Biomass estiomation using LiDAR data

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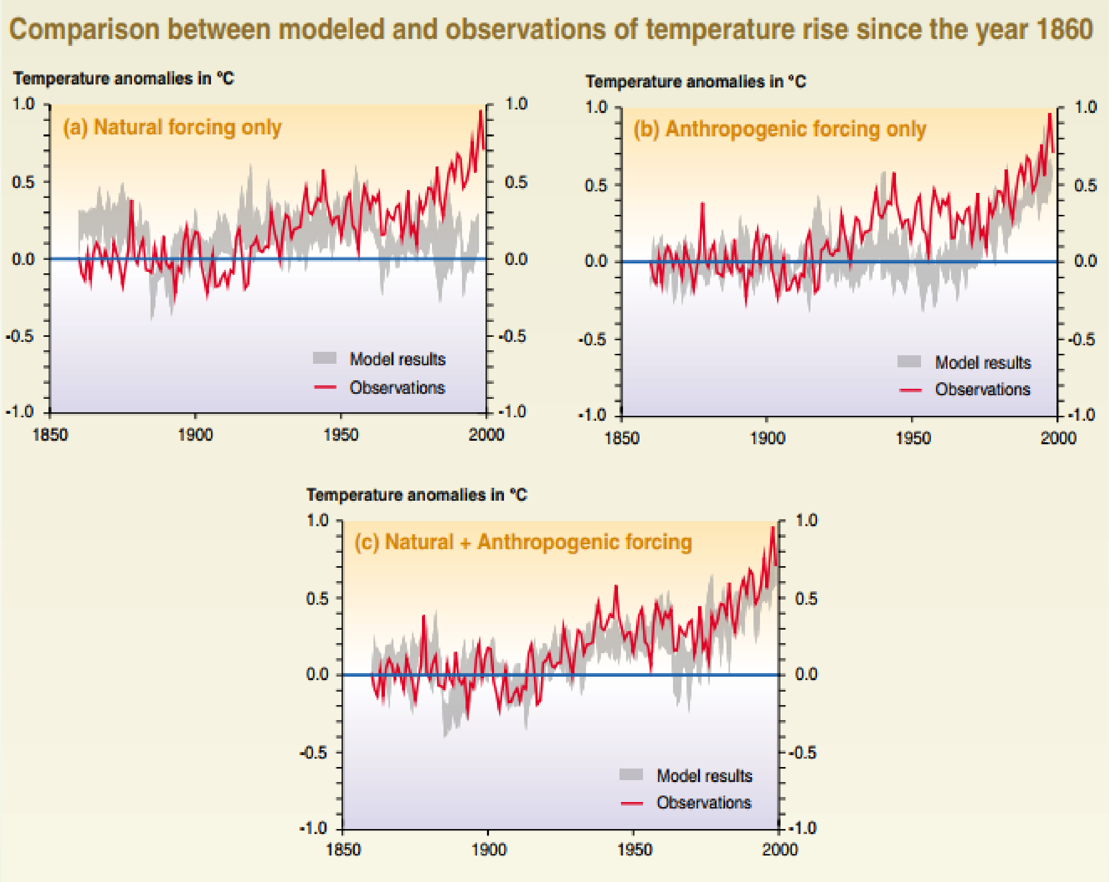
1. Introduction



IPCC, 2001

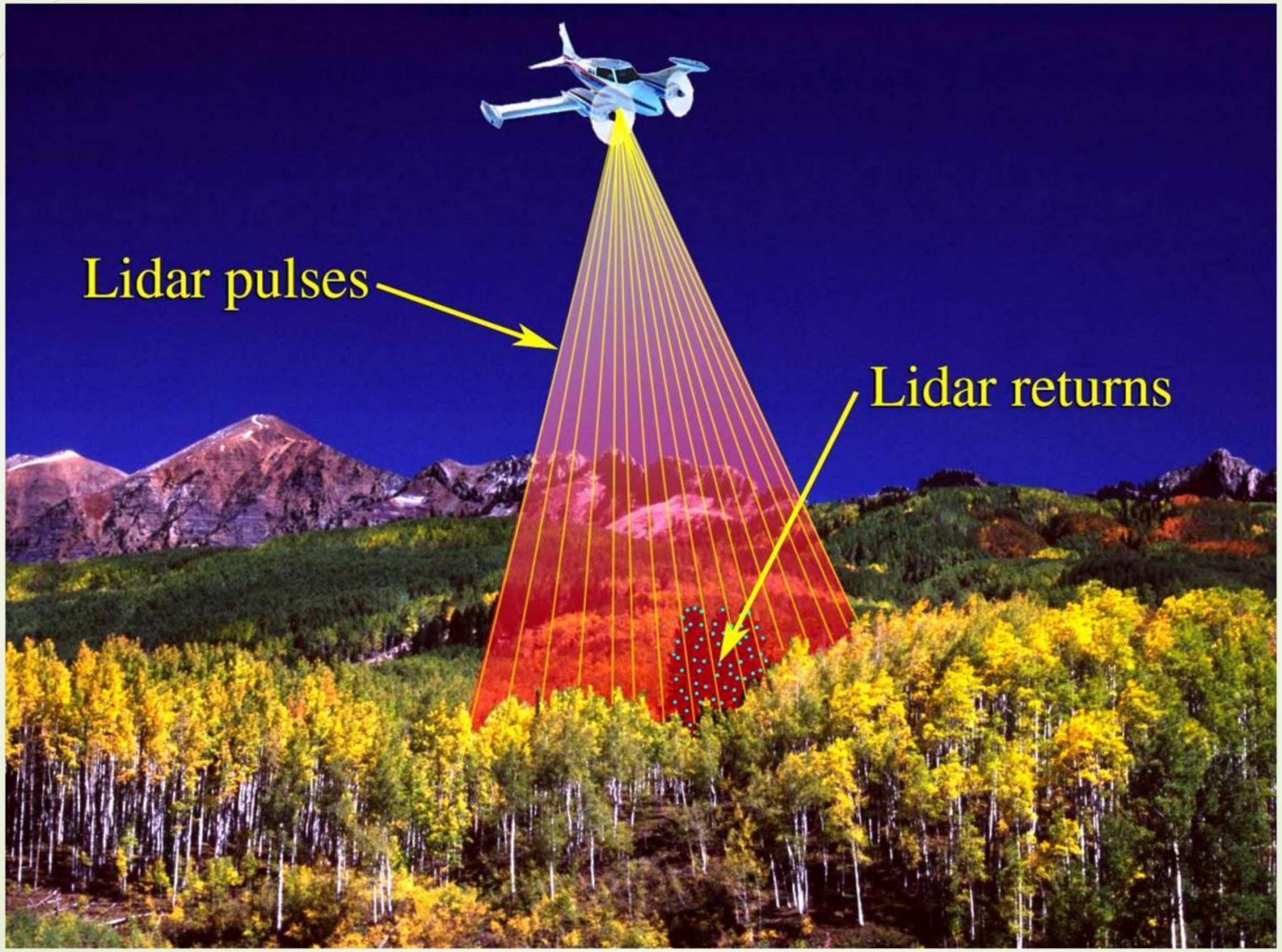
1. Introduction

- The main gas responsible for the greenhouse effect is carbon dioxide (CO_2), which concentrations have been seriously altered by humans in the carbon cycle.
- The deforestation causes big effects in the carbon cycle because of the loss of the photosynthetic ability of the eliminated forest vegetation and the simultaneous liberation of big quantities of carbon accumulated in the forest ecosystems for a long time. The sustainable development of the silviculture can contribute to mitigate the climate change in the long term, because it avoids the insertion of new carbon in the active cycle.
- The quantity of carbon retained in the biomass is one of the important aspects in the carbon cycle and it can be easily calculated from the dry biomass of the forest species.

