So you want to use LiDAR? - A guide on how to use LiDAR in forestry

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There has been a great deal of interest in LiDAR recently, and the industry seems set on acquiring LiDAR data in the near future. Opportunities such as highly accurate ground mapping, tree heights, tree counts and maps showing within-stand variation in volume and basal area can add value individually, but in combination offer a huge benefit to foresters.

With all the hype, forest managers could be forgiven for believing that for a dollar or two per hectare LiDAR could tell them everything they wish to know about their whole estate. In reality though, the expression 'rubbish in rubbish out' holds expensively true, and a reasonable amount of care and knowledge is needed to ensure that the forester gets a worthwhile return from his investment. Used appropriately LiDAR holds huge potential for New Zealand forestry, and this article explains how to reap the benefits of LiDAR whilst keeping realistic about its limitations.

So what is LiDAR?

LiDAR, or Light Detection And Ranging, is the light equivalent of RaDAR (Radio Detection And Ranging. A laser, typically operating in the near-infrared (NIR) range (which live foliage efficiently reflects), sends a pulse of light at a target and measures the time taken to reflect back to a sensor next to the laser. This cycle is referred to as a 'return', and by knowing the speed of light the distance to the target can then be calculated. This technology has been used for measuring the altitude of aerosols (e.g. clouds) almost since the invention of the laser in the 1960s. It has since been used for distancing in robotics, police speed cameras, Hollywood CGI, Radiohead's 'House of Cards' music video (youtube it) and many other applications.

Placing a LiDAR unit in an aircraft (aerial LiDAR) and scanning the ground is standard practice for generating extremely accurate Digital Elevation Model (DEMs). This technique has proven uses in hydrology, archaeology, mining, and construction. For these applications, the LiDAR information is filtered to remove any returns from above the ground surface, such as due to vegetation. Within forestry the DEM is extremely valuable for roading and infrastructure, and this function alone can justify the cost of LiDAR on steep erodible sites. When the DEM is subtracted out from the data, the remaining returns contain useful information about the structure of the forest above. This information is inherently incomplete; akin to keeping up with the daily news by reading every twentieth word in the paper. Nonetheless, when this data is combined

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with a series of ground plots, the information available to the forester can bring in a whole new paradigm of spatial precision and management.

There are a number of systems in use by the various companies willing to fly in New Zealand. Make sure your supplier has the following:

- A Near Infra Red (NIR) laser - most airborne systems tend to use this. Note bathymetric systems (designed for surveying through water) will operate in the green spectrum, and this is not as good for forestry. Although trees clearly reflect green light, they are actually 5-6 times more reflective in the NIR band. Ensure the laser is the most powerful Class IV type.
- Multi-return capability. For a single pulse of outgoing light, modern systems can record several returns. This differentiation between *outgoing pulses* and *incoming returns* is important, and a common source of confusion. A pulse of light will typically have spread out to around 200mm in diameter by the time it hits the ground, from which it is partially reflected and partially absorbed. Some of this reflected light reaches the sensor and counts as a single return. As a tree canopy is not smooth at a scale of 200mm, a pulse can hit the tree several times on the way down and different parts of the beam will be reflected from different heights through the canopy. The reflected signals from the canopy will return to the sensor before the light that hit the ground (see Fig.1). Modern LiDAR units can collect 'multiple returns', and record several differently heighted returns for a single pulse. This greatly improves the chances of getting ground returns, and will significantly increase your effective point density over vegetated areas.

So you want a Digital Elevation Model?

A digital elevation model (DEM) is the most established use of aerial LiDAR, and puts foresters in good company. Metre-accurate DEMs have been determined through thick native bush for hydrodam planning by commercial suppliers here in New Zealand. Filtering algorithms for separating ground and vegetation returns have been in development for decades and - whilst not perfect - are capable of handling even dense understorey.

