Accuracy of a DTM Derived from Full-waveform Laser Scanning Data under Unstructured Eucalypt Forest: A Case Study

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CONTEXT AND MOTIVATION

- Context
  - In inland Portugal the most important raw material for hardwood pulps is eucalypt (Eucalyptus globulus Labill.)
  - Eucalypt stands occupy 22.9% of its 31,700 Km2 of forest.
  - Its management is mainly done by short rotations of about 10 to 12 years plantations and with a topping tree diameter situated between 5 and 10 cm.
  - The understory of Eucalypt stands is heterogeneous and is mainly composed of whin, fern, heath, and baccharis.
  - Research project for estimating forest inventory parameters and fuel variables under eucalypt stands in Mediterranean climates using full-waveform ALS data
- Motivation
  - Evaluating the vertical precision of the DTM obtained by automatic filtering of full-waveform ALS data.
  - The errors in the DTM will propagate to the DSM and therefore to the derivation of the forest inventory variables, like the tree height, and of the fuel variables, like the shrub height.

LITERATURE REVIEW

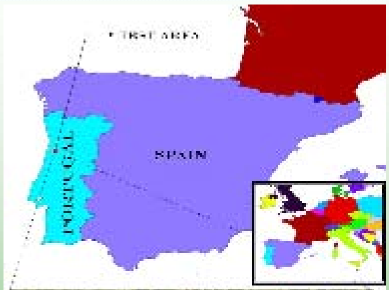
Authors	Area extent (km^2)	Point density (pts/m^2)	Number of check points	RMSE and bias (cm)	Study area characteristics
Kraus and Pfeifer (1998)	91	0.1	466	57; 20	Beech
Hyyppa et al. (2000)	1	24	740	22 (STD)	Beech
Reutebuch et al. (2003)	5	4	347	32; 22	Boreal forest. Norway spruce and Scots pine.
Hodgson et al. (2004)	2000	0.25	654	21.4; not reported	ALS data of six land cover categories: pavement, low grass, high grass, brush/low trees, evergreen and deciduous
Takahashi et al. (2005)	two study areas of 2500 and 625	11.2	283	39; 14	Sugi plantations (Cryptomeria japonica D. Don)
Yu et al. (2005)	8 study areas of 1	10 5	1474	9 30 (STD)	Boreal Forest (Kalkkinen test site). Norway spruce and Scots pine.
Su and Bork (2006)	27	0.75	256	59; not reported	Riparian Meadows, Upland Grasslands, Shrublands and Aspen Forest
Hollaus et all (2006)	128	1.8	2200	Flat areas: 10; no reported Slopped areas (>60°) 50; not reported	ALS data along road-sides in a valley

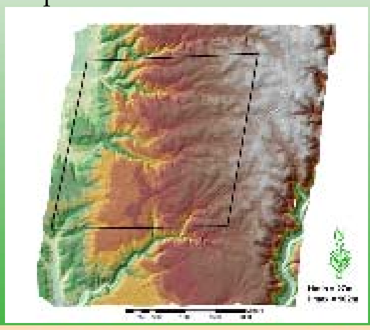
OBJECTIVES

- Objectives
  - Assessment of the vertical accuracy of a DTM obtained by automatic filtering of full-waveform ALS data.
  - In addition to the peculiar characteristics of the study area, which are often avoided in related studies, the accuracy estimation is carried out in a novel way.
  - By novel way, its meant an exhaustive, well planned collection of reliable control data under an eucalypt forest comprising regular as well as irregular spacing plantations.
  - Prior to the vertical accuracy assessment of the DTM, the quality of the delivered laser data was also evaluated.
  - To this end, measurements on horizontal and inclined bare surfaces were used.