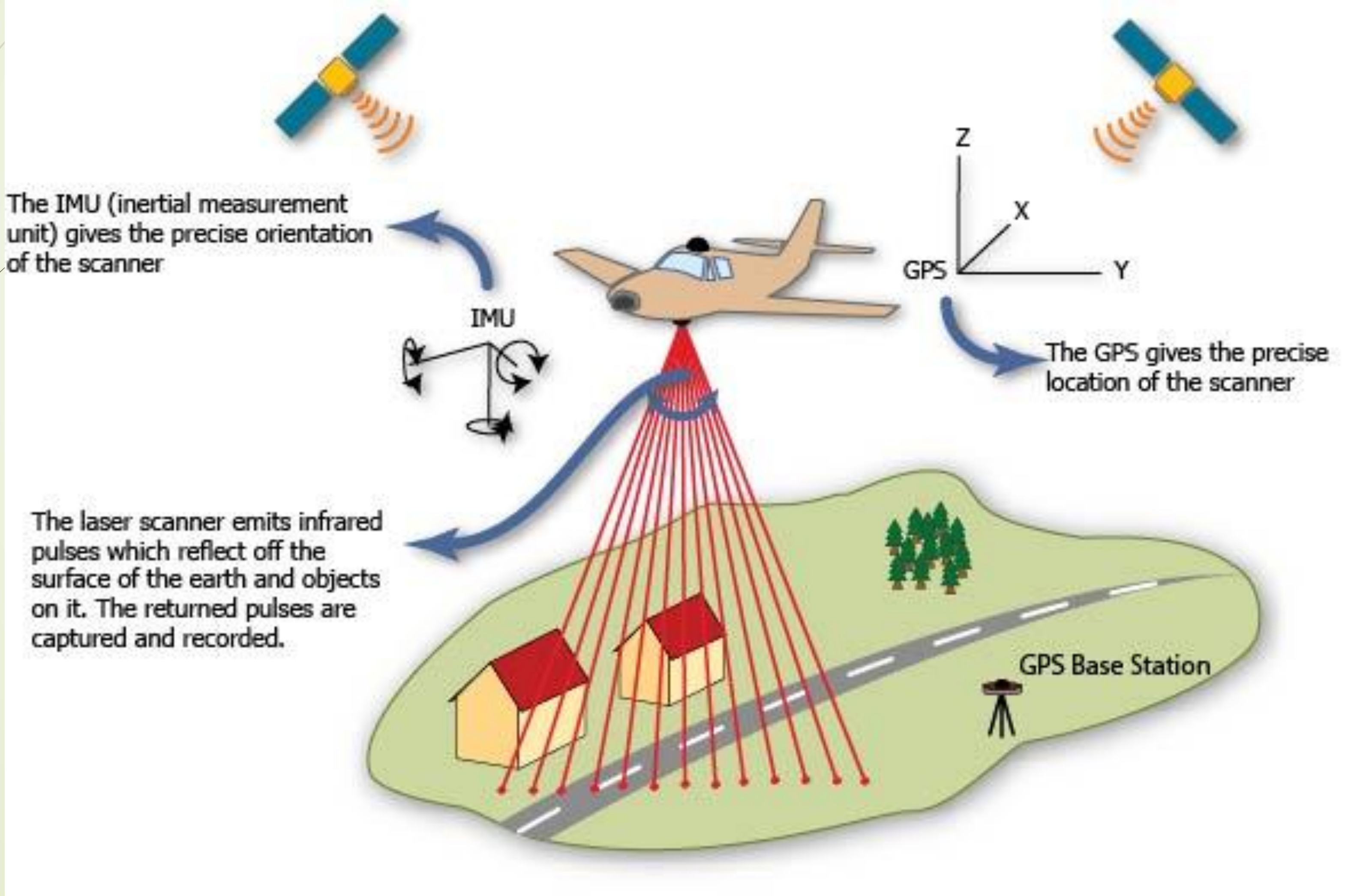
2. Objective

- Estimate above ground biomass for Pinus Radiata in the Arratia-Nervión region, evaluating the suitability of the LiDAR data provided for the entire Spanish territory in the frame of the National Plan of Aerial Orthophotography (PNOA) with a low sampling density of 0.5 pulse/m^2.

3. LiDAR

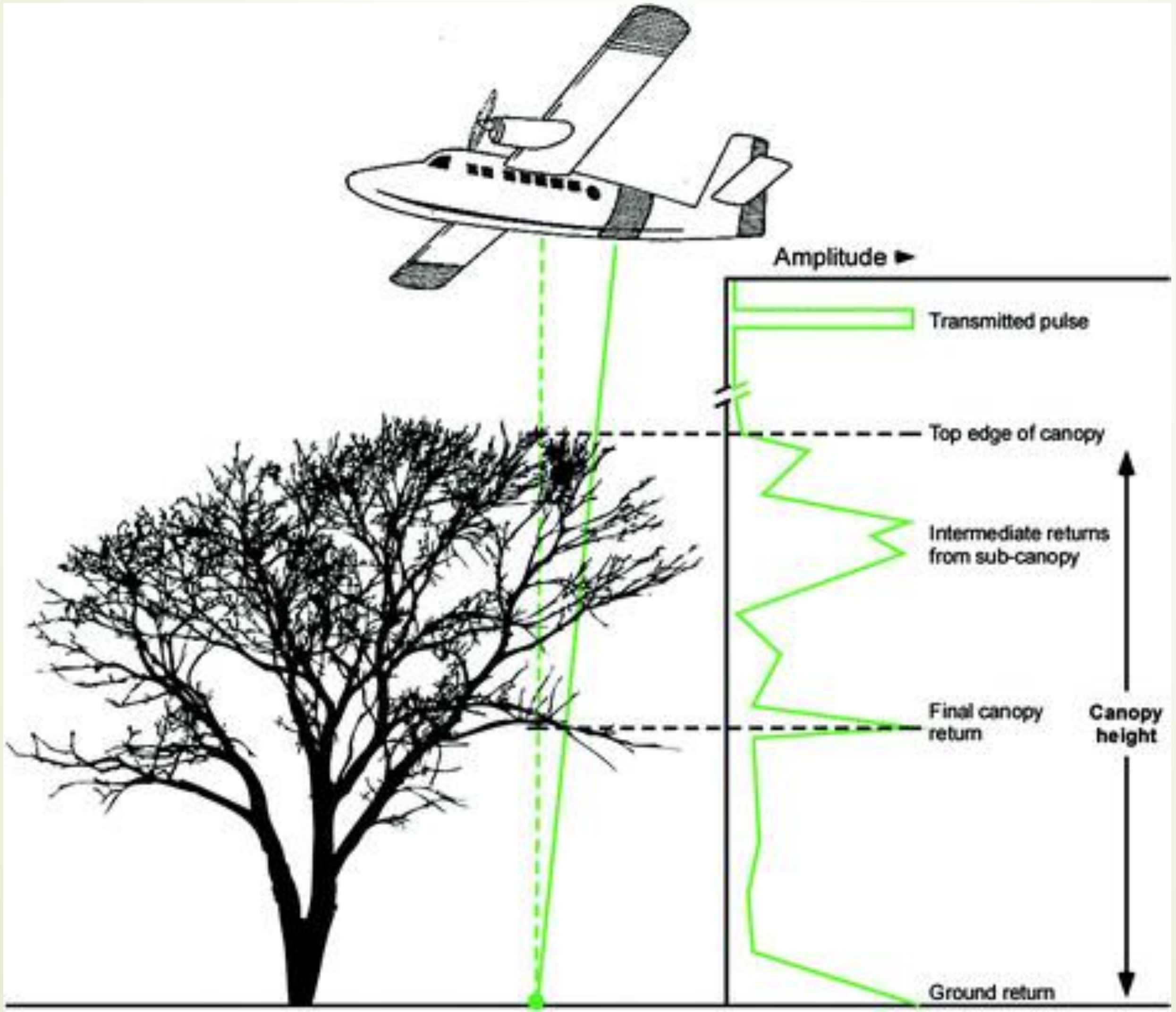


3. LiDAR



The IMU (inertial measurement unit) gives the precise orientation of the scanner
IMU
Z
X
GPS
Y
The GPS gives the precise location of the scanner
The laser scanner emits infrared pulses which reflect off the surface of the earth and objects on it. The returned pulses are captured and recorded.
GPS Base Station