The question for a forester however, is how accurate a DEM do you want to pay for? The vertical accuracy of a single return is determined by the hardware and GPS precision, but the horizontal precision depends on how many pulses actually hit the ground. The more ground returns received; the easier it is to remove understorey, and the finer level of detail that is visible. As a rough rule-of-thumb, around 10% of pulses over heavy vegetation will yield a ground return (NZAM, pers. comm.).
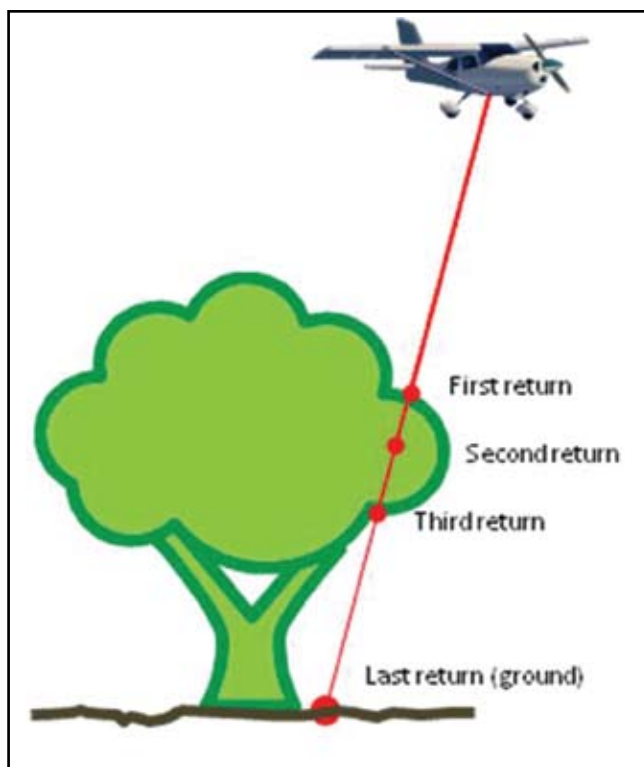
Figure 1: Multi-return LiDAR

So at 1 pulse per square metre, you are actually only getting 1 ground return per 10 square metres, making them on average 3.2m apart. So a linear feature - such as a cliff - that was apparent over a 10m scale would only receive 3 returns and probably be smoothed out as a consequence. This result would leave you possibly no better off than your pre-existing 5m contour map. At 10 pulses per square metre however, it would receive 30 hits and be easily spotted (see figure 2).
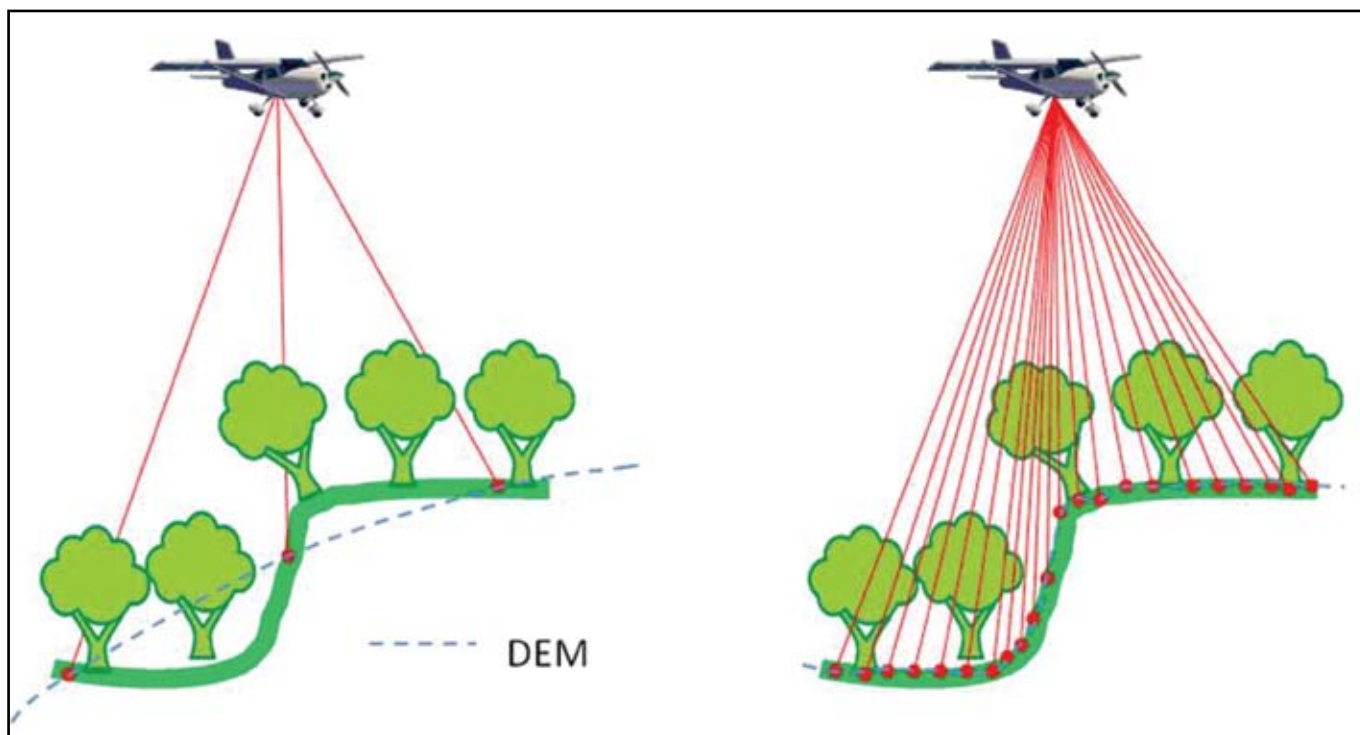
Planted forests, including radiata and particularly eucalypts, have a lower canopy cover than native forest and a greater proportion of light reaches the ground. Steep features such as cliffs also tend to be less heavily vegetated, again improving (but not guaranteeing) their visibility. Modern multi-return sensors will further improve the number of pulses yielding ground returns. Although there is no definition yet for the ideal point density for a given species or canopy cover, Forestry Tasmania are extremely satisfied with the results at 2-3 points per m^2 (Mannes 2009). Within New Zealand DEMs generated with 1 point or more per m^2 routinely show more detail than 5m contour maps (NZAM, pers. comm.).

