mapping plant area index of tropical forest by Lidar: calibrating ALS with TLS. In: Silvilaser 2015, La Grande Motte, France, pp 223-225

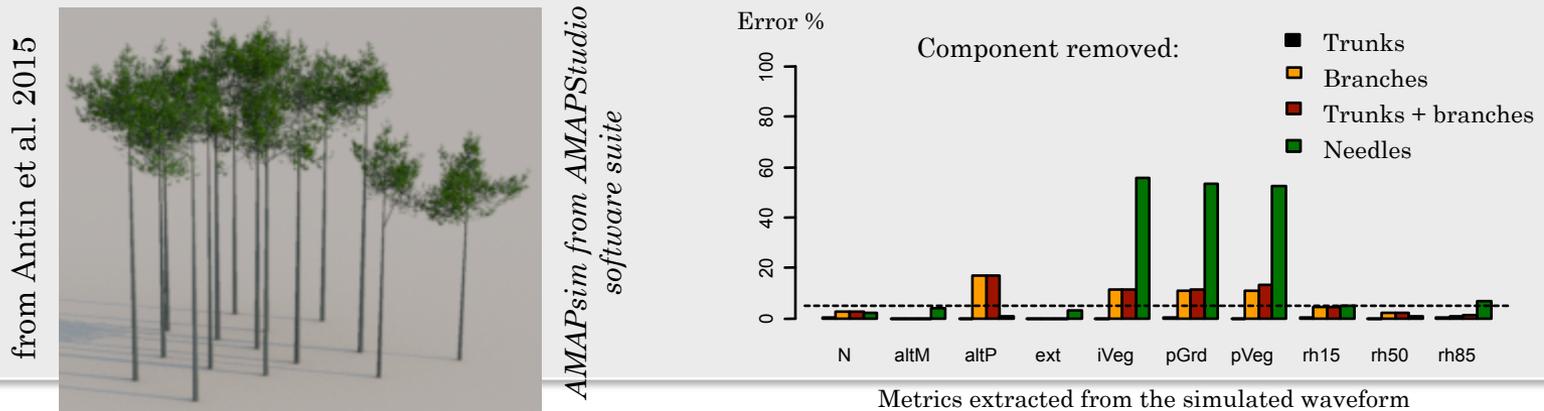


ILLUSTRATION : CHÂÎNE DE TRAITEMENT/ SIMULATIONS INTÉGRÉES

