- *This study is a preliminary examination of the potential of LiDAR (Light Detection and Ranging) for forest resource assessment in Ireland.*
- *LiDAR allows the capture of forest data in 3D format, yielding information on the vertical structure of the forest.*
- *LiDAR-derived maximum canopy heights across thinned and unthinned plantations of Sitka spruce were compared with top height measurements in the field.*
- *The results of this study revealed that the use of laser-derived estimates of tree height compares very favourably with conventional field-based measurement.*
- *No significant differences between estimates of height from LiDAR and field measurement were observed.*
- *The mean difference between field and LiDAR estimates of height was 0.2 m, with an absolute difference of 4% between measurements.*

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A preliminary evaluation of the application of multi-return LiDAR for forestry in Ireland

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Introduction

LiDAR (Light Detection and Ranging) is an active remote sensing system that allows for capture and analysis of forest data in 3D format, yielding information on the vertical structure of the forest. The technology, mounted on an aircraft (helicopter or plane), uses a rapid pulsing laser scanner that emits laser pulses and measures the time for each beam to travel to and from a target (Figure 1). High precision timepieces record the location of every return, to produce a dense array of refection points (Reutebuch et al. 2005).

Travel time of the pulse from emittence to return is measured, providing a distance from source to target and yielding x, y and z co-ordinates for each pulse returned. LiDAR can be use to generate canopy height models and thus tree heights by subtracting values of known ground positions from the canopy height. Commercial LiDAR systems can collect information from 20,000 to 75,000

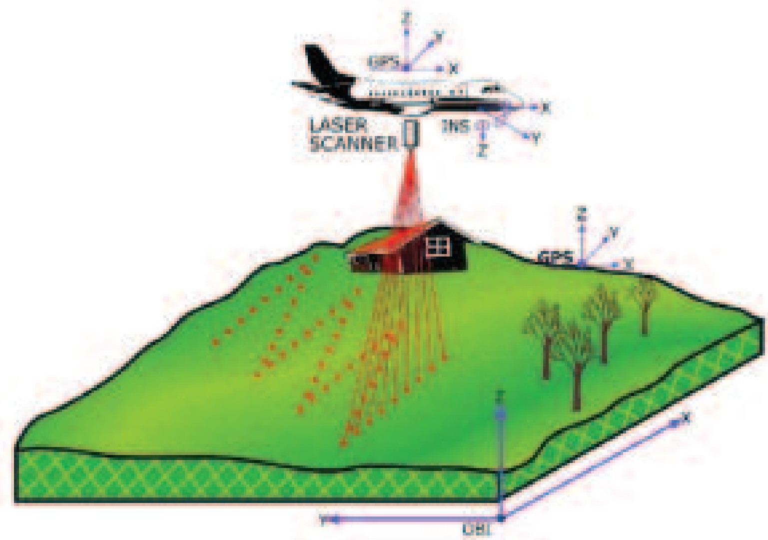

Figure 1: Aerial LiDAR scanning, using differential GPS for positioning and orientation (after Renslow et al. 2000).

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points per second. Accuracy on the horizontal and vertical scales ranges from 20-30 cm and 5-20 cm respectively (Suarez et al. 2005).

The overall goal is to integrate the use of LiDAR in forest inventory for measurement of variables such as top height. Estimates of top height are essential in forest inventory and as inputs to stand management models. Top height is strongly correlated with stand volume in fully stocked stands and is generally not significantly affected by thinning or initial stocking. Potential productivity can be assessed using top height and age to derive a site index or general yield class for a stand. This will facilitate thinning, management of plantations and overall forecast planning. Estimates of top height can also be obtained from photogrammetric processes using aerial photographs, but the process is time-consuming (Evans et al. 2006). LiDAR is a more cost-effective method, providing stand height estimates with accuracies comparable with field-based methods (Naesset 1997 and 2004, Hopkinson et al. 2006).