Greater point densities require lower, slower or more overlapping flight lines. More time in the air and more data inevitably mean more cost to the forester. A good LiDAR supplier will spend the time to determine a flight path to match your needs, acknowledging that the pulse density needs to be higher over forest. Be aware that if you are sourcing data from elsewhere (e.g. a regional council) that the data will have been collected for a different use to forest management and that the DEM within a forest may not be as accurate as quoted. It is common practice to quote DEM accuracy in open ground only.

So you want height data?

LiDAR has been famously used by Forestry Tasmania to find the world's tallest eucalypt, named Centurion at 99.6m. Projects are also underway in America to fly the Californian Redwoods and possibly usurp Hyperion as the world's tallest tree (115m). Once the DEM has been

Figure 2: Comparison of DEM resolution at different pulse densities.

subtracted from the LiDAR data, the effect of topography is removed and you are left with a surface known as a Canopy Height Model (CHM). This surface is useful for gauging how average tree height varies across a stand, and the tallest trees are easily visible using free visualisation packages (see 'so you want to work with the data yourself?'). Finding the heights of the highest few trees is fundamentally easier than finding the height of every tree. Individual tree heights require identification of each tree within the point cloud, which is a much more involved task as detailed below.

So you want stocking?

There are no 'off-the-shelf' tools available to derive stocking information from LiDAR. However, methods do exist and NZAM and several formative European companies (e.g. Land Consult[1] and Silva Consult) are happy to provide a case-by-case consultancy service. Segmenting individual trees from LiDAR is inherently easier than using orthophotos as it is not prone to shading, ambient light or ortho-rectification issues. The quality of the segmentation - and hence tree count - is heavily dependent on the point density. The minimum considered for mature trees should be around 3 returns per m^2 (Holopainen et al. 2009), more for higher stockings and younger trees, which increases the cost considerably. Even with the best data set there is no proven segmentation method, and parameters must be trialled for a given site, age and species. Coarse stocking estimates can be achieved relatively easily with some programming knowledge, and this may be sufficient for many companies. However, accurate stocking does not just 'fall out of' the LiDAR data, and requires considerable extra cost and effort.