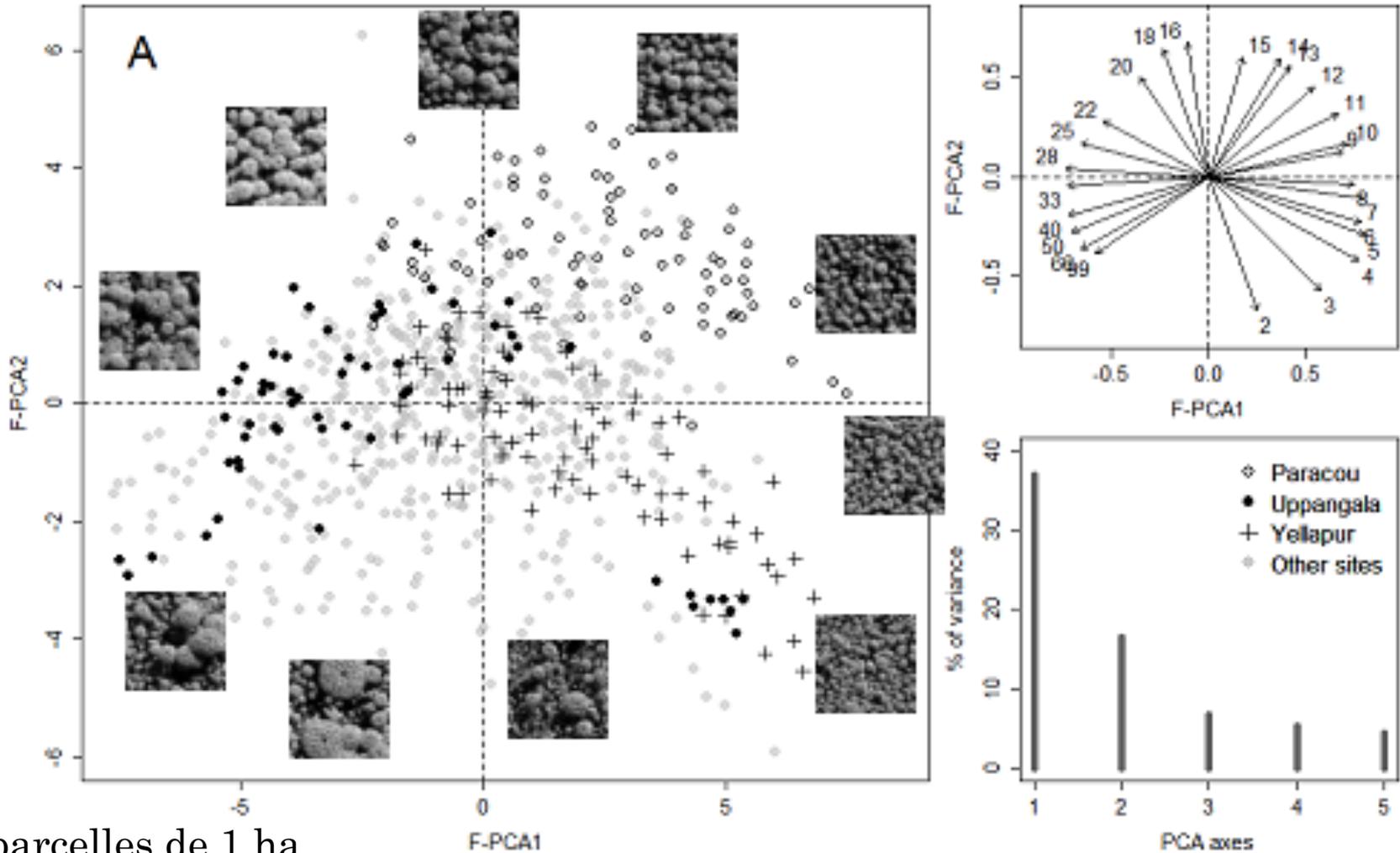
- Vegetation density estimation from ALS-TLS data fusion and Lidar raytracing simulation in a voxel space



- In silico analyse de sensibilité aux composants de l'arbres avec maquettes détaillées



