



HAL
open science

Développements récents en matière de modélisation à partir de données de Lidar aérien

Jean-Pierre Renaud, J. Bock, C. Vega, Laurent Saint-André, M. Bouvier, Sylvie Durrieu

► **To cite this version:**

Jean-Pierre Renaud, J. Bock, C. Vega, Laurent Saint-André, M. Bouvier, et al.. Développements récents en matière de modélisation à partir de données de Lidar aérien. CAQSI 2015, Computer-Aided Projection of Strategies In Silviculture (CAPSIS)., Apr 2015, Nancy, France. 38 p. hal-02801318

HAL Id: hal-02801318

<https://hal.inrae.fr/hal-02801318>

Submitted on 5 Jun 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Journées CAQSIG 2015 – Nancy - 7-9 avril 2015

Développements récents en matière de modélisation à partir de données de Lidar aérien

JP Renaud, J. Bock (*Dept RDI, ONF*)

C. Vega (*LIF, IGN*)

L. Saint-André (*BEF, INRA*)

M. Bouvier, S. Durrieu (*IRSTEA, TETIS*)



La Région
Lorraine

AGENCE NATIONALE DE LA RECHERCHE
ANR

Travaux Projet ANR Foresee :

Améliorer la précision des modèles Lidar aéroportés (G, V : env. 20-30%)

3 études récentes :

Revisite des approches « *placette* » / « *arbre* » ...

(André *et al.* 2015)

Vers plus de « *mécanisme* »...

(Bouvier *et al.* 2015)

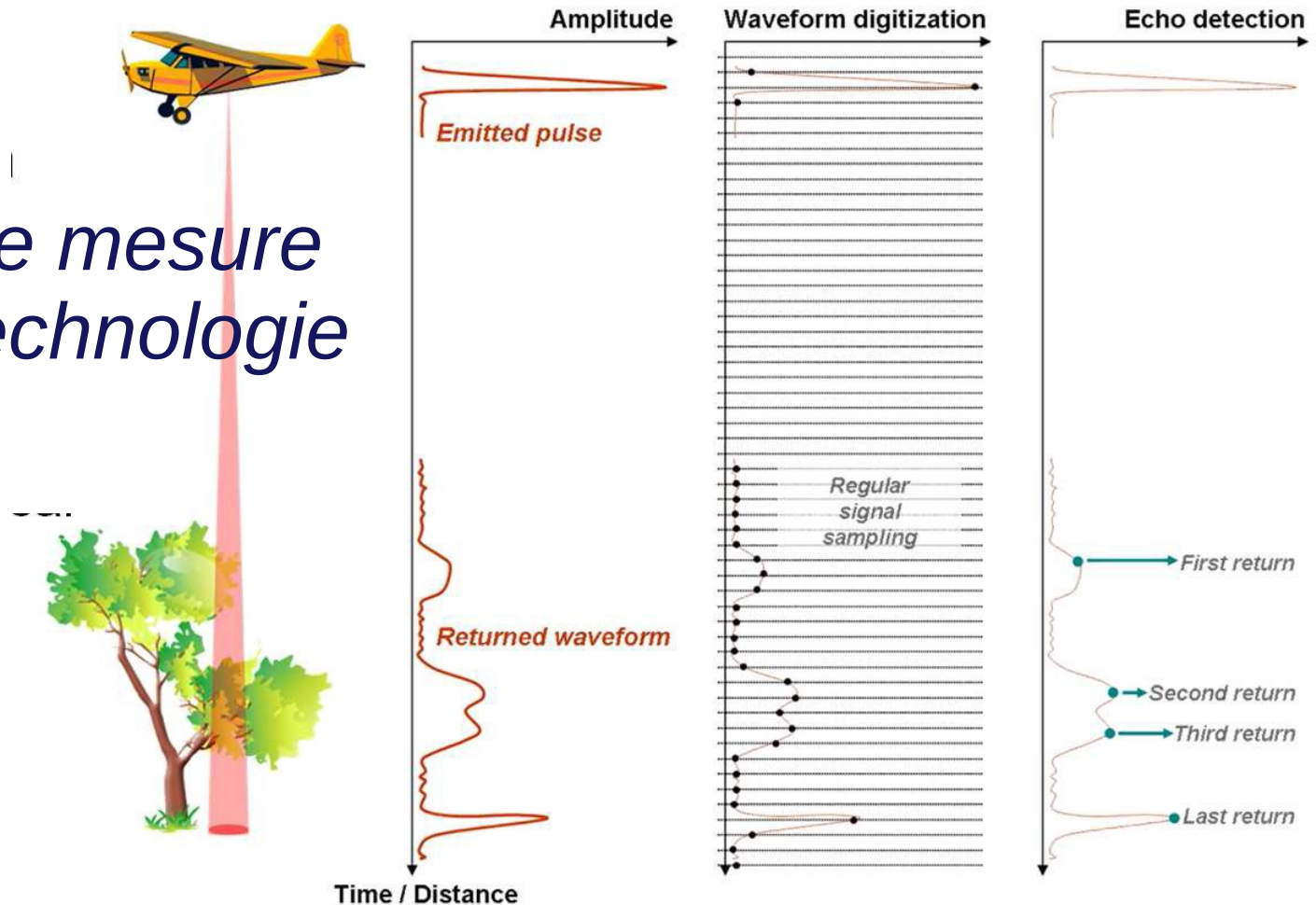
Revisite de la ...

(Véga *et al.* 2015) *pénétration du signal*

Vers l'intégration de notions dendrométriques dans les modèles...

INTRODUCTION

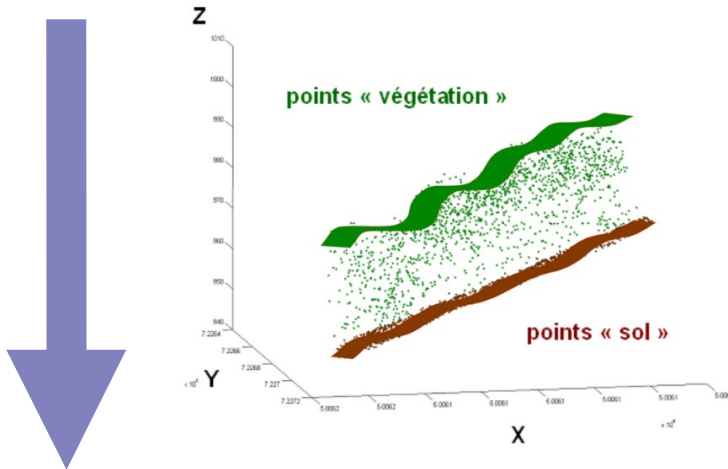
*Principe de mesure
de cette technologie
« active »*



(Durrieu *et al.* 2015)

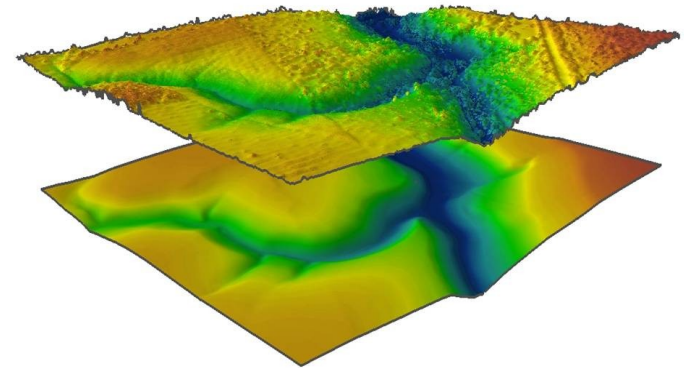
(premier paradigme = normalisation en H)

Normalisation du nuage

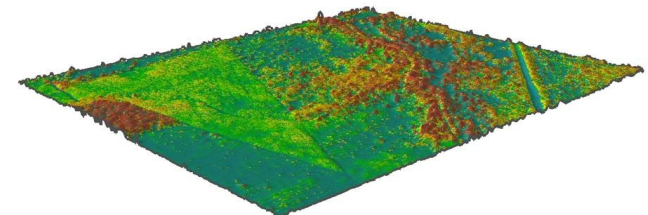


**Nuage de points en H
à partir du MNH**

MNS : Modèle numérique de surface



MNT : Modèle numérique de terrain

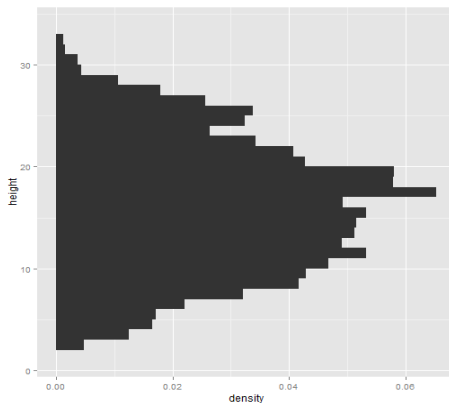


MNH: Modèle numérique de hauteur

2 Approches à partir du nuage : Distribution / Segmentation

Méthode standard: résume la placette en Déciles H et densité

Approche « distribution »



First / last / only / All

Hmax	---d9	---h95
	---d8	...
	---d7	
24m	---d6	---hm
	---d5	...
12m	---d5	---hp _{30%}
	---d4	---hp _{20%}
8m	---d3	---hp _{10%}
	---d2	---2m ou 1m
1m	---d1	
	---d0	

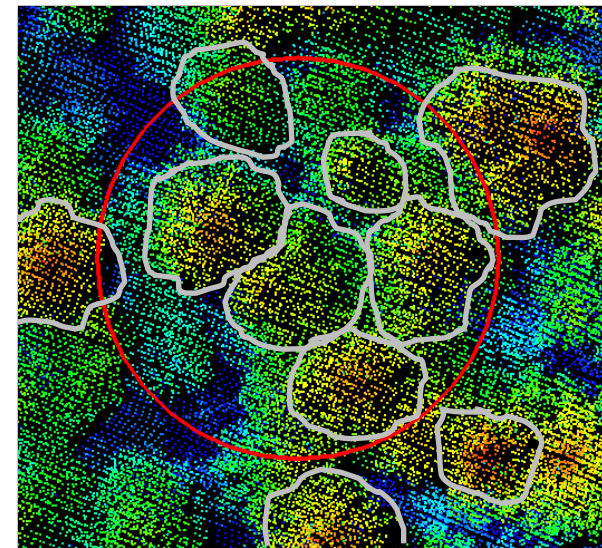
(Naesset 2002)

Avantage: - rapide ; peu sensible à la densité

Problème : - généricité (ppts / espèces)
- biais des H dans les pentes

Méthode de segmentation

Approche « *arbre* »



Avantage: - plus proche du terrain

Problème : - Forte densité requise
- biaisée (qualité segmentation)
- allométrie liée aux espèces

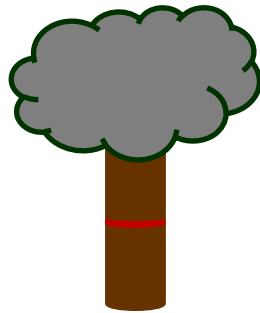
(lourd)

Hyp. : Etude André et al.

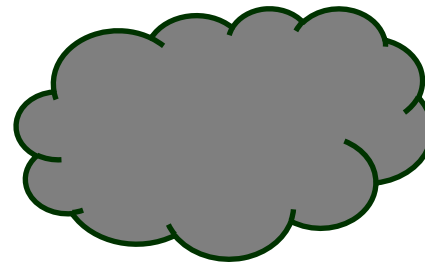
**La méthode standard (1D) , ne rend pas bien compte
de la structure des peuplements**

(info spatiale?)