STUDY AREA

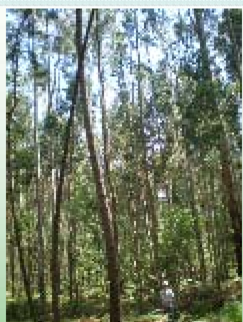
- Situated in the Northern part of Portugal
- Area = 900 ha (3km*3Km)
- Dominated by unmanaged eucalyptus plantations with some few pine stands and few built-up areas
- Topography varies from gentle (2.5%) to locally stepped slopes (34.2%) with a mean slope of 10.0%

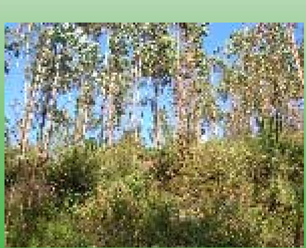


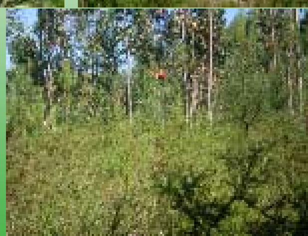


STUDY AREA

- Stand characteristics
  - Regular and irregular spacing plantations
  - Even and uneven-aged stands
  - With and without extensive undergrowth

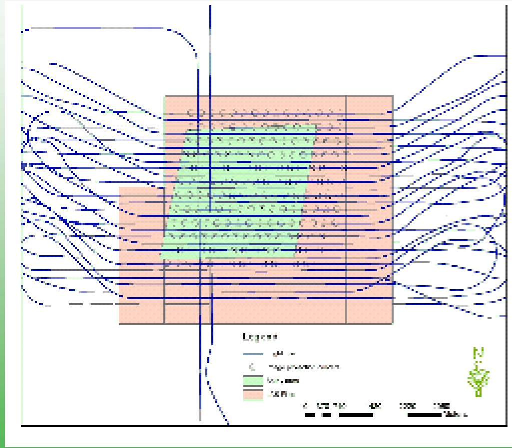






DATA ACQUISITION

- ALS and image data acquired simultaneously on 14th of July of 2008
- Reference data acquired between May and October 2008
- Forest inventory of 45 circular plots (r=11.28m) acquired between June and July 2008



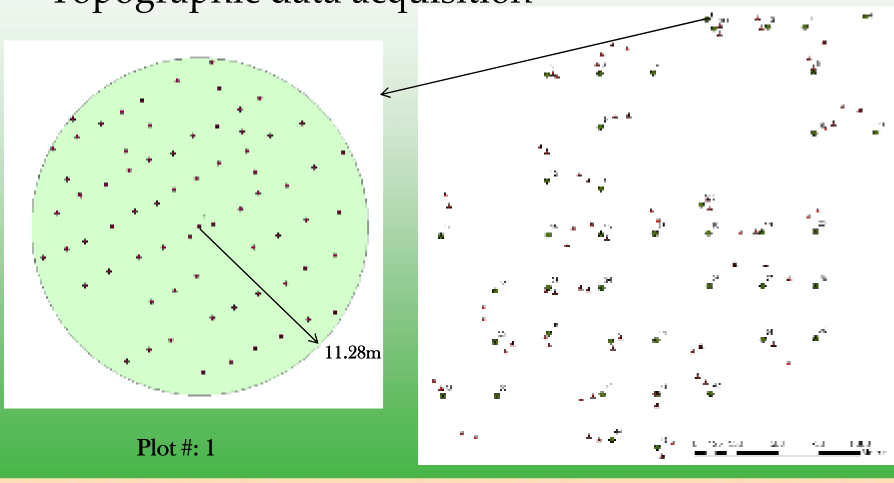
DATA ACQUISITION

- ALS data and image acquisition parameters

ALS	Image
Lidar sensor: Riegl LMS-Q560	Camera sensor: Digicam H39 + 50mm focal length
Wavelength: 1064 nm	Wavelengths in CIR mode (nm):
Scan angle: 45°	-> B=500-620; G=580-800; R=800-1000
Pulse rate: 150 Khz	Image repetition rate: 1.9sec
Effective Measurement rate: 75kHZ	
Beam divergence: 0.5 mrad	
Ground speed: 46.26 m/s	
Flying height above terrain: 700m	Flying height above terrain: 700m
Swath: 497m	Overlap: 60%
Sidelap: 70%	Sidelap: 30%
Single run density: 3.3pt/m2	Pixel forward: 7216
Expected final density: 9.9pt/m2	Pixel sideward: 5412
Distance between lines: 150m	
Spot diameter: 30cm	Ground sampling distance (GSD): 8.2cm

