



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, S. Durrieu

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Journées CAQSIS 2015 – Nancy - 7-9 avril 2015

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

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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)

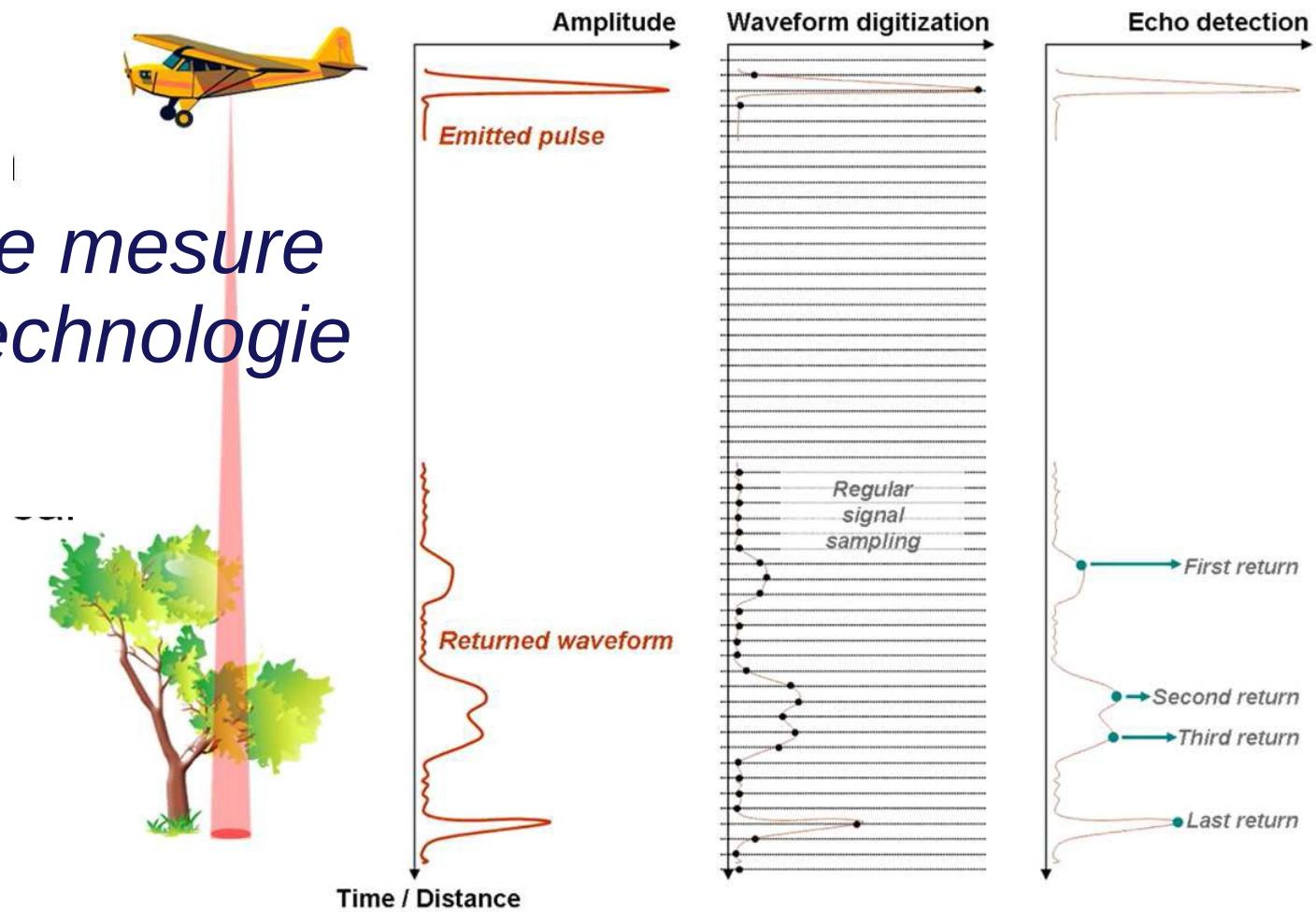
Vers plus de « *mécanisme* »...
(Bouvier *et al.* 2015)

Revisite de la ...
(Véga *et al.* 2015) *pénétration du signal*

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

INTRODUCTION

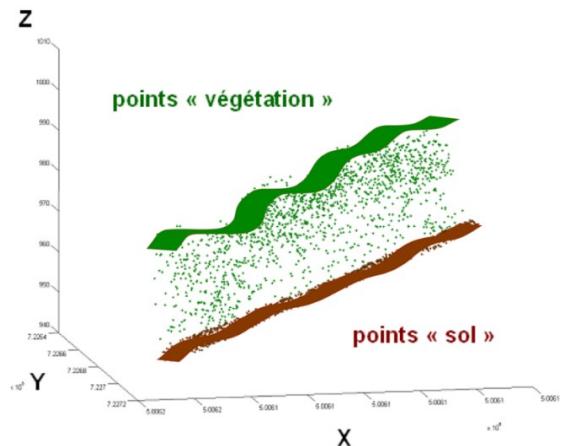
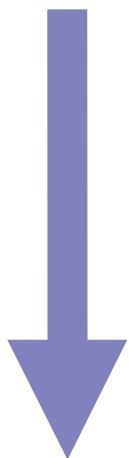
*Principe de mesure
de cette technologie
« active »*



(Durrieu et al. 2015)

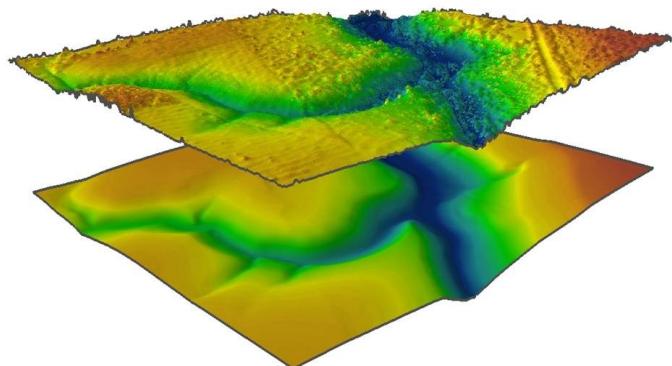
(premier paradigme = normalisation en H)

Normalisation du nuage

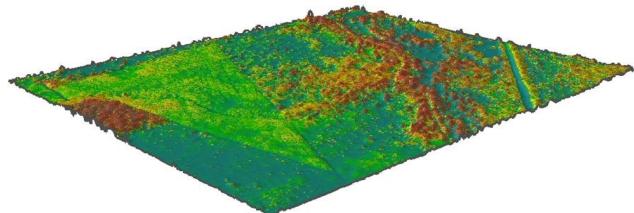


Nuage de points en H
à partir du MNH

MNS : Modèle numérique de surface



MNT : Modèle numérique de terrain

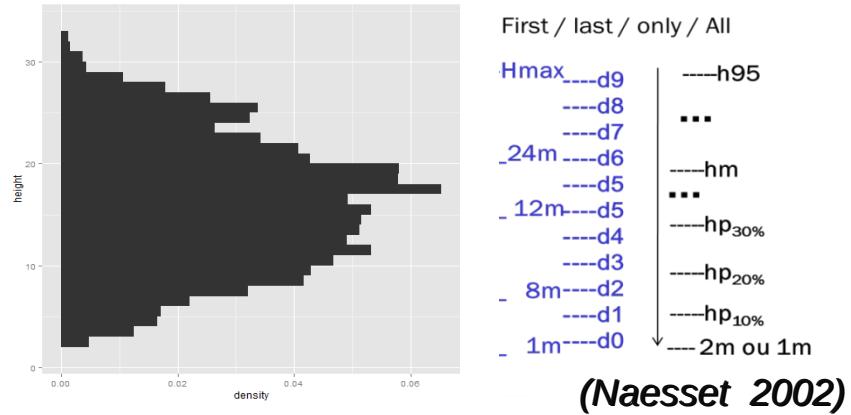


MNH: Modèle numérique de
hauteur

2 Approches à partir du nuage : Distribution / Segmentation

Méthode standard: résume la placette en Déciles H et densité

Approche « distribution »

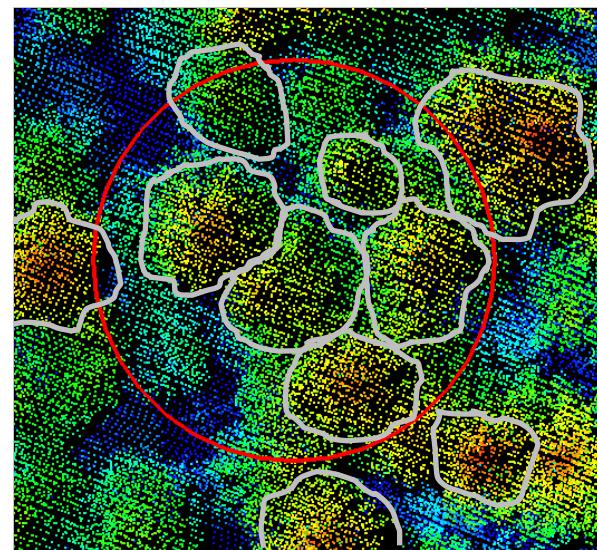


Avantage: - rapide ; peu sensible à la densité

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

Méthode de segmentation

Approche « arbre »



Avantage: - plus proche du terrain

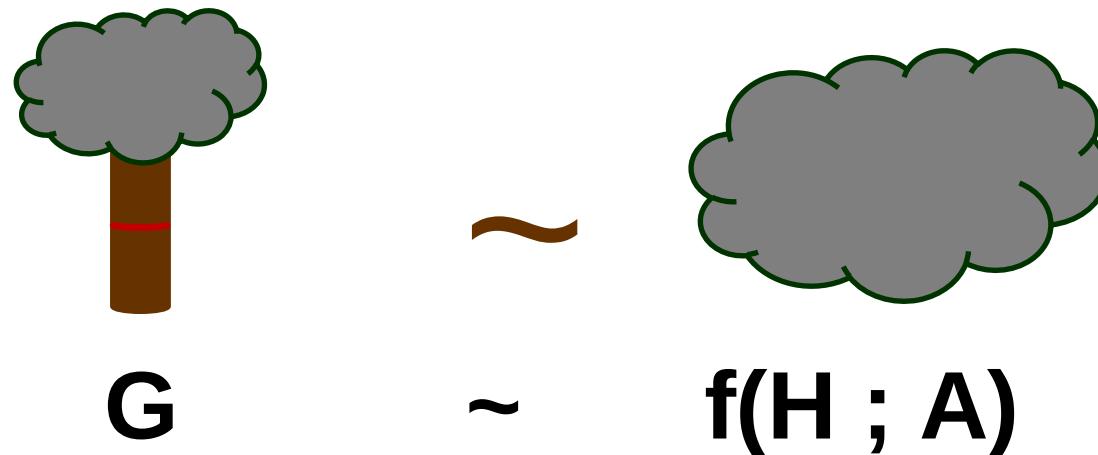
Problème : - **Forte densité requise**
- biaisée (**qualité segmentation**)
- allométrie liée aux **espèces**

(lourd)