**La combinaison des approches (std + seg.) permet
d'améliorer les estimations au niveau placette**

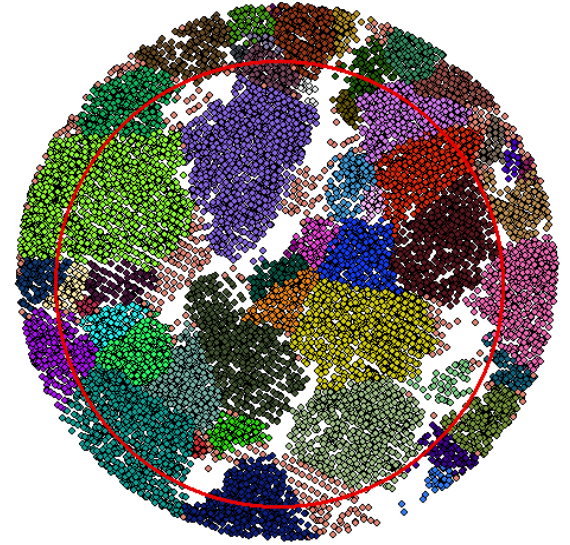
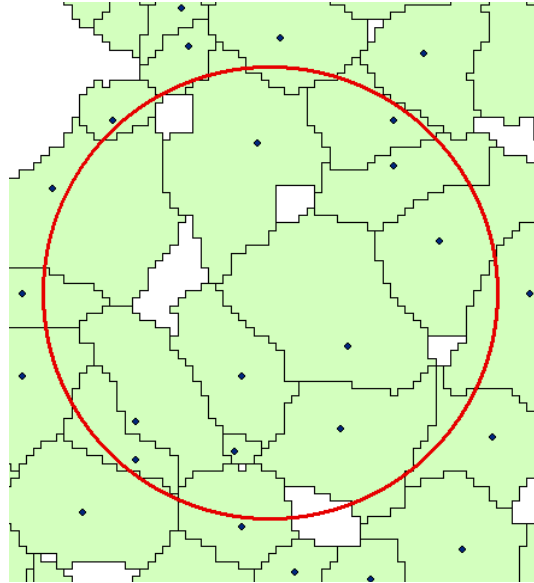
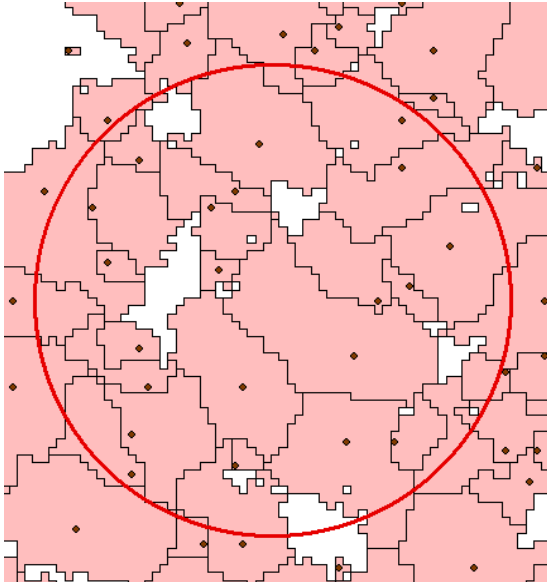


G



f(H ; A)

3 méthodes de segmentation :



Ptrees (Véga et al. 2014)

Qualité de la détection des arbres

Méthode	N arbres	Recall	Exactitude
BVv1	670	81%	42%
BVv2	670	72%	72%
P	670	82%	89%

*Pas beaucoup
d'omis*

*Pas beaucoup de
fausses
détectons*

Résultats :

Variable	Formule	R ² a	AIC	Erreur.cv	%Erreur.cv
H0	Std_H90_1st	0.98	85	1.0	3.7
	Std_H80_1st + Std_d3_fst	0.99	77	0.9	3.2

Variable	Formule	R ² a	AIC	Erreur.cv	%Erreur.cv
G	BVf1m1_H.A.sum	0.83	225	7.6	27.0
	BVf1m1_H.A.sum + BVf1m2_H.Q5	0.87	216	7.3	25.9
	Std_H40_fst + Std_Tp.8 + BVf1m1_H.A.sum	0.91	206	5.8	20.7
Vtot	BVf1m1_H.A.sum	0.87	409	117.0	27.9
	Std_Tp.8 + BVf2m1_H.A.sum	0.92	393	91.9	21.9
	Std_N.24m + Std_Tp.82 + BVf1m2_A.Q99	0.95	379	76.9	18.3
V7	BVf1m1_H.A.sum	0.85	408	116.0	32.0
	Std_Nr.24m + BVf1m2_A.Q99	0.93	385	83.4	23.0
	Std_N.24m + Std_Tp.8 + BVf1m2_A.Q99	0.96	368	68.0	18.8

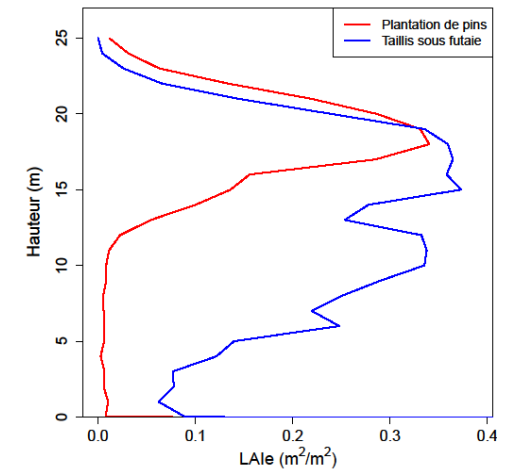
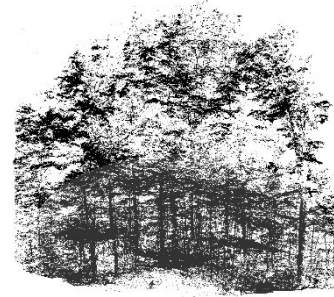
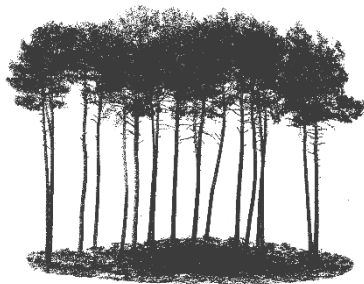
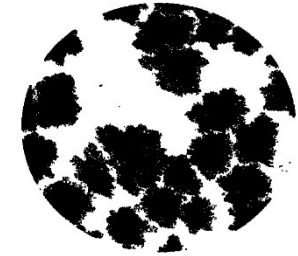
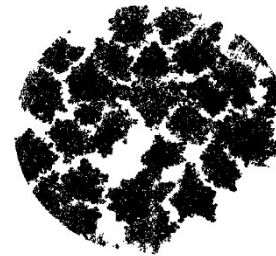
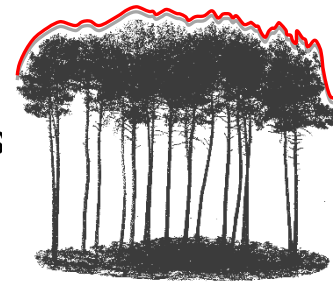
G ou \sim Sum()

V
Modèles à 3 variables : RMSE de 18 – 21%

Plus « mécaniste »... (Bouvier *et al.* 2015)

4 variables ont été identifiées pour décrire:

- La hauteur du peuplement
 - *Moyenne de l'altitude des premiers échos*
- L'hétérogénéité verticale
 - *Variance de l'altitude des premiers échos*
- La distribution horizontale du couvert
 - *Proportion d'échos au dessus de 2 m*
- La présence d'arbres dominés
 - Coefficient de variation du profil de densité foliaire

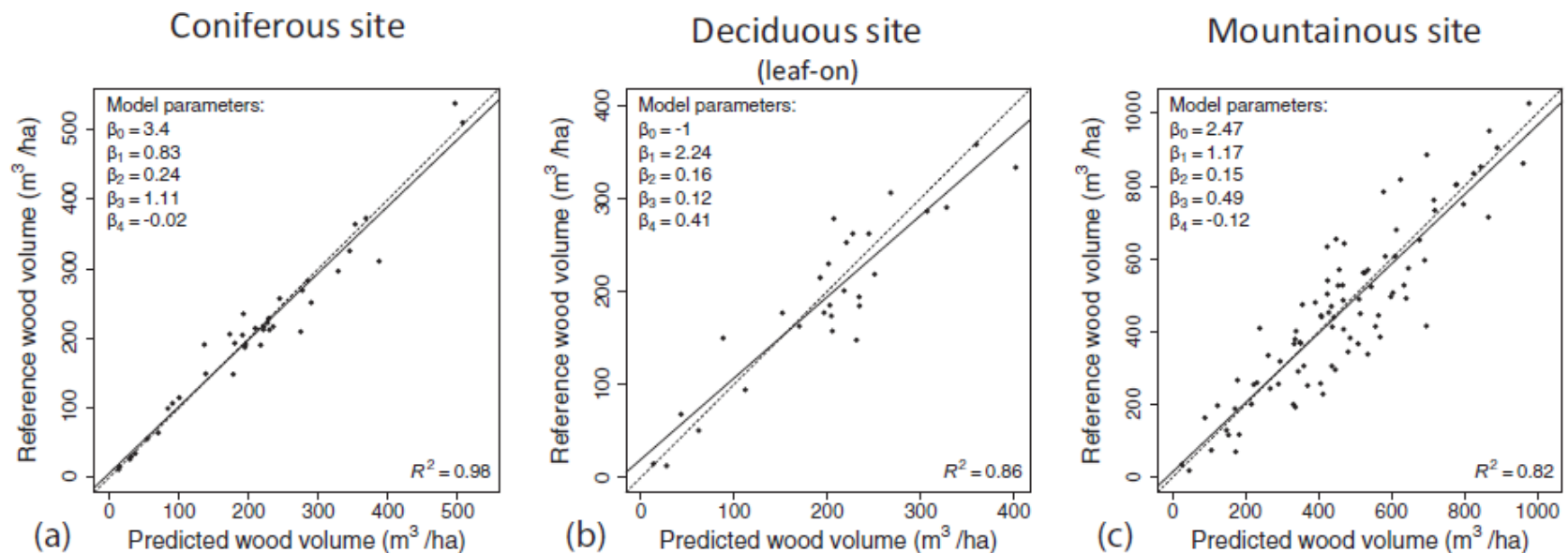


$$\hat{y} = \beta_0 \mu_{CH}^{\beta_1} \sigma_{CH}^{2\beta_2} P_f^{\beta_3} C v_{LAD}^{\beta_4}$$

Résultats :

Précision de 12.4% à 24.2%

Avantage d'avoir une seule forme de modèle à paramétrer par site/vol lidar



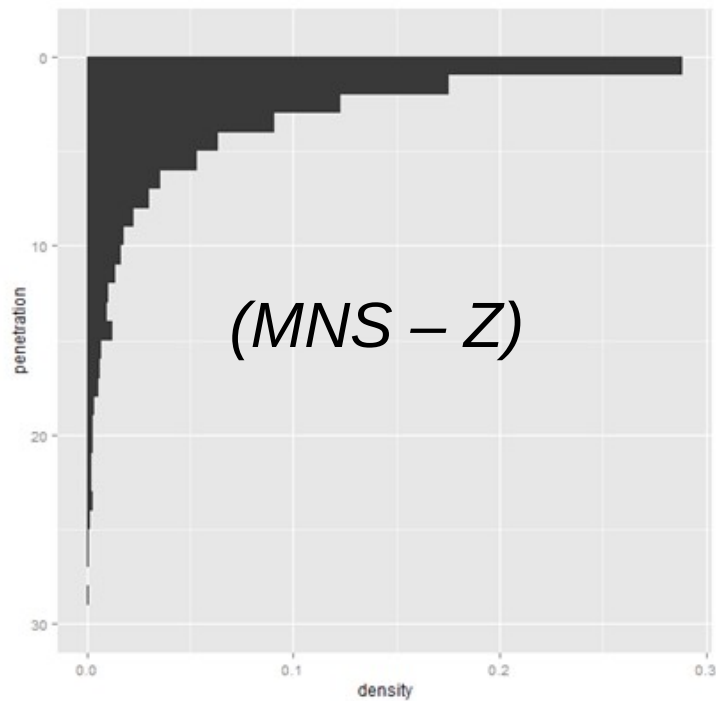
*Pour le calcul de la pénétration du signal dans la canopée, elle ajoute un biais lié à **l'hétérogénéité structurelle** (p.ex. trouées)*

La solution : ne pas la faire !