Study area

As part of the forest cluster research project undertaken by Teagasc and COFORD, a LiDAR survey was carried out in Co Roscommon, in north central Ireland. Two study areas were chosen. Study area A was located near Frenchpark, Co Roscommon, and covered an area of approximately 14 km^2 of which 10 km^2 was covered by forest. Study area B was located in the Curlew Hills, near Boyle, in Co Roscommon, covering an area of 25 km^2 of which 15 km^2 was covered by forest (Figure 2).

Data acquisition

LiDAR data were captured by the Ordnance Survey Ireland (OSI) from 19 to 31 April 2009 using a Leica ALS50 II system mounted on a two-seater Piper fixed-wing aircraft (Figure 3). The four return system is capable of a pulse rate of 150,000 kHz. The area was flown at a height of 1,700 m. A scan angle of less than 12 degrees off nadir was specified with an average of seven returns per m^2. Data were received from OSI in .LAS format containing the x, y, z co-ordinates of each pulse, return number, intensity and scan angle, together with a Digital Terrain Model (DTM). Survey parameters are shown in Table 1.

Figure 2: LiDAR study area in Roscommon and (inset) study areas A and B.

Figure 3: Leica aerial laser scanner (top), mounted on a computer and the aircraft used.

Images courtesy of Ordnance Survey Ireland.

Table 1: LiDAR survey parameters.

Parameter	Value
Sensor	ALS 50 II
Frequency	137300 Hz
Flying height	1700 m
Footprint diameter	0.39 m
Scan angle off nadir	12 degrees
Sampling density	7 returns per m^2
Elevation accuracy	0.07 m

Objectives

The objectives of the study were to develop a surface and canopy model for Sitka spruce stands and to assess if relationships could be derived between top height and canopy height from active laser scanning.

Methodology

Raw LiDAR data were split into two files: first returns and last returns. First return LiDAR heights corresponding to the forest canopy and last returns were derived for stands (Figure 4). Last returns were filtered to identify returns representing the ground only. The filtering algorithm used (adapted from Kraus and Pfeifer 1998) is based on linear prediction and uses an iterative process. Initially all points are assigned equal weights, resulting in a surface that lies between the canopy and the ground. The distance and direction of each point relative to this surface is used to compute weights for each point, removing non-ground points while maintaining the maximum number of ground hits (McGaughey 2009). Different kernel sizes were experimented with until an accurate digital terrain model (DTM) of 1 x 1 m resolution was produced. This DTM was used to normalise the height of the raw LiDAR data, with canopy heights computed as the difference between the first return height data and the DTM (Figures 5 and 6).

Using the derived ground surface, heights of first returns representing the canopy were normalised to produce height data matrices. Percentiles, together with segmentation techniques, were used for stand height estimation. Fusion software, available from the USDA Pacific North-West Research Station, was used to derive canopy height based percentiles.

