FORESEE
Forest Resource Estimation for Energy

FORESEE Workshop - Forestry applications of remote sensing technologies
8-10 October 2014 - INRA Champenoux - France

Combining LIDAR and growth and yield models to assess standing biomass in various forest ecosystems

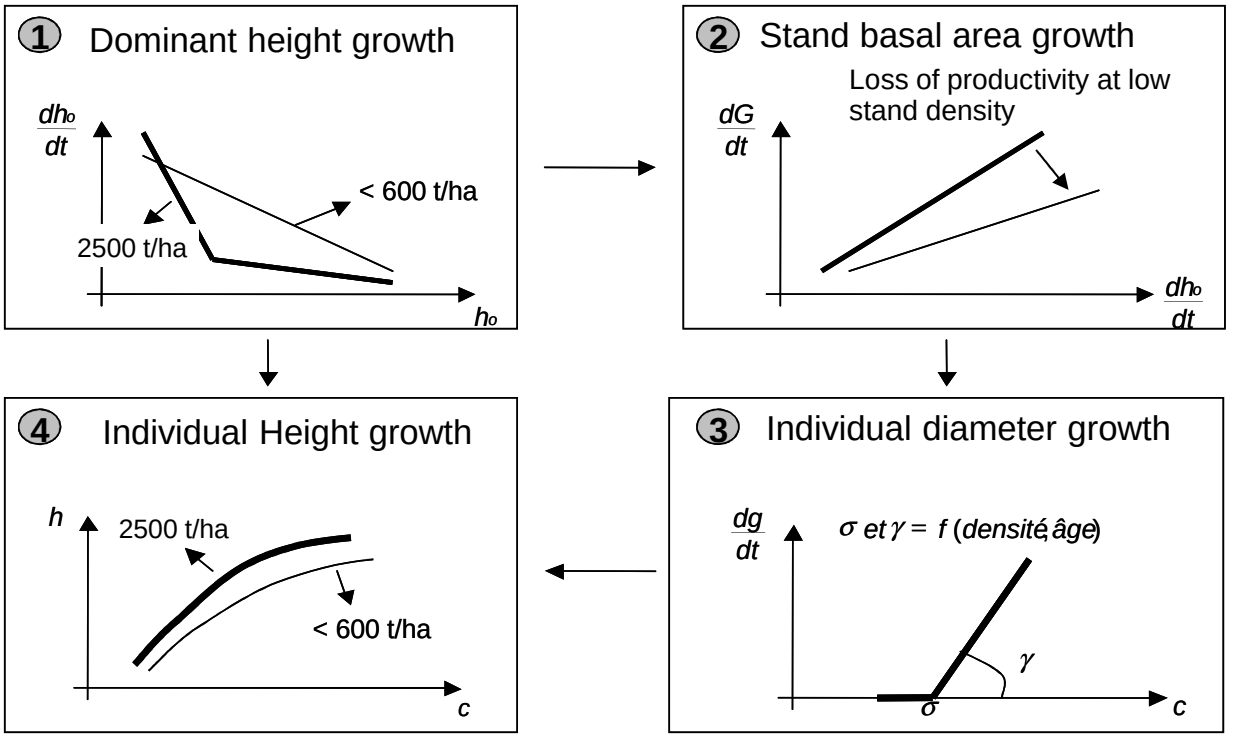
Saint-André L., JP Renaud, J. Bock, C. Vega

INTRODUCTION

Growth and Yield Theory

A robust approach to assess tree and stand growth

Where forest attributes are interrelated in a comprehensive way

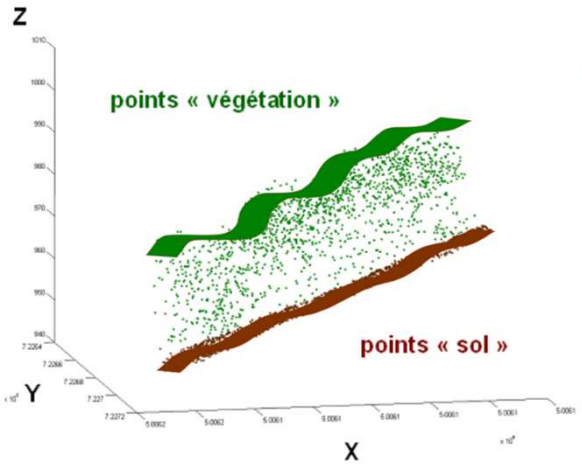


INTRODUCTION

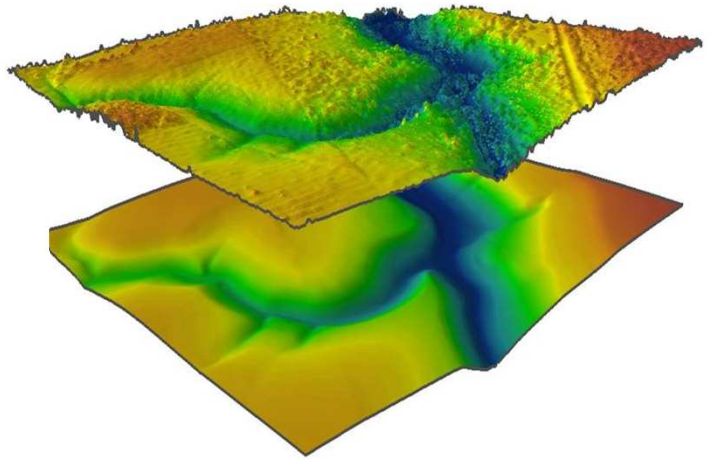
Aerial LIDAR

A robust approach to assess tree height (CHM) from DTM and DSM

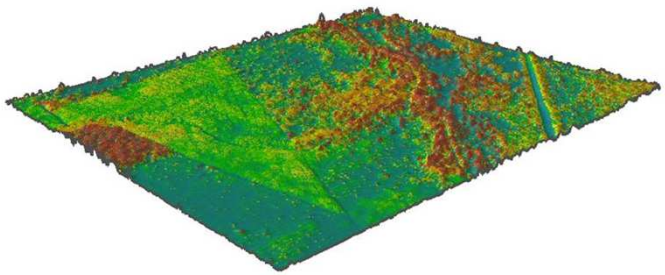
Gives access to the stand structure in 3D