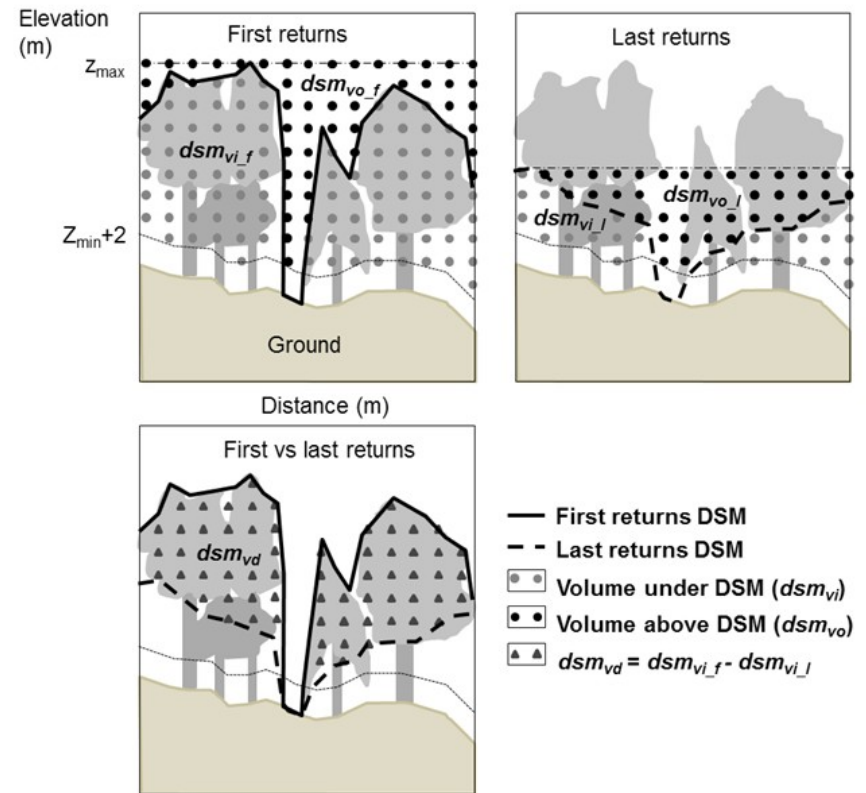
passer par le MNS pour calculer cette pénétration à travers la canopée!

(Véga et al. 2015)

La vraie pénétration se calcule à partir du MNS !



... d'autres métriques liées à la structure 3D des pts



Résultats pour G :

Site	Metrics	Formula	Raster cell size (m)	RMSE _{cv} (m ² .ha ⁻¹)	rRMSE _{cv} (%)	R ² adj
All	All	$p_{d5v_l} + p_{d5f_f} + p_{rim3_a} + dsm_{vr_f} + dsm_{vi_l}$	mean	9.18	26.83	0.64
	p/DSM	$p_{d5v_l} + p_{d5f_f} + p_{rim3_a} + dsm_{vr_f} + dsm_{vi_l}$	mean	9.18	26.83	0.64
Bure	All	$h_{lm4_l} + h_{vd} + p_{10_f} + p_{40_l} + p_{d5v_l}$	mean	1.14	6.09	0.98
	p/DSM	$p_{40_f} + p_{40_l} + p_{d3f_l} + p_{lm3_f}$	0.5	1.93	10.27	0.94
	h/CHM	$h_{lm3_f} + h_{lm5_l}$	0.5	4.83	25.67	0.67
Aillon	All	$h_{d9v_l} + p_{d4f_f} + p_{cm2_f} + dsm_{ra_l} + dsm_{vd}$	0.5-HF	5.75	12.83	0.76
	p/DSM	$p_{d9v_l} + p_{d4f_f} + p_{cm2_f} + dsm_{ra_l} + dsm_{vd}$	0.5-HF	6.21	13.86	0.72
	h/CHM	$h_{d9v_l} + h_{d4f_f} + h_{cm4_a} + h_{ra_l} + h_{vd}$	0.5-HF	6.62	14.76	0.69
Vercors	All	$p_{10_l} + p_{d9v_a} + p_{d5f_f} + p_{gap_f} + dsm_{vd}$	mean	8.59	22.95	0.69
	p/DSM	$p_{10_l} + p_{d9v_a} + p_{d5f_f} + p_{gap_f} + dsm_{vd}$	mean	8.59	22.95	0.69
	h/CHM	chm_{vi_f}	0.5-HF	9.61	25.65	0.61
Landes	All	$h_{d5v_a} + h_{d3f_f} + chm_{vo_f} + p_{lm3_a} + p_{cm5_l}$	2	1.97	8.11	0.92
	h/CHM	$h_{d5v_a} + h_{d3f_f} + h_{d5f_f} + h_{cm2_l} + chm_{vo_f}$	1	2.15	8.89	0.90
	p/DSM	$p_{d3f_a} + p_{gap_f} + p_{rm5_l} + dsm_{vo_f} + dsm_{ra_l}$	1	2.86	11.07	0.84

Gain en précision d'un facteur 4!

Vers l'intégration de notions dendrométriques ...

LIDAR (H)

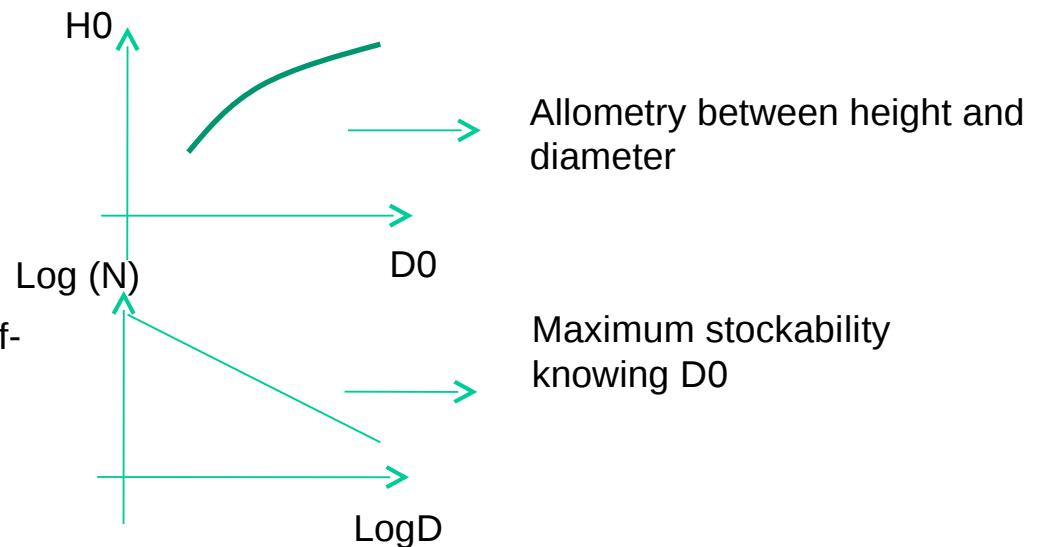
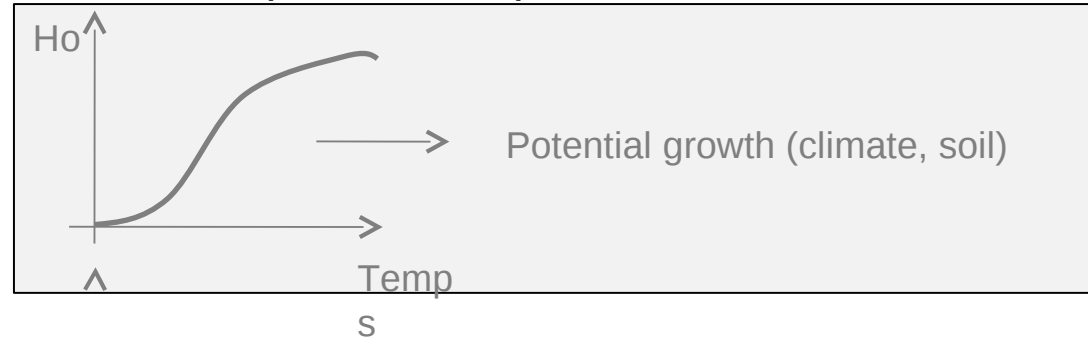
↓
Ho Dominant height

↓
D0 Dominant diameter

↓
Nmax and Gmax from the self-thinning law

↓
Gratio (G/Gmax) predicted from the canopy 3D

Séries temporelles de photos



LIDAR (3D forest structure)

Quelques exemples variés :

Estimateur de post-stratification pour les inventaire ...

(Stepper *et al.* 2015, Renaud *et al.* 2015)

Séries temporelles de prises de vues aériennes ... et indice de fertilité

(Véga et St-Onge 2005, 2008, 2009)