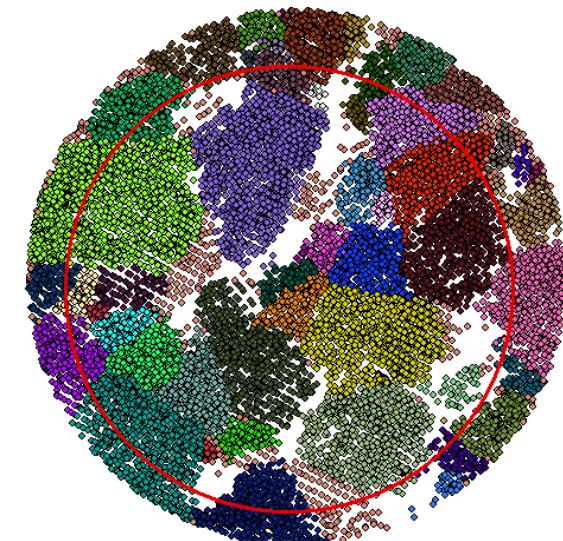
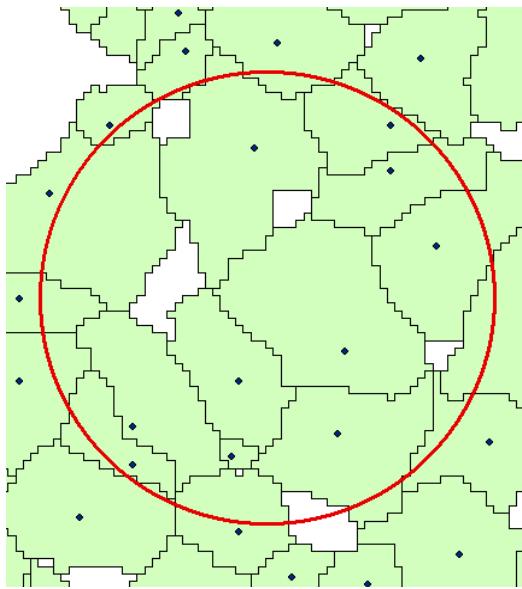
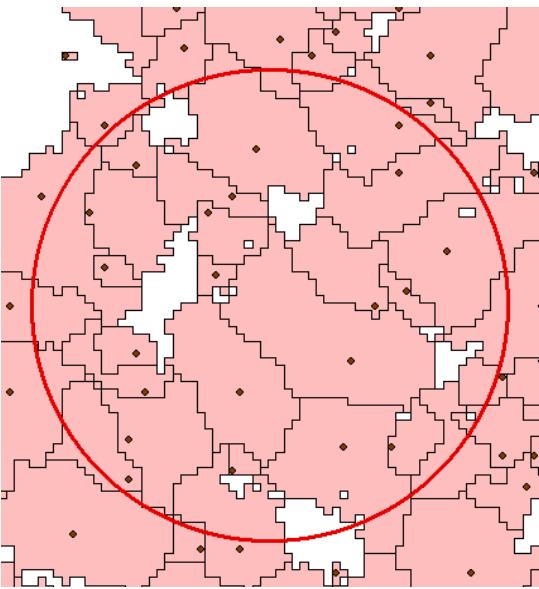
Hyp. : Etude André *et al.*

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



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*

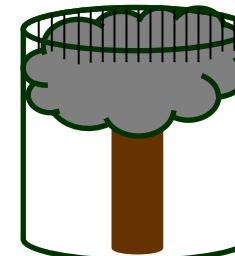
*Pas beaucoup de
fausses
détections*

Résultats :

Variable	Formule	R²a	AIC	Erreur.cv	%Erreur.cv
H0	Std_H90_lst	0.98	85	1.0	3.7
	Std_H80_lst + Std_d3_fst	0.99	77	0.9	3.2

Variable	Formule	R²a	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 ~Sum()

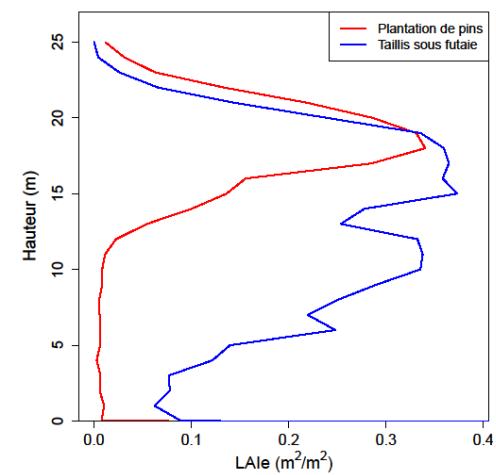
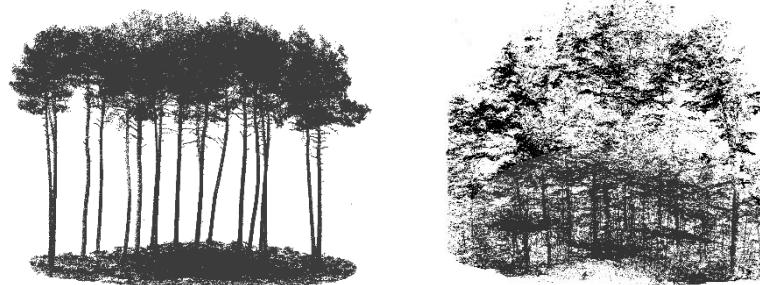
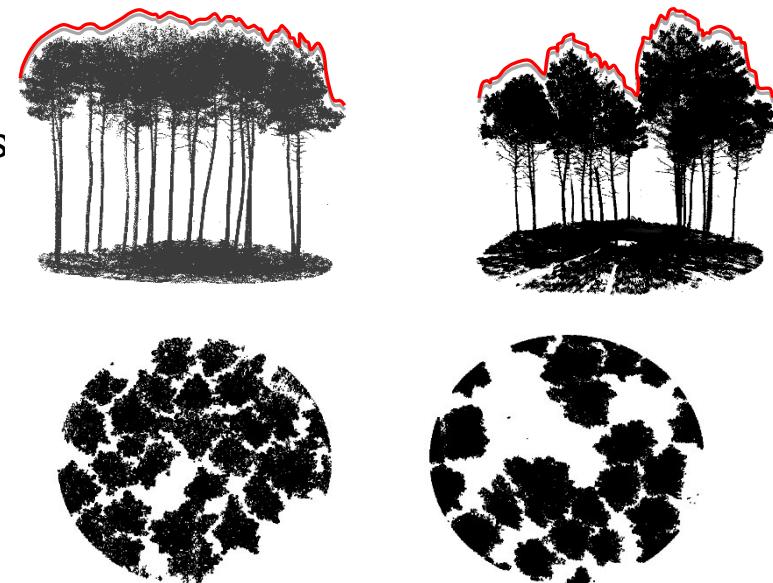


Modèles à 3 variables : RMSE de 18 – 21%

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

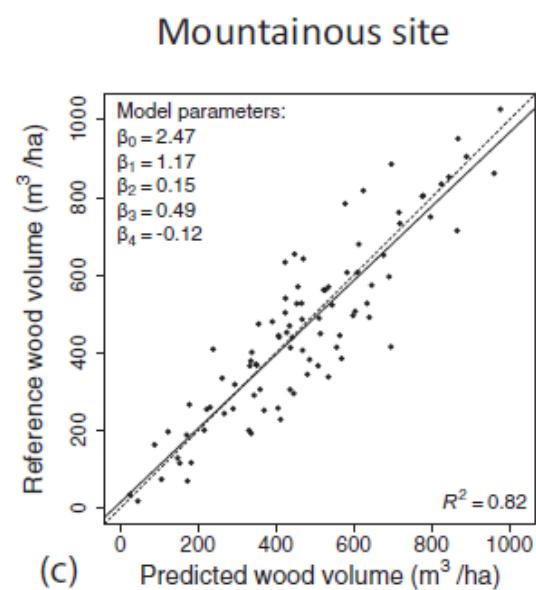
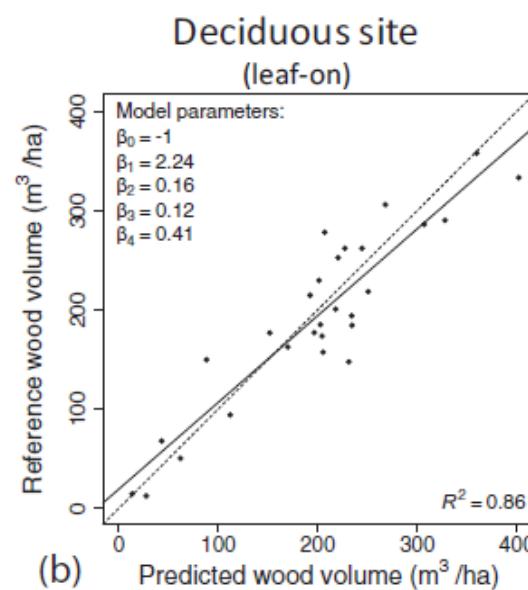
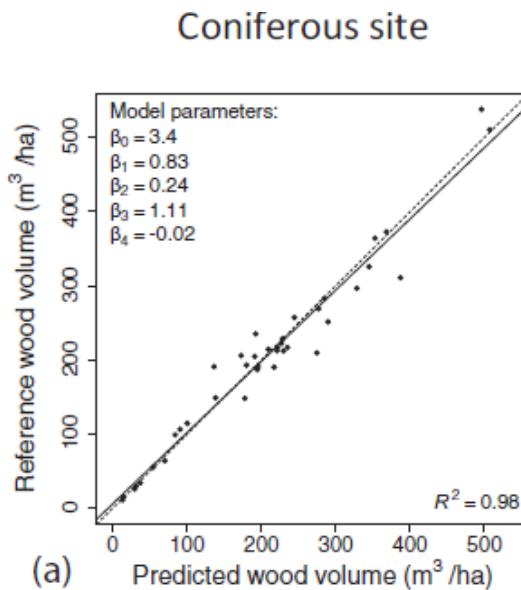


$$\hat{y} = \beta_0 \mu_{CH}^{\beta_1} \sigma_{CH}^{2\beta_2} P_f^{\beta_3} Cv_{LAD}^{\beta_4}$$

Résultats :

Précision de 12.4% à 24.2%

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



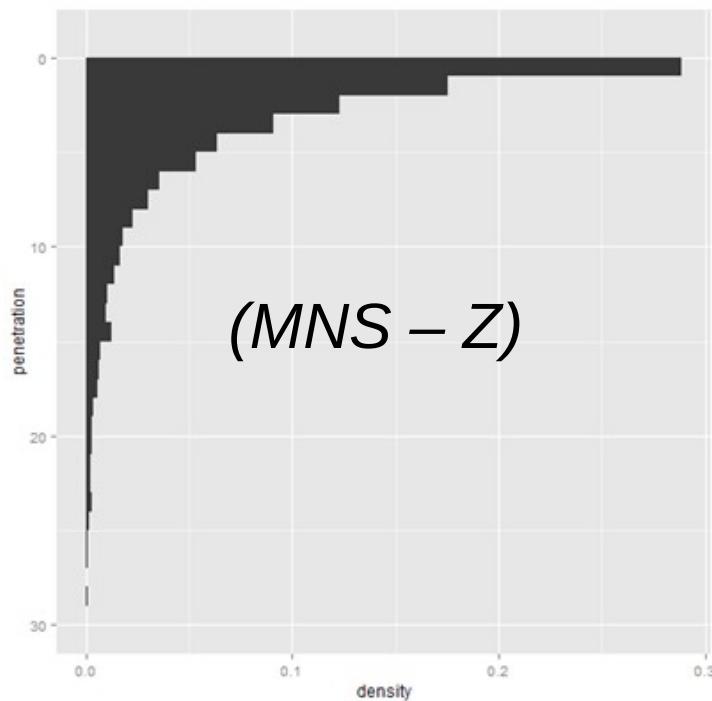
*Pour le calcul de la pénétration du signal dans la canopée,
elle ajoute un biais lié à l'hétérogénéité structurelle
(p.ex. trouées)*

La solution : ne pas la faire !