MNS : Modèle numérique de surface



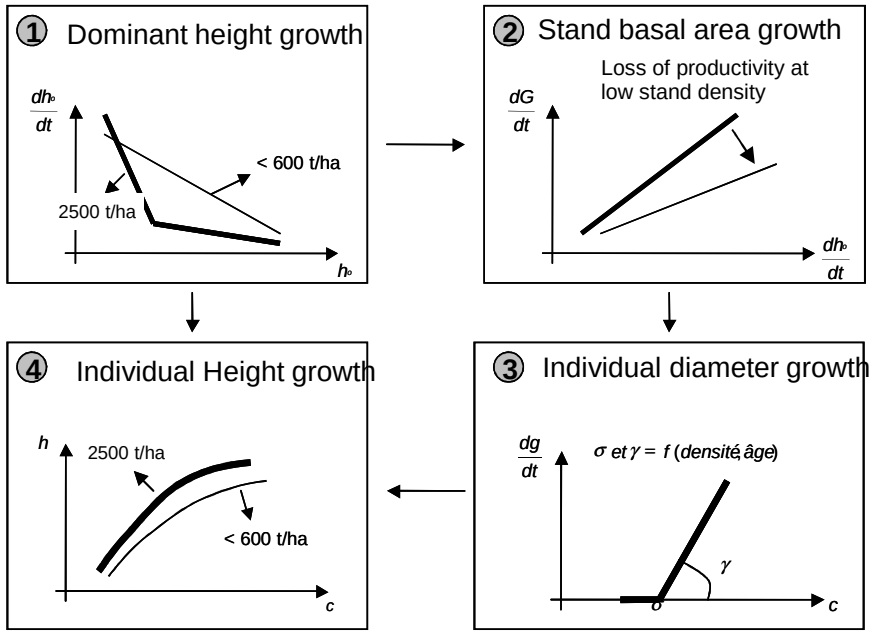
MNT : Modèle numérique de terrain



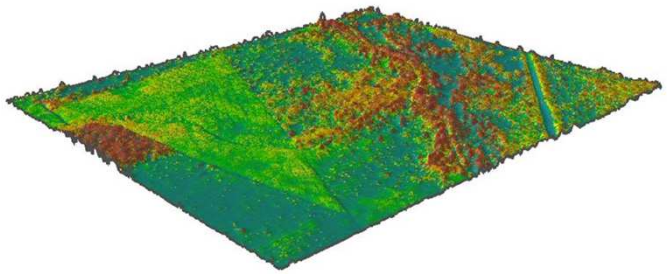
MNH: Modèle numérique de hauteur

INTRODUCTION

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

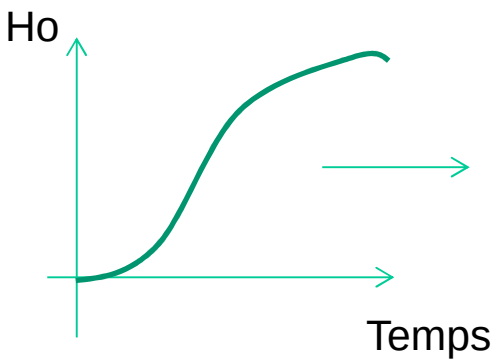
01

Methodological issues and flowchart diagram

Chosen approach

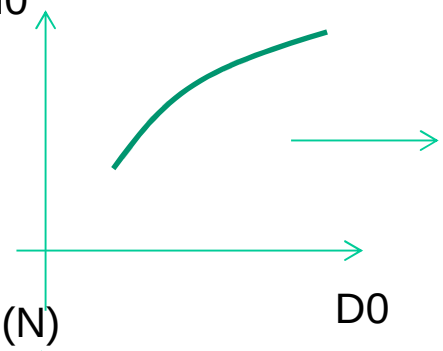
LIDAR (H)

Ho Dominant height



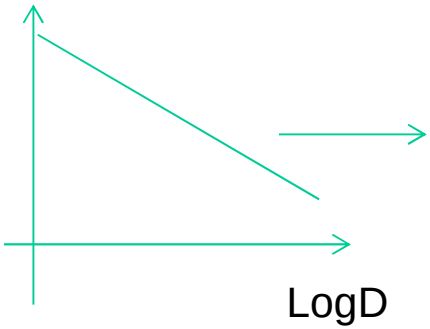
Potential growth (climate, soil)