So you want individual tree heights?

Once trees have been segmented, obtaining individual tree heights is easy within the programming environment that the segmentation occurred in. It needs reiterating though that obtaining accurate segmentation is not a simple process.

So you want to know how Total Standing Volume (TSV) varies across the forest?

Aerial LiDAR does not directly measure tree diameters at any point on the stem. Hence basal area (BA) and TSV are inferred from a model based on other structural metrics found from the LiDAR point cloud. This model is created by putting in a series of ground plots, then sampling the LiDAR for each plot and correlating this against the desired metric (such as TSV or BA). This regression model can then be applied over any trees, stands or forests that are represented by the ground plots. If the ground plots

[1] See www.landconsult.de

used are from pre-harvest inventory and all the trees are a single age-class, then the model cannot be applied to younger trees. Specific age class models are likely to be more accurate than generic models across a broad spectrum of ages and sites, although require a greater number of plots. The example in Figure 3 is a volume map for a forest in Esk consisting of five compartments, planted in 1982 and 1983. The model used was derived from 50 pre-harvest inventory plots.

As TSV is measured per hectare, not per tree, we can conveniently sidestep the segmentation issue. Good results have been obtained on flat sites in Australia for radiata pine at pulse densities as low as 0.3-0.4 pulses per m^2 (Rombouts et al. 2010). This pulse density is too low for steep sites or sites with significant understorey. As we are dealing with an inferred measure, we need extremely good ground measurements of TSV with which to create a model. This requires some preliminary effort from the forester.
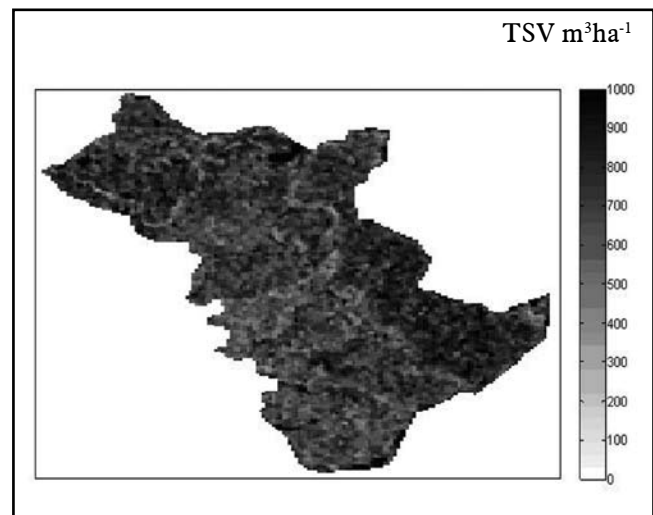

Figure 3: Example volume map

Firstly, GPS your ground plots as accurately as possible, as plots are seldom exactly where specified (Fig. 4). GPS units do not work well under canopy or in steep terrain, so use the longest aerial available or triangulate a position based on markers in skids and roadways. Check the position of your plots every time a field crew goes out there, and leave the GPS in position collecting points for as long as possible. Aim to collect at least 500 points, and use differential correction software to improve the accuracy back in the office. Do not believe the post-processed accuracy quoted by the software. Use the most up-to-date GPS you can afford or rent, this technology is improving every year and your five-year-old handhelds just don't cut it for this application.

If the plot is meant to be circular, check that it is. If it is rectangular or square, then GPS the corners as well. When the LiDAR is acquired, you need to be able to specifically locate the exact patch of ground that relates to that plot. Free software can do the clipping, but you need to go out

and get the coordinates.

Secondly stocking has a large effect on volume. If the plots are small and the stocking low - so they contain only 10 or so trees per plot - the TSV across plots will be very noisy. At 10 trees per plot, the inclusion or exclusion of a single tree can make ±10% difference between otherwise identical plots. Basing your model on noisy data like this will lead to poor correlations, and averaging around 20 trees per plot is recommended. This will apparently reduce the range in TSV but improve the fit of the model. Using segmentation techniques can reduce stocking bias, but requires a ten-fold increase in computational time and effort. Better just to use bigger plots.