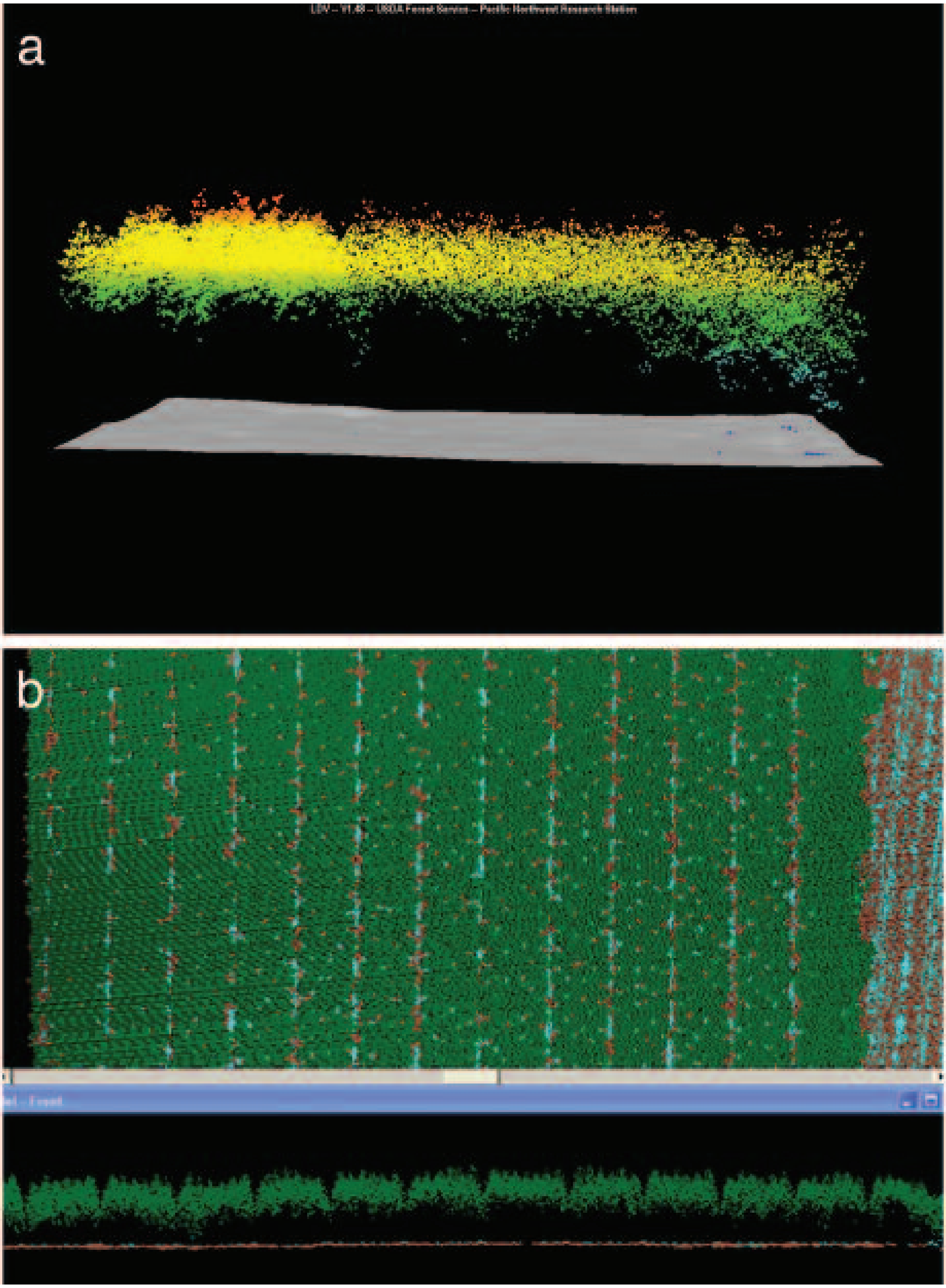

Figure 4: First returns displayed over the surface model to create a canopy surface model (a) and plan and elevation view of stand showing thinning racks and ground surface level and tree height (b).

Figure (b) courtesy of Ordnance Survey Ireland.