D0 Dominant diameter



Allometry between height and diameter

Nmax and Gmax from the self-thinning law

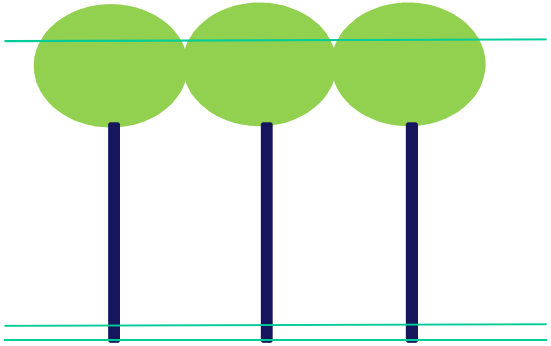


Maximum stockability knowing D0

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

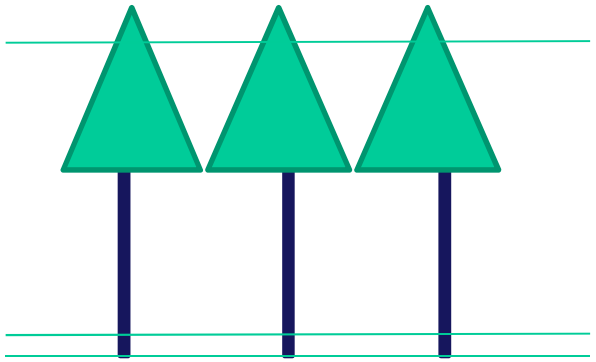


TxPen1m0.5H99_0.8H99.upp

TxPen1m0.5H99_0.8H99.low

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

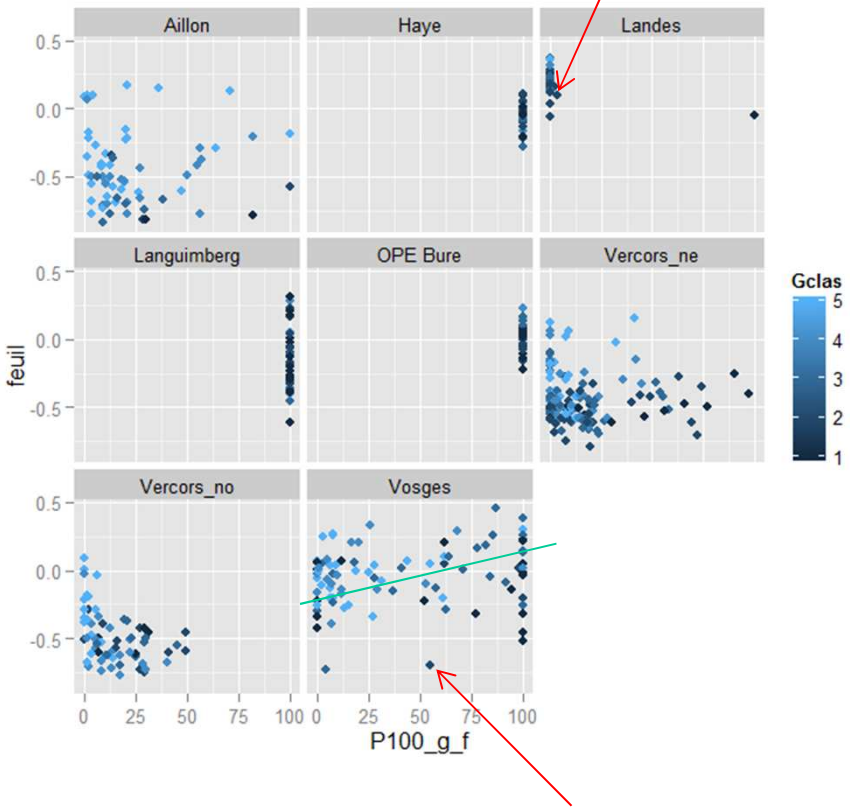
For coniferous, Feuil tends to be **negative** (lower extinction of the signal due to the canopy structure)



TxPen1m0.5H99_0.8H99.upp

TxPen1m0.5H99_0.8H99.low

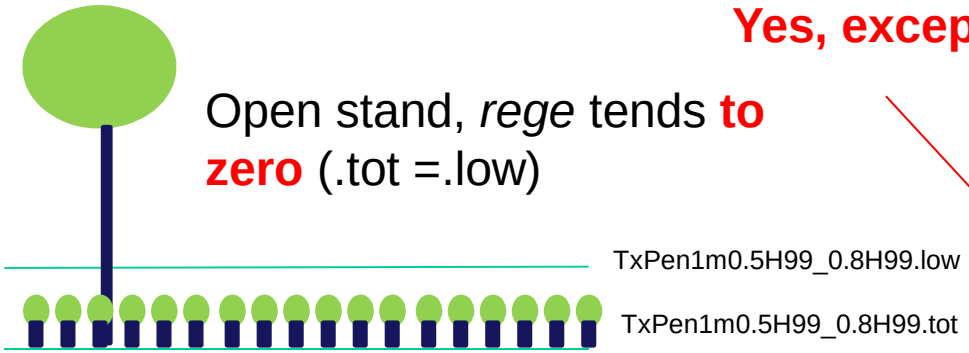
It works except for the Landes (looks like broadleaves)……



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

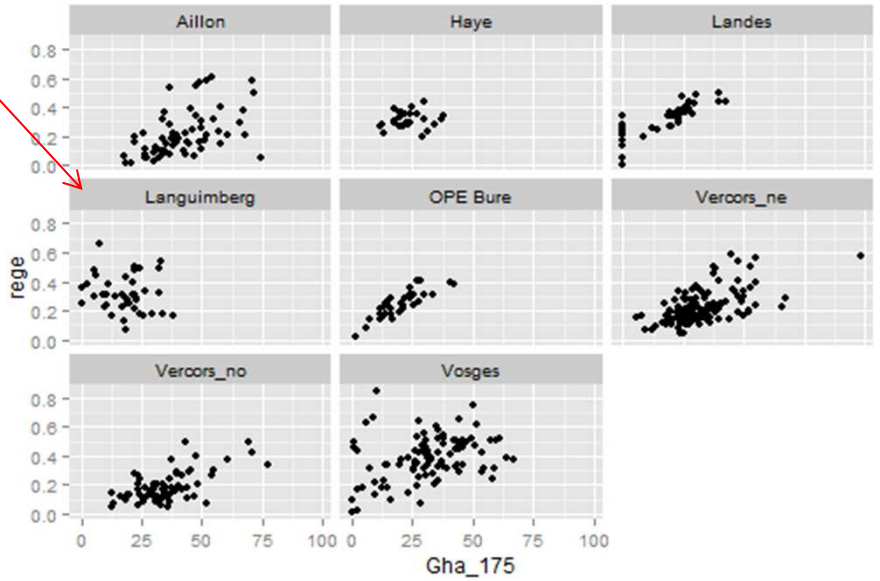
rege = TxPen1m0.5H99_0.8H99.low-TxPen1m0.5H99_0.8H99.tot