Once spatial coincidence is taken care of, how coincident are the plot measurements and the LiDAR data in time? If the plots were measured more than a growth season before or after the LiDAR was flown, then they need to be grown forwards or backwards with a suitable growth model. Ideally, the two measurements should be made as close as possible to each other.

The next step is to generate LiDAR metrics for the sample with which to correlate the plot data. FUSION, a free LiDAR analysis tool from the US Forest Service is
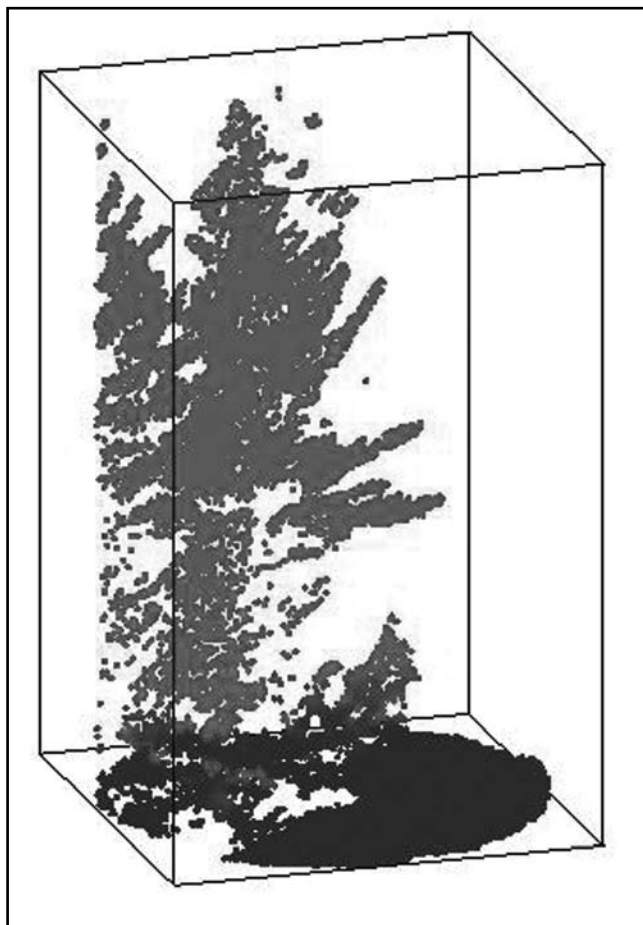

Figure 4 - LiDAR data of an alleged eight tree plot, showing two trees and a road, from the 12 pulses m² data used in Fig. 3. This is an example of why plots must be accurately GPSed

a good way to do this without directly dealing with the data. The output is a spreadsheet of fairly abstract metrics such as number of returns, vertical distribution statistics, and percentage canopy cover. Using any statistics package regression models can be constructed to infer the desired parameter (e.g. TSV) from the LiDAR metrics. Like any stats, the more plots across the whole range of the forest the better the model you will construct. The workload here requires some command-line programming to operate FUSION and some basic stats knowledge. Companies such as NZAM, Silva Consult and Land Consult could take care of this for a fee, although other consultants exist and will do in the near future.

Once a model has been constructed, the whole LiDAR area can be cut into a grid and parameterised in the same manner (FUSION does this). These parameters can be fed into the model and the output is a volume map for the whole forest. The grid should be of a comparative size to the sample plots. Although it is tempting to go for a finer resolution with a smaller grid, this is not the scale at which the model was defined. Likewise, if the sample plots were all in mid-rotation radiata pine, your model is unlikely to work for seedlings or mature stands, and especially not for other species. Even roads and skids are likely to return erroneous results (such as negative or very high volumes) unless the model was also calibrated with these zero values.

So you want to work with the data yourself?