CADRAGE DE L'ANALYSE DE TEXTURE DE CANOPÉE (FOTO) AVEC DES SCÈNES SIMULÉES

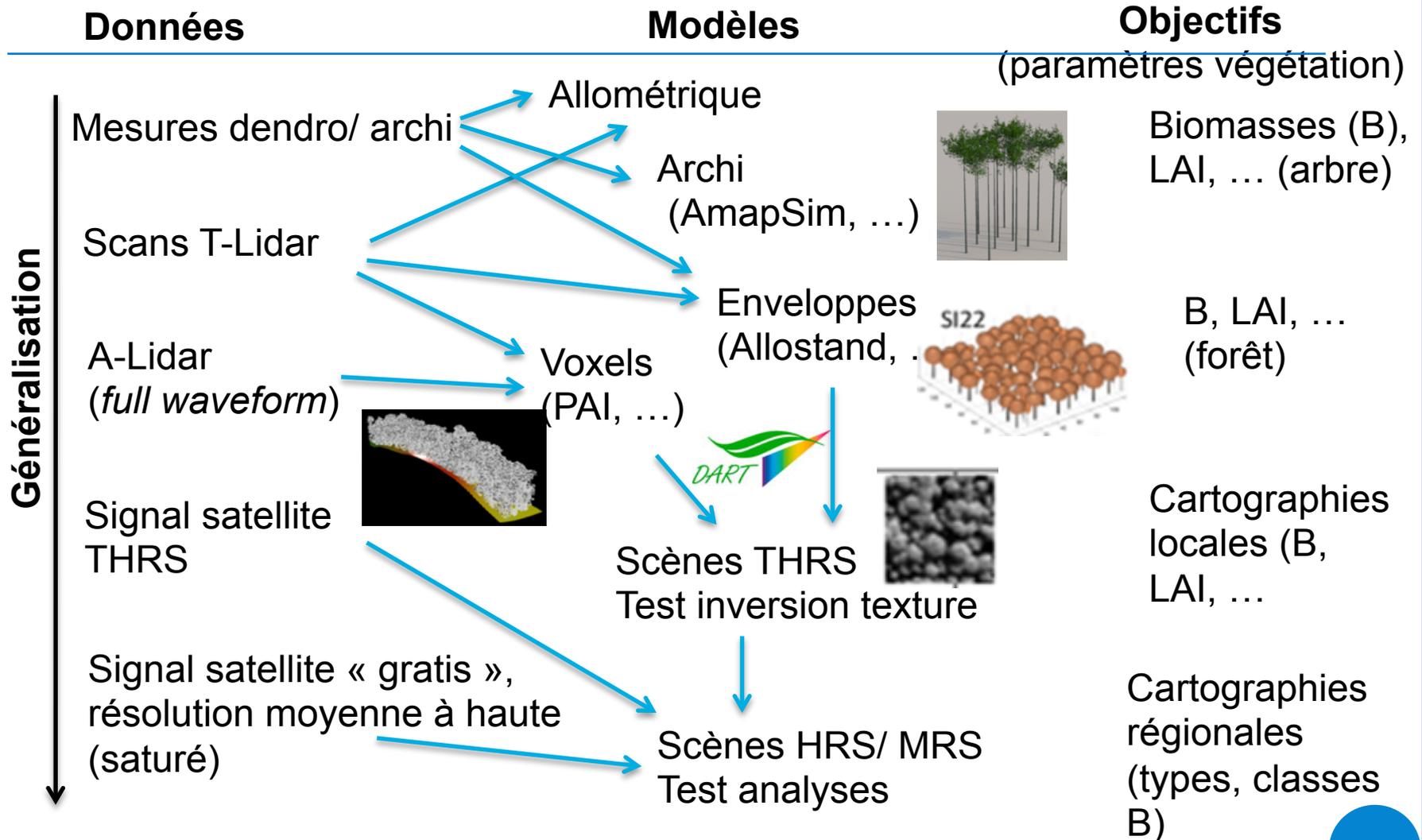


279 parcelles de 1 ha
Pantropical

Ploton et al. 2017, RSE, en révision



PERSPECTIVES : VERS DES CHAÎNES INTÉGRÉES



CONCLUSIONS

- On peut concevoir des chaînes intégrées :

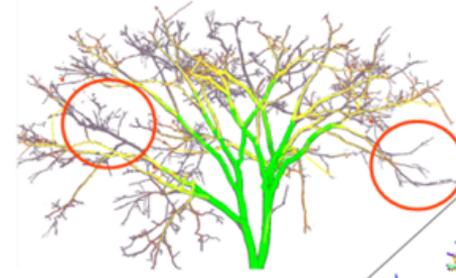
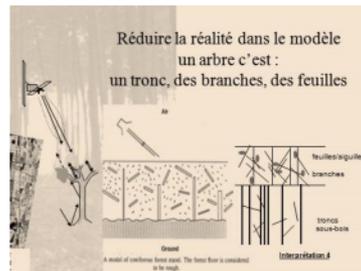
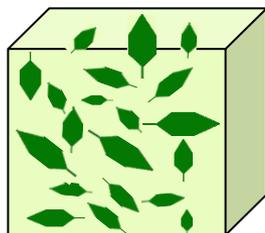
- Analyses, traitements, modélisations
- À des échelles emboîtées
- Le lien entre terrain et obs. spatiale peut sortir de la « boîte noire corrélative » pour devenir plus explicite

« ... il y a peu d'attention à la façon dont on décrit l'arbre par rapport à ... la façon dont on décrit la propagation de l'onde. ... les choix qui sont faits ne sont pas pensés comme des choix. » « ... cette description est traitée comme une non-question ... peut-être parce que c'est un objet naturel, ..., mesurable par des moyens simples. »

I. Champion, 2015

- Les « données » deviennent « composites » :