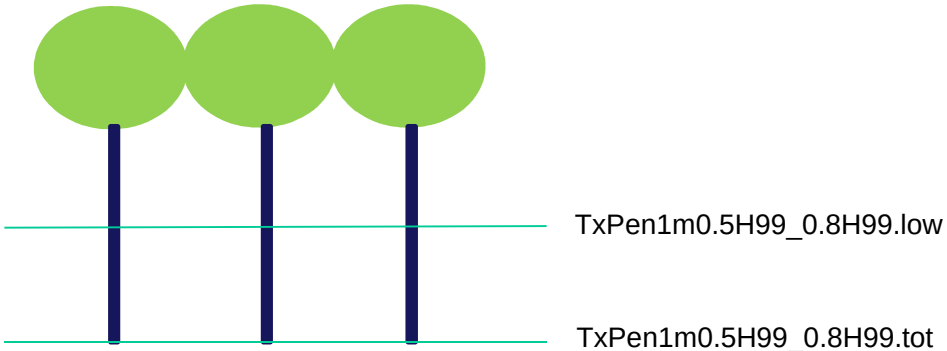
Some new metrics



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

Yes, except Languimberg……

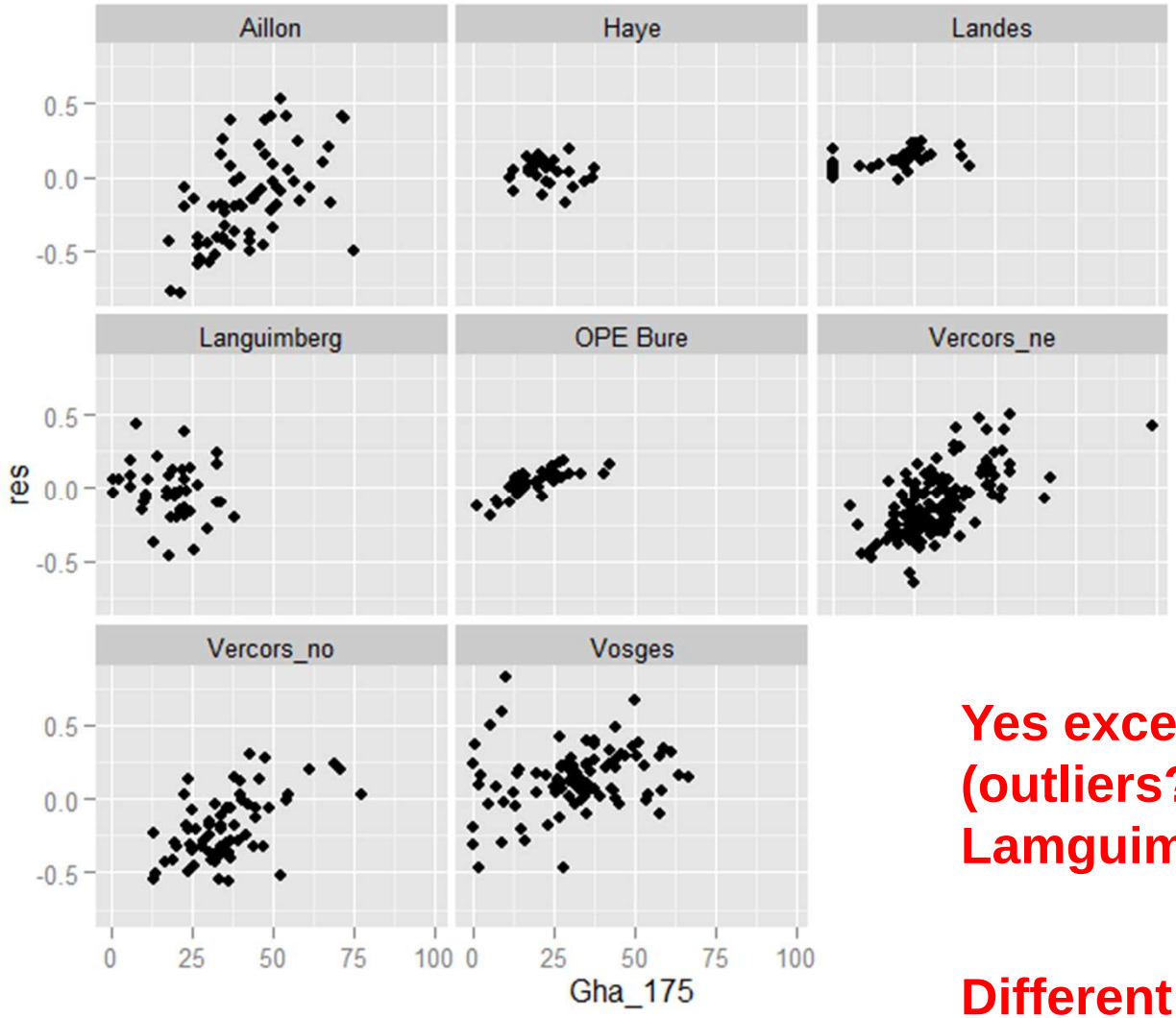




Close stand, *rege* **increases** because .tot is close to zero

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 Lamguimberg (Broadleaves)

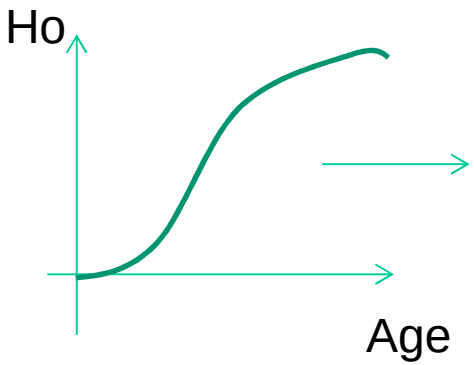
Different slopes between sites

02

Results

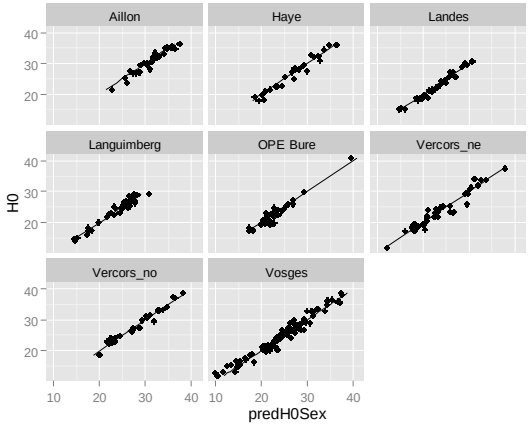
LIDAR

Ho Dominant Height



STEP1

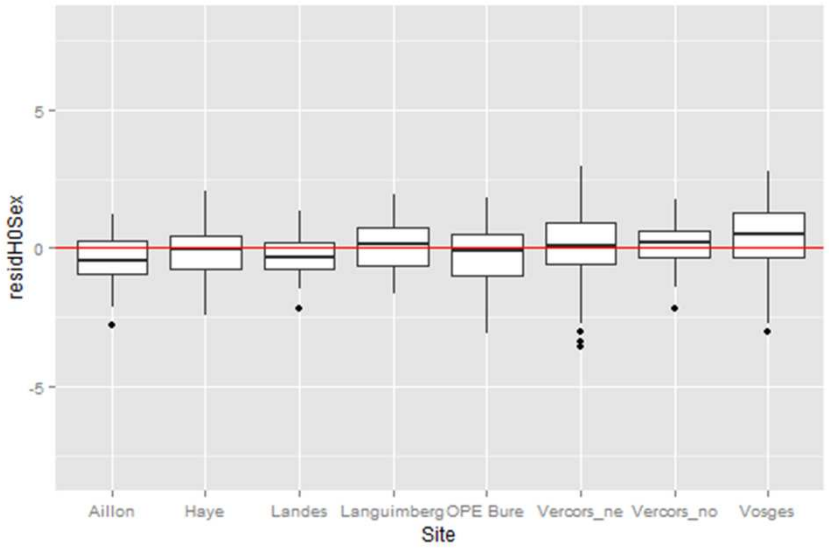
Potential growth (climate, soil)