LiDAR data over even a moderate sized forest takes up Gigabytes of hard disk, and is impossible to hold simultaneously in the memory of a standard desktop PC. Converting whole LiDAR datasets into raw point coordinates is a fast track to 'Out of Memory' errors and overnight runs. Solutions exist, and are implemented in free and licensed software. Even Arc GIS has the functionality to grid up LiDAR returns into 'multipoints' since version 9.3.1 (ESRI 2010). Free software exists for the conversion and visualisation of LiDAR data. LasTools (Isenburg 2010) is open source software for clipping, converting and basic visualisation of datasets. FUSION (McGaughey 2010) has been developed by the US Forest Service specifically for forestry, and has extra functionality beyond LasTools for creating DEMs, generating LiDAR metrics, and gridding up whole areas for use with a model such as for Total Standing Volume. It will not however segment individual trees, give an estimate of stocking, or determine the statistical models you need for inferred metrics such as TSV or BA. FUSION requires some basic command-line programming to use most of the functionality. Although details are scant, 'TreeVis' from Germany offers LiDAR visualisation, DEM extraction, and single tree-delineation and is commercially available for an undisclosed sum (Koch 2010).

It is possible to write your own software to process LiDAR data (as most research institutions have) which

gives infinite flexibility and adaptability, but this requires a lot of time and specialist knowledge. It is probably not ideal for every New Zealand forestry company to write their own software, when a commercially available solution may be just around the corner.

Until such a solution arises, if forest companies do not have time to experiment with the free tools but want the results, they should go to a consultant. NZAM, Land Consult and Silva Ag perform this service, and it is likely several more will emerge in the near future. Conversely, a company that invests in the capability now may find themselves at an advantage in the future when LiDAR is more commonplace.

Can you afford it?

LiDAR is prohibitively expensive for small forests and woodlots. Much of the cost is simply getting the plane in the air, so for a 50 hectare forest you might be looking at several $100 per ha. Conversely - depending on the deliverables - large forests can be flown a dollar or two per hectare, such as Forestry Tasmania flying 32,000ha (Mannes 2009) or Forestry SA flying 10,000ha of radiata pine in SE Australia (Rombouts et al. 2010). Note that prices are dependent on the site's shape, terrain and size; as well as its proximity to vendors and GPS base-stations. Within New Zealand these factors, combined with reduced fine-weather opportunities, mean that prices are likely to be higher this side of the Tasman.

For a small woodlot owner in New Zealand, it may be possible to acquire second-hand data from a large scale survey (such as by a regional council), but this is likely to be of poor quality for forestry for the reasons given above. The other option is to form a syndicate with other land owners, collectively covering a large enough area for new data collection to become economically viable.

Although the initial cost of LiDAR is substantial, the benefits in roading, harvest planning, inventory, management and reduced field work mean that when used to its fullest, LiDAR can pay for itself - and keep on paying out - in as little as five years (Mannes 2009).

So are you ready for LiDAR?

Do you:
- Realistically know how accurate you require your DEMs to be?
- Have accurate locations for all plots used in your regression models?
- Have up to date plot data?
- Have good growth models if your plots are not up to date?
- Have a data supplier who knows about forestry?
- Either have staff happy working with command-line tools and stats packages, a full-time programmer or a

consultant to deal with the data?
- Have a GIS system to hold the results in?
- Have enough forest to be economically viable, or a syndicate of other land owners to share the cost?
- Have an idea of how to use the spatially referenced information more effectively than your previous mean ha-1 inventory statistics?

If the above requirements are met, then LiDAR has a lot to offer New Zealand forestry. The real danger is the industry getting hold of second hand LiDAR data, mixing it with outdated poorly located plot data, achieving poor results and losing all enthusiasm for this new technology that has the potential to become a valuable and integral part of our industry. Used correctly, LiDAR could be 'the next GIS', bringing spatial precision, cost effectiveness and targeted management and raising the competitiveness of the whole industry. FFR are in the process of setting up a up a "ginger" group under the NZFOA umbrella to promote the use of LiDAR, develop a generic business case and encourage collaboration in data acquisition. The pieces are falling into place for LiDAR, what remains to be seen is if the industry is ready for the raft of advantages it can bring.

Acknowledgements

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