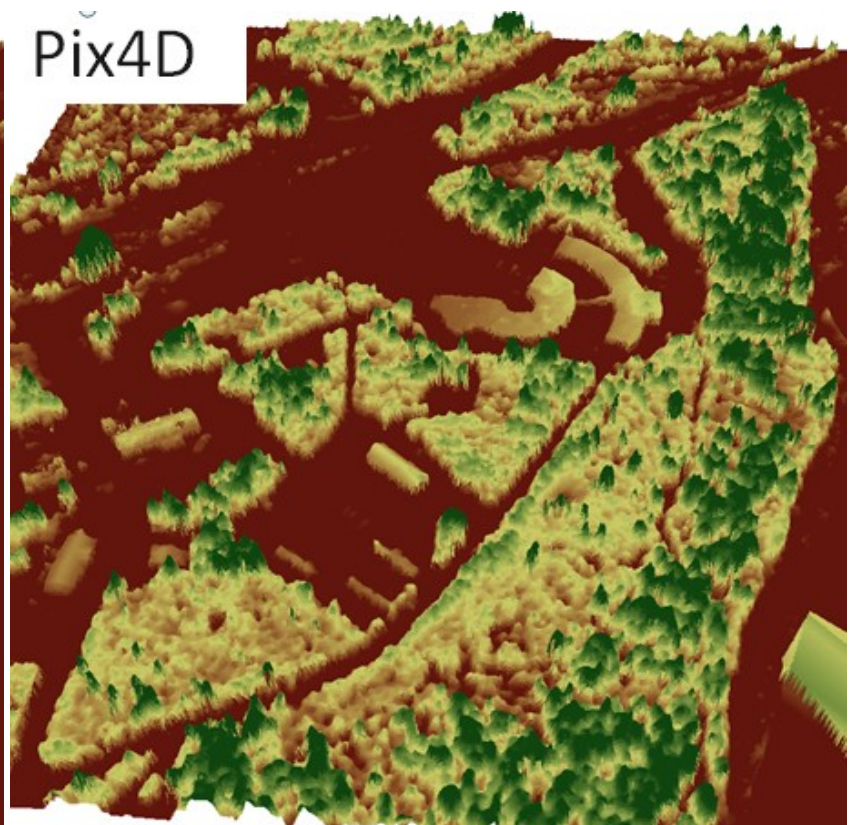
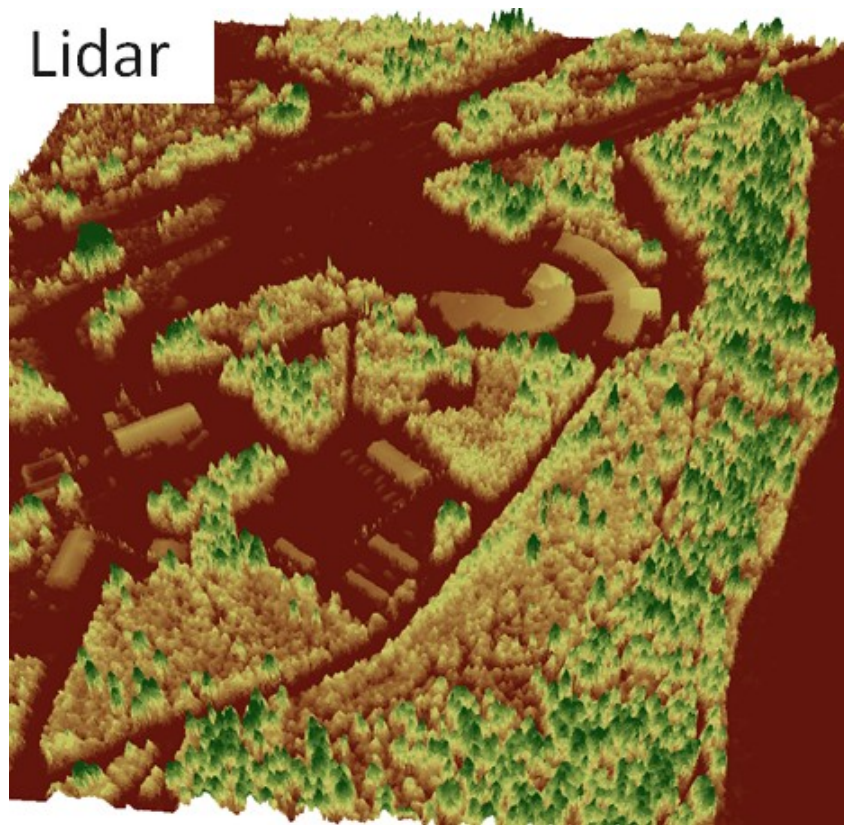
Estimation des dégâts de tempêtes

(Honkavaara *et al.* 2013)

Estimation des prélèvements ...! Cost Usewood (Bauerhansl *et al.* 2014)

Les MNH photogrammétriques, l'avenir du Lidar?

Des outils performant de production de MNH existent...
et ouvrent la porte à des mesures de hauteurs à grande échelle...



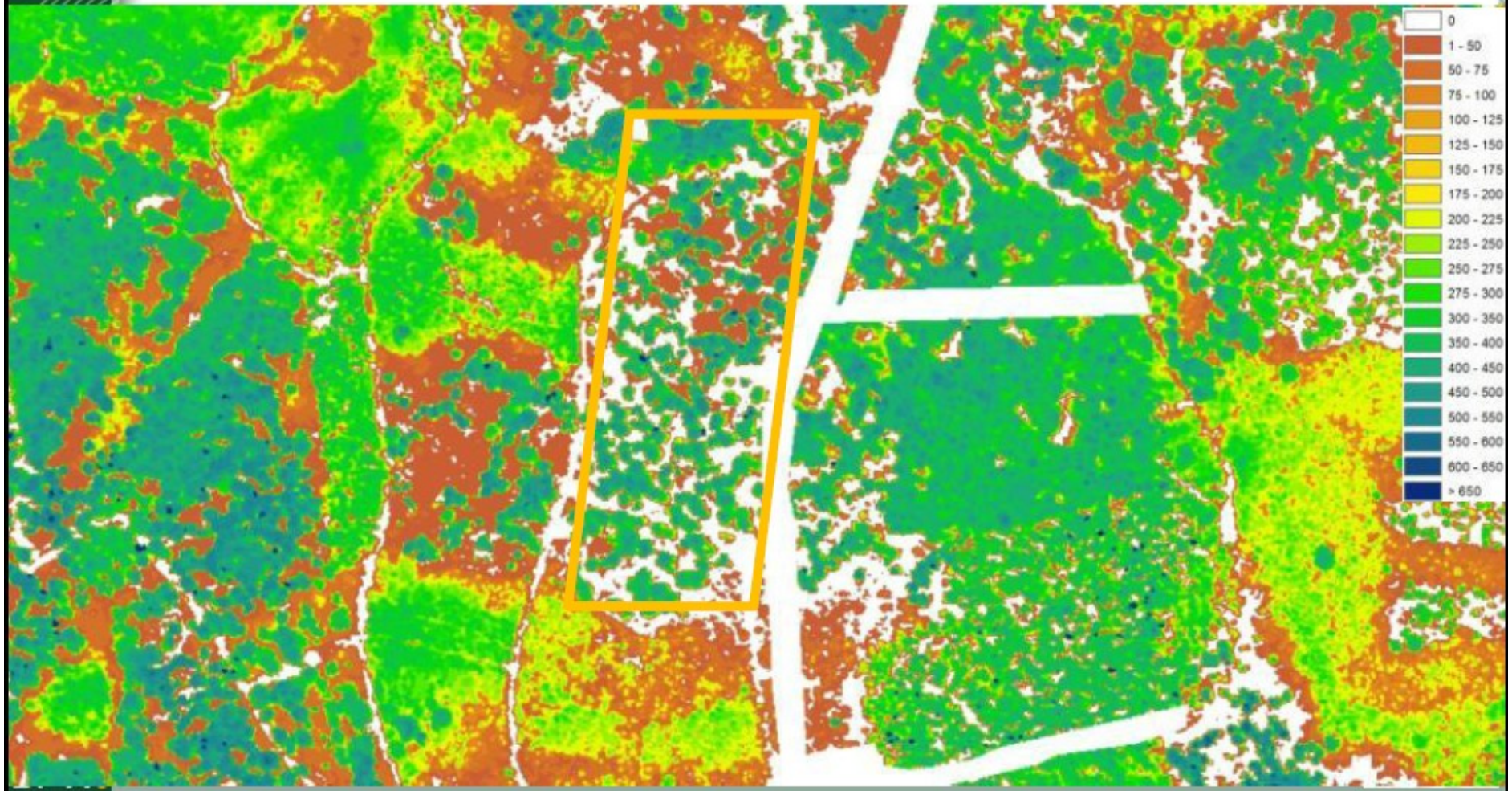
(St-Onge 2015)



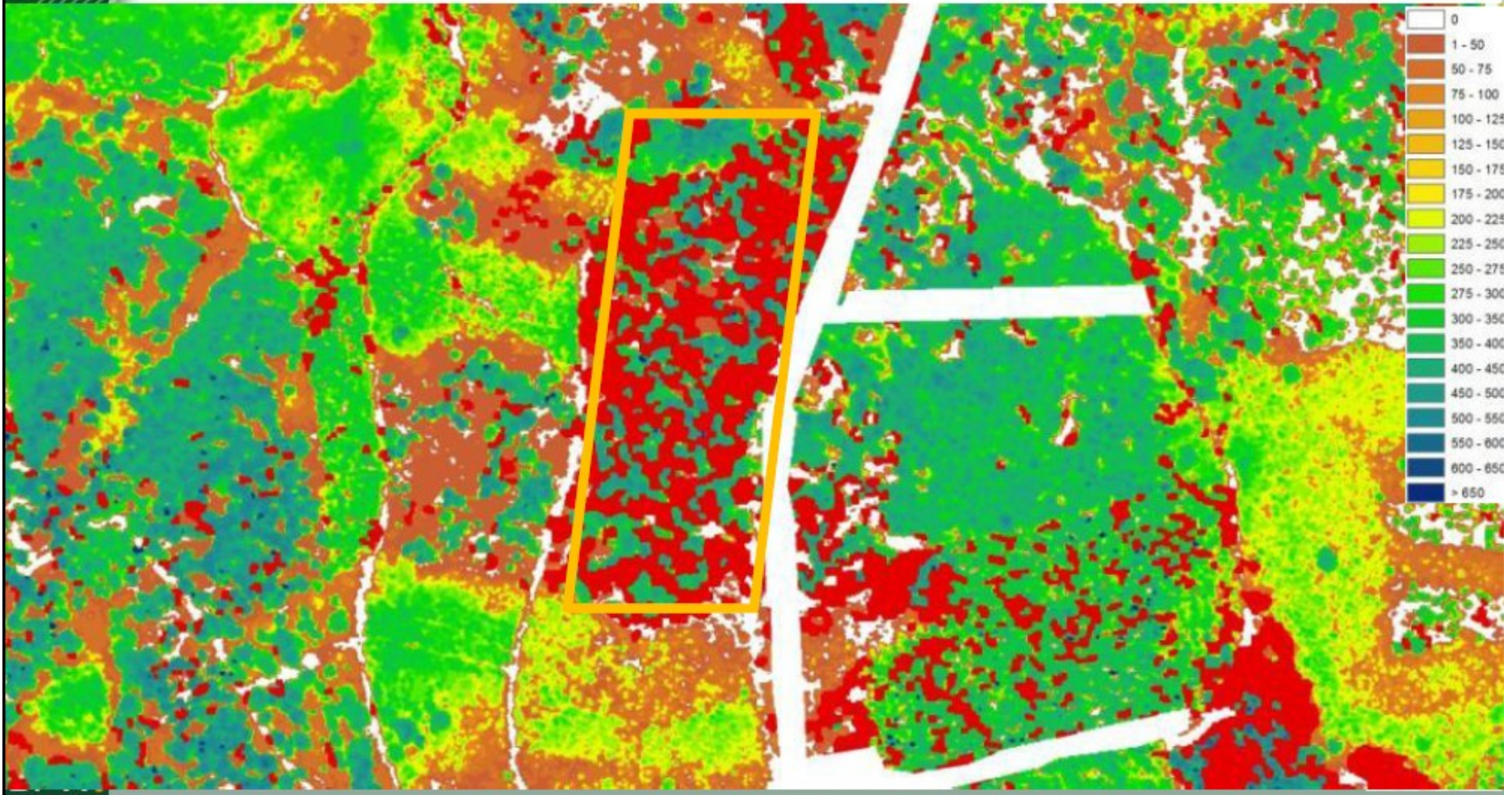
Volumes estimés à partir de MNH photogrammétriques

(Bauerhansl, Schadauer and Hollaus 2014)