Call:

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

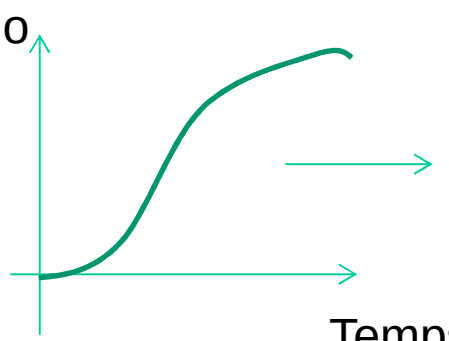
```
Formula: H0 ~ a1 + a2 * Pente_plac + (b1 + b2 * rege) * Hmv6_Bd

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

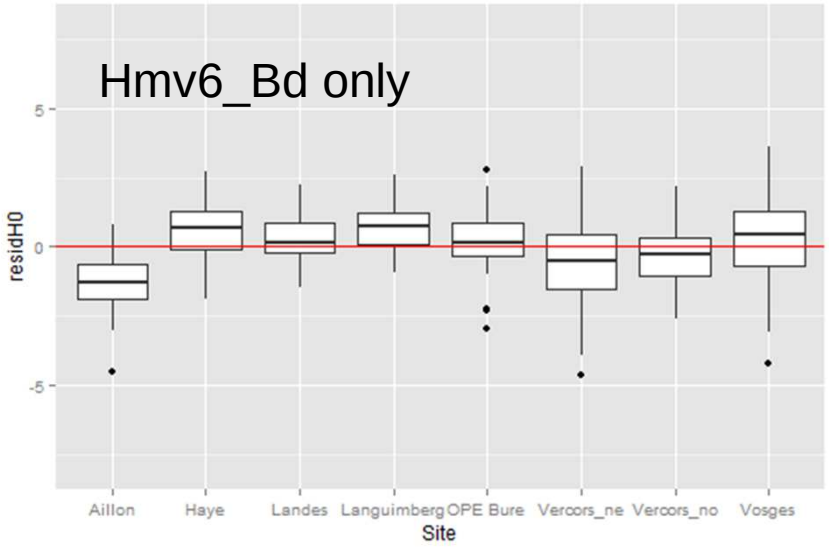
Ho hauteur dominante

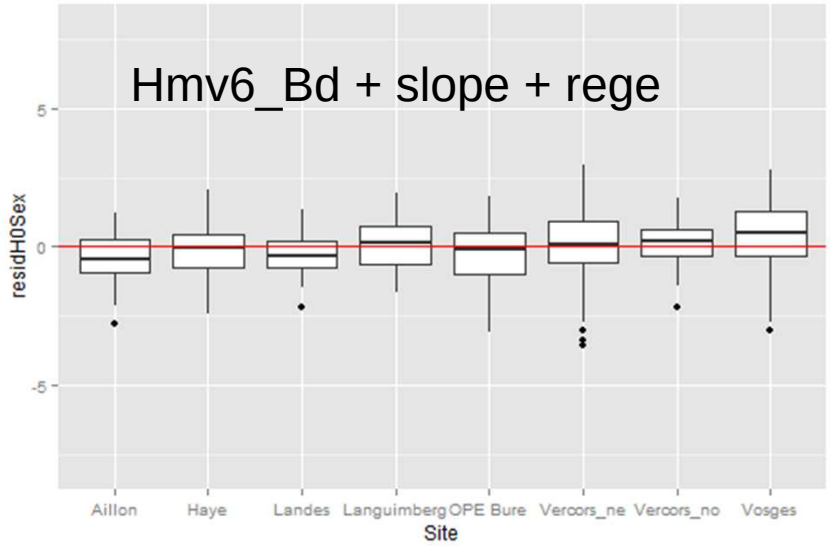


STEP1

Potentiel du milieu (climat, sol)

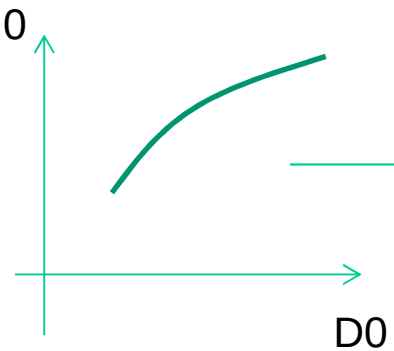
Model used for the rest of the study : **Hmv6_Bd**, corrected with « slope » (technical correction), and « rege » (stands with few big trees)





STEP2

D0 Dominant diameter

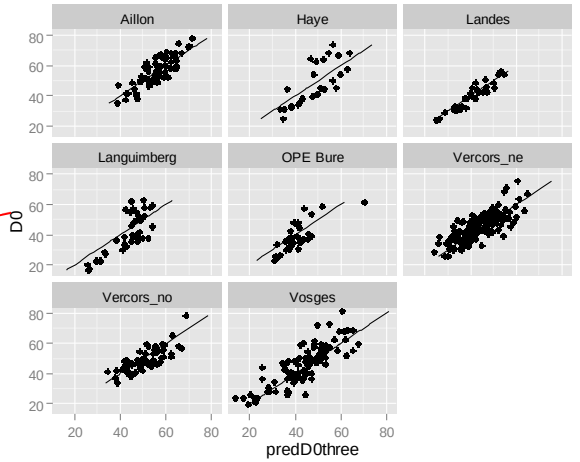


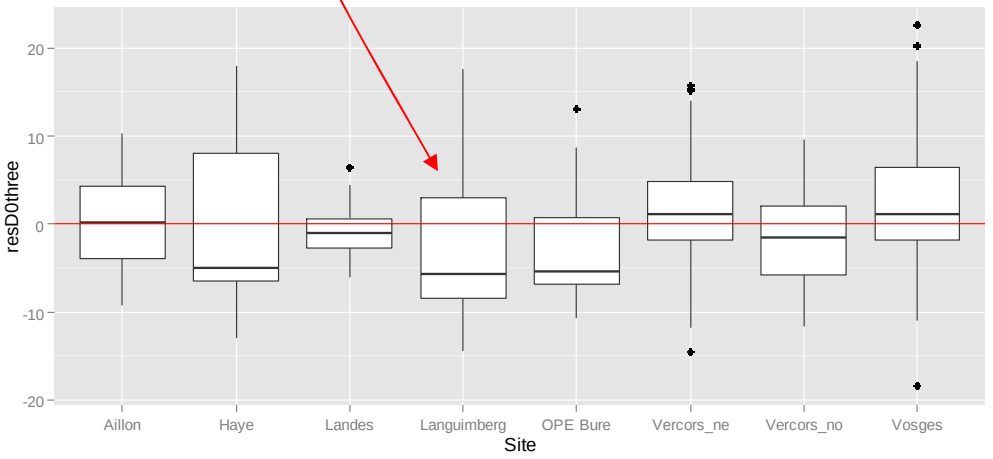
Allometry between height and diameter