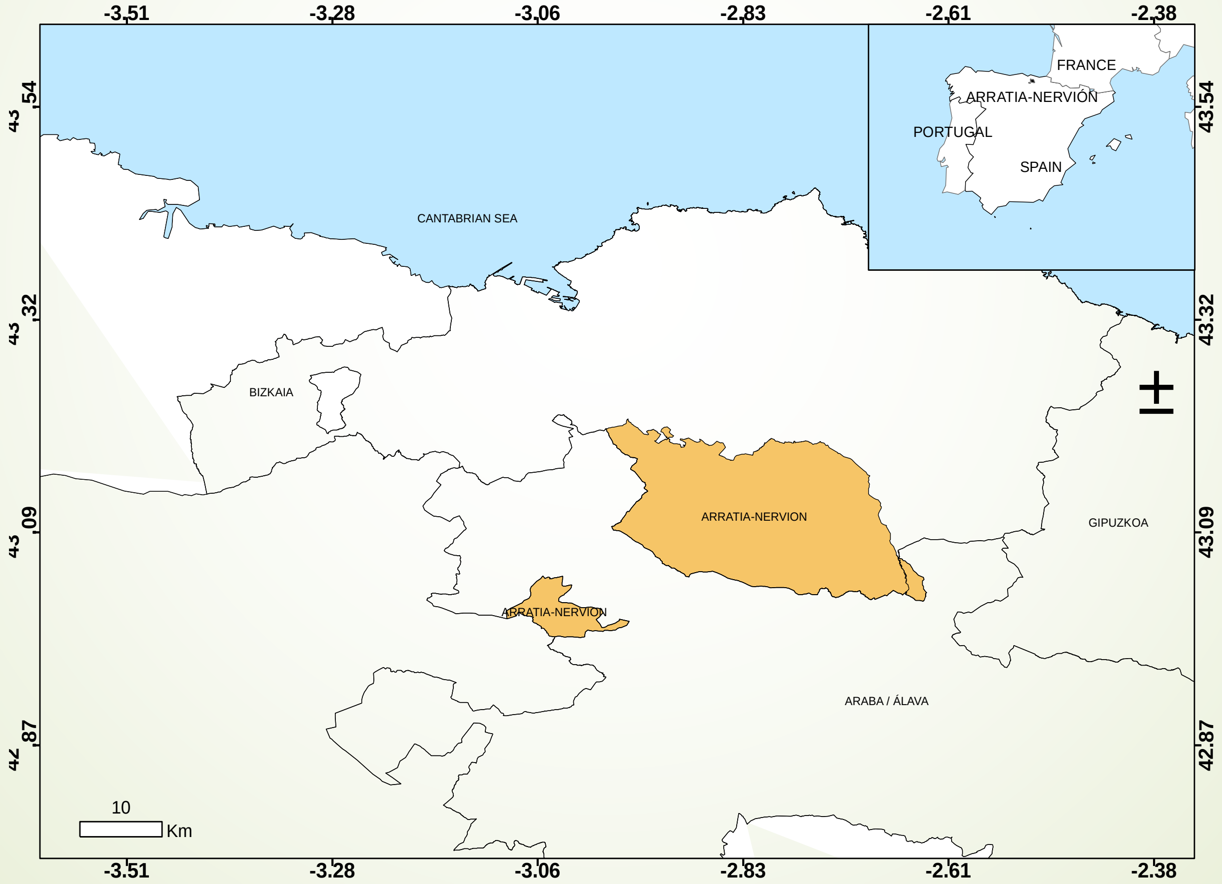
3. LiDAR



Amplitude ►
Transmitted pulse
Top edge of canopy
Intermediate returns from sub-canopy
Final canopy return
Canopy height
Ground return

4. Biomass estimation

- 4.1. Study area:

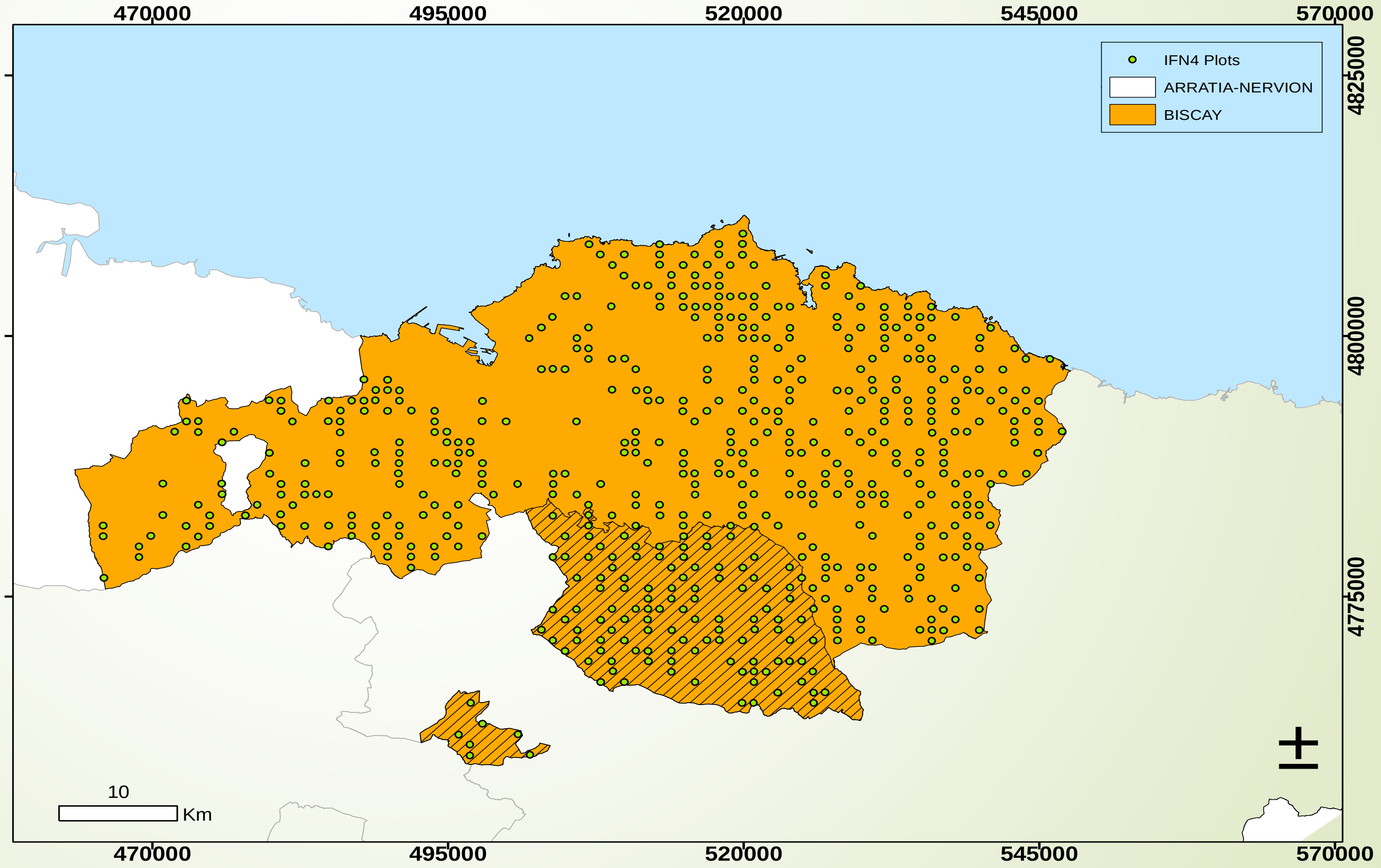


Arratia-Nervión región in Biscay, Basque Country

4. Biomass estimation

4.2 National Forestal Inventory 4 (NFI 4)

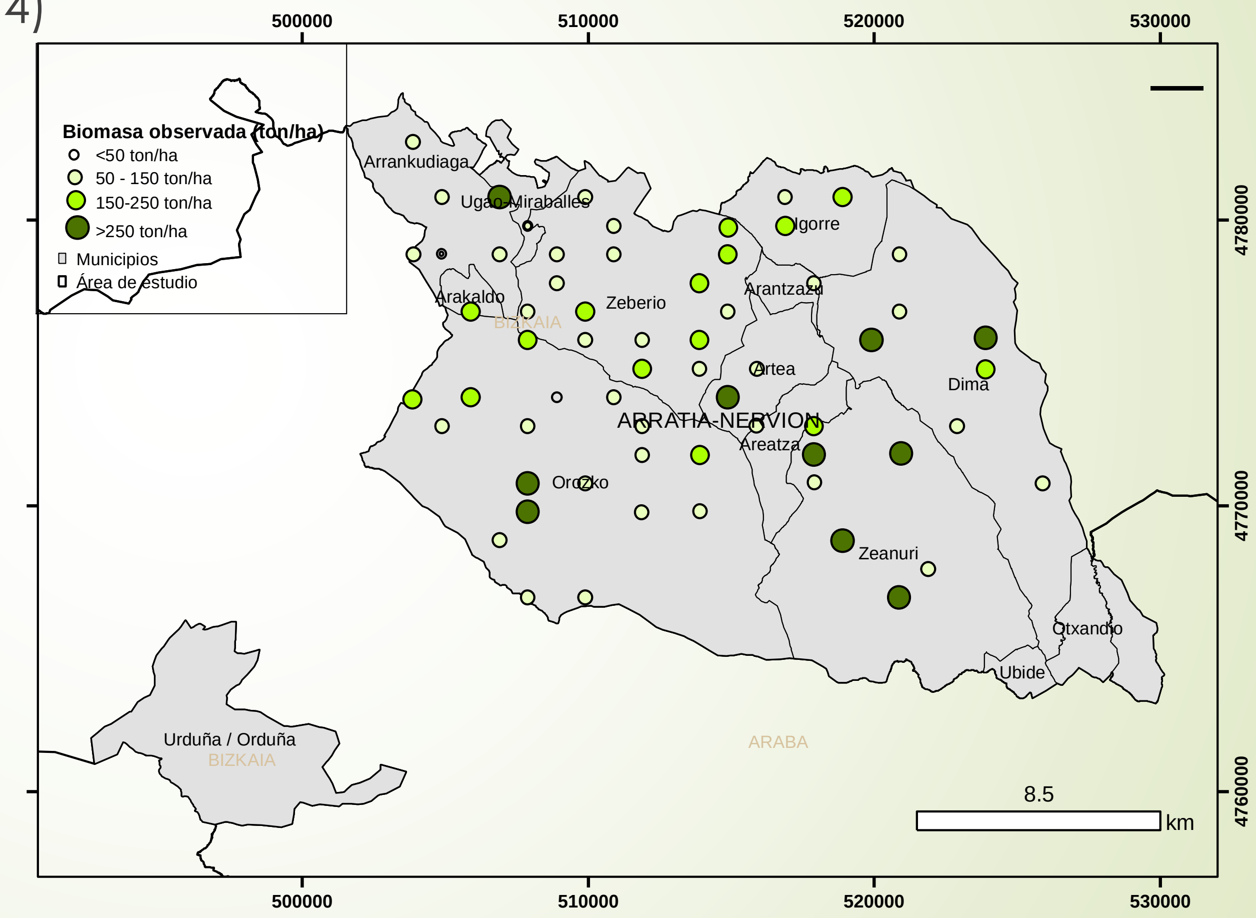
- 118 nested plots of 25 m radius (0.2 ha)



4. Biomass estimation

4.2 National Forestal Inventory 4 (NFI 4)

From the 118 plots located in the selected region, only the ones where the dominant specie was Pinus Radiata with> 80% occupation were selected (63 samples).

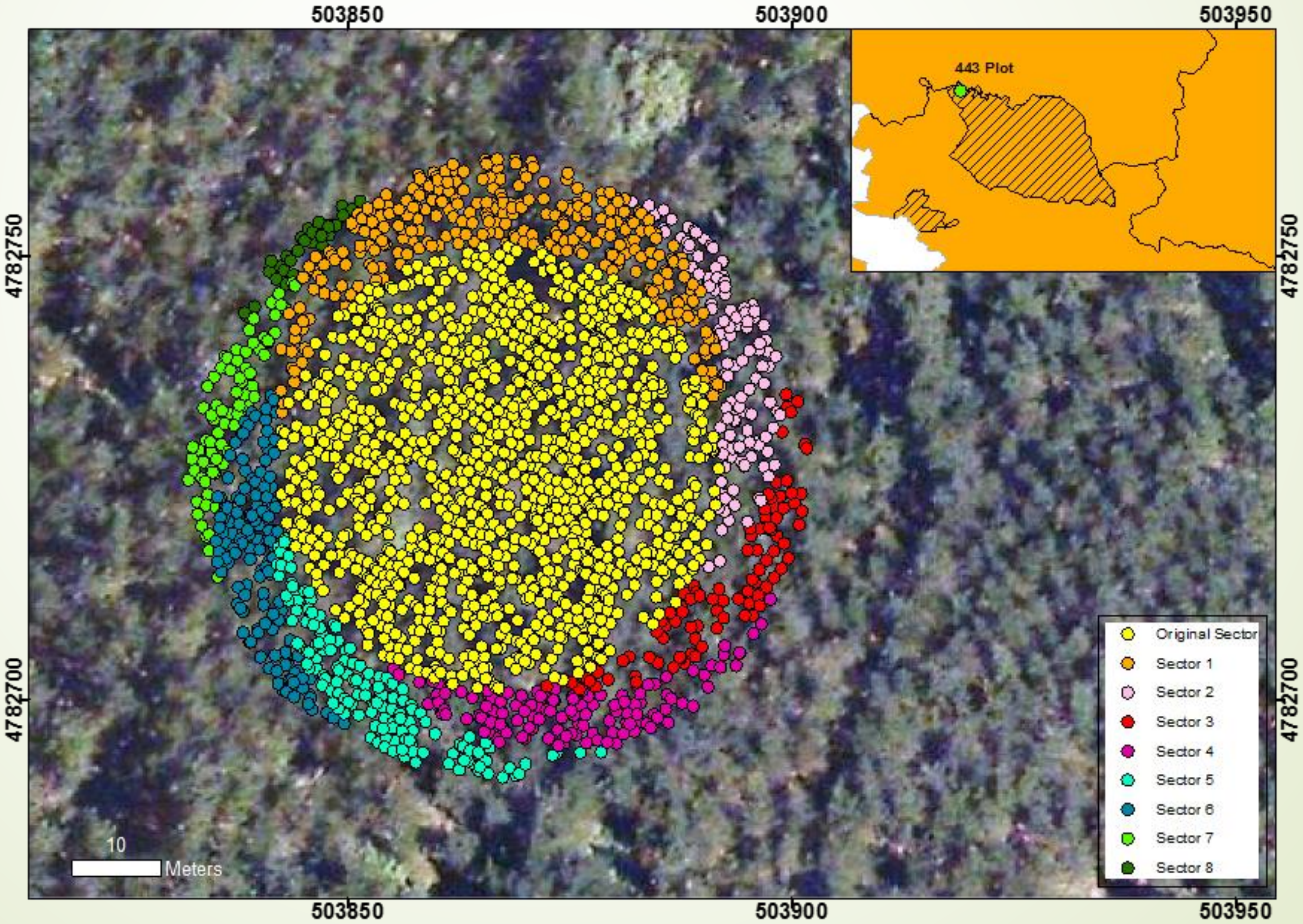


$$W_{(\frac{ton}{ha})} = 0.0009892(d^2h)^{1.023} - 0.00434d^2h + 61.57 - 6.978d + 0.3463d^2$$