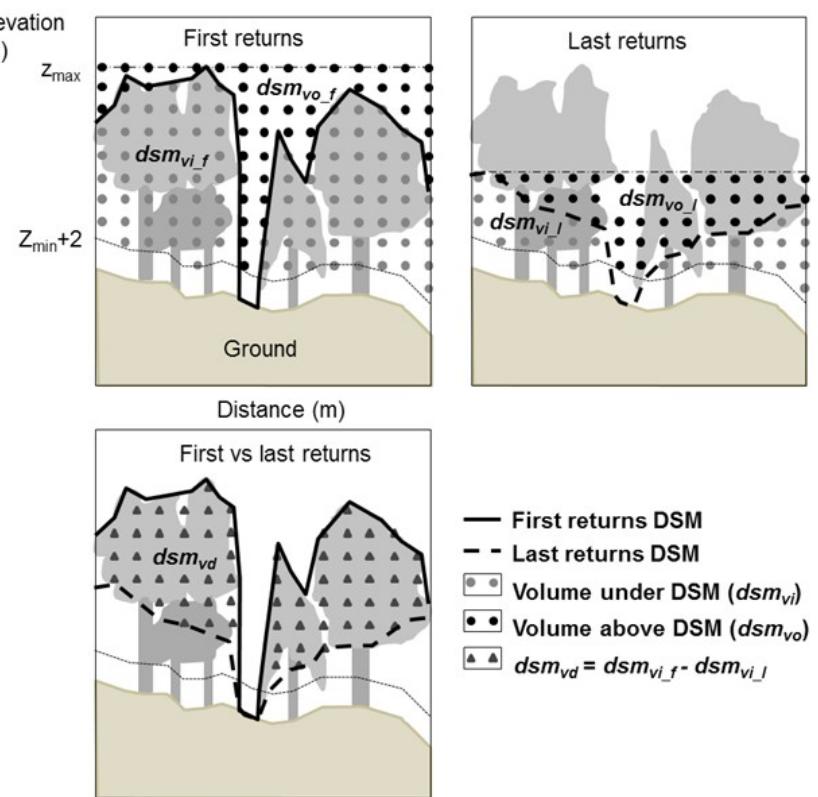
*passer par le MNS pour calculer cette pénétration
à travers la canopée!*

(Véga et al. 2015)

La vraie pénétration se calcule à partir du MNS !



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



Résultats pour G :

Site	Metrics	Formula	Raster cell size (m)	RMSE _{cv} (m ² .ha ⁻¹)	rRMSE _{cv} (%)	R ² adj
All	All	$p_{d5v_l} + p_{d5f_f} + p_{rlm3_a} + dsm_{vr_f} + dsm_{vi_l}$	mean	9.18	26.83	0.64
	p/DSM	$p_{d5v_l} + p_{d5f_f} + p_{rlm3_a} + dsm_{vr_f} + dsm_{vi_l}$	mean	9.18	26.83	0.64
	Bure	$h_{lm4_l} + h_{vd} + p_{10_f} + p_{40_l} + p_{d5v_l}$	mean	1.14	6.09	0.98
Aillon	All	$p_{40_f} + p_{40_l} + p_{d3f_l} + p_{lm3_f}$	0.5	1.93	10.27	0.94
	p/DSM	$h_{lm3_f} + h_{lm5_l}$	0.5	4.83	25.67	0.67
	Bure	$h_{d9v_l} + p_{d4f_f} + p_{cm2_f} + dsm_{ra_l} + dsm_{vd}$	0.5-HF	5.75	12.83	0.76
Aillon	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)

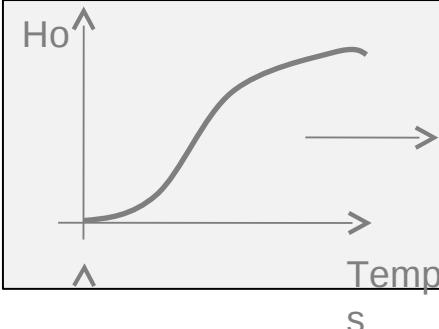
Ho Dominant height

D0 Dominant diameter

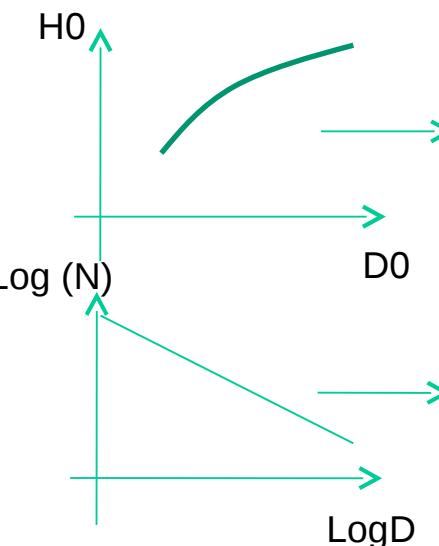
Nmax and Gmax from the self-thinning law

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

Séries temporelles de photos



Potential growth (climate, soil)



Allometry between height and diameter

Maximum stockability knowing D0

LIDAR (3D forest structure)

Autres perspectives ... vers + d'utilisation de MNH

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)

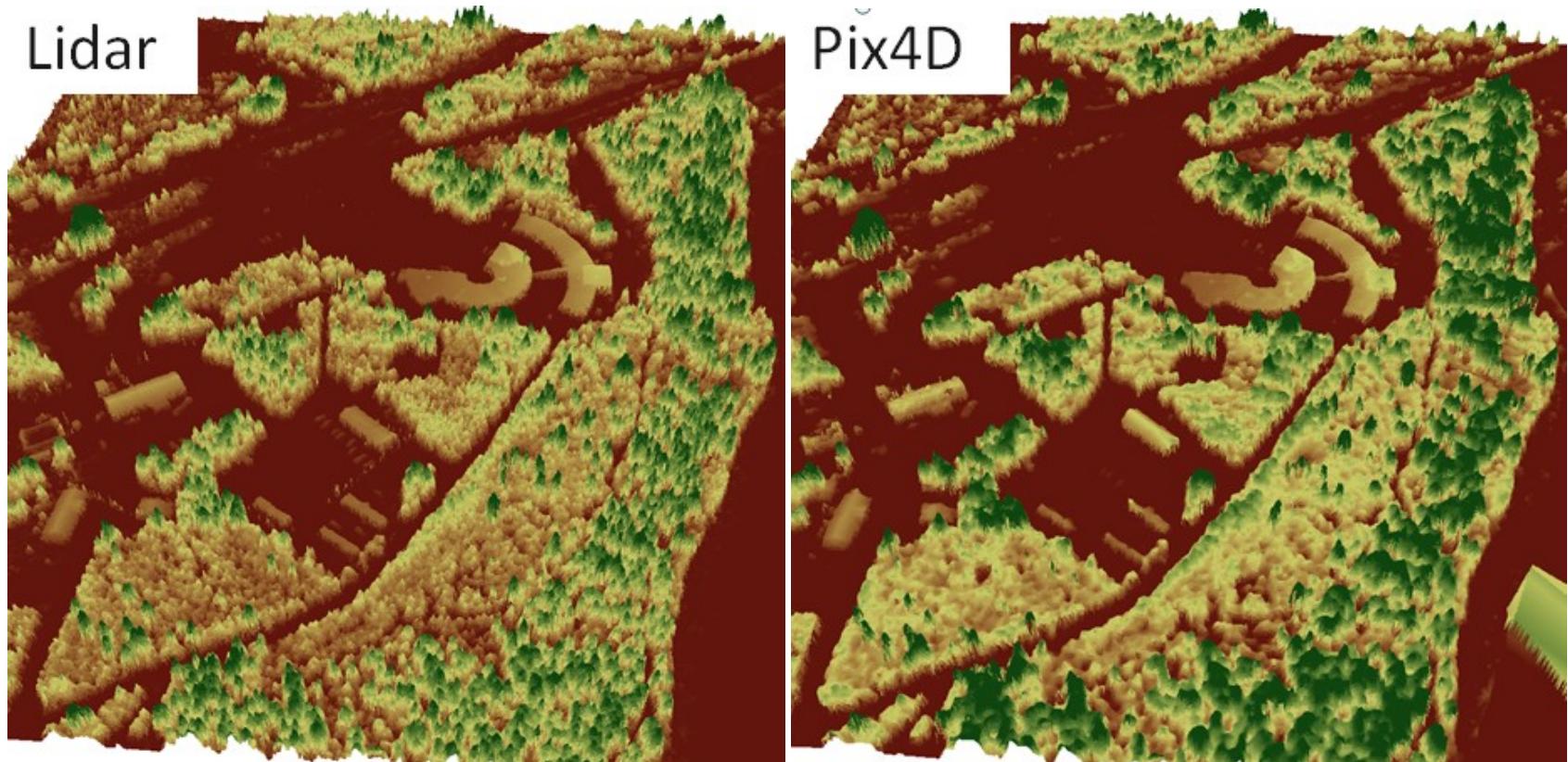
Estimation des dégâts de tempêtes

(Honkavaara *et al.* 2013)