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 * 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

Log (N)

Nmax and Gmax from the self-thinning law

LogD

Maximum stockability knowing D0

STEP3

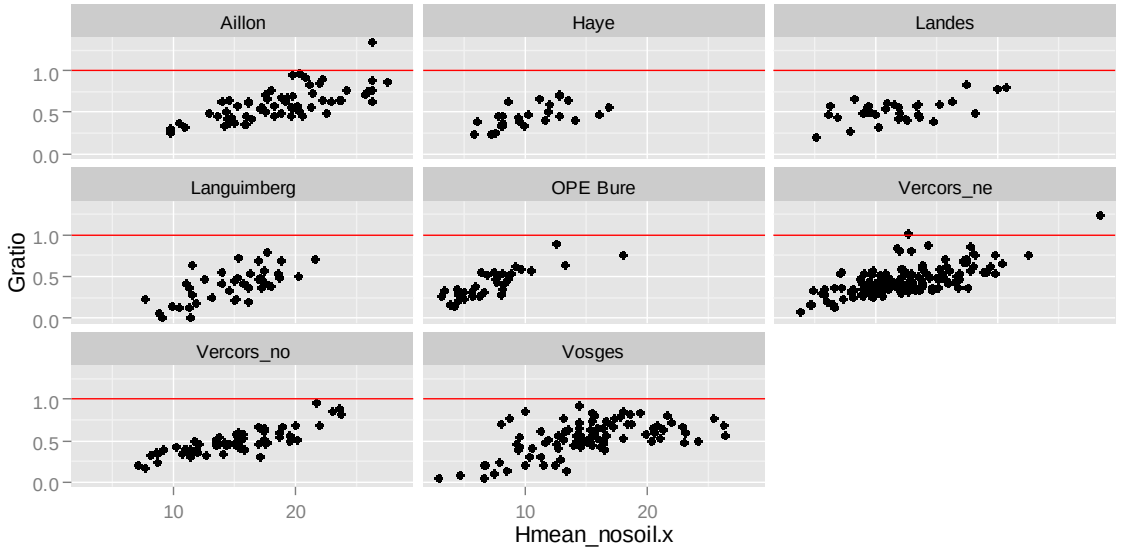
		rdi_a	rdi_b			rdi_a	rdi_b
Pubescent	oak	12.27	-1.809		A.F	12.50975	-1.85475
Pedunculate	oak	12.138	-1.758		AUL	12.50975	-1.85475
Sessile	oak	12.681	-1.911		BOU	12.50975	-1.85475
Common	beech	12.95	-1.941		CED	12.3472857	-1.73757143
Scots	pine	11.993	-1.615		CHA	12.50975	-1.85475
Aleppo	pine	12.512	-1.881		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, litterature data (Charru et al. 2012, Pretzch and Mette 2008, Pretzch 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