Volume map 2013



Volume map 2013 with fellings areas





Journées CAQSIG 2015 – Nancy - 7-9 avril 2015

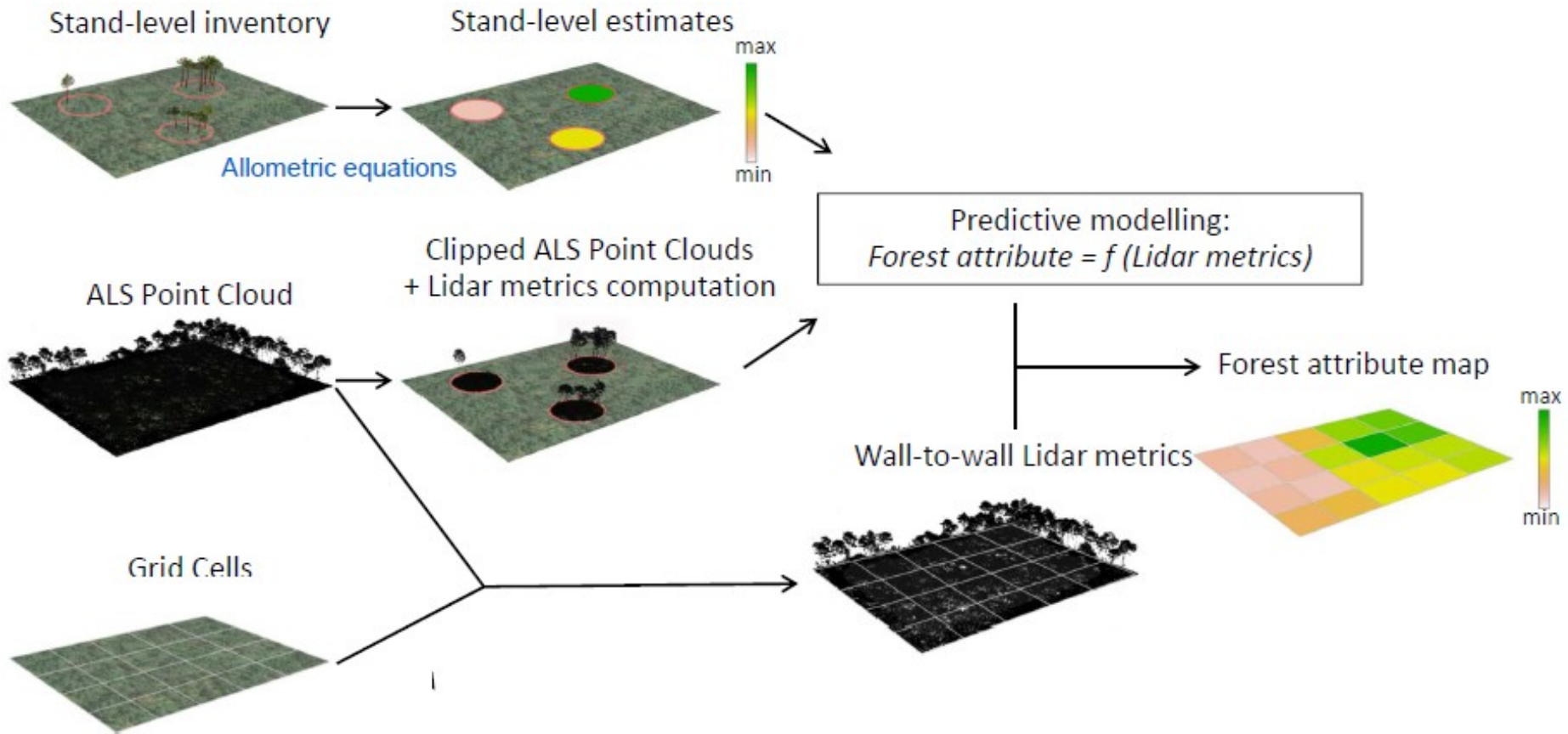
***Merci
de
votre
Attention !***



La Région
Lorraine

AGENCE NATIONALE DE LA RECHERCHE
ANR

Schéma de la cartographie d'attributs forestiers par l'approche de « distribution »

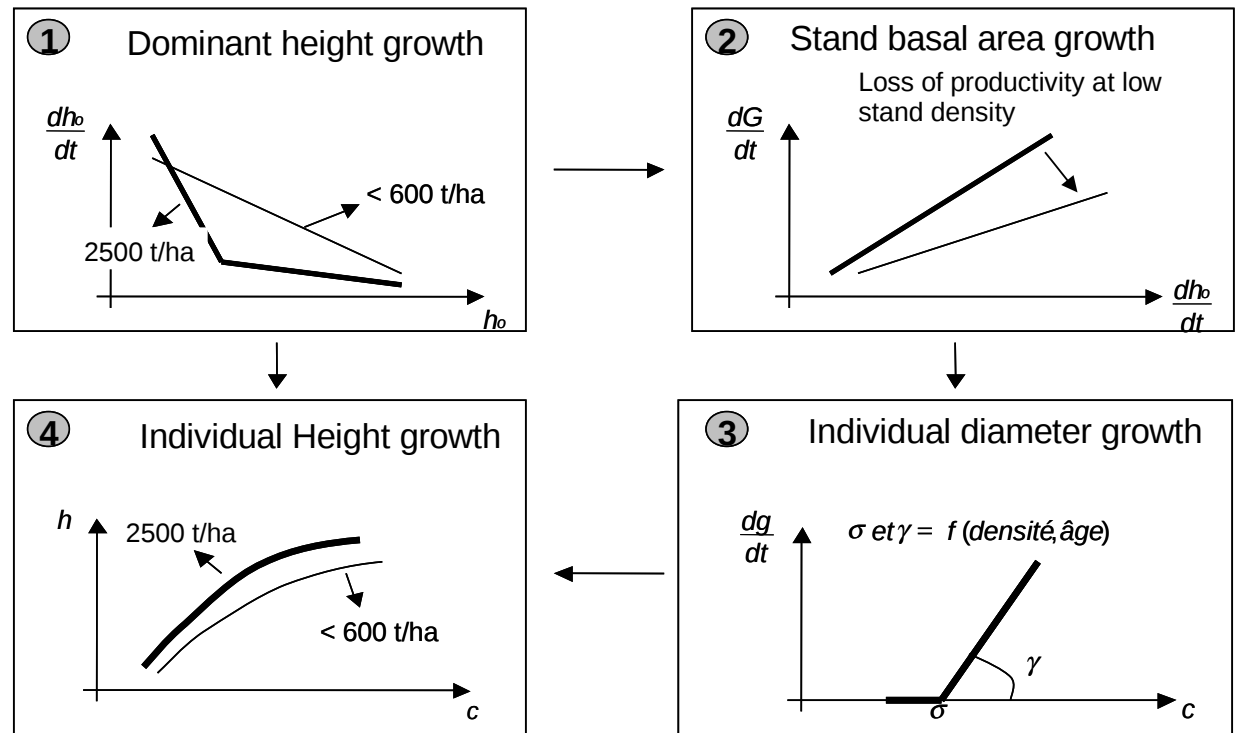


(Bouvier 2015)

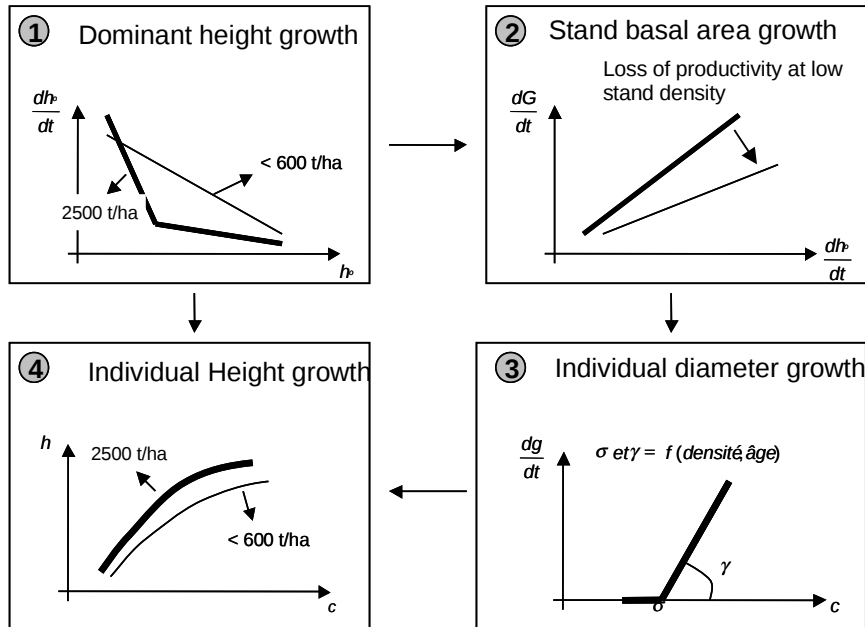
Growth and Yield Theory

A robust approach to assess tree and stand growth

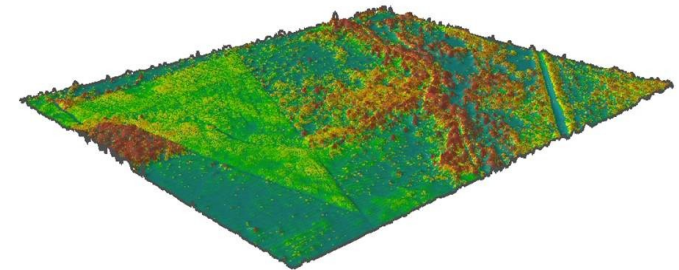
Where forest attributes are interrelated in a comprehensive way



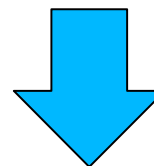
Growth and Yield Models



LIDAR Data sets



MNH: Modèle numérique de hauteur



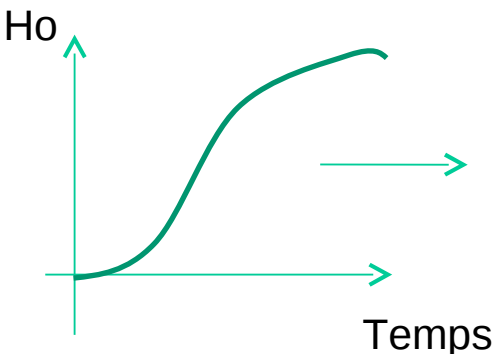
Hypothesis – Combining the strength of each approach will improve the prediction of forest stand attributes from Aerial LIDAR campaigns

01

Methodological issues and flowchart diagram

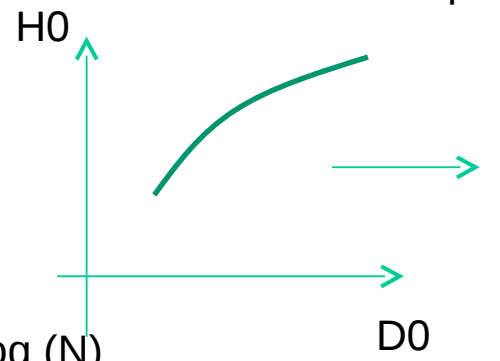
LIDAR (H)
↓
Ho Dominant height

Chosen approach



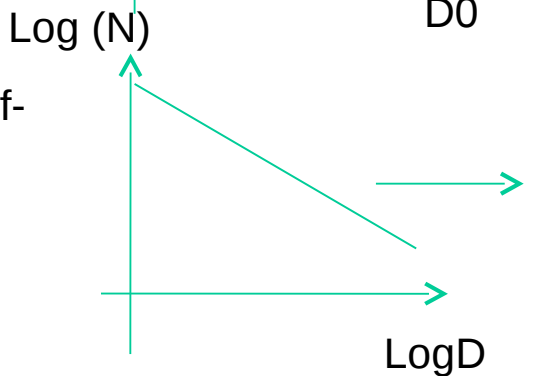
Potential growth (climate, soil)