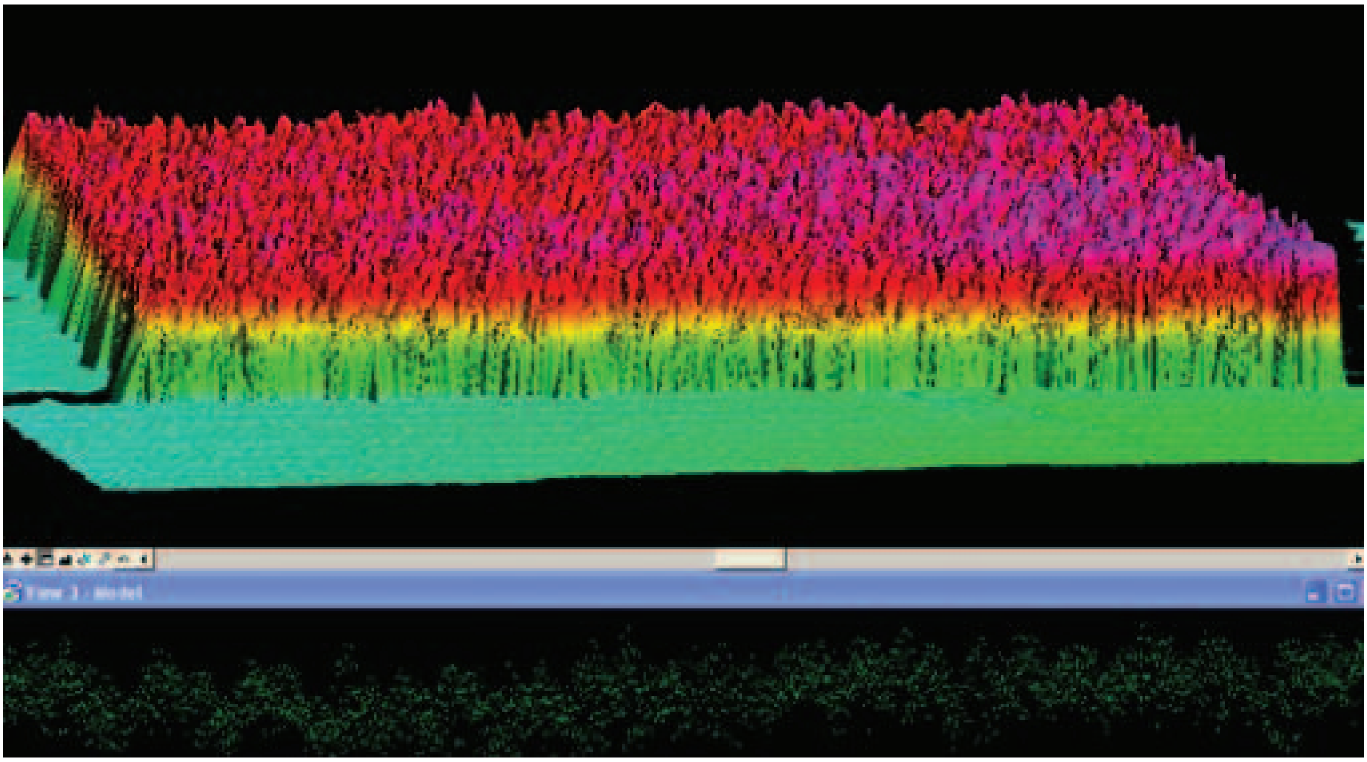

Figure 5: 3D visualisation of Sitka spruce stand showing stand height structure.

Image courtesy of Ordnance Survey Ireland.