DATA ACQUISITION

- Topographic data acquisition



Plot #: 1

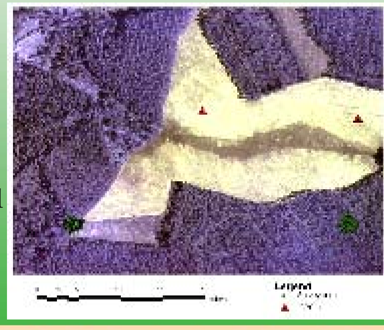
METHODS

- Procedures for **acquisition** and quality assessment of **reference data**
  - Objectives: evaluate the precision and reliability of the DTM produced by means of the laser data and a filtering algorithm
  - Methodology
    - Coordinate system for ALS and image data
      - WGS84 UTM zone 29N for X and Y
      - WGS84 ellipsoidal height for Z
    - Attach to each plot two points (benchmarks named GPS base) whose coordinates are measured with two GNSS geodetic receivers

METHODS

Procedures for acquisition and quality assessment of reference data

- Methodology used for the geodetic survey
  - Minimum time of observation of 60’ (normally it took 120’)
  - Minimum number of 7 satellites
  - PDOP (Position Dilution of Precision) less than 3.
- Methodology used for the topographic survey
  - The two GPS points (GPS base) are used to determine the Total Station position and bearing.
  - The irradiation method was used to acquire the terrain points located aside trees, which give also the locations of the trees, and prominent terrain points, like terrain breaklines.



METHODS

- Full waveform processing
  - The full-waveform analysis is done in a post-processing step (after flight) using a Gaussian Pulse Fitting (GPF) method available in the RiAnalyze 560 software from Riegl.
  - For each detected target of the emitted pulse the following information is extracted
    - Range, scan angle
    - x,y,z coordinates
    - Pulse width and amplitude
    - First, second,…, last target indication

METHODS

- Point cloud filtering
  - Input: the last return of each pulse
  - Filtering algorithm: progressive TIN (Triangular Irregular Network) densification algorithm implemented in the TerraScan® software
  - Parameters used in the TerraScan®

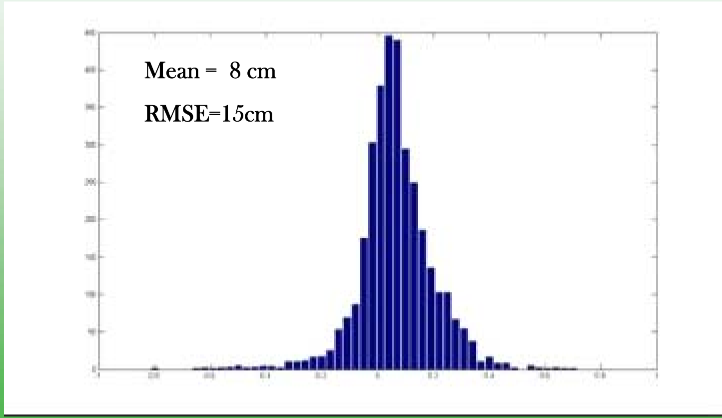
BldSz (m)	MaxAng (°)	IterDst (m)	IterAng (°)
10	88	1.4	6

METHODS

- DTM accuracy assessment
  - Create a TIN from the filtered ALS data
    - The density of ALS terrain points is higher than that of reference points (3.8 versus 0.2 points/m2)
  - For each reference point with the coordinates (x,y) compute the difference dz
    - $dz = TIN_{(x,y)} - H_{(x,y)}$
  - For each circular plot (A=400m2) compute the following stats
    - Mean, standard deviation and RMSE of the dz_i