D0 Dominant diameter



Allometry between height and diameter

Nmax and Gmax from the self-thinning law



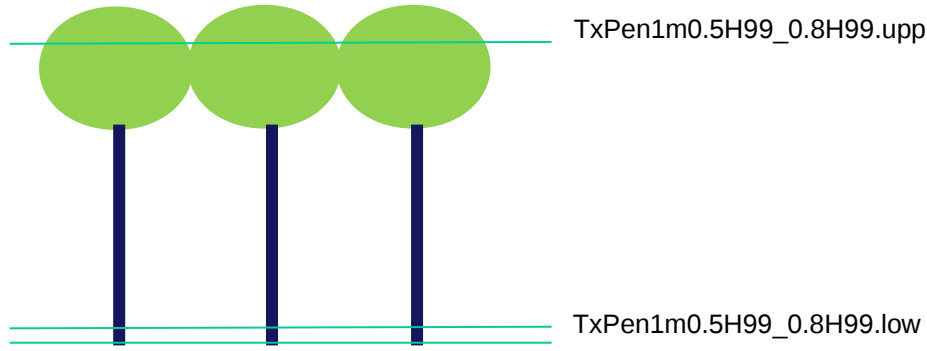
Maximum stockability knowing D0

Gratio (G/Gmax) predicted from the canopy 3D

LIDAR (3D forest structure)

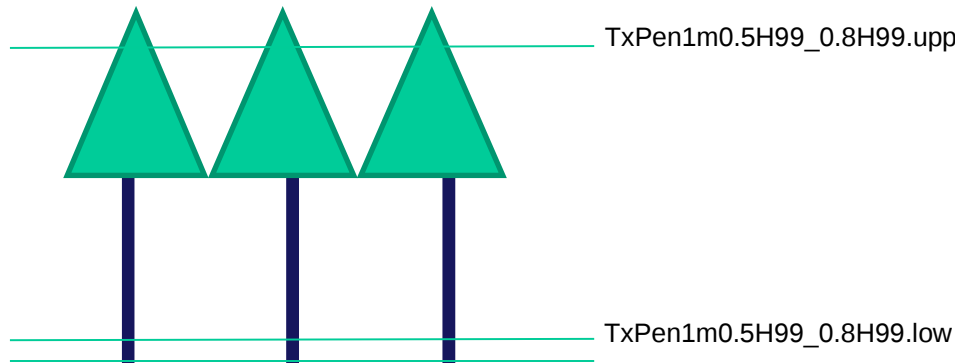
Feuil = TxPen1m0.5H99_0.8H99.low-TxPen1m0.5H99_0.8H99.upp

Some new metrics

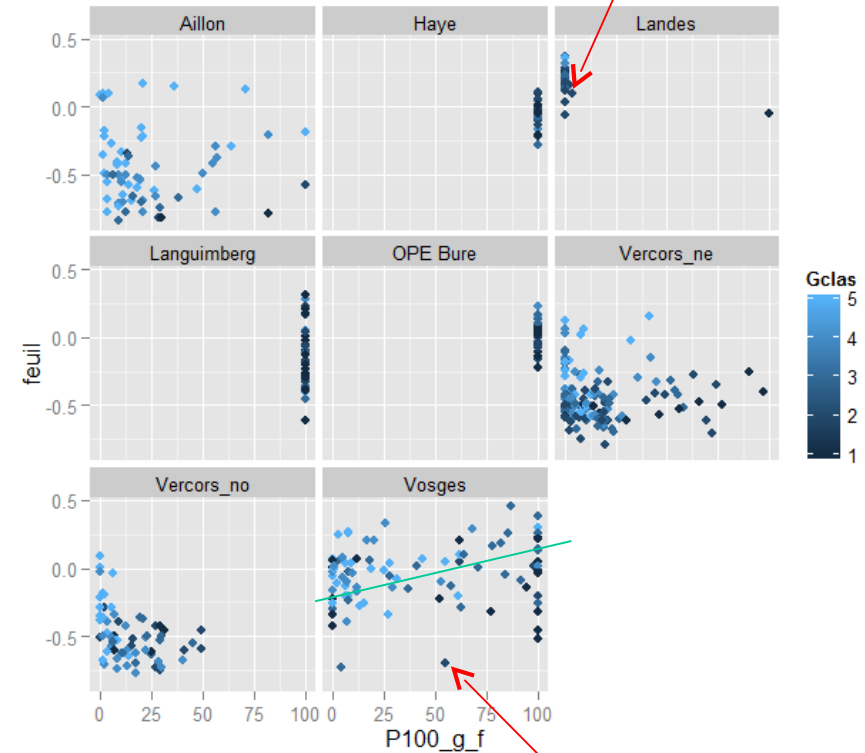


For broadleaves, *Feuil* tends to be **centered on zero** (rapid extinction of the signal)

For coniferous, *Feuil* tends to be **negative** (lower extinction of the signal due to the canopy structure)



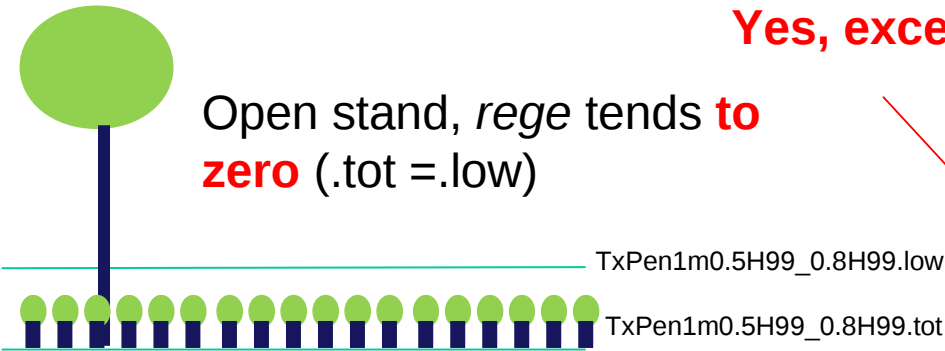
It works except for the Landes (looks like broadleaves).....



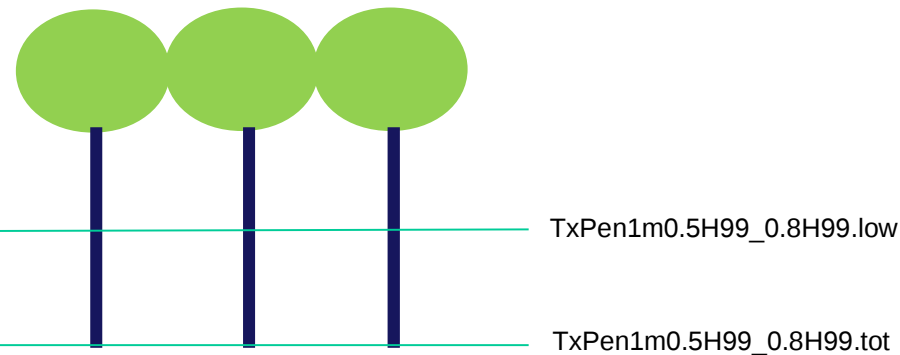
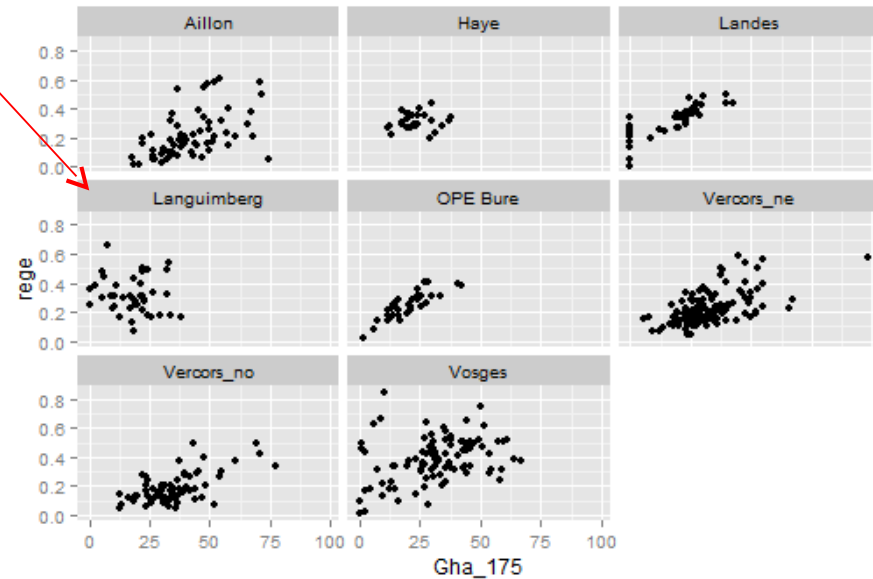
Confirmation that the Vosges case study is general enough (range from pure coniferous to pure broadleaves forests)

$$\text{rege} = \text{TxPen1m0.5H99_0.8H99.low} - \text{TxPen1m0.5H99_0.8H99.tot}$$

Some new metrics



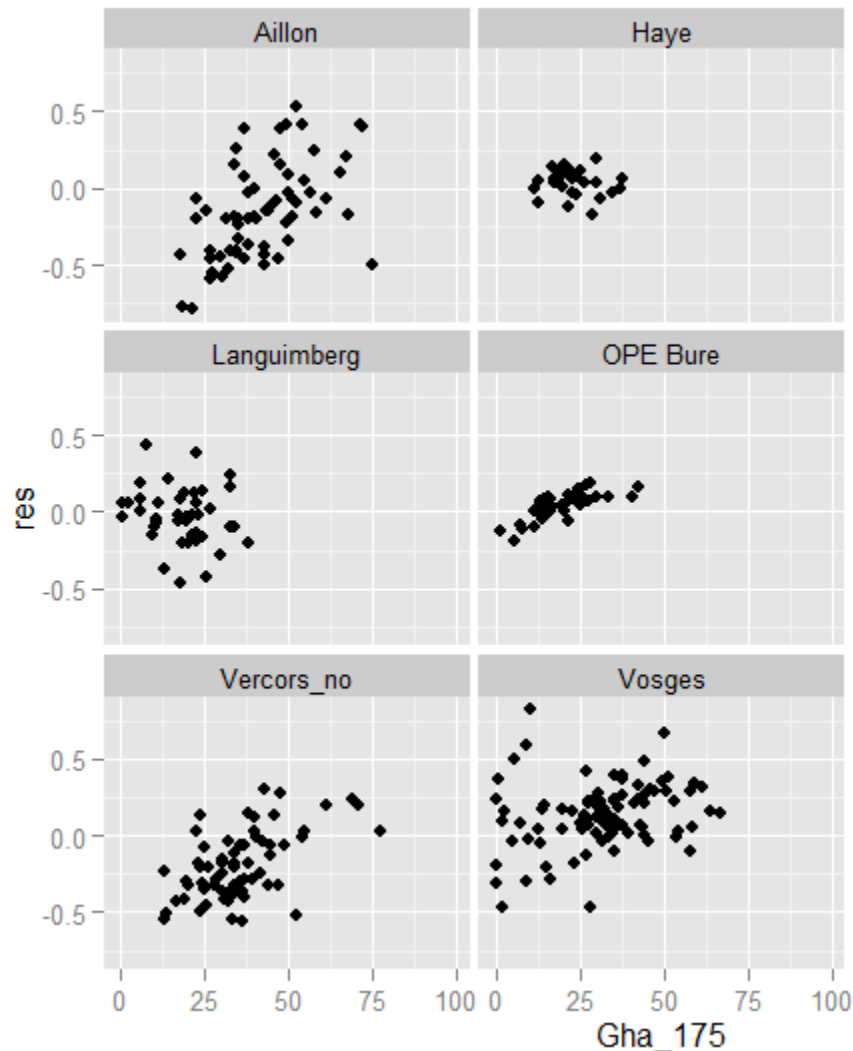
Yes, except Languimberg.....