- Plusieurs métrologies, résultats de modélisation, ...
- Leur nature peut être « réfléchi », par dialogue entre un potentiel métrologique et un objectif de modélisation, fonction d'enjeux thématiques





Merci pour votre attention



pierre.couteron@ird.fr

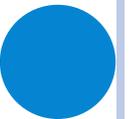
SÉLECTION DE PUBLICATIONS

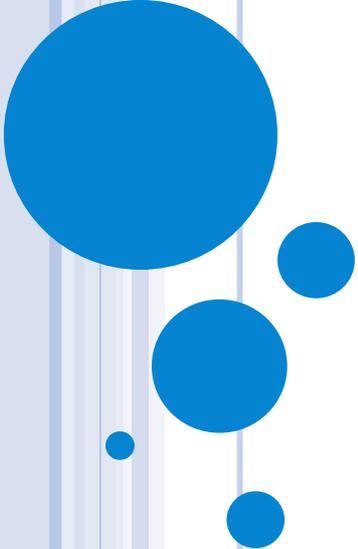


Montpellier

- Ploton, P. et al. 2017. Combining canopy texture metrics allows consistent pantropical forest (AG) biomass modelling from very high resolution optical satellite images, *Remote Sensing of Environment*, en révision
- Vincent, G., Antin, C., Laurans, M., Heurtebize J., C. Lavalley, Grau, E., Durrieu, S., Dauzat, J., in prep. Mapping plant area index of tropical evergreen forest by ALS. A cross-validation study using LAI2200 optical sensor, *RSE*, en révision.
- Vincent, G., Antin, C., Dauzat, J., Grau, E., Durrieu, S., 2015. Mapping plant area index of tropical forest by Lidar: calibrating ALS with TLS. Presented at the Silvilaser conference 2015, La Grande Motte, pp. 223–225.
- Barbier N., Couteron P. 2015. Attenuating the bidirectional texture variation of satellite images of tropical forest canopies, *Remote Sensing of environment*, 171, 245–260.
- Bastin J-F, Barbier N, Adams B, Shapiro A, Couteron P, Bogaert J, De Cannière C. 2014 Aboveground biomass mapping of African forest mosaics using canopy texture analysis from contrasted acquisitions: towards a regional approach. *Ecological Applications*, 24, 1984–2001.
- Griffon, S., de Coligny, F., 2014. AMAPstudio: an editing and simulation software suite for plants architecture modelling. *Ecological Modelling*, 290 (1) : 3-10.
- Couteron, P., Barbier, N., Proisy, C., Péliissier, R., Vincent, G., 2012. Linking remote-sensing information to tropical forest structure: the crucial role of modelling. *Earthzine*, : 1-4.
- Vincent, G., Sabatier, D., Blanc, L., Chave, J., Weissenbacher, E., Péliissier, R., Fonty, E., Molino, J.-F., Couteron, P., 2012. Accuracy of small footprint airborne LiDAR in its predictions of tropical moist forest stand structure. *Remote Sensing of Environment*, 125 : 23–33.
- Barbier, N., Couteron, P., Gastellu-Etchegorry, J. P., Proisy, C., 2012. Linking canopy images to forest structural parameters: potential of a modeling framework. *Annals of Forest Science*, 69 (2): 305-311.
- Ploton, P., Péliissier, R., Proisy, C., Flavenot, T., Barbier, N., Raj, S. N., Couteron, P., 2012. Assessing above-ground tropical forest biomass using Google Earth canopy images. *Ecological Applications*, 22 (3): 993-1003.
- Barbier, N., Proisy, C., Vega, C., Sabatier, D., Couteron, P., 2011. Bidirectional texture function of metric resolution optical images of tropical forest: an approach using LiDAR hillshade simulations. *Remote Sensing of Environment*, 115: 167-179.
- Barbier, N., Couteron, P., Proisy, C., Malhi, Y., 2010. The variation of apparent crown size and canopy heterogeneity across lowland Amazonian forests. *Global ecology and biogeography*, 19 (1): 72-84.
- Barczy J, Rey H, Caraglio Y, De Reffye P, Barthélémy D, Qiao XD, Fourcaud T (2007) AMAPsim: an integrative whole-plant architecture simulator based on botanical knowledge. *Ann Bot* 101:1125–1138
- Proisy, C., Couteron, P., Fromard, F., 2007. Predicting and mapping mangrove biomass from canopy grain analysis using Fourier-based textural ordination (FOTO) of IKONOS images. *Remote Sensing of Environment*, 109: 379-392.
- Couteron, P., Péliissier, R., Nicolini, E., Paget, D., 2005. Predicting tropical forest stand structure parameters from Fourier transform of very high resolution canopy images. *Journal of Applied Ecology*, (42): 1121-1128.
- Couteron P. 2002. Quantifying change in patterned semi-arid vegetation by Fourier analysis of digitized aerial photographs. *int. j. remote sensing*, 23, 3407–3425.