(Canga et al. 2013)

4. Biomass estimation

- 4.3 Field plots positioning



4. Biomass estimation

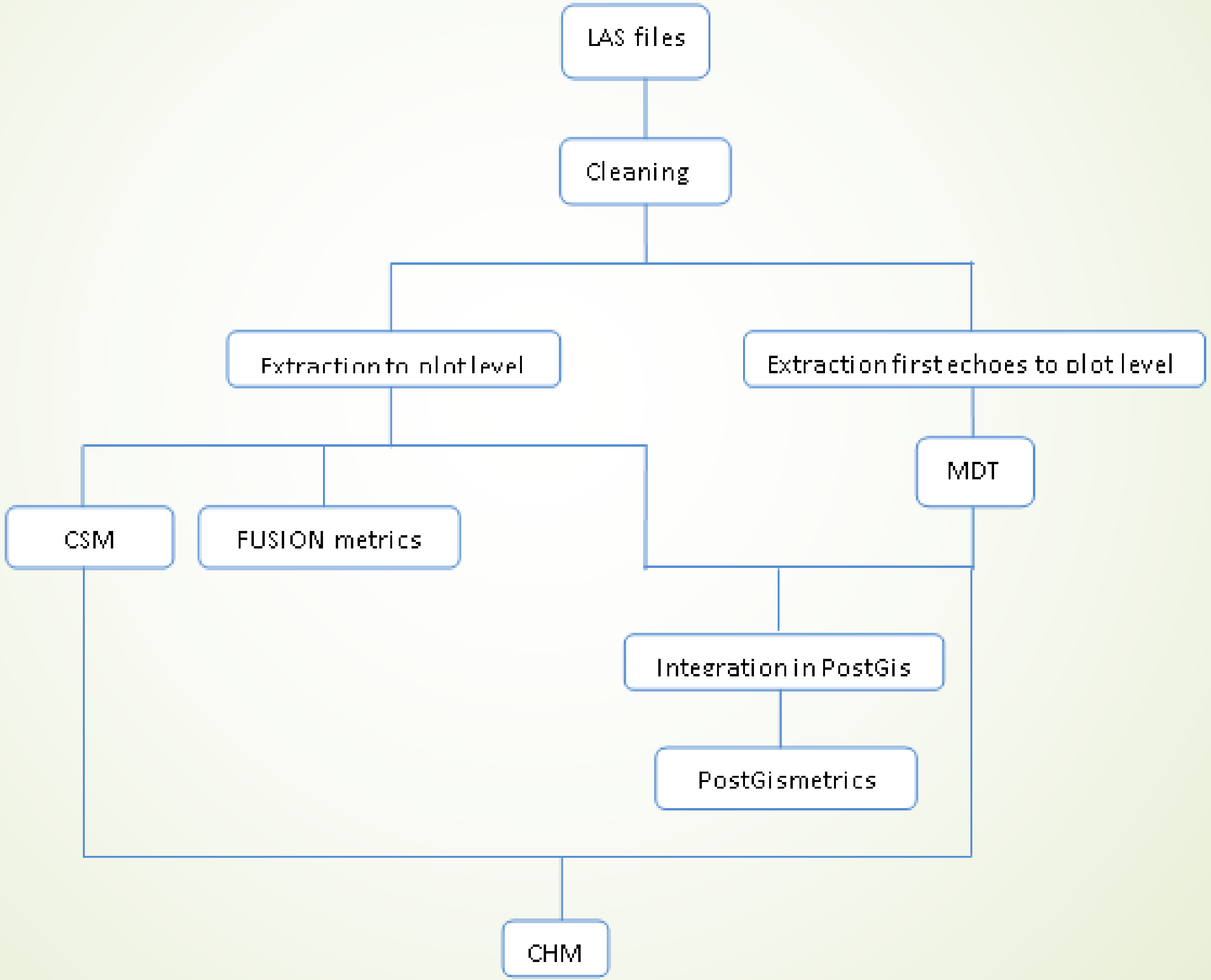
4.4 LiDAR data

- Collected between the 12th July to 28th August 2012

LiDAR flight parametrers	
Scan angle	60 °
Pulse Repetition Rate (PRR)	100 kHz
Scan frequency	70 kHz
Divergence	<0.5 mrad
Speed	51.4 m/s
Point density	0.5 points/ m^2
Height	1500 m

4. Biomass estimation

4.4 LiDAR data



Flow chart of the LiDAR data

4. Biomass estimation

- 4.4 LiDAR data

The algorithm developed to calculate the canopy density metrics divided the point clouds into 10 vertical layers of equal height, setting the low limit on 2m, to avoid shrubs and the upper limit as the percentile 95 of the height distributions.

The routine calculates the proportion of points of the total number of points contained above each layer, so 10 canopy densities were computed (tr_1...tr_10).

4. Biomass estimation

4.5 Multiple regression technique

$$\hat{y} = b_0 + b_1 x_1 + \cdots + b_k x_k$$

1. Correlation matrix between observed biomass and the obtained metrics
2. Two variable or three variable combinations
3. R^2 (coefficient of determination)
4. Principles of the lineal regression technique

4. Biomass estimation

4.6 Results

	0	1	2	3	4	5	6	7	8
0	1.00	0.99	0.99	0.97	0.96	0.98	0.98	0.98	0.98
1	0.00	1.00	0.99	0.96	0.94	0.95	0.95	0.97	0.98
2	0.00	0.00	1.00	0.98	0.95	0.95	0.95	0.96	0.96
3	0.00	0.02	0.00	1.00	0.98	0.98	0.94	0.93	0.91
4	0.00	0.00	0.00	0.00	1.00	0.98	0.94	0.93	0.91
5	0.00	0.00	0.00	0.00	0.02	1.00	0.98	0.97	0.95
6	0.00	0.00	0.02	0.00	0.02	0.02	1.00	0.99	0.96
7	0.00	0.00	0.00	0.00	0.00	0.02	0.02	1.00	0.98
8	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Cohen concordance test for parcel 443

4. Biomass estimation

4.6 Results

	Variables	R^2	R^2 ajus.	SE	Shapiro-Wilk	Breustch-Pagan	Durbin-Watson	VIF	RESET	Bonferroni
1	Elev P99-(All returns above mean) / (Total first returns) * 100	0.77	0.76	0.26	0.10	0.12	0.54	1.28	0.62	0.04
2	Elev P95-(All returns above mean) / (Total first returns) * 100	0.77	0.76	0.26	0.07	0.23	0.55	1.27	0.64	0.06
3	Elev P95-tr_30	0.76	0.75	0.26	0.30	0.24	0.54	1.11	0.25	0.05
4	Total return count above 2.00-Elev P95	0.76	0.75	0.26	0.13	0.19	0.69	1.10	0.96	0.05
5	Elev P95-(All returns above 2.00) / (Total first returns) * 100	0.76	0.75	0.26	0.18	0.20	0.61	1.12	0.49	0.05
6	Elev P95-tr_20	0.76	0.75	0.26	0.10	0.23	0.58	1.10	0.28	0.06
7	Elev P95-tr_10	0.76	0.75	0.26	0.18	0.20	0.60	1.11	0.51	0.05
8	Elev P95-tr_40	0.76	0.75	0.26	0.08	0.23	0.52	1.14	0.14	0.05
9	Elev P90-(All returns above mean) / (Total first returns) * 100-	0.76	0.75	0.26	0.03	0.29	0.57	1.27	0.56	0.05