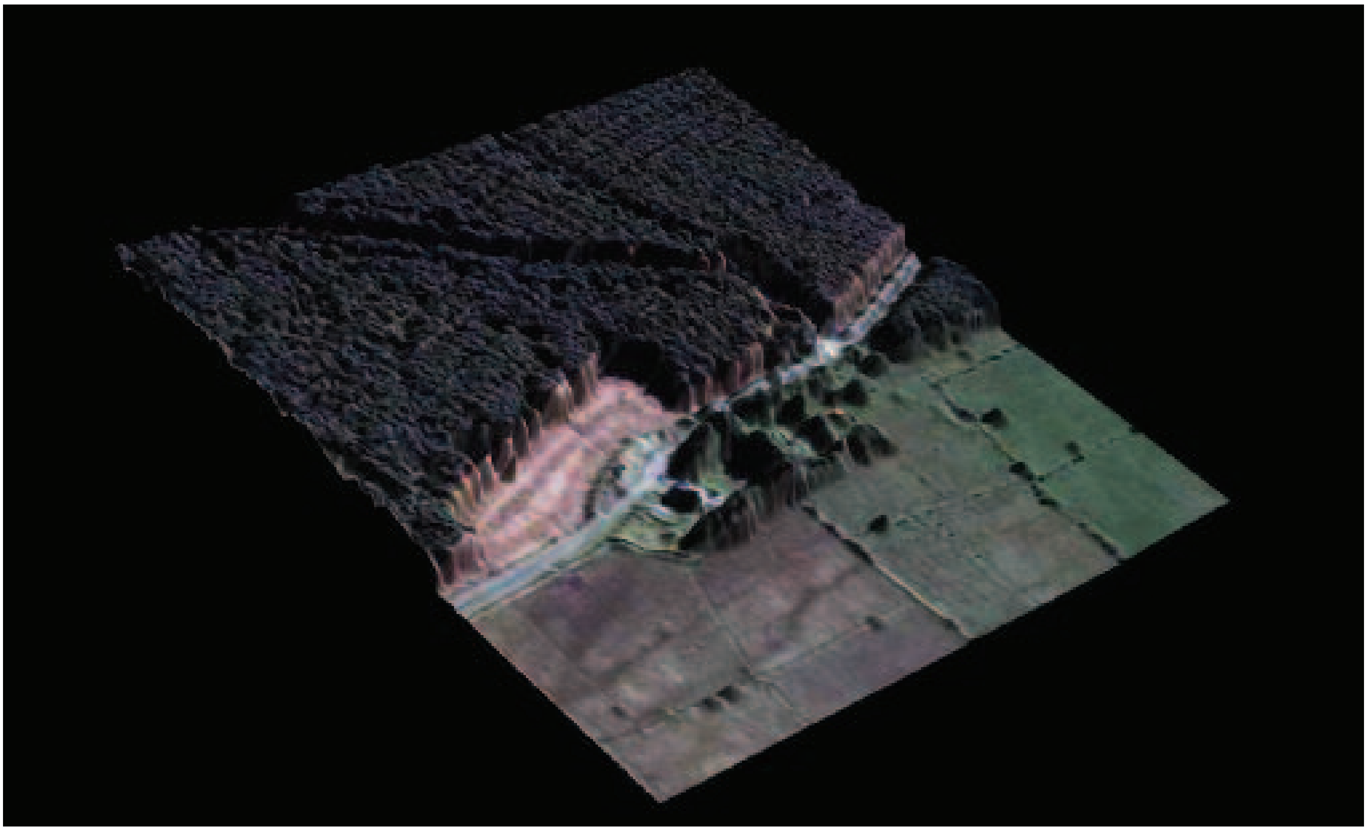

Figure 6: Exaggerated 3D canopy surface layer derived from LiDAR enhanced with digital orthophotography (Quickbird), showing stand structure, bell mouth entrance and main extraction racks.

Ten uniform, even-aged, fully stocked stands of Sitka spruce were chosen to compare field measurements of top height with LiDAR-derived height measurements. Five plots were taken in thinned stands and the rest were taken in unthinned stands. A 30 x 30 m plot was laid down within each stand. Mean top height (height of tree(s) with largest dbh) were determined in each plot. Plot centres were identified in the field using a real-time differentially corrected GPS.

For each stand, a segmentation procedure was used to capture the variability in LiDAR-derived canopy height. This involved placing a 50 x 50 m grid over the stand and computing height percentiles for each cell. Using the boundaries of forest stands, normalised first return LiDAR data were extracted. The maximum height return value for each grid cell was then calculated. Grid cell values were summarised based on each stand and a mean maximum height value obtained. LiDAR-derived heights were compared with the mean top height value obtained in the field.

Results

Canopy height-top height relationship

Surveyed stand ages ranged from 17 to 36 years. Mean top height from the field survey was 18.4 m. The mean maximum canopy height from the LiDAR survey was 18.2 m (Table 2).

The relationship between LiDAR derived height and stand-derived top height was analysed using a regression analysis and was found to be significant (R^2 0.91, $p \leq 0.01$) (Figure 7).

Table 2: Summary statistics of age, top height and LiDAR canopy height.