DIAPO SUPPLÉMENTAIRES

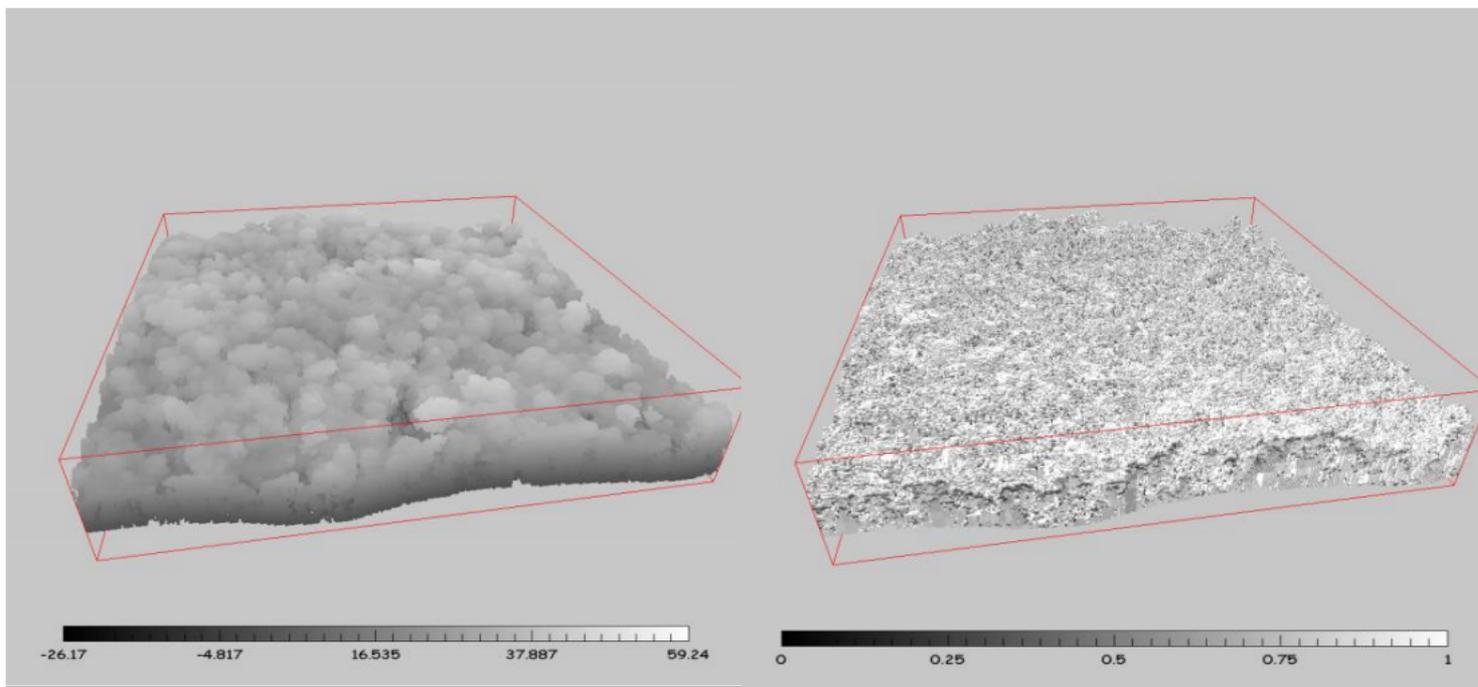


Figure 4: Views of the 300x300m forest area studied voxelised at one-m resolution. 4a: Voxels are colored according to height above ground (grey levels). 4b: voxels are colored according to their transmittance value (AMAPvox [http:// amap-dev.cirad.fr/projects/voxelidar/wiki/](http://amap-dev.cirad.fr/projects/voxelidar/wiki/))