STEP4

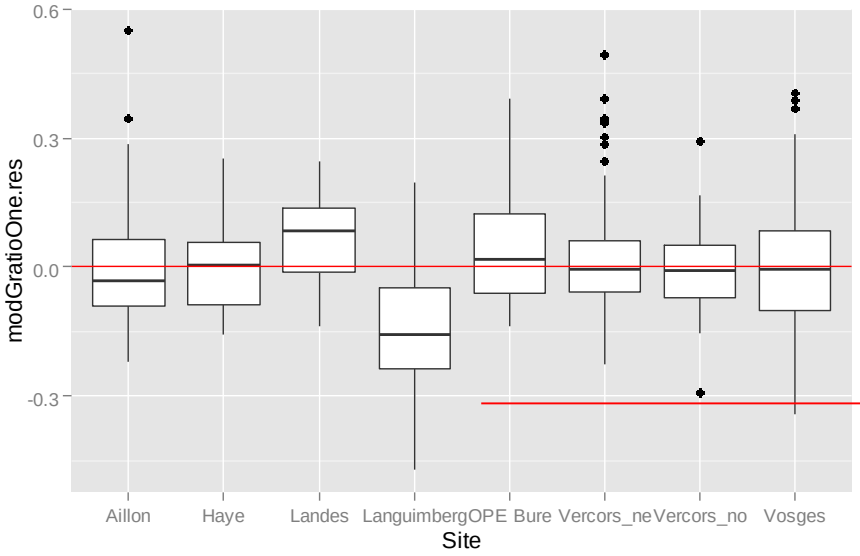
Call:

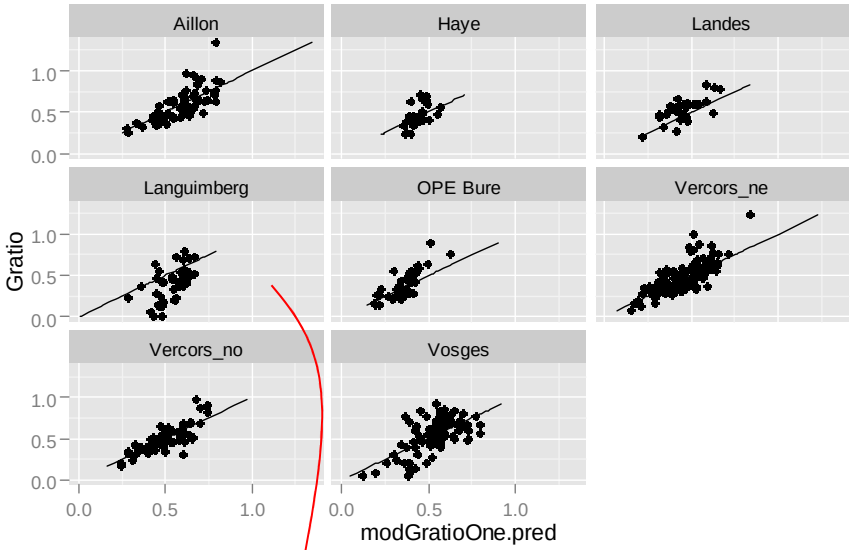
hMean_Nosoil, + intercept function of « percentTrou »
(account for stand stockability)

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: **0.4838**





Bias for Languimberg

Back Transformation to G

STEP5

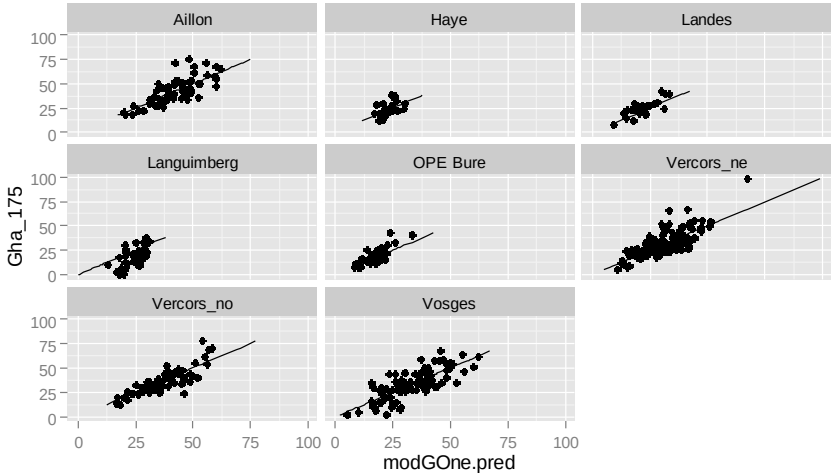
$$G = preGRatio * (D0)^2 * \exp(rdi\_a + rdi\_b * \log(D0))$$

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	***

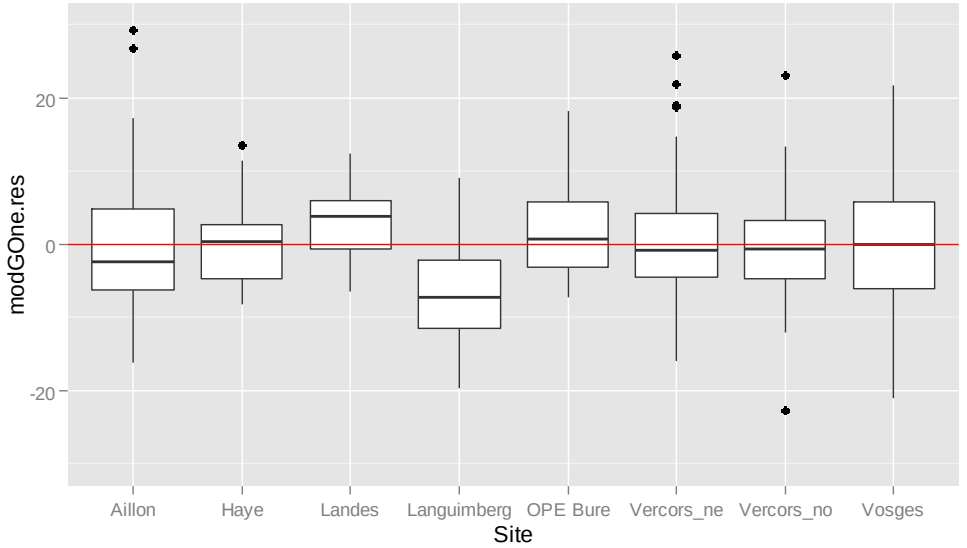
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: **7.95** on 509 degrees of freedom
Multiple R-squared: **0.6808**, Adjusted R-squared: **0.6801**
F-statistic: 1085 on 1 and 509 DF, p-value: < 2.2e-16