	Mean	Range	Standard deviation
Age	22	17-36	5.1
Top height	18.4	13.5-24.0	2.9
Canopy height	18.2	13-25.3	3.1

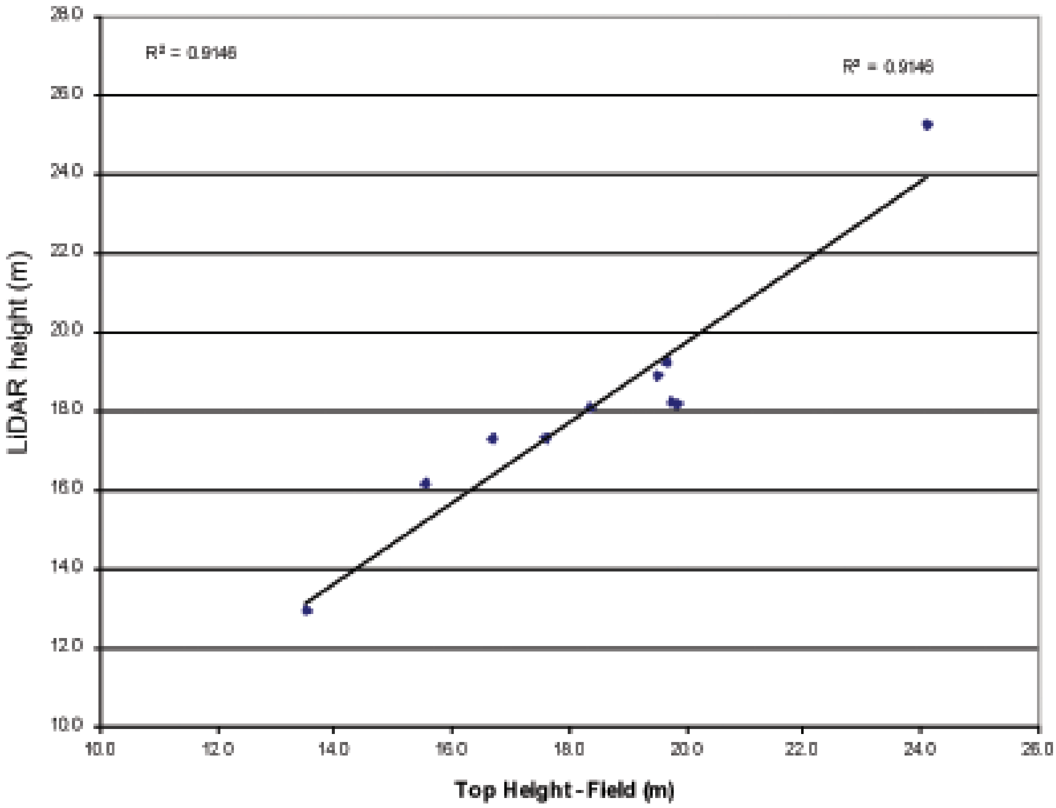

Figure 7: The relationship between field-based top height and LiDAR-derived height.

Assessment of bias

Tree heights from the field measurements were compared to the LiDAR-derived height measurements, yielding an absolute difference of 0.8 m (4%) with a standard deviation of 0.5 (3%). The residuals (field top height – laser height) suggest that the laser-derived measurement is biased towards an under-estimate of top height, with 7 out of 10 measurements being less than the stand-derived top height (Figure 8).

Conclusion and discussion

This study was a preliminary examination of the potential for the use of LiDAR for forest resource assessment. The methodology demonstrated the feasibility of LiDAR to develop canopy and ground surface models for thinned and unthinned Sitka spruce stands between the ages of 17 and 36 years of age. Although limited by the amount of time and data available, significant relationships between LiDAR- and strand-derived top heights were found. The results were similar to other studies where good relationships have been demonstrated between observed top height in the field and LiDAR height data.

LiDAR underestimated height compared with stand-derived measurement; on average by 0.8 m. Underestimation may be due to pulses hitting the crown shoulder rather than the tip of the tree. In cases where laser heights were greater than top height measurements, errors in the surface model may have been the cause.