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

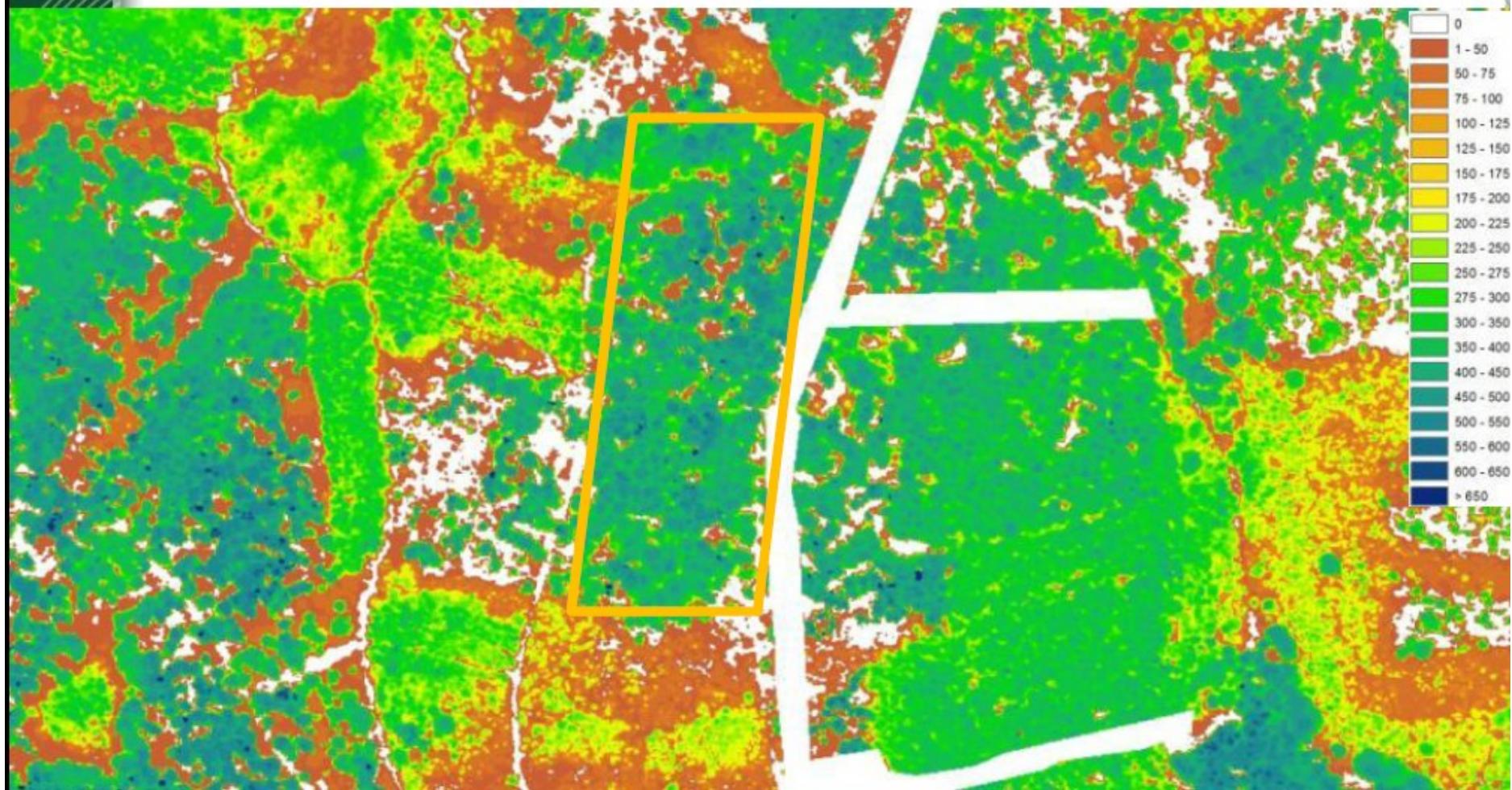
Les MNH photogrammétriques, l'avenir du Lidar?

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



(St-Onge 2015)

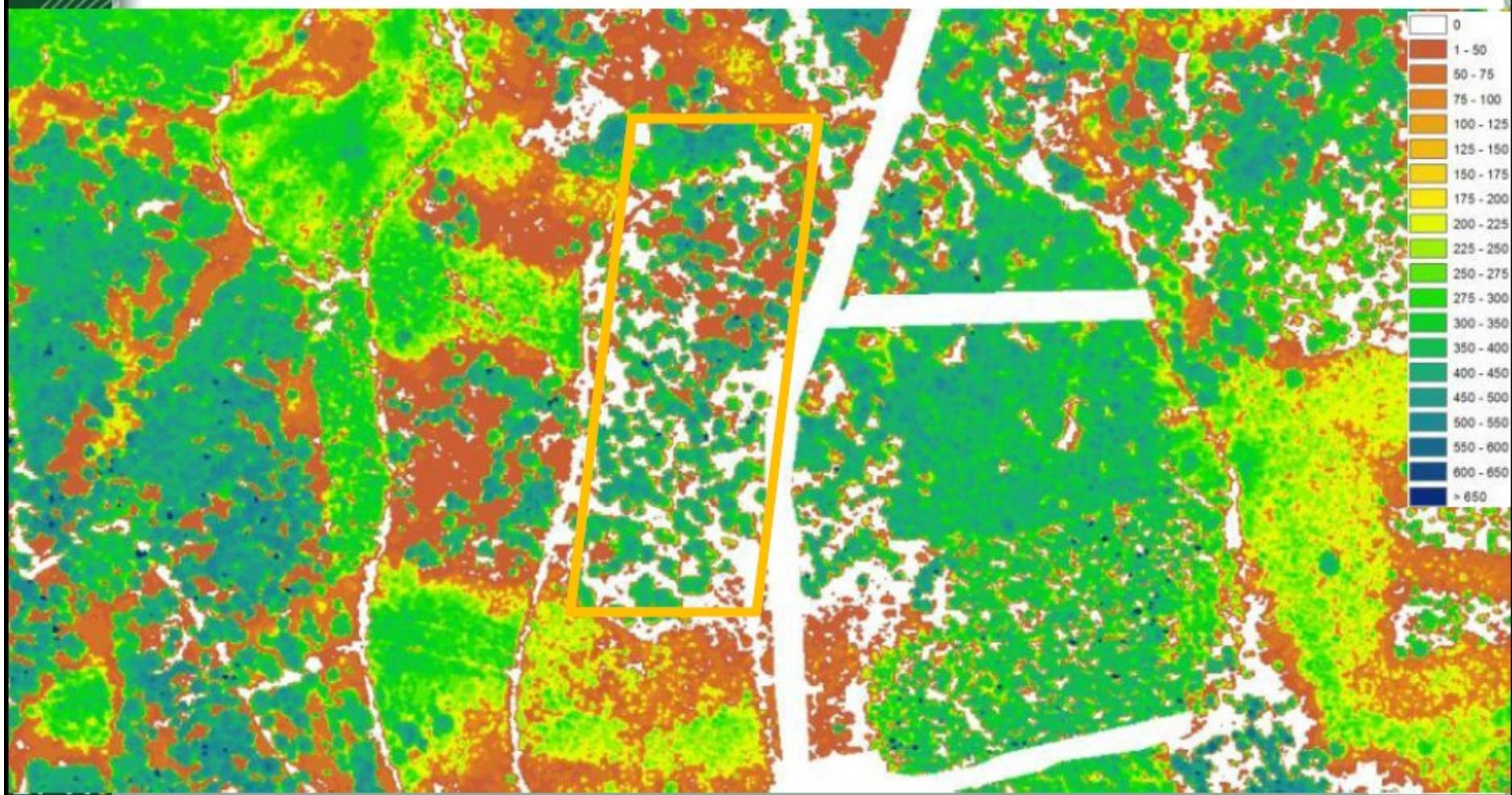
Volume map 2010 Estimation des prélevements ...!



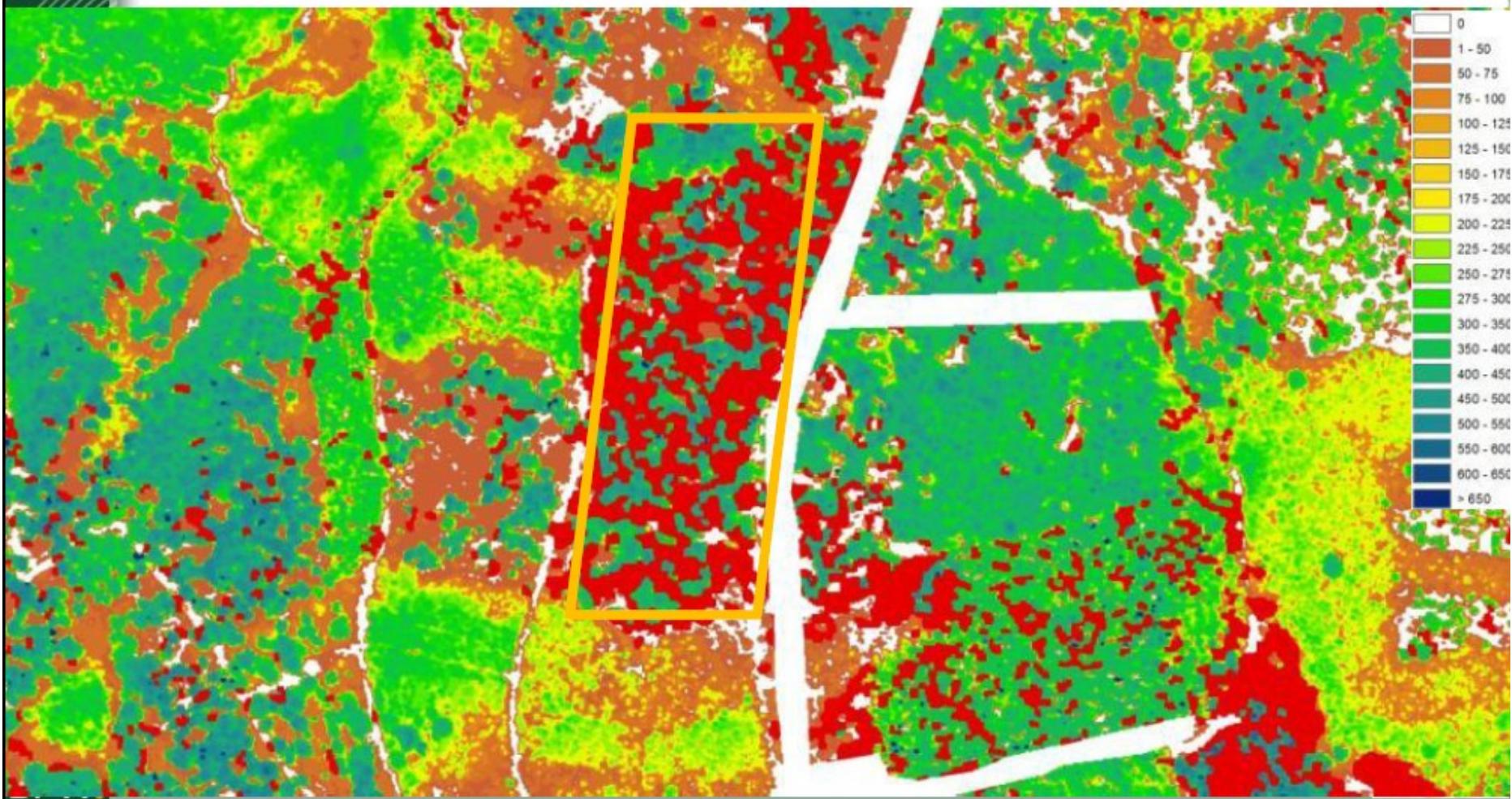
Volumes estimés à partir de M NH photogrammétriques

(Bauerhansl, Schadauer and Hollaus 2014)