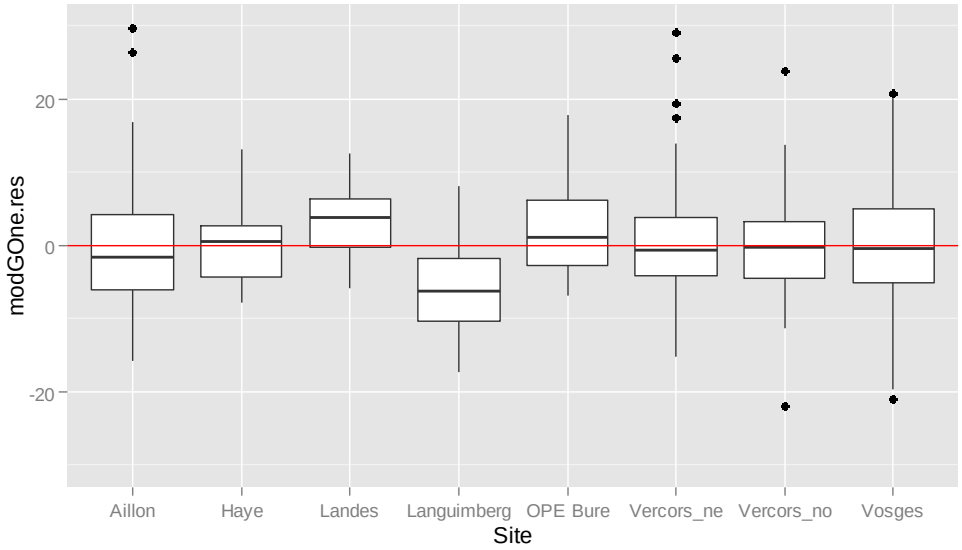
Good results but still a bias for Languimberg

- *Error progagation ?*
- *Site effect ?*

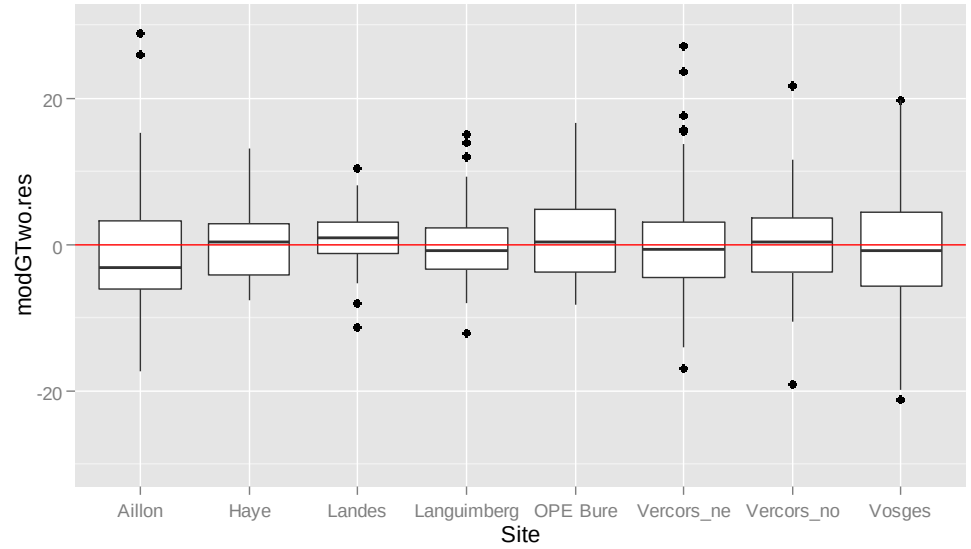


Back Transformation to G, error analysis

STEP5



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

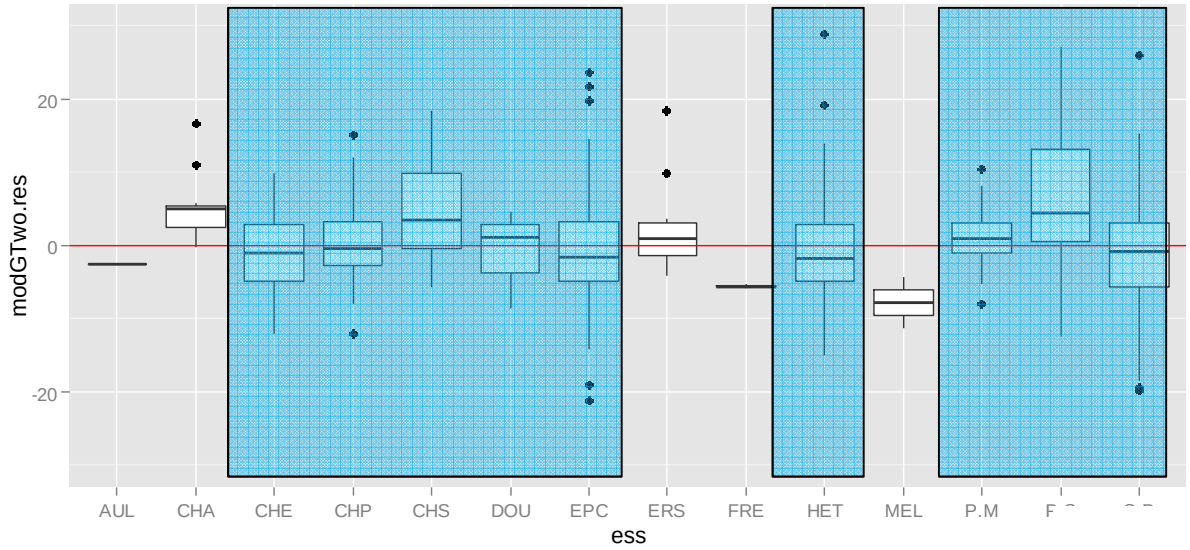


Gmax calculated with the measured D0 + fit site by site
R2=0.73, RMSE=7.28 m2/ha

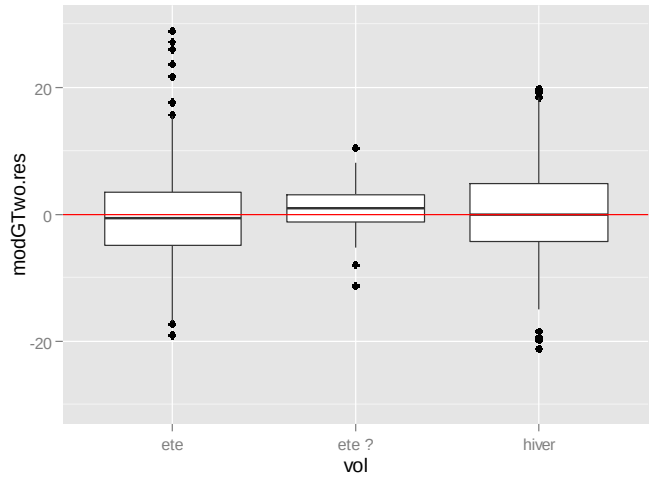
BOTH !

Back Transformation to G, error analysis

STEP5

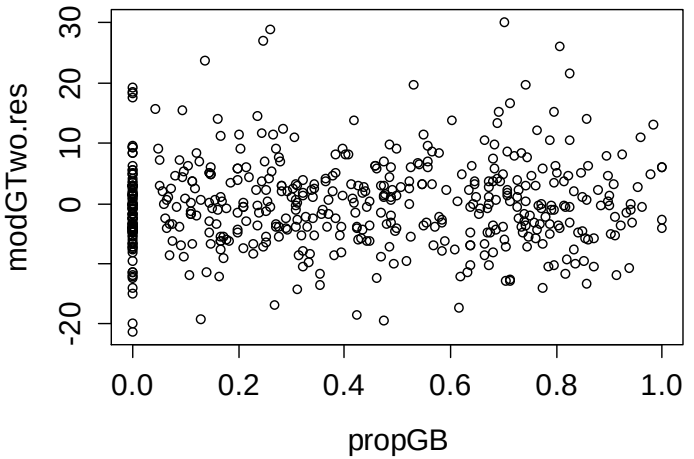


Species effect but not necessarily related to the lack of RDI equation



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 (rho*V), and number of stems/ha (but not yet done)