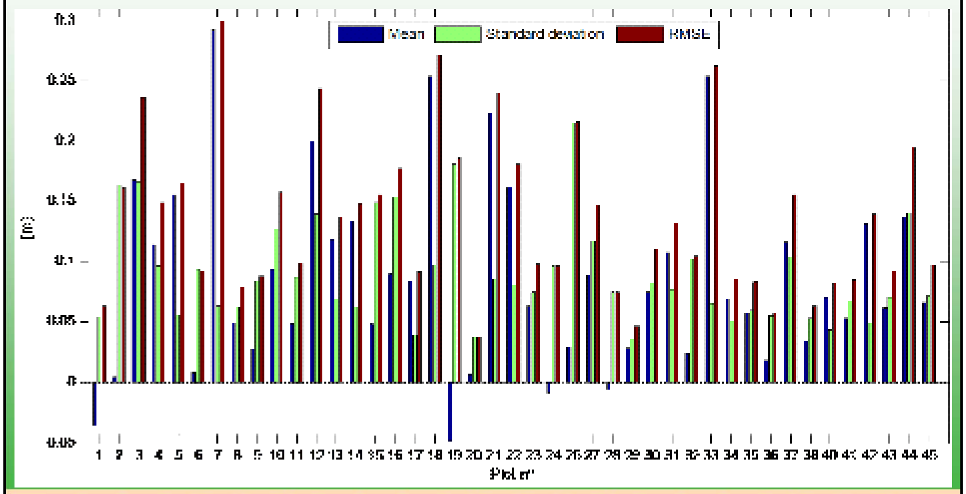
RESULTS

- Histogram of the 3356 differences (dz_i) in meters



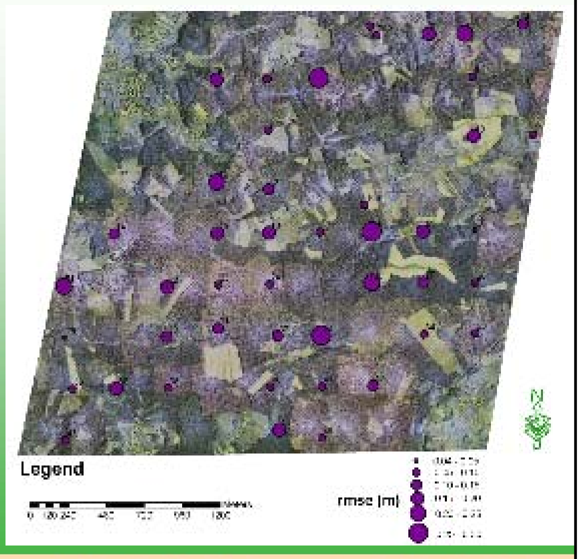
RESULTS

- Values per plot of the mean, standard deviation and RMSE of residuals



RESULTS

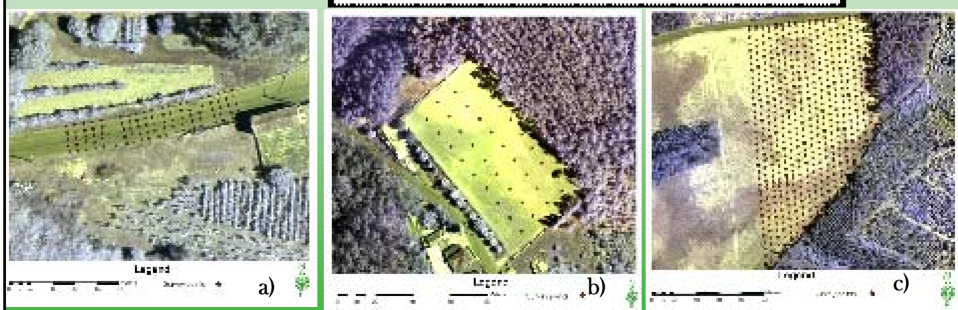
- Spatial distribution of the RMSE value per plot