Results of the best models

4. Biomass estimation

4.6 Results

lnBiomass=3.237172+(0.063358·p95)+$(0.475342 \cdot tr\_3)$

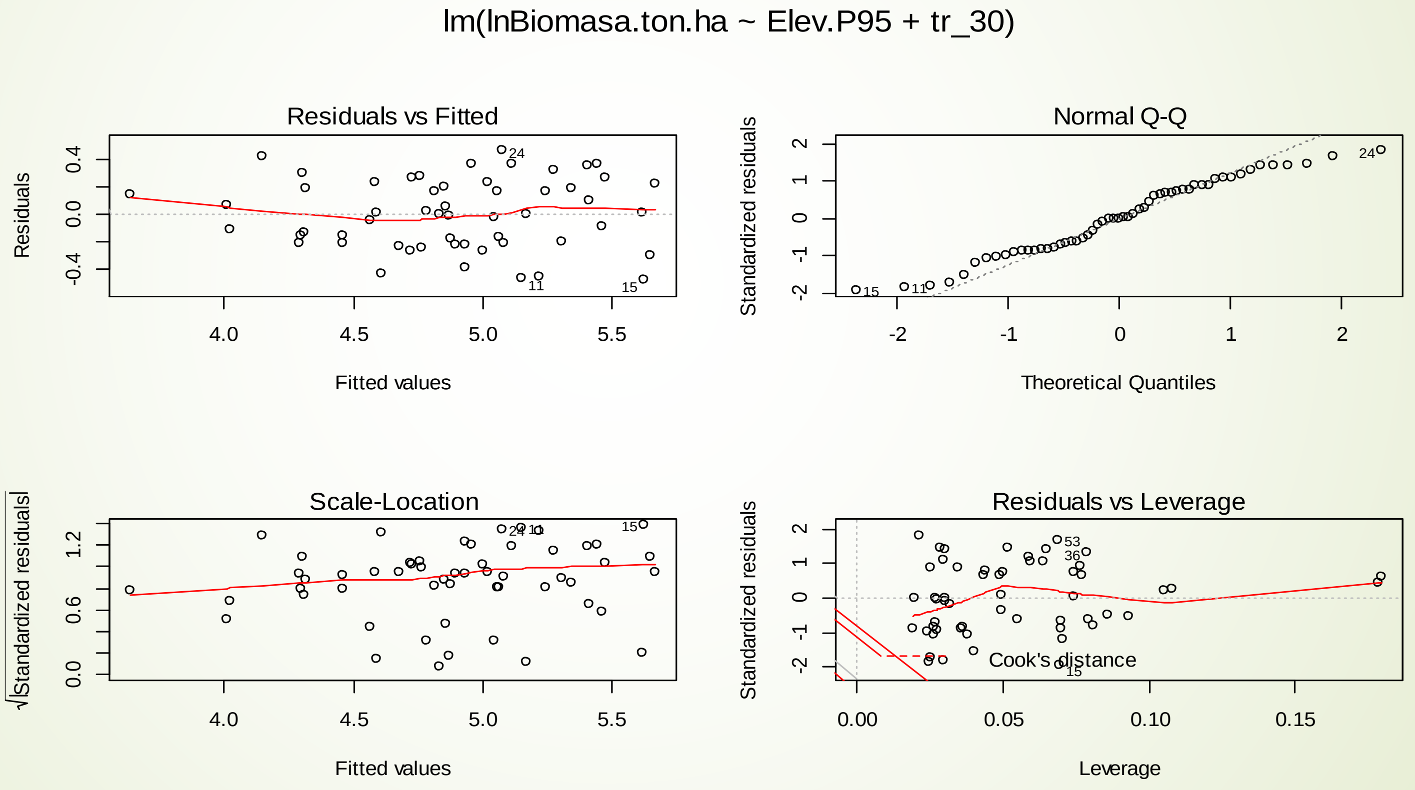
The mathematical transformation from logarithmic to arithmetic values implies certain asymmetry in the distribution of the arithmetic values that can produce a sub estimation of the biomass, so a correction factor depending on the standard error estimation of the model should be applied:

$$FC = e^{\left(\frac{SEE^2}{2}\right)} = 1.034162913$$

$$\boxed{Biomass_{\left(\frac{ton}{ha}\right)} = 1.034162913 * e^{\left((3.237172+(0.063358 \cdot p95)+(0.475342 \cdot tr_3)\right)}}$$

4. Biomass estimation

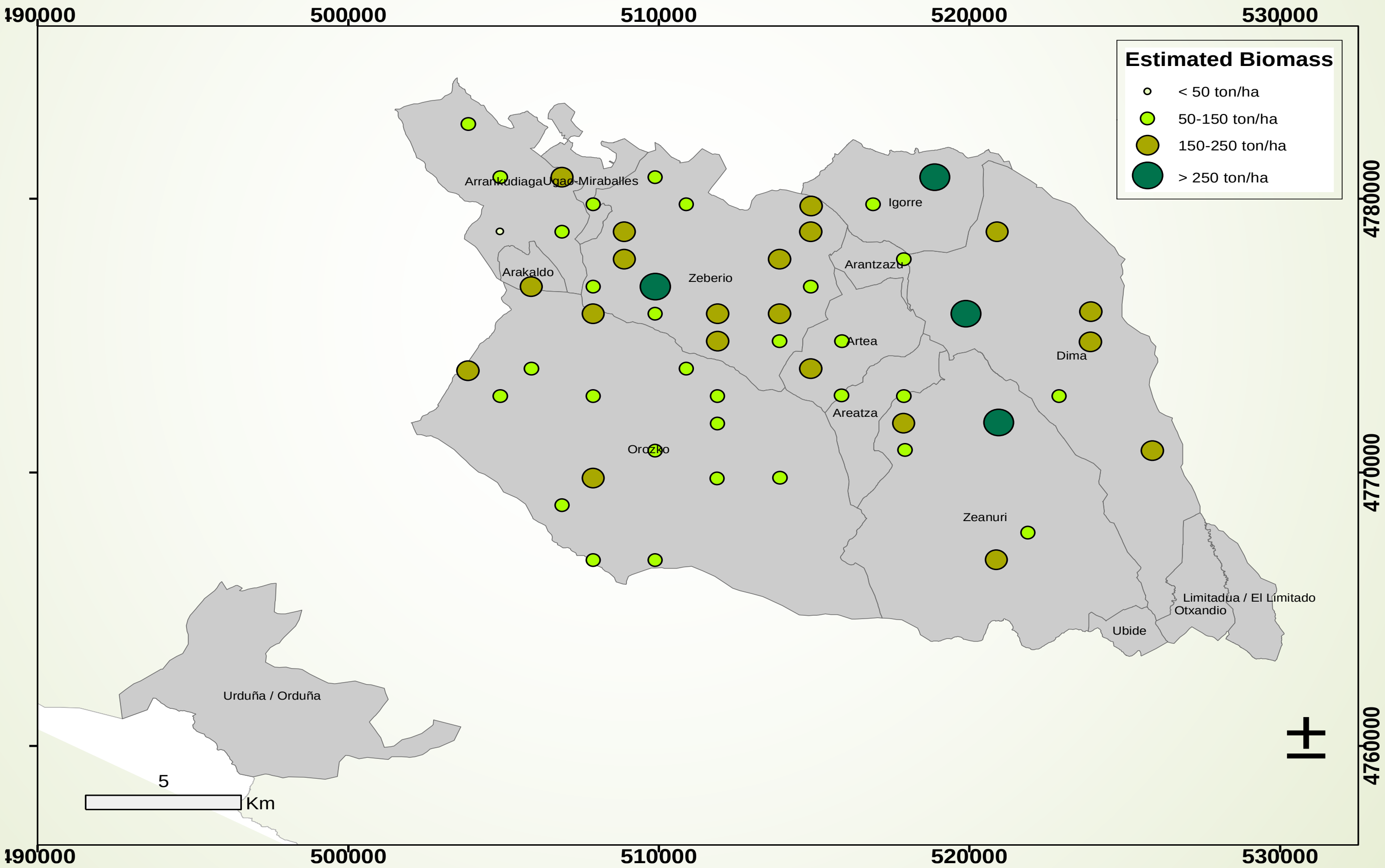
4.6 Results



Extensive diagnostics graphics for the chosen model

4. Biomass estimation

4.6 Results



Estimated biomass of the sample plot

4. Biomass estimation

4.6 Results

Variables	S_i	S_{Ti}	Variance	D_1	D_t
p95	0.8128	0.9453	0.1314	0.1068	0.0072
tr_3	0.8513	0.8404	0.1426	0.1214	0.0228

Sensitivity analysis results

4. Biomass estimation

4.6 Results

Strudy area	Model obtained	Basque Goverment	Error
Encartaciones	2,084,520.43 ton	2,936,472.48 ton	29%

Validation of the model in the Encartaciones region

"leave-one-out" or "k fold" cross-validation:
The original sample was divided in 5 folds, with 11 elements per fold. The mean value of the addition of the square of the residuals oscillates between 0.0674 and 0.0682 logarithmic units, more or less the 0.7% of the mean value of the field biomass.