Close stand, *rege* **increases**
because .tot is close to zero

Res = TxPen1m0.5H99_0.8H99.low-TxPen1m0.5H99_0.8H99.int

Some new metrics



Linear relationship
between *Res* and
the stand basal area

**Yes except Vosges.....
(outliers?), Haye et
Languimberg (Broadleaves)**

Different slopes between sites

02

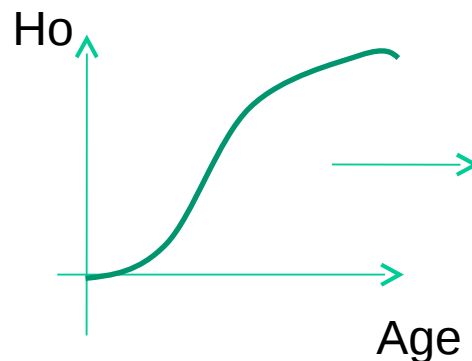
Results

STEP1

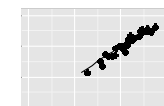
LIDAR



Ho Dominant Height



Potential growth (climate, soil)



Call:
Hmv6_Bd corrected with « slope » (technical correction),
 and « rege » (stands with few big trees)

```
Formula: H0 ~ a1 + a2 * Pente_plac + (b1 + b2 * rege) * Hmv6_Bd
```

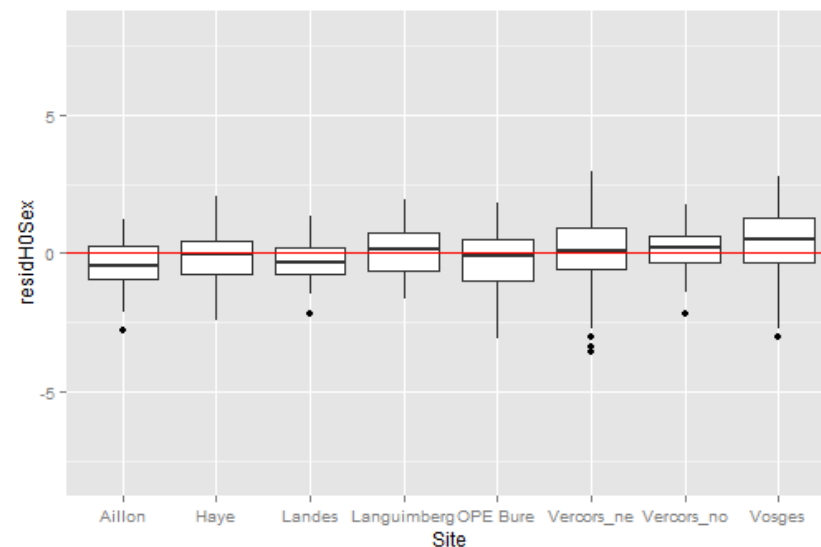
Parameters:

	Estimate	Std. Error	t value	Pr(> t)	
a1	1.49446	0.28288	5.283	2.36e-07	***
a2	-0.02700	0.00285	-9.475	< 2e-16	***
b1	0.92135	0.01242	74.216	< 2e-16	***
b2	0.12291	0.01817	6.764	6.46e-11	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: **1.18** on 318 degrees of freedom

Multiple R-squared: **0.9595** Adjusted R-squared: **0.9594**



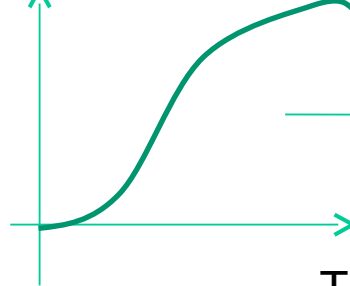
Interaction between rege and Hmv6

LIDAR



Ho hauteur dominante

Ho

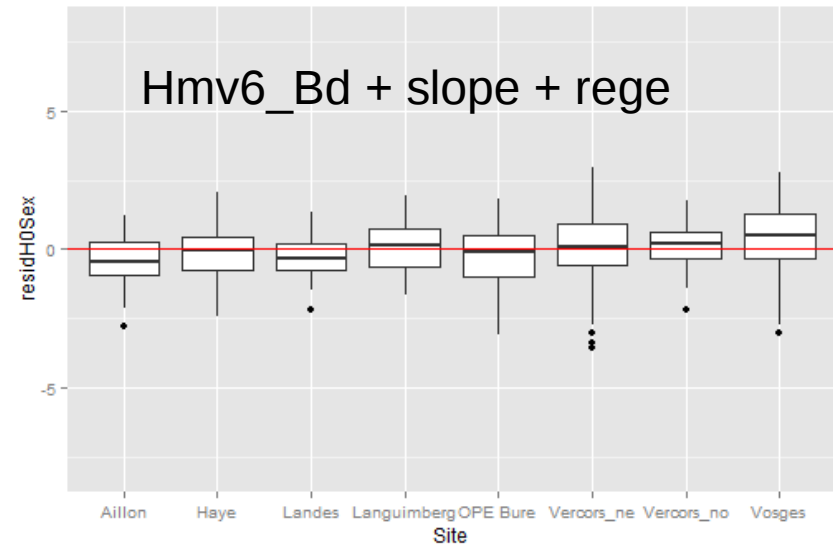
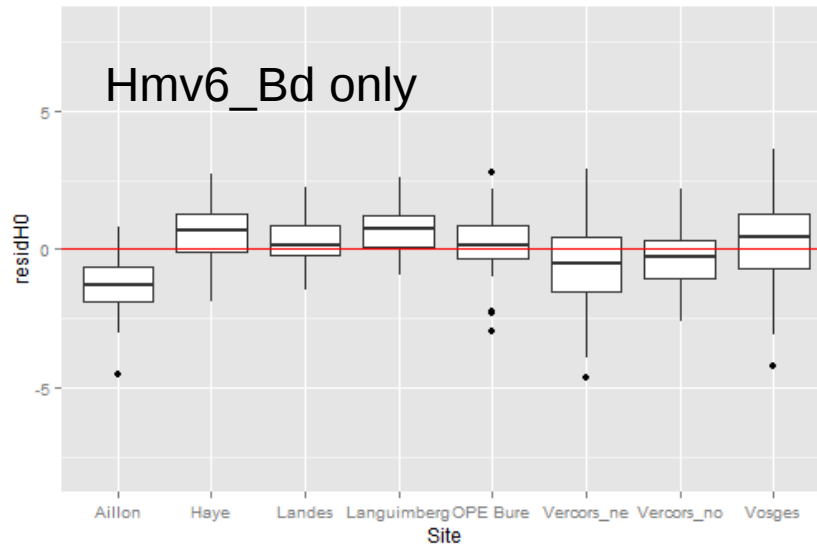


Potentiel du milieu (climat, sol)

Temps

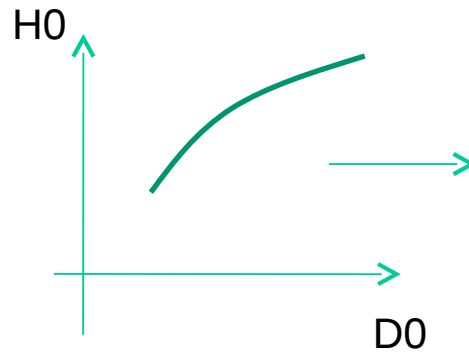
STEP1

Model used for the rest of the study : **Hmv6_Bd**, corrected with « slope » (technical correction), and « rege » (stands with few big trees)

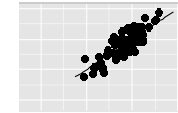


STEP2

D0 Dominant diameter



Allometry between height and diameter



Call:

predH0sex, + intercept function of « res »
 (account for stand density effect – the higher “res” is,
 the lower is D0 at a given H0)

Nonlinear mixed-effects model fit by maximum likelihood

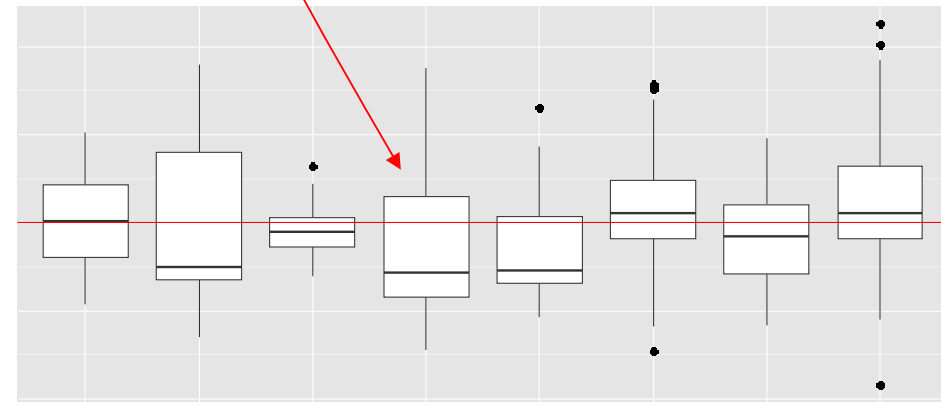
Model: $D0 \sim (d1 * res + e * predH0Sex)$

	Value	Std.Error	DF	t-value	p-value
d1	-8.310254	1.2078235	509	-6.88035	0
e	1.801105	0.0113343	509	158.90800	0

Residual standard error: **6.506** on 509 degrees of freedom

Multiple R-squared: **0.6863**, Adjusted R-squared: **0.6857**

No significant bias, but a clear pattern for Languimberg



Nmax and Gmax from the self-thinning law

STEP3

Maximum stockability knowing D0

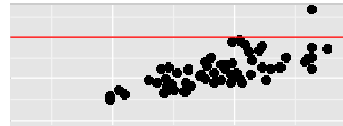
Log (N)

LogD

		rdi_a	rdi_b		rdi_a	rdi_b
Pubescent	oak	12.27	-1.809	A.F	12.50975	-1.85475
Pedunculate	oak	12.138	-1.758	AUL	12.50975	-1.85475
Sessile	oak	12.681	-1.911	BOU	12.50975	-1.85475
Common	beech	12.95	-1.941	CED	12.3472857	-1.73757143
Scots	pine	11.993	-1.615	CHA	12.50975	-1.85475
Aleppo	pine	12.512	-1.881	CHE	12.4095	-1.8345
Corsican	pine	12.104	-1.653	CHP	12.138	-1.758
Maritime	pine	11.982	-1.711	CHS	12.681	-1.911
Norway	spruce	13.086	-1.878	CHY	12.4063636	-1.78018182
Silver	fir	12.621	-1.779	DOU	12.133	-1.646
Douglas	fir	12.133	-1.646	EPC	13.086	-1.878
				ERS	12.50975	-1.85475
Coniferous		12.3472857	-1.73757143	FRE	12.50975	-1.85475
Broadleaves		12.50975	-1.85475	HET	12.95	-1.941
Oak		12.4095	-1.8345	MEL	12.3472857	-1.73757143
Pine		12.14775	-1.715	NA	12.4063636	-1.78018182
General		12.4063636	-1.78018182	P.M	11.982	-1.711
				P.N	12.14775	-1.715
				P.S	11.993	-1.615
				P.X	12.14775	-1.715
				S.P	12.621	-1.779
				SAU	12.50975	-1.85475
				TRE	12.50975	-1.85475