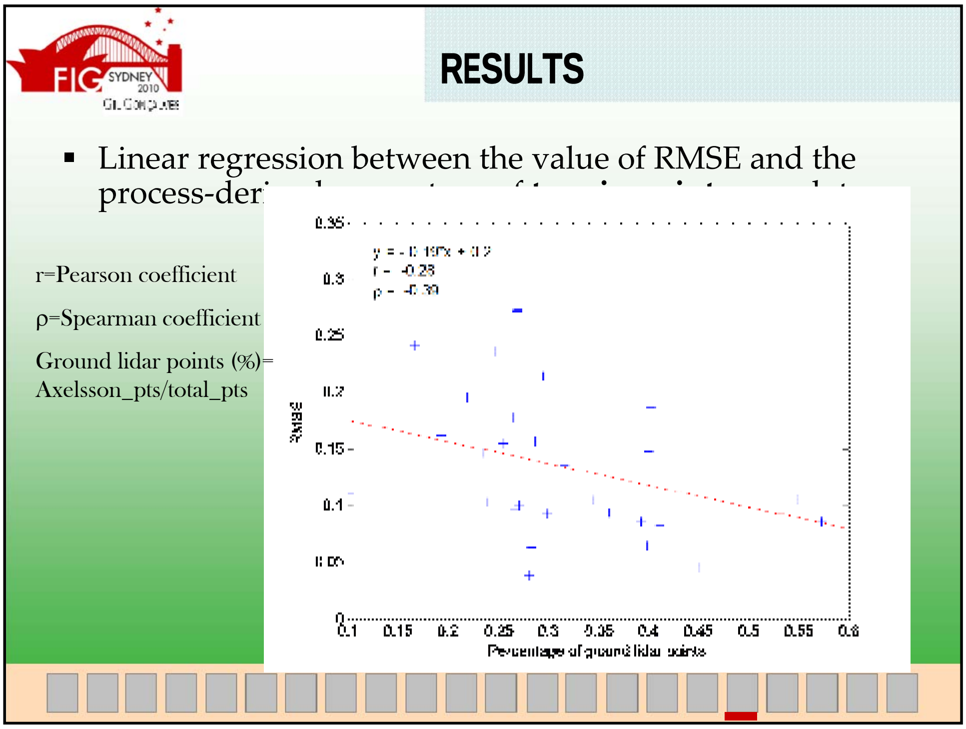


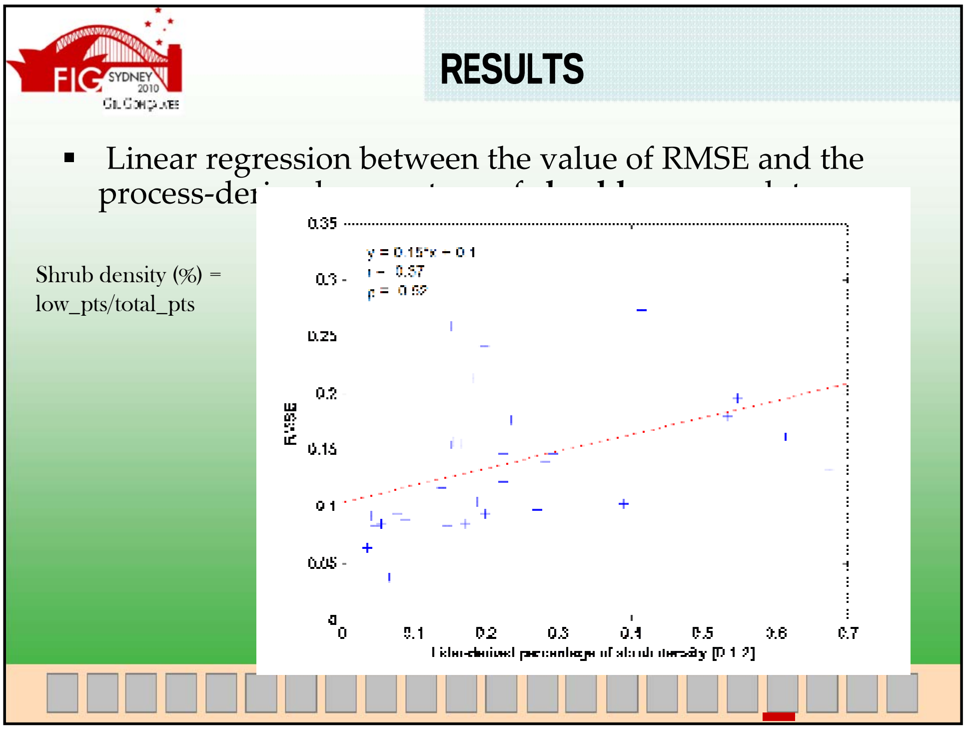
RESULTS

- Reference data for ALS quality assessment. Survey points on bare surfaces: a) paved road, b) football field and c) arable field.

	Mean (cm)	RMSE (cm)
Paved road	2.8	3.2
Football field	1.8	3.4
Arable field	6.8	8.4



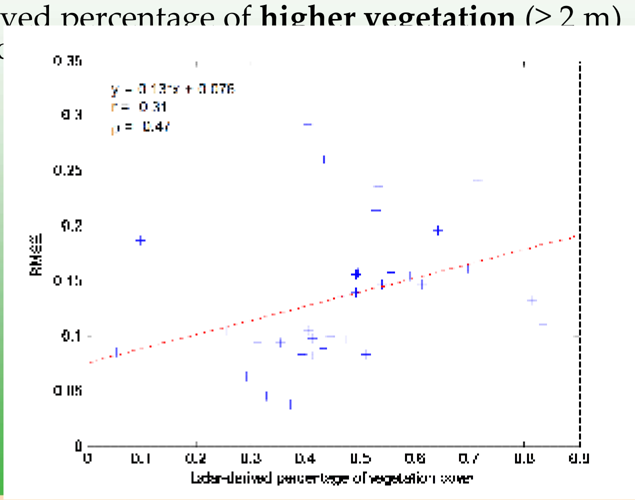

RESULTS
Linear regression between the value of RMSE and the
process-der
r=Pearson coefficient
ρ=Spearman coefficient
Ground lidar points (%)=
Axelsson_pts/total_pts
RMSE


RESULTS
Linear regression between the value of RMSE and the
process-der
Shrub density (%) =
low_pts/total_pts
RMSE

RESULTS

- Linear regression between the value of RMSE and the process-derived percentage of **higher vegetation** (> 2 m) cover per plo

Vegetation cover (%)= high_pts/total_pts



CONCLUSIONS

- The work done in this study to properly assess the quality of full-waveform ALS data and of a derived DTM is quite demanding:
  - It requires an exhaustive and well-planned collection of reliable control data
  - The GNSS techniques are very time consuming in environments where a high density of high vegetation predominates.
  - The topographic measurements in plots covered with high shrubs are also difficult to execute.

CONCLUSIONS

- The **15 cm** obtained for the vertical accuracy (rmse) of the produced DTM in forest environments **is very good** and suitable for a great number of applications.
- The **3 cm** in rmse obtained in bare surfaces shows an improvement in the vertical accuracy of the full-waveform systems
- The **filtering algorithm** based on the filter of Axelsson (1999 and 2000) also proved to be **very robust** to terrain with the aforesaid characteristics.
- The low values obtained for the correlation coefficients between the RMSE values per plot and the percentages of the number of points classified by the filtering process as terrain, as shrubbery with height varying from 10 cm until 2 m and as higher vegetation cover indicate that there is almost **no correlation between the quality of the DTM and the vertical structure of vegetation**.