Volume map 2013



Volume map 2013 with fellings areas





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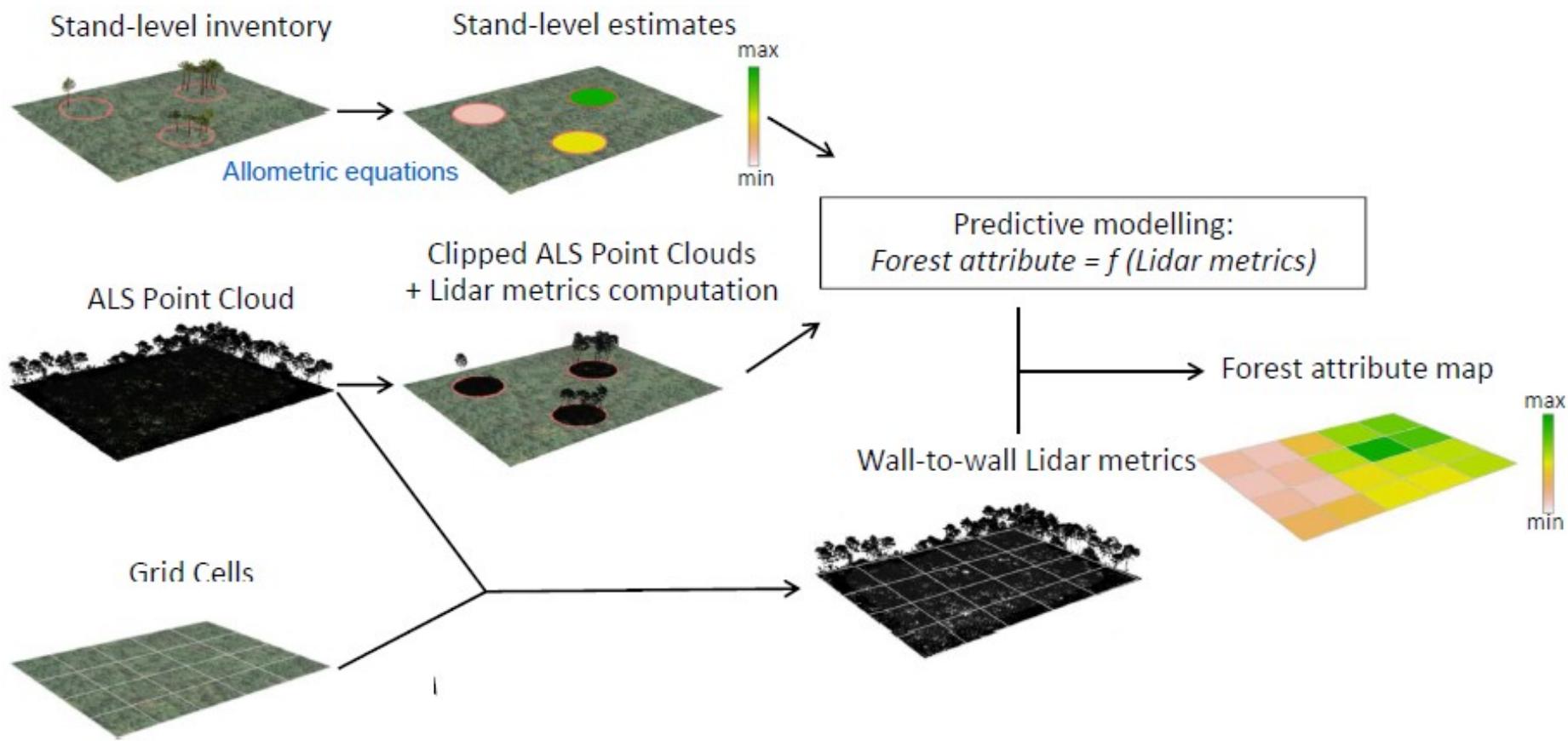
*Merci
de
votre
Attention !*



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



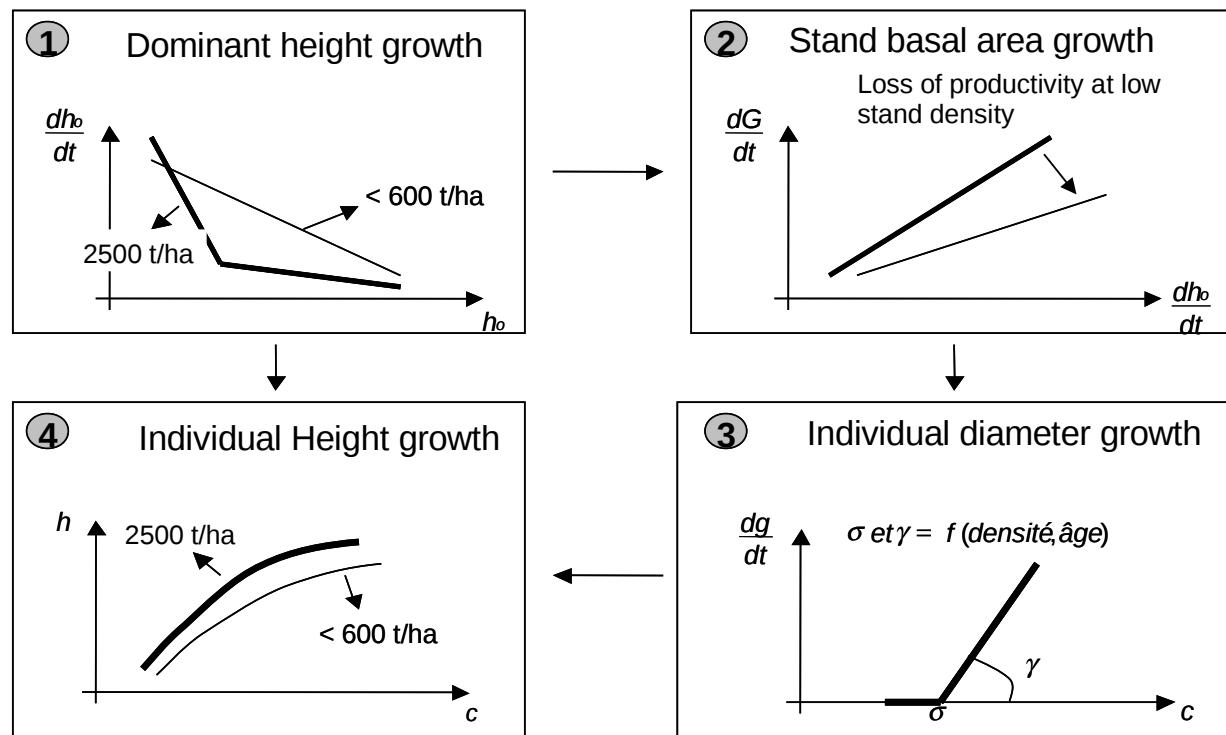
(Bouvier 2015)

Vers l'intégration de notions dendrométriques ...

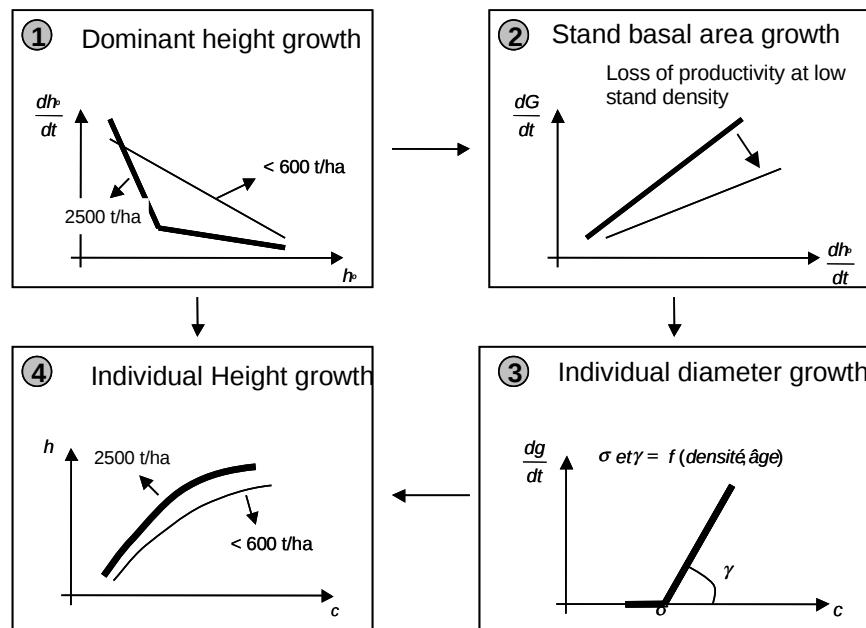
Growth and Yield Theory

A robust approach to assess tree and stand growth

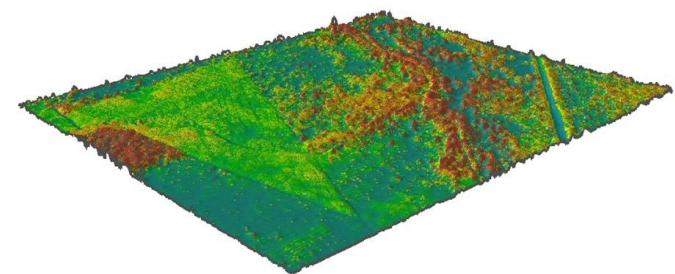
Where forest attributes are interrelated in a comprehensive way



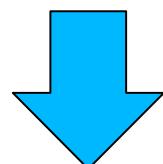
Growth and Yield Models



LIDAR Data sets



MNH: Modèle numérique de hauteur



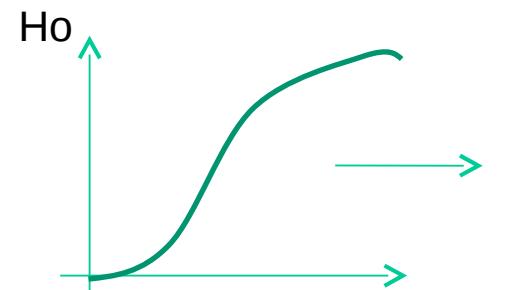
Hypothesis – Combining the strength of each approach will improve the prediction of forest stand attributes from Aerial LIDAR campaigns

01

Methodological issues and flowchart diagram

LIDAR (H)

H_0 Dominant height



Chosen approach

Potential growth (climate, soil)

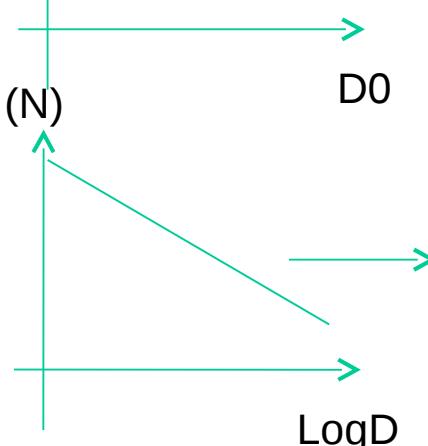
D_0 Dominant diameter



Allometry between height and diameter

N_{max} and G_{max} from the self-thinning law

Log (N)