4. Biomass estimation

4.7 Conclusions

- This study has shown a highly automatic and simply process to estimate biomass using LiDAR data from a low point density flight (0.5 points/m^2) for PinusRadiata specie, that can be extrapolated to other areas, becoming a very powerful tool for this purpose and avoiding other traditional methods (NFI) which supposes a very high investment of time and money. The LiDAR data used in this study are totally public and continuous in time, they are collected every 4/5 years, this circumstance supposes having actualized and free data.
- Major sources of unexplained variance of the AGB regression model: The first is miss registration of the ground plot locations to the LiDAR point cloud, but, as has been proved during the study, the positional differences between them are not statistically influential in the results. The second is the application of allometric equations and the ground measurements. The third error source would be related with the LiDAR dataset, where classification errors could interfere in the results.

5. Practical Examples

1. Catalog Command

C:\Windows\system32\cmd.exe

```
C:\Users\LEIRE>catalog F:\ERASMUS\LiDAR_data\514-4786.las F:\ERASMUS\LiDAR_data\catalog
Catalog v2.11 (FUSION v3.42) (Built on Mar 28 2014 09:43:58) DEBUG
Command line: catalog  F:\ERASMUS\LiDAR_data\514-4786.las F:\ERASMUS\LiDAR_data\catalog
Run started: Tue Oct 03 15:32:51 2017
   Scanning file 1 of 1: F:\ERASMUS\LiDAR_data\514-4786.las...Done
Validation image file produced:
   F:\ERASMUS\LiDAR_data\catalog.html     Oct 3, 2017 @ 3:32 PM
Run finished: Tue Oct 03 15:32:55 2017 (elapsed time: 4 seconds)
Done

C:\Users\LEIRE>
```

catalog.csv - Microsoft Excel

Inicio Insertar Diseño de página Fórmulas Datos Revisar Vista PDF Architect 2 Creator

A1 FileName

	A	B	C	D	E	F	G	H	I	J
1	FileName	ModDateChk	MinX	MinY	MinZ	MaxX	MaxY	MaxZ	PtDensity	#Pts
2	F:\ERASMUS\	1481245465	514000	4784000	40.15	515999.99	4785999.99	1004.35	0.5989	2395627
3										

5. Practical Examples

2. GridSurfaceCreate and dtmm2ascii Commands

Símbolo del sistema

```
LiDAR_data\514-4786.las
GridSurfaceCreate v1.96 (FUSION v3.42) (Built on Mar 28 2014 09:43:09) DEBUG
Command line: gridSurfaceCreate  /class:2  F:\ERASMUS\MDT\dtm\514-4786.dtm 1 M M 0 0 0 0 F:\ERASMUS\
LiDAR_data\514-4786.las
Run started: Tue Oct 03 15:50:48 2017
Using 1 data files:
   F:\ERASMUS\LiDAR_data\514-4786.las: 1092947 pts
Surface model file produced:
   F:\ERASMUS\MDT\dtm\514-4786.dtm    Oct 3, 2017 @ 3:51 PM
Run finished: Tue Oct 03 15:51:05 2017 (elapsed time: 17 seconds)
Done

C:\Users\LEIRE>dtm2ascii %1\dtm\%%~nf.dtm %1\%%~nf.asc
   Cannot open input surface model: %1\dtm\%%~nf.dtm

C:\Users\LEIRE>dtm2ascii F:\ERASMUS\MDT\dtm\514-4786.dtm F:\ERASMUS\MDT\asc\514-4786.asc
DTM2ASCII v1.31 (FUSION v3.42) (Built on Mar 28 2014 09:42:54) DEBUG
Command line: dtm2ascii  F:\ERASMUS\MDT\dtm\514-4786.dtm F:\ERASMUS\MDT\asc\514-4786.asc
Run started: Tue Oct 03 15:52:20 2017
ASCII grid file produced:
   F:\ERASMUS\MDT\asc\514-4786.asc    Oct 3, 2017 @ 3:52 PM
Run finished: Tue Oct 03 15:52:42 2017 (elapsed time: 22 seconds)
Done

C:\Users\LEIRE>
```