Species specific Self-thinning equations, literature data (Charru et al. 2012, Pretzch and Mette 2008, Pretzch 2006)

$$G_{max} = (D_0)^2 * \exp(rdi_a + rdi_b * \log(D_0))$$



Consistent G/Gmax < 1

Well correlated to HmeanNsoil

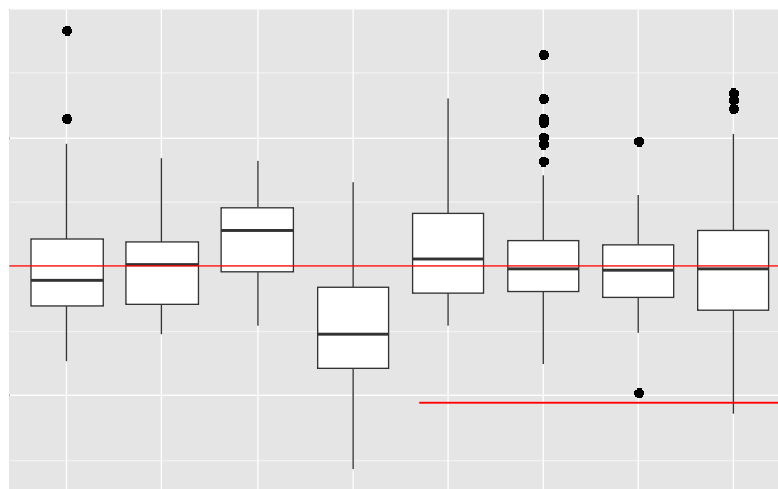
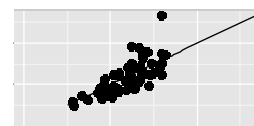
Gratio (G/Gmax) predicted from the canopy 3D

Call:
hMean_Nosoil, + intercept function of « percentTrou »
 (account for stand stockability)

Nonlinear mixed-effects model fit by maximum likelihood
 Model: $\text{Gratio} \sim a + b * \text{Hmean_nosoil.x} + c * \text{PercentTrou}$

	Value	Std.Error	DF	t-value	p-value
a	0.24577906	0.020446396	508	12.020654	0
b	0.02078299	0.001260104	508	16.493081	0
c	-0.22873478	0.030583267	508	-7.479083	0

Residual standard error: **0.1347** on 509 degrees of freedom
 Multiple R-squared: **0.4848**, Adjusted R-squared: **0.4822**



Bias for Languimberg

Back Transformation to G

$$G = \text{preGRatio} * (D0)^2 * \exp(\text{rdi_a} + \text{rdi_b} * \log(D0))$$

Coefficients:

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	-0.29922	0.99919	-0.299	0.765
modGOne.pred	1.00964	0.03064	32.947	<2e-16 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

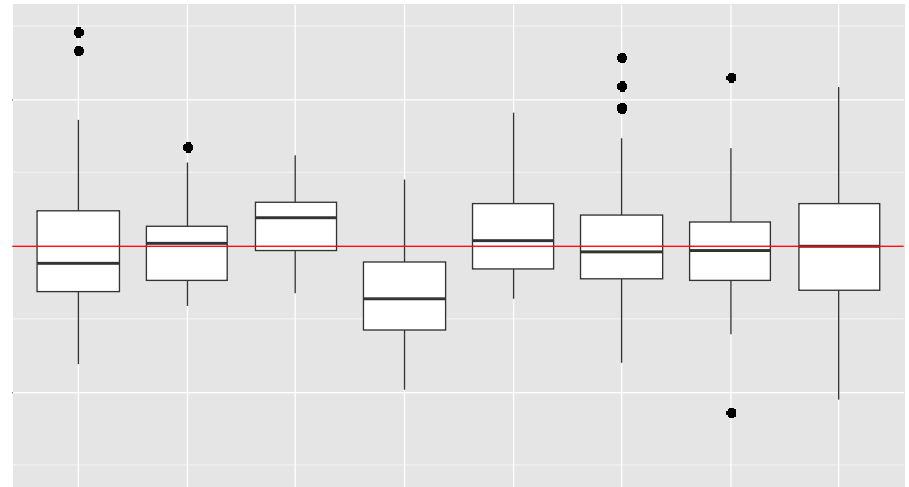
Residual standard error: **7.95** on 509 degrees of freedomMultiple R-squared: **0.6808**, Adjusted R-squared: **0.6801**

F-statistic: 1085 on 1 and 509 DF, p-value: < 2.2e-16



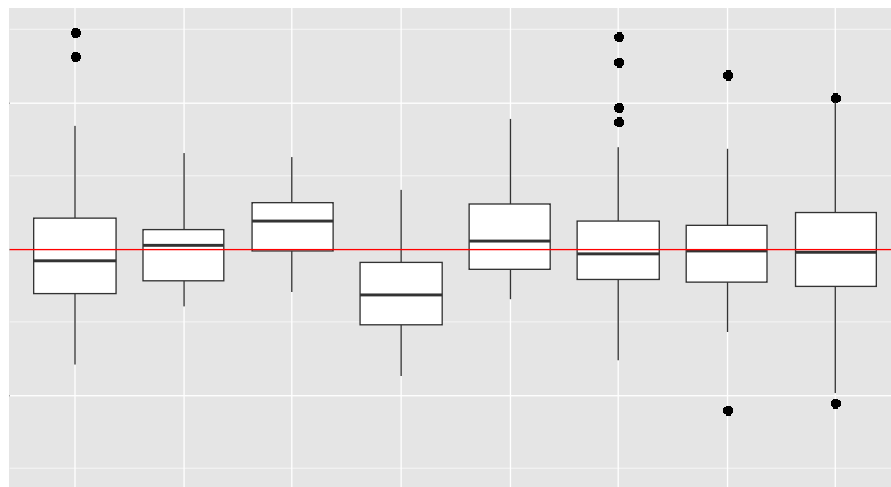
Good results but still a bias for
Languimberg

- *Error propagation ?*
- *Site effect ?*

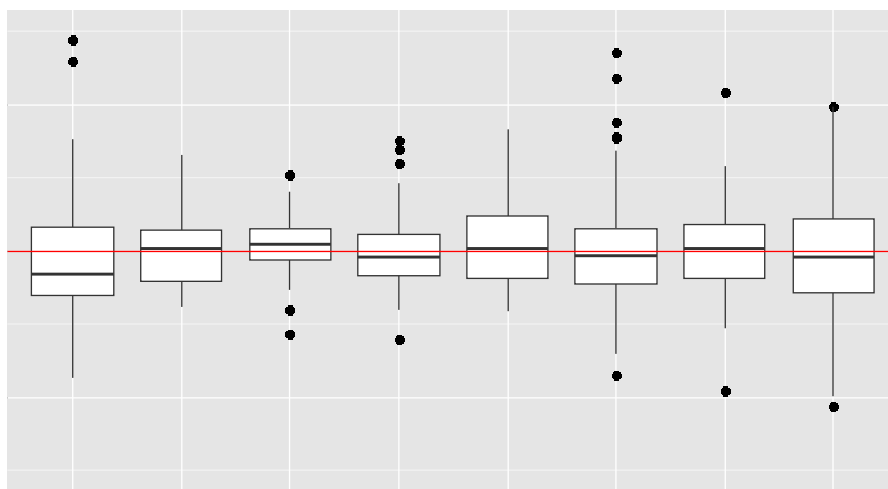


STEP5

Back Transformation to G, error analysis



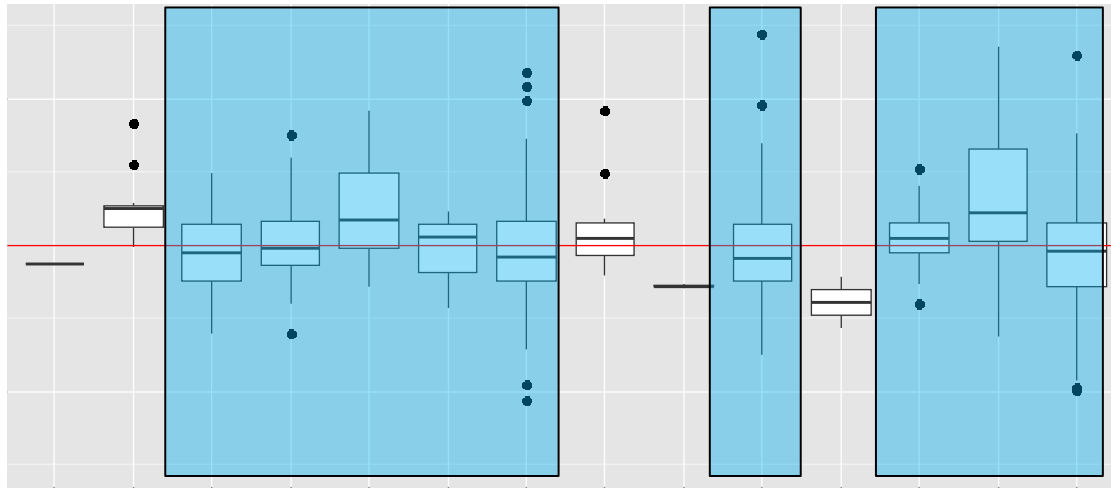
Gmax calculated with the measured D0
 $R^2=0.70$, $RMSE=7.68$ m²/ha



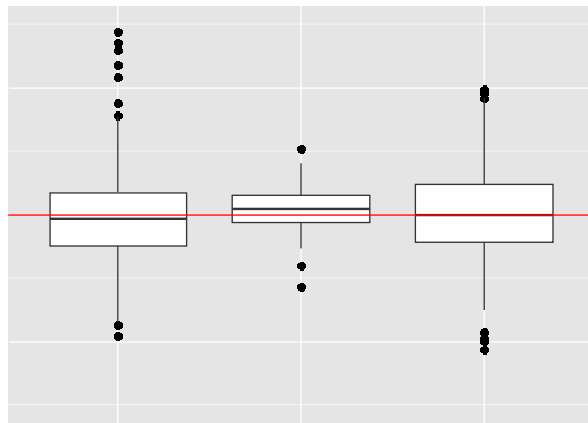
Gmax calculated with the measured D0 + fit site by site
 $R^2=0.73$, $RMSE=7.28$ m²/ha

BOTH !

Back Transformation to G, error analysis

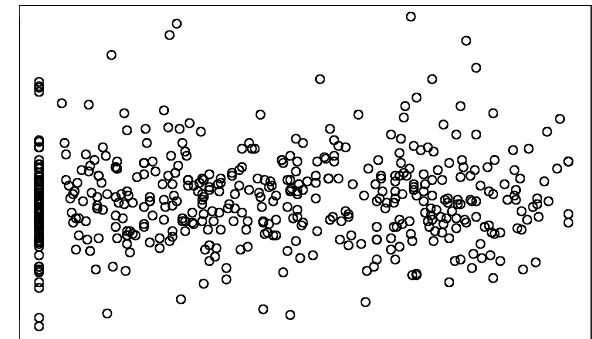


Species effect but not necessarily related to the lack of RDI equation



No seasonal effect

No clear effect of the type of the forest



Conclusion

- The combination is working and gives accurate estimates of dominant height (all case studies) and stand basal area (all but Languimberg)
- The chain integrates the strength of each approaches (growth and yield, LIDAR) in a consistent and comprehensive way – not only additive or multiplicative combination of metrics
- Can be improved
 - vertical porosity of the 3D cloud is not yet used but see Vega et al. hereafter
 - species specific RDI equations ? (site dependant)
- Can also provide volume ($f \cdot G$), biomass ($\rho \cdot V$), and number of stems/ha (but not yet done)