INFLUENCE OF VOXEL RESOLUTION

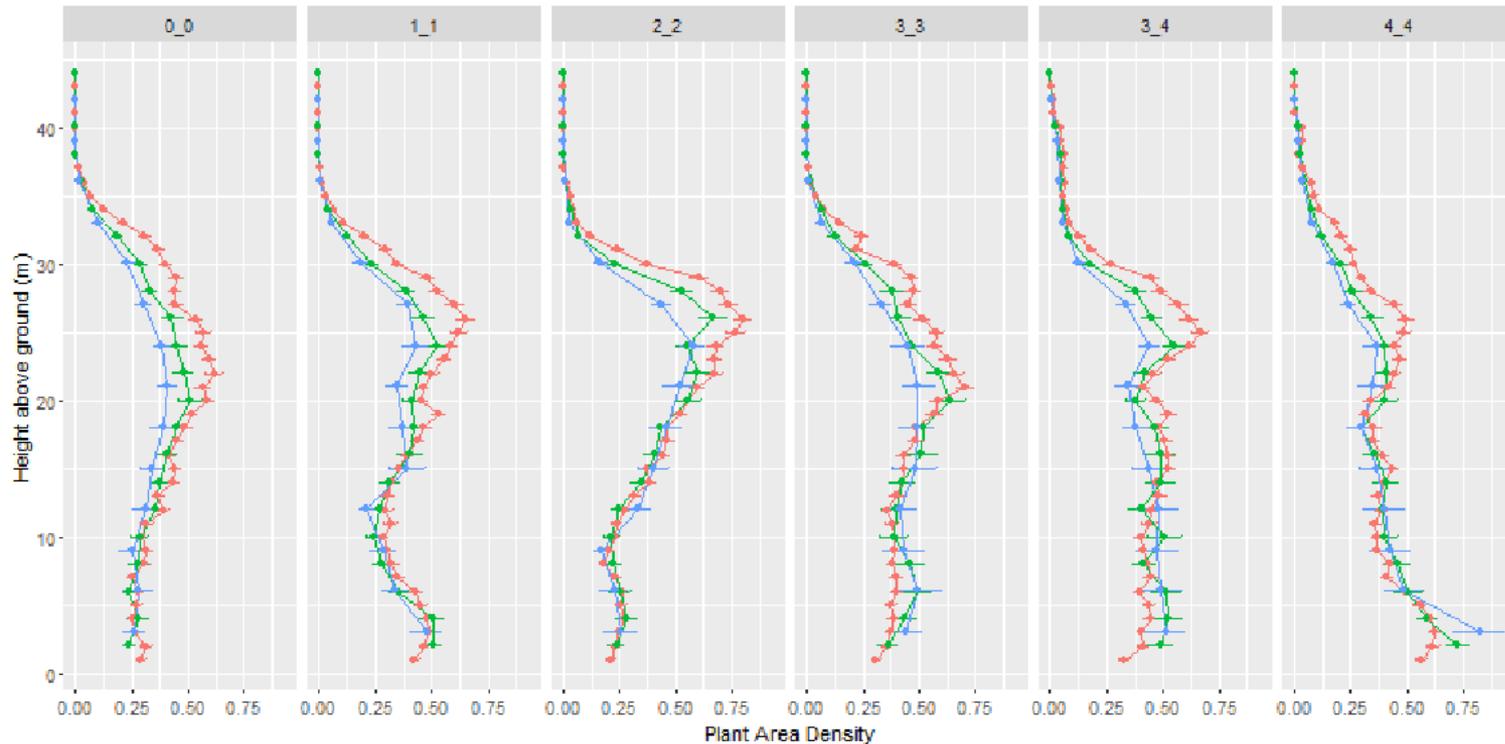


Figure 5: Vegetation profiles obtained from ALS at three voxel resolutions (red: 1m, green: 2m, blue: 3m) in 60x60m-plots of rainforest.