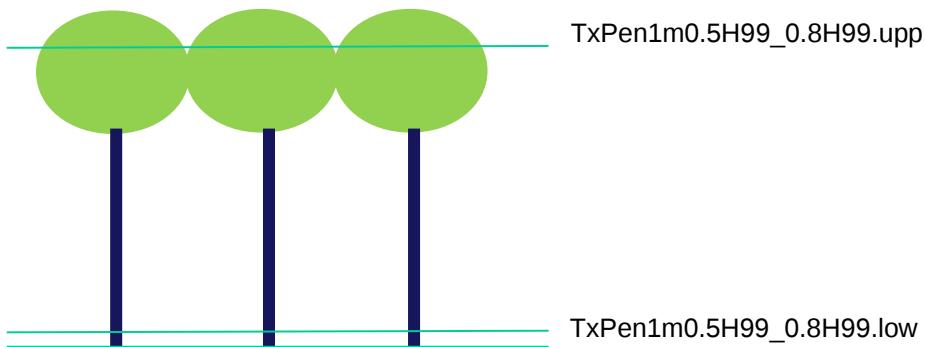


Maximum stockability knowing D_0

Gratio (G/G_{max}) predicted from the canopy 3D

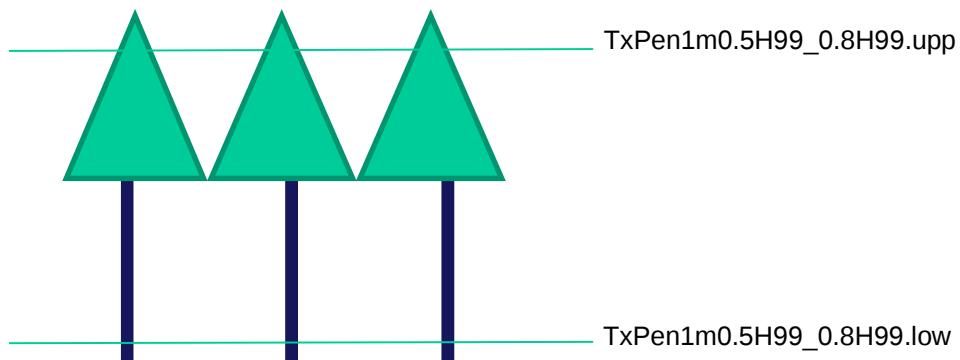
LIDAR (3D forest structure)

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



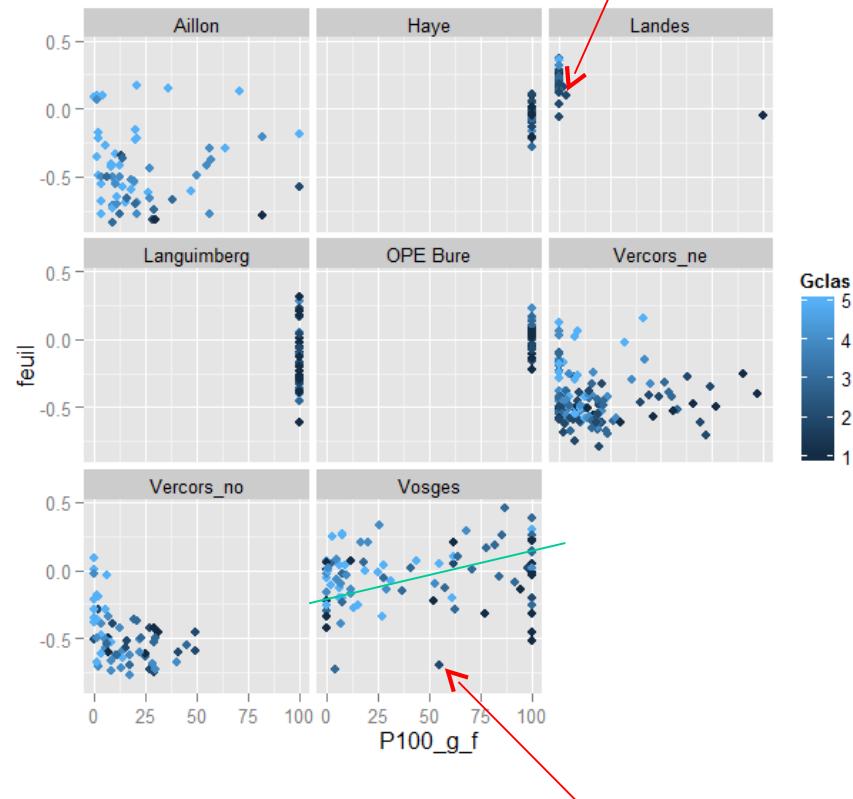
For broadleaves, *Feuil* tends to be **centered on zero** (rapid extinction of the signal)

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



Some new metrics

**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)

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

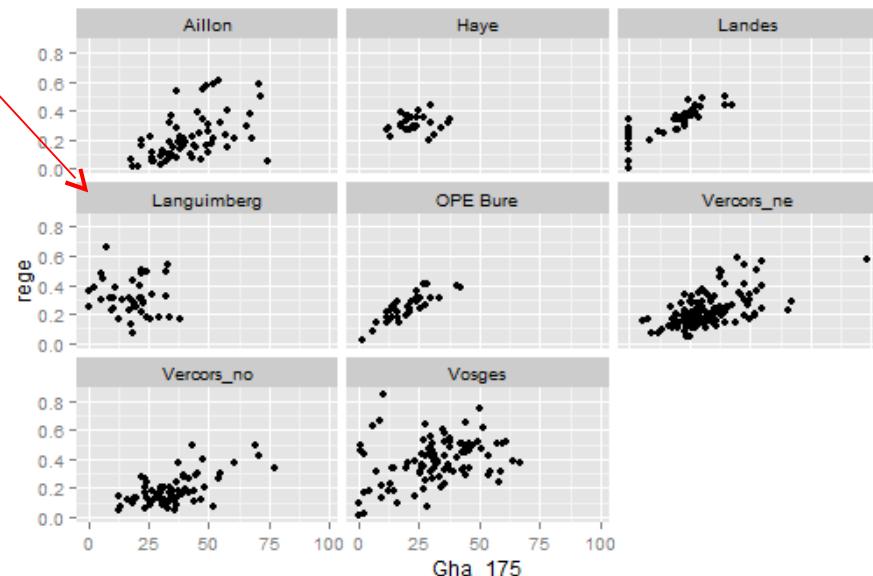
Some new metrics

Yes, except Languimberg.....

Open stand, rege tends to zero (.tot = .low)

TxPen1m0.5H99_0.8H99.low

TxPen1m0.5H99_0.8H99.tot



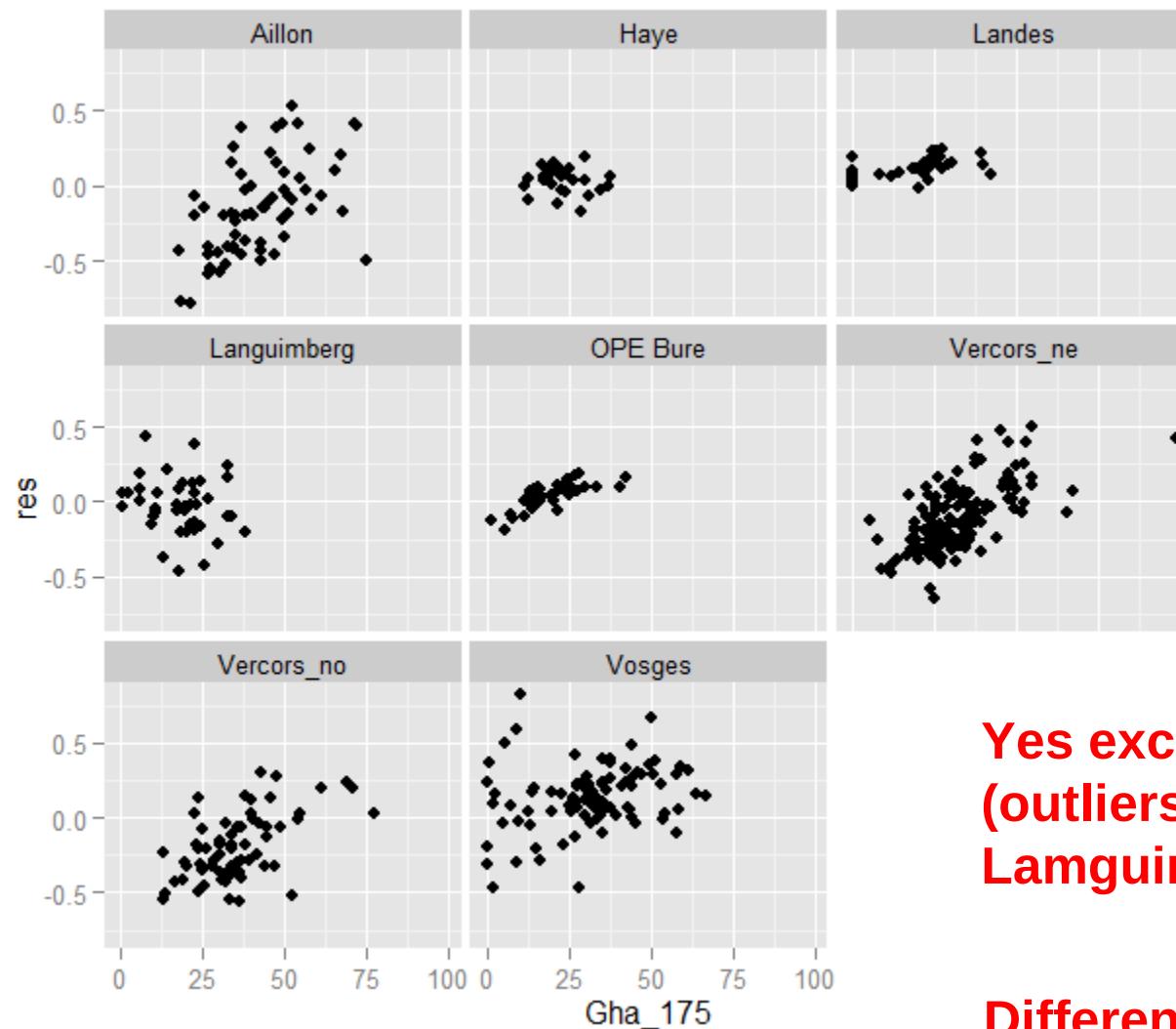
Close stand, rege increases
because .tot is close to zero

TxPen1m0.5H99_0.8H99.low

TxPen1m0.5H99_0.8H99.tot

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

Some new metrics



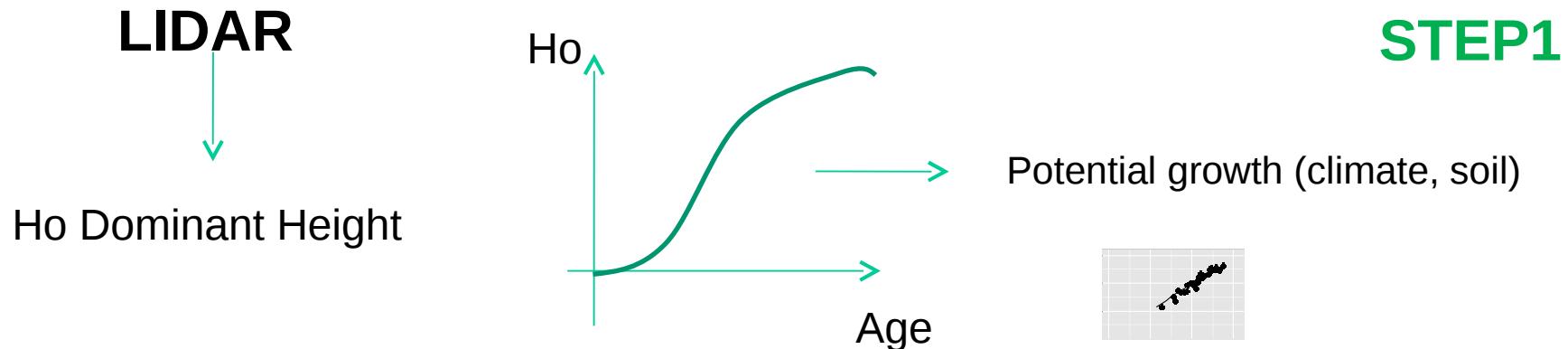
Linear relationship
between *Res* and
the stand basal area