LiDAR technology is used in Scandinavia (Naesset 2007), where there is a long history of implementing remote sensing in forest inventories and where more than 20% of forested land is inventoried using LiDAR (Carson et al. 2004). LiDAR surveys, once prohibitively expensive, are now a realistic option for forest resource assessment. As the technology becomes more readily available, the cost of acquisition decreases, and a number of operators in Ireland are already capable of carrying out such surveys. Ultimately the uptake of this technology will be based on its cost effectiveness and favourable comparison with field-based methods. Further research is needed to develop relationships between other stand parameters such as yield class, basal area and volume and LiDAR-derived data.

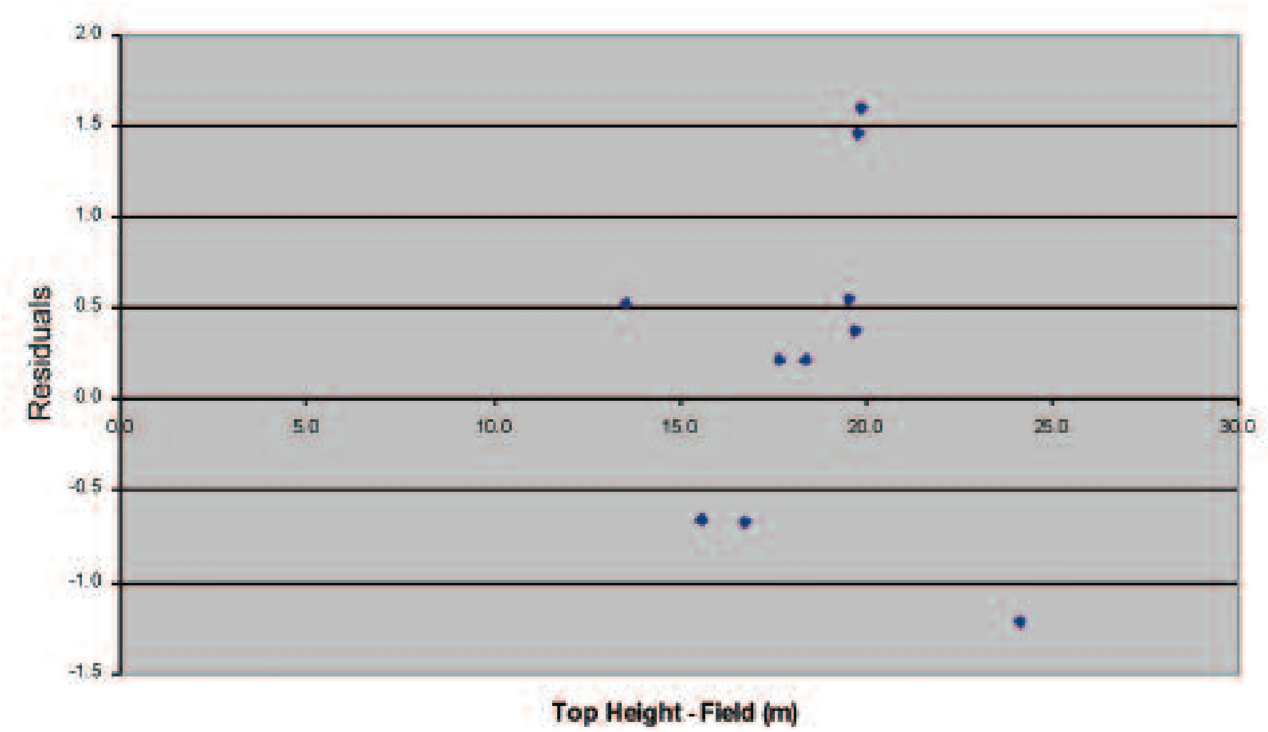

Figure 8: Residuals between stand-derived top height and LiDAR-derived height.

Acknowledgements

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