Mean Plant Area Index over 25 plots covering 9 ha is 14.0, 12.6 and 11.5 for resolutions 1 (red line), 2 (green line) and 3m (blue line).

Horizontal bars represent 95% confidence intervals.

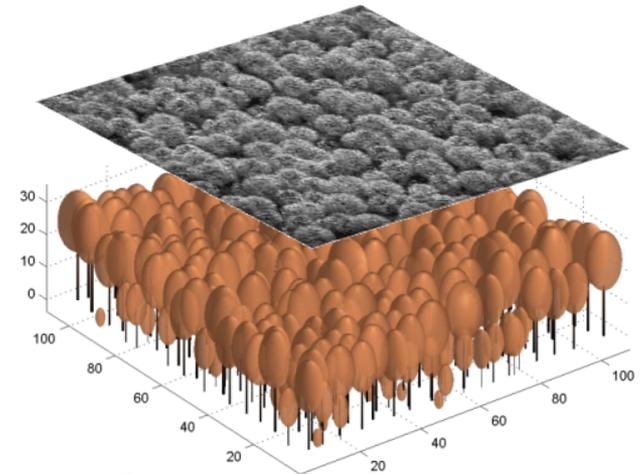


Hence, PAI values derived from LiDAR data and LAI2200 records differ by less than one unit PAI (5.9 and 6.8, Fig 9) before any adjustment is attempted. After adjusting local transmittance by modifying canopy transmittance per unit length by a fixed factor the discrepancy in PAI values estimated by LAI2200 measures (either simulated or actual) is reduced to 0.5 LAI unit ($PAI_{adjusted}=6.4$, Fig 9). Those estimates of PAI are however very different from PAI estimates obtained by vertical integration of local PAD in the focal plot (i.e. 13.6 without correction of transmittance and 13.2 after correction). The large discrepancy between PAI estimated using simulated LAI2200 measurements and nominal PAI in the 3D space illustrates the strong effect of clumping.

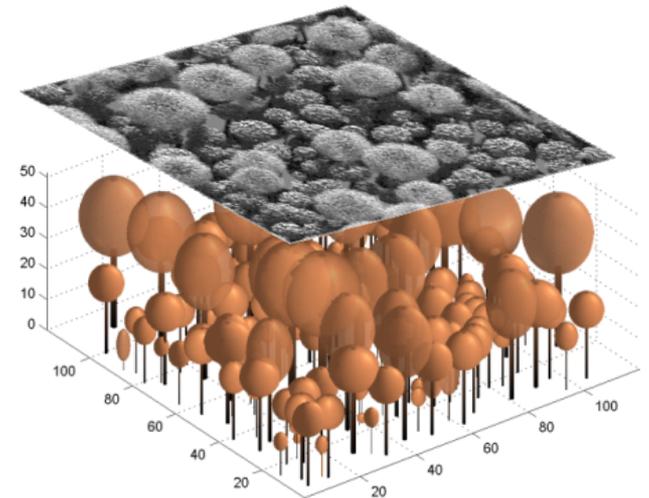


Benchmarking FOTO with virtual forest scenes

- Step 1 : simulation of 3D virtual stands of known parameters using forest models (Allostand, MesoFON, Stretch under Capsis platform, etc.)



- Step 2 : simulation of virtual satellite images using a Discrete Anisotropic Radiative Transfer model (DART)



SUPPLÉMENTAIRE

Masqué

De la transmittance à la densité surfacique de végétation

Entire canopy level :

$$P_{\text{gap}}(\theta) = e^{-k(\theta) \cdot \text{PAI} / \cos\theta} = e^{-G(\theta) \cdot \Omega \cdot \text{PAI} / \cos\theta}$$

Elementary volume of canopy:

$$P_{\text{gap}}(\theta) = e^{-G(\theta) \cdot \Omega \cdot \text{PAD} \cdot l}$$

- θ view angle
- $K(\theta)$ extinction coefficient
- $G(\theta)$ ratio of foliage area projected in direction θ to actual area
- Ω clumping factor
- PAD Plant area density
- l optical path length