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

Different slopes between sites

02

Results

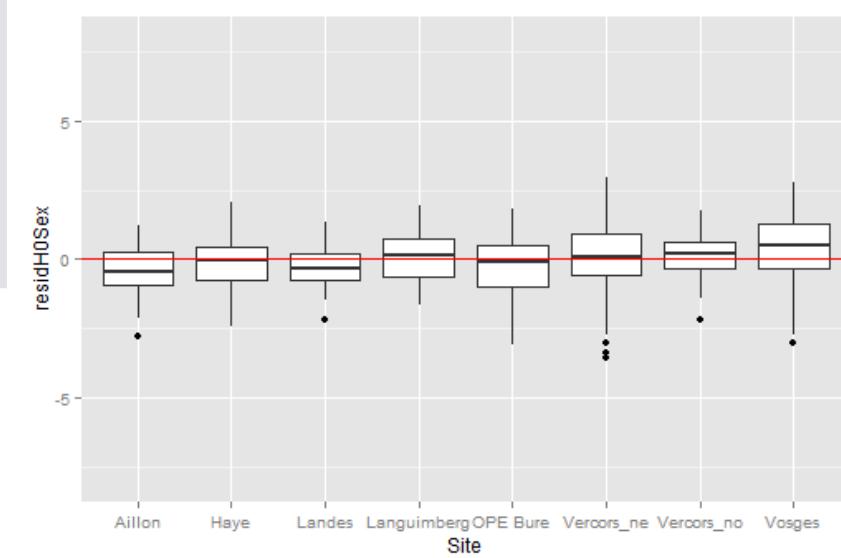


Call:

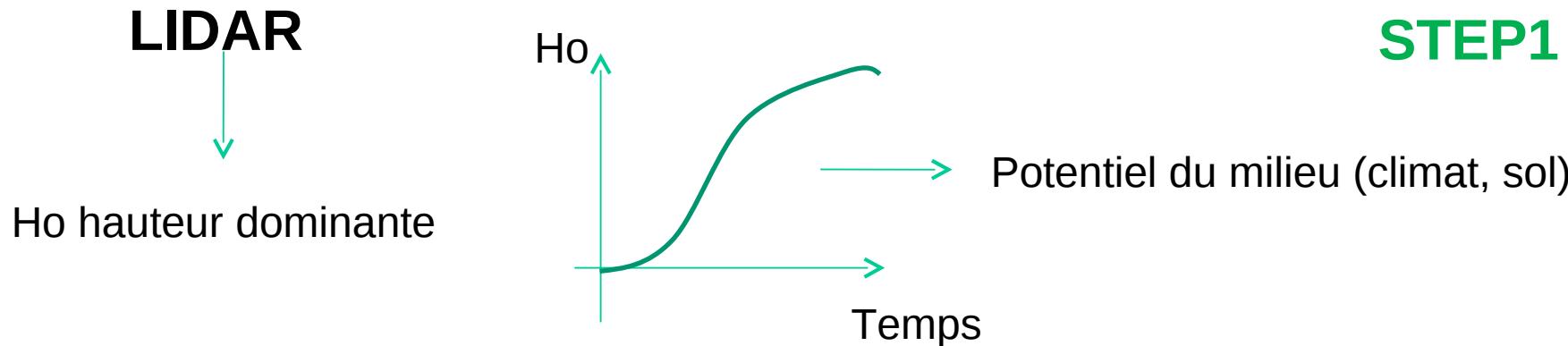
Hmv6_Bd corrected with « slope » (technical correction),
and « rege » (stands with few big trees)

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

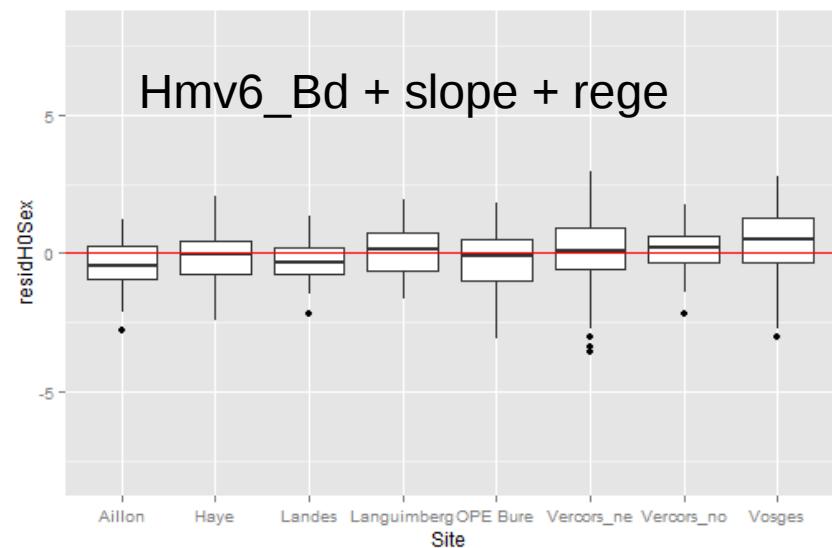
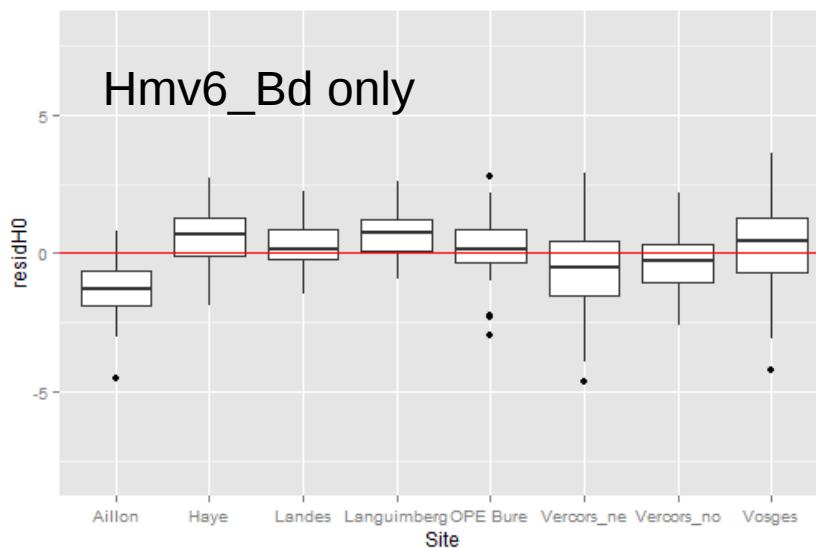
Parameters:
Estimate Std. Error t value Pr(>|t|)
a1 1.49446 0.28288 5.283 2.36e-07 ***
a2 -0.02700 0.00285 -9.475 < 2e-16 ***
b1 0.92135 0.01242 74.216 < 2e-16 ***
b2 0.12291 0.01817 6.764 6.46e-11 ***
---
Signif. codes: 0 '****' 0.001 '***' 0.01 '**' 0.05 '*' 0.1 ' ' 1
Residual standard error: 1.18 on 318 degrees of freedom
Multiple R-squared: 0.9595   Adjusted R-squared: 0.9594
```



Interaction between rege and Hmv6

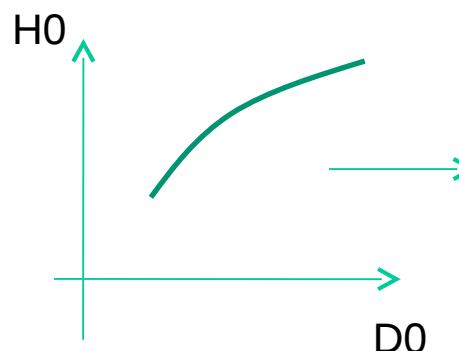


Model used for the rest of the study : **Hmv6_Bd**, corrected with « slope » (technical correction), and « rege » (stands with few big trees)

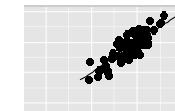


STEP2

D0 Dominant diameter



Allometry between height and diameter



Call:

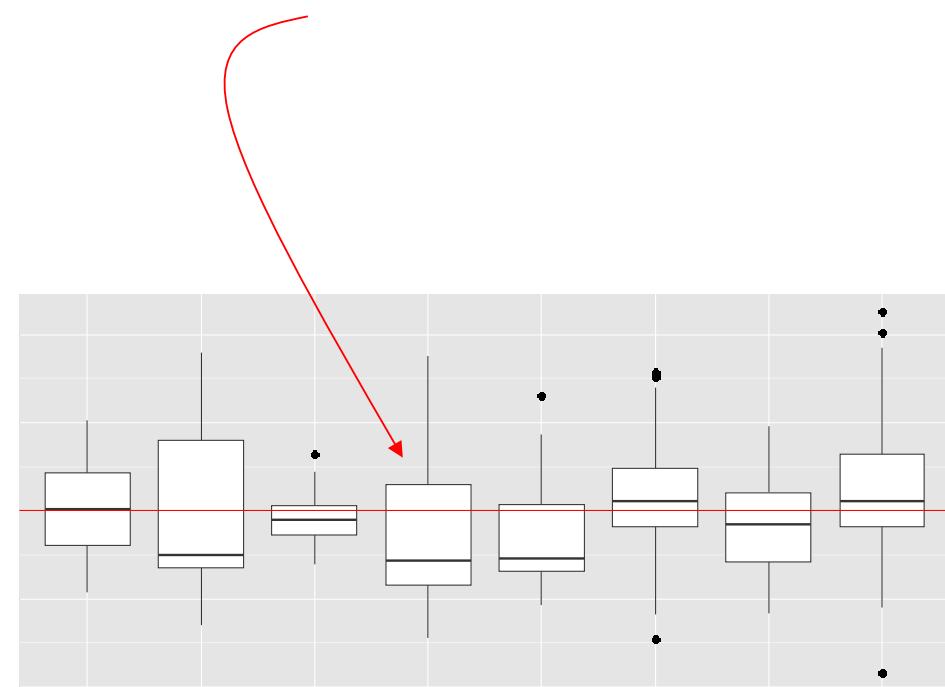
predHOsex, + intercept function of « res »

(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 ~ (d1 * res + e * predHOsex)
      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
```

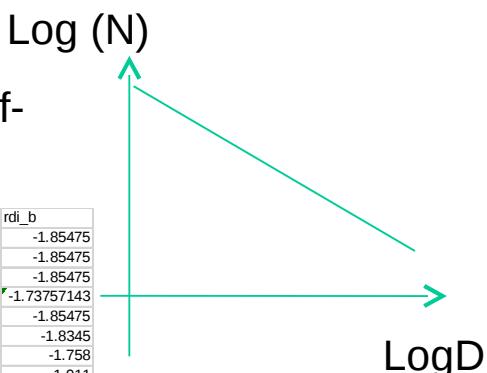
Residual standard error: **6.506** on 509 degrees of freedom
Multiple R-squared: **0.6863**, Adjusted R-squared: **0.6857**