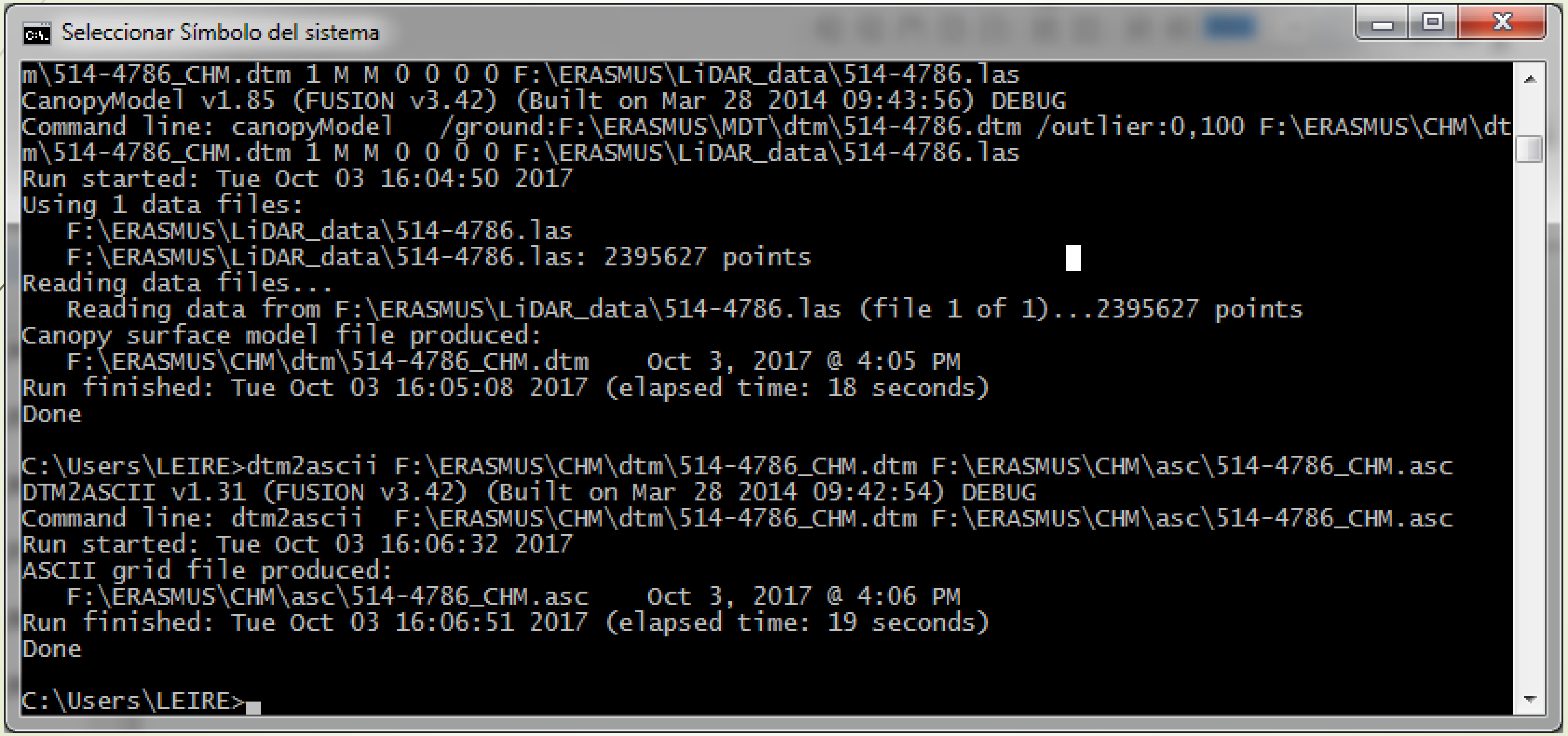
5. Practical Examples

2. GridSurfaceCreate and dtmm2ascii Commands

MDT

5. Practical Examples

3. CanopyModel Command



5. Practical Examples

3. CanopyModel Command

CH
M

5. Practical Examples

4. GridMetrics Command

Símbolo del sistema

```
C:\Users\LEIRE> gridmetrics   /first  /minht:2   /nointdtm /outlier:2,50  F:\ERASMUS\MDT\dtm\514-478
6.dtm  2 500   F:\ERASMUS\Metrics\514-4786_metric F:\ERASMUS\LiDAR_data\514-4786.las
GridMetrics v3.37 (FUSION v3.42) (Built on Mar 28 2014 09:30:30)
Command line: gridmetrics   /first  /minht:2   /nointdtm /outlier:2,50  F:\ERASMUS\MDT\dtm\514-4786
.dtm  2 500   F:\ERASMUS\Metrics\514-4786_metric F:\ERASMUS\LiDAR_data\514-4786.las
Run started: Tue Oct 03 16:15:27 2017
   F:\ERASMUS\LiDAR_data\514-4786.las: 2395627 points
   Total first returns used for all metrics: 2295387 points

Grid metrics file produced:
   F:\ERASMUS\Metrics\514-4786_metric_first_returns_intensity_stats.csv    Oct 3, 2017 @ 4:15 PM
ASCII raster grid header file produced:
   F:\ERASMUS\Metrics\514-4786_metric_first_returns_intensity_stats_ascii_header.txt    Oct 3, 2017
@ 4:15 PM
Grid metrics file produced:
   F:\ERASMUS\Metrics\514-4786_metric_first_returns_elevation_stats.csv    Oct 3, 2017 @ 4:15 PM
ASCII raster grid header file produced:
   F:\ERASMUS\Metrics\514-4786_metric_first_returns_elevation_stats_ascii_header.txt    Oct 3, 2017
@ 4:15 PM
Run finished: Tue Oct 03 16:15:33 2017 (elapsed time: 6 seconds)
Done

C:\Users\LEIRE>
```

5. Practical Examples

4. GridMetrics Command

514-4786_metric_all_returns_elevation_stats.csv - Microsoft Excel

row	col	center X	center Y	Total return	Elev minimu	Elev maximu	Elev mean	Elev mode	Elev stddev	Elev varianc	Elev CV	Elev IQ	Elev skewne	Elev kurtosis	Elev AAD	Elev L1
4	0	514000	4786000	39803	-2.029	88.68	2.0837	-0.5892	4.8786	23.8007	2.3414	0.9854	3.7483	30.3215	3.0975	2
4	1	514500	4786000	68700	-4.8633	37.5035	4.9471	-0.1559	7.2294	52.2643	1.4613	8.8457	1.4935	4.4693	5.8623	4
4	2	515000	4786000	73096	-7.1013	29.0467	3.9973	-0.216	5.4046	29.2102	1.3521	7.1805	1.3221	3.7965	4.4624	3
4	3	515500	4786000	60968	-9.4751	32.6496	5.979	-0.1141	7.3138	53.4917	1.2232	10.4848	1.0544	2.9389	6.1817	
4	4	516000	4786000	42083	-1.7942	286.32	5.9964	-1.7942	9.0917	82.6597	1.5162	13.0747	3.9847	92.6952	7.5049	5
3	0	514000	4785500	64043	-8.3046	30.2646	6.1064	-0.3459	7.292	53.1734	1.1942	11.6656	0.9193	2.543	6.3251	6
3	1	514500	4785500	130003	-5.7304	32.6443	3.0368	-0.2483	5.3892	29.0436	1.7746	4.3321	1.9488	6.3877	4.1108	3
3	2	515000	4785500	146539	-6.306	49.7658	4.9845	-0.0758	7.3323	53.7632	1.471	9.0444	2.1311	9.7012	5.7194	4
3	3	515500	4785500	161122	-5.3753	886.9902	3.1969	-5.3753	5.947	35.3663	1.8602	4.5306	21.9303	3032.1991	4.2284	3
3	4	516000	4785500	69778	-3.276	36.4954	1.847	-0.1196	3.7271	13.8915	2.0179	1.0284	2.4971	9.1065	2.5125	
2	0	514000	4785000	80784	-3.5328	36.9171	6.3492	-0.3225	8.2305	67.7412	1.2963	11.8081	1.0951	2.9748	6.9616	6
2	1	514500	4785000	174773	-5.56	35.6077	3.8735	-0.3323	6.4709	41.8722	1.6706	5.4539	1.7337	4.981	4.9814	3
2	2	515000	4785000	155079	-7.5025	350.9004	4.9228	-1.8136	7.077	50.0841	1.4376	9.2664	2.0945	41.2756	5.8463	4
2	3	515500	4785000	147358	-2.1168	28.6363	1.4477	-0.1642	3.1238	9.758	2.1578	0.5723	2.4329	8.7583	2.1697	1
2	4	516000	4785000	74262	-2.0577	827.7894	4.2383	-2.0577	9.1213	83.1988	2.1521	3.3993	11.7656	900.2599	6.0546	4
1	0	514000	4784500	66165	-3.7918	201.7944	8.3651	-0.5286	10.1753	103.5369	1.2164	16.3669	1.2103	8.3806	8.8084	8
1	1	514500	4784500	156372	-3.3843	43.3941	6.5449	-0.4142	9.32	86.8618	1.424	11.9301	1.2315	3.2013	7.8132	6
1	2	515000	4784500	143232	-4.4941	113.7719	5.8747	-0.7396	7.1722	51.4409	1.2209	11.2982	1.0077	3.2441	6.1915	5
1	3	515500	4784500	157634	-5.1546	36.2134	2.8511	-0.5582	4.6337	21.471	1.6252	5.8067	1.4603	4.0879	3.8374	2
1	4	516000	4784500	73666	-3.0574	33.5068	2.4895	-0.1555	5.6144	31.5213	2.2552	1.0943	2.7463	10.3105	3.6988	2
0	0	514000	4784000	37356	-0.6103	180.24	4.4959	-0.6103	7.2136	52.0363	1.6045	8.9472	3.9601	68.0595	5.7243	4
0	1	514500	4784000	77561	-3.5391	28.8732	2.811	0.0623	4.6576	21.6929	1.6569	3.372	1.7615	5.045	3.6137	
0	2	515000	4784000	75053	-4.6026	32.4677	3.3902	-0.4836	5.6508	31.9319	1.6668	5.0416	1.7605	5.3175	4.3831	3
0	3	515500	4784000	80246	-3.9969	26.4683	1.6265	-0.1283	3.671	13.4763	2.257	0.4125	2.4217	8.1543	2.5088	1
0	4	516000	4784000	39951	-2.5383	381.0226	1.5832	-2.5383	4.5874	21.0444	2.8976	0.4984	30.9578	2230.2236	2.3955	1

Metrics