No significant bias, but a clear pattern for Languimberg



Nmax and Gmax from the self-thinning law

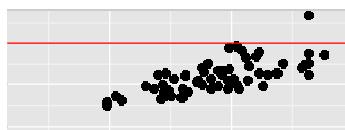
		rdi_a	rdi_b			rdi_a	rdi_b
Pubescent	oak	12.27	-1.809		A.F	12.50975	-1.85475
Pedunculate	oak	12.138	-1.758		AUL	12.50975	-1.85475
Sessile	oak	12.681	-1.911		BOU	12.50975	-1.85475
Common	beech	12.95	-1.941		CED	12.3472857	-1.73757143
Scots	pine	11.993	-1.615		CHA	12.50975	-1.85475
Aleppo	pine	12.512	-1.881		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
Coniferous		12.3472857	-1.73757143		ERS	12.50975	-1.85475
Broadleaves		12.50975	-1.85475		FRE	12.50975	-1.85475
Oak		12.4095	-1.8345		HET	12.95	-1.941
Pine		12.14775	-1.715		MEL	12.3472857	-1.73757143
General		12.4063636	-1.78018182		NA	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



Maximum stockability knowing D0
STEP3

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

$$Gmax = (D0)^2 * \exp(rdi_a + rdi_b * \log(D0))$$



Consistent G/Gmax<1

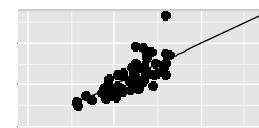
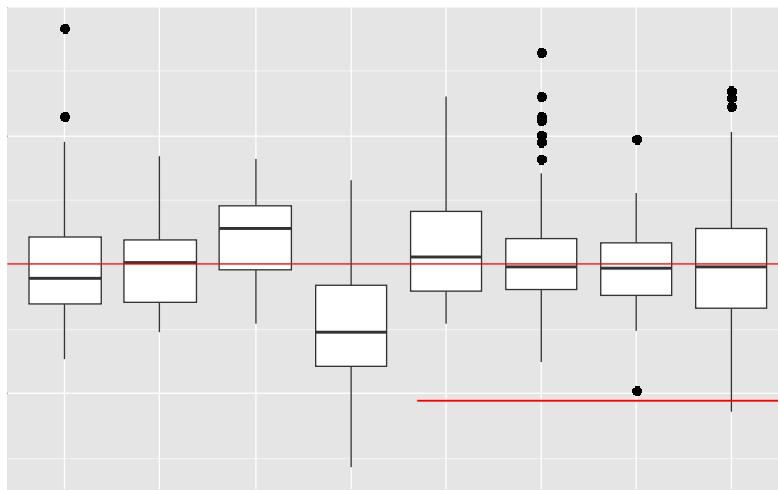
Well correlated to HmeanNosoil

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: Gratio ~ a + b * Hmean_nosoil.x + c * PercenTrou
      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:
0.4839
```



→ Bias for Languimberg

Back Transformation to G

STEP5

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

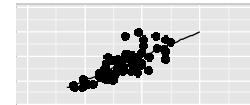
Coefficients:

		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

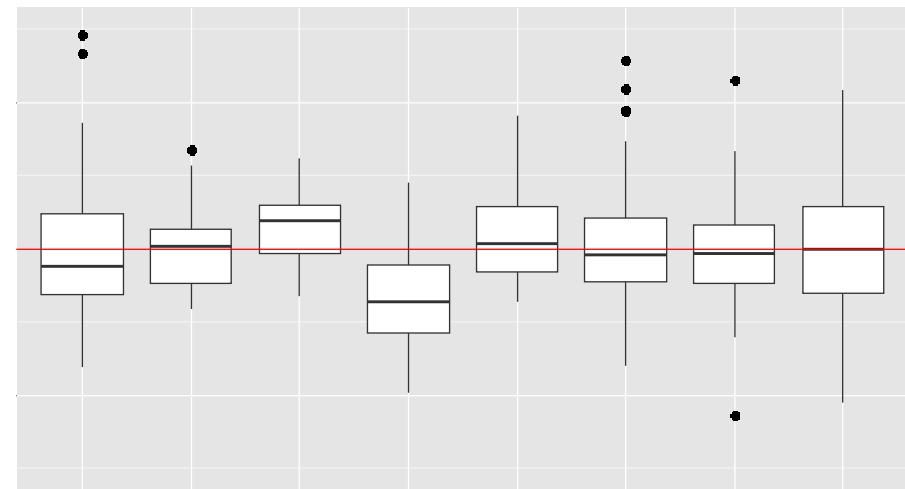
Residual standard error: **7.95** on 509 degrees of freedomMultiple R-squared: **0.6808**, Adjusted R-squared: **0.6801**

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



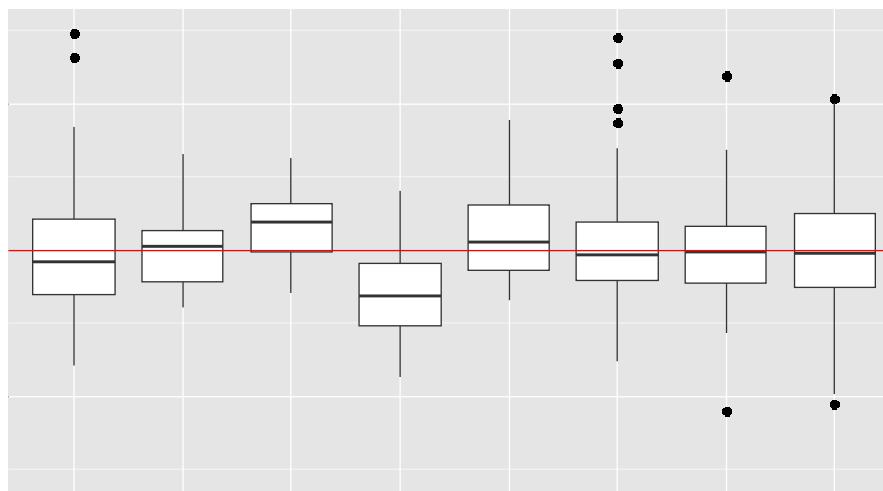
Good results but still a bias for
Languimberg

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

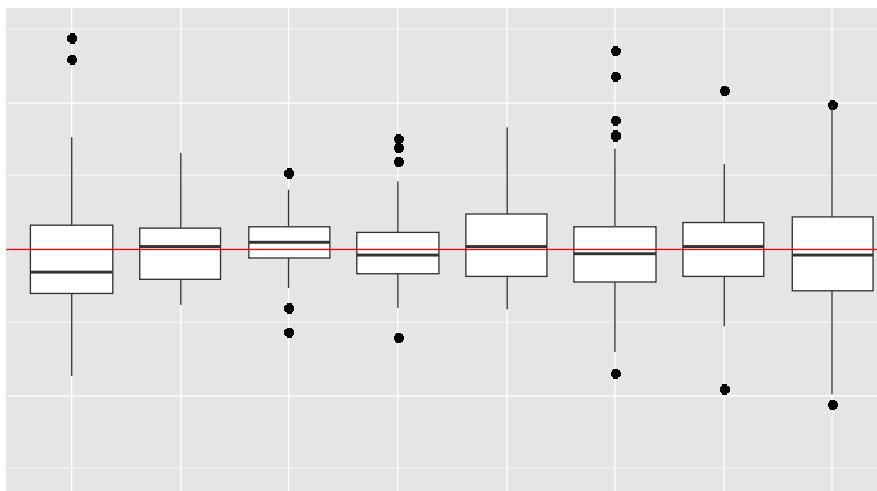


Back Transformation to G, error analysis

STEP5



Gmax calculated with the
measured D0
R²=0.70, RMSE=7.68 m²/ha

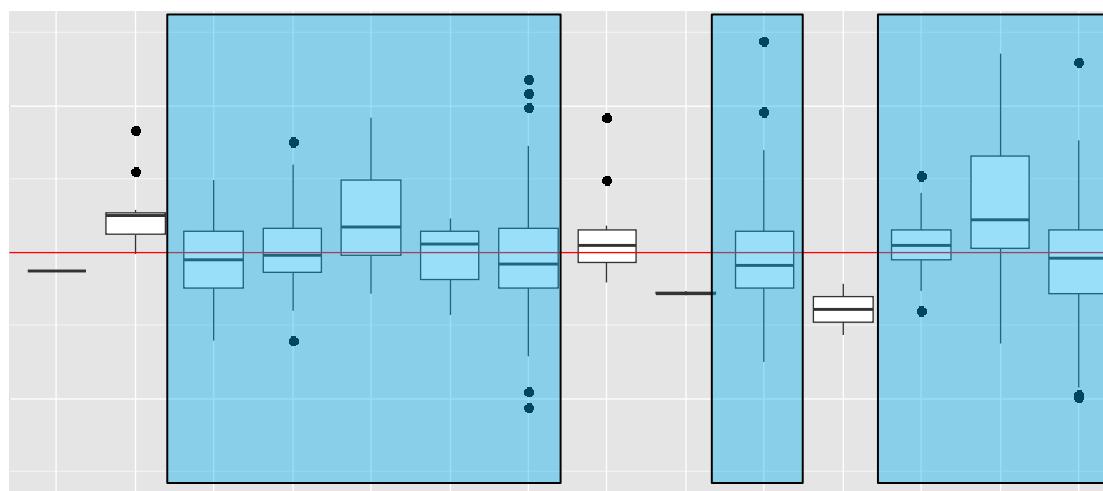


Gmax calculated with the
measured D0 + fit site by site
R²=0.73, RMSE=7.28 m²/ha

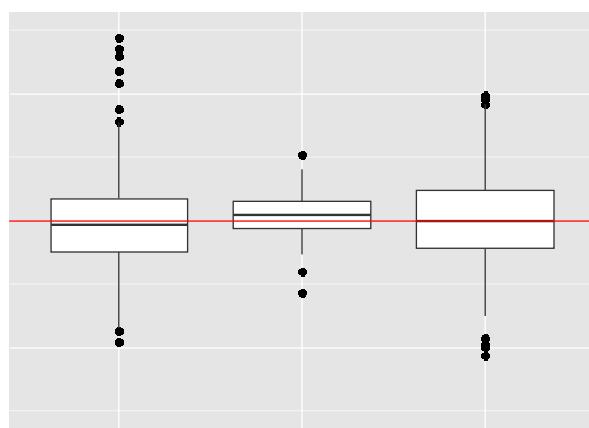
BOTH !

Back Transformation to G, error analysis

STEP5

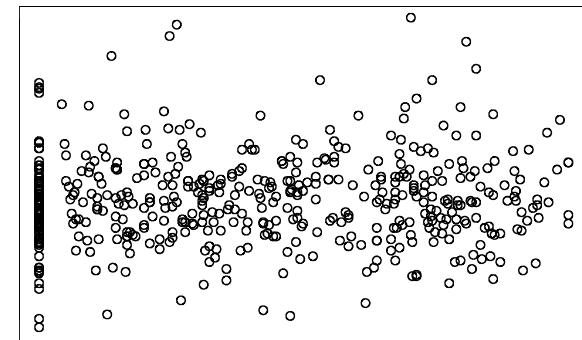


Species effect but not necessarily related to the lack of RDI equation



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^*G), biomass (ρ^*V), and number of stems/ha (